NIC
Bolometer Users Guide

A **NIC** working group software
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Version 1.4-07

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The NIC working group is a collaborative project of the CEA de Saclay (1), the MPIfR in Bonn (2), the Observatoire de Grenoble (3) and IRAM (4,5). We acknowledge contributions by P.André[1], J.Braine[4], M.Bremer[4], D.Broguière[4], C.G.T.Haslam[2], R.Lemke[2], U.Lisenfeld[5], F.Motte[2], R.Moreno[4], R.Neri[4], A.Perrigouard[4], A.Sievers[5], T.Snijders[4], H.Wiesemeyer[4], J.Wink[4] and R.Zylka[2].

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Contents

Novelties and important modifications to version `V1.4-07` are labeled *NEW*. Just read these sections if you're already an experienced `NIC` user.

1 Introduction NEW

This document[1] gives a description of the NIC software package. NIC was originally developed to reduce continuum data taken with the bolometer arrays of the MPIfR/Bonn. Today, it provides also some limited support for users of SHARC, the linear bolometer array in use at the CSO. NIC has grown on top of pre-existing software[2] and was designed with essentially one goal in mind: maintain full access to the SIC monitor and the Grenoble graphic utility package GreG and use a command language as close as possible to that of CLASS and CLIC to facilitate getting started with NIC. In addition, it was designed to provide a minimal gateway via ASCII or FITS to other software packages. NIC is distributed[3] via anonymous ftp and is to be installed exactly the same way as for instance CLASS.

Though NIC is largely self-documented (type HELP NIC\ and don't forget the backslash), NIC's on-line help will in no case replace this document. Here you will find the basic concepts of bolometer array operation, data acquisition as well as hints and recipes for data reduction (with no claim to completeness). However, users that need to get acquainted with the Gildas working group software packages should first read the related documentation on the SIC monitor and on the GreG utility.

NEW Please note that NIC does not require anymore the NAG library for the FIT command. The command, however, requires SLATEC, an extensive public-domain source code library.

1.1 Customizing NIC

Though NIC works without particular settings, it is recommended to customize its environment before starting. This has to be done just once, by creating (modifying) the .gag.dico file in your home directory (watch for lowercase letters if the operating system is case-sensitive) to create user defined logical links to specific directories:

- BOLO_DATA: defines the directory where the raw data (bolometer input files with the .nmb or .asc extension), preferably from a single session, is stored. The logical assignment is required by a few standard procedures like SIGNAL, TOTPOW,...
- GAG_LOG: defines the protocol directory. NIC stores here the files named nic.log, nic.mes, nic.short where a track of all 'effective' commands and messages is kept. The default is the home directory,
- GAG_INIT: defines the procedure directory from which NIC retrieves all user-defined procedures. The default is the home directory.

To customize .gag.dico add the following lines (watch for the colons and the terminating slash):

```
BOLO_DATA:   /this/is/my/data/directory/
GAG_LOG:     /this/is/my/protocol/directory/
GAG_INIT:    /this/is/my/procedure/directory/
```

[1] Please inform Roberto Neri (neri@iram.fr), Dominique Broguière (broguier@iram.fr), Helmut Wiesemeyer (wiesemey@iram.fr) or Albrecht Sievers (sievers@iram.es) on shortcomings and on any error you might have found in this manual.

[2] The software was originally written at the MPIfR and at IRAM and was based on the NOD2 library. The acronym NIC stands for New Imaging Concept and follows a suggestion of G.Haslam from the MPIfR.

[3] Information on how to retrieve the latest distribution files can be found on the back of the IRAM Newsletter.

Unlike GAG_LOG: and GAG_INIT: which are assigned by default to your home directory, the logical BOLO_DATA: is undefined on NIC's first start. If not defined in .gag.dico, NIC will automatically assign the logical BOLO_DATA: to your $HOME/nmb/ directory and add an appropriate entry in init.nic[4]. As an alternative, you may not only define logical links by customizing the files .gag.dico or init.nic, but also once you enter the interactive level of NIC by typing:

```
NIC> sic log BOLO_DATA:   "/this/is/my/data/directory/"
```

To keep the rules, it is recommended to make the logical assignments either in gag.dico or init.nic (see also APPENDIX D). Finally, if you are working with an older version of NIC and if you wish to use systematically the IRAM standard reduction procedures add the one-word symbol INPUT to the initialization file init.nic, or type each time you get started with NIC:

```
NIC> INPUT
```

NIC creates widgets for ON-OFF and ON-THE-FLY scans if the X-Window mode is active. Modify variable SIC$WINDOW in init.nic to enable or disable the widgets.

1.2 Getting started

To start NIC type nic or NIC, whatever is defined on your computer system. Once started, NIC will establish all logical links, execute the initialization file init.nic if it exists, print out a few text lines, and finally, indicate readiness by prompting for new input. If it finds the file nic.sky on your local directory NIC will print out an additional message:

- "Retrieving SKYDIPs ..." This is a self-explanatory message indicating that previous calibrations (only skydip results) are retrieved from a file named nic.sky (on your local directory) and that variables of the skydip section (SKYDIP_OPACITY and SKYDIP_TIME) are set accordingly. The reason is to avoid repeated reducing of skydip scans.

Currently, all bolometers configurations from February 1993 up to the current bolometer campaign are implemented in NIC. If you wish to use alternative beam efficiencies and offsets you either have to supply these constants using FIT and the sequence of commands as listed in the INFO to Version 1.3-04 or simply by writing the FIT results to the file nic.fit. If NIC finds such a file once it gets started it will print out an additional message:

- ""Retrieving FITs ..." This message confirms that, if possible, all beam parameters will be retrieved from a file named nic.fit (on your local directory) for all the scans that follow in time the scans from which the beam parameters were determined. Just watch out that nic.fit contains the constants for *all* the channel in the array. The variables of the bolometer section (CHAN_AZ_OFF, CHAN_EL_OFF and CHAN_GAIN) will be set accordingly.

Please refer to APPENDIX D for all possible messages that NIC might print out when getting started.

At this stage NIC will accept the basic commands FIELD, FILE and FIND (in addition to HELP, INFO and VERSION) and the standard procedure SIGNAL and TOTPOW (in addition to INPUT). Please consult either the NIC\ LANGUAGE INTERNAL HELP section and the PROCEDURES section for further details.

[4]The initialization file init.nic which is located in your home directory, is customized on NIC's first start and executed on each start. Updates introduced by subsequent versions of the software are indicated.

2 Procedures

We distribute `NIC` with a set of procedures[5] that we make available on a "as-is" basis. The procedures which intend to simplify the reduction of multi-beam data obtained via the `MPIfR` bolometers, may be modified to match specific requirements. Access to the procedures is provided via the shell procedure `INPUT`, either manually, by typing:

```
NIC> INPUT INPUT
```

`INPUT` (twice) or automatically, by customizing the `init.nic` initialization file as described in section 1.1. Access is confirmed by listing the names of the procedures currently installed. A short help which displays the current setting and the meaning of the variables used in the procedures is available for each procedure by typing `INPUT` followed by the name of the procedure.

We give here a short description of the current procedures:

QUICKLOOK was written for the purpose of rough reduction, visualization and verification of bolometer data recorded at the telescope. The procedure reduces automatically any scan as soon as it is written to the observer's default data directory (type `sic log BOLO_DATA:` to verify the link to the data directory). Just let yourself be guided by the procedure.

REDUCE performs a standard reduction of `ON-THE-FLY` and `ON-OFF` scans.

SIGNAL displays temporal bolometer data for all or selected channels of a multi-beam cluster. The content of the variable `SIGNAL` is plotted (so far, it takes into account the data reduction steps that were already carried out). `SIGNAL` with a scan number as parameter, reads raw data from a file located in the directory with the logical assignment `BOLO_DATA:` (see section 1.1). The procedure protocols (almost) all data reduction steps with some additional information on scan type, source name, and so on, in a separate panel. Moreover it activates automatically the corrections for the receiver gains and for the attenuation used in the signal amplification stage.

TOTPOW displays total power data, if available, for channels in a multi-beam cluster. This feature is currently only available for data obtained begin of 1998 with the 37-channel bolometer array developed at the MPIfR.

MAKPLAN activates the (external) task `MAKPLAN` that produces double-beam maps for all un`FLAG`ged channels of the multi-beam cluster. The procedure provides system parameters as well as additional parameters (watch values by typing `INPUT MAKPLAN`). Files are written with the extension `.mdb` that can be viewed using the procedure `MAP`.

MAP plots maps generated via the external tasks `MAKPLAN`, `RESTORE` or `CONVERT`. It automatically takes the file extension associated to the last used task. `MAP` with a parameter plots the map associated to the file with the parameter as filename. Type `INPUT MAP` to take advantage of all the features.

RESTORE activates the (external) task `RESTORE` that produces single-beam maps for all un`FLAG`ged channels of a multi-beam cluster following the Emerson-Klein-Haslam algorithm[6]. The procedure provides system parameters as well as additional parameters (watch values by typing `INPUT RESTORE`). Files are written with the extension `.ekh` that can be viewed using the procedure `MAP`.

SHIFT_AND_ADD activates the (external) task `SHIFT_AND_ADD` that creates single-beam maps with the extension `.saa` for all un`FLAG`ged channels directly from variable `SIGNAL`. We refer to section 7.4 for more details. Type `INPUT SHIFT_AND_ADD` to get a list of all the required input variables.

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[5] A procedure is a file that contains a sequence of commands.

[6] Emerson,D.T., Klein,U., Haslam,C.G.T, 1979, *Astron.Astrophys.*, 76, 92

CONVERT activates the (external) task CONVERT that converts restored single-beam maps from the horizontal to the equatorial system. The transformation is done by combining individual channel maps to a single converted map. CONVERT allows for mosaicing (combination of several fields) using the list of scans specified in the variable SCAN_LIST. The result of the mosaicing is written to a file whose name is the name of the source actually read by SIGNAL. The second plane in files generated by the task CONVERT is the weighting function according to the weights of the single-beam maps and of the scans used in the conversion process. The procedure provides system parameters as well as additional parameters (watch values by typing INPUT CONVERT). Files are written with the extension .cnv that can be viewed using the procedure MAP.

ONOFF activates an (external) task that produces files with the extension .onf. The files contain the counts (or fluxes) associated to the channels in the multi-beam cluster. Flagged channels have zero result and zero rms. The files have to be further processed via GREG commands or GRAPHIC tasks. The procedure provides system parameters as well as additional parameters (watch values by typing INPUT ONOFF).

FLUX use this procedure to measure the flux density within an interactively defined polygon in units of Jy, mJy or counts. Use variable BEAM_AZ and BEAM_EL (write enable is only possible by command var ant wr) to define alternative beamsizes to the ones proposed.

We plan to distribute NIC with additional procedures in the near future. Procedures written by users are welcome.

3 A Typical Reduction Session

NIC is intended to be as easy to use and as fully documented as the IRAM reduction software CLASS and CLIC. In order to simplify your first data reduction steps with NIC, we give here a few commonly used commands, to be used as cookbook. You can use these sample sessions to reduce SKYDIP, ON-THE-FLY and ON-OFF observations, respectively. Please consult the calibration section for additional information on how to reduce SKYDIP data and on how to deal with FOCUS and POINTING scans.

3.1 Reducing SKYDIPs

You may use the following commands to select and reduce a sequence of SKYDIPs and to append the results (zenith opacities, Counts/K factors and others) to the file nic.sky. As it gets started, NIC automatically retrieves these results on condition that the file is on your local directory. The file keeps track of all SKYDIP data reduced with the SOLVE /FILE command.

```
NIC> FIND /SCAN 6500 6550 /TYPE SKYD

     Scan : 6502   Mode : SKYDIP      Source : SKYDIP
     Scan : 6512   Mode : SKYDIP      Source : SKYDIP
     Scan : 6540   Mode : SKYDIP      Source : SKYDIP
```

→ At this stage all SKYDIP scans in between scan number 6500 and 6550 are selected. Variable FOUND is set according to the number of found scans and variable SCAN_SEQUENCE contains now the associated scan numbers listed in the first column. The Mode column lists the type of scan (in this case a SKYDIP) while the Source column lists the name of the sources observed (there is no source in this case).

```
NIC> SET GAIN_AMPLIFIER ON         ! is obsolete (already enabled in init.nic)
NIC> FOR I 1 TO FOUND
NIC:   SIGNAL 'SCAN_SEQUENCE[I]'   ! or alternatively   GET N
NIC:   SOLVE /FILE
NIC: NEXT

     Defaulted to 6502.nmb
     Number of subscans:  6
     Number of records:  126
     Defaulted to 6512.nmb
     Number of subscans:  6
     Number of records:  126
     Defaulted to 6540.nmb
     Number of subscans:  6
     Number of records:  125
```

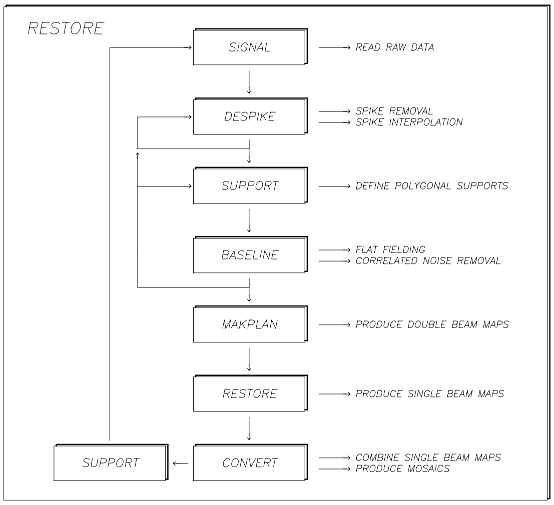
→ Three scans are solved for the zenith opacity and the results (see below and command SOLVE) are written to nic.sky, as default file. There are six subscans per file, one for each elevation, and the last file is shorter by one record, though it does not prove to be faulty. The SET GAIN_AMPLIFIER ON command (unless disabled, it is automatically activated at start) applies a fixed scaling factor to the data (usually ×256) and is used to compensate the amplifier gain which in the case of SKYDIPs is lowest in order to avoid signal saturation. The command affects just the computation of the Counts/K conversion.

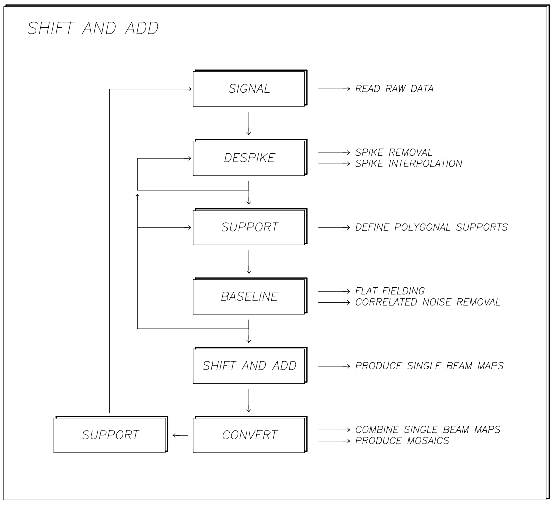
```
NIC> TYPE NIC.SKY
!
!   Universal Time  Opacity   Water (mm) Azimuth (deg)  Counts/K    Scan
!
 19950317.12762730    .209       2.828      150.000        35221     6502
 19950317.18974146    .216       2.940      170.000        35821     6512
 19950317.28098802    .254       3.504      205.000        36607     6540
```

→ The file nic.sky contains now the results of the three scans. All results are appended to this file, a single line for each SKYDIP that is reduced using the option /FILE. Moreover, the zenith opacity and the time are appended to the indexed variables SKYDIP_OPACITY and SKYDIP_TIME. The variables will be interpolated in time and opacity on command SET OPA ON to correct continuum records for atmospheric extinction. Provided the file nic.sky is on your local directory, it will be automatically loaded into NIC (in the variables SKYDIP_OPACITY and SKYDIP_TIME) each time you get started.
→ An esclamation mark is inserted at the beginning of a row if NIC was not able to find a good fit to the data. A bad fit to the zenith opacity often shows up with a different Counts/K factor. Since the factor shouldn't change for well-determined opacities watch out for any strong variation affecting this factor. A sudden drop or a raise might show up as a serious problem and not just as the consequence of change in the efficiency of the reference channel. During the observations, in case you face such a situation, please inform immediately the astronomer on duty.

3.2 Reducing ON-THE-FLYs

The main data reduction steps are shown in the panel below. Raw data is read by means of procedure SIGNAL which activates the receivers gains (if known) and corrects for the amplifier gain. Spike removal is done with the command DESPIKE. Flat-fielding (i.e. baseline removal), plotting the average beam to beam signal correlation, removing correlated noise (excess noise) is done with the BASELINE command. The definition of polygonal supports for flat-fielding is done with command SUPPORT either on double-beam maps or single-beam maps. All the BASELINE computations are carried out on the original (temporal) data samples. The `MAKPLAN` procedure produces double-beam maps which are deconvolved to single-beam maps by the `RESTORE` procedure. Alternatively, single-beam maps may also be obtained with the `SHIFT_AND_ADD` procedure.





The conversion from horizontal to equatorial coordinates and (optionally) the merging with additional maps is carried out by means of the `CONVERT` procedure.

Here we give an example. We recommend to read a single scan using the `SIGNAL` procedure (see also the section `PROCEDURES`). Though the procedure makes it easier for you, you may also use the basic `FILE IN` command.

```
NIC> DEVICE IMAGE WHITE
NIC> SIGNAL 6505    or alternatively   FILE IN BOLO_DATA:6505
                    or alternatively   GET 6505

   Defaulted to 6505.nmb
   Number of subscans:  34
   Number of records:  3225
   I-BEAM,[6505] Using date: 04-Dec-1998 - 19 Beam parameter set
   I-OPACITY,[6505] Using a mean zenith opacity of  .213
```

→ Opening a color X-window display (and depending on variable `noname` also an X-widget) and reading raw data from scan number 6505. The data records are written to the homonymous variable `SIGNAL`. Type `SIGNAL` without scan number, to plot the current content of the variable `SIGNAL`. The difference between the procedure `SIGNAL` and the `FILE IN` command becomes obvious once a graphics display is available.

→ `NIC` applies the set of channel parameters (positional offsets and relative gains) as determined on December 4th, 1998. Alternative parameters may be used either by using a file called `nic.fit` (see online help on command `FIT`) or by modifying manually the appropriate set of parameters.

→ The software applies a time dependent opacity correction by interpolating the `NIC` variable `SKYDIP_OPACITY` associated to the skydips immediately preceding and following this scan. Please note that the opacity correction is always activated by default. Use `SET OPACITY OFF` to disable the atmospheric opacity correction.

→ Note that the logical assignment `BOLO_DATA:` is softwired in `SIGNAL` whereas it can be omitted when typing the `FILE IN` command. `FILE IN` without `BOLO_DATA:` is equivalent to the `GET` scan command. At this stage you may ask for some scan associated parameters by using command `HEADER`, `LIST` or even `SHOW`. To verify data consistency in azimuth, elevation and time use command `CHECK`.

Then flag bad channels (or bad rows = subscans) with the FLAG command and remove spikes (if any) from the signal with the DESPIKE command. Though DESPIKE goes straight through all channels, it breaks off with the first spike when it processes a channel (iterating twice is usually enough, see commands DESPIKE /ITERATION for more information):

```
NIC> FLAG /CHANNEL 13 18
NIC> DESPIKE /INTERPOLATE
```

→ Channels may suffer at times from interferences that show up with noise in excess, some channel may even be totally bad. As the nature of these defects remains in general poorly or even completely unknown, it might be advisable to flag channels that present such disturbances, especially in view of CONVERT. Here we flagged channels number 13 and 18.

→ As repeated use of the DESPIKE command is possible, NIC keeps track of every removed spike and blanks it to -99999.5, NIC's internal blanking value[4]. On option /INTERPOLATE it will replace them all at once by a linear interpolation that will use directly adjoining data points. Since spikes, essentially cosmic ones, occur roughly at a rate of eight per beam and hour, their removal will in general be unavoidable for long-duration scans like ON-OFFs and ON-THE-FLYs. Use option /CHANNEL to operate on a single channel. The DESPIKE command works on variable SIGNAL

Once, the spike removal and the opacity correction are completed, you may produce double-beam maps using the MAKPLAN procedure:

```
NIC> MAKPLAN    or alternatively   RUN MAKPLAN /EDIT

     I-RUN,  Task makplan running, logfile is
             /users/softs/nic/makplan.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico

     I-RUN,  Elapsed       1.3  User       1.1  System       0.2
     I-RUN,  Task makplan completed successfully
```

→ The alternative is to activate directly the task MAKPLAN by using the RUN command. This is, however, quite more difficult as you have to supply several parameter. Moreover, there is no direct advantage in doing so, unless specific requirements have to be met. Watch the output messages (different messages are possible depending on the operating system). The procedure produces the double-beam map file 6505.mdb (a Gildas Data File) that you might visualize with the MAP procedure.

