The Exposure Time Calculator for the upgraded Giant Metrewave Radio Telescope*

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January 4, 2020

Introduction

The upgraded Giant Metrewave Radio Telescope (uGMRT) Exposure Time Calculator (ETC) is an online tool that aims to help a user to estimate the total time required to achieve a particular sensitivity for a particular set of observational parameters, for typical observing conditions at the uGMRT. The different fields are described and explained below.

There are two uses of the ETC:

- Given a set of observational parameters, calculate the on-source and total observing times (including all overheads) required to achieve a given root-mean-square (RMS) noise sensitivity, in flux density units, or
- Given a set of observational parameters, calculate the RMS noise sensitivity that would be achieved in a given on-source time. In passing, also calculate the total observing time, including all observational overheads.

Default values are included for many of the input parameters. However, the user may choose to over-ride these values. If so, the user should justify this in the technical justification section. These boxes would be marked in magenta in the web form and the PDF output file. In both the webpage and the PDF output file, empty white boxes indicate values that must be provided by the user, while yellow boxes indicate outputs of the ETC; magenta boxes indicate places where the user has modified a default value. If the user clicks "Calculate" (see below) without entering all required inputs, the required boxes will be indicated by red borders in the webpage. Note that shifting from

*In case of queries, please send mail to gmrtcalc@ncra.tifr.res.in one observing mode to another may result in changes in the default parameter values. It would be safest to click "Reset" before changing any parameter, so that all parameters are set to their default values. This is especially important for the Fudge Factor.

The user should click "Calculate" to carry out the required calculation, and "Save as a PDF" to save the output as a PDF file. The final version of the PDF file should be attached to the proposal, in the NCRA Archive and Proposal System (NAPS).

Browser issues:

We have tested the ETC using different versions of the Firefox and Chrome browsers on Linux and MacOS systems, and somewhat less thoroughly using the Safari browser in a MacOS system. Issues with colour in the PDF output files have been noticed with the Safari browser. We recommend that users use Firefox or Chrome at the present time. Please report any issues to gmrtcalc@ncra.tifr.res.in .

1 Observation Type

The user has to choose one of three observation types from the drop-down menu: (1) Continuum, (2) Spectral Line, and (3) Pulsars/Transients (Time-Domain Studies). Note that, at present there are two separate ETCs, one for the "Continuum" and "Spectral Line" **Observation Types**, and another for the "Pulsars/Transients" **Observation Type**.

2 Observing Mode

For the "Pulsars/Transients" **Observation Type**, there are two allowed **Observing Modes**: (1) "Folded profile", and (2) "Single pulse". For a study of pulsars with "Folded profiles" the data are folded at the period of the pulsar; such studies thus benefit from longer integrations. Conversely, the "Single pulse" mode is applicable for calculating the sensitivity for the detection of individual pulses from pulsars and rotating radio transients, as well as that for fast radio bursts, and other individual transient events. We emphasize that the only effect of increasing the On-source Time for a "Single pulse" search is to increase the number of detected single pulses for the specific the case of pulsars, assuming that the pulses are bright enough to be detected above some signal-to-noise ratio (S/N) threshold. Similarly, for individual transients like FRBs, increasing the On-source Time increases the likelihood of detecting an individual transient event, but does not increase the actual sensitivity.

3 Observing Band

The uGMRT has four observing bands: (1) Band-2, covering $\approx 125 - 250$ MHz, (2) Band-3, covering $\approx 250 - 500$ MHz, (3) Band-4, covering $\approx 550 - 850$ MHz, and Band-5, covering

$\approx 980 - 1500$ MHz. The user should choose one of these bands from the drop-down menu.

4 Representative Frequency / Line Frequency

For the "Continuum" and "Pulsars/Transients" **Observation Types**, the **Representative Frequency** will be chosen automatically for the different bands, based on the default uGMRT observational settings for these observations. The user may choose to modify the default **Representative Frequency**, although this is not recommended for these two **Observation Types**. If the user chooses to modify the **Representative Frequency**, s/he should explain this in the Technical Justification of the proposal. For the "Spectral Line" **Observation Type**, the **Line Frequency** is the observing frequency of the spectral line of interest (in either MHz or GHz).

5 Beam Mode

This parameter is for the "Pulsars/Transients" **Observation Type** alone. The two choices are incoherent array ("IA") and phased array ("PA"). The "PA" mode gives higher sensitivity, by a factor of $\sqrt{N}$, where N is the number of antennas that are phased together, via observations of a strong phase calibrator.

6 Number of Antennas

The number of antennas may be chosen from the drop-down menu. The default number of available antennas is 26 in the "Continuum" and "Spectral Line" **Observation Types**, and 22 and 26, respectively, for phased-array and incoherent-array observations in the "Pulsars/Transients" **Observation Type**.

