

FAST Observation Modes

V2.9

National Astronomical Observatories, Chinese Academy of Sciences

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1. Overview

The current observation modes of the FAST telescope are mainly divided into 10 categories: drifting scan, tracking, rectangular sky scan, position switch, snapshot, solar system target scan, meridian scan, multi-beam calibration, user-defined scan and others. A total of 20 observation modes are available, the specific characteristics and functions of the modes are shown in Table 1.1. PIs can select the mode according to their observational requirements. For the 19-beam receiver, all observation modes eliminate field rotation by default.

Table 1.1 Features and Purpose of 20 types of observation modes of FAST telescope

Type	Model Name	Characteristics	Purpose
Drifting scan	Drift	the telescope stands still.	Sky survey etc.
	DriftWithAngle	the 19-beam receiver dedicated, the telescope is stationary, and the multi-beam feed angle at pointing time can be specified when drifting.	Sky survey etc.
	DecDriftWithAngle	the 19-beam receiver dedicated, the receiver keeps adjusting to compensate the proper motion of the Earth so that the telescope keeps pointing to a fixed J2000 declination coordinates in the sky.	Sky survey etc.
Tracking	Tracking	The telescope tracking the target.	Target Tracking
	TrackingWithAngle	the 19-beam receiver dedicated, when tracking the target, the field of view can be controlled to rotate, and the multi-beam feed angle can be specified.	Target Tracking
Rectangular sky scan	OnTheFlyMapping	Telescope scans designated rectangular sky area.	Scan
	MultiBeamOTF	the 19-beam receiver dedicated, the multi-beam feed angle can be specified when scanning the rectangular sky area..	Scan
position switch	OnOff	ON/OFF point reciprocating switching tracking; maximum gap 1 degree, ON point and OFF point observation time is equal. OnOff mode extension, the ON/OFF point observation time can be set separately.	Spectral line observation, etc.
	SwiftCalibration	The separation between OFF and ON in the right ascension direction is -5/-10armin.	Pulsar timing etc.
	PhaseReferencing	OnOff mode extension, the maximum gap is 3 degrees, the ON/OFF point observation time can be set separately.	VLBI, etc.
SnapShot	SnapShot	the 19-beam receiver dedicated, quick coverage of the galactic surface, composed of 4 tracking.	Sky survey etc.
	SnapShotCal	Snapshot mode extension, the first tracking time is 2 min longer than other tracking times.	Sky survey etc.
	SnapShotDec	the 19-beam receiver dedicated, Fast coverage of the Equatorial coordinate system, composed of 4 tracking.	Sky survey etc.
	SnapShotZCal	Snapshot mode extension, It is composed of four "snapshot" observation modes.	Sky survey etc.
Solar system target scan	SolarSysTracking	Solar system planet and moon tracking	Planet and Moon Tracking
	SolarSysDrift	Solar system planets and moon drift	Planet and Moon drift
Meridian scan	BasketWeaving	The telescope scans back and forth in the meridian circle	Scan
Multi-beam calibration	MultiBeamCalibration	the 19-beam receiver dedicated, Tracking the target in sequence from beam 1 to beam 19	Calibration
User-defined scan	User-defined	Observe the manually programmed trajectory target.	Ohter

2. Description of Observation Modes

2.1 Drifting scan

2.1.1 Drift

1) Mode description

In this mode, the position of the feed cabin is fixed. To avoid the pointing offset caused by the cooling of oil in the actuator, the actuators employed for shaping the paraboloidal surface are adjusted constantly to keep the same paraboloidal shape in this mode. Both the reflector and receiver are fixed to one direction. As a result of the Earth rotation, the telescope scans the sky along the RA direction. There are four main parameters needed to be defined in this mode: source name, source coordinate in the epoch of J2000, observational time range and rotating angle that represents the angle between the line along beams 8, 2, 1, 5 and 14 and the line of constant Dec. The rotating angle has a limit of $[-80, 80]$ degree.

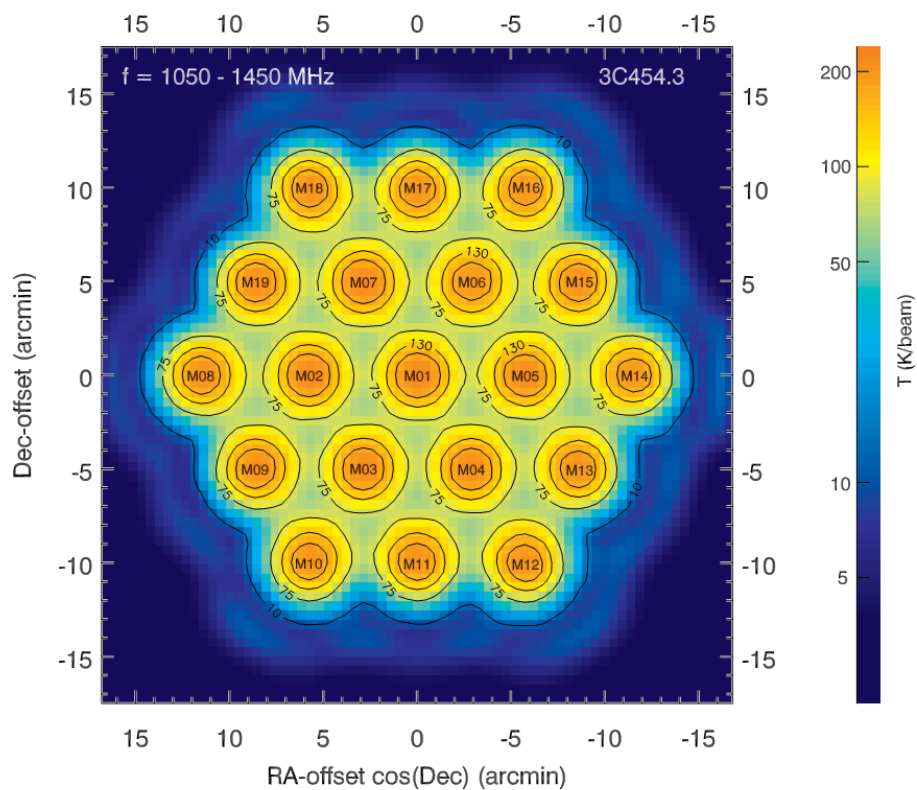


Fig.2.1.1.1 The X- and Y -axes indicate the RA- and Dec-offsets relative to the center of beam M01. The numbering of the 19 beams (M01–M19) is marked in the plot.

