IRAM Memo 2010-2

IRAM-30m MAMBO time/sensitivity estimator

J. Pety[1,2], G. Quintana-Lacaci[3], R. Zylka[1], S. Bardeau[1], E. Reynier[1]

1. IRAM (Grenoble)
2. Observatoire de Paris
3. IRAM (Granada)

Jun, 30th 2010
Version 1.0

Abstract

This memo describes the equations used in the IRAM-30m MAMBO time/sensitivity estimator available in the `GILDAS/ASTRO` program.

Contents

1 Generalities

1.1 Noise as a function of time for a single bolometer

The rms noise (σ) of the data obtained with a single bolometer is related to the on-source integration time (t_σ) in a given direction of the sky through

$$\sigma = \frac{\mathrm{NEFD}\ \exp\left(A\,\tau_\mathrm{zen}\right)}{\sqrt{t_\sigma}}, \tag{1}$$

where NEFD is the noise equivalent flux density of the bolometer, $A \simeq 1/\sin(\mathrm{el})$ the airmass and τ_zen the zenith atmospheric opacity.

1.2 Estimator philosophy

The goal of a time estimator is to find the elapsed telescope time (t_tel) needed to obtain a given rms noise, while a sensitivity estimator aims at finding the rms noise obtained when observing during t_tel.

The time needed 1) to do calibrations (*e.g.* pointing, focus, skydip) and 2) to slew the telescope between on-source integrations have to be added to t_σ to get the elapsed telescope time. The observing procedures to use MAMBO are standardized. This enables to decompose the telescope time into a succession of calibrations, scans and subscans, which will be close to the actual observing setup. We nevertheless include an additional efficiency factor (ϵ_tel), which will take into account the possibility of bad weather and/or technical problems. The idea is that on average the PIs will reach their scientific goals, including possible hazards.

1.3 Decomposing the elapsed telescope time

If the PI wants to reach the same rms noise (σ) on n_source sources (they must share the same calibrator sources), during a given elapsed telescope time (t_tel), we have

$$\epsilon_\mathrm{tel}\,t_\mathrm{tel} = n_\mathrm{source}\,t_\mathrm{source} + n_\mathrm{cal}\,t_\mathrm{cal}, \tag{2}$$

where t_cal is the time required to acquire the calibration information and n_cal the number of such calibration suits.

The calibration time can be written as

$$t_\mathrm{cal} = \eta_\mathrm{cal}\left(t_\mathrm{pointing} + t_\mathrm{focus} + t_\mathrm{skydips} + t^\mathrm{cal}_\mathrm{onoff}\right), \tag{3}$$

where t_pointing, t_focus, t_skydips and $t^\mathrm{cal}_\mathrm{onoff}$ are respectively the typical times needed to perform a pointing, focus and skydip measurement and an OnOff measurement on a calibrator. η_cal is a multiplicative factor (> 1) which takes into account the time to slew to the pointing and/or focus source as well as the possible need to do such calibrations twice in a row. The number of such calibrations is dictated by the fact that the maximum duration between two such calibration suits must be d_cal. This gives

$$n_\mathrm{source}\,t_\mathrm{source} \le n_\mathrm{cal}\,d_\mathrm{cal} \quad \textit{i.e.} \quad \epsilon_\mathrm{tel}\,t_\mathrm{tel} \le n_\mathrm{cal}\left(d_\mathrm{cal} + t_\mathrm{cal}\right) \quad \text{or} \quad \frac{\epsilon_\mathrm{tel}\,t_\mathrm{tel}}{d_\mathrm{cal} + t_\mathrm{cal}} \le n_\mathrm{cal}. \tag{4}$$

The time spent per source (t_source) is linked to the integration time (t_σ) through the succession of $n^\mathrm{tot}_\mathrm{subscan}$ subscans, each subscan having an on-source integration time of t_subscan and an overhead time of $t^\mathrm{overhead}_\mathrm{subscan}$. The $n^\mathrm{tot}_\mathrm{subscan}$ subscans are grouped into scans, with an additional overhead time of $t^\mathrm{overhead}_\mathrm{scan}$ per scan. If one scan can contain at most $n^\mathrm{max}_\mathrm{subscan}$ subscans, the number of scans (n_scan) and the residual number of subcans ($n^\mathrm{res}_\mathrm{subscan}$) are computed through

$$n_\mathrm{scan} = \mathrm{floor}\left(\frac{n^\mathrm{tot}_\mathrm{subscan}}{n^\mathrm{max}_\mathrm{subscan}}\right), \tag{5}$$

$$n^\mathrm{res}_\mathrm{subscan} = n^\mathrm{tot}_\mathrm{subscan} - n_\mathrm{scan} n^\mathrm{max}_\mathrm{subscan}. \tag{6}$$

