

# Effelsberg continuum mapping

## A brief instruction manual

### Location of the Raw Data

The raw data of the 100m Effelsberg telescope is stored in MBFITS-Format. In Effelsberg the files are located in the directory `/daten/Raw` which should be available on every **Observer-PC**. Older data can be found in `/daten/Raw/Raw-YYYY-MM`.

Every 30 minutes the raw data is synced to Bonn. It is accessible in `/eff/data/`. More details on the location of data can be found here under [Data storage and archive](#)

### Initial data reduction

The subscans are combined to a MBFITS map that should be processed with the "toolbox". This can be done on the "observer7" PC in Effelsberg. For MPIfR observers the login can be done with their own LDAP account. Please add the directories `/opt/bin` and `/soft/astro/nod/Ubuntu14_32bit/bin.gfortran` to your path. Note: If you want to use a different PC than observer7, which is running on Ubuntu Version 14, you have to adjust the nod2 path to use the appropriate version compiled for your operating system.

```
# For bash
export PATH=$PATH:/opt/bin:/soft/astro/nod/Ubuntu14_32bit/bin.gfortran

# For csh
set path = ($path /opt/bin)
set path = ($path /soft/astro/nod/Ubuntu14_32bit/bin.gfortran)
```

For all other observers a common account called "obs2" can be used (ask the operator for the actual password). The toolbox performs some basic baselevel subtraction and filtering of strong radio-frequency interference (RFI) signals. Some parameters can be modified by hand if needed (see [Reduction of pointing measurements](#) for toolbox options). Transformation into NOD2 format, restoration of multi-horn data, transformation into right ascension/declination coordinates and Gaussian fitting for calibrators is done by dedicated automatic pipelines developed for each receiver.

The pipeline scripts can be found in `/opt/actual_scripts/` There are scripts for cal maps that are called `ketXXcal.script` and perform an additional Gaussian fitting to check the (polarization) calibration. Scripts for target maps are called `ketXXmap.script`. The XX is some acronym for each receiver mostly the wavelength in cm or mm. For the 6cm receiver there are scripts with "db" for double beam and "sb" single beam reduction. Just copy the script in your directory and call it with the scan number to be reduced.

e.g. for a 11cm calibration map with scan number 0340:  
`ket11cal.script 0340`

Scripte name	Function
ket21cal.script	21cm PFK calibration map
ket21map.script	21cm PFK target map
ket11cal.script	11cm SFK calibration map
ket11map.script	11cm SFK target map
ket6dbcal.script	6cm SFK double beam calibration map
ket6dbmap.script	6cm SFK double beam target map
ket6sbmap.script	6cm SFK single beam target map
ket36cal.script	3.6cm SFK calibration map
ket36map.script	3.6cm SFK target map
ket28cal.script	2.8cm SFK calibration map

The resulting raw maps in NOD2 format are provided as files named "mpXXXX.nod" (where XXXX is the 4-digit "scan number"). These include a map of sidereal times, a map of parallactic angles, followed by quartets of maps of the 4 Stokes channels (R, L, U and Q) for each horn and for each frequency channel. The data format is NOD2 and can only be reduced using the NOD2 software.

As circular polarization is generally very weak, the maps in R and L are similar and can be averaged in the later steps of data reduction.

Automatic 2-D Gaussfits are provided for the maps of calibrators, stored as "GSXXXX" (single horn) and "gsiuqXXXX" (multi-horn, after restoration). These can be used for calibration of the flux scale and polarization angle, and to check the telescope pointing.

NOTE: NOD2 assumes that the maps are in B1950 coordinates, but single-horn maps can be observed in J2000 without problems.

## Detailed data reduction with OZMAPAX

The raw maps include artifacts which need to be removed:

- RFI spikes which have not been removed by the automatic RFI filter
- Bad points at the beginning or end of a row or column
- Scanning effects due to clouds
- Base-level distortion due to a source near the edge of a map

This can be done with the NOD2-based software package called "Ozmapax". In Effelsberg you can find it on the "observer3", user "nod2". The program is started with the command `Oz`.

