National Centre for Radio Astrophysics

Internal Technical Report
GMRT/TGC/R312–Feb2023

Antenna Scan Command Implementation & Testing in the TGC

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Objective : The provision for '***scan'*** command implementation was made during TGC development by considering optional arguments in a generic antenna 'track' command. However, implementation and testing of the 'scan' command at a subarray level (aggregation-node in the CMC), and at the antenna LMC-node was remained. Therefore, to implement a scan command both at individual antenna, and Sub-array level, a TGC code is modified, and also added new code wherever it necessitate in CMC and LMCs. After the implementation, verification & validation testing done From July 9th to 28th , 2022. It is ensured from the validation tests that antennas pointing offsets measured using the 'scan' command are matching with that of the antenna pointing offsets measured using the 'grid-pointing' procedure.

Revision	Date	Modification/ Change
Ver 1.0	Nov 7, 2022	Final report after discussion in the TGC meeting.

Internal Technical Note on :

Antenna Scan Command Implementation & Testing in the TGC

Jitendra Kodilkar $ Version 1.0, Nov 7, 2022 $

1. INTRODUCTION

To measure antenna pointing offsets, two types of proceudures are used at the GMRT , one is '**grid-pointing'** procedure where antenna track on equidistant points across Azimuth/Elevation axis on a target celestial point source. And in another procedure, antenna is slewed with known slewing-rate in Azimuth or Elevation axis (or in Right Ascension/Declination) across the celestial source. Antenna is slewed using the **'scan'** command with input arguments - slewing rate, and peak-time at which antenna is expected exactly on target-source. In both of these methods, total-power or visibility data is acquired using the GMRT backends (GSB or GWB).

- In the scanning method, antenna offset for Azimuth or Elevation axis is calculated as follows :

***Antenna offsets** (in deg. Or arc-min) **= (Observerd Peak-time – Expected Peak-time in Scan-command) * scan-rate** (in deg or arc-min per minute)*

The provision for 'scan' command implementation was made during TGC development by considering optional arguments in a generic antenna 'track' command. However, implementation and testing of the 'scan' command at a subarray level (aggregation-node in the CMC), and at the antenna LMC-node was remained. Therefore, to implement a scan command both at individual antenna, and Sub-array level, a TGC code is modified, and also added new code wherever it necessitate in CMC and LMCs. After the implementation, verification & validation testing done From July 9th to 28th , 2022. It is ensured from the validation tests that antennas pointing offsets measured using the 'scan' command are matching with that of the antenna pointing offsets measured using the 'grid-pointing' procedure.

In this report, ***Section 2*** describe SOP to execute the 'scan' command using the GUI, and Scripting interface. ***Section 3*** describe test observations conducted to validate the scan-command, and discuss the obtained results from the test observations so that 'scan' command can be released for the usage.

*The s/w code changes or new development done in the CMC and LMC for 'scan' command is mentioned in **Appendix-I.***

2. SOP to use the 'scan' command :

In the TGC , command can be executed either from the GUI or using the scripting-interface. The scan command in various modes are available for usage, which is as follows :

2.1 Sub-array Scan Commands :

To scan all antenna across the source in Azimuth or Elevation or both the axis, a new '***track_array_scan_az_el***' command is introduced in the TGC. This command can be issued from either the TGC GUI or Scripting-terminal interface.

- **track_array_scan_az_el (sub_array_id, source-name, outertrack, az_rate, el_rate, peak_length, **keywords)**

  sub_array_id (Integer 0 to 30) :

  Subarray Id created in the work-station

  source-name (String) :

  Target source name from the uploaded astronomical catalog.

  Outertrack (Interger 0 or 1) :

  0 – Inner Azimuth track, 1 – Outer Azimuth track for Servo.

  az_rate (float , degree per minute) :

  Azimuth rate for the antenna slewing in degree/min.

  el_rate (float , degree per minute) :

  Elevation rate for the antennaslewing in degree/min.

  peak_length (hh:mm or degree) :

  If peak time given in HH:MM , antenna will slew to reach the target source by adjusting the length according to current time, and given peak-time. If the scan-length is given in degrees, then peak-time will be calculated based on scanning rate and scan-length (peak-time will be communicated to the CMC by message-response).