We note that the actual number of scan is $n_{\rm scan}+1$ when $n_{\rm subscan}^{\rm res} \geq 1$ and $n_{\rm scan}$ when $n_{\rm subscan}^{\rm res} = 0$. The time spent per source is thus given by

$$
\begin{aligned}
t_{\rm scan} &= n_{\rm subscan}^{\rm max}\,(t_{\rm subscan} + t_{\rm subscan}^{\rm overhead}) + t_{\rm scan}^{\rm overhead}, && (7)\\
t_{\rm source} &= n_{\rm scan}\,t_{\rm scan} + \left[n_{\rm subscan}^{\rm res}(t_{\rm subscan} + t_{\rm subscan}^{\rm overhead}) + t_{\rm scan}^{\rm overhead}\right]. && (8)
\end{aligned}
$$

2 OnOff

In the OnOff observing mode, the secondary is symmetrically wobbled around the sky direction to be observed. In this case, Eq. 1 holds with

$$t_\sigma = n_{\rm subscan}^{\rm tot}\,t_{\rm subscan}. \tag{9}$$

In this case, the maximum number of subscans per scan and the subscan times are usually fixed to a conventional value.

3 Mapping

3.1 Observing strategy

A bolometer measures other contributions (*e.g.* the atmospheric emission), which usually domintes the measured signal. Moreover, MAMBO bolometers have a finite time response. The strategy to map a source must take care of both effects. One way is to wobble the secondary in the scanning direction. We note that it is customary to scan in the azimuthal direction because this allows to scan at nearly constant airmass (*i.e.* at constant elevation). However, when mapping an elongated source (*e.g.* an edge-on galaxy disk), the restoration algorithms work best when scanning along the smallest source size. In addition, the observing mode (wobbling) introduces strong boundary conditions, which in general implies that the whole array must scan over the full source size. In addition, a portion of blanked sky (typically 3 times the full width at half maximum of the telescope beam) must be be observed to baseline the data.

In summary, if the PI wants to map a source of size $\Delta_{\rm sou}^{\parallel} \times \Delta_{\rm sou}^{\perp}$, the total scanned size will have to be $\Delta_{\rm tot}^{\parallel} \times \Delta_{\rm tot}^{\perp}$ with

$$
\begin{aligned}
\Delta_{\rm tot}^{\perp} &= \Delta_{\rm sou}^{\perp}, && (10)\\
\Delta_{\rm tot}^{\parallel} &= \Delta_{\rm sou}^{\parallel} + \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}, && (11)
\end{aligned}
$$

where $\Delta_{\rm array}$ is the linear array size, $\Delta_{\rm throw}$ is the wobbler throw and $\Delta_{\rm base}$ is the size of blanked sky used for baselining. The rows of the map (*i.e.* the subscans) are scanned at constant velocity, $v_\parallel$. The size of the row will be $\Delta_{\rm tot}^{\parallel}$. Each row will be an independent subscan of duration $t_{\rm subscan}$. The separation between two rows will be δ. If the area to be mapped is called $\Omega_{\rm map}$, the time to cover it once is called $t_{\rm cover}$ and the number of subscans per coverage is called $n_{\rm subscan}^{\rm cover}$, the following relationships hold

$$\Omega_{\rm map} = n_{\rm subscan}^{\rm cover}\,\delta\,\Delta_{\rm tot}^{\parallel} \quad \text{with} \quad n_{\rm subscan}^{\rm cover} = {\rm ceil}\left(\frac{\Delta_{\rm tot}^{\perp}}{\delta} + 1\right); \tag{12}$$

$$\Delta_{\rm tot}^{\parallel} = v_\parallel\,t_{\rm subscan} \quad \text{and} \quad t_{\rm cover} = n_{\rm subscan}^{\rm cover}\,t_{\rm subscan}; \tag{13}$$

$$\Omega_{\rm map} = t_{\rm cover}\,\delta\,v_\parallel. \tag{14}$$

Note that the grouping of the subscans in coverages is independent of the grouping of the subscans in scans, *e.g.* the same scan can finish a coverage of the source and start a new one.