2) Purpose and conditions of use

Purpose:

- Survey the sky along RA direction.

Conditions of use:

- Sources are sampled at a fixed Declination coordinate in (ICRS)J2000 system.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode:<Drift>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Object DateTime	/	pointing time:<Start time><Transit time>
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.1.2 DriftWithAngle

1) Mode description

This is based on the drift mode, the rotation angle of the 19-beam receiver is specified so that when the source is passing through the sky, the 19-beam receiver is rotated by a fixed angle(θ) relative to the line of constant declination.

2) Purpose and conditions of use

Conditions of use:

- Source coordinate in (ICRS)J2000 system;
- For 19-beam receiver (1.05-1.45GHz) only;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <DriftWithAngle>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Object DateTime	/	pointing time :<Start time><Transit time>
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Angle	degree	The 19-beam receiver rotates at a fixed angle relative to the declination line at the pointing time. Range:(-80,80)

2.1.3 DecDriftWithAngle

1) Mode description

This mode is similar to the DriftWithAngle mode, except that the receiver cabin is adjusted constantly to compensate the proper motion of the Earth so that the telescope keeps pointing to a fixed J2000 declination coordinate. With the rotation of the Earth, the telescope scans the sky along the RA direction with a strictly fixed J2000 declination.

2) Purpose and conditions of use

Conditions of use:

- source coordinate in J2000 system;
- For 19-beam receiver (1.05-1.45GHz) only;

3) Parameter description

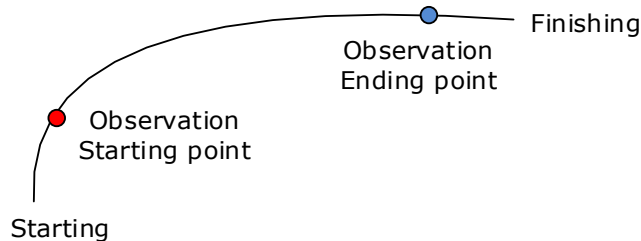
Input parameter	Unit	Note
Observation Mode	/	observation mode: <DecDriftWithAngle>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Drift on Meridian	/	<True>: Drift on Meridian, Invalid RA. <False>: pointing time =<Start time>
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Angle	degree	The 19-beam receiver rotates at a fixed angle relative to the declination line at the pointing time. Range:(-80,80)

2.2 Tracking

2.2.1 Tracking

1) Mode description

In this mode, the source can be tracked continuously.



2) Purpose and conditions of use

Conditions of use:

- Source coordinate in (ICRS)J2000 system.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <Tracking>

Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.2.2 TrackingWithAngle

1) Mode description

This mode is developed for tracking a source continuously while achieving the following operations:

1. Compensation for the rotation of the Earth to keep tracking;
2. Compensation for the focal plan rotation of the 19-beam receiver: the angle(θ) between the 19-beam Pointing and the declination line is fixed. If this is set to NO, The multi-beam feed is stationary after turning from 0 deg. mechanically to angle(θ). A range of $[-80,80]$ degrees is allowed.

2) Purpose and conditions of use

Conditions of use:

- Source coordinate in (ICRS)J2000 system.;
- For 19-beam Receiver(1.05-1.45GHz) only;

■ This mode does not use the "back-illumination" strategy, so the observation zenith angle is not allowed to exceed 30 degrees, otherwise the system will return error;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <TrackingWithAngle>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Rotation Offset	/	<Yes> <No>,<Yes>:Eliminate field rotation
Angle	degree	Multi-beam rotation angle(θ), Range:(-80,80)

2.3 Rectangular sky scan

2.3.1 OnTheFlyMapping (OTF).

1) Mode description

This mode is designed for mapping a sky area with Beam 1 only. Six parameters are needed to set the observations: source name, source position, observational time range, sky coverage (e.g., $7' \times 7'$ of the mapping region), scanning separation (e.g., $1'$ between two parallel scanning lines and scanning direction (along RA or Dec). Scanning speed is 15 arcsec/s by default.

Time for switching scan line along right ascension: $T_{switch} = \text{round}(12 \times \frac{ScanGap}{1 \text{ arc min}})s$.

Time for switching scan line along declination: $T_{switch} = 18s$.

Total observation time:

$$T_{RA} = \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanSpeed}\right) \times \text{round}\left(\frac{|EndRA - StartRA|}{ScanGap} + 1\right) \\ + T_{switch} \times \text{round}\left(\frac{|EndRA - StartRA|}{ScanGap}\right)$$

$$T_{DEC} = \text{round}\left(\frac{|EndRA - StartRA|}{ScanSpeed}\right) \times \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanGap} + 1\right) \\ + T_{switch} \times \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanGap}\right)$$

Description:

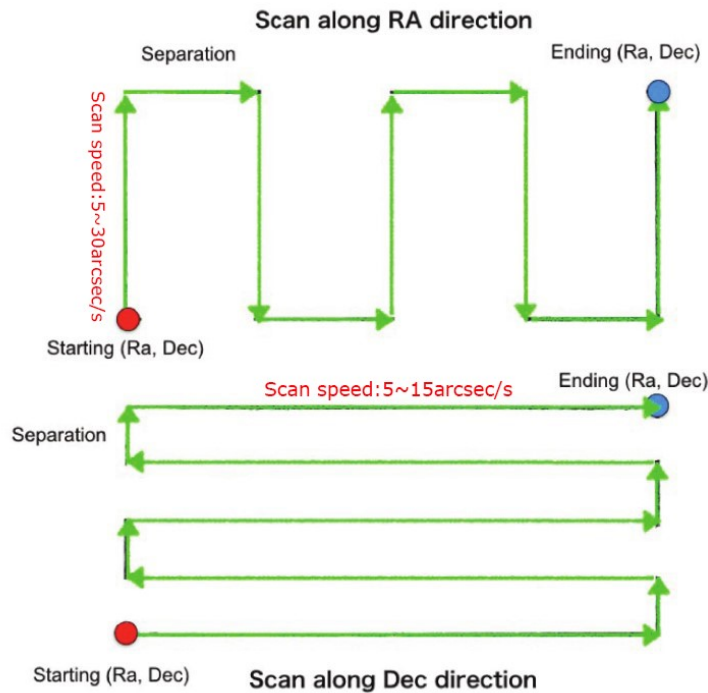


Figure2.3.1.1 Schematic diagram of the OTF mode. The green line represents scanning trajectory. The top and bottom panels show scan information along RA and Dec directions, respectively.

