Effelsberg continuum mapping

A brief instruction manual

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1. Effelsberg receivers for continuum observations

1.3-1.7 GHz (18-23 cm): half-power beamwidth (HPBW) 9.3’ at 21cm, polarimeter with 8 small-band (4 MHz wide) frequency channels + one broad-band channel (32 MHz). The frequency channels can be chosen in two ranges: 1290-1430 MHz and 1580-1725 MHz. RFI is strong in parts of these bands. Checking the small-band channels for RFI is recommended. Instrumental polarization is about 2%, but higher in the range 1290-1330 MHz.

1.29-1.43 GHz (21-23 cm), 7 horns, of which the central horn has R+L channels and can be connected to the 8-channel polarimeter (still in test phase).

2.64 GHz (11.4 cm): HPBW 4.5’, 1 horn, polarimeter with 8 small-band (10 MHz wide) frequency channels (covering 2600-2680 MHz) + one broad-band channel (80 MHz). The first small-band channel (2600-2610 MHz) is often affected by RFI, which also affects the broad-band channel. Use of the remaining 7 small-band channels (2610-2680 MHz) is recommended. Instrumental polarization is about 2% in channels 3-6 and lower in the other channels.

4.75 GHz (6.3 cm): HPBW 2.4’, 2 horns, each 1 broad-band (500 MHz) frequency channel; free of RFI over most of the time.

8.35 GHz (3.6 cm): HPBW 1.4’, 1 horn, 1 broad-band (1100 MHz) frequency channel; RFI mostly at low elevations.

10.45 GHz (2.9 cm): HPBW 1.1’, 3 horns, each 1 broad-band (300 MHz) frequency channel

32 GHz (9mm): HPBW 25”, 7 horns (4 with R+L channels), 1 broad-band frequency channel (4 GHz). This system is still in test phase.

All receivers except for the two 1.4 GHz systems are permanently mounted in the secondary focus cabin. The 1.4 GHz systems need to be moved into the primary focus. The receivers in the above list are equipped with feeds to detect circular polarization (R and L). Unpolarized emission gives the same signal in the R and L channels. From the R and L data, the polarimeter backend computes linear polarization data (U and Q). As the result, data in the 4 Stokes channels (R, L, U and Q) are provided from each horn and (in case of the 8-channel polarimeter) from each frequency channel. NOTE: Real signals can be negative in U and Q!

Multi-horn systems allow restoration of the difference signals (software beam switching) and hence overcome part of distortions by clouds.

Three continuum observation modes are available:

- Mapping
- Cross-scans
- On-off observations

This document describes the mapping mode. For cross-scan and on-off observations, please contact the station manager. The sensitivities for continuum mapping can be found on:

http://www.mpifr-bonn.mpg.de/div/effelsberg/calibration/cont_sens.html

2. Mapping in Effelsberg

Single-horn systems: Maps ("scans") can be scanned in any coordinate system, i.e. right ascension/declination or Galactic longitude/latitude, and can be turned to align with the major axis of an elongated target. Alternating mapping in two perpendicular directions (e.g. right ascension and declination) is strongly recommended. An individual scanned line or column is called "subscan". For full sampling of structures, the distance between lines should be at least 2.5 times smaller than the half-power beamwidth. The pixel distance in the scanning direction is much smaller in the raw data, but is increased in the first reduction stage to achieve square pixels.

Multi-horn systems: As the horns are fixed in the secondary focus, scanning must be done in **azimuth-elevation system** to allow for restoration of the signals. The maps need to be larger in azimuth by the maximum beam separation on sky, plus one additional beam at each side to improve the baselevel determination

NOTE: At present multi-horn mapping must be done in B1950.0 coordinates.

Flux calibration is done by observing maps around at least two primary calibrators per session (3C48, 3C138, 3C286) for which the fluxes at all frequencies are well known. 3C138 and 3C286 are highly polarized and can also be used for calibration of the polarization angle. Maps on calibrators have standard sizes for each receiver (about 4x HPBW). 3C147 and 3C295 can be used as unpolarized calibrators.

3. Initial data reduction

The subscans are combined to a MBFITS map with "toolbox" on the "observer3" PC in Effelsberg (login as "nod2", ask the operator for the actual password), including baselevel subtraction and filtering of strong radio-frequency interference (RFI) signals. Some parameters can be modified by hand if needed. 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 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.

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

4. 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
- Scanning effects due to clouds
- Base-level distortion due to a source at the edge of a map

This is done on your UBUNTU PC with the NOD2-based software package called "Ozmapax". 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.
- 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. 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, only a very small area around the pixel center should be marked; better 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 at one edge, just set the new base-level in a region away from the source. If a RFI spike 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” smooths 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. 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”: 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 U 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: **intflux** (89)

- Simple algebraic combination of two maps as subtraction, addition, multiplication, logarithm, … : **algebra** (64)

- Smoothing to lower resolution: **smooth** (25)

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“.

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

NOTE: “fchop” changes 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 an 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”.

5. 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:

turboplaitbig < “input file” (maps in right ascension/declination or in Galactic l,b), or

tupltheta < “input file” (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 (PC): **poldeniuq** – needs knowledge of the rms noise σ in the I, U and Q maps to compute errors in polarization angle and percentage. Recommended thresholds to compute p: 1x σ (U,Q) and 5x σ (I). The bias in PI due to noise is corrected. Offsets in polarization angle can also be corrected if necessary.

NOTE: “poldeniuq” stores the polarization angle (x10) in the maps 4 (PI) and 5 (PC) 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!

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 (CDELT3).
- Transformation from FITS coordinates (J2000, B1950) into NOD2: **fitsr2000** - needs specification of HPBW.

6. Data analysis

- Spectral index maps: **beta**
- Faraday rotation measure maps: **rmmap** (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, 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**