  Keywords : dradec_reftime (float optional) :

  In case of the SUN or planetary system observation reference time in Hrs at which RA-DEC rate is specified.

Examples :

- scan antennas in sub-array zero on '3C147' source with outer-track, azimuth-rate is zero, elevation rate is 0.5 degree/min, and peak-time is 10:43 at which antennas are expected on-source.

  track_array_scan_az_el(0, '3C147', 1, 0, 0.5, "10:43") *// In scripting Interface*

  track_array_scan_az_el 0 '3C147' 1 0 0.5 10:43 *// In the TGC GUI*

To scan all antennas from subarrray across the given target-source in **Right Ascension or Declination**, following command can be used.

- **track_array_scan_ra_dec(sub_array_id , source-name, outertrack , ra_rate , dec_rate, peak_length, **keywords)**

All arguments for this command is same as mentioned for the 'track_array_scan_az_el' command except following different arguments -

***ra_rate (float, degree per minute)* :**

Rate for the antenna slewing across the source in Right Ascension axis.

***dec_rate (float, degree per minute)* :**

Rate for the antenna slewing across the source in Declination axis.

Note – dradec_reftime keyword is not applicable in this command as ra_rate / dec_rate is given as an argument for the command.

Examples :

// For scripting

- scan antennas in subarray number one, on '3C147' source with outer azimuth track, declination scan rate 0.5 degree per minute. Expected On-source time is 13h05m.
  track_array_scan_ra_dec(1,'3C147',1,0,0.5,"13:05")

- scan antenna in subarray number 2, on 'CRAB' source with inner track, Right Ascension rate is 0.5 degree per minute, and expected on-source time is 13h49m.

  track_array_scan_ra_dec(2, target='3C286', outertrack=0, ra_rate=0.5, dec_rate=0, peak_length="13:32")

// for the GUI

- Go to expert Tab -> CMC -> AGN, select required AGN from 0 to 5, and give the following command.

track_array_scan_ra_dec 1 '3C147' 1 0.5 0.0 13h49m

2.2 Antenna Scanning Commands :

If individual antenna, or group of antennas need to execute scan procedure, then following commands are available using the GUI or scripting interface.

(a) GUI Interface :

Go to : Control -> 'expert' Tab -> 'LMC' panel, Select Sub-System 'Servo' , and desired antenna.

- ***track_scan_az_el (az_rate , el_rate, peak_length)***
- ***track_scan_ra_dec(ra_rate, dec_rate, peak_length)***

(b) Scripting Interface : In MNC Script-Manager, user can issue following commands.

- ***scan_az_el(antenna name , az_rate, el_rate , peak_length)***
- ***scan_ra_dec(antenna_name , ra_rate, dec_rate, peak_length)***

In above commands, az_rate, el_rate or ra_rate, dec_rate are in *deg/minute*. peak_length – either give expected on-source or peak-time in *hh:mm* or total length for the scan across source in *degrees.*

3. Verification and Validation Testing :

The new scan commands for array are incorporated in TGC, mainly '***track_array_scan_az_el***' and '***track_array_scan_ra_dec***'.

Existing '***scan_az_el_[script]'*** and '***scan_ra_dec_[script]***' internal command prefixed with a keyword '*track*' so that it can be forwarded from the CMC to antenna (previously, these command(s) were not working from the CMC). Low-level astronomical calculation library code modified for unit-conversions, and Java code modified or new code written at the LMC and CMC level along with database changes in the CMC and LMCs of all antennas. Details of code development and modification for the scan commands is mentioned in the ***Appendix-I.***

3.1 Test Observations :

After modifications in the TGC, several tests were conducted in July 2022 to validate the correctness of scan-command.
Validation Method : Pointing offsets are deduced using the grid-pointing method, and uploaded at all antenna(s) so that resultant offsets are expected to be near zero when the pointing experiment is done. The 'track_array_scan_az_el' or '*track_array_scan_ra_dec*' used for the scan-command testing , and verified that resultant antenna offsets are zero or near zero within a threshold.