Note that for observations that are limited by surface brightness sensitivity, rather than point-source sensitivity, the user must decide the number of antennas that would be needed to achieve the required angular resolution. For example, one might compute the surface brightness sensitivity of the central square by assuming 14 antennas, and an angular resolution of $\approx 35''$ at ≈ 1420 MHz. For such observations, the user should explain the assumptions used to convert the point-source sensitivity provided by the ETC to a surface brightness sensitivity.

7 Bandwidth

This is the bandwidth to be set at the GMRT Wideband Backend (GWB), the uGMRT correlator. For the "Continuum" and "Pulsars/Transients" **Observation Types**, the default bandwidth is 200 MHz in Band-2 and Band-3, and 400 MHz in Band-4 and Band-5; the user may modify these values using the drop-down menu, which provides bandwidths of 400 MHz, 200 MHz, and

100 MHz, for these modes. For the "Spectral Line" **Observation Type**, no default bandwidth is selected; the user should select the GWB bandwidth from the drop-down menu, with allowed values ranging from 400 MHz to 0.78125 MHz, in steps of factors of 2. Users should note that the selected GWB bandwidth will have no effect on the time or RMS noise estimates below.

8 Usable bandwidth / Spectral Resolution

For "Continuum" and "Pulsars/Transients" **Observation Types**, this is the bandwidth (in either kHz or MHz) that is expected to be "usable", i.e. not significantly affected by radio frequency interference (RFI). Default values are 50 MHz, 120 MHz, 200 MHz, and 280 MHz in Band-2, Band-3, Band-4, and Band-5, respectively, for **Bandwidths** of 100/200 MHz in Band-2, 200/400 MHz in Band-3, and 400 MHz in Band-4 and Band-5. For **Bandwidths** of 200 MHz in Band-4 or Band-5, the default usable bandwidth is 150 MHz in both bands. The user may choose to modify these values, with an explanation in the Technical Justification of the proposal. This bandwidth, assumed to be centred at the **Representative Frequency**, will be used in the RMS noise estimates. This bandwidth is used by the ETC to integrate the sensitivity curve, to obtain the final RMS noise for a given on-source time (or *vice versa*). This is discussed in detail in Appendix II.

For the "Spectral Line" **Observation Type**, the user should provide the required spectral resolution, either in frequency units (in kHz or MHz), or in velocity units (in the rest frame of the target source), in km/s.

Note that it is the **Usable Bandwidth** (for "Continuum" or "Pulsars/Transients" modes) or the **Spectral Resolution** (for "Spectral Line" mode) that is the critical input for the RMS noise and the On-Source Time. The **Bandwidth** parameter is simply a setting for the GMRT Wideband Backend, and is not used in the calculation.

9 Channel resolution

The **Channel resolution** $\Delta\nu$ is a parameter for the "Pulsars/Transients" mode, which gives the smearing of the pulse due to its dispersion across a channel. Specifically, the width of the pulse due to such dispersion smearing is

$$W_{\rm DM} = K_{\rm DM} \times {\rm DM} \times \frac{\Delta\nu}{\nu^3} \quad , \tag{1}$$

where DM (in pc cm^{-3}) is the dispersion measure of the pulsar, $K_{\rm DM} = 8.3 \times 10^6$ ms, $\Delta\nu$ is the **Channel resolution** (in MHz), ν is the **Representative Frequency** (in MHz), and the width $W_{\rm DM}$ is in ms (Lorimer and Kramer 2004).

The default value of the **Channel resolution** is 0.1 MHz ($\approx$ 2048 channels across 200 MHz), to ensure that $W_{\rm DM}$ is small compared to the intrinsic pulse width for normal pulsars and DM values. If the intrinsic pulse width of the target of interest is relatively low at the **Representative**

Frequency, users should reduce the **Channel resolution**; the user may choose up to 8192 channels, implying best **Channel resolutions** of ≈ 0.025 MHz and ≈ 0.05 MHz for bandwidths of 200 MHz and 400 MHz, respectively. Users should also ensure that their observational setup uses sufficient channels to obtain the quoted **Channel resolution**.

10 Number of Polarizations

In the "Continuum" and "Spectral Line" **Observation Types**, the user should choose "2 (Total Intensity, Stokes-I)" for standard "Stokes I" observations. For single polarization observations, the user should choose "1 (RR or LL)". Note that for polarimetric measurements, where both parallel and cross-polar components (i.e. RR, LL, RL, LR) are measured, the number of polarizations remains 2.