3.2 EKH vs shift-and-add restoration

Two kinds of restoration algorithms for wobbler switched data are available: The EKH [Emerson et al. 1979] and shift-and-add algorithms. EKH is much more elaborated and it enables to recover all the source structure as long as the source stays undetected at the edges of the map along the scanning direction. However, it works well only for relatively small source size (*i.e.* $\Delta^{\parallel}_{\rm sou} < 0.5°$). Now, there are scientific projects which search for point sources (at least sources whose size is smaller than the half wobbler throw) on much larger sky areas. For these (*i.e.* search for point sources on very large field of views), the shift-and-add restoration method works well.

We thus offer the user the following choice:

EKH restoration The PI must give the source size in both perpendicular directions: $\Delta^{\parallel}_{\rm sou} \times \Delta^{\perp}_{\rm sou}$. The PI can request $n_{\rm source}$ unrelated sources in this mode (the sources must share the same pointing calibrator...).

Shift-and-add restoration The PI must give the sizes of the final mosaic: $\Delta^{\parallel}_{\rm mos} \times \Delta^{\perp}_{\rm mos}$. We then assume that this area will be observed in square submaps, whose typical duration is set to $d_{\rm submap}$ so that $d_{\rm cal}/d_{\rm submap}$ is an integer number. If we define $\Delta_{\rm edge} = \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}$, we then find the size $\Delta_{\rm submap}$ through the following equation:

$$\Delta_{\rm submap}\,(\Delta_{\rm submap} + \Delta_{\rm edge}) = d_{\rm submap}\,\delta\,v_{\parallel}. \tag{15}$$

This second order equation has a single physical solution

$$\Delta_{\rm submap} = \frac{\sqrt{\Delta^2_{\rm edge} + 4 d_{\rm submap}\,\delta\,v_{\parallel}} - \Delta_{\rm edge}}{2}. \tag{16}$$

There are then two cases:

1. If $\Delta^{\parallel}_{\rm mos}\,\Delta^{\perp}_{\rm mos} \le \Delta^2_{\rm submap}$, then we use the user inputs:

$$\Delta^{\perp}_{\rm tot} = \Delta^{\perp}_{\rm mos}, \tag{17}$$
$$\Delta^{\parallel}_{\rm tot} = \Delta^{\parallel}_{\rm mos} + \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}, \tag{18}$$
$$n_{\rm source} = 1. \tag{19}$$

2. Else we use:

$$\Delta^{\perp}_{\rm tot} = \Delta_{\rm submap}, \tag{20}$$
$$\Delta^{\parallel}_{\rm tot} = \Delta_{\rm submap} + \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}, \tag{21}$$
$$n_{\rm source} = \frac{\Delta^{\parallel}_{\rm mos}\,\Delta^{\perp}_{\rm mos}}{\Delta^2_{\rm submap}}. \tag{22}$$

We note that in this case, $n_{\rm source}$ is not a real number of sources in this case. It is a number of submap and it thus does not need to be an integer.

3.3 Associated noise

When mapping, the noise per independent resolution element in the map ($\sigma_{\rm beam}$) is given by

$$\sigma_{\rm beam} = \frac{\mathrm{NEFD}\,\exp\left(A\,\tau_{\rm zen}\right)}{\sqrt{t_{\rm beam}}} \quad \text{with} \quad t_{\rm beam} = \frac{n_{\rm cover}\,t_{\rm cover}}{n^{\rm bol}_{\rm beam}}, \tag{23}$$

where t_{beam} is the total integration time per independent resolution element, n_{cover} is the number of repeated coverages and $n_{\mathrm{beam}}^{\mathrm{bol}}$ is the number of independent resolution elements per bolometer of the array. This number is easily obtained through

$$n_{\mathrm{beam}}^{\mathrm{bol}} = \frac{\Omega_{\mathrm{map}}}{n_{\mathrm{bol}}^{\mathrm{tot}}\,\Omega_{\mathrm{beam}}} \quad \text{with} \quad n_{\mathrm{bol}}^{\mathrm{tot}} = n_{\mathrm{bol}}^{\mathrm{max}} - n_{\mathrm{bol}}^{\mathrm{dead}} \quad \text{and} \quad \Omega_{\mathrm{beam}} = \frac{\eta_{\mathrm{grid}}\,\pi\,\theta^2}{4\,\ln(2)}, \tag{24}$$