Ozmapax is steered by keywords or key-numbers. The most important are:

- **help** (98) - gives a list of available options.
- **help** "option" - gives a brief description of the option.
- Define input file (e.g. mpXXXX): **openin** (-1)
- Read in map: **mapin** (2) - followed by a map number; negative number shows the titles of the maps
- Display map on screen: **graph** (29) - displays the range between min and max values.
- Simple contour plot: **plot** (5)

- High-quality plot: **finplot** (91)
- Check minimum and maximum numbers and their location in the map: **maxmin** (77)
- Check value and coordinates of a specific pixel: **posi** (35)
- Check noise and mean value in a region: **noise** (4) - needs specification of a "quiet" region by giving the row & column interval or by using the cursor (always go from left to right).
- Remove bad pixels by setting areas to dummy: **dummy** (17) - needs specification of the distorted region by giving row & column interval or by using by the cursor (always go from left to right). The values in that region can be replaced by dummy values, a constant value or values taken from a reference map.

NOTE: for removing one point in a map, specify the row and column, or mark a very small area around the pixel center with the cursor, or use "mpfiltb".

- Remove RFI spikes: **mpfiltb** (14) - needs definition of the bad pixel with the cursor. The spike will be replaced by the mean value of the four neighboring points.
- Base-level modification: **basis** (37) - needs specification of points (about 3) on both sides of the row or column (depending on the scanning direction) where the new base-level should be computed. If a source is located near one edge, just set the new base-level in a region away from the source. If a RFI spike or bad point is located at the edge, remove this with "dummy" and then run "basis" using non-dummy points.
- Polynomial fit of columns or rows: **polfit** (9) - e.g. in case of long subscans in order to remove the ground radiation (second-order fit) or for improving the base-levels, as an alternative to "basis".
- Plotting and editing individual rows or columns: **rowcol** (11) - in case that other procedures do not give the desired result.
- Suppression of scanning effects by weather: **presse** (51)

"presse" is a powerful but tricky option which needs care and some experience. "presse" smoothes the map with an elliptical beam, fits the differences between the original and smoothed map and corrects all base-levels. The smoothing beam should be slightly larger than the telescope's half-power beam width in the scanning direction and about 3x the HPBW perpendicular (non-scanning) direction. "presse" needs specification of a threshold for the rejection of strong sources in the map. Start with first-order fits and not too many iterations. Be careful: **Second-order fits may remove real emission!**

NOTE: If "presse" does not work properly, the map has to be re-loaded with "mapin".

More details about "presse": see Sofue & Reich 1979, AAS 38, 251

- 2-D Gaussian fit: **gaus2** (26) - fits one source within the area defined by the cursor. The fit results (coordinates, flux and size) appear on the screen. The full output table of fits results including fit errors are written on "fort.33" or on the file which has been specified by "**opengs**" (-4). First apply "twist" (allowing for non-homogeneous background) and allow for elliptical fits. For weak sources only circular fits without "twist" may work.
- 2-D Gaussian fit: **gauss** (18) - fits all sources in the map above a given level. The fit area can be specified.

"gauss" or "gaus2" are needed to measure the total flux of a source, to determine its polarization angle (from Gauss-fits in U and Q) and to check the telescope pointing with help of strong sources in the individual maps.

NOTE: Only positive sources can be fitted. Negative sources in U or Q need scaling by -1 before fitting,

see below.

- Scaling: **scale** (23)
- Subtraction of a hyper-plane (twisted plane): **twist** (7)
- Flux integration in a circle or rectangle: **influx** (89)
- Simple algebraic combination of two maps as subtraction, addition, multiplication, logarithm, ... : **algebra** (64)
- Smoothing to a larger beam: **smooth** (25)

NOTE: “smooth” needs the value of the actual beam which is not always correctly stored in the header of the map. This is why “smooth” asks for the correct values (in RA and DEC).

NOTE: “smooth” does not change the scale. In case of scaling in Janskys per beam, the **scale** needs to be corrected by applying scale with the value:  $scale=(new\ beamsize/old\ beamsize)^2$ .