11 Image weighting

This parameter is for the "Continuum" and "Spectral Line" **Observation Types**. Weighting provides a balance between the RMS sensitivity and the angular resolution, by weighting the data in the U-V plane. The user may choose between Natural weighting, Uniform weighting, and Robust weighting. Natural weighting gives equal weights to all visibilities, and hence yields the highest sensitivity, but a coarser angular resolution. Conversely, uniform weighting weights each visibility point by the inverse of the density of the U-V samples around it. This has the effect of giving a higher weight to visibilities on long baselines, and thus yields a more "pointy" synthesized beam, with lower sidelobes, at the cost of RMS sensitivity. Robust weighting (devised by Dan Briggs; Briggs et al. 1999) provides a compromise between the two, with intermediate sidelobes and synthesized beam, and intermediate RMS noise sensitivity. At the present time, only Natural weighting is allowed by the ETC. Of course, the user may use whatever weighting they require when analysing the data. Since the sensitivity for uniform or robust weighting would be worse than for natural weighting, the user may account for this loss in sensitivity in the **Fudge Factor**, with details provided in the Technical Justification.

12 Source co-ordinates (J2000)

The user should enter the J2000 co-ordinates of his/her target source. This will be used to estimate the sky temperature in the target direction, extrapolating from the all-sky 408 MHz image of Haslam et al. (1982). Further, the presence of bright sources in the Galactic Plane may cause the final images to be limited by dynamic range rather than raw sensitivity. If the source lies within $10°$ of the Plane, the ETC will provide a warning about possible dynamic range issues.

The ETC will further use the **source co-ordinates** to determine how long the target source is observable above $17°$ elevation at the GMRT. For cases of multiple observing runs, this will be used to estimate the length of each observing run. Users should hence enter the source co-ordinates correctly.

The ETC will search the source catalogue of the 1.4 GHz NRAO VLA Sky Survey (NVSS; Condon et al. 1998) for the presence of bright sources (NVSS flux density $\geq$ 50 mJy) within the FWHM of the primary beam, that might limit the dynamic range. The ETC will provide an estimate of the image dynamic range, assuming a low-frequency spectral index of $\alpha = -0.7$ (for flux density $S_\nu \propto \nu^\alpha$) to infer the source flux density at the representative frequency from the NVSS 1.4 GHz flux density; a warning will be provided if the dynamic range is $> 50,000$. A warning will also be provided if there are similar bright radio sources at or somewhat below the half-power point of the uGMRT primary beam, that might limit the dynamic range due to primary beam asymmetries.

The ETC will also provide a rough estimate of the angular resolution of the image, assuming uniform weighting, i.e. synthesized beam full-width-at-half-maximum $\approx 2.473/\nu''$, where ν is the **Representative Frequency**, in GHz. This estimate also assumes the use of the full uGMRT array, and assumes that the source transits at the zenith of the array. In other words, this estimate is the best angular resolution that can be obtained with the uGMRT at the **Representative Frequency**; the actual obtained angular resolution will depend on the source declination, the actual antenna availability, and, of course, the weighting scheme, and the **On-Source Time**.

13 Period

This parameter is for the "Pulsars/Transients" **Observation Type** alone. The user should enter the pulsar period, in units of either seconds or ms.

14 Pulse Width

This parameter is for the "Pulsars/Transients" **Observation Type** alone. The user should enter the pulsar pulse width, in units of either seconds or ms.

15 Dispersion Measure

This parameter is for the "Pulsars/Transients" **Observation Type** alone. The user should enter the pulsar dispersion measure, in units of pc cm^{-3}.

16 Sky Temperature

The **Sky Temperature** at the **Representative Frequency** or **Line Frequency** is automatically estimated by the ETC, extrapolating from the all-sky 408 MHz image of Haslam et al. (1982)

(see also Haslam et al. 1981; Remazeilles et al. 2015). This is done by inferring the 408 MHz sky temperature at the target source location, by interpolating between the Haslam et al. measurements. This sky temperature is then scaled to the **Representative Frequency** using an assumed spectral index of $\alpha = -2.55$ for the brightness temperature of Galactic synchrotron emission. This value is shown in the box **Sky Temperature**. Note that this displayed temperature does not include the contribution of of 2.726 K from the cosmic microwave background.

17 Calculation Type

At present, there are two allowed **Calculation Types**: (1) On-Source Time, where the user enters the required RMS noise sensitivity and the ETC estimates the On-Source and Total observing times, and (2) RMS Noise, where the user enters the planned on-source time, and the ETC estimates the RMS noise sensitivity, and the Total observing time. The default is "On-Source Time".