2) Purpose and conditions of use

Conditions of use:

- Source coordinate in (ICRS)J2000 system;
- Scan speed: 1 ~ 30 arcsec/s along the ascension line; 1 ~ 15 arcsec/s along the declination line
- Scanning separation: Greater than 0 arcmin, 1 arcmin by default.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode:<OnTheFlyMapping>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
Start RA	hours,minutes,seconds	00 00 00.00
Start DEC	degrees,arcminutes,arcseconds	+00 00 00.0
End RA	hours,minutes,seconds	00 00 00.00
End DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Scan Direction	/	Longitude:< > Latitude:<:>
Scan Gap	arcmin	
Scan Speed	arcsec/s	Range along Longitude:[1,30], Range along Latitude:[1,15]

2.3.2 MultibeamOTF

1) Mode description

This mode is used to map the sky with 19 beams simultaneously. Compared to the OTF mapping, the MultiBeamOTF mapping mode has a similar scanning trajectory but a larger separation (e.g., 20arcmin) between parallel scans. Besides, the rotation angle can be set in this mode.

Time for switching scan line along right ascension: $T_{switch} = 54s$

Time for switching scan line along declination: $T_{switch} = 90s$

Total observation time:

$$T_{RA} = \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanSpeed}\right) \times \text{round}\left(\frac{|EndRA - StartRA|}{ScanGap} + 1\right) \\ + T_{switch} \times \text{round}\left(\frac{|EndRA - StartRA|}{ScanGap}\right)$$

$$T_{DEC} = \text{round}\left(\frac{|EndRA - StartRA|}{ScanSpeed}\right) \times \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanGap} + 1\right) + T_{switch} \times \text{round}\left(\frac{|EndDEC - StartDEC|}{ScanGap}\right)$$

2) Purpose and conditions of use

Purpose:

Conditions of use:

- Source coordinate in (ICRS)J2000 system;
- For 19-beam Receiver (1.05-1.45GHz) only;
- Scan speed: 1 ~ 30 arcsec/s along the ascension line; 1 ~ 15 arcsec/s along the declination line
- Scanning separation: Greater than 0 arcmin, 1 arcmin by default.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode:<MultiBeamOTF>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
Start RA	hours,minutes,seconds	00 00 00.00
Start DEC	degrees,arcminutes,arcseconds	+00 00 00.0
End RA	hours,minutes,seconds	00 00 00.00
End DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Scan Direction	/	Longitude:< > Latitude:<:>
Scan Gap	arcmin	
Scan Speed	arcsec/s	Range along Longitude:[1,30], Range along Latitude:[1,15]
Angle	degree	The 19-beam receiver rotates at a fixed angle(θ) relative to the declination line at the pointing time. Range:(-80,80)

2.4 Position switch

2.4.1 OnOff

1) Mode description

Position switch. The design of position mode is to achieve quick switching between source ON and source OFF in order to reduce baseline variation. There are four main parameters in this

mode.

- Coordinate of ON position.
- Coordinate of OFF position. The position of OFF source is designed to be within 1 degree from that of ON source.

- T_{on} : Integration time of single ON source. (Integration time of single OFF source equal Integration time of ON source.).

- n : The number of ON-OFF cycles.

Overhead time between ON and OFF position depends on separation of ON and OFF position, $\Delta\theta$. It is $30s(T_{switch})$ for $\Delta\theta \leq 20'$ and is $60s(T_{switch})$ for $20' < \Delta\theta \leq 60'$;

The total observation time is:

$$T_{total} = (T_{on} \times 2 + T_{switch} \times 2) \times n - T_{switch}$$

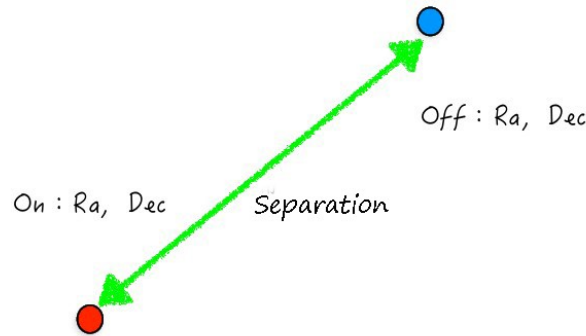


Fig. 2.4.1.1 Schematic diagram of the OnOff mode.

2) Purpose and conditions of use

Purpose:

- Spectrum observation, etc.

Conditions of use:

- Source coordinate in (ICRS)J2000 system;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <OnOff>
Source Name	/	the source name
ON RA	hours,minutes,seconds	00 00 00.00
ON DEC	degrees,arcminutes,arcseconds	+00 00 00.0
OFF RA	hours,minutes,seconds	00 00 00.00
OFF DEC	degrees,arcminutes,arcseconds	+00 00 00.0
Time Length for ON	second	Integration time of single ON source:>0
Repeat Num	/	The number of ON-OFF cycles.
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>

Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
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2.4.2 SwiftCalibration

1) Mode description

The telescope will track at the OFF point for a period of time, and then switch to the ON point to track for a period of time. Enter only the coordinates of the ON point; the coordinates of the OFF point are (RA: ON point right ascension -5 arcmin or -10 arcmin, DEC: ON point declination);

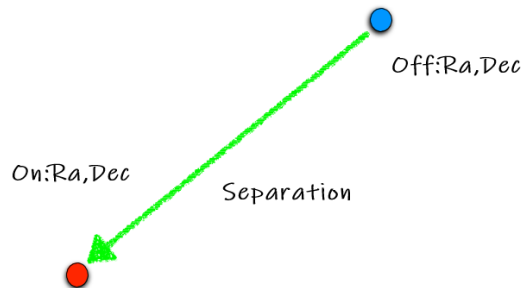


Fig. 2.4.2.1 Schematic diagram of the SwiftCalibration mode.