→ There is no need to run MAKPLAN to define a support, unless option /CURSOR is required on the SUPPORT command.

→ Contrary to the RESTORE task, SHIFT_AND_ADD works directly with the variable SIGNAL, not on double-beam maps. In other words there is no need to run MAKPLAN for the SHIFT_AND_ADD algorithm.

→ Type INPUT MAKPLAN to get the list of main parameters used by the homonymous task.

```
NIC> MAP    or alternatively   MAP 6505
```

→ MAP is automatically executed after MAKPLAN, RESTORE, SHIFT_AND_ADD and CONVERT. Type INPUT MAP to get the list of variables used by MAP.

Flat-fielding, removing correlated noise, defining supports for specific aims, all that is done with the SUPPORT and the BASELINE commands:

```
NIC> SUPPORT /CURSOR
NIC> BASELINE /ORDER 1 /CORR
     I-BASE,[6505] Variable CHAN_RMS updated ...
```

[4]The same blanking value is used for RG files created by NIC.

→ The SUPPORT command defines a region of points completely enclosed by a polygonal support. Depending on the TYPE variable, the support is either defined in horizontal or equatorial coordinates. In this example the support is defined interactively using /CURSOR on the dual-beam map of the reference channel. Unless option /CHANNEL is specified, the polygonal support is shifted according to the elevation dependent azimuth and elevation offsets of the off-axis channels so that, by default, the execution of the BASELINE command will be referenced with respect to the tracking center of the telescope. Just type LET DO_SUPPORT NO before MAP, to disable plotting the support used for each channel.
→ A support is always defined for all types: MDB, EKH, SAA, CNV. Each support is available as a variable array (e.g. SUPPORT_MDB). The following conversions rules apply:

MDB $\overset{=}{\leftarrow}$ EKH, SAA $\rightleftarrows$ CNV

For instance, a support defined in the equatorial frame of a CNV file (single-fields or mosaics) will automatically be transformed to the EKH- and SAA-frame (horizontal) and finally stretched in azimuth by an amount equal to the WOBBLER_THROW for the corresponding MDB-support. As a rule, when the morphology of the source is known, it is preferable to define a support on the CNV map rather than on the MDB map of the reference channel which is affected by parallactic and Nasmyth rotation.
→ Moreover, the reference support for each scan will always be equatorial. In other words, if you plan to reduce a new scan, NIC will automatically compute four new support types (MDB, EKH, SAA and CNV) from the last defined equatorial support (CNV).
→ Note, as indicated by the equal sign, that supports defined in the horizontal frame of a dual-beam map (MDB) will not shrink to the horizontal frame of single-beam maps (EKH, SAA), since this transformation is not unique.
→ SUPPORT defines regions for *(1)* the BASELINE command to avoid points within a polygonal support for the determination of (in the order of execution) *(a)* the flat-field that will be subtracted from the temporal signal, *(b)* the beam-to-beam noise correlation function and *(c)* the root-mean-square (not the standard deviation) of the signals, or *(2)* for the RESTORE task to consider only the points within the support (while blanking out all others) for the purpose of single-beam restoration. The polygonal support by default (SUPPORT without options and no parameter) defines a rectangular region that extends up to 12″ from the edges of the map.
→ The BASELINE commands acts on the original data (i.e. the time series, or equivalently variable SIGNAL). In the example above, the BASELINE command removes a polynomial surface of order one (using /ORDER) from the NIC variable SIGNAL, plots the mean beam-to-beam noise correlation function (using /CORR) and computes the root-mean-square (variable CHAN_RMS) of the signal for all the channels.

```
NIC> BASELINE /NOISE

   I-BASE,[6505] Noise removal is experimental ...
   I-BASE,[6505] Variable CHAN_RMS updated ...
```

→ An additional line witnesses for the noise removal from variable SIGNAL. The BASELINE command requires a polygonal support (to be defined with SUPPORT) which is used to define a region to avoid in the noise removal process. The support region which should be as small as possible is shifted according to the positions of the off-axis channels. We refer to the Appendix B Removal of the correlated noise term for more details on the technique.
→ The suppression of the correlated noise term reveals sometimes the existence of hidden, low intensity spikes. Remove these residuals with the DESPIKE command and, depending on their number and intensity, repeat the baseline subtraction once more.

To bring the raw data to a flux density scale (that's probably what you're looking for), use the following command:

```
NIC> SET JANSKY ON 3300
```

→ The SET JANSKY command scales variables SIGNAL and CHAN_RMS according to the COUNTS_PER_JY factor which in this particular example was fixed to 3300 Counts/Jy. We refer to the section Data Calibration on how to determine the conversion. Please do also consult the IRAM staff. Note that once the conversion is turned on, it will automatically be applied to any further scan, except SKYDIPs.

→ We advise you not to modify the variable COUNTS_TO_JY by a SIC command.

Then you may produce calibrated, baseline-subtracted double-beam maps:

```
NIC> MAKPLAN    or alternatively   RUN MAKPLAN /EDIT

     I-RUN,  Task makplan running, logfile is
             /users/softs/nic/makplan.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico

     I-RUN,  Elapsed       0.8  User       0.6  System       0.2
     I-RUN,  Task makplan completed successfully
```

→ Once the despiking, the flat-fielding and (optionally) the removal of the correlated noise terms have been carried out, the content of the NIC variable SIGNAL is translated, channel by channel, into double-beam maps. *Currently:* as the RESTORE procedure acts directly on double-beam maps (not on the variable SIGNAL) double-beam maps need to be computed, otherwise all actions occurred on command BASELINE will not be taken into account.

You may restore (deconvolve) the double-beam maps to single-beam maps using the RESTORE procedure:

```
NIC> LET BEAMSEP 31.0
NIC> RESTORE    or alternatively   RUN RESTORE /EDIT

     I-RUN,  Task restore running, logfile is
             /users/softs/nic/restore.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico

     I-RUN,  Elapsed       0.5  User       0.2  System       0.0
     I-RUN,  Task restore completed successfully

NIC> MAP    or alternatively   MAP 6505
```

→ The RESTORE procedure is started on completion of the MAKPLAN procedure. As for the latter, the alternative is to activate directly the task RESTORE by using the RUN command.
→ As the effective angular separation of the two wobbler phases is less than the selected wobbler throw, we recommend to measure it first on a strong, compact source for optimum restoration of the single-beam maps. As a rule the effective ON to OFF beam separation is equal to the wobbler throw minus one[5]. As above, the measured separation (in arcseconds) needs to be written to the NIC variable BEAMSEP. This is done automatically while reading a scan from disk, but can also be done either manually or using the FIT command and automatically when readinga scan . RESTORE produces maps in the horizontal frame of reference and writes these to files with the extension .ekh that you might visualize with the MAP procedure.

Finally convert the single-beam maps to the equatorial frame of reference and combine all the (unflagged) channels to a single map:

```
NIC> CONVERT    or alternatively   RUN CONVERT /EDIT

     I-RUN,  Task convert running, logfile is
             /users/softs/nic/convert.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico
```

[5] BEAMSEP is more or less equal to the wobbler throw minus the azimuthal velocity VAZM in ($''$/sec) multiplied by half the wobbler period (i.e. the duration of a single wobbler phase). With standard values (VAZM = $4''$/sec, WOBBLER_PERIOD = 250 msec) the ON to OFF beam separation is equal to (WOBBLER_THROW-1$''$).

```
I-RUN,  Elapsed      2.5  User      0.8  System      0.1
I-RUN,  Task convert completed successfully
```

```
NIC> MAP    or alternatively   MAP 6505
```

→ CONVERT is told to combine all channels (except channel number 13 and 18) to a unique map with an equatorial center of reference. Use the MAP procedure to visualize the result. Note that files produced via CONVERT have always two planes: (a) the image obtained from the multi-beam system in the first one, and (b) the global weighting function generated from the combination of the beam weights (variable CHAN_RMS).
→ The focal positions of the multi-beam system can be retrieved from fitting Gaussians to either the double-beam or the single-beam maps of strong compact sources. You may use the FIT command to retrieve relative positions with respect to the tracking center of the telescope. These positions are written to the NIC variables FIT_AZ_OFF and FIT_EL_OFF to which you can have access with the VAR FIT command. As the positions can change as a result of a dewar displacement (such as helium refilling), we recommend to measure these at regular intervals. Use the next sequence of commands to switch to the fitted positions:

```
NIC> VAR FIT
NIC> VAR BOLOMETER WRITE
NIC> LET CHAN_AZ_OFF FIT_AZ_OFF
NIC> LET CHAN_EL_OFF FIT_EL_OFF
NIC> SHOW      to verify the current parameters
```

→ In case you wish to combine several coverages of a given mapping field in order to achieve adequate sensitivity or to merge distinct fields for the purpose of mosaicing proceed as follows:

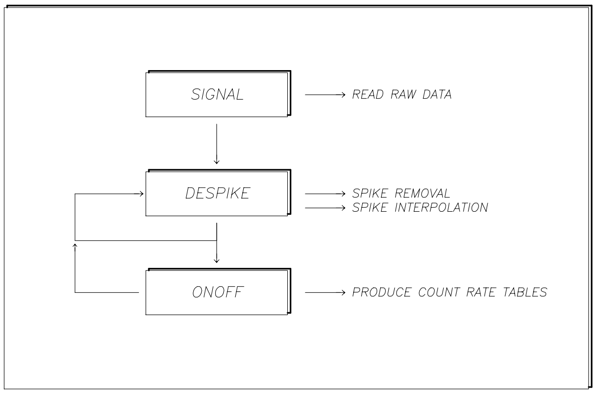
```
NIC> LET SCAN_LIST "6550 6587"
NIC> CONVERT or alternatively RUN CONVERT /EDIT

     I-RUN,  Task convert running, logfile is
             /users/softs/nic/convert.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico
         Reading map  6550.cnv ; Map unit is  Jansky
         Reading map  6587.cnv ; Map unit is  Jansky

     I-RUN,  Elapsed      0.5  User      0.3  System      0.1
     I-RUN,  Task convert completed successfully

NIC> MAP MY_SOURCE
```

→ At first assign to SCAN_LIST the list of scans to combine. Here CONVERT was told to add the scans number 6550 and 6587 (watch the log) and to write the results to a map with an equatorial center of reference as in scan 6550 and as filename the name of the source (*NOT* the scan number). The filename is taken over from variable SOURCE.
→ The MAP procedure requires the name of the source as input (in this case MY_SOURCE), otherwise it switches automatically to the map associated with the variable SCAN. You may check out the source name by looking at CONVERT's input parameters (type INPUT CONVERT).
→ We recommend to watch for changes in the position of the multi-beam system and in the pointing of the telescope, as these changes have a detrimental effect on the result.

Once you combined all channels and fields to a unique map with an equatorial center of reference, define a support on your CNV file and repeat all the data reduction steps. The support which is supposed to follow the shape of the source, delineates the horizontal limits of the source much better than any other support you may define. This is important especially for baseline fitting and for the current noise reduction algorithm.

3.3 Reducing ON-OFFs

The main data reduction steps are shown in the panel below. Raw data is read by means of procedure SIGNAL which activates the receivers gains (if known) and corrects for the amplifier gain. Spike removal is done with the command DESPIKE. Removal of the baseline in case of unsymmetric scans, removal of correlated noise and writing out flux densities (or uncalibrated countrates) is done with the ONOFF procedure.



Here we give an example. We recommend to read a single scan using the SIGNAL procedure (see also the section PROCEDURES). Though the procedure makes it easier for you, you also may use the basic FILE IN command.

```
NIC> DEVICE IMAGE WHITE
NIC> SIGNAL 6510    or alternatively   FILE IN BOLO_DATA:6510

     Defaulted to 6510.nmb
     Number of subscans:  12
     Number of records:  238
     I-OPACITY,[6510] Using a mean zenith opacity of  .220
```

→ Opening a color X-window display and reading raw data from scan number 6510. The difference between the procedure SIGNAL and the FILE IN command becomes obvious once a graphics display is available. Note, however, that the logical assignment BOLO_DATA: is softwired in SIGNAL whereas it can be omitted when typing the FILE IN command. FILE IN without BOLO_DATA: is equivalent to the GET scan command. At this stage you may ask for some scan associated parameters by using command HEADER, LIST or even SHOW. To verify data consistency in azimuth, elevation and time use command CHECK.

→ The software applies a time dependent opacity correction by interpolating the NIC variable SKYDIP_OPACITY associated to the skydips immediately preceding and following this scan. Please note that in the older versions of NIC, the opacity correction was not activated by default.

Then flag bad channels with the FLAG command and remove spikes (if any) from the signal with the DESPIKE command. Though DESPIKE goes straight through all channels, it breaks off with the first spike when it processes a channel (iterating twice is usually enough, see commands DESPIKE /ITERATION for more information):

```
NIC> FLAG /CHANNEL 6
NIC> DESPIKE /INTERPOLATE
```

→ Channels may suffer at times from interferences that show up with noise in excess (some channel may even be totally bad). As the nature of these defects remains in general poorly or even completely unknown, it might be advisable to flag channels that present such disturbances, especially in view of CONVERT. Here we flagged channel number 6.

To bring the raw data to a flux density scale (that's probably what you're looking for), use the following command:

```
NIC> SET JANSKY ON 3300
```

→ The SET JANSKY command scales variables SIGNAL according to the COUNTS_PER_JY factor which in this particular example was fixed to 3300 Counts/Jy. We refer to the section Data Calibration on how to determine the conversion. Please do also consult the IRAM staff. Please note that once the conversion is turned on, it will automatically be used by the SIGNAL procedure and it will be applied to any further scan, except SKYDIPs.

Then you may write out calibrated data using the ONOFF procedure, as follows:

```
NIC> ONOFF    or alternatively   RUN ONOFF /EDIT
     I-RUN,  Task onoff running, logfile is
             /users/softs/nic/onoff.gildas
     I-SIC_GTLGTR,  Using user defined logical name table .gag.dico

     ! 18-FEB-1995 LST:14.111 RA: **:**:**.*** (Equ)  DEC: ***:**:**.** EPOCH:1995.1
     ! Scan  Source           Az        El         oRa      oDec     oAz      oEl
     ! 6515  Mysource         287.81    29.97      .00      .00     -.01      .00
     ! UT:  4.558  Subscans =  12  symm. = T  median = F  gain = 1  beamthrow = 60.0
     ! Noise reduction =  T    Fitting method = mean
     ! Channel   AZ(")     EL(")     RA(")    DEC(")      Mean(Jy) +- RMS(Jy)
          1         .00       .00       .00       .00     2.13550    .01148
          2      -18.18      9.63      9.43     18.28      .03176    .00657
          3      -17.54    -10.95     20.65      1.01      .08898    .00752
          4         .84    -20.62     11.07    -17.41      .07503    .00882
          5       18.30     -9.74     -9.46    -18.45      .01916    .00750
          6       17.69     10.82    -20.70     -1.21      .01666    .00652
          7        -.47     20.58    -11.36     17.17      .01800    .00609
     !
     ! Reference channel:  2.09867 Jy    (.01682)    SNR =  124.75   (= Channel  1)
     ! Adjacent channels:   .03683 Jy    (.01229)    SNR =    3.00
     !
     ! The flux of the reference channel was determined by removing the flux
     ! density of the adjacent  6 channels (i.e. their weighted mean.)
     ! Of the adjacent channels  0 were flagged.
     !
     I-RUN,  Elapsed       0.2  User       0.1  System       0.1
     I-RUN,  Task onoff completed successfully
```

→ Writing calibrated data to 6515.onf. Such an ASCII file is produced for every ON-OFF scan reduced with the ONOFF procedure. The suppression of correlated noise is carried out by default, please refer to INPUT ONOFF on how to opt for no noise removal. Note that the noise suppression algorithm assumes that only the central channel is looking at the source. Actually, this is the case of unresolved sources where the weighted mean of the six, directly adjacent channels, supposed to be free of any source emission, is used to subtract the noise in excess from the central channel. Please note that the current NIC Version has no built-in command to remove this term in case of extended sources. Refer to the TASK section 7.2 for more information on the skynoise suppression.

→ NIC allows sequences of ON-OFF scans of the same object to be written to separate files. The results are appended to a file with the extension .onf and with the filename as specified in the ONOFF_FILE variable. This is useful for archiving results in single files and, in particular, for detection experiments. Moreover, each time a scan is added to the archiving file, ONOFF starts an additional procedure to compute the mean, the rms and the signal to noise ratio obtained in the central channel on averaging the integral sequence of scans. Currently, these results are only written to the display.

→ Additional help to individual variables is provided in the TASK section 7.2.

```
NIC> SIGNAL
```

→ As the noise corrected data is written back to *variable* `SIGNAL`, use the *procedure* `SIGNAL` to verify the result.

As the results are written to `ASCII` files, you may retrieve these with the `COLUMN` and `ACCEPT` commands (both available in the `GREG` environment). To set an example, we list here the content of the file `6515.onf` (7-beam system) and we give the appropriate `COLUMN` command to retrieve the channel numbers (variable `X`), the countrates (variable `Y`) and the associated errors (variable `Z`) to each channel:

```
NIC> TYPE 6515.ONF

! 18-FEB-1995 LST:14.111 RA: **:**:**.*** (Equ)  DEC: ***:**:**.** EPOCH:1995.1
! Scan  Source           Az        El         oRa      oDec     oAz      oEl
! 6515  Mysource         287.81    29.97      .00      .00     -.01      .00
! UT:   4.558  Subscans =  12  symm. = T  median = F  gain = 1  beamthrow = 60.0
! Noise reduction =  T    Fitting method = mean
! Channel   AZ(")     EL(")     RA(")    DEC(")      Mean(Jy) +- RMS(Jy)
     1         .00       .00       .00       .00     2.13550    .01148
     2      -18.18      9.63      9.43     18.28      .03176    .00657
     3      -17.54    -10.95     20.65      1.01      .08898    .00752
     4         .84    -20.62     11.07    -17.41      .07503    .00882
     5       18.30     -9.74     -9.46    -18.45      .01916    .00750
     6       17.69     10.82    -20.70     -1.21      .01666    .00652
     7        -.47     20.58    -11.36     17.17      .01800    .00609
!
! Reference channel:  2.09867 Jy    (.01682)    SNR =  124.75   (= Channel  1)
! Adjacent channels:   .03683 Jy    (.01229)    SNR =    3.00
!
! The flux of the reference channel was determined by removing the flux
! density of the adjacent  6 channels (i.e. their weighted mean.)
! Of the adjacent channels  0 were flagged.
!

NIC> COLUMN X 1 Y 6 Z 7 /FILE 6515.ONF
```

4 Preparing Observations

This first thing to do is to look through the bolometer documentation[7]. The next few lines are meant for beginners to give a basic and *not* exhaustive idea of what is possible. Two standard types of observations are available: `ON-OFF` mainly for point sources and `ON-THE-FLY` for extended sources. The `FIELD` command was designed to help plan your observations in the most efficient way (see section 4.3 for examples).

`ON-OFF` just moves the telescope `ON` and `OFF` source by a specific amount and takes the difference `ON` minus `OFF`, much like when using wobbler switching for spectral line measurements. There are four parameters: the *wobbler throw*, the *number of* `ON` *and* `OFF` *phases*, the *observing mode* and the *duration* of a single phase. The observing mode is either `symmetric` (`ON-OFF-OFF-ON-ON`$\cdots$ – this is the default) or `unsymmetric` (`ON-OFF-ON-OFF`$\cdots$). The minimum useful phase duration is 10 seconds, under that observing is less effective.

`ON-THE-FLY` is more complicated. Here the telescope creates a so-called double-beam map by drifting in azimuth and stepping in elevation while the wobbler moves back and forth by a specific amount in azimuth. There are four main parameters: the *map size* in azimuth and elevation, the *skew*, and the *wobbler throw*.

`Azimuth size` Every element of the multi-beam bolometer should go through the source with at least a wobbler throw's distance to either side. The minimum subscan length which is the map size in azimuth is therefore the sum of the angular size of the source plus the size of the bolometer array ($\simeq 55''$ for the 7-beam array, $\simeq 100''$ for the 19-beam array) plus twice the wobbler throw.

`Elevation size` The integration time is directly proportional to the map size in elevation. See below on command `FIELD` for more details and refer also to Appendix A. As the likelihood of weather changes increases with scan duration, integration times of more than one hour are not recommended.

