

Acceptance Review report on the new K (H22)-/Q (Z45)-bands simultaneous observation system in the NRO 45 m telescope



HINOTORI Team

Hybrid Installation Project in Nobeyama, Triple-band Oriented

Ver. 6 on 2023 June 20

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HINOTORI has been composed of the members in Kagoshima University, Yamaguchi University, Osaka Metropolitan (Prefecture) University, Ibaraki University, Mizusawa VLBI/Chile/ Nobeyama Radio Observatories of the National Astronomical Observatory of Japan. We also deeply appreciate VERA, NRO and Koran VLBI Network of Korea Astronomical and Space Science Institute for providing machine time for technical commissioning of VLBI.

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1. Introduction and scope of this document

HINOTORI has been motivated towards construction of a simultaneous triple-bands observation system with the NRO 45 m telescope using the H22, H40, and TZ receivers with perforated frequency separation filter plates (Okada et al. 2020, PASJ, 72, 7). Installation of the new VLBI backend system is also another driving force of the project (see Figure 1).

The new technology of the frequency separation using a thick (3—6 mm) and large (~60 cm) plate is a key of this project, enabling us to simultaneously observe in two frequency bands. As a result, one can consider pairs of receivers that can be used for such efficient observations.

On the other hand, the pair of the H22 and Z45 receivers also should provide a unique scientific capability to simultaneously monitor maser lines in 20–25 GHz and 40–46 GHz with higher sensitivity in the latter frequency bands than the pair of H22 and H40. Precise measurement of intensities between molecular lines in those frequency bands is also in the scientific scope of the telescope users.

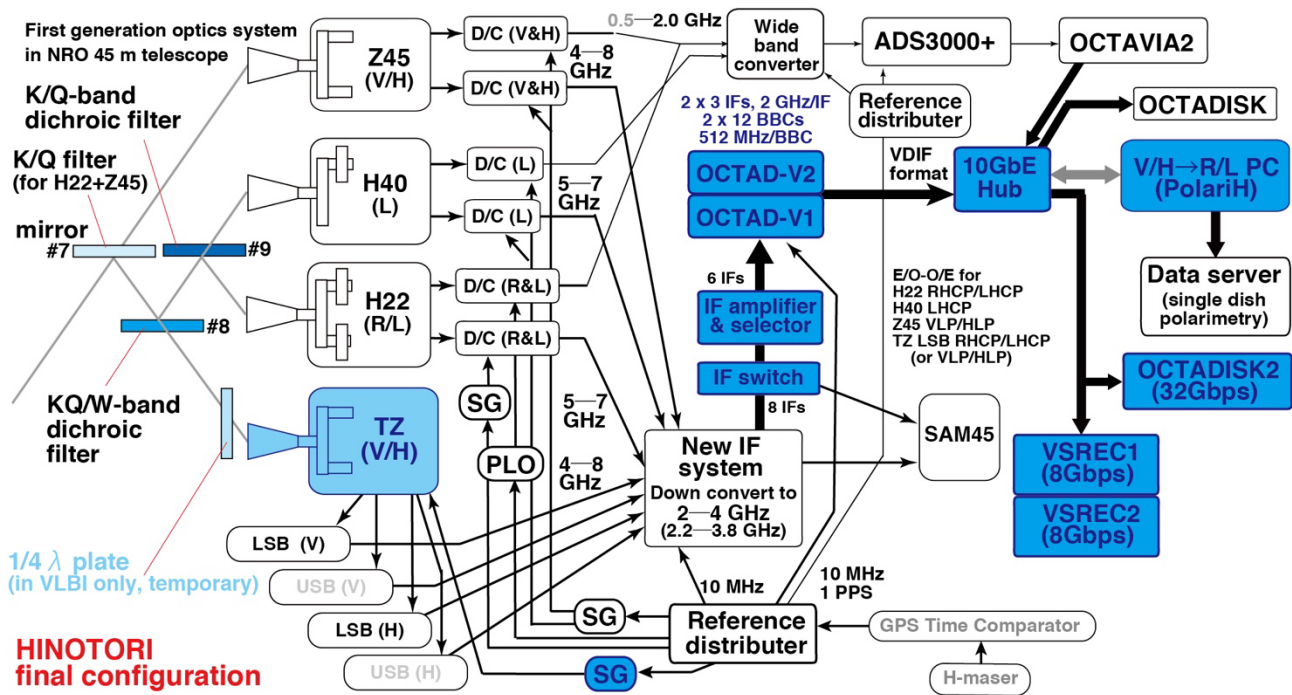


Figure 1: Diagram of the signal flows in the NRO 45 m telescope, from the quasi-optics to digital spectrometer and VLBI backend from the left to the right. Blue- or cyan-shaded blocks show the equipments installed by HINOTORI. This document focuses our attentions to the signal flows from H22 and Z45 to SAM45.