2) Purpose and conditions of use

Purpose:

Conditions of use:

■ source coordinate in the epoch of J2000;

Total observation time:

$$T_{total} = T_{OFF} + T_{ON} + T_{switch}$$

T_{ON} :ON point duration

T_{OFF} : OFF point duration

T_{switch} :

1. The interval between OFF right ascension and ON point is -5 arcmin, and the switching time is 15 seconds;
2. The interval between OFF right ascension and ON point is -10 arcmin, and the switching time is 20 seconds;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SwiftCalibration>
Source Name	/	the source name
ON RA	hours,minutes,seconds	00 00 00.00
ON DEC	degrees,arcminutes,arcseconds	+00 00 00.0
Time Length for ON	second	Integration time of single ON source:>0

Time Length for OFF	second	Integration time of single OFF source:>0
The interval of RA	arcmin	<-5><-10>
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.4.3 PhaseReferencing

1) Mode description

Expand on the basis of OnOff observation mode. This mode can set the integration time of the ON point and the OFF point. In addition, the distance between the ON point and the OFF point has been expanded to the range of (0,3) degrees; There are five main parameters in this mode.

- Coordinate of ON position.
- Coordinate of OFF position. The position of OFF source is designed to be within 3 degree from that of ON source.

- T_{on} : Integration time of single ON source.

- T_{off} : Integration time of single OFF source.

- n : The number of ON-OFF cycles.

Overhead time between ON and OFF position depends on separation of ON and OFF position, $\Delta\theta$.

Table 17.1 Overhead time between ON and OFF position

ID	separation $\Delta\theta$	Switch time T_{switch}	ID	separation $\Delta\theta$	Switch time T_{switch}
	(arcminutes)	(seconds)		(arcminutes)	(seconds)
1	(0,10]	15	10	(90,100]	130
2	(10,20]	30	11	(100,110]	145
3	(20,30]	40	12	(110,120]	150
4	(30,40]	55	13	(120,130]	160
5	(40,50]	70	14	(130,140]	170
6	(50,60]	80	15	(140,150]	180
7	(60,70]	95	16	(150,160]	190
8	(70,80]	105	17	(160,170]	200
9	(80,90]	120	18	(170,180]	205

The total observation time is:

$$T_{total} = (T_{on} + T_{off} + T_{switch} \times 2) \times n - T_{switch}$$

2) Purpose and conditions of use

Purpose:

■ VLBI,etc.

Conditions of use:

■ Source coordinate in (ICRS)J2000 system;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <OnOff>
Source Name	/	the source name
ON RA	hours,minutes,seconds	00 00 00.00
ON DEC	degrees,arcminutes,arcseconds	+00 00 00.0
OFF RA	hours,minutes,seconds	00 00 00.00
OFF DEC	degrees,arcminutes,arcseconds	+00 00 00.0
Time Length for ON	second	Integration time of single ON source:>0
Time Length for OFF	second	Integration time of single OFF source:>0
Repeat Num	/	The number of ON-OFF cycles.
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.5 SnapShot

2.5.1 SnapShot

1) Mode description

This mode is used to map the sky with 4 pointings. This type of mapping is not a Nyquist sampling mappig, but could map a region with relatively deep integration time. This is especially beneficial for searching pulsars on the Galactic plane.

As shown in Figure 2.5.1.1, movement of the 19 beam receiver would ensure fully covering the sky along the same Galactic latitude. Required parameters include source name, beginning and ending coordinates(RA and Dec),observational time range and scanning speed(less than $30' s^{-1}$).

For the 19-beam receivers, there are gaps between beams. The SnapShot model is designed to fill the gaps by tracking observations of four positions in a sequence:

Tracking position 1:Galactic longitude 1 (L_1), Galactic latitude 1 (B_1);

Track location 2: $L_2 = L_1 - \cos(\theta) \times \frac{d}{2}$; $B_2 = B_1 + \sin(\theta) \times \frac{d}{2}$;

Track location 3: $L_3 = L_2 - \cos(\theta_2) \times \frac{d}{2}$; $B_3 = B_2 - \sin(\theta_2) \times \frac{d}{2}$;

Track location 4: $L_4=L_3+\cos(\theta)\times\frac{d}{2}$; $B_4=B_3-\sin(\theta)\times\frac{d}{2}$;

Description: d =Beam spacing=0.0016696969(rad); $\theta = 0$; $\theta_2 = \frac{\pi}{3}$ (rad)

Users just need to provide the right ascension and declination of the first position, and the control system will automatically convert them into latitude and longitude, and plan the remaining 3 positions.

Total observation time:

$$T_{total} = T_{singletrack} \times 4 + T_{switch} \times 3$$

(T_{switch} :The single switching time is 20 seconds).

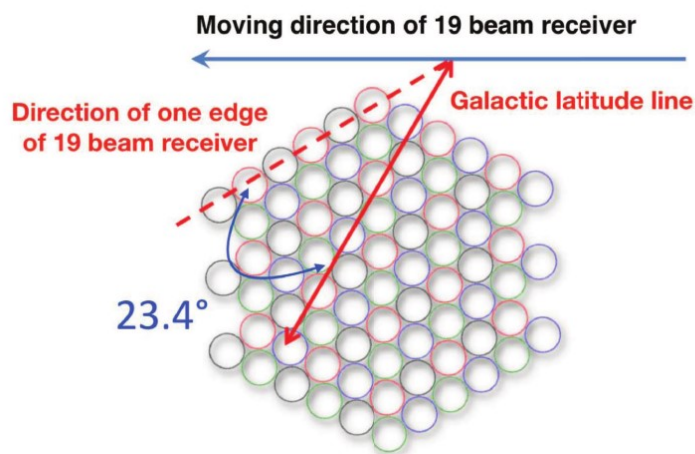
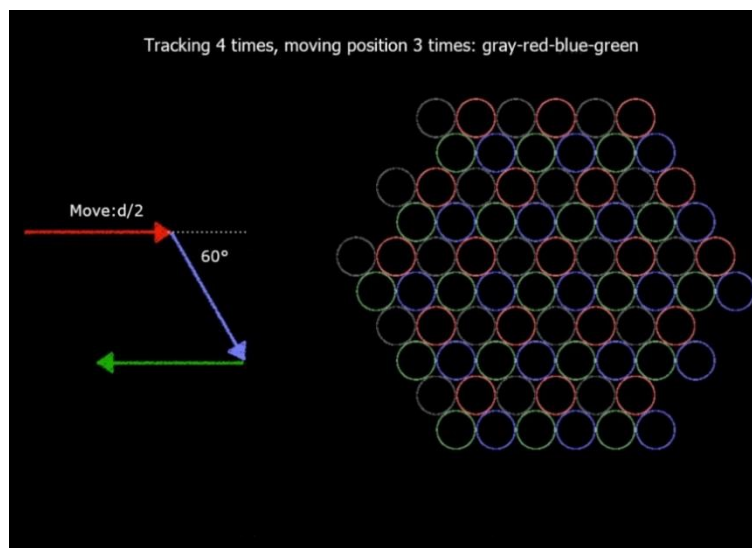


Fig.2.5.1.1 Schematic diagram of the snapshot mode. Blue line represents moving direction of the 19 beam receiver. Dashed red line represents the direction of one edge of the 19 beam receiver. Galactic latitude line is represented with the solid red line. The angle between the dashed and solid red lines is 23.4°

2) Purpose and conditions of use

Purpose:

- Galactic pulsar search, etc.