The most standard use of the ETC is to estimate the required **On-Source Time** in order to achieve a desired **RMS Noise**. For this mode, users should set the **Calculation Type** to **On-Source Time**. However, if the sensitivity is likely to be limited by UV coverage or other issues, or if the user requires a minimum amount of **On-Source Time** (e.g. to detect a minimum number of single pulses from a pulsar; see below), the user should set the **Calculation Type** to **RMS Noise**. This would provide an estimate of the theoretical **RMS Noise** for the chosen **On-Source Time**, as well as the **Overheads** and **Total Time**. The user should justify the choice of **On-Source Time** in the Technical Justification.

Note that the "Single pulse" search in the "Pulsars/Transients" **Observation Type** will simply provide an estimate of the RMS noise that would be obtained over an **On-Source Time** equal to the pulse width. For this mode, the user must *separately* set the **On-Source Time** which will allow her/him to either observe multiple single pulses from a pulsar or carry out a search for individual pulses from a transient source (brighter than some S/N threshold) for the desired time. This will lead to a sensible calculation of the **Overheads** and the **Total Time**.

The dependence of the uGMRT sensitivity ($G/T_{\rm sys}$, in Jy^{-1}) on frequency is described in Appendix-I, which also provides polynomial fits to the measured sensitivity as a function of frequency, for the four observing bands. Since the sensitivity is a function of frequency, the standard radiometer equation must be modified to take into account this dependence. Details of the calculation to obtain the **On-Source Time** for a given desired **RMS noise**, or *vice versa*, are provided in Appendix-II.

18 RMS Noise

For **Calculation Type**="On-Source Time", the user should enter the required RMS noise here, in either mJy/Bm, or μJy/Bm (selected from the drop-down menu). For **Calculation Type**="RMS

Noise", this box will be yellow and will contain the output RMS Noise that would be obtained for the target On-Source Time.

19 On-Source Time

For **Calculation Type**="On-Source Time", this box will be yellow, and will contain the output On-Source Time that would be needed to achieve the target RMS Noise sensitivity. For **Calculation Type**="RMS Noise", the user should enter the On-Source time here, in hours or minutes (selected from a drop-down menu).

However, for a "Single pulse" study, the user may not select "On-Source Time" as a **Calculation Type**; s/he is required to enter the desired "On-Source Time" directly (note that the sensitivity for a single-pulse search is a function of only the pulse width, and does not depend on the "On-Source Time" (for values larger than the pulse width, of course). For "Single pulse" studies, the user should choose an "On-Source Time" based on either (for pulsar studies) the number of single pulses that s/he aims to detect to achieve the science goals, or (for transient searches) the length of time that s/he would like to search for a transient. The choice of the "On-Source Time" must be explained in detail in the Technical Justification.

20 Fudge Factor

This is the "typical" fudge factor for observations at the **Representative Frequency**, which gives the ratio of the actual On-Source Time that would be needed to achieve a given RMS noise to the theoretical On-Source Time. The default value is 1. For "Spectral Line" observations, the **Fudge Factor** for uGMRT is typically 1.5. For "Continuum" observations, the **Fudge Factors** are different in the different bands and typically lie in the range $\approx (2-3)$, for **On-Source Times** of $\approx 1-10$ hours. The user may enter the assumed **Fudge Factor** in this box, with an explanation provided in the Technical Justification.

For the "Single pulse" search in the "Pulsars/Transients" **Observation Type**, the Fudge Factor is set to unity and may not be modified by the user.

21 Total On-Source Time including Fudge Factor

This is the total on-source time including the Fudge Factor, i.e. the product of the On-Source Time of Section 19 and the Fudge Factor entered by the user. This is an output of the ETC and cannot be modified by the user.

22 Overheads

The time required for observing overheads is estimated here, including time for set-up, slewing, and flux and phase calibration. NOTE: This does *not* include time for additional bandpass or polarization calibration. It assumes that either the flux density calibrator or the phase calibrator (or both) are bright enough to accurately calibrate the system passband.

22.1 "Continuum" and "Spectral Line" Observation Types

The set-up of the observations is assumed to take 20m for the "Continuum" and "Spectral Line" **Observation Types**. The ETC assumes 10m for flux density calibration and slewing for an on-source time ≤ 4 hours, and 20m for on-source time > 4 hours.

For phase calibration, the ETC assumes observations of a nearby secondary calibrator every 30m at Band-2, every 35m at Band-3, every 40m at Band-4, and every 45m at Band-5. It also assumes 8m for each phase calibration scan, typically 5m on the calibrator and 3m of slewing time to and from the calibrator. The phase calibration time is then estimated as $(N + 1) \times$ 8m, where

$$N = Integer[\Delta \mathrm{t_{ON}}/\Delta t] \ . \tag{2}$$

Here, $\Delta \mathrm{t_{ON}}$ is the On-Source Time (in minutes) and $\Delta t = 30, 35, 40, 45$m for Band-2, Band-3, Band-4, and Band-5, respectively.