However, due to maintenance activities there were many constraints for conducting scan-command validation tests such as :
(i) Not all antenna(s) are available, and limited time to conduct test (~ 1 to 2 hrs).
(ii) Only GSB backend was available for the test.
(iii) The program 'vxget' for Cross visibility data, and 'getoffsets' for the total power data (written by Prof. V.K. Kulkarni) gives resultant antenna offsets and FWHM in integer (arc-minute) format. Hence, deviation from average value or range of min-max value is limited by arc-minute unit.
(iv) One or two antenna(s) which show larger offsets for a given test-result is negelected while concluding the average antenna offsets values.

Table 1 : Test observations to validate scan command

Date	Obs. Frequency	Number of Antenna	Source	Scan-Axis	Peak-Time	Average Offsets	Remark
09 Jul	**591 MHz**	26	3C147	**EL**	10:16	**+/- 2'**	Cross antenna pointing with "scan rate is +0.5 deg/1m" Azimuth larger offsets due to high elevation.
				EL	11:19	**+/- 1'**	
				EL	11:57	**+/-2'**	
				AZ	12:19	**0 to 4'**	
09 Jul	**591 MHz**	26	Crab	**AZ**	14:39	**+/- 5'**	On crab – Self pointing was done Neglected a few 2 to 3 out of threshold points
				EL	14:59	**+/-5'**	
14 Jul	**306 MHz**	16	3C147	**EL**	12:55	**-2' to +4'**	C01, E06 as reference antenna. Negative Scan rate is -0.5 deg/1m (Neglected W05 and S04 +/- 10' for Elevation Axis, AZ is OK)
				AZ	14:00	**-2' to +5'**	
				DEC	14:52	**-2 to 4'**	Scan rate is +0.5 deg/1m
			3C286	**RA**	16:04	**Invalid**	No consistent antenna offsets due to program error, 1/cos(dec) factor need to be considered
21 Jul	**591 MHz**	16	3C147	**RA**	13:45	**+/- 5'**	Reference Ant : E02, "scan rate is +0.5 deg/1m". ****** After 1/cos(dec) correction scan in RA axis showing consistent results.
				DEC	13:58	**+/-3' except c04 is 9'**	
28 Jul	**1371 MHz**	16	3C147	**RA**	13:05	**+/-1'**	Reference Antenna E02
		16		**DEC**	13:18	**+/-2'**	
		14		**RA**	13:32	**+/-1'**	Few antenna took for maint.
		16		**DEC**	13:49	+/-1'	

3.1 Antenna Offsets Measurements :

The '***vxget***' program used for data-analysis which takes reference antenna, scan-rate in deg/min, stat-stop, and peak time in hh:mm to calculate antenna offsets, FWHM, and antenna-gain by fitting a Gussian curve to the averaged cross visibility data across observing band (channels).