The main scope of this document is focused on the system and the scientific operation of the H22+Z45 simultaneous observation system with the perforated 22 GHz/43 GHz band separation filter plate (hereafter the H22+Z45 filter). Through the commissioning scientific verification (CSV) until 2023 April, HINOTORI team has been confident that this system is ready for scientific observations.

Other scientific capabilities, such as triple-bands simultaneous observation system, shall be considered separately in separate documents.

2. Instrument performance report

2.1 Beam squint

The beam squint measurement was conducted on 2022 March 12 under a night-time, low wind-speed (<3 m/s) condition.

Firstly, the antenna pointing was adjusted using the Z45 receiver *without* the H22+Z45 filter. The beam squint was measured with the H22+Z45 filter every ~ 20 minutes. The antenna beams of H22 and Z45 with the H22+Z45 filter have a systematic offset of $5''$ — $7''$ in the antenna elevation. This offset is still within an acceptable level (less than $1/5$ of the Z45 beam size, $\sim 38''$).

Secondly, the antenna pointing was adjusted using the Z45 receiver *with* the H22+Z45 filter. The left panel of Figure 2 shows the pointing offsets of the Z45 and H22 beams in this measurement. Most offsets of the H22 and Z45 beams were wrapped within $3''$ of the zero-offset. The right panel of Figure 2 shows the differences of the pointing offsets between the H22 and Z45 beams that were measured simultaneously. A systematic offset of $\sim 1.5''$ is visible, indicating the relative beam squint between the two receiver beams. Thus, the beam squint is within the acceptable level and can be well adjusted by this method of the antenna pointing, which is recommended in the scientific observations.

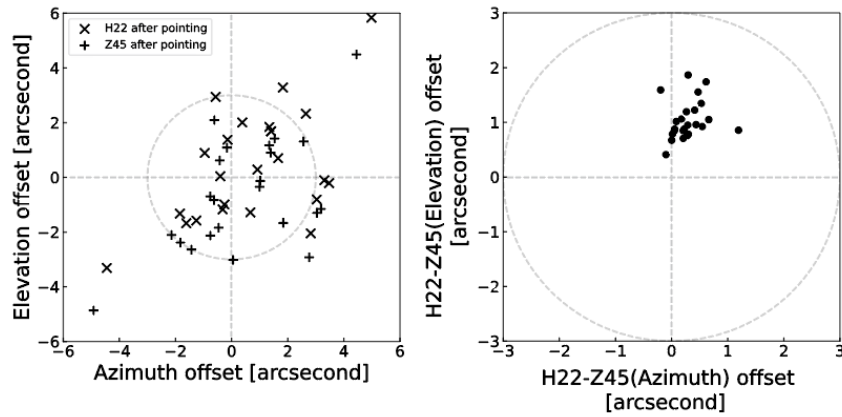


Figure 2: Performance of the simultaneous H22 and Z45 observation system that was found in the beam squint measurement using circumstellar H_2O and $\text{SiO } \nu=1$ and $2 J=1 \rightarrow 0$ maser sources (VY CMa and NML Tau). *Left*: Pointing offsets of the H22 and the Z45 beams found after adjusting the antenna pointing with the Z45 beam and the H22+Z45 filter. *Right*: Difference in the pointing offsets of the Z45 and H22 beams measured simultaneously. (The figures were kindly provided by R. Matsusaka.)

2.2 Gain loss

Possible gain loss is evaluated by a rise in a system noise temperature. Similarly to the H22+H40 simultaneous observation mode (Okada et al. 2020), the gain loss looks negligible for the H22 output in the H22+Z45 mode. According to the statistics of the system noise temperature during the season of 2022 November—2023 April (Figure 3), the nominal system noise temperature was ~ 130 K, by ~ 30 K higher than that reported in the Status Report. Thus, even the rise in the system noise temperature, the H22+Z45 mode can effectively save the observation time compared with the observations using the H22 and Z45 receivers separately and the H22+H40 mode.