where $n_{\mathrm{bol}}^{\mathrm{tot}}$ is the total number of valid bolometers (equal to the maximum number of bolometers minus the number of dead ones), Ω_{beam} is the solid angle of the resolution element in the map (assumed to be a Gaussian), η_{grid} is the factor due to gridding and θ is the telescope full width at half maximum. Using the equations derived from the mapping strategy, it is easy to obtain

$$\sigma_{\mathrm{beam}} = \frac{\mathrm{NEFD}}{\sqrt{n_{\mathrm{bol}}^{\mathrm{tot}}\,\Omega_{\mathrm{beam}}}}\,\exp\left(A\,\tau_{\mathrm{zen}}\right)\,\sqrt{\frac{\delta\,v_{\parallel}}{n_{\mathrm{cover}}}}. \tag{25}$$

In the case of MAMBO,

$$\frac{\mathrm{NEFD}}{\sqrt{n_{\mathrm{bol}}^{\mathrm{tot}}\,\Omega_{\mathrm{beam}}}} \simeq 0.2\,(\mathrm{mJy/Beam})\,\sqrt{\mathrm{s}}\,/''. \tag{26}$$

However, this noise value stands before any data processing. The restoration will multiply the above noise level by the square root of the number of chopper throws used to compute the brightness at any given position. This makes the actual noise value dependent on the total map size in the scanning direction. Moreover, the methods to restore the source are not perfect[1]. Altogether, we thus use

$$\sigma_{\mathrm{actual}} = \alpha(\Delta_{\mathrm{sou}}^{\parallel})\,\exp\left(A\,\tau_{\mathrm{zen}}\right)\,\sqrt{\frac{\delta\,v_{\parallel}}{n_{\mathrm{cover}}}}, \tag{27}$$

where $\alpha(\Delta_{\mathrm{sou}}^{\parallel})$ value is deduced from the experience of the previous bolometer pools with MAMBO at the IRAM-30m.

3.4 Maximum number of subscans in a scan

To compute the maximum number of subscans in a scan ($n_{\mathrm{subscan}}^{\mathrm{max}}$), we assume that the maximum duration of a scan is d_{scan} so that $d_{\mathrm{cal}}/d_{\mathrm{scan}}$ is an integer number. The value $n_{\mathrm{subscan}}^{\mathrm{max}}$ is then defined with

$$n_{\mathrm{subscan}}^{\mathrm{max}}\,(t_{\mathrm{subscan}} + t_{\mathrm{subscan}}^{\mathrm{overhead}}) + t_{\mathrm{scan}}^{\mathrm{overhead}} \leq d_{\mathrm{scan}} \quad \text{or} \quad n_{\mathrm{subscan}}^{\mathrm{max}} \leq \frac{d_{\mathrm{scan}} - t_{\mathrm{scan}}^{\mathrm{overhead}}}{t_{\mathrm{subscan}} + t_{\mathrm{subscan}}^{\mathrm{overhead}}}. \tag{28}$$

4 Algorithms

4.1 Sensitivity estimation

Step #1: Initialization Initialize the values of ϵ_{tel}, d_{submap}, d_{scan}, d_{cal}, η_{cal}, t_{pointing}, t_{focus}, t_{skydips}, $t_{\mathrm{scan}}^{\mathrm{overhead}}$, $t_{\mathrm{subscan}}^{\mathrm{overhead}}$, Δ_{array}, Δ_{throw}, Δ_{base}, etc...

Step #2: User input Get the telescope time (t_{tel}), the number of sources (n_{source}) and the elevation (el). For mapping, get the map sizes. There are two cases:

EKH restoration The following checks and computations must be done.

$$\begin{aligned}
\Delta_{\mathrm{sou}}^{\parallel} &\leq 0.5^\circ, && (29)\\
\Delta_{\mathrm{tot}}^{\perp} &= \Delta_{\mathrm{sou}}^{\perp}, && (30)\\
\Delta_{\mathrm{tot}}^{\parallel} &= \Delta_{\mathrm{sou}}^{\parallel} + \Delta_{\mathrm{array}} + \Delta_{\mathrm{throw}} + \Delta_{\mathrm{base}} && (31)\\
\alpha &= \text{an empirical increasing function of } \Delta_{\mathrm{sou}}^{\parallel}. && (32)
\end{aligned}$$

[1] The imperfections are dominated by the baselining step.