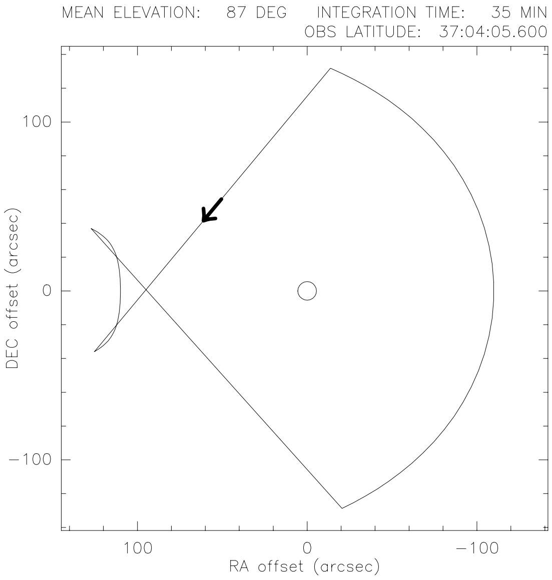
`Skew` The skew is the azimuth shift between two adjacent subscans and produces a skewed map. A substantial gain in time is frequently possible allowing the starting point of the azimuth drifts (subscans) to move parallel to the source. See option `/SKEW` in command `FIELD`.

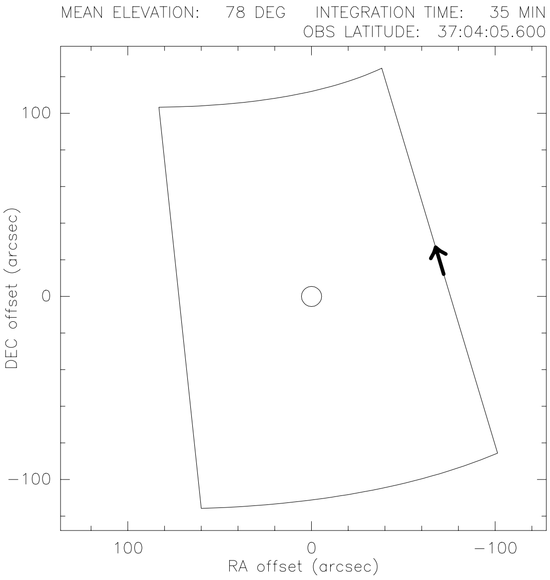
`Wobbler throw` The wobbler throw should be as small as possible to eliminate excess noise from the atmosphere effectively. However, the throw depends on source and program objectives. Here also, we refer to Appendix A for more details.

The `NIC` language provides the `FIELD` command for the preparation of observing programs with the `MPIfR` bolometers, it might, however, also be useful in the course of observations. Observers, indeed, are used to reckoning with unexpected problems during their observations and even with the most careful preparation of their programs, they may sooner or later face situations were quick decision-making is required. In these cases decision-making can possibly be relieved with the `FIELD` command.

The `FIELD` command is very useful to quickly identify the times (hour angles) at which one cannot observe the source. The figures on the next page show the area observed for an `ON-THE-FLY` map made near and shortly after transit for a source at 40 degrees declination. It is immediately obvious that the map made during transit is not useful. The figures shows however, that less than one hour later observations again become feasible. These effects are highly dependent on the source declination.

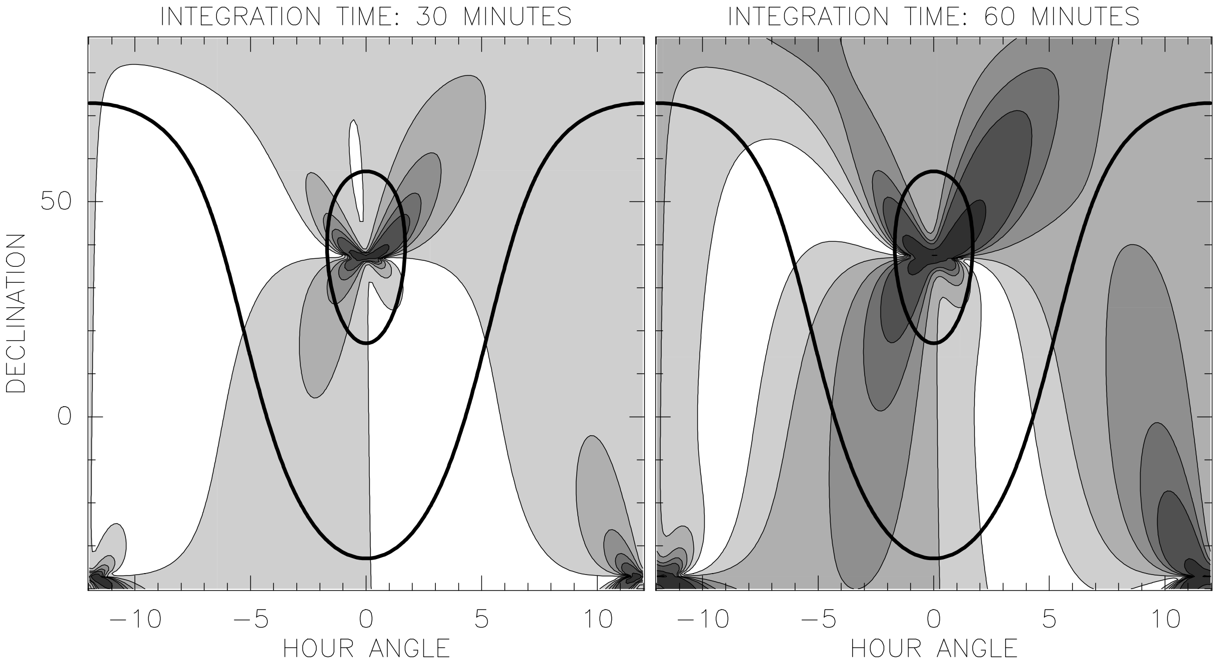
[7]W.Wild, *The 30m Manual*, 1995





`FIELD/DECL 40:00:00/SIZE 260 140/HOUR 0` `FIELD/DECL 40:00:00/SIZE 260 140/HOUR 1`

The `FIELD` command with option `/SMEAR` computes the beam smearing on the sky for arbitrary beam offsets. This is important if an extended source is observed in `ON-OFF` mode. We refer to the section on the commands for further details.



4.1 Some advice

Experience shows that the quality of ON-THE-FLY observations depends a lot on the observing strategy. A lack of planning leads to annoying errors which not even the best software package will rectify. To improve your observing strategy just keep in mind the following rules:

- *Keep individual observations reasonably short.*

  When making great demands to sensitivity, it is preferable to map large fields by combining successive coverages of smaller areas rather than mapping all at once. Smaller fields are in general easier to reduce than larger ones as they tend to be less affected by field-rotation (objects that transit close to zenith), by atmospherical instabilities (opacity fluctuations), by changes in the optics (pointing, beam spillover), and in some cases by data acquisition problems (corrupted data). But keep in mind that the smaller the map, the less sensitive to large scale emission the data. As a rule we recommend to split up fields that require more than one hour of observing time.

- *We recommend repeated mapping of a given field to filter out noisy patterns from the single-beam images.*

  There are two kinds of noisy structures that may affect the image reconstruction: the first resulting from the spatial frequency response of the dual-beam function, the second resulting from the horizontal scanning technique. The first kind of noisy structures shows up as vertical (elevation) ridges in the RESTOREd map whose spacing corresponds to the far-field separation of the ON and OFF beams. These noisy periodicities are almost completely suppressed when combining individual single-beam maps to a final image by the weighted shift and add technique used in CONVERT. However, if the field rotation between successive coverages of a given field is marginal and if high sensitivity mapping is needed, a more effective removal of the undesired throw frequency is achieved by switching to alternative wobbler throws. In this case select the throw according to the following rule: either smaller or larger by at least a beamwidth and no multiple of the previous beam separation.

  The second noisy feature which shows up as stripes in the scanning direction reflects uncertainties in the zero-level of individual subscans. As this kind of noise gets more pronounced with increasing subscan length because of short-time fluctuations in the background power loading, its removal becomes sometimes a difficult undertaking for long-duration maps. Here we recommend to break up the scanning direction by reobserving the field at different hour angles. In general two independent data sets are sufficient to remove this artifact.

- *If possible, keep the same wobbler throw throughout the run.*

  Switching between different wobbler throws would need the effective separation of the ON and OFF beams to be measured, and this at the expense of observing time. However, as a rule, just keep in mind that the effective double-beam separation is less than the selected wobbler throw by one arcsec. Moreover, we recommend to use small throws to attain to maximum wobbler efficiency and to yield the most effective sky noise cancellation. The spatial frequency response obtained after restoration to the equivalent single-beam observations, using the EKH algorithm, tends to show less conspicuous vertical ridges when using wobbler throws a multiple of the sampling interval.

- *If possible, avoid wobbling into strong sources at the edge of the field of view*

  Select the hour angle to avoid `ON`- or `OFF`-beam contamination due to strong emission regions lying just at the edge of the field. Restoration of these maps is far more complicated as the `ON`- or `OFF`-beams need to be removed systematically from each of the single channel maps.

4.2 How to prepare your `ON-THE-FLY` observations ?

After having chosen the astronomical sources one is interested in, the next step is to thoroughly plan the observations and estimate the observing time necessary. In the following we give two examples.

→ *How big must the maps be ?*

The minimum map size is:

$$\Delta_{AZ} = \texttt{array size} + \texttt{WobblerThrow} + \texttt{estimated source size}$$
$$\Delta_{EL} = \texttt{array size} + \texttt{estimated source size}$$

where the size of the bolometer array is $\simeq 55''$ for the 7-beam array and $\simeq 100''$ for the 19-beam array. Small fields are generally preferable because the field rotation is minimised and because the atmosphere is less likely to change than for a larger field. Combining several small fields to form a larger one is straightforward.

→ *How big should the wobbler throw be ?*

The smaller the wobbler throw...

- the more effective atmospheric noise removal becomes,
- the cleaner the beam,
- the smaller the map, making it possible to repeat the map more often in a given time.

If the wobbler throw can be made larger than the source size, such that the `ON` and `OFF` beams are never both on the source, then this means one can use the `SHIFT_AND_ADD` technique, which generally gives less noisy results than a `RESTORE`. The wobbler throw should not be significantly greater than $60''$.

If a small wobbler throw is used for a large field, then the `RESTORE` process brings in noise from the map edges (see below the η_R parameter).

Once an approximate wobbler throw has been chosen, choose the next multiple of $4''$ (the pixel size in standard observations) and add $1''$ (for purely technical reasons).

→ *How much time is required per map ?*

A fairly good estimation of the duration time T in minutes of an `ON-THE-FLY` scan is

$$T \simeq 1.9\,10^{-2} \times \frac{\Delta_{AZ}('') \times \Delta_{EL}('')}{V_{AZ}(''/s) \times S_{EL}('')}$$

$$\boxed{\simeq 1.2\,10^{-3} \times \Delta_{AZ}('') \times \Delta_{EL}('')}$$

which includes a 10% correction for telescope slew motions. The duration time depends on several parameters: the drift velocity of the telescope in azimuth, V_{AZ}, the subscan spacing in elevation, S_{EL}, and the size of the field in azimuth and elevation, Δ_{AZ} and Δ_{EL}. The `FIELD` command does the calculation for you. Standard values are $V_{AZ} = 4''/\mathrm{sec}$ and $S_{EL} = 4''$. We assume these in the following. As an indication:

$$\begin{array}{lcl} \Delta_{AZ}('') \times \Delta_{EL}('') = 200'' \times 160'' & \rightarrow & T \simeq 40\,\mathrm{min} \\ \Delta_{AZ}('') \times \Delta_{EL}('') = 280'' \times 220'' & \rightarrow & T \simeq 70\,\mathrm{min} \end{array}$$

→ *How many maps (coverages) are necessary ?*

The rms uncertainty in a measurement of the flux density close to the center of a map[8] with an array of N channels, standard observing conditions and a given `NEFD`[9] can approximatively be estimated to:

$$\delta S = \eta_R \frac{\texttt{NEFD}}{\sqrt{N \Delta T}} \sim \eta_R \frac{\sqrt{2} \cdot \texttt{NEFD}}{\sqrt{N}}$$

where $\Delta T = 500\,\mathrm{msec}$ (the typical data acquisition rate) and $\eta_R \simeq 0.3$ for a `RESTORE`d[10] map and $\eta_R \simeq 0.15$ for a map reduced with the `SHIFT_AND_ADD` method.

Thus, if $\eta_R = 0.3$ and `NEFD`= $70\,\mathrm{mJy}\sqrt{\mathrm{sec}}/\mathrm{beam}$, the noise level should be about $\simeq 7\,\mathrm{mJy/beam}$ for a map obtained with a 19 channel array under good observing conditions. Thus, to reach a sensitivity of $4\,\mathrm{mJy/beam}$, the source should be mapped 3 times.

4.2.1 Examples

Suppose we are interested in observing *(a)* an extended ($1.5'$) dark cloud and *(b)* an edge-on galaxy ($6.5'$) or some filamentary source.

(a) A $90''$ source is too large to be covered in one wobbler throw. The Δ_{AZ} map size should be about $\simeq 200'' +$ `WobblerThrow`, and perhaps a bit more if the dimensions of the source are poorly known. If the ratio of Δ_{AZ}/`WobblerThrow` is significantly greater than 5, then a significant amount of noise will likely be brought into the map during the restore. Some of this can probably be reduced by masking (see `INPUT RESTORE`). A $45''$ wobbler throw would probably be a reasonable compromise, yielding a total azimuth scan length of about $250''$ and, if the source is circular, an elevation size of $\simeq 200''$. The time without calibrations is thus roughly 60 minutes per map. Despite the long scan length, it would be difficult to break this observation into several parts.

[8] Even if we assume steady observing conditions (i.e. no sensitivity variations), the sensitivity in the final map will vary all over the map because of *(a)* the conversion from horizontal to equatorial coordinates and *(b)* the field of views of the channels. In general the lowest sensitivity is found towards the edges of the map, the highest close to the center.

[9] The mapping sensitivity depends on the nominal instrumental sensitivity corrected for atmospheric extinction. Under typical atmospheric conditions ($\tau_z \simeq 0.1 - 0.2$) and intermediate elevations ($40^\circ - 60^\circ$) the noise equivalent flux density (`NEFD`) of the `MPIfR` bolometers is expected to vary between $70\,\mathrm{mJy}\sqrt{\mathrm{sec}}$ and $100\,\mathrm{mJy}\sqrt{\mathrm{sec}}$. Observing request for the `MPIfR` bolometers should use the sensitivities specified in the most recent "Call for Observing Proposals on the 30m Telescope". Although sensitivity variations of 20% are found among the channels, the formula above assumes equal sensitivity for all the channels in the bolometer array.

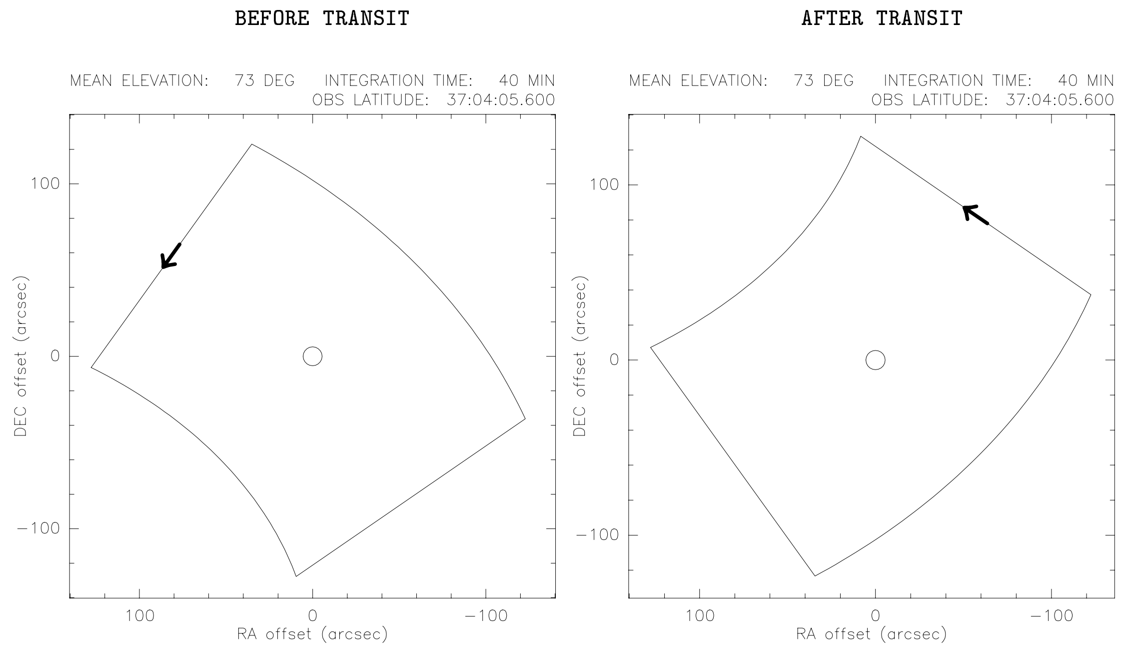
[10] η_R varies in general between 0.25 and 0.35. The coefficient depends essentially on the ratio of the azimuthal size of the map to the wobbler throw and increases because the `RESTORE` procedure brings noise in from the edges. The lowest coefficient is for a ratio of 4, the highest for a ratio of 8.

Suppose the declination of the source is 30 degrees. The command `FIELD/DECL 30 /SIZE 250 200/HOUR 0` will give the shape of the region observed. It is clear that transit is *not* a good time for these observations. Time could be requested either before transit, after, or both. The total time required to reach a 4 mJy/beam noise level is thus about 3×60 minutes$\simeq$ 3 hours+1 hour of overhead for calibration. Request additional mapping time if the shape of the beam needs to be measured accurately with a strong and compact source.

(b) Now let suppose we have a source about $\simeq 400''$ long by $25''$ wide with a position angle of 45 degrees and a declination of 50. Here we can use the shift-and-add method as long as the azimuth direction is close to perpendicular to the source. When the `AZ` direction is really perpendicular to the source, a wobbler throw of $45''$ is ample. For these scans, then, the `AZ` size is $100'' + 45'' + 25'' \simeq 170''$. The whole length of the source cannot be observed in one map but could be divided into 2 or 3 smaller maps centered about positions offset from the center. The sequence of commands

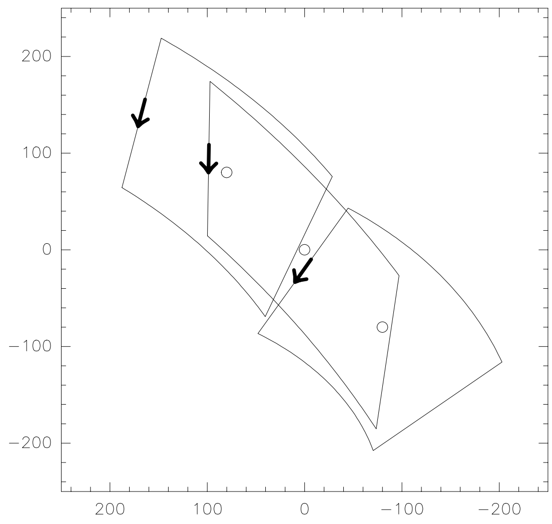
```
NIC> FIELD /DECL 50/SIZE 170 200/HOUR -1
NIC> FIELD /DECL 50/SIZE 170 200/HOUR +1
```

yields the figures below. The arrow indicates the scanning (azimuth) direction. We learn that each map takes about 40 minutes. Looking at them carefully, shows that after transit the scanning direction is nearly parallel to the source. The good hour angles are thus mostly before transit. One could expect to make 2 or 3 maps in this time.



Replotting individual `FIELD` diagrams reveals that the region covered does not fit an elongated source of this position angle very well. However, the observations can be made much more efficient if a "skew" is used. A skew is an azimuthal displacement added at every new elevation (i.e. the telescope is moved up `SINT`$= 4''$ and moved over by skew). The following sequence of commands could possibly fit the observing plan.

```
NIC> LIM 250 -250 -250 250
NIC> BOX
NIC> FIELD /DECL 50/SIZE 170 200/HOUR -3/NOFRAME/SKEW 3.7
NIC> FIELD /DECL 50/SIZE 170 200/HOUR -2/NOFRAME  80  80/SKEW 1.5
NIC> FIELD /DECL 50/SIZE 170 200/HOUR -1/NOFRAME -80 -80
```



4.3 How to prepare your ON-OFF detections ?

After having chosen the astronomical source you wish to detect, the next step is to select an appropriate wobbler throw and to estimate the observing time necessary.

→ *How big should the wobbler throw be ?*

The smaller the wobbler throw the more effective atmospheric noise removal becomes. However, when using small wobbler throws avoid `ON` to `OFF` beam separations corresponding to the offset position of a channel (use throws larger than 30″ for the seven channel bolometer array). Indeed, depending on telescope elevation, wobbler throw and bolometer array it is possible to move signal from a target source to an off-axis channel, making this off-axis channel useless for the analysis. Unless your source is extended, please keep in mind that the wobbler throw should never be significantly greater than 60″.

→ *What type of* `ON-OFF` *scans should I start ?*

Unsymmetric scans gather data in series of `ON-OFF-ON-OFF-...` where an `ON` is defined as having the radio source of interest in one of the two beams and where an `OFF` places the object in the other beam, whereas symmetric scans gather data in series of `ON-OFF-OFF-ON-ON-...` The `SYM`metric method is superior compared to the `UNSYM`metric one, as (a) it increases the observing efficiency (i.e. the telescope is moved half as often), and

(b) the data reduction algorithms allows allows for longer integration to be done without worrying too much about changes in the sky (though unsymmetric scans could in principle be reduced like symmetric one, the data reduction steps are in practice different – see section 7.2 for a description for the two data reduction algorithms).

