Planning pulsar observations with uGMRT

Yogesh Maan
(maan@astron.nl)

Planning and conducting pulsar-mode observations with GMRT might appear a complex task at times, especially for someone who does not have experience in observing pulsars using an interferometer/multi-dish telescope. This document describes the observing procedure from an observer's point of view, without getting into all the nitty-gritties which are generally handled by the on-duty operators at the telescope. A python script is now available (https://github.com/ymaan4/GMRT-Observation-planner) that produces a command-file and description of the planned observations with the GMRT wide-band backend, helps in streamlining the preparation for observations, and reduces the scope for any human error in this process. The resultant files can also directly be sent to the operators for availing absentee mode observations. More details of the script are given later in this document.

GMRT consists of 30 dishes, each with a diameter of 45 metres, arranged roughly in a Y-shaped array. For pulsar-mode observations, one would like to *coherently* add the voltage signals from all dishes, so that collecting area potentially equivalent to those of all the dishes can be utilized. From observations point of view, the whole process primarily happens in the following steps:

1. Equalize the gains of various dishes using a **flux calibrator**.
2. Calibrate the phase-offsets for various dishes using a **phase calibrator**.
3. Record the (pulsar-mode) data on intended sources/directions for a specified time.
4. Repeat the above 2 steps.

The ionosphere introduces time-varying phases in the incoming signals. The step 2 above calibrates out those differences along with any instrumental phase-offsets. However, the ionosphere induced phases can potentially also vary differently for different dishes, especially for the low frequencies and long baselines at which GMRT operates. To keep getting the full sensitivity, the phase-calibration needs to be repeated at regular intervals (that is why the step#4 above). The duration of the interval varies hugely, and might go from 15 minutes to several hours depending on the observing frequency, which dishes are being used and the ionospheric conditions on a given day. If one uses only the dishes in the central square (i.e., only short baselines), then at 250−500 MHz and higher frequency bands a typical interval of 45 minutes to 1 hour between successive rounds of phasing can be used without much loss in sensitivity.

For planning a pulsar-mode observation, the observer needs to select appropriate flux and phase calibrators. Generally, one of the three strong flux-calibrators 3C286, 3C48 and 3147, which is visible during the observing session is chosen, but some other reasonably strong source can also be used. For phase-calibration, the observer needs to chose a source that is fairly strong (10 Jy or more is recommended), unresolved for the baselines involved in the selected set of dishes to be used as well as not very far (typically within 20°) from the target pulsar/source. One can use the search tool available at `http://gmrt.ncra.tifr.res.in/~astrosupp/calib/vlacal.html` to first list all sources within a desired angular distance from the target and then choose an appropriate phase calibrator satisfying above mentioned criteria. The list from above search tool also specify calibrator-codes, one should choose the calibrators with codes P or S (i.e., primary and secondary, respectively). The list shows the codes for different baseline-configurations (A, B, C and D) of VLA. For using only the central square dishes, one can examine the calibrator properties under the most

compact configuration (i.e., D) of VLA. For other combination of dishes, the properties under correspondingly appropriate VLA configuration can be examined. For each observing session, the observer needs to provide following to the telescope operators:

1. A list of sources (including calibrators) and their coordinates.
2. Detailed information of the desired setup.
3. A detailed plan of the observations.
4. A command file to steer the dishes and record data.

All of the above can be provided in separate simple text files. Each line in the file containing the list of sources should specify the source-name and its coordinates in the following format:

```
3C48          01h37m41.30s  +33d09'35.13" 2000
B1820-30A     18h23m40.40s  -30d21'40.10" 2000
```

The last column specifies the epoch of coordinates, and as many sources can be listed as one wishes. The list serves as a source-catalog, and there can be more number of sources than desired to be observed in a particular session.

The information about the desired setup includes information on the observing band, number of channels, sampling time, etc. In principle the setup information can be provided in a free format, but a typical and commonly used set-up file looks like following:

```
-------------------------------------------------------------------------
Project Code    : <Proposal code>
Project Title   : <The Proposal Title>
User's Name     : <Observer's Name>
User's email    : <Observer's email-id>
Date of Obs     : <Date, e.g., 01/12/2017>
Start Time(IST hours) : <e.g., 14:00>
BACKEND USED    : GWB
BAND            : <Desired band, e.g., BAND 3 (300-500 MHz)>
MODE            : REALTIME
LTA1            : 4 ( In GWB Configuration Window)
LTA2            : 2 ( Post Integration Multiplier)
LTA Integraton  : 5 Sec
ACQ BW          : <e.g., 200 MHz>
NO OF CHAN      : <e.g., 4096>
TPA SELECTION   : MANUAL
DDC MODE        : OFF
BEAM 1          : <e.g., PA TOTAL INTENSITY>
BEAM INTEGRATION: <e.g., 16  (would imply 0.32 ms sampling for 4096 channels)>
GAB LO          : <e.g., 500 MHz  LSB>
Observation Type: <e.g., Continum AND Pulsar, or just Pulsar>
GAB Filter BW   : <200 MHz>
OFC-Attenuations: <e.g., 10-10 dBm (Default for P band)>
=========================================================================
Any Special Requirement (If any)
1. Interferometric data to be recorded simultaneously.
2. FOR PHASING THE ARRAY, PLEASE USE <source-name>.
```

```
Source list   :  src.list
Command file  :  obs.txt
Setup file    :  setup.txt (this file)
--------------------------------------------------------------------------------
```

If one is not interested in recording the interferometric data in parallel with the time-domain data, then the LTA related parameters can be skipped or kept as default.

The python script `plan_uGMRT_obs.py` can be used to prepare the command-file for observing a desired set of sources using the GWB. The script is well tested in python 2.7, and executing it without any arguments would present a usage information. The script takes a file as input, each line of which should have the following information:

```
<Source-Name>   <Source-type>  <Observing duration (minutes)>
```

The source name should match with the one present in the separately provided list of sources. The source-type could be one of the following: phase (i.e., this source will be used as a phase-calibrator), psr (i.e., record data in pulsar mode on this source), and intp (a separate phase-calibrator for interferometric observations in parallel, if needed). A simple input file can have just following two lines:

```
3C380           phase        1
J2021+4026      psr          30
```

implying that phase-calibrate the array using 3C380 (typically by recording 1 minute on this), then observe J2021+4026 for 30 minutes, and do this process in a loop till the end of the session. The input file can have repetions and as many lines as desired, which might even cover the full observing session duration (naturally, these will not get looped then). This aspect provides freedom to arrange the observations during a session in any desired manner. The other two inputs needed by the script are proposal code and the flux-calibrator name to be used for gain calibration in the beginning. Apart from the command file, the script also produces a simple text file containing the general plan of the observations. This plan file also mentions which dishes to be used while phasing the array. By default, all the central square and first two dishes from each of the arms are listed. But it can be manually modified, in case a different set of dishes is desired. Section 4 in this file lists the actions to be taken via command file, and should not be modified (all other sections can be modified as desired). The plan file is useful for the telescope operators to understand what is planned, and especially how to proceed if some unfortunate technical interruptions happen during the observing session.

Providing above information to the operators is helpful and generally suffices for a successful observation. However, contacting the operators well in advance and keeping them well informed about what is planned is always helpful.