Shift-and-add restoration The following checks and computations must be done.

1. α is set to the minimum of the empirical increasing function of $\Delta^{\parallel}_{\rm sou}$ because this restoration algorithm assumes that the restored sources are almost point-like.
2. $\Delta_{\rm submap} = 0.5\left(\sqrt{\Delta^2_{\rm edge} + 4 d_{\rm submap}\,\delta\, v_{\parallel}} - \Delta_{\rm edge}\right)$ with $\Delta_{\rm edge} = \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}$.
3. If $\Delta^{\parallel}_{\rm mos}\,\Delta^{\perp}_{\rm mos} \leq \Delta^2_{\rm submap}$, then

$$\begin{aligned} \Delta^{\perp}_{\rm tot} &= \Delta^{\perp}_{\rm mos}, && (33)\\ \Delta^{\parallel}_{\rm tot} &= \Delta^{\parallel}_{\rm mos} + \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}, && (34)\\ n_{\rm source} &= 1. && (35) \end{aligned}$$

4. Else

$$\begin{aligned} \Delta^{\perp}_{\rm tot} &= \Delta_{\rm submap}, && (36)\\ \Delta^{\parallel}_{\rm tot} &= \Delta_{\rm submap} + \Delta_{\rm array} + \Delta_{\rm throw} + \Delta_{\rm base}, && (37)\\ n_{\rm source} &= \frac{\Delta^{\parallel}_{\rm mos}\,\Delta^{\perp}_{\rm mos}}{\Delta^2_{\rm submap}}. && (38) \end{aligned}$$

We note that in this case, $n_{\rm source}$ is not here a real number of source but more a number of submap: It does not need to be an integer.

Step #3: Computation of $n_{\rm cal}$ and $t_{\rm source}$

$$1. \qquad n_{\rm cal} = {\rm ceil}\left(\frac{\epsilon_{\rm tel}\, t_{\rm tel}}{d_{\rm cal} + t_{\rm cal}}\right), \qquad (39)$$

$$2. \qquad t_{\rm source} = \frac{\epsilon_{\rm tel}\, t_{\rm tel} - n_{\rm cal}\, t_{\rm cal}}{n_{\rm source}}. \qquad (40)$$

If $t_{\rm source} < 0$, then return the following error message: "The telescope time must at least be $t_{\rm cal}/\epsilon_{\rm tel}$."

Step #4: Computation of $t_{\rm subscan}$, $n^{\rm max}_{\rm subscan}$ and $t_{\rm scan}$

OnOff

$$1. \qquad t_{\rm subscan} \text{ and } n^{\rm max}_{\rm subscan} \text{ are fixed}, \qquad (41)$$

$$2. \qquad t_{\rm scan} = n^{\rm max}_{\rm subscan}\,(t_{\rm subscan} + t^{\rm overhead}_{\rm subscan}) + t^{\rm overhead}_{\rm scan}. \qquad (42)$$

Mapping

$$1. \qquad t_{\rm subscan} = \frac{\Delta^{\parallel}_{\rm tot}}{v_{\parallel}}, \qquad (43)$$

$$2. \qquad n^{\rm max}_{\rm subscan} = {\rm floor}\left(\frac{d_{\rm scan} - t^{\rm overhead}_{\rm scan}}{t_{\rm subscan} + t^{\rm overhead}_{\rm subscan}}\right), \qquad (44)$$

$$3. \qquad \text{if} \quad n^{\rm max}_{\rm subscan} < 1, \quad \text{then send an error message advising to increase } d_{\rm scan}, \qquad (45)$$

$$4. \qquad t_{\rm scan} = n^{\rm max}_{\rm subscan}\,(t_{\rm subscan} + t^{\rm overhead}_{\rm subscan}) + t^{\rm overhead}_{\rm scan}. \qquad (46)$$