→ *How much time is required for a detection ?*

A fairly good estimation of the time T in minutes of a single `ON-OFF` scan with subscans of standard length (i.e. 20 records) is

$$\boxed{T \simeq \texttt{Total\_number\_of\_records}/80}$$

which includes a 50% correction for telescope slew motions. As an indication, a scan with 16 subscans, each 20 records long, takes $\simeq$ 4 minutes. However, 32 subscans, each 10 records long take already more than 5 minutes. Note also that longer subscans will reduce the time overhead but tend to be more affected by atmospheric emissivity fluctuations.

The rms uncertainty in the measurement of the flux density can in principle be estimated to:

$$\delta S = \frac{\texttt{NEFD}}{\sqrt{N\Delta T}} \sim \frac{\sqrt{2}\cdot\texttt{NEFD}}{\sqrt{N}}$$

where N is the number of records in the scan, ΔT is the data acquisition rate (typically 500 msec) and where `NEFD` $\sim$ 50 mJy$\sqrt{\text{sec}}$/beam is the sensitivity for observations made with the 7 channel bolometer array (see also Appendix A, section Technical Specifications) under typical observing conditions ($\tau \sim 0.2$). For a radio source with a flux density of 10 mJy observed with subscans of standard length, we expect to achieve under such observing conditions a 5σ detection after $T = (\texttt{NEFD}/\delta S)^2/40 = 15\,\text{min}$.

→ *Can I use* `ON-OFF` *instead of* `ON-THE-FLY` *scans to map extended objects ?*

Yes, but for the time being we strongly recommend to carry out `ON-THE-FLY` observations to map extended radio sources. Please note that data taken on extended objects cannot be reduced using the `ON-OFF` task available under `NIC`.

5 Data Calibration

The `MPIfR` bolometers are extremely sensitive. However the use of such sensitive detectors implies that variations in the total background loading will cause variations in the instrumental responsivity, hence, introduce non-linearities in the calibration. Since the `MPIfR` bolometers have no internal calibration unit, the atmospheric transmission has imperatively to be measured as often as possible. As the atmosphere can vary significantly on very short timescales, shorter than the duration of most `ON-THE-FLY` scans, and across the sky, unsufficient 'monitoring' of the atmospheric transmission can be the limiting factor in your calibration procedure.

5.1 Skydip

A skydip is a sequence of measurements of the sky emission T_{sky} at almost equidistant air masses A that aim at a measure of the atmospheric zenith opacity τ_Z.

Contrary to heterodyne observations where the instrumental calibration is carried out from power measurements on an absorber at ambient temperature and on a load at liquid nitrogen temperature, current bolometer observations cannot make use of this calibration facility. As bolometer counts (power units) cannot be transformed directly to a flux density (or a surface brightness) scale, all bolometer data is stored in backend internal numbers. Hence, the counts expected from the bolometer (incoherent optics) are given by

$$\texttt{counts} \propto dP/d\nu = 2k\ M(\nu)\ f(\nu)\ J(\nu, T)$$

where $dP/d\nu$ is the power per frequency unit received from a source of temperature T, k is the Boltzmann constant, $M(\nu)$[11] are the number of modes, $f(\nu)$ is the transmission profile of the instrument, and $J(\nu, T)$ is the radiation temperature of the source. For the bolometer which operates in single-mode over almost the entire bandwidth (ν_L, ν_H) and whose transmission function can to first order be approximated by a top-hat profile, we can write

$$\texttt{counts} \propto P = 2k \int_{\nu_L}^{\nu_H} J(\nu, T)\ d\nu$$

The difference ΔP of the power detected from the sky P_{sky} and from the chopper blade P_{chp} (as the bolometer measures only variations of the total power) is given by

$$\Delta P = P_{sky} - P_{chp} = 2k \int_{\nu_L}^{\nu_H} [(1 - \eta_{eff})\ J(\nu, T_{amb}) + \eta_{eff}\ (J(\nu, T_{sky}) + J(\nu, T_{cb})) - J(\nu, T_{chp})]\ d\nu$$

where $T_{sky} = T_{atm}\ (1 - e^{-\tau_Z A})$ is the temperature of the sky in the Rayleigh-Jeans approximation (η_{eff} is the forward sky coupling efficiency), T_{atm} is the temperature of the atmosphere, T_{amb} is the ambient temperature (we assume that all losses due to the telescope which occur in front of the calibration chopper are terminated in the same temperature), $T_{chp} \sim T_{amb}$ is the temperature of the absorber, and $T_{cb} = 2.7\ e^{-\tau_Z A}$ is the temperature of the cosmic microwave background.

5.1.1 Estimation of the zenith opacity τ_Z $\boxed{NEW}$

The atmospheric opacity τ_Z is determined from fitting the precipitable water vapor to a standard atmospheric model (`NIC\SOLVE − ATM` J.Cernicharo and M.Bremer) according to the following set of input parameters:

- the skydip counts $\propto \Delta P$ at equidistant airmasses A,
- the effective (frequency averaged) forward efficiency η_{eff},

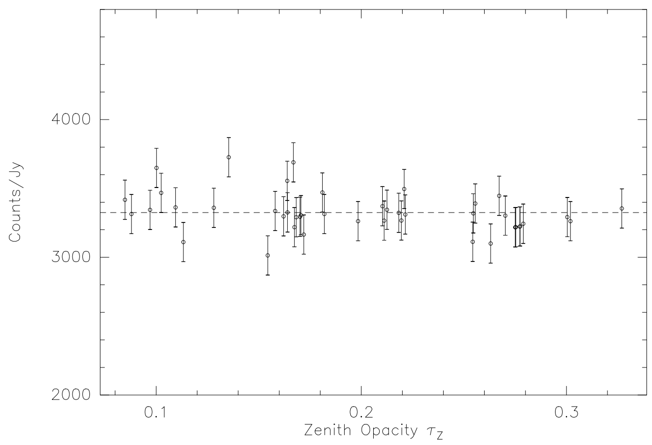
[9]The number of modes $M(\nu)$ in a circular waveguide is described by a quadratic step function $\propto (\nu/\nu_L)^2$ where $\nu_L = \mathtt{TE}_{11}/(2\pi\, a) \sim 200$ GHz (a is the inner radius of the guide) is the frequency at which the system radiates a single mode. The `MPIfR` bolometer optics is single moded up to the frequency of the $\mathtt{TM}_{01}$ mode ~ 260 GHz. Only the $\mathtt{TE}_{11}$ and $\mathtt{TM}_{01}$ modes are permitted.

NEW
- the bandpass profile $f(\nu)$ of the bolometer for which we assume unit transmission all over the 200 GHz to 280 GHz frequency range. The profile of Mambo II (MPIfR - 37 channel bolometer array) is enabled on option `/BAND`. Use variables `BAND_FREQ` and `BAND_TRANS` to define alternative instrumental bandpass profiles and `BAND_ATMOS` to retrieve the atmospheric transmissivity.
- the temperature T_{chp} of the chopping absorber,
- the ambient temperature T_{amb} and pressure P_{amb},
- the altitude of the site.

Together with seasonal variations of the standard atmosphere, the fitting procedure determines a mean temperature of the sky emission $T_{sky} \sim J(\nu, T_{sky})$, the apparent water content and the transmission $\tau = \tau_Z A$ at airmasses A for the effective frequency of the global passband profile (atmospheric plus instrumental). Since the amount of water vapour is the most variable constituant of the atmosphere, it is recommended to measure the atmospheric opacity as frequently as possible: at least, every hour.

5.1.2 Estimation of the counts per Kelvin conversion

Once a good convergence in T_{sky} and τ_Z is obtained, the conversion factor `counts/K` (internal backend counts per Kelvin) is computed. From the `counts/K` one might derive the `counts/Jy` conversion factor by taking the standard, however frequency dependent, `Jy/K` conversion value (`IRAM Newsletter 19, January 1995`)



The `counts/Jy` conversion factor was obtained from skydips on a period of 5 days on March 17th to 21th, 1995 by using a mean flux density per Kelvin conversion value of `10.8 Jy/K`. Despite large variations of the atmospheric zenith opacity, the `counts/Jy` conversion factor (close to `3300 counts/Jy`) remained remarkably constant throughout the observing period. The forward sky coupling efficiency was fixed to `0.86`

As shown in the figure (section 5.1.4) the measurement of the zenith opacity is straightforward under stable atmospheric conditions. The curvature of the skydip graph depends on the atmospheric opacity, which is fitted by varying the amount of precipitable water in a broad-band atmospheric model while cabine temperature and forward efficiency remain fixed. The signal is either positive or negative depending on the phasing of the load switch arrangement.

A few more remarks:

- Checking the `counts/Jy` conversion factor can almost be done instantaneously with skydips. However, we highly recommend to determine the absolute flux density scale from maps of small diameter planets, compact HII regions (or whatever) rather than from skydips. Moreover, as the two scaling factors should match, the skydip conversion factor qualifies the goodness of the atmospheric model fit.

- Though the normalized system response $f(\nu)$ of the MPIfR bolometer array(s) deviates strongly from a top-hat profile, the fitting time strongly depends on the sampling of $f(\nu)$ whereas the fitting accuracy will not. Indeed, the sky emission detected with a top-hat profile covering an equivalent frequency band (ν_L, ν_H) will not vary by more than 3%.
- Since skydips require maximum (`Ref_Gain = 9`) signal attenuation to match the dynamic range of the voltage to frequency converters (most observing is done at `Ref_Gain = 1`) non-linearities in the bolometer elements and in the signal amplification chain might affect the `counts/K` scale.
- Since the load switch phases (from the sky to the absorber or viceversa) are different for each channel, signal integration is started as the chopper wheel passes by the central channel (since the 1993 campaign `channel = 1` of the bolometer array). Hence fitting skydips for channels other than the central one will in general slightly go wrong.

5.1.3 Summary of Parameters $\boxed{NEW}$

Here are the names of the NIC variables used to reduce skydip scans:

INPUT:	◦ SIGNAL	the skydip counts $\propto \Delta P$	counts[6]
	◦ EL	the elevation of the telescope	degree
	◦ FORWARD_EFF	the mean forward sky coupling efficiency[7]	
	◦ CHOPPER_TEMP	the temperature of the hot load	Kelvin[8]
	◦ AMB_TEMP	the ambient (outside) temperature	Kelvin
	◦ AMB_PRES	the air pressure at the site	millibar
	◦ SITE_ALTITUDE	the altitude of the site	meter
	◦ [BAND_FREQ]	the frequencies defining the RF profile	GHz
	◦ [BAND_TRANS]	the transmission of the RF profile	
	◦ [BAND_ATMOS]	the atmospheric transmission profile	
OUTPUT:	◦ COUNTS_PER_K	the counts per Kelvin conversion factor	
	◦ SKYDIP_OPACITY	the zenith opacity of all reduced skydips	neper
	◦ SKYDIP_TIME	the universal time of all reduced skydips	second
	◦ WATER_VAPOUR	the amount of precipitable water vapour	millimeter
	◦ [BAND_ATMOS]	the atmospheric transmission profile	

See the next section for more detailed information on parameters BAND_FREQ, BAND_TRANS and BAND_ATMOS.

5.1.4 Solving the Skydips

The forward efficiency has to be known for a proper calibration. NIC assumes 0.86, as a default. Ask the staff if it has changed, and if yes, use the following commands to modify it:

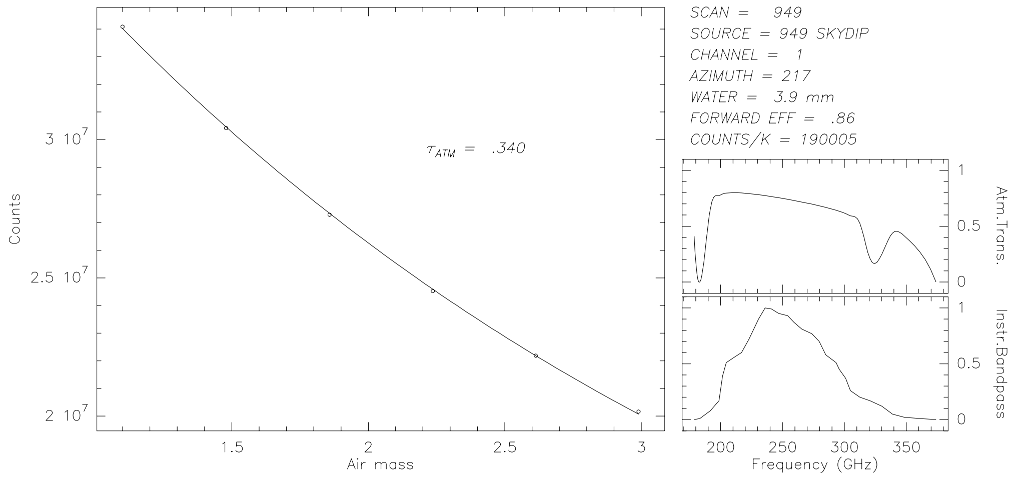
```
NIC> VAR ANTENNA WR
NIC> LET FORWARD_EFF new_value
```

[6] Jansky instead of counts if the counts/Jy conversion factor is active.
[7] A valid efficiency is in the range [0.7,1.0]. The forward efficiency is not in percentage.
[8] The software assumes a chopper temperature of 290 K in the case that its temperature is unknown.

Similar commands have to be supplied by hand for the ambient temperature and pressure if the weatherstation is not able to operate. In general, skydips are reduced all at once. Use the next commands to reduce a SKYDIP scan:

```
NIC> GET Scan_number
NIC> SET GAIN_AMPLIFIER ON
NIC> SOLVE /FILE
```

The SET GAIN_AMPLIFIER ON correction for the signal attenuation will not affect the computation of the zenith opacity. It will, of course, affect the determination of the counts/K conversion factor.



The SOLVE command generates a plot as shown above.

→ The small box on the lower right is the assumed instrumental bandpass profile (currently Mambo II, the 37 channel bolometer array of the MPIfR) whereas the box on top of it shows the calculated atmospheric transmission profile which is stored in variable BAND_ATMOS. The boxes are plotted only if option /BAND is used or if the profile is defined through the one dimensional variables BAND_FREQ and BAND_TRANS[12] that contain the frequency in GHz and the transmission coefficient normalized to one (not in percent). *Please note:* even if modifications of the instrumental bandpass function will produce only small changes in the opacity, the sky temperature (and the Counts/K factor), the amount of water and the atmospheric trasmission profile may change considerably. It is therefore important to use the same bandpass for all skydip reductions to obtain a consistent calibration.

Once you have reduced all skydips, NIC will apply a time-dependent opacity correction to a scan (except skydips, of course) by a linear interpolation of the opacity between the skydip preceding and the one following the scan. This is done with the command:

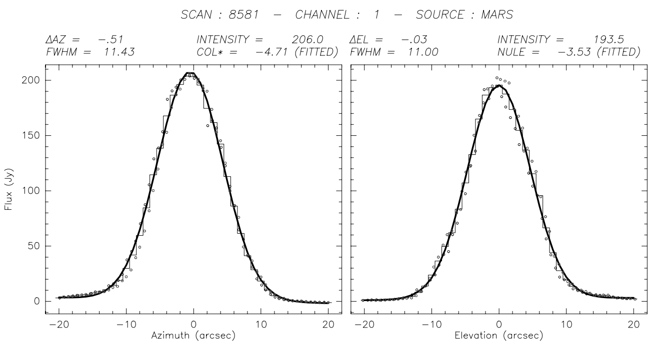
```
NIC> SET OPACITY ON
```

Although a linear correction is applied to all the records, NIC prompts back the mean zenith opacity used upon correction (stored in variable SCAN_OPACITY). Beware of switching between scans, since NIC activates opacity corrections for a scan only upon request.

[12] The three variables BAND_FREQ, BAND_TRANS and BAND_ATMOS have to be created via the DEFINE command in SIC (BAND_FREQ and BAND_TRANS need to contain the RF profile, BAND_ATMOS has to be left free), or have to be enabled via option /BAND, otherwise a profile with unity transmission in the frequency range from 200 to 280 GHz is assumed.

5.2 Pointing

A good knowledge of the relative pointing offsets of the individual beams within the multi-beam cluster is very important for `ON-THE-FLY` observations. With a single beam there is less guarantee of consistency of telescope pointing and this is particularly crucial in the case of `ON-OFF` observations of point sources. In order to achieve adequated sensitivity, `ON-THE-FLY` observations may be repeated several times, and even if there is no guarantee that successive coverages of the area will be correctly pointed, it is however required that the pointing within a single coverage with the multi-beam system remains consistent. Hence, the combination of several coverages of a given field, need absolute pointing errors to be removed from each individual map. This is quite a critical issue when there is no reliable correlation amongst the maps. In this case one has to rely on the pointing model of the telescope and to verify before and after the mapping its consistency.



The one sigma uncertainty limit in the determination of the pointing errors depends essentially on the intensity of the reference source and can roughly be estimated to half the beamwidth of the telescope times the signal to noise ratio in the peak. Unless repeated pointing measurements are carried out, errors below this uncertainty limit cannot be considered as significant. The plot on the left side was produced by the `SOLVE` command.

5.2.1 Summary of Parameters

Here are the names of the `NIC` variables used to reduce the pointing scans:

INPUT:

◦ `SIGNAL`	the pointing counts	`counts`
◦ `SCAN_COORD[1]`	the azimuth offsets	`tenths of arcsec`
◦ `SCAN_COORD[2]`	the elevation offsets	`tenths of arcsec`
◦ `COL*`	so-called azimuthal collimation correction	`arcsec`
◦ `NULE`	so-called null elevation correction	`arcsec`

OUTPUT:

◦ `BEAM_AZ`	the azimuth FWHP of the fit	`arcsec`
◦ `BEAM_EL`	the elevation FWHP of the fit	`arcsec`

The two variables `BEAM_AZ` and `BEAM_EL` are used to plot the telescope beam when using the `MAP` procedure supplied with `NIC`. Reset the two variables to zero to avoid plotting the beam. In the case of observations at the IRAM 30m telescope, the fitted corrections `COL*` and `NULE` (the ones shown in the plot) should be entered at the levels of `OBS` (the control program of the telescope).

5.2.2 Solving the Pointings

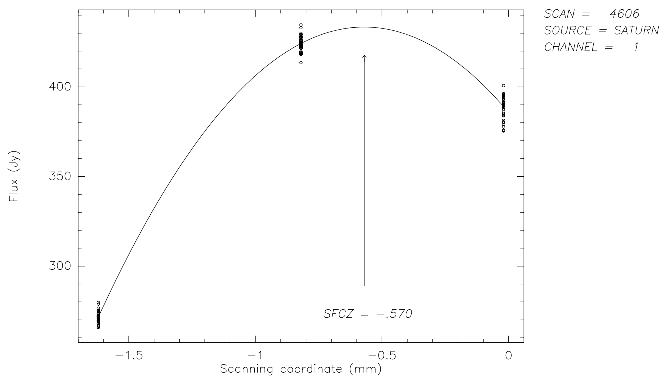
To verify the pointing of the telescope, select a pointing scan in `NIC` and reduce it with the `SOLVE` command, as follows:

```
NIC> GET Scan_Number
NIC> SOLVE
```

`NIC` selects the central channel (this is the default, see option `/CHANNEL` to change the reference channel) and plots the results of the fit as shown above. The fitted amplitudes are not corrected for errors in azimuth and elevation.

5.3 Focus

Focus variations are instrumental drifts to which (almost) every observation is subjected. These may result in changes in illumination, changes in receiver gain and so on. Since a field can be mapped so much faster with a multi-beam cluster compared to a single-beam system, the opportunity for such instrumental drifts during a field coverage is much less. A good observing strategy is to verify the focus stability as often as possible, with particular emphasys on the morning (sunrise) and on the evening (sunset).



The plot on the left side was generated by the `SOLVE` command. A parabolic fit on the central channel is done to determine the offset of the subreflector from its target position.

5.3.1 Summary of Parameters

Here are the names of the `NIC` variables used on input to fit the focus:

○ `SIGNAL`	the pointing counts	`counts`
○ `SCAN_COORD`	the focus offsets	`micron`

5.3.2 Verifying the Focus

To verify the focus, select a focus scan in `NIC` and reduce it with the `SOLVE` command, as follows:

```
NIC> GET Scan_Number
NIC> SOLVE
```

The software selects the central channel (this is the default, see option `/CHANNEL` to switch over the channels) and plots the results of the fit as shown above.