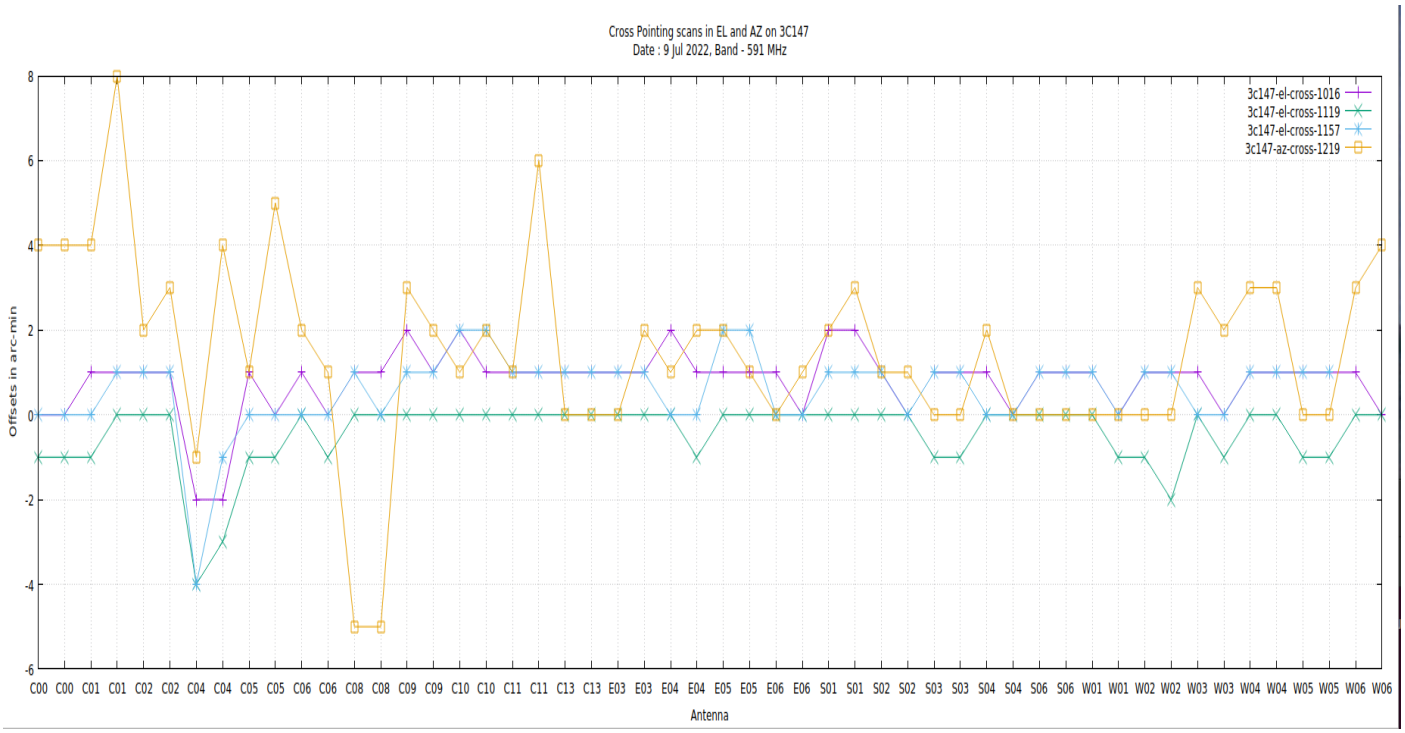

Figure 1 - 09 July 2022 : Cross Pointing scan in El and Az on 3C147 at 591 MHz

Average resultant offsets for antenna is +/- 2 arc-min in Elevation. Azimuth offsets are around 0 to 4 arc-min for most of the antenna(s).