Conditions of use

■ source coordinate in Galactic Coordinates (the input parameters are ICRS(J2000), the control system automatically convert them to Galactic Longitude and Galactic Latitude).

- For 19-beam Receiver (1.05-1.45GHz) only;

■ This mode does not use "back-illumination" technique, so the observation zenith angle cannot exceed 30 degrees, otherwise the system will return error;

- Multi-beam rotation is parallel to Galactic latitude.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SnapShot>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>60
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

4) Others

Fault-tolerant handling for multi-beam angle overruns: 19 beams are parallel to the Galactic latitude, and in the high Galactic latitude area, the multi-beam automatically rotates ± 60 degrees to prevent the angle from exceeding the limit.

2.5.2 SnapShotCal

1) Mode description

The extension of the SnapShot observation mode, This mode is used to map the sky with 4 pointings. The difference is that the first tracking time (T_{track1}) in SnapShotCal mode is 2 minutes longer than the other 3 tracking times (T_{track2} , T_{track3} , T_{track4}), which is used for calibration observation of injected noise. The other 3 tracking times remain unchanged.

Observation time at 4 locations:

$$T_{track1} = \frac{T_{total} - T_{switch} \times 3 - 120}{4} + 120 \text{ (s)}$$

$$T_{track2} = T_{track3} = T_{track4} = \frac{T_{total} - T_{switch} \times 3 - 120}{4} \text{ (s)}$$

(T_{total} : Observation duration;

T_{switch} :The single switching time is 20 seconds).

2) Purpose and conditions of use

Purpose:

■ Galactic pulsar search,etc.

Conditions of use

■ source coordinate in Galactic Coordinates (the input parameters are ICRS(J2000), the control system has been converted to Galactic Longitude and Galactic Latitude).

■ For 19-beam Receiver (1.05-1.45GHz) only;

■ This mode does not use "back-illumination" technique, so the observation zenith angle cannot exceed 30 degrees, otherwise the system will return error;

■ Multi-beam rotation is parallel to Galactic latitude.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SnapShotCal>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>180
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

4) Others

Fault-tolerant handling for multi-beam angle overruns: 19 beams are parallel to the Galactic latitude, and in the high Galactic latitude area, the multi-beam automatically rotates ± 60 degrees to prevent the angle from exceeding the limit.

2.5.3 SnapShotDec

1) Mode description

The SnapShot mode is developed for the galactic plane, and SnapShotDec is developed for the J2000 system. For the 19-beam receivers, there are gaps between beams. The SnapShotDec model is designed to fill the gaps by tracking observations of four positions in a sequence:

Tracking position 1: right ascension(RA_1), declination(DEC_1);

Track location 2: $RA_2 = RA_1 - \cos(\theta) \times \frac{d}{2}$; $DEC_2 = DEC_1 + \sin(\theta) \times \frac{d}{2}$;

Track location 3: $RA_3 = RA_2 - \cos(\theta_2) \times \frac{d}{2}$; $DEC_3 = DEC_2 - \sin(\theta_2) \times \frac{d}{2}$;

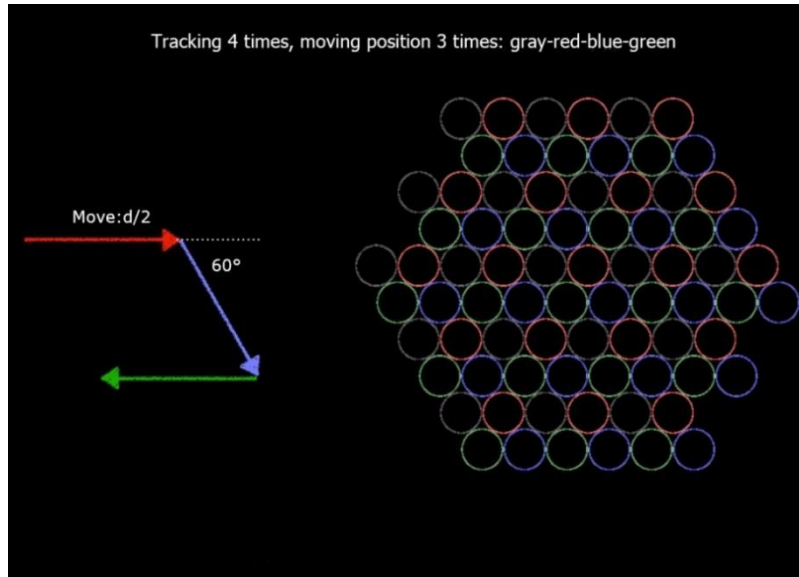
Track location 4: $RA_4 = RA_3 + \cos(\theta) \times \frac{d}{2}$; $DEC_4 = DEC_3 - \sin(\theta) \times \frac{d}{2}$;

Description: d =Beam spacing=0.0016696969(rad); $\theta = 0$; $\theta_2 = \frac{\pi}{3}$ (rad)

Total observation time:

$$T_{total} = T_{singletrack} \times 4 + T_{switch} \times 3$$

(T_{switch} :The single switching time is 20 seconds).



2) Purpose and conditions of use

Purpose:

- pulsar search, etc.

Conditions of use

- source coordinate in J2000 system;
- For 19-beam Receiver (1.05-1.45GHz) only;
- This mode does not use "back-illumination" technique, so the observation zenith angle cannot exceed 30 degrees, otherwise the system will return error;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SnapShotDec>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>60
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.5.4 SnapShotZCal

1) Mode description

The extension of the SnapShot observation mode, If there are multiple “Snapshot” modes for sky survey, in view of the close distance between each snapshot, in order to shorten the source overhead time of each task for observation, this mode can be considered.