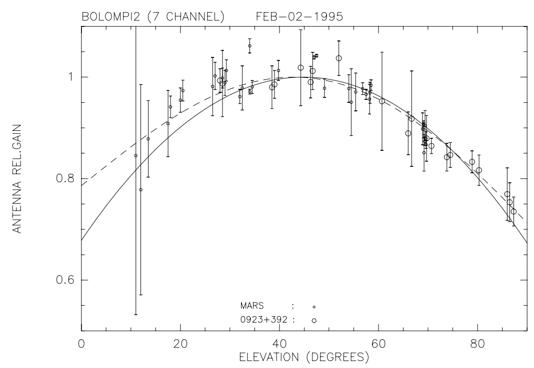
5.4 Gain-elevation correction

The on-axis gain of the telescope is a less known instrumental parameter at the frequency of 240 GHz. As the telescope moves to extreme elevations (low and high) quasi-random homology deformations appear which modify the on-axis sensitivity of the beam. Though the sensitivity drops by 10% to 20%, the shape of the main beam is mostly preserved. The curve is measured on quasars, compact HII regions, small planets and is generally used to correct the on-axis loss of sensitivity for small object, smaller than the size of the main beam. So far, we recommend use of this correction only for the central channel (i.e. `ONOFF` case - see also Greve, Neri, Sievers 1998, A&AS 132, 413).

To apply the standard gain-elevation correction[13], select a pointing scan in `NIC` and activate the correction with the `SET` command, as follows:

```
NIC> GET Scan_Number
NIC> SET GAIN_ELEVATION ON
```

Proceed similarly to switch off the correction. See the `ONLINE HELP` for more details on the command.



Continuous line : $c_0 = +0.6783$, $c_1 = +0.1436E-01$, $c_2 = -0.1602E-03$
Dashed line : $c_0 = +0.7862$, $c_1 = +0.7716E-02$, $c_2 = +0.1162E-04$, $c_3 = -0.2280E-05$, $c_4 = +0.1219E-07$

The curve on the left was measured under very good observing conditions by `ON-OFF` scans on Mars and 0923+392. The measurements, which are corrected for atmospheric opacity effects, provide up to now the best evaluation of this effect for bolometer observations. The continuous curve is currently used by the software.

[13] Greve, A., Neri, R., Sievers, A., 1998, *Astron.Astrophys.Suppl.Ser.*, 132, 413

6 Data Organization SECTION WILL SOON BE UPDATED

6.1 The Input Data

Currently, data acquisition is possible either via CAMAC or via DRUMBEAT[14]. Data via CAMAC is stored in the extensive format[15] available at the telescope for routine heterodyne observations, data via DRUMBEAT is stored in a format tailor-made for bolometer observations, the so-called NMB[16] format. However, the DRUMBEAT based data acquisition scheme is experimental, DRUMBEAT not being fully integrated in the backend system of the telescope; in particular focus, pointing and skydip scans are currently not supported by DRUMBEAT.

6.1.1 Raw Bolometer Data

There is a threefold advantage in using the NMB format for bolometer data: first, the bytewise coding is computer-independent (trouble-free binary file transfers with FTP), secondly, there is just one file per scan (in the case of raw 'heterodyne' data OBSINP generates two files per sub-scan) and finally, a NMB file needs ten to twenty times less diskspace, depending on scan type. For these reasons, NIC was designed to accept the NMB format which is also the only format currently supported by the NIC\FILE command. The NMB format has an ASCII readable header followed by data written in binary integers (data other than header information needs to be integer). The header section does not conform fully to the FITS standard, there are in particular no fixed length records and the majority of the header parameters does, presently, not have keywords.

In the NMB format a file is a scan, whether it is a FOCUS, an ON-OFF, an ON-THE-FLY, a POINTING or a SKYDIP. As the telescope nods in azimuth while it wobbles with the secondary, it records data samples every 250 ms, each data sample corresponding to a wobbler phase. The signal difference between two subsequent samples is called a record (these are the data points accessible under NIC), a sequence of records at constant elevation is called a subscan, and a sequence of subscans is called a scan.

6.1.2 Data Conversion Utilities

Since NIC needs input data in the NMB format, all the scans created during an observing session need to be converted to the NMB format. At the observatory, as soon as bolometer data is written to disk, a batch program named VAX_TO_NMB starts to convert the CAMAC data to the NMB format and to write files in the NMB format under your project account. Although conversion is also possible at your home institute by using a VAX/VMS specific conversion program, the advantage of the on-line utility is twofold: first, the outcome of the conversion is written to the file LOGBOOK.NMB, hence providing an immediate consistency check for the recording of raw bolometer data, and secondly, the amount of NMB data (and files) to transfer on other computers is far less important.

[14] DRUMBEAT (Digital Recording Using Multichannel BackEnd AT) is a digital backend developed at the MPIfR. DRUMBEAT's architecture is based on a M68030 processor which controls up to 64 (currently) counters with a D/A output for chart recording. The whole unit is controlled via an integrated 8086/286 Philips computer module.

[15] W.Brunswig, The Raw Data Format at the IRAM 30M Telescope, *IRAM document*, 1990
J.Schmidt, Data Recording Formats, *MPIfR document*, 1985

[16] T.Snijders, A description of the NMB file format, *IRAM document*, 1995 downloadable from World-Wide-Web at http://iram.fr/papers/reports/reports.html. The NMB (Nic2 Multi-Byte) data format was introduced by G.Haslam of the MPIfR.

Just in case software other than NIC is used to reduce the data, an additional utility is at your disposal that converts the binary NMB format to its ascii equivalent. NIC accepts both, the binary and the ascii NMB formats and identifies them by the extension name of the input file:

.asc extension for ascii NMB files. The filename is the four-figure number associated to the scan. The file is created via the conversion utility NMB_TO_ASC.

.nmb extension for binary NMB files (this is the default). The filename is the four-figure number associated to the scan. The file is created via the conversion utility VAX_TO_NMB.

The source code and the make files for both conversion utilities are obtainable upon request from nic@iram.fr.

6.2 The Output Data

Like for input files, there are two output formats for files created under NIC: the ASCII and the RG (Regular Grid) array format which is equivalent to the so-called GDF type IMAGE file format. We refer to the GREG MANUAL for a throughout discussion of the basic data structures (GDF files and internal buffers) supported by NIC. Commands executed with the /FILE option write results to, or read input parameters from ASCII files. Only the BASELINE and the FIT commands need RG files as input, however, not via the /FILE option.

Although the NIC language makes no requirements with regard to file extensions, some of the image processing task activated through the TASK language need files with definite file extension. Therefore, we recommend to use and keep all the following file extensions to ensure clarity:

.cnv extension for RG image files created and used for combining by the CONVERT task

.ekh extension for RG image files created with the RESTORE task and used by the CONVERT task,

.fit extension for ASCII files created with the FIT command,

.mdb extension for RG image files created with the MAKPLAN task and used by the RESTORE task,

.onf extension for ASCII files created with the ONOFF task,

.pol extension for ASCII files created and used by the SUPPORT command.

.sky extension for ASCII files created by the SOLVE skydip command.

Since NIC makes no use of the GRAPHIC language, RG image files cannot be accessed via the command IMAGE. So far, it is recommended to use the SIC\DEFINE IMAGE command in NIC or to switch to GRAPHIC for further image processing.

6.3 NIC variables

NIC provides a large set of SIC variables, most of which (see section NIC LANGUAGE INTERNAL HELP) can be addressed by read[17] and write operations. Scan associated variables are automatically updated on the FILE IN command, while other variables like those associated to the calibration are generally not. Computer memory is dynamically allocated on scan reading (files with the extension .nmb or .asc) to fit the size of the scan and of the scan associated variables. Some of the SIC variables (the indexed ones) are stored in shared memory regions in order to be accessible (as all the non-indexed variables) to external processes.

SIC variables are defined for most (if not all) data and can either be enabled or disabled using the group-specific command VAR. The same command is used to modify the read and write permission of any group of variables. We refer to the NIC LANGUAGE INTERNAL HELP section on how the SIC variables are grouped.

[17]For some of the permanently enabled variables only the read access is available.

6.3.1 Shared Memory

The NIC language comprises the VECTOR language which is documented in the GILDAS User Manual and Task Reference and which allows to run external processes (tasks like MAKPLAN, ONOFF, RESTORE, CONVERT in addition to all the tasks of the GILDAS library) under the NIC environment (i.e. with full access to all the non-indexed variables available in NIC). To have also access to indexed variables, like channel countrates, a shared memory identifier (variable DATA_SHMID, see also the online HELP section on the HEADER variables) has to be passed in addition to the external tasks. Hence with this address, external tasks will have read and write access to almost all variables in NIC. This has the advantage that software to be written and tested for the NIC environment will not need a recompilation of NIC.

The shared memory region is a sequence of indexed variables to which external tasks have read and write access. The memory region is organized in four sections, as follows :

→ General parameters :

◦ number_of_channels	NCHAN+NCALPOW	INTEGER*4
◦ number_of_parameters_section2	Number of parameters in section 2 (=5)	INTEGER*4
◦ number_of_parameters_section3	Number of parameters in section 3 (=4)	INTEGER*4

→ NIC variables of dimension NCHAN indexed by channel number : (section 2)

◦ CHAN_AZ_OFF	Nasmyth azimuth offset from radio axis at EL = 0	REAL*4
◦ CHAN_EL_OFF	Nasmyth elevation offset from radio axis at EL = 0	REAL*4
◦ CHAN_FLAG	channel flag. Flag unuseable channels via command FLAG	LOGICAL*4
◦ CHAN_RMS	rms of channel countrates obtained via command BASELINE	REAL*4
◦ CHAN_GAIN	channel gain normalized to the gain of the central channel	REAL*4

→ Variables of dimension NSUBSCAN indexed by subscan : (section 3)

◦ subscan_number	sequential identification number of subscans in a scan	INTEGER*4
◦ subscan_epoch	subscan start time (year plus fraction of year)	REAL*4
◦ subscan_time	subscan start time universal time	REAL*4
◦ NSUBREC	number of records by subscan	INTEGER*4

→ NIC variables of dimension NRECORD and NCHAN : (section 4)

◦ LST	local sideral time in seconds	[NRECORD]	REAL*4
◦ AZ	telescope encoder azimuth in degrees	[NRECORD]	REAL*4
◦ EL	telescope encoder elevation in degrees	[NRECORD]	REAL*4
◦ SIGNAL	channel countrates	[NRECORD,NCHAN]	REAL*4
◦ CALPOW	totalpower countrates	[NRECORD,NCALPOW]	REAL*4
◦ SCAN_COORD	azimuth and elevation scanning offsets	[NRECORD,2]	REAL*4
◦ n_support_mdb	number of points of MDB support		INTEGER*4
◦ SUPPORT_MDB	polygonal support for dual-beam maps	[*,2,NCHAN]	REAL*4
◦ n_support_ekh	number of points of EKH support		INTEGER*4
◦ SUPPORT_EKH	polygonal support for single-beam maps	[*,2,NCHAN]	REAL*4

The shared memory region is removed and recreated whenever the FILE IN command is executed. This allows NIC to adapt the amount of memory to the requirements. We recommend to the user that wishes to write programs in the environment of NIC to take a program, like

`MAKPLAN`, as an example.

7 Tasks

7.1 MAKPLAN

MAKPLAN creates double-beam maps of ON-THE-FLY scans. The task prepares the data for RESTORE. MAKPLAN uses the position variable SCAN_COORD to resample the data variable SIGNAL on an azimuth-elevation grid G. The data is gridded line by line (subscan by subscan), apodized in azimuth to the frequency cutoff of the telescope using the envelope of a sinc function tapered over a gliding window F, weighted according to the inverse density factor W required to obtain uniform data sampling and, finally, written to a file with the extension .mdb. The size of the gliding window is chosen to be 5× the beamwidth at the effective observing frequency. The weighting factor W is introduced to control the form of the beam, and its value is related to the area density of the data at any point j in the new grid:

$$W_j = \sum_F \frac{\sin u_j}{u_j} T_j$$

$$u_j = A \cdot \pi \cdot D/\lambda \cdot (j - \texttt{SCAN\_COORD})$$

where T is an optional apodization function and A is the ratio of the halfpower width of the gridding function W to the beamwidth of the telescope. T can either be truncated-gaussian (by default), parabolic, linear or equal to unity (no taper). So far, the i-th point of a specific line in the double-beam map G can be written to:

$$G_i = W_i^{-1} \cdot \sum_F \texttt{SIGNAL} \cdot \frac{\sin u_j}{u_j} T_j$$

Apodization in elevation is done according to the setting of the logical SMOOTH_EL. The grid cells are by default quadratic and their size is set either to the sampling interval in azimuth or in elevation, whichever is larger. However, different sizes in both directions can be set using variable MAP_CELL. Flagged channels are not reduced.

7.2 ONOFF

ONOFF produces tables of signal counts or flux densities, whichever is available, from ON-OFF scans. ONOFF lists for each channel, the horizontal and the equatorial offsets from the telescope's tracking center, and finally the mean signal and its standard deviation. The following steps are carried out for each channel k:

- compute the mean signal $< S_j(k) >$ and its variance $\sigma_j^2(k)$ for all subscans j
- only in the case of unsymmetric scans[18] (ON-OFF-ON-OFF-...) remove a baseline from the raw signal by least-square fitting to a straight line the weighted sequence of ON and OFF means:

  $< S_1(k) > + < S_2(k) >, \ldots, < S_j(k) > + < S_{j+1}(k) >, \ldots, < S_{N-1}(k) > + < S_N(k) >$

[18] In the unsymmetric case the mean is calculated for each pair of phases. A straight line is then fitted to the series of pairs, subsequently the difference between each phase and the straight line is calculated and the average of the differences between the two phases taken with the appropriate polarities. Fitting a straight line makes greater demand to the data than a simple average, and the noise necessarily increases. This is not the case of symmetric scans.

- only in case variable `NOISE` is true, remove the high frequency excess noise. In this case the task computes for the whole scan:

$$\begin{aligned} < S^{\,\texttt{ON}}(k) > \;&= \textstyle\sum_{j=1}^{N/2} < S_j{}^{\texttt{ON}}(k) > \sigma_j^{-2\,\texttt{ON}}(k) / \sum_{j=1}^{N/2} \sigma_j^{-2\,\texttt{ON}}(k) \\ < S^{\,\texttt{OFF}}(k) > \;&= \textstyle\sum_{j=1}^{N/2} < S_j{}^{\texttt{OFF}}(k) > \sigma_j^{-2\,\texttt{OFF}}(k) / \sum_{j=1}^{N/2} \sigma_j^{-2\,\texttt{OFF}}(k) \end{aligned}$$

  `ONOFF` then removes for all records i and for each channel k the difference between the signal and, depending on subscan, either $< S^{\,\texttt{ON}} >$ or $< S^{\,\texttt{OFF}} >$ averaged over all other channels except the reference[19] one:

$$S^i(k)^{\,\texttt{ON}} = S^i(k)^{\,\texttt{ON}} - \sum_{\substack{k' \neq 1 \\ k' \neq k \\ d(k',k) < d_M}} \frac{S^i(k')^{\,\texttt{ON}} - < S^i(k')^{\,\texttt{ON}} >}{\sigma_j^2(k')^{\,\texttt{ON}}} \Big/ \sum_{\substack{k' \neq 1 \\ k' \neq k \\ d(k',k) < d_M}} \frac{1}{\sigma_j^2(k')^{\,\texttt{ON}}}$$

  with a similar expressions for the signal in the `OFF` phase ($d(k', k)$ is the angular distance between channels k' and k and d_M is the maximum inter-channel distance[20] used for the noise removal). Alternatively[21], it is possible to remove a plane or a paraboloidal fit to the data instead of the weighted mean. After having removed the excess high frequency noise from all the channels, `ONOFF` then computes the mean noise corrected signal $< S_j >$ and its standard deviation σ_j.

- depending on the `COUNTS_PER_JY` conversion factor compute either counts or fluxes and the errors W by averaging all weighted differences between the `ON` and `OFF` phases:

$$S(k) = \frac{\sum_j W_j(k) \cdot (S_j(k)^{\texttt{ON}} - S_j(k)^{\texttt{OFF}})}{\sum_j W_j(k)}$$

  and where $W_j(k) = (\sigma_j^2(k)^{\,\texttt{ON}} + \sigma_j^2(k)^{\,\texttt{OFF}})^{-1}$.
- compute the estimated error on the flux density by calculating the average of the errors determined from the `ON` and `OFF` phases.
- write the baseline and noise corrected signals $S(k)$ back to variable `SIGNAL[`k`]`.
- and finally convert all the beam offsets from the horizontal to the equatorial frame of reference for the epoch corresponding to the source coordinates.

The results are written to files with the extension `.onf`. The format of the output can be changed with the `FORMAT` variable.

Avoid repetitive noise removal. If the fluctuations in two adjacent channels i and j are correlated, we expect to find the variance in both channels increased by the covariance $\sim \sigma_{ji}^2$ between the two channels. However, once the correlated term is removed, we expect the fluctuations to have faded away leaving uncorrelated noise with variance $\sigma_i^2 \approx \sigma_j^2$. Suppose the noise removal was very effective and no scrap of correlated noise is left, then every further attempt to reduce the fluctuations with `ONOFF` will fail. Indeed, as the fluctuations will be independent further removal will tend to increase on average the variance of the j-th channel by $\sim \sigma_j^2/M$, where M is the

[19] Sometimes the central channel is not the most sensitive one. In such case, it is preferable to observe the target source with an off-axis channel. The change the channel of reference use the `SET REFERENCE` command in `NIC`. Ask the astronomer on duty how observe with channels other than the central channel

[20] Use variable `ONOFF_FIT_DIST` to fix the maximum distance between channels.

[21] This is done by setting variable `ONOFF_FIT`. Setting the variable to `4` (i.e. automatic optimization) forces `NIC` to select the best solution (in terms of `RMS`) among the weighted mean, the plane and the paraboloidal fit.

number of channels from which ONOFF derives the correlated noise contribution.

Be aware that ONOFF data can be perturbed by low frequency noise that can create false positive or negative sources. Moreover, the low frequency skynoise variation can hardly be estimated (in general, not at all) and, so far, is not taken into account in the σ_j of the ONOFF results.

To avoid possible biases in the noise removal and flat-fielding process, channels which are within the OFF-beam of the telescope are not taken into account. The so-called channel avoidance region is currently preset to a size of 10.5″, equivalently to a beamsize (variable ONOFF_BEAM).

7.3 RESTORE

The most frequently-used method for making 'single-beam' maps from dual-beam data is implemented in RESTORE. It uses the Emerson-Klein-Haslam (EKH) algorithm,[22] a two-step process, in which the two-dimensional dual-beam map of the source is treated as a set of separate one-dimensional strips, so-called subscans. The following is executed:

- the dual-beam maps obtained via MAKPLAN are convolved with a function which filters out spatial frequencies of wavelength equal to multiples of the double-beam spacing, and
- the double-beam maps are convolved using a discrete "up-and-down" comb-like restoring function to deconvolve the maps of the dual-beam response due to the wobbling.

The first step is executed if the relative gain [23] of the ON to OFF beams is either equal to plus or to minus one (UNBAL= ± 1), the second one is executed if RESTORE_FILTER is true. Finally, if variable RESTORE_MASK[24] set to true, RESTORE restricts both steps to a region within a polygonal support defined via the SUPPORT command. Flagged channels are not reduced.

7.4 SHIFT_AND_ADD

The SHIFT_AND_ADD method for making 'single-beam' maps from dual-beam data is recommended when there is a clear-cut separation of the ON and OFF images. This is the case of many filamentary structures, edge-on galaxies, and all object for which wobbling "in-the-object" can a priori be avoided. Contrary to RESTORE the single-beam maps are computed directly from variable SIGNAL) (the calibrated temporal sequence of dual-beam data) and *not* from the dual-beam maps obtained via MAKPLAN. The position variable SCAN_COORD is used to resample the data variable SIGNAL on an azimuth-elevation grid G. The signal is displaced by half the effective ON to OFF beam separation BEAMSEP once towards positive azimuths and once to negative azimuths, is gridded line by line (subscan by subscan), apodized in azimuth to the frequency cutoff of the telescope using the envelope of a sinc function tapered over a gliding window F and weighted according to the inverse density factor W required to obtain uniform data sampling. The size of the gliding window is chosen to be $5\times$ the beamwidth at the effective observing frequency. The weighting factor W is introduced to control the form of the beam, and its value is related to the area density

[22] Emerson,D.T., Klein,U., Haslam,C.G.T, 1979, *Astron.Astrophys.*, 76, 92

[23] Use the FIT command on a double-beam image of a strong and compact object to determine FIT_AMP_POS and FIT_AMP_NEG, the amplitudes of the ON and OFF beams, compute the ratio of the two variable arrays and set UNBAL to the sign inverted mean value.