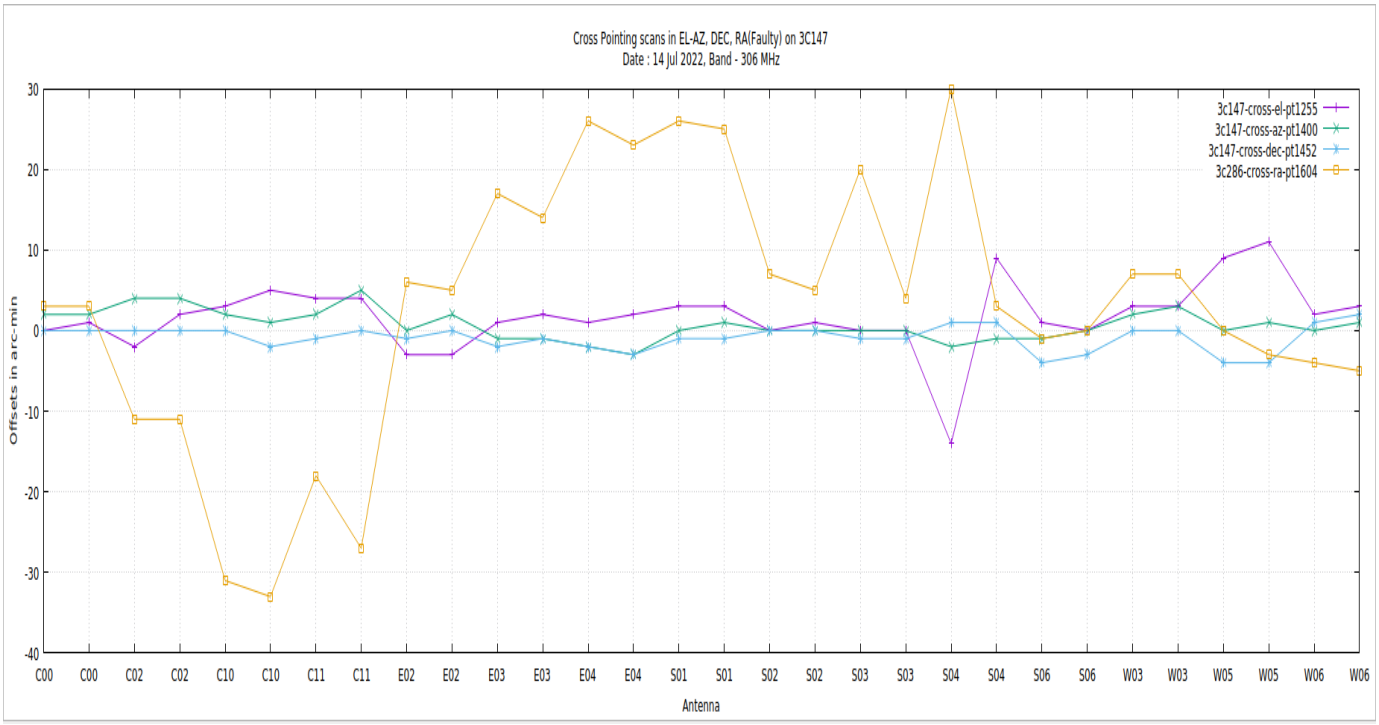

Figure 2 : 14 Jul 2022 Cross Pointing on 3C147 in EL, AZ, and RA, DEC Axis at 306 MHz

Average resultant offsets for antennas are ~ -2 to +5 arc-min in Az, EL , and Declination. But in RA Axis , Pointing offsets are not correct and inconsistent because “1/cos(dec)” factor was not applied in the program.