N is the integer immediately larger than the ratio $[\Delta \mathrm{t_{ON}}/\Delta t]$, unless the fractional part of this ratio is < 0.1, in which case it is taken as the integer immediately lower than this ratio. For example, if $[\Delta \mathrm{t_{ON}}/\Delta t] = 2.1$, then $N = 2$; however, if $[\Delta \mathrm{t_{ON}}/\Delta t] = 2.7$, then $N = 3$.

The total time for Overheads is then 20m + 10m (or 20m) + $(N + 1) \times$ 8m for Continuum and Spectral Line observations.

22.2 "Pulsars/Transients" Observation Type

For the "Pulsars/Transients" **Observation Type**, the set-up at the beginning of the observations is assumed to take 30m, including time for phasing up the array, in the default single sub-array mode. If the array will be configured into 2 sub-arrays, the user should modify the Overheads, assuming an additional 30m at the start of the run, for setting up the multiple sub-arrays.

In addition, the ETC assumes 10m of **Overheads** for every hour of **On-Source Time** for phasing up the array. In other words, for "Pulsars/Transients" observations, the net **Overheads** (in minutes) are $30 + 10 \times \mathrm{M}$, where M is the integration time in hours (rounded up to the nearest integer). This gives the default **Overheads** for the "Pulsars/Transients" observing mode. We emphasize that this expression is valid only for observations with a single sub-array. For observations with multiple sub-arrays, the user should modify the Overheads to $60 + 10 \times \mathrm{M}$ minutes.

22.3 User modifications

If the user chooses to modify the default overheads, this must be explained in the Technical Justification of the proposal.

Standard interferometry (i.e. "Continuum" or "Spectral Line") situations in which the user should modify the Overheads are if (1) the target source is a phase calibrator (i.e. no phase calibration necessary), (2) the target source is both a phase calibrator and a flux calibrator (i.e. no flux or phase calibration necessary), (3) a flux calibrator can be used as the phase calibrator (i.e. no additional flux calibrator necessary), (4) a good continuum image is available for the field, which can be used as an initial model for self-calibration, but calibration of the passband must be carried out, or (5) polarimetry is being carried out. For these cases, use the Overheads below:

- Case 1: If no phase calibration is needed, the Overheads would be equal to 20m + 10m = 30m for On-Source times ≤ 4h, or 20m + 20m = 40m for On-Source times > 4h.
- Case 2: If no flux or phase calibration is needed, the Overheads would be simply 20m for set-up.
- Case 3: If no additional flux calibration is needed, the Overheads would be 20m + $(N + 1) \times$ 8m.
- Case 4: If no flux or phase calibration is needed, the Overheads would be 20m, and the user should include the time for Bandpass calibration in Box 14.

For "Pulsars/Transients" observations using multiple sub-arrays, the user should change the **Overheads** to $60 + 10 \times \mathrm{M}$ minutes, to account for the extra set-up time at the start of the run, where M is the integration time in hours (rounded up to the nearest integer). Pulsar polarimetry studies would also require additional overheads; the user should include this in the **Overheads**, and should provide details in the Technical Justification.

22.4 Multiple Observing runs

After the initial estimate of the **Overheads**, the ETC combines the **On-Source Time**, the **Fudge Factor**, the **Overheads**, and any extra time requested by the user for **Bandpass/Polarization calibration** (see the next section), to obtain the total observing time. The ETC further estimates the time for which the target source would be observable at the GMRT in a single observing run, i.e. the time for which the target is above an elevation limit of 17°. If the total time is longer than the time for which the source is observable at the GMRT in a single observing run, the ETC assumes that the total time will have to be split into multiple observing runs. Each extra interferometry observing run will require an additional 20m for setup, 20m for flux calibration (assuming runs ≥ 4 hours), and 8m for a final phase calibration run on each additional observing run. Similarly, each additional pulsar/beamformer observing run with a single sub-array will require an extra 30m for setup. The ETC includes an estimate of these additional overheads, by assuming multiple observing runs, each of duration equal to the time for which the source is above 17° elevation at the GMRT. For sources that are continuously observable for more than 11 hours, the ETC assumes that each run is of 11-hour duration. The additional overheads due to the multiple observing runs are finally combined with the original estimate of the overheads to obtain the final estimate of the **Overheads**; this final estimate is written as the **Overheads** output of the ETC.

If the user chooses to enter her/his own estimate of the **Overheads** into the ETC, s/he is advised to check the first sentence of the ETC output which would list the ETC estimate of the number of observing runs, and to adjust the **Overheads** to take this into account.