[24] By default RESTORE_MASK=NO, RESTORE_FILTER= YES and UNBAL= 1. Use negative values of UNBAL to swap the ON and OFF beams.

of the data at any point j in the new grid:

$$W_j = \sum_F \frac{\sin u_j}{u_j} T_j$$

$$u_j = 2 \cdot A \cdot \pi \cdot D/\lambda \cdot (j - \texttt{SCAN\_COORD})$$

where T is an optional apodization function and A is the ratio of the halfpower width of the gridding function W to the beamwidth of the telescope. T can either be truncated-gaussian (by default), parabolic, linear or equal to unity (no taper). So far, the i-th point of a specific line in the single-beam map G can be written to:

$$G_i = W_i^{-1} \cdot (\sum_F \texttt{SIGNAL}_j \cdot \frac{\sin u_j}{u_j} T_j - \sum_{F'} \texttt{SIGNAL}_k \cdot \frac{\sin u_k}{u_k} T_k)$$

However, depending on variable `SAA_MASK` two different processes are executed:

- `SAA_MASK` is set to false/`NO`: only data inside a window whose limits are defined by half the beam separation from either side of a line of position angle `PA` and whose equatorial offsets from the tracking center of the telescope are given in `OFFSET`, is retained.
- `SAA_MASK` is set to true/`YES`: only data inside a polygonal support defined via `SUPPORT` is retained. Note, however, that the boundaries of the support region are equally clipped in each line (subscan) to the effective separation of the `ON` and `OFF` beams.

Finally, the retained data is written to a file with the extension `.saa`. Apodization in elevation is done according to the setting of the logical `SMOOTH_EL`. The grid cells are by default quadratic and their size is set either to the sampling interval in azimuth or in elevation, whichever is larger. However, different sizes in both directions can be set using variable `MAP_CELL`. As for `RESTORE` compute `UNBAL` from the mean sign inverted ratio of the `ON` to `OFF` beam amplitudes. Flagged channels are not reduced.

7.5 CONVERT

`CONVERT` produces files that contain two planes: the source in the first, the weighting function in the second. The `MAP` procedure plots the weights if the variable `PLOTWEIGHT` is true (Default value of `PLOTWEIGHT` is no). Depending on variable `SCAN_LIST` two different processes are executed:

- `SCAN_LIST` is left open: `CONVERT` combines the single-beam maps of all unflagged channels which were obtained with `RESTORE` or with the `SHIFT_AND_ADD` technique to a single equatorial map. The horizontal maps are weighted with their one sigma noise level[25] squared, shifted to a common reference position, transformed to the equatorial frame of reference and, finally, combined to a single map. By default, `CONVERT` uses the same gridding function as `MAKPLAN`.
- `SCAN_LIST` contains a list of scans: `CONVERT` creates a mosaic from the equatorial maps associated with a list of scans. Each map is weighted according to its weighting function, shifted to the common center of reference, and added. Modify the center of reference and the size of the mosaic by setting the appropriate input variables. Type `INPUT CONVERT` to verify the content of the variables. As `CONVERT` produces mosaics with the source name as filename, use command `MAP Source_Name` to plot the results.

[25] The one sigma noise level is written to variable `CHAN_RMS` by the `BASELINE` command.

8 NIC Language Internal Help NEW

We give here a *fac simile* of the internal HELP file for NIC. In case of trouble, the user should refer directly to the internal help which is always accurately kept up to date. Type HELP NIC\ for the list of command currently available in NIC.

8.1 BASELINE NEW

```
NIC\BASELINE [/BYSUBSCAN] [/CHANNEL Bolometer_channel]
             [/CORR Number_of_Records] [/PEN Color]
             [/FILE [Filename [NEW]]]
             [/NOISE [Number_of_Points [Beam_separation]]]
             [/ORDER [Order]] [/SUPPORT [Az+ [El+ [Az- [El-]]]]]
```

```
This command has diverse effects: the removal of correlated noise using
option /NOISE, the removal of baselines of order Order using option
/ORDER, and the definition of support regions which can either be defined
interactively or using the option /SUPPORT (not supported anymore).
  A baseline correction is applied to the variable SIGNAL according to the
focal positions of the bolometer channels and to the slope of the signal
outside of the polygon. The focal positions are read from the variables
CHAN_AZ_OFF and CHAN_EL_OFF. Baseline corrections to be applied only on
definite channel need option /CHANNEL. Retrieval of the fitted baseline
is only possible via SIC\ commands.
  The NOISE option is currently experimental. It removes noise from the
variable SIGNAL (use option /CHANNEL for individual channels) according
to a channel to channel noise correlation matrix and to a defined sup-
port. The correlation matrix is time dependent and is computed using a
sliding window whose extent in seconds is equal to the Number_of_Points
divided by two. The mean noise correlation coefficients are computed
from the variable SIGNAL and is plotted vs the separation of the beams
if option /CORR is specified. Only records outside the support are used.
With option /NOISE the correlated noise term is removed from the beams
(i.e. variable SIGNAL - a single iteration is sometimes required).
Option /NOISE and /ORDER are mutually exclusive.

       /BYSUBSCAN        : fits independently subscan by subscan
       /CHANNEL          : a channel number (Default is channel 1)
       /CORR             : show mean correlation coef vs beam separation
                           The parameter is the size (= number of records)
                           of the window over which the correlation
                           coefficients are calculated (Default = 61)
    [  /FILE     ]       : file rd/wr for polygon support (Default = read)
                           See also command SUPPORT. /SUPPORT is not
                           supported any more.
```

```
    /NOISE          : compute correlated noise with the parameter
                      as for option /CORR and remove it. In addition
                      it is possible to use only the noise computed
                      on channels up to a definite beam separation
                      (in arcs). (Default is maximum separation)
    /ORDER          : order of polynomial (Default is 0 = const)
    /PEN            : added to option /CORR plots the result in the
                      present box with a new pen.
 [  /SUPPORT  ]     : defines the polygon for baseline removal
                      Four optional arguments define the frame of the
                      support region. Each argument is the distance
                      in arcsecs from the map center. With no argu-
                      ments it defines a rectangular region that
                      extends up to 12 arcsec from the edges of a
                      double-beam map. See also command SUPPORT.
                      /SUPPORT is not supported any more.
```

8.2 CHECK NEW

```
NIC\CHECK [/REPAIR]
```

Though breakdowns in data acquisition should never occur, CHECK finds out whether the dataset lacks of records (of course it never retrieves any lost data). The command checks for consistency in time, azimuth and elevation. NIC flags data records which are affected by big timing problems when option /REPAIR is used.

```
    /REPAIR         : flags some problematic data records
```

8.3 DESPIKE

```
NIC\DESPIKE [/FUNCTION [Filter [Parameter]]] [/XRMS Threshold]
 [/WINDOW Window] [/ITERATION Number] [/CHANNEL List_of_channels]
 [/INTERPOLATE]
```

Remove spikes (cosmic, microphonic,...) from data stored in the two-dimensional variable SIGNAL. DESPIKE replaces spikes with a blanking value (fixed to -99999.5) if option /INTERPOLATE is not used. Remove the baseline first if you wish to use /XRMS, since the RMS threshold is in units of the Root-Mean-Square of SIGNAL and not of the standard deviation from the mean.

```
    /FUNCTION       : available Filters are 1 (Default), 2 and 3
                        1 = variable width (= Parameter) sin(x)/x
```

```
                             2 = gradient filter
                             3 = level cutting, no filtering
     /XRMS                : RMS threshold after filtering (Default=5)
     /WINDOW              : window in record units for RMS (Default is scan)
     /ITERATION           : number of iterations (Default = 1)
     /CHANNEL             : a list of channels (Default is all channels)
     /INTERPOLATE         : replace spikes by linear interpolation of
                            adjoining data (Default is no interpolation)
```

8.4 FIELD *NEW*

```
NIC\FIELD [/DECL [Delta]] [/HOUR [hour_angle]] [/SMEAR [Time]]
          [/SIZE [Az [[El]]] [/SKEW [Azimuth]]
          [/NMB Scan_Number Wobbler_throw Number_of_channels]
          [/NOFRAME [Offset_RA [Offset_DEC]]]
          [/NOISE Mean_Rms Mean_Corr]
```

The command FIELD has two different actions: the /SMEAR option (see next paragraph) is used to compute the beam smearing on the sky, while any other combination of options is used to trace the field to map with the on-axis beam (central channel) in the case of ON-THE-FLY scans. In his case the /DECL option, in conjunction with /HOUR and /SIZE is used to fix in time (hour angle) and space (size of the field to map) the observations. The hour angle is the time at which the central channel goes to the center of the field. Option /SKEW allows to add an offset to the mean azimuthal position of subsequent scans. Option /NOFRAME has to be specified to overlay several field coverages. FIELD allows to estimate the time (rounded to the next 5 minutes) to cover a field with the central channel of a multi-beam cluster. If the HEADER variables are not defined through the last scan (watch for pointing scans for which VAZM usually varies between 80 and 120 arcs/min), standard default values are taken for TELESCOPE (Pico Veleta), for SINT (4 arcs) and for VAZM (4 arcs/sec). An 11 arcsec wide beam is plotted in the field center and the scanning direction towards positive azimuth coordinates is plotted for the first subscan. An empty NMB file which can be used as input for the SIMULATE command is created with the /NMB option. Currently, it produces empty files for bolometer arrays with 7, 19, or 37 channels (see also command SIMULATE). Option /NOISE in conjunction with /NMB adds high frequency noise with a RMS as given by Mean_Rms and with a mean degree of correlation between adjacent pairs of channels as given by parameter Mean_Corr.

The action of the FIELD command differs for the /SMEAR option. In this case it plots the beam smearing on the sky for arbitrary beam offsets from the central beam and a given integration time. The thin contours delimit seven shaded regions from bright to dark in steps of 10%, 20%, 30%, 40%, 50% and 100% of the smearing in a declination vs hour angle diagram. That is, for beams at 45" from the central channel and a given integration time, the blank field identifies the regions in declination and hour angle where the smearing is expected to be less than 10%, or 4.5" equivalently. The two thick lines delimit the region of observability: the open line which drops at the meridian identifies the 20 deg elevation limit, the oval around zenith is the 80 deg elevation limit. The asymmetry of the diagram is due to the elevation dependent rotation of the multi-beam cluster on the sky. The sign of the hour angles might invert depending on the number of intervening mirrors in the optical path.

```
/DECL            : source declination (Default is 00:00:00.0)
/HOUR            : a valid hour angle (Default is transit)
/NMB             : create an empty NMB format file of the map.
                                      (Default is scan number 9999)
/NOFRAME         : overlay other fields offsetted by an Offset_RA
                   and an Offset_DEC to be specified in arcs
                                      (Default are zero offsets)
/SIZE            : Azimuth and Elevation size of the field
                                      (Default is 200" 100")
/SKEW            : subscan to subscan azimuthal displacement
                                      (Default is 0 arcsec)
/SMEAR           : specify integration time (Default is 20 min)
```

8.5 FILE

```
NIC\FILE IN [Directory]Scan_Number
```

Selects the input scan. Valid scan extensions are ASC and NMB (= Default). Scan_Numbers are in the range 0 to 9999. Logical directory assignment is possible via bolo_data: (e.g. SIC LOG BOLO_DATA: "/users/bolometer/data/") or at the level of the ~/.gag.dico file.

8.6 FIND

```
NIC\FIND [/SCAN [Scan_first [Scan_Last]]] [/FILE [Filename]]
         [/TYPE Scantype] [/EXTEN [ASC|NMB]] [/SOURCE Sourcename]
         [/WAIT [Before [After]]] [/APPEND]
```

Lists the scan number, the scan type and the source name of a selected range of scans located on the directory pointed by the logical BOLO_DATA: Scantype is either FOCUS, ON-OFF, ON-THE-FLY, POINTING, SKYDIP or UNKNOWN and can be abbreviated. In case of Scantype ON both ON-OFF and ON-THE-FLY scans are listed. Sourcename is a substring of the source name. Variable

SCAN_SEQUENCE of dimension FOUND contains the scan list. Option /WAIT is required at the telescope when data reduction has to be suspended until a new scan is completed. Use CTRL-C to stop finding. Note that on CTRL-C variables FOUND and SCAN_SEQUENCE still contain the list of found scans. Use command LIST to list the scans found with the last FIND.

```
/APPEND          : appends a list of scans to a previous one
/EXTEN           : scan type, either ASC or NMB (Default is NMB)
/FILE            : write output to filename (Default is screen)
/SCAN            : valid range of scans (Default is all scans)
/SOURCE          : name of the source (Default is all sources)
/TYPE            : select type of scan (Default is all types)
/WAIT            : seconds to wait before and after selection
                         (Default is 5 sec before, none after)
```

8.7 FIT

```
NIC\FIT [/INPUT Filename] [/CHANNEL Bolometer_channel]
  [/FUNCTION function_code [param1 ... param6]]
  [/FILE [Filename [NEW]] [/LEVEL Percent]
```

This command fits a function on a image file (*.mdb, *.ekh or *.cnv). By default, the input file is defined by NIC variables SCAN and TYPE. For double-beam maps, only circular gaussians are fitted and the wobbler throw, BEAMSEP, is evaluated. BEAMSEP is used by the RESTORE procedure. The channels offsets are computed if input file is of type mdb or ekh. All results are written to the NIC variables of the section FIT. Specify a threshold in percent (values below and downto zero level are blanked for fitting) by using option /LEVEL. The fitting algorithm uses a subroutine of the NAG library or, if NAG is not available, a subroutine of the SLATEC library. Depending on file type FIT lists:

MDB: Channel (Col1), offset positions of the positive beam (Col2/3), offset positions of the negative beam (Col4/5), intensity of the positive and negative beams (Col6/7), gaussian circular width (Col8), sigma of the fit (Col9) and fit goodness (Col10). In NAG context, fit is good when ifail=0. In SLATEC context, fit is good when info=1,2 or 3.

EKH: Channel (Col1), offset positions of the beam (Col2/3), intensity (Col4), either circular width (Col5) and telescope elevation at the position of the beam (Col6) or major, minor axis and position angle of the beam (Col5/7), sigma of the fit (Col9) and fit goodness (Col 10).In NAG context, fit is good when ifail=0. In SLATEC context, fit is good when info=1,2 or 3.

```
CNV: Plane (Col1), offset positions of the source (Col2/3), inten-
          sity (Col4), either circular width (Col5) and mean telescope
          elevation (Col6) or major, minor axis and position angle of
          the source(Col5/7), sigma of the fit (Col8) and fit goodness
          (Col10). In NAG context, fit is good when ifail=0. In SLATEC
          context, fit is good when info=1,2 or 3.

        /INPUT            : select input file (Default is 'SCAN'.'TYPE')
        /CHANNEL          : a channel number (Default is all channels)
        /FUNCTION         : available functions are 1 and 2 (default is 1)
                               1 = circular gaussian
                               2 = elliptic gaussian (only *.ekh and *.cnv)
                             param1 ... param6 can be used to set the start
                             parameters (x,y,amplitude,major,minor,angle)
                             x,y       :  the position in arcsec
                             amplitude :  the amplitude in map units
                             major     :  the major axis width in arcsec
                             minor     :  the minor axis width in arcsec
                             angle     :  the position angle in degrees
        /FILE             : define output filename (Default is Scan_number)
                             If the file is called "nic.fit" and is located
                             on your local directory, NIC will use it (watch
                             message when it gets started) to retrieve beam
                             parameters for different epochs. An epoch is
                             defined by FIT results obtained for two scans
                             well separated in time.
                             scan for all scans observed later on.
        /LEVEL            : define a threshold (No Default)
```

8.8 FLAG *NEW*

```
    NIC\FLAG [/CHANNEL List_of_channels] [/SUBSCAN List_of_subscans]
             [/RESET]

  Flag a list of channels. If option /SUBSCAN is selected, flag (or reset)
  only the subscans specified. The syntax for a List_of_channels and a
  List_of_subscans allows to specify one or more ranges of subscans. FLAG
  without options lists currently active flags.

        /CHANNEL          : a list of channels (Default is all channels)
                          : ex: /CHANNEL 1 7 9 flags channels 1, 7 and 9
        /SUBSCAN          : a list of subscans
                          : ex: /SUBSCAN 6 to 9 13 flags 6, 7, 8, 9, 13
        /RESET            : reset flag (Default is all channels)
```

8.9 GET

```
NIC\GET [F]|[L]|[N]|[P]|[Scan_Number]
```

Load a scan. GET with option F loads the first scan in the list of scans found with command FIND, with option L the last scan. GET N, which is the default, loads the next scan, with option P the previous one. GET with option Scan_Number loads the specified scan from the BOLO_DATA: directory.

8.10 HEADER NEW

```
NIC\HEADER [/FILE Filename [NEW]]
```

Lists scan related information. The display output depends on the scan type. Complementary information can be retrieved with the SHOW command. HEADER provides information on source name, observing mode, scan number, source coordinates and epoch, throw and period of the wobbler, signal attenuation coefficient, date of observation and, in the case of mapping observations, size of the field and skew.

```
/FILE             : writes the information to disk
```

8.11 INFO

```
NIC\INFO
```

Informs about the history of modifications NIC has gone through since February 1996.

8.12 LIST

```
NIC\LIST [/SUBSCAN]
```

LIST echoes the lists of scans retrieved by the last FIND command. On option /SUBSCAN it lists the subscan numbers and the corresponding start times (LST, UT and the hour angle) of a single scan. Column 2 lists the year and the fraction of year (day), column 3 lists the time in seconds. Column 4 lists the hour angle of the source for ON-THE-FLY and ON-OFF scans.

```
/SUBSCAN          : lists the subscans within a scan
```

8.13 POWER

```
NIC\POWER /SCAN First_scan [Last_scan]
```

```
Use POWER to retrieve total power data from individual scans or from
a sequence of maximum 20 scans. The command prepares variable POWER
for read-only access with TOTPOW[1] = UT, TOTPOW[2] = EL and TOTPOW[3]
.. TOTPOW[N] = total power data from total power channel 1 to N-2.

      /SCAN           : to select NMB files
```

8.14 SET

```
NIC\SET Something [Value1 [Value2 [...]]]
```

```
This command is used to set a value for a NIC parameter.
```

8.14.1 SET BEAM

```
NIC\SET BEAM [Azimuth [Elevation [Gain]]] /CHANNEL Number /DEFAULT
```

```
Specify the beam for a single channel. Parameter are relative Azimuth,
relative Elevation, and relative Gain. All parameters are with respect
to a previously defined reference channel. Enter "=" where no modifica-
tion is required.

     /CHANNEL          : a bolometer channel (no Default)
     /DEFAULT          : reset to default values (if available)
```

8.14.2 SET GAIN_AMPLIFIER

```
NIC\SET GAIN_AMPLIFIER [State [Attenuation]]
```

```
The amplifier gain correction is applied if State is ON (Default).
State OFF disables the correction. Enter Attenuation, an integer
value between 1 and 9, if variable BOLGAIN, the amplifier gain cor-
rection is set to zero. Variable SIGNAL is scaled according to

     SIGNAL = SIGNAL x 2^(BOLO_GAIN-1)

State ON sets variable AMPLIFIER_FLAG to true, State OFF to false.
To find out the gain correction use command HEADER or check the
```

content of variable BOLGAIN.

8.14.3 SET GAIN_ELEVATION

```
NIC\SET GAIN_ELEVATION [State [Coef1 [Coef2 [...]]]]
```

```
The gain elevation corrections are computed and applied to the variable
SIGNAL to correct for the on-axis sensitivity of the beam. For more
details on the gain elevation curve refer to section 5.4. The mean
correction is written to variable MEAN_GAIN_CORR. Default State is ON.
State OFF disables corrections and equals GAINE_FLAG to zero. The gain
elevation curve is defined as a power series in elevation (deg).

         Normalized Gain = Coef0 + Coef1.El + Coef2.El^2 + ....

Up to 8 polynomial coefficients are allowed. If not specified (and only
if available) the default gain elevation curve will be used instead.
We recommend to use the gain elevation correction only for ON-OFF
observations of on-axis objects.
```

8.14.4 SET GAIN_CHANNEL

```
NIC\SET GAIN_CHANNEL [State [Gain1 [Gain2 [...]]]]
```

```
The channel gain corrections are computed and applied to the variable
SIGNAL. Default State is ON. State OFF enables the corrections. It is pos-
sible to specify a gain coefficient for each channel. If not specified
(and only if available) default gain corrections will be used instead.
State ON equals variable GAINC_FLAG to true, State OFF to false. Note
that the SET BEAM command and the SIC\LET CHAN_GAIN command operate on
the same Gain coefficients. The coefficients are multiplicative factors
which are used to correct for differences in the instrumental response
of the channels. As the gain of the reference channel is normally used
as reference (= set to unity), gains larger than one are required for
less sensitive channels.
```

8.14.5 SET JANSKY

```
NIC\SET JANSKY State [Counts/Jy]
```

```
A counts per Jy conversion factor is applied if State is ON. State OFF
disables the correction. You have to enter the conversion factor as an
additional argument in the command, and not by changing COUNTS_PER_JY.
```

State ON sets variable JANSKY_FLAG to true, State OFF to false. The counts/Jy conversion factor is used to convert count rates to flux densities once the amplifier gain correction (BOLGAIN) and the relative channel gain corrections are activated.