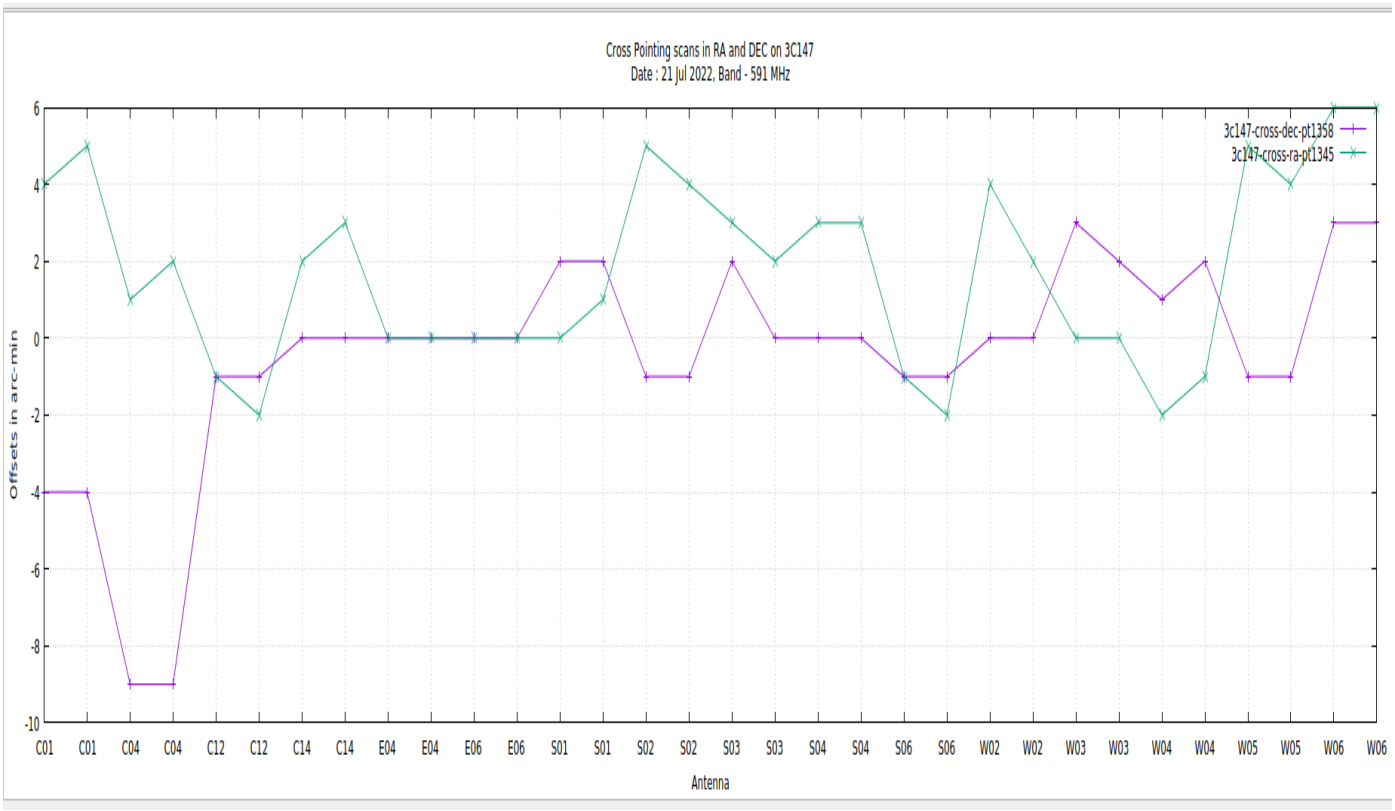

Figure 3 : 21 Jul 2022 Cross pointing scan on 3C147 across RA, DEC at 591 MHz

After correcting "1/cos(dec)" factor, resultant antenna offsets are -2 to 4 arc-min for most of the antennas.