NOTE: “smooth” can be applied only to maps in Stokes I, U and Q – but never to maps in polarized intensity, polarization angle and Faraday rotation measure!

- Smoothing to lower resolution by cutoff in Fourier space: **fchop** (68)

NOTE: “fchop” may change the resolution, so that “scale” needs to be applied (see above).

- Finding pointing errors by cross-correlation of two maps: **acorr** (47) – plots the correlation coefficient (multiplied by 500) as a function of offsets in X and Y.
- Overlay of sources of several catalogs (SNRs, pulsars, SAO, ...): **over1** (48)
- When ready, define output file: **openout** (-2), e.g. “outname”.

NOTE: only needed **once** if a set of maps e.g. from 4 Stokes channels is reduced.

- Write output map: **mapout** (3) – needed for every map.

NOTE: “openout” does NOT actually write out the map!

- Stop: **stop** (1) - needs confirmation.

The reduced maps are then available under the name specified in “outname”.

## Further reduction steps

- Correction of pointing errors (if needed): **comshif**
- Transform a map to a different field center or extent: **comshif**
- Removal of beam side-lobes: **rebeam**
- Copy all maps to one file: **cat mp\* > mp.all**
- Selection of maps from a file: **sep**
- Selection of maps from a file with additional scaling: **sepsc**
- Combination of all reduced maps to one map in either Stokes I or U or Q:
  - **turboploitbig** < “input file” (for maps in right ascension/declination or in Galactic l,b), or
  - **tupltheta** < “input file” (for maps scanned with an angle with respect to RA/DEC, **always** for multi-horn systems)

These have to be run separately for Stokes I (i.e. R and L together) and U and Q. Preparation of the

several text files (“input file”) with separate input parameters for I and U and Q is recommended.

- Scaling the final maps in I and U and Q to the correct flux scale as determined from the maps of the calibrators: **Ozmapax** (with **scale**)
- Combination of final U and Q maps to maps in polarized intensity (PI), polarization angle (PA) and polarization degree (p, scaled by 1000): **poldeniuq** – needs knowledge of the rms noise  $\sigma$  in the maps of I, U and Q, to compute errors in polarization angle and percentage. Recommended thresholds to compute p:  $1x \sigma$  (U,Q) and  $5x \sigma$  (I). The positive bias in PI due to noise is corrected. Offsets in polarization angle can also be corrected if necessary.

NOTE: “poldeniuq” stores the polarization angle (PA/1000) in the maps 4 (PI) and 5 ( $p*1000$ ) as the fractional part. Hence only the integer part contains information on PI and PC. In deep maps of weak sources, the PI intensities can be very low so that clipping the fractional part in “poldeniuq” **reduces the dynamic range or may even remove all information**. Scaling the maps by a large a factor (e.g. scaling to microjy/beam) is strongly recommended!

NOTE: Check whether signal-free areas in the PI map have an average value of zero. If not, repeat “poldeniuq” with a corrected value for the rms noise.

Maps of polarized intensity can also be computed with the “algebra” option 6 of “Ozmapax”, but without correction of the noise bias, and hence should be used only for a rough estimate and not for the final map.

- Weighted addition and/or scaling of several maps: **tuwa**
- Transformation from B1950 to J2000 equinox: **combin** (in “Ozmapax”)
- Transformation from NOD2 into FITS format: **fitsw.new** - needs specification of the scale (e.g. mJy/beam) and the frequency bandwidth (CDELTA3).
- Transformation from FITS coordinates (J2000, B1950) into NOD2: **fitsr2000** - needs specification of HPBW.

## Data analysis

- Spectral index maps: **beta**
- Faraday rotation measure maps: **rmmmap** (LINUX version in prep)
- Flux integration and radial profile: **drint**

NOTE: Integration or averaging is only allowed for maps of the Stokes parameters I, Q and U, but NOT for maps in PI, PA, p, spectral index and RM!

- Integration in sectors of rings or ellipses around the center of an object: **sector**
- Computation of equipartition magnetic field strengths: **bfeld**.

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