8.14.6 SET OPACITY

```
NIC\SET OPACITY [State [Opacity]]
```

An atmospheric opacity correction is applied if State is ON (Default). State OFF disables the correction. The correction is computed from a linear interpolation of zenith opacities derived from adjacent skydips. If no interpolation is possible, a constant extrapolation is done (... watch messages). Enter zenith opacities by hand if you have rock solid values. State ON sets variable OPACITY_FLAG to true, State OFF to false.

8.14.7 SET REFERENCE

```
NIC\SET REFERENCE Bolometer_channel
```

Enter a new reference channel by its logical number. Observations carried out with a reference channel other than the bolometer channel 1 (=central channel) need to be re-referenced using this command. Bolometer array properties remain unchanged.

8.15 SHOW

```
NIC\SHOW
```

This command is used to display NIC's main parameters. The display is with no claim to completeness.

8.16 SIMULATE NEW

```
NIC\SIMULATE /SCAN Scan_Number [UPDATE] [/INPUT File_Name]
             [/GAUSS x y z b]
```

This command is used to simulate observations taken with an N channel bolometer. Scan_number is an NMB file which is used as a template (you may use either a scan created via FIELD, or an "observed" one) and which

```
fixes the size of the signal array, its orientation in the sky, the
number of bolometer channels and the wobbler throw. The /INPUT file
requires an equatorial gildas image of the source. Its center is made
to coincide with the NMB map. Map coordinates need to be in radians.
Alternatively, one may use the /GAUSS option to have a Gaussian source
as input image. Gaussian parameters are in arcsec. Simulated observations
overwrite the SIGNAL variable. With parameter UPDATE simulated data is
also written down to file "Scan_Number.nmb". Use input files or Gaussian
beams with amplitudes in the working range of the bolometers (i.e.
counts: 100 - 100000 or mJy: 10 - 10000 depending on the unit in use).

Example:    field /decl 57:34 /hour 3 /size 400 300 /nmb 4527 46 37
            simulate /scan 4527 /input myimage.gdf

       /SCAN            : The reference number of an NMB file (No default)
                          which needs to be on your local directory
       /INPUT           : The equatorial image (default extension: .cnv)
       /GAUSS x y z b
                          x,y       :  gaussian position in arcsec
                          z         :  gaussian amplitude in map units
                          b         :  gaussian width in arcsec
```

8.17 SOLVE NEW

```
    NIC\SOLVE [/BEAM Beam_size] [/CHANNEL Number] [/FILE Filename]
              [/TRUNCATE Number_of_edge_pixels] [/ALL]

Gives the main parameters of a calibration scan, such as focus offset,
pointing offsets... for a selected channel. Pointing scans are process-
ed by gaussian fits. Widths (FWHM) as well as offsets in azimuth and
elevation are in arcsecs. Intensities from pointings are either in counts
or Jansky depending on variable COUNTS_PER_JY. Focus corrections are
processed by a parabolic fit and are in microns. Atmospheric opacity is
currently provided by skydips. The opacity is written to array variable
SKYDIP_OPACITY, the time (UT) of the skydip to SKYDIP_TIME and the sol-
ved skydip number to NSKYDIP.The user is allowed to reset both the array
variables SKYDIP_OPACITY and SKYDIP_TIME by setting NSKYDIP to zero.
The mean opacity of a scan is written to SCAN_OPACITY. File "nic.sky"
(created via option /FILE) is read once you enter NIC (watch message
"Retrieving SKYDIPs ...") to avoid repeated solving.

Use option /ALL to make a 2D-map of a pointing scan and to fit a
double-beam to the map. Use this option to retrieve the pointing
parameters of the telescope (= col* and nule) i.e. whenever the
central channel is off by more than a beam.
```

```
/ALL              : takes all channels into consideration
/BEAM             : fix beam size to fit POINTING scans
/CHANNEL          : selected channel (Default is channel 1)
/FILE             : add result to file (only for SKYDIPs)
                                   (Default is file "nic.sky")
/TRUNCATE         : drop edge pixels when fitting POINTING scans
```

8.18 SUPPORT

```
NIC\SUPPORT [par1 [par2 [par3 [par4]]]]
            [/FILE [Filename [NEW]]] [/CURSOR] [/DELETE]
```

A support region is required for baseline removal, for the RESTORE task with active masking and other stuff. In the interactive case type R (or left mouse button on X11 displays) to define the first summit of the support region, L (or middle mouse button) to move to the next summit, and E (or right mouse button) to end the polygon definition. The polygon will automatically be closed. A polygon is defined via a map. For proper operation a bitmap color device is required.

Defines the summits of a polygon, non-interactively using option /FILE or with one to four parameters. It assumes equatorial coordinates in the case of CNV files and horizontal for MDB, EKH and SAA files. On option /FILE it reads the summit coordinates from a file, unless parameter NEW is specified in which case it writes the current summit coordinates to disk. All coordinates are relative to the image center.

```
/CURSOR           : use cursor to define polygon summits
/DELETE           : remove a previously defined support
/FILE             : read or write polygon summits to disk
par1 .. par4        Four optional arguments define the frame of the
                    support region. Each argument is the distance
                    in arcsecs from the map center. With no argu-
                    ments it defines a rectangular region that
                    extends up to 12 arcsec from the edges of a map.
```

8.19 VARIABLES

```
NIC\VARIABLES Section [State] [Access]
```

This command is used to enable/disable NIC variables of one of six sections. Additional information is available for each of the sections. "*" enables all the sections. Parameter State is either ON or OFF, default is ON. Parameter Access can either be READ (Default) or WRITE. Variables which are enabled by default are marked with a [Def] in the sections. There is only READ access for some of these. Variables with a [No] still need to be implemented.

8.19.1 VARIABLES ANTENNA

```
NIC\VARIABLES ANTENNA [ON]|[OFF] [READ|WRITE]

Antenna Section ------------------------------------   Name of SIC variables

telescope () =                   character*8  x 1    - TELESCOPE
site_altitude (m) =              real*4       x 1    - SITE_ALTITUDE
site_latitude (rad) =            real*4       x 1    - SITE_LATITUDE
site_longitude (rad) =           real*4       x 1    - SITE_LONGITUDE
antenna_efficiency () =          real*4       x 1    - ANTENNA_EFF     [No]
beam_efficiency (%) =            real*4       x 1    - BEAM_EFF        [No]
beam_azimuth (") =               real*4       x 1    - BEAM_AZ
beam_elevation (") =             real*4       x 1    - BEAM_EL
forward_efficiency (%) =         real*4       x 1    - FORWARD_EFF
az_zero_point_error (") =        real*4       x 1    - NULA
el_zero_point_error (") =        real*4       x 1    - NULE
collimation_error (") =          real*4       x 1    - COLSTAR
focus (mm) =                     real*4       x 6    - FOCUS           [No]
wobbler_device () =              integer*4    x 1    - WOBBLER_DEVICE
number_of_phases () =            integer*4    x 1    - NUMBER_PHASES   [No]
wobbler_period (s) =             real*4       x 1    - WOBBLER_PERIOD
wobbler_throw (") =              real*4       x 1    - WOBBLER_THROW   [Def]
velocity_azimuth (deg/min) =     real*4       x 1    - VAZM            [Def]
subscan_elevation_step (") =     real*4       x 1    - SINT            [Def]
record_integration_time (s) =    real*4       x 1    - RECORD_TIME
```

8.19.2 VARIABLES BOLOMETER

```
NIC\VARIABLES BOLOMETER [ON]|[OFF] [READ|WRITE]

Bolometer Section ----------------------------------   Name of SIC variables

reference_channel () =           integer*4    x 1    - REF_CHAN
bolometer_gain () =              real*4       x 1    - BOLGAIN
channel_number () =              integer*4    x ?    - CHANNEL_NUMBER
channel_az_offset (") =          real*4       x ?    - CHAN_AZ_OFF
channel_el_offset (") =          real*4       x ?    - CHAN_EL_OFF
frequency (GHz) =                real*4       x 1    - FREQUENCY
bandwidth_equivalent (GHz) =     real*4       x 1    - BANDWIDTH_EQUIV [No]
```

8.19.3 VARIABLES CALIBRATION

```
NIC\VARIABLES CALIBRATION [ON]|[OFF] [READ|WRITE]

Calibration Section --------------------------------   Name of SIC variables

ambient_pressure (mbar) =          real*4       x 1    - AMB_PRES
ambient_temperature (c) =          real*4       x 1    - AMB_TEMP
humidity (%) =                     real*4       x 1    - AMB_HUMI
refraction (") =                   real*4       x 1    - REFRACTION
site_altitude (m) =                real*4       x 1    - SITE_ALTITUDE
water_vapour (mm) =                real*4       x 1    - WATER_VAPOUR
atmospheric_temperature (c) =      real*4       x 1    - ATM_TEMP
atmospheric_opacity () =           real*4       x 1    - OPACITY          [No]
chopper_temperature (K)=           real*4       x 1    - CHOPPER_TEMP
cold_load_temperature (K) =        real*4       x 1    - COLD_LOAD_TEMP   [No]
sky_counts () =                    real*4       x 1    - SKY_COUNTS       [No]
system_temperature (K) =           real*4       x 1    - SYSTEM_TEMP      [No]
frequency (GHz) =                  real*4       x 1    - FREQUENCY
bandwidth_equivalent (GHz) =       real*4       x 1    - BANDWIDTH_EQUIV  [No]
Jansky_per_Kelvin (Jy/K) =         real*4       x 1    - JY_PER_KELVIN    [No]
counts_per_Jansky (counts/Jy) =    real*4       x 1    - COUNTS_PER_JY    [Def]
counts_per_Kelvin (counts/K) =     real*4       x 1    - COUNTS_PER_K
chopper_counts () =                integer*4    x ?    - CHOPPER_COUNTS   [No]
cold_load_counts () =              integer*4    x ?    - COLDLOAD_COUNTS  [No]
channel_temperature (K) =          real*4       x ?    - CHAN_TEMP        [No]
channel_gain () =                  real*4       x ?    - CHAN_GAIN
channel_rms () =                   real*4       x ?    - CHAN_RMS         [Def]
mean_gain_elevation_correction ()  real*4       x 1    - MEAN_GAIN_CORR
```

8.19.4 VARIABLES CALPOW

```
NIC\VARIABLES CALPOW [ON]|[OFF] [READ|WRITE]

Total Power Section --------------------------------   Name of SIC variables

Total_power_signal () =            real*4       x ?    - CALPOW
Total_power_channel_number () =    integer*4    x ?    - CALPOW_NUMBER
Total_power_channel_flag () =      logical*4    x ?    - CALPOW_FLAG
Total_power_channel_gain () =      real*4       x ?    - CALPOW_GAIN
```

8.19.5 VARIABLES DATA

```
NIC\VARIABLES DATA [ON]|[OFF] [READ|WRITE]

Calibration Section --------------------------------   Name of SIC variables
```

```
record_quality () =                integer*4    x ?    -                 [No]
record_update () =                 integer*4    x ?    -                 [No]
record_code () =                   integer*4    x ?    -                 [No]
local_sidereal_time (sec) =        real*4       x ?    - LST             [Def]
az_coordinate (deg) =              real*4       x ?    - AZ              [Def]
el_coordinate (deg) =              real*4       x ?    - EL              [Def]
scan_coordinate (see DAP descr) =  real*4       x ?    - SCAN_COORD
channel_counts () =                integer*4    x ?    - SIGNAL          [Def]
channel_counts_phase_one () =      integer*4    x ?    - PHASE1          [Def]
channel_counts_phase_two () =      integer*4    x ?    - PHASE2          [Def]

The scan_coordinate is available for the following scan types:

 FOCUS      (displacements along the optical axis in microns   = SCAN_COORD[1])
 ON-OFF     (relative offsets in Az and El in tenths of arcsec = SCAN_COORD[2])
 ON-THE-FLY (relative offsets in Az and El in tenths of arcsec = SCAN_COORD[2])
 POINTING   (relative offsets in Az and El in tenths of arcsec = SCAN_COORD[2])
```

8.19.6 VARIABLES FIT

```
                 NIC\VARIABLES FIT [ON]|[OFF] [READ|WRITE]

Fit Section - For POINTING and FOCUS ---------------   Name of SIC variables

pointing_fit_parameters            real*4       x 12   - FIT_POINTING
fitted_focus_position              real*4       x 1    - FIT_FOCUS

Fit Section - For one-beam fit ---------------------   Name of SIC variables

x_coord () (")                     real*4       x ?    - FIT_AZ or FIT_RA
y_coord () (")                     real*4       x ?    - FIT_EL or FIT_DEC
amplitude  (current unit)          real*4       x ?    - FIT_AMP
minor_axis_width  (")              real*4       x ?    - FIT_MINOR
major_axis_width  (")              real*4       x ?    - FIT_MAJOR
angle_from_xaxis  (deg)            real*4       x ?    - FIT_ANGLE
channel_az_offset  (")             real*4       x ?    - FIT_AZ_OFF
channel_el_offset  (")             real*4       x ?    - FIT_EL_OFF

Fit Section - For double-beam fit ------------------   Name of SIC variables

x_coord_positiv_beam () (")        real*4       x ?    - FIT_AZ_POS
y_coord_positiv_beam () (")        real*4       x ?    - FIT_EL_POS
x_coord_negativ_beam () (")        real*4       x ?    - FIT_AZ_NEG
y_coord_negativ_beam () (")        real*4       x ?    - FIT_EL_NEG
amp_positiv_beam  (current unit)   real*4       x ?    - FIT_AMP_POS
amp_negativ_beam  (current unit)   real*4       x ?    - FIT_AMP_NEG
width (")                          real*4       x ?    - FIT_FWHM
```

```
channel_az_offset  (")           real*4       x ?    - FIT_AZ_OFF
channel_el_offset  (")           real*4       x ?    - FIT_EL_OFF
```

8.19.7 VARIABLES FLAG

```
                  NIC\VARIABLES FLAG [ON]|[OFF] [READ|WRITE]

Data Section ---------------------------------------   Name of SIC variables

amplifier_flag () =              logical      x 1    - AMPLIFIER_FLAG
channel_gain_flag () =           logical      x 1    - GAINC_FLAG
atmospheric_opacity_flag () =    logical      x 1    - OPACITY_FLAG
noise_removal_flag () =          logical      x 1    - NOISE_FLAG
spike_removal_flag () =          integer      x ?    - DESPIKE_FLAG
channel_flag () =                integer      x ?    - CHAN_FLAG
gain_to_elevation_correction () =  real*4     x 1    - GAINE_FLAG
```

8.19.8 VARIABLES HEADER

```
                  NIC\VARIABLES HEADER [ON]|[OFF] [READ|WRITE]

         General information related variables

Header Section -------------------------------------   Name of SIC variables

project_code () =                character*8  x 1    -                  [No]
source_name () =                 character*8  x 1    - SOURCE           [Def]
source_lambda (deg) =            real*8       x 1    - LAMBDA           [Def]
source_beta (deg) =              real*8       x 1    - BETA             [Def]
source_flux (Jy) =               real*4       x 1    - FLUX             [Def]
field_center () =                character*25 x 1    - FIELD_CENTER
telescope () =                   character*8  x 1    - TELESCOPE
site_altitude (m) =              real*4       x 1    - SITE_ALTITUDE
site_latitude (rad) =            real*8       x 1    - SITE_LATITUDE
site_longitude (rad) =           real*8       x 1    - SITE_LONGITUDE
data_format () =                 integer*4    x 1    - DATA_FORMAT
data_size () =                   integer*4    x 1    - DATA_SIZE        [No]
data_address () =                integer*4    x 1    - DATA_SHMID
onoff_mode () =                  integer*4    x 1    - ONOFF_MODE       [Def]
scan_type () =                   integer*4    x 1    - SCAN_TYPE        [Def]
scan_number () =                 integer*4    x 1    - SCAN             [Def]
number_of_subscans () =          integer*4    x 1    - NSUBSCAN         [Def]
number_of_records () =           integer*4    x ?    - NRECORD          [Def]
records_in_subscan () =          integer*4    x ?    - NSUBREC          [Def]
number_of_selected_scans () =    integer*4    x 1    - FOUND            [Def]
```

```
coordinate_system () =               integer*4    x 1    - COORD_SYST
date_of_reduction () =               integer*4    x 1    - DATE_REDUCTION  [No]
date_of_observation () =             integer*4    x 1    - DATE_OBSERV
epoch (yrs) =                        real*4       x 1    - EPOCH
skew (arcsec) =                      real*4       x 1    - SKEW
name_of_reducer () =                 character*8  x 1    - NAME_OF_REDUCER [No]
number_of_available_channels () =    integer*4    x 1    - NCHAN           [Def]
number_of_total_power_channels ()    integer*4    x 1    - NTOTPOW         [Def]

Additional parameter from the NMB file format are:

number_of_dumps () =                 integer*4    x 1    - NBI
longitude_offset (deg) =             real*4       x 1    - OLAM
drift_velocity (deg/min) =           real*4       x 1    - VLAM
latitude_offset (deg) =              real*4       x 1    - OBET
telescope_azimuth (deg) =            real*4       x 1    - SAZM
offset_azimuth_to_start (deg) =      real*4       x 1    - OAZM
scan_azimuth_velocity (deg/min) =    real*4       x 1    - VAZM
offset_elevation_to_start (deg) =    real*4       x 1    - OELV
scan_elevation_velocity (deg/min)    real*4       x 1    - VELV
subscan_spacing_elevation (") =      real*4       x 1    - SINT
subscan_azimuth_width (deg) =        real*4       x 1    - DAZM
scanning_method () =                 integer*4    x 1    - ISRP2
```

8.19.9 VARIABLES SKYDIP

```
                 NIC\VARIABLES SKYDIP [ON]|[OFF] [READ|WRITE]

Skydip Section -------------------------------------   Name of SIC variables

frequency (GHz) =                    real*4       x 1    - FREQUENCY
bandwidth_equivalent (GHz) =         real*4       x 1    - BANDWIDTH_EQUIV
number_of_skydips () =               integer*4    x 1    - NSKYDIP
skydip_time (UT in yrs) =            real*8       x ?    - SKYDIP_TIME
skydip_opacity () =                  real*4       x ?    - SKYDIP_OPACITY
scan_opacity () =                    real*4       x 1    - SCAN_OPACITY
```

8.20 VERSION

```
    Prints out version number and date of the release you are currently
    using.
```

8.21 END

APPENDIX A The Bolometer Arrays

Details on technical specifications, instrumental calibration and principles of operation are available in several reports from the MPIfR[26] and IRAM[27] and are summarized in the following section. For a general understanding of millimeter wave bolometers we refer to a comprehensive review[28]. The purpose of this section (quite incomplete) is to introduce the observer to the MPIfR bolometers in order to facilitate the preparation, execution and reduction of his (or her) observational programs.

Principle of operation

The MPIfR bolometers are among the most sensitive detectors with diffraction-limited performance for continuum measurements at millimeter wavevelength, the large $\nu/\Delta\nu \sim 3$ bandwidth having a determining influence on the sensitivity of these instruments. As the power that impinges on the bolometer elements is proportional to the instrumental bandwidth[29] and roughly proportional to the temperature of the loads, the (quasi-)continuous power input term is essentially determined by:

$$P \propto \Delta\nu T \propto \Delta\nu \left(\eta_{sky}\eta_{eff}T_{sky} + (1-\eta_{eff}+\eta_{opt})\,T_{cab} + T_{chn}\right)$$

where T_{sky} is the effective sky temperature (see the calibration section for a more accurate discussion), T_{cab} the ambient temperature in the receiver cabin, T_{chn} the noise temperature of the channel, η_{eff} the forward coupling efficiency of the telescope, and where $\eta_{sky} = 1-\exp(-\tau)$ and η_{opt} are the atmospheric and optical system losses, respectively. Only under best observing conditions (observing near zenith with $\tau \sim 0.1$) and with the current optical settings ($\eta_{opt} \sim (1-\eta_{eff}) \sim 0.1$), all the external terms become equal in weight:

$$\eta_{eff}\,\tau\,T_{sky} \sim (1-\eta_{eff})\,T_{cab} \sim \eta_{opt}\,T_{cab}$$

However, as the background power loading varies strongly with opacity, any additional radiation power will have some influence on the instrumental responsivity. Actually, the system sensitivity departs most of the time from the nominal instrumental sensitivity, the limiting factor being thermal emission[30] from the atmospheric patch in the field of view of the detector.