23 Extra Bandpass/Polarization Time

In interferometry observations, if the flux density or phase calibrators are not bright enough for bandpass calibration, or if additional bandpass calibration is deemed necessary, or if the observations do not require flux or phase calibration, but do require bandpass calibration, enter the required time for bandpass calibration here. Similarly, for interferometric polarimetry, additional calibration will be needed to determine the polarization leakage terms and the absolute polarization angle; this additional time could also be entered here. If filled, based on the science requirements, this entry should be explained in the Technical Justification.

24 Total Observing Time

This is the total time required for the observations, obtained as (Fudge Factor × On-Source Time + Overheads + Extra Bandpass Time).

25 RMS Confusion

For **Observation Type**="Continuum", this provides an estimate of the RMS confusion σ_c^* at the **Representative Frequency**, based on extrapolating from the results of Condon et al. (2012). The RMS confusion is given by

$$\sigma_c^* = 1.2\mu\mathrm{Jy/Bm}\ \left[\frac{\nu}{3.02}\right]^{-0.7} \left[\frac{\theta}{8''}\right]^{10/3} , \tag{3}$$

where ν is the **Representative Frequency** (in GHz) and θ is the synthesized beam (in $''$, assuming uniform weighting) (Condon et al. 2012). The assumed angular resolution is mentioned below the ETC output. The ETC will provide a warning if the target RMS noise is comparable to or lower than σ_c^*, as this would imply that the imaging performance would be limited by source confusion, and not by raw sensitivity. If the user plans to taper the data, or to use robust or natural weighting, the angular resolution would be poorer than that with uniform weighting, implying a higher **RMS Confusion** than that listed by the ETC.

For **Observation Type**="Spectral Line" or "Pulsars/Transients", the RMS Confusion is set to 0.

Acknowledgments

We thank Apurba Bera, Bhaswati Bhattacharyya, Jayanta Roy, and Jayaram Chengalur for carefully testing different versions of the calculator, and providing much-needed suggestions and criticism. We also thank Jayanta Roy for providing the details of the pulsar sensitivity equations. Finally, the design of the uGMRT calculator was influenced by that of the VLA Exposure Calculator (at https://obs.vla.nrao.edu/ect/).

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Appendix-I: The sensitivity of the uGMRT array

The dependence of the uGMRT sensitivity on frequency was obtained by carrying out polynomial fits to the measured sensitivity ($G/T_{\rm sys}$, in Jy^{-1}) as a function of frequency, for the four observing bands. The polynomial fit parameters a_i are summarized in Table 1, where the fit has the form

$$G/T_{\rm sys} = a_0 + a_1\nu + a_2\nu^2 + a_3\nu^3 + a_4\nu^4 + ... , \tag{4}$$

with ν in MHz and $G/T_{\rm sys}$ in Jy^{-1}.

		Band-2	Band-3	Band-4	Band-5
a_0	–	-0.0274432341259116	-3.94269512191062	-60.9659547181797	-57.790674973176
a_1	$\times 10^{-4}$	6.53316475755705	609.220731323399	5298.1146165773	2831.83485351112
a_2	$\times 10^{-6}$	-5.75221466249264	-388.278427948319	-1911.99335049503	-576.846763506177
a_3	$\times 10^{-8}$	2.26066919981535	130.788311514484	366.739380599885	62.5315209850824
a_4	$\times 10^{-11}$	-3.30079139610497	-245.688427095004	-394.286904604421	-38.047941517696
a_5	$\times 10^{-13}$	–	24.4226778956594	22.5267804015136	1.23211866985187
a_6	$\times 10^{-17}$	–	-100.460621956708	-53.4321835013018	-1.65909077237512

Table 1: Polynomial fits to the uGMRT sensitivity ($G/T_{\rm sys}$) curves. See Appendix-I for details.

The four panels of Fig. 1 show the sensitivity curves of the four GMRT bands, with $1000 \times (G/T_{\rm sys})$ (in Jy^{-1}) plotted against frequency, in MHz.