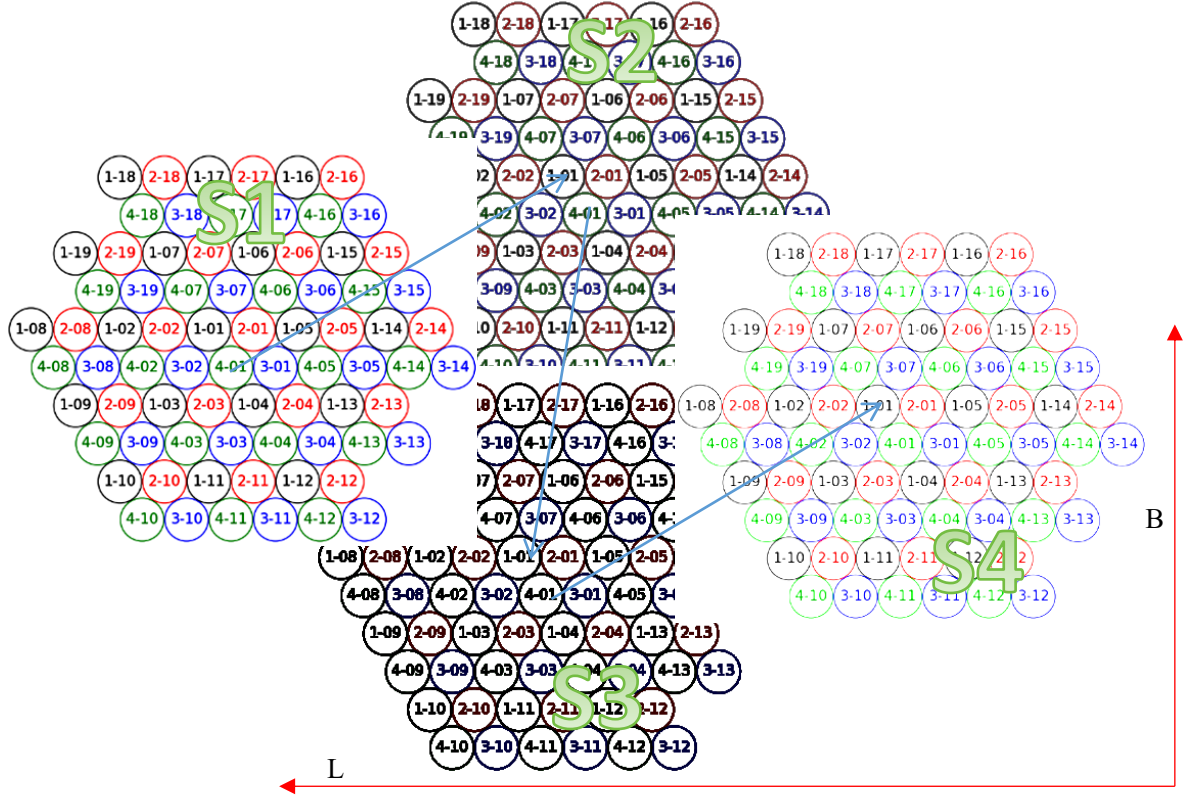


Fig.2.5.4.1 Schematic diagram of the SnapShotZCal mode.

General remark:

- 1) The pointing trajectory of the telescope is shown in Fig.2.5.4.1. It is composed of four “snapshot” observation modes (S1,S2,S3 and S4), and three inter-target switchings are required (S1→S2;S2→S3;S3→S4), each switching time is 40 seconds;
- 2) The first tracking time of S1(T_{s1_1}) and the fourth tracking time of S4(T_{s4_4}) are 1 minute longer than the other tracking times, which are used to inject noise for calibration.
- 3) The starting position of S1 to S4 :

Position of S1(1): Galactic longitude 1 (L_{s1_1}), Galactic latitude 1 (B_{s1_1});

Position of S2(1): $L_{s2_1}=L_{s1_1}-3.5d$; $B_{s2_1}=B_{s1_1}+3\times\sin(60^\circ)\times d$;

Position of S3(1): $L_{s3_1}=L_{s2_1}-0.5d$; $B_{s3_1}=B_{s2_1}-5\times\sin(60^\circ)\times d$;

Position of S4(1): $L_{s4_1}=L_{s3_1}-3.5d$; $B_{s4_1}=B_{s3_1}+3\times\sin(60^\circ)\times d$;

Description:

$d = 0.0017075138$ (rad): S(i) switching beam spacing;

L_{s2_1} :The position of Galactic longitude starting from S2 (L_{s3_1}, L_{s4_1} Similarly, no further explanation.)

B_{s2_1} :The position of Galactic latitude starting from S2 (B_{s3_1}, B_{s4_1} Similarly, no further explanation.)

Total observation time:

$$T_{total} = S_i \times 4 + 40 \times 3$$

$$= (T_{S_i} \times 4 + 20 \times 3) \times 4 + 40 \times 3 + 60 \times 2(s)$$

Observation time at per locations(except for S1(1) and S4(4):

$$T_{S_i} = \left(\frac{T_{total} - 60 \times 2 - 40 \times 3}{4} - 20 \times 3 \right) \times \frac{1}{4} (s)$$

2) Purpose and conditions of use

Purpose:

■ Galactic pulsar search,etc.

Conditions of use

■ source coordinate in Galactic Coordinates (the input parameters are ICRS(J2000), the control system has been converted to Galactic Longitude and Galactic Latitude).

■ For 19-beam Receiver (1.05-1.45GHz) only;

■ This mode does not use "back-illumination" technique, so the observation zenith angle cannot exceed 30 degrees, otherwise the system will return error;

■ Multi-beam rotation is parallel to Galactic latitude.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SnapShotZCal>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>480
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G>

		<1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
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4) Others

Fault-tolerant handling for multi-beam angle overruns: 19 beams are parallel to the Galactic latitude, and in the high Galactic latitude area, the multi-beam automatically rotates ± 60 degrees to prevent the angle from exceeding the limit.

2.6 Solar system target scan

2.6.1 SolarSysTracking

1) Mode description

In this mode, The planets and moon of the solar system can be tracked continuously. The coordinates of the target are derived from JPL DE436.

There are four main parameters in this mode.

- Target number.
- Integration time of target number.
- RA offset: RA offset is 0 second by default.
- DEC offset:DEC offset 0 arcsec by default.