To remove most efficiently the atmospheric contribution (and to recover, with highest possible gain, radiation power from an astronomical source) signals are modulated via the secondary mirror. The modulation frequency which is adjusted according to system parameters (wobbling secondary and electronics), however, is not allowed to vary. Though the wobbling is done in azimuth to minimize sky emissivity gradients, some residual photon noise will still affect the data stream from the bolometer whether there is a source in the beam or not. However, as the water vapour column above the telescope is almost the same for all the channels in the array, residual noise from the atmosphere will in general be highly correlated[31] amongst the channels. Though

[26] e.g.: E.Kreysa, *Proc.29th Liège ESA SP-314*, 265, 1990

[27] e.g.: C.Thum, *IRAM Working Report 212*, 1992

[28] e.g.: P.L.Richards, *J.Appl.Phys*, 76, 1, 1994

[29] The bandwidth is centered at roughly 240 GHz and delimited at the low frequency end by circular waveguides that canalize radiation from the horns to the underlying absorbers and by an optical filter at the high frequency end. The guides are very effective high pass filters, the cutoff frequency of the lowest mode being close to 200 GHz. The responsivity of the optical filter is not well known (the cutoff frequency is close to 280 GHz).

[30] The power fluctuations from the sky are essentially due to radiation from bubbles of moist air whose spatial distribution and size is related to the turbulent transport of energy in the atmosphere.

[31] To have perfect cancellation, the sky, or better its excess low frequency component, has to be correlated for times equal to the wobbling period over distances of the order of the telescope diameter plus the wobbler throw.

the wobbler throw is allowed to vary from 20″ to 90″, it is strongly recommended to adjust the throw to a useful minimum, in accord with the observations.

Small wobbler throws are in general more effective than larger ones. As the amount of sky noise tends to increase (almost) linearly with the wobbler throw, bolometer observations with small throw will suffer less from sky noise. Moreover, as the two wobbler phases (the `ON` and the `OFF` positions) tend to distort the illumination pattern of the telescope, observations of point sources with large wobbler throws will effect sensitivity losses that increase according to the amplitude of the throw. As a rule, 90″ throws use to reduce the point source sensitivity of the telescope by 5%.

The close-packed hexagonal array elements sample the sky with diffraction-limited resolution, but their beam patterns are separated by four times the Nyquist criterion for fully-sampled maps (this is equivalent to twice the beam size). Since undersampling is the consequence of an optimized array efficiency (as the aperture efficiency for a single conical horn is maximum when the aperture of the horn is twice the size of the diffraction spot, and as larger and smaller horn apertures yield efficiencies lower than what expected by their geometrical areas), Nyquist sampling has to be carried out by means of telescope shifts in azimuth and elevation.

As a rule, the tracking rate of the telescope in the case of `ON-THE-FLY` observations is 4″/sec in azimuth. As the sky signal is integrated continuously (the bolometer is a thermal device), with a wobbler frequency of 2 Hz and a dwell time efficiency of roughly 60%-80% at each position, integration time is roughly 150 ms – 200 ms for wobbler throws between 90″ and 30″. This is equivalent to a maximum smear (data is integrated continuously even in between the `ON` and `OFF` phases) of $(250 - 150\,\mathrm{ms}) \times 4''/\mathrm{sec} \sim 0.4''$ at each position, or less than 4% for a maximum angular resolution of 11″. This allows for source structure information to be carried over a frequency range of $4''/\mathrm{sec}/11'' \sim 0.4\,\mathrm{Hz}$ either side of 2Hz. Note, however, that the tracking rate can be changed. The spacing of the azimuth tracks (= subscans) in elevation is controlled by the `OBSINP` variable `SINT` and is set to 4″, as standard value.

As the plane of reference of the instrument is located in the Nasmyth focus of the telescope, all the beams rotate around the central channel by an amount which depends on the elevation of the telescope. In Nasmyth coordinates the transformation from absolute zero to an arbitrary elevation is a rotation matrix with the elevation of the telescope as rotation angle. The sign of the rotation (mirrored in the plane of the sky), depends on whether the number of mirrors in the optical path is even or odd. In order to facilitate the data reduction of maps during your observing run, a predetermination of zero elevation Nasmyth coordinates[32] of the bolometer channels will be carried out at the telescope by the `IRAM` and the `MPIfR` staff on a best effort basis[33] (and thereupon fitted to the data reduction software).

The relative pointing offsets of individual beams within the array is very stable, telescope pointing errors being the same for all the beams. Though there is no guarantee that successive maps will be correctly pointed, the pointing offsets of individual beam will be relatively consistent. However, in order to achieve adequate positional accuracy, repeated mapping observations on strong sources is required. A good mapping strategy is to cover a given field rapidly and to build up the required sensitivity by averaging repeated coverages of the same region.

There are essentially five observing modi: `POINTING` scans to adjust and verify the collimation of the optics (in addition to a measure of the shape and the size of the beam), `FOCUS` scans to focus the optical system (a 0.5 mm displacement of the subreflector from its nominal position corresponds to roughly a 15% loss of sensitivity in the focal plane due to the beam widening),

[32]These are the variables `channel_az_offset` and `channel_el_offset` in the `BOLOMETER` section. See online help on command `VARIABLES` to modify these and other variables.

[33]In order to counter the uncertainties in the determination of these constants (as the bolometer is regularly dismounted for helium refilling), we highly recommend you to redetermine the Nasmyth coordinates of the bolometer array.

SKYDIP scans to measure the atmospheric opacity correction, ON-OFF scans mostly to detect astronomical objects and, finally, ON-THE-FLY scans for the purpose of mapping. For the observations, we recommend starting the scan by using the documented[34] OBS procedures. As soon as one of these scans is written to disk, an automatic routine is started that converts the data to the NMB format. Since there is no calibration facility associated to the instrument, all data is from the start uncalibrated and in units of counts. Calibration to flux density, temperature (or whatever you need) has to be carried out *a posteriori* by using a conversion factor which has to be determined indirectly.

The determination of the conversion factor is one of the most critical calibration issues. Actually, the most reliable values are determined from maps of small primary calibrators, small compared to the beamsize. From the flux of planets $\propto \nu^2$ (and other objects with known spectral index, like compact HII regions and quasars), integrated over the bolometer bandpass, conversion factors with uncertainties of 10% (as a low limit, this depends essentially on source strength and on the assumed bandpass profile) can be measured.

Technical Specifications

The first panel lists the main observational telescope parameters. In the rightmost column are the associated NIC\VARIABLES. The point source sensitivity decreases with the throw of the wobbler: for wobbler throws up to 90″ the sensitivity loss is less than 5%. Wobbler throws above 90″ and up to 150″ are possible, but need to be accepted by the astronomer on duty. Tracking rate and subscan spacing in elevation are standard values for ON-THE-FLY observations.

The second panel lists the main bolometer parameters[35] for one of two 7-channel bolometers; in the rightmost column the associated NIC\VARIABLES. The effective frequency is the instrumentally weighted bandpass center. Deviations are expected depending on atmosphere opacity and to some extent on the spectral index of the source observed. See the online HELP on command NIC\SET GAIN_AMPLIFIER for the signal attenuation. The total field of view depends on the bolometer array: whether the 7 or the 19 multi-beam cluster. Variations of the nominal sensitivity among the beams is within 20% (depending on the bolometer arrays further variations can exist). The channel sensitivity is the nominal one sigma point source sensitivity as measured on an absorber in 1995 with a 7-channel bolometer. It's the signal of a source that is detected after one second with a signal to noise of one. The ON-THE-FLY mapping sensitivity improves according to the number N of good channels. Note that the effective mapping sensitivity depends also on the square root of the subscan rate (VAZM). As the field coverage is rectangular (see FIELD /SKEW command for a rhombuslike pattern) in azimuth and elevation, pixel sensitivity will also depend on the mapping region when projected to equatorial coordinates.

[34] C.Thum and C.Kramer, **A short guide for observations with the MPIfR 7-channel bolometer at the IRAM 30m radiotelescope**, *IRAM document, 1994*

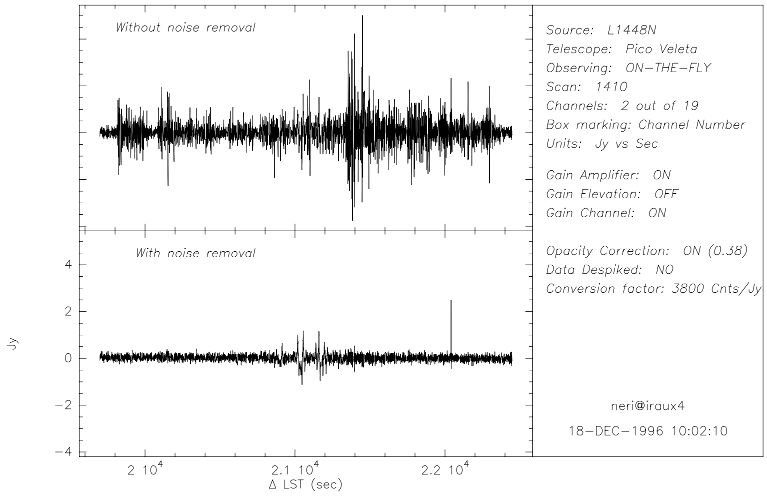
[35] As instrumental characteristics are subjected to changes consult the IRAM staff and/or the IRAM Newsletter for the most recent ones.

wobbler throw:	20 - 90	″	WOBBLER_THROW
wobbler frequency:	2	Hz	WOBBLER_PERIOD
wobbler sensitivity loss:	0 - 5	%	
beamwidth (FWHP):	11	″	BEAM_AZ, BEAM_EL
forward efficiency:	0.86		FORWARD_EFF
flux density to Kelvin:	10 - 11	Jy/K	
subscan rate (azimuth):	4	″/sec	VAZM
subscan step (elevation):	4	″	SINT

effective frequency:	240	GHz	FREQUENCY
bandwidth:	200 - 280	GHz	BANDWIDTH_EQUIV
signal attenuation:	$2^0 - 2^8$		REF_GAIN
total field-of-view:	45 or 90	$''$	
channel sensitivity:	30	mJy.sec$^{\frac{1}{2}}$/beam	
mapping sensitivity:	$30/\sqrt{N}$	mJy.sec$^{\frac{1}{2}}$/beam	

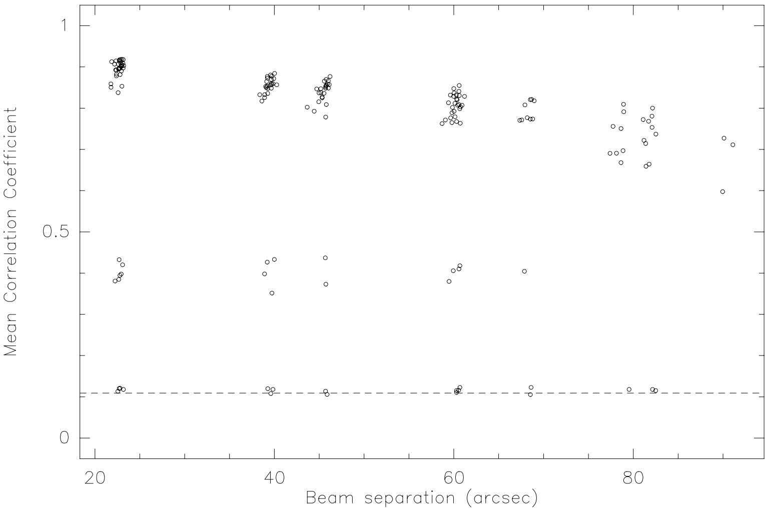
APPENDIX B Noise Removal

The righthand figure is a trace of the signal recorded by one of the beams *before* (upper panel) and *after* (lower panel) noise removal. The amount of correlated noise in this particular scan is high, but not exceptionally high. The noise in excess was removed using an algorithm based on beam to beam correlations (see below). The gain in sensitivity obtained for this scan was drastic, almost 4×. One can see the source which shows up in the middle of the scan and an isolated noisy spike on the right.



Currently this is the only noise removal algorithm currently implemented in `NIC`, a second one is in the planning. The current algorithm assumes that the morphology of the object is known, at least roughly.

To remove the high frequency noise in excess, first delimit a region around the object using `SUPP/CUR` and plot the amount of existing correlated noise using `BASE/CORR`. The figure shows that in the case shown above, the beam to beam correlation decreases smoothly with distance. Moreover, the signal of one of the beams is less correlated and is even completely uncorrelated for a second one. The purpose of the noise removal algorithm is to bring all the beams to the level of complete uncorrelation (dashed line).



The following is done for an array of N beams:

- `BASE /CORR`: $N(N-1)/2$ mean linear correlation coefficients are computed which measure the degree of correlation between pairs of signals. Coefficients are computed for each record[36], averaged over all records and finally plotted as in Figure 2. To estimate the amount of correlated noise a dashed line is plotted which indicates the correlation coefficient estimated from a random sample of uncorrelated data points. This coefficient depends on the width of the window over which the correlation is calculated (large windows give low correlations, small windows give large values). We recommend to produce such plots before and after noise removal in order to verify qualitatively the efficiency with which the noise in excess was removed. Flagged subscans and data within the polygonal support are not taken into account.

- `BASE /NOISE:` linear slopes[37] b_{ij} and b_{ji} and linear correlation coefficients $r_{ij} = \sqrt{b_{ij} b_{ji}}$ are computed which measure the degree of 'correspondance' between pairs of baseline-corrected signals. Slopes and correlation coefficients are computed for each record, and used in the following formula to compute the noise corrected signal S_i' (`= SIGNAL[I]`) at each point:

$$S_i' = S_i - \left(\sum_{\substack{j=1\\i\neq j}}^{N} b_{ij} r_{ij} \cdot S_j\right) / \left(\sum_{\substack{j=1\\i\neq j}}^{N} r_{ij}\right)$$

Option `/NOISE` accepts two parameters: the width of the window over which slopes and correlations are computed and the maximum beam distance between pairs of channels over which the calculation of the noise term is carried out. Flagged subscans and data within the polygonal support are not taken into account.

Here a simple recipe:

- `NIC> SUPPORT` selects a polygonal support. Data within the support is 'the-object', data outside is 'the-sky',
- `NIC> BASE /ORDER ?` removes a baseline,

  `NIC> DEF REAL SAVE NOISE/LIKE SIGNAL`
  `NIC> LET SAVE SIGNAL` saves the baseline-corrected signal
- `NIC> BASE /CORR` estimates the amount of correlated high frequency noise,
- `NIC> BASE /NOISE` removes the noise in excess
- `NIC> BASE /CORR` estimates the correlated noise residual,
- `NIC> LET NOISE SAVE-SIGNAL` gets the correlated noise term

At this stage, perhaps with a few iterations, you are in principle ready to produce 'noise-free' channels map. By replacing variable `SIGNAL` with variable `NOISE`

- `NIC> VAR DATA WRITE`
- `NIC> LET SIGNAL NOISE`

you are also ready to make maps of the noise term. As a rule, signal existing in the 'noise' maps is a clear indication that the noise removal algorithm has not only removed noise in excess but also part of 'the-object'. In this case repeat the procedure with a different polygonal support.

[36] The signals are correlated within a window centered on the record. The width of a window is defined in number of records. See the `HELP` for the default.

[37] As the signals need to be baseline-corrected b_{ij} and b_{ji} are the fitted linear slopes between pairs of signal i and j according to b_{ij} = `SIGNAL[I]/SIGNAL[J]` and b_{ji} = `SIGNAL[J]/SIGNAL[I]`

APPENDIX C Effective observing frequency NEW

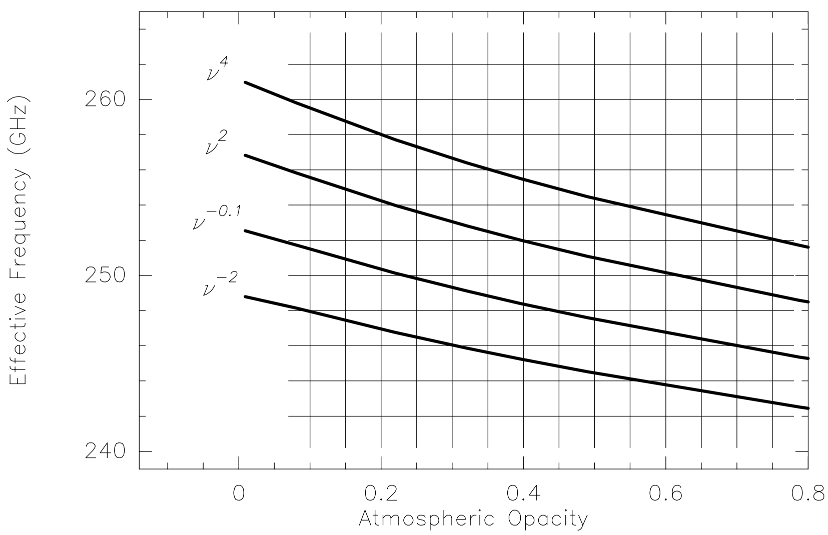
The dependence of the effective observing frequency on the atmospheric extinction is given by the following expression:

$$\nu_{eff}^{\alpha} = \int_{\nu_L}^{\nu_H} S(\nu)A(\nu,\tau)D(\nu)\,d\nu / \int_{\nu_L}^{\nu_H} A(\nu,\tau)D(\nu)\,d\nu$$

where $S(\nu) = \nu^{\alpha}$ is the spectral profile of the target source, α its power-law index, $D(\nu)$ the instrumental bandpass profile, $A(\nu,\tau)$ the atmospheric transmission function for a given opacity τ, and finally ν_L and ν_H the frequencies limiting the instrumental bandwidth.

Using this expression, the instrumental bandpass profile of Mambo II (MPIfR 37 channel bolometer array) and a standard atmospheric model (Cernicharo, Bremer), we have computed effective observing frequencies for radio sources with different emissivity indexes α.

The figure on the righthand shows the dependence of the effective observing frequency on the atmospheric opacity for radio sources with a spectral index of -2, -0.1, 2 and 4. Would we observe a planet under best atmospheric conditions ($\tau \sim 0.05$ in the line of sight), the effective observing frequency would be close to 256 GHz. Though this is the frequency currently adopted for measurements on planets, this value is subjected to changes under less optimum conditions.



In fact, under conditions of $\tau_z = 0.2$ and for low elevations ($\sim 25°$), one can see that the effective observing frequency would rather be close to 249 GHz ($\tau \sim 0.7$). Such a difference in frequency translates into a $(256/249)^2 \sim 6\%$ drop in the expected flux density, a difference which has clearly to be ascribed to the atmosphere. The expected drop in flux density is roughly the same when looking at HII regions or dust-obscured high-redshift galaxies. With this in mind, since the determination of the `Counts/Jy` calibration factor often relies on the flux density measurements of planets and HII regions, we advise caution for calibration measurements done with high atmospheric opacities.

APPENDIX D NIC Welcome Messages

Depending on how NIC gets started, one of the following messages might appear on your screen:

- "ipcrm -m numid" where numid is a shared memory identifier. Such a message indicates that a previous NIC session was aborted (or had crashed) without having had the chance to remove its shared memory segments and the data structure associated with it. To cope with this difficulty, NIC releases systematically previously used shared memory segments by executing a script file named rsm (which produces this message) once it gets started.
- "sh: /pud/bin/rsm: not found" where /pud is a place filler for the parent utility directory. Such an error message indicates that NIC is not able to locate the rsm script file. In the case you are not able to fix the problem please:
  - ask your system manager to watch out for shared memory segments that were not properly deallocated, since these segments are virtually lost for the whole operating system,
  - contact nic@iram.fr
- "Retrieving SKYDIPs ..." This is a self-explanatory message indicating that previous calibrations (only skydips) are retrieved from a file named nic.sky on your local directory and that variables of the skydip section are set accordingly. The reason is to avoid repeated reducing of skydip scans.
- ""Retrieving FITs ..." This is a self-explanatory message indicating that the beam parameters will be retrieved from a file named nic.fit (on your local directory) for all the scans that follow in time the scans from which the beam parameters were determined.
- "Logical BOLO_DATA: multiple definition ..." This is a self-explanatory message indicating that the logical link to your raw data directory is defined twice: once in the initialization file $HOME/init.nic and once in $HOME/.gag.dico, the file for logical assignments. Preferably remove the directory assigned to BOLO_DATA: from the former file.

APPENDIX E Bolometer Hotlines

Whenever a problem occurs, whether it is software or hardware, please first contact the local staff.

Software (General)	A.Sievers	(Spain)+	Granada Office
Software (Backend)	W.Brunswig	(Spain)+	Granada Office
Hardware (Backend)	J.Penalver	(Spain)+	Pico Veleta
Hardware (Frontend)	S.Navarro	(Spain)+	Granada Office
	J.Penalver	(Spain)+	Pico Veleta

For problems that can only be solved with the help of an external expert, please contact:

Software (Reduction)	D.Broguiere	(France)+	4-768249-46
	R.Neri	(France)+	4-768249-82
	H.Wiesemeyer	(France)+	4-768249-86
Hardware (Backend)	E.Kreysa	(Germany)+	228-525-269
Hardware (Frontend)	E.Kreysa	(Germany)+	228-525-269

Please contact the hotline `nic@iram.fr` for any other problem that does not require an urgent intervention from the `IRAM` staff.
This documentation is made available via the `WWW` browser by connecting to the `IRAM` Grenoble page `http://iram.fr/doc/gildas.html`.

APPENDIX F *NEW*

We give here the complete list of references used in the `NIC` documentation.

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