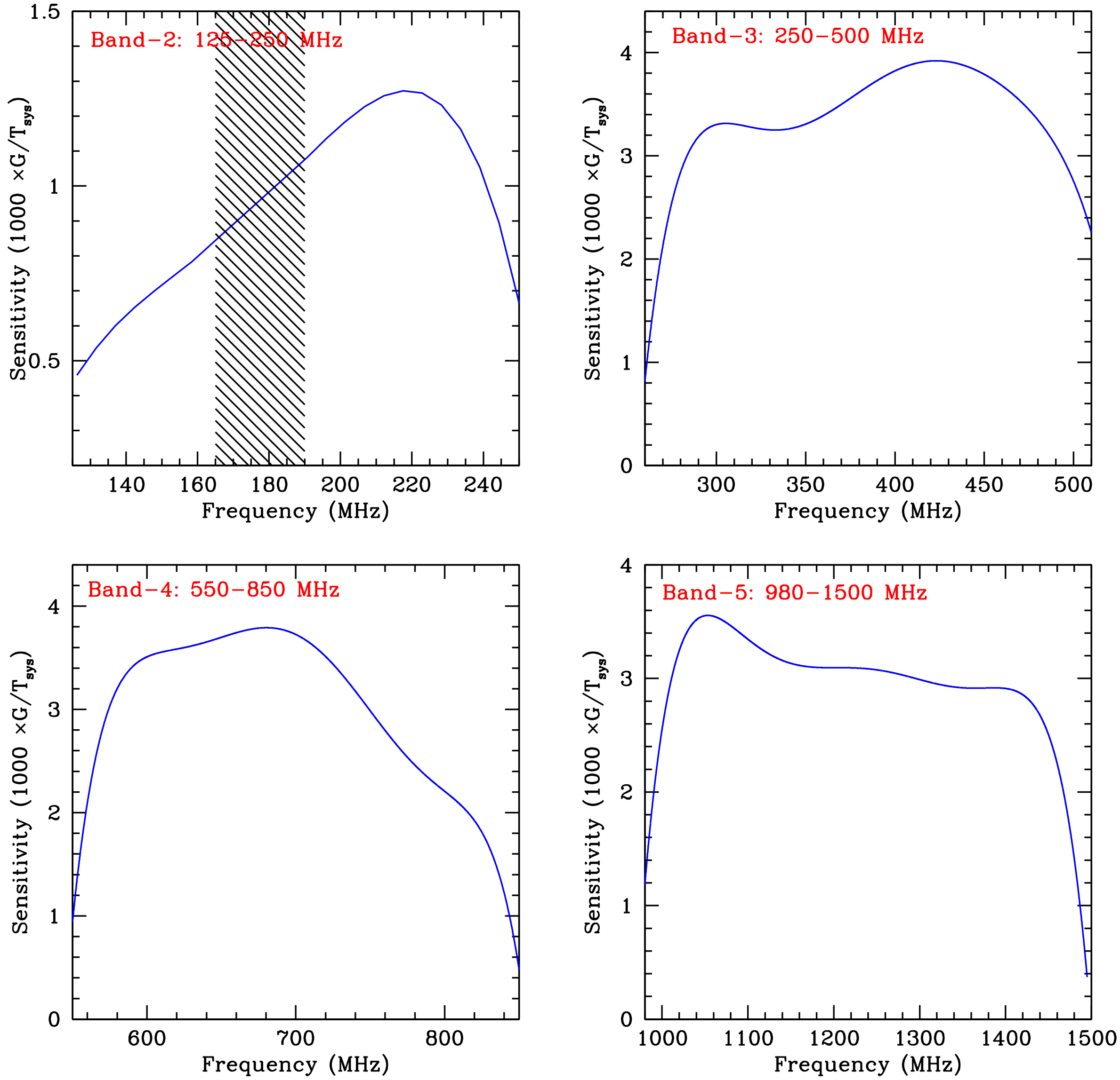

Figure 1: The sensitivity [$1000 \times (G/T_{\rm sys})$, in $\rm Jy^{-1}$] plotted against frequency for the four uGMRT observing bands. The shaded area in the top left panel for Band-2 indicates a frequency range ($\approx 165 - 190$ MHz) that is rendered unusable by strong RFI and a notch filter.

Appendix-II: The sensitivity equations

25.1 Continuum and Spectral Line observations

For "Continuum" and "Spectral Line" observations, the RMS noise (in Jy) is estimated from the standard equation

$$\mathrm{RMS} = \frac{T_{\mathrm{sys}}}{G\sqrt{[N(N-1)/2] \times N_{pol} \times 2 \times \Delta\nu \times \Delta t}} \quad , \tag{5}$$

where N is the number of antennas, N_{pol} is the number of polarizations (1 or 2), $\Delta\nu$ is the bandwidth, in Hz (see below), and Δt is the On-Source Time, in seconds.

For "Spectral Line" observations, the calculator uses the value of G/T_{sys} at the **Line Frequency**, while $\Delta\nu$ is the desired spectral resolution. For "Continuum" observations, the RMS noise is estimated by taking into account the variation of G/T_{sys} across the band (see Appendix-I). This is done by estimating the RMS noise in 1 MHz chunks across the **Usable bandwidth** centred at the **Representative Frequency**, using the G/T_{sys} value at the central frequency of each 1 MHz chunk, and then combining these RMS values to obtain the final RMS noise.