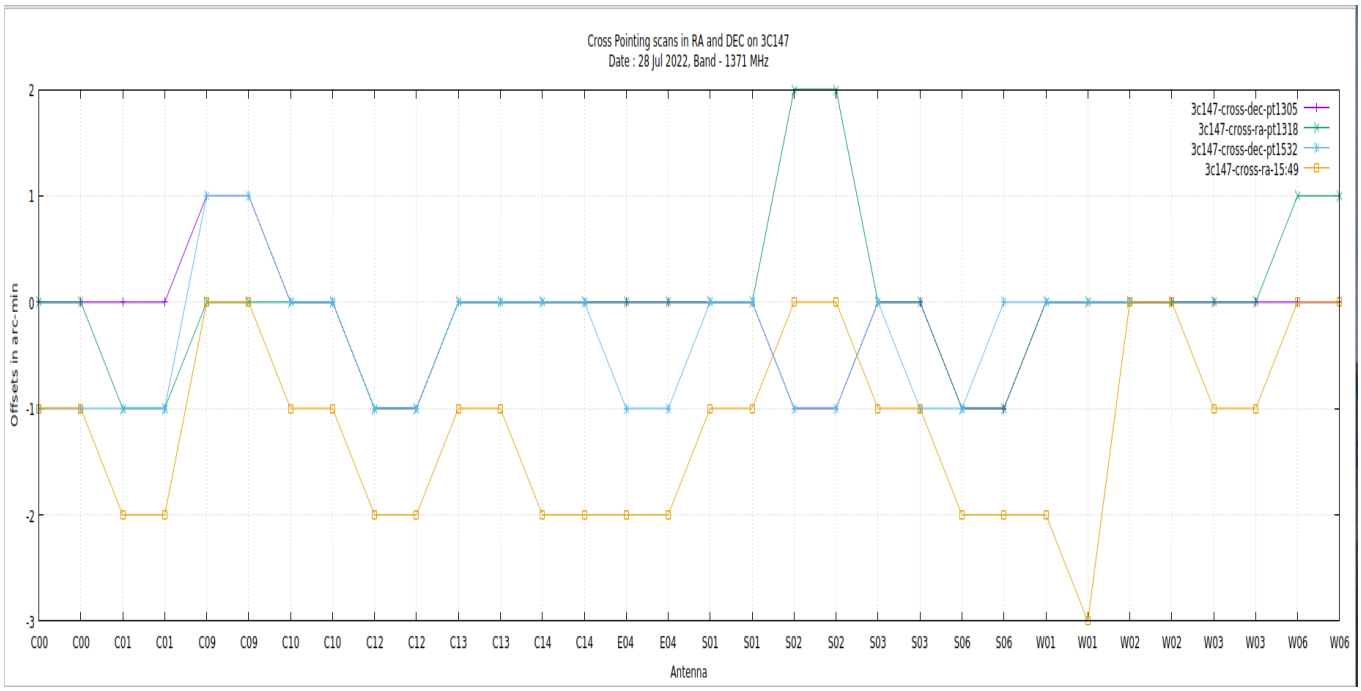

Figure 4 : 28 Jul 2022 Cross pointing scan on 3C147 in RA, DEC at 1371 MHz

Antenna pointing offsets in RA, and DEC, scan are within +/- 2 arc-min only

Sub-sequent plots show that antenna offsets either in AZ-EL or RA-DEC axis obtained using the vxget program are consistent within a few arc-min range (+/- 1 to 5 arc-min) at various observing bands. This ensures that the **'*track_array_scan_az_el*'** or **'*track_array_scan_ra_dec*'** command is working correctly.

3.1 Resultant FWHM from test observations :

Figure 5 shows that total eleven test observations conducted on various sources on different dates show consistent FWHM values with respect to observing frequencies viz. 86.27 +/- 4 arc-min at 306 MHz , 48.30 +/-4 arc-min at 591 MHz, and 17.28 +/-3 arcmin at 1371 MHz.