Step #5: Computation of $n_{\rm scan}$, $n^{\rm res}_{\rm subscan}$ and $n^{\rm tot}_{\rm subscan}$

$$1. \qquad n_{\rm scan} = {\rm floor}\left(\frac{t_{\rm source}}{t_{\rm scan}}\right), \qquad (47)$$

$$2. \qquad n^{\rm res}_{\rm subscan} = {\rm floor}\left(\frac{t_{\rm source} - n_{\rm scan} t_{\rm scan} - t^{\rm overhead}_{\rm scan}}{t_{\rm subscan} + t^{\rm overhead}_{\rm subscan}}\right), \qquad (48)$$

$$3. \qquad n^{\rm tot}_{\rm subscan} = n_{\rm scan} n^{\rm max}_{\rm subscan} + n^{\rm res}_{\rm subscan}. \qquad (49)$$

Step #6: Computation of $n_{\rm cover}$ (Mapping only)

$$1. \qquad n_{\rm subscan}^{\rm cover} = {\rm ceil}\left(\frac{\Delta_{\rm tot}^{\perp}}{\delta}+1\right), \tag{50}$$

$$2. \qquad n_{\rm cover} = {\rm floor}\left(\frac{n_{\rm subscan}^{\rm tot}}{n_{\rm subscan}^{\rm cover}}\right), \tag{51}$$

$$3. \qquad \text{if} \quad n_{\rm cover} < 1, \quad \text{then send an error message advising to increase } t_{\rm tel}, \tag{52}$$

$$4. \qquad n_{\rm subscan}^{\rm tot} = n_{\rm cover}\, n_{\rm subscan}^{\rm cover}. \tag{53}$$

Step #7: Computation of actual $n_{\rm scan}$ and $n_{\rm subscan}^{\rm res}$ (Mapping only)

$$1. \qquad n_{\rm scan} = {\rm floor}\left(\frac{n_{\rm subscan}^{\rm tot}}{n_{\rm subscan}^{\rm max}}\right), \tag{54}$$

$$2. \qquad n_{\rm subscan}^{\rm res} = n_{\rm subscan}^{\rm tot} - n_{\rm scan} n_{\rm subscan}^{\rm max}. \tag{55}$$

Step #8: Computation of σ

OnOff

$$1. \qquad t_{\sigma} = (n_{\rm scan}\, n_{\rm subscan}^{\rm max} + n_{\rm subscan}^{\rm res})\, t_{\rm subscan}, \tag{56}$$

$$2. \qquad \sigma = \frac{\rm NEFD\ \exp\,(A\,\tau_{\rm zen})}{\sqrt{t_{\sigma}}}. \tag{57}$$

Mapping

$$\sigma = \alpha\ \exp\,(A\,\tau_{\rm zen})\,\sqrt{\frac{\delta\,v_{\|}}{n_{\rm cover}}}, \tag{58}$$

Step #9: Computation of the actual $t_{\rm source}$, $n_{\rm cal}$ and $t_{\rm tel}$ We note that 1) the actual number of scan is $n_{\rm scan}+1$ when $n_{\rm subscan}^{\rm res} \geq 1$ and $n_{\rm scan}$ when $n_{\rm subscan}^{\rm res} = 0$ and 2) the true elapsed telescope time might be smaller than the user input.

$$1. \qquad t_{\rm source} = n_{\rm scan}\, t_{\rm scan} + \left[n_{\rm subscan}^{\rm res}(t_{\rm subscan} + t_{\rm subscan}^{\rm overhead}) + t_{\rm scan}^{\rm overhead}\right], \tag{59}$$

$$2. \qquad n_{\rm cal} = {\rm ceil}\left(\frac{n_{\rm source}\, t_{\rm source}}{d_{\rm cal}}\right), \tag{60}$$

$$3. \qquad t_{\rm tel} = \frac{n_{\rm source}\, t_{\rm source} + n_{\rm cal}\, t_{\rm cal}}{\epsilon_{\rm tel}}. \tag{61}$$

The noise computation is done for three different values of $\tau_{\rm zen}$ (excellent, good and average conditions).

4.2 Time estimation

Step #1: Initialization Initialize the values of $\epsilon_{\rm tel}$, $d_{\rm submap}$, $d_{\rm scan}$, $d_{\rm cal}$, $\eta_{\rm cal}$, $t_{\rm pointing}$, $t_{\rm focus}$, $t_{\rm skydips}$, $t_{\rm scan}^{\rm overhead}$, $t_{\rm subscan}^{\rm overhead}$, $\Delta_{\rm array}$, $\Delta_{\rm throw}$, $\Delta_{\rm base}$, etc...