25.2 Surface Brightness sensitivity

For interferometric observations, the RMS noise obtained above yields the *point source sensitivity* of the array. Observations of extended emission (e.g. HI 21 cm emission from the Milky Way or nearby galaxies, continuum emission from supernova remnants, HII regions, or clusters) may be limited by surface brightness sensitivity or U-V coverage, rather than by the point-source sensitivity. For observations limited by surface brightness sensitivity, users can set the number of antennas that will actually be used in the imaging, and should verify that their surface brightness sensitivity requirements are met; this should be explained clearly in the technical justification. Note that the angular resolution listed by the ETC is for uniform weighting, assuming all 30 antennas, at the **Representative Frequency** or the **Line Frequency**. Users should use the angular resolution appropriate for their science goals to estimate the surface brightness sensitivity. For example, one might compute the surface brightness sensitivity of the central square by assuming 14 antennas, and an angular resolution of $\approx 35''$ for observations of Galactic or nearby HI 21 cm emission at ≈ 1420 MHz.

25.3 Pulsar observations

For "Pulsars/Transients" observations, the RMS noise is estimated in a manner similar to that for "Continuum" observations, taking into account the variation of G/T_{sys} across the observing band. This is done by estimating the RMS noise in 1 MHz chunks across the **Usable bandwidth** centred at the **Representative Frequency**, using the G/T_{sys} value at the central frequency of each 1 MHz chunk, and then combining these RMS values to obtain the final RMS noise. The sensitivity equations for the different "Pulsars/Transients" observing modes are detailed below.

25.3.1 Folded profile mode

For "Pulsars/Transients" observations, the sensitivity equations for "Folded profile" studies are (e.g. Lorimer and Kramer 2004)

$$\mathrm{RMS} = \frac{T_{\mathrm{sys}}}{G\sqrt{N_{\mathrm{PA}}^2 \times N_{pol} \times \Delta\nu \times \Delta t}} \sqrt{\frac{W_{eff}}{P - W_{eff}}} \qquad \text{(PA mode)}, \tag{6}$$

and

$$\mathrm{RMS} = \frac{T_{\mathrm{sys}}}{G\sqrt{N_{\mathrm{IA}} \times N_{pol} \times \Delta\nu \times \Delta t}} \sqrt{\frac{W_{eff}}{P - W_{eff}}} \qquad \text{(IA mode)}, \tag{7}$$

where N_{PA} and N_{IA} are the number of antennas combined together in the "PA" and "IA" modes, respectively, P is the pulsar period, and W_{eff} is the final pulse width, including contributions from the intrinsic pulse width W_{int}, the smearing due to intra-channel dispersion W_{DM}, and scatter broadening W_{scatt}:

$$W_{eff} = \sqrt{[W_{int}^2 + W_{\mathrm{DM}}^2 + W_{scatt}^2]} \quad , \tag{8}$$

Here, the smearing due to intra-channel dispersion is given by

$$W_{\mathrm{DM}} = K_{\mathrm{DM}} \times \mathrm{DM} \times \frac{\Delta\nu}{\nu^3} \quad , \tag{9}$$

where DM (in pc cm^{-3}) is the pulsar dispersion measure, $K_{\mathrm{DM}} = 8.3 \times 10^6$ ms, $\Delta\nu$ is the **Channel resolution** (in MHz), ν is the **Representative Frequency** (in MHz), and the width W_{DM} is in ms. The effects of scatter broadening are quantified by (Bhat et al. 2004)

$$\log[W_{scatt}] = -6.46 + 0.154 \times \log[\mathrm{DM}] + 1.07 \times \log[\mathrm{DM}]^2 - 3.86 \times \log[\nu] \tag{10}$$

where W_{scatt} is in ms, and ν is the **Representative Frequency**, in GHz.

25.3.2 Single pulse mode

Finally, for the "Single pulse" mode, the sensitivity equations are

$$\mathrm{RMS} = \frac{T_{\mathrm{sys}}}{G\sqrt{N_{\mathrm{PA}}^2 \times N_{pol} \times \Delta\nu \times W_{eff}}} \qquad \text{(PA mode)}, \tag{11}$$

and

$$\mathrm{RMS} = \frac{T_{\mathrm{sys}}}{G\sqrt{N_{\mathrm{IA}} \times N_{pol} \times \Delta\nu \times W_{eff}}} \qquad \text{(IA mode)}, \tag{12}$$

where W_{eff} is in seconds, and the remaining terms have the same meanings and units as in the previous section.