Target number	Name	Note
1	Mercury	
2	Venus	
4	Mars	
5	Jupiter	
6	Saturn	
7	Uranus	
8	Neptune	
9	Pluto	
10	Moon	

2) Purpose and conditions of use

Conditions of use:

- During the observation process, the separation between the target and the sun must be greater than 5 degrees.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SolarSysTracking>
Source Name	/	the source name
TargetNumber	/	[1,2,4,5,6,7,8,9,10]
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G>

		<1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
RA offset	arcsec	RA offset is 0 second by default.
DEC offset	arcsec	DEC offset is 0 arcsec by default.
Lunar L	hours,minutes,seconds	00 00 00.00 A point on the lunar surface in the lunar geographic coordinate system (GB/T 30112-2013), Lunar L is 0 by default. This parameter is valid only when observing the moon (target number is 10).
Lunar B	degrees,arcminutes,arcseconds	+00 00 00.0 A point on the lunar surface in the lunar geographic coordinate system (GB/T 30112-2013), Lunar B is 0 by default. This parameter is valid only when observing the moon (target number is 10).

2.6.2 SolarSysDrift

1) Mode description

In this mode, You can use drift scan mode to observe the planets and moon of the solar system. The coordinates of the target are derived from JPL DE436.

There are five main parameters in this mode.

- Target number.
- Pointing time.
- Integration time of target number.
- RA offset: RA offset is 0 second by default.
- DEC offset: DEC offset 0 arcsec by default.

Target number	Name	Note
1	Mercury	
2	Venus	
4	Mars	
5	Jupiter	
6	Saturn	
7	Uranus	
8	Neptune	
9	Pluto	
10	Moon	

2) Purpose and conditions of use

Conditions of use:

- During the observation process, the separation between the target and the sun must be greater than 5 degrees.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <SolarSysDrift>
Source Name	/	the source name

TargetNumber	/	[1,2,4,5,6,7,8,9,10]
DurationTime	second	total observation time:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
RA offset	arcsec	RA offset is 0 second by default.
DEC offset	arcsec	DEC offset is 0 arcsec by default.
Lunar L	hours,minutes,seconds	00 00 00.00 A point on the lunar surface in the lunar geographic coordinate system (GB/T 30112-2013), Lunar L is 0 by default. This parameter is valid only when observing the moon (target number is 10).
Lunar B	degrees,arcminutes,arcseconds	+00 00 00.0 A point on the lunar surface in the lunar geographic coordinate system (GB/T 30112-2013), Lunar B is 0 by default. This parameter is valid only when observing the moon (target number is 10).

4) Others

The current FAST website pointing time in this mode is the start time.

2.7 Meridian scan

2.7.1 BasketWeaving

1) Mode description

This mode is to scan the sky with the feed moving along a meridian line in the telescope frame. Scanning speed ranges from 1 to 30 arcsec/s. Setting parameters include starting time, starting Dec, ending Dec, Scanning speed and time duration.

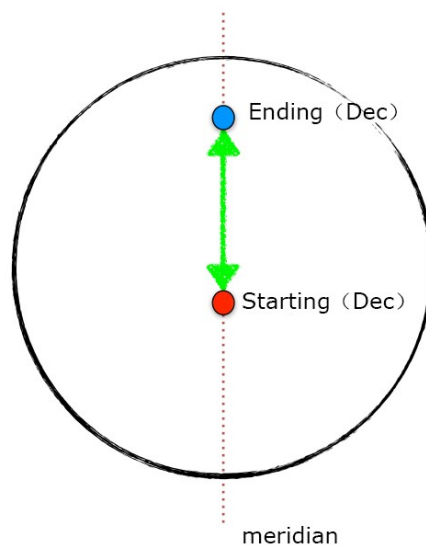


Fig. 2.7.1.1 Schematic diagram of the BasketWeaving mode.

2) Purpose and conditions of use

Conditions of use:

■ Under the apparent declination coordinate system, weave scanning along the meridian;

■ Scan speed: 5~30 arcsec/s.

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <BasketWeaving>
Source Name	/	the source name
ON RA	hours,minutes,seconds	00 00 00.00
ON DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>60
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default
Scan Speed	arcsec/s	Range:[1,30]

2.8 Multi-beam calibration

2.8.1 MultiBeamCalibration

1) Mode description

In this mode, each beam of the 19-beam receiver will be switched on in sequence to track a calibrator, allowing for quick calibration of the gain of 19 beams in 30 minutes. Switching time between two beams is 40s. The integration time for each beam is a parameter that needs to be set. The schematic diagram of this mode is drawn in Figure 2.8.1.1.

The 19-beam receiver uses 19 beams to aim at a certain position one by one for observation. Special note: To ensure the test accuracy, beam 1 is tracked repeatedly. Namely, the 19-beam observation sequence is: 1-1-2-3-4-5-6-7-19-8-9-10-11-12-13-14-15-16-17-18.

Total observation time:

$$T_{total} = (T_{singletrack} + T_{switch}) \times 20 - T_{switch}$$

$T_{singletrack}$: Single beam observation time

T_{switch} :The single switching time is 40 seconds.

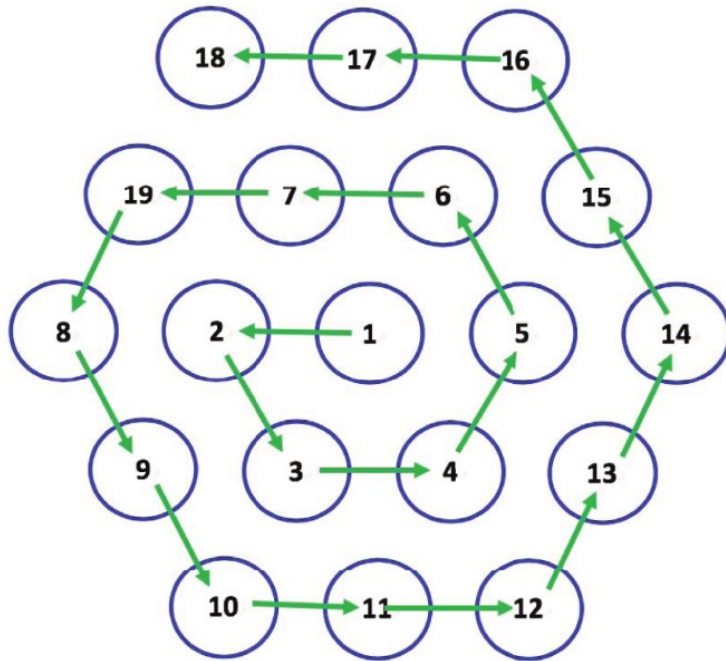


Fig.2.8.1.1. Schematic diagram of MutiBeamCalibration mode. Green arrows represent the beam sequence for observing the calibrator.