Step #2: User input Get the rms noise (σ), the number of sources ($n_{\rm source}$) and the elevation (el). For mapping, get the map sizes and transform them using the same formula as Step #2 in the sensitivity estimation.

Step #3: Computation of $t_{\rm subscan}$, $n_{\rm subscan}^{\rm max}$ and $t_{\rm scan}$ Same as Step #4 in the sensitivity estimation.

Step #4: Computation of $n_{\rm subscan}^{\rm tot}$ from σ

OnOff

$$1. \qquad t_\sigma = \left[\frac{\text{NEFD}\,\exp\left(A\,\tau_{\text{zen}}\right)}{\sigma}\right]^2, \tag{62}$$

$$2. \qquad n_{\text{subscan}}^{\text{tot}} = \text{ceil}\left(\frac{t_\sigma}{t_{\text{subscan}}}\right). \tag{63}$$

Mapping

$$1. \qquad n_{\text{cover}} = \text{floor}\left\{\delta\, v_\parallel \left[\frac{\alpha\,\exp(A\,\tau_{\text{zen}})}{\sigma}\right]^2\right\}, \tag{64}$$

$$2. \qquad \text{if} \quad n_{\text{cover}} < 1, \quad \text{then send an error message advising to decrease } \sigma, \tag{65}$$

$$3. \qquad n_{\text{subscan}}^{\text{cover}} = \text{ceil}\left(\frac{\Delta_{\text{tot}}^{\perp}}{\delta} + 1\right), \tag{66}$$

$$4. \qquad n_{\text{subscan}}^{\text{tot}} = n_{\text{cover}} n_{\text{subscan}}^{\text{cover}}. \tag{67}$$

Step #5: Computation of n_{scan} and $n_{\text{subscan}}^{\text{res}}$ Same as Step #7 in the sensitivity estimation.

Step #6: Computation of t_{source}, n_{cal} and t_{tel} Same as Step #9 in the sensitivity estimation.

Step #7: Computation of the actual noise We note that the reached sensitivity will be slightly larger than requested by the user because of the ceil function in the computation of $n_{\text{subscan}}^{\text{res}}$. We thus recompute the sensitivity as in the Step #8 of the sensitivity estimation.

All these computations are done for three different values of τ_{zen} (excellent, good and average conditions).

5 Parameter values

Table 1: Values of parameters independent of the observing mode.

Parameter	Value	Unit
NEFD	30	(mJy/beam) $\sqrt{\text{s}}$
d_{cal}	1	hr
t_{pointing}	3	min
t_{focus}	2	min
t_{skydips}	5	min
$t_{\text{onoff}}^{\text{cal}}$	4	min
η_{cal}	1.5	—
ϵ_{tel}	1	—

Table 2: Values of used zenith opacities (τ_{zen}) as a function of weather conditions for summer and winter.

	Excellent	Average	Poor
Winter	≤ 0.10	≤ 0.30	≤ 0.50
Summer	≤ 0.20	≤ 0.35	≤ 0.50

Table 3: User defined values of parameters for the mapping observing mode.

Parameter	Default	Minimum	Maximum	Unit
$v_\parallel$	8	4	10	arcsec s^{-1}
δ	8	5	24	arcsec
Δ_{throw}	60	30	90	arcsec

Table 4: Fixed values of parameters for the mapping observing mode.

Parameter	Value	Unit
Δ_{base}	30	arcsec
Δ_{array}	245	arcsec
$n_{\text{bol}}^{\text{max}}$	117	—
$n_{\text{bol}}^{\text{dead}}$	14	—
d_{submap}	1	hr
d_{scan}	1	hr
$\alpha(40'')$	0.4	mJy/beam.$\sqrt{\text{sec}}$/arcsec
$\alpha(2')$	1.2	mJy/beam.$\sqrt{\text{sec}}$/arcsec

Table 5: Values of parameters for the On-Off observing mode.

Parameter	Value	Unit
n_{subscan}	20	—
t_{subscan}	60	sec
$t_{\mathrm{subscan}}^{\mathrm{overhead}}$	4	sec
$t_{\mathrm{scan}}^{\mathrm{overhead}}$	15	sec

References

[Emerson et al. 1979] Emerson, D. T., Klein, U. and Haslam, C. G. T., *A&A*, 1979, 76, 92.