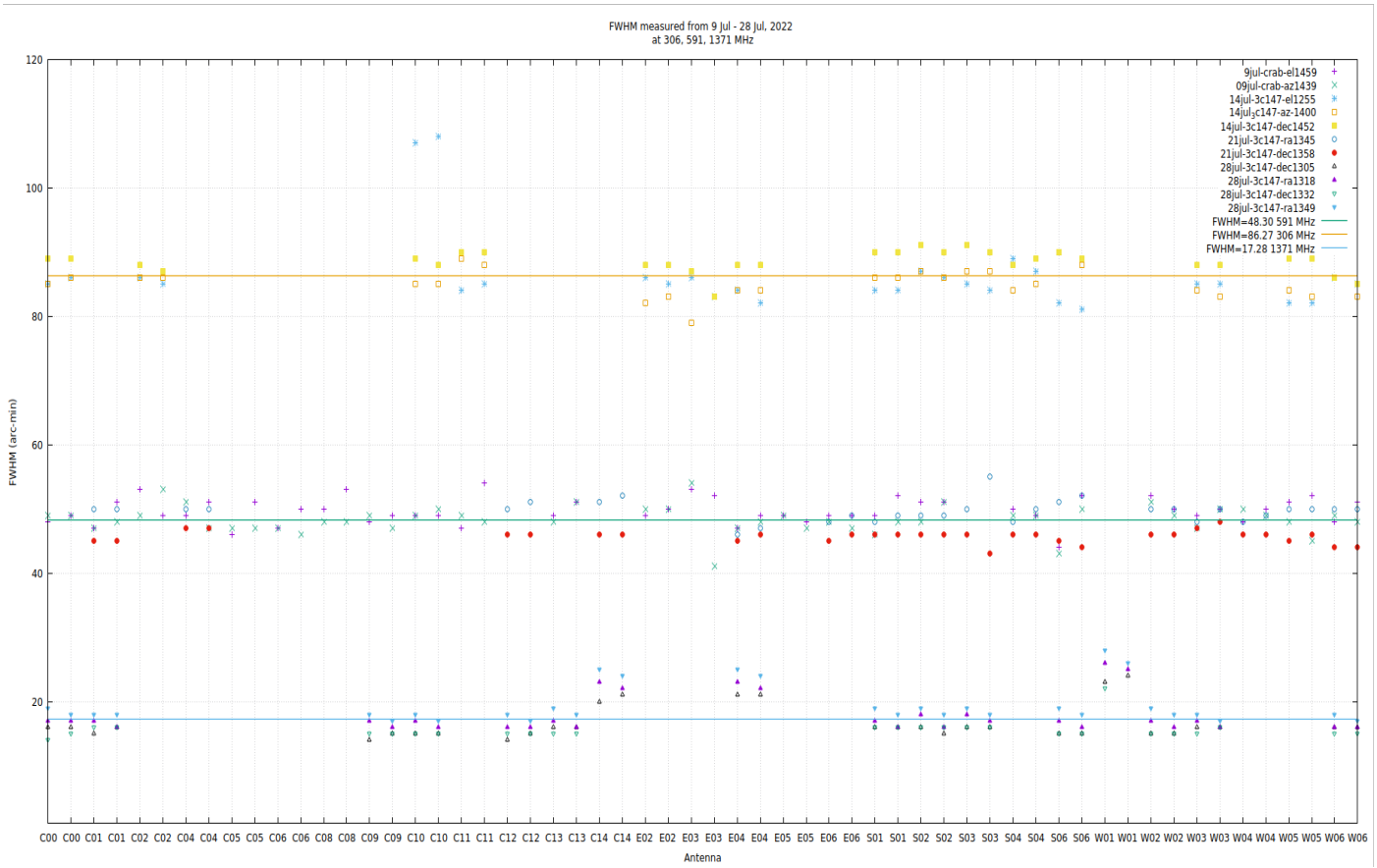

Figure 5 : The resultant FWHM after data analysis from Jul 9-28, 2022 using the vxget or getoffsets

FWHM is 86.27 +/- 4 arc-min at 306 MHz, 48.30 +/- 4 arc-min at 591 MHz, and 17.28 +/-3 arc-min at 1371 MHz

4. Conclusion :

Several test observations conducted at different-bands (from band-3 to band-5) using the validation test method of first updating antenna pointing offsets using the grid-pointing method, and then conducting antenna scans in AZ-EL or RA-DEC axis to verify whether

the resultant antenna-offsets are zero after axis-corrections. It is found that using the scan command, resultant antenna offsets are in the range of 0 to 5 arc-min. Also, FWHM of antennas at various frequency bands is consistent with +/- 4 arc-min deviation. This show that the implementation of scan-command in the TGC is working correctly.

The antenna-offsets measurement procedure using the scan-command comparatively take less time ~10 minutes as compare to grid-pointing procedure which takes ~14 to 16 minutes per axis.

In future the scan-execution time can be optimized so that it can be used in the raster-scan for beam-pattern measurement experiment of the GMRT antennas.

APPENDIX-I : Code Implementation in the TGC

File	Modules	Description
Code modification at the Central Monitor & Control		
mnc_custom_db.sql	Tables : command, command_assoc_argument, argument_default_value, argument_valid_range	Tables modified to **(i)** introduce new 'track_array_scan_az_el' , 'track_array_scan_ra_dec' commands. **(ii)** prefixed *scan_az_el[ra_dec]/_script* commands with 'track' keyword.
Preprocessing.java	Thread	case "track_array_scan_az_el" :{..} and case "track_array_scan_ra_dec":{..} new command introduced.
GroupCommandFormation.java	IndividualCommandProcessingInGrpCmd(), processOriginalCommand()	Track keyword prefix to define it is agn command.
Track.java	setSubarrayAttributeValues	Assigning dradec_reftime argument.
cmcapi.py	track_array_scan_az_el/ [ra_dec]	New scripting interface added for the scripting
servo.py	scanradec, scanazel	_get_length_peaktime() module written to take either 'peak_time' (hh:mm) or 'scan_length' in degree for the scan command.
Code modification at the Local Monitor & Control (Antenna)		
lmc_custom_db.sql	Tables : command, argument_range_value	scan_az_el[ra_dec]/_script changed to track_scan_az_el[rad_dec]/_script. Argument range value for AZ change to -270 to +270 for astro calculation. time_str format changed with range from 00:00:00 to 23:59:59
CmdProcessingFunctions.java	CmdProcessingFunctions	(i) Arguments for track_scan_az_el[ra_dec]/_script modified. (ii) scan_az_el[ra_dec]/_script command names prefixed with 'track' keyword.
SubSystem.cpp	periodicCommandBufferReader(), calculateScanPara()	**(i)** Scan rate Need to be multiply by dra * 1/cos(DEC). **(ii)** dradec_reftime converted from hrs to radian. **(iii)** scan_az_el[ra_dec] prefixed with 'track' keyword
servo.py	scanazel(), scanradec() _get_length_peaktime()	Get either peak-time or length for the scan. Also modified scanazel, scanradec routine for implementation of

		the scan.