2) Purpose and conditions of use

Purpose:

Conditions of use:

- source coordinate in J2000 system;
- For 19-beam Receiver (1.05-1.45GHz) only;
- This mode does not use “back-illumination” technique, so the observation zenith angle cannot exceed 30 degrees, otherwise the system will return error;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: <MultiBeamCalibration>
Source Name	/	the source name
RA	hours,minutes,seconds	00 00 00.00
DEC	degrees,arcminutes,arcseconds	+00 00 00.0
DurationTime	second	total observation time:>760
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

2.9 User-defined scan

2.9.1 User-defined

1) Mode description

In this mode a trajectory file is compiled manually and imported into the control system for observations;

2) Purpose and conditions of use

Purpose: If none of the pre-defined observing modes can meet the scientific requirements, user can design their own observations using the User-defined mode and set up a trajectory file to control the telescope movements.

Conditions of use:

3) Parameter description

Users should provide a txt file to specify the observational parameters in a 100ms cycle which contains corrected Julian Day, Azimuth and Altitude.

2.10 Others

2.10.1 MultiPos

1) Mode description

By tracking multiple coordinates, the target position accuracy (r) can be improved from 1.5 arcmin to 0.5 arcmin. This mode will track eight points ($P_{off} - P_0 - P_1 - P_2 - P_3 - P_4 - P_5 - P_6$) in turn, and the position ($P_0 \sim P_6$) tracking time (T_0) is the same. The tracking time (T_{off}) of OFF point (T_0) can be set separately. It is generally used for calibration observation of injected noise, and the switching time (T_{switch}) of each point is 20s. The trajectory planning of this mode is shown in the following figure.

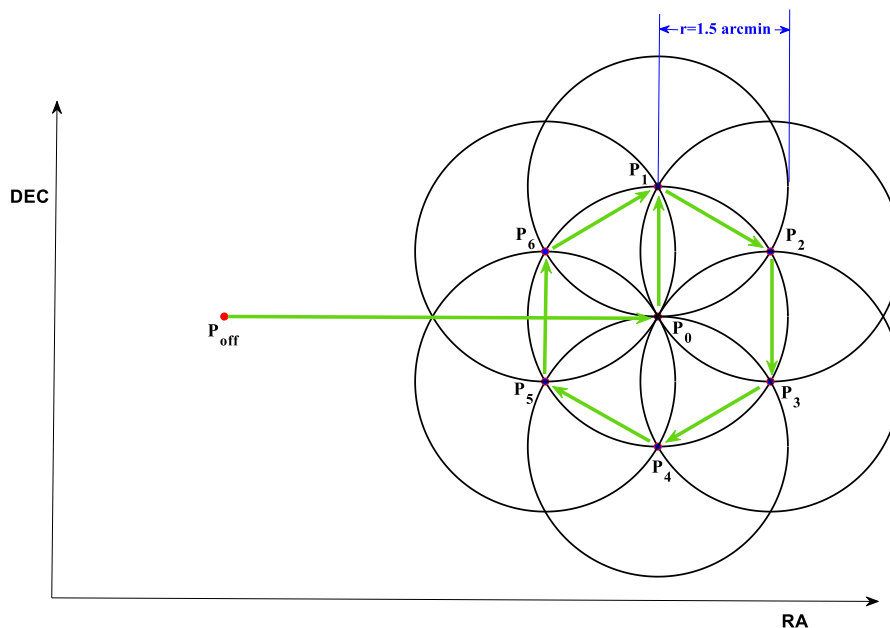


Fig. 2.10.1.1 Schematic diagram of the MultiPos mode.

Given the P_0 coordinate position (ra_0, dec_0) , the coordinates of the remaining 7 positions are

as follows:

$$P_{off} : ra_{off} = ra_0 - 10 \text{ arc min}, dec_{off} = dec_0$$

$$P_1 : ra_1 = ra_0, dec_1 = dec_0 + r$$

$$P_2 : ra_2 = ra_0 + r \times \sin\left(\frac{\pi}{3}\right) \times \frac{1}{\cos(dec_0)}, dec_2 = dec_0 + r \times \cos\left(\frac{\pi}{3}\right)$$

$$P_3 : ra_3 = ra_0 + r \times \sin\left(\frac{\pi}{3}\right) \times \frac{1}{\cos(dec_0)}, dec_3 = dec_0 - r \times \cos\left(\frac{\pi}{3}\right)$$

$$P_4 : ra_4 = ra_0, dec_4 = dec_0 - r$$

$$P_5 : ra_5 = ra_0 - r \times \sin\left(\frac{\pi}{3}\right) \times \frac{1}{\cos(dec_0)}, dec_5 = dec_0 - r \times \cos\left(\frac{\pi}{3}\right)$$

$$P_6 : ra_6 = ra_0 - r \times \sin\left(\frac{\pi}{3}\right) \times \frac{1}{\cos(dec_0)}, dec_6 = dec_0 + r \times \cos\left(\frac{\pi}{3}\right)$$

Total observation time:

$$T_{total} = T_{off} + 7 \times T_0 + 7 \times 20s$$

2) Purpose and conditions of use

Purpose: Improve target position accuracy.

Conditions of use:

■ source coordinate in the epoch of J2000;

3) Parameter description

Input parameter	Unit	Note
Observation Mode	/	observation mode: < MultiPos >
Source Name	/	the source name
RA(P0)	hours,minutes,seconds	00 00 00.00
DEC(P0)	degrees,arcminutes,arcseconds	+00 00 00.0
Time Length for (P0)	second	Integration time of single ON source:>0
Time Length for OFF	second	Integration time of single OFF source:>0
Allow Delay	/	whether to allow delay:<Yes> <No>
Focus Ratio	/	<0.4621>
Feed	/	selection of feeds :<70M-140M> <140M-280M> <270M-1.62G(UW)><560M-1020M> <1.1G-1.9G> <1.05G-1.45G(MB)> <2G-3G>,<1.05G-1.45G(MB)> by default

References

Peng Jiang, Ning-Yu Tang, Li-Gang Hou, et al. 2020, *The fundamental performance of FAST with 19-beam receiver at L band*, RAA,20,5 (64)