2.3 Beam patterns

Figure 4 and 5 show the pattern of the Z45 beam with and without the H22+Z45 filter, respectively. Small elongation of the beam is visible in both the cases with and without the filter but in different directions. The difference in the beam elongation may be attributed to that in the sources observed in different directions. A possible effect of the filter on the beam pattern deformation should be within this difference. The slight difference in the beam pattern is visible between our measurement and that by Nakamura et al. (2015, PASJ, 67, 117), including difference in the locations of the brightest side lobe with respect to the main beam. The brightest side lobe is at a level of $\sim 4\%$, consistent with the side lobe level found by Nakamura et al. (2015) ($\sim 3\%$). From the measurement, we obtained the beam size to be $38.0'' \pm 1.8''$, with excellent agreement (within $1''$) with that measured by Nakamura et al. (2015).

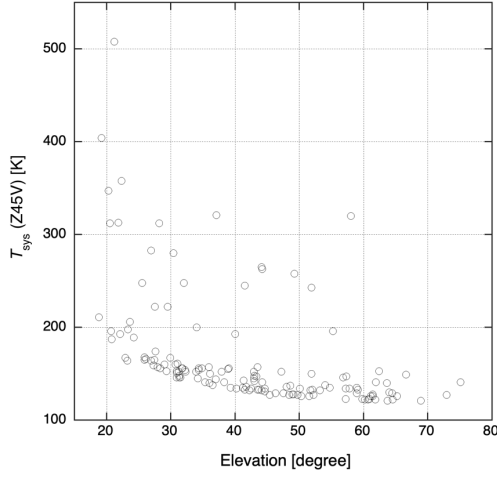


Figure 3: Distribution of the system noise temperatures of the Z45 (Z45V) receiver against the antenna elevations. The data were taken during 2022 November—2023 April in the program G22001.

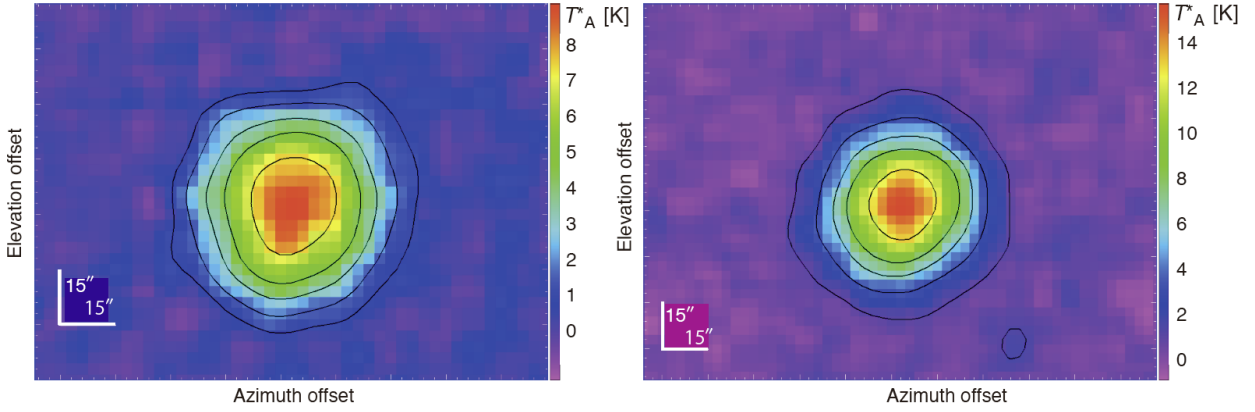


Figure 4: Beam pattern of the Z45 beam with the H22+Z45 filter obtained when observing SiO $J=1 \rightarrow 0$ masers of T Cep (northern sky) taken on 2022 September 1 in an elevation range of $57^\circ - 55^\circ$ (going down). The pixel size is set to $3''$. *Left*: Beam pattern taken in the SiO $v=1$ line at $V_{\text{LSR}} = -27.5$ km/s. The $1-\sigma$ noise level is 0.31 K. The peak brightness is 9.1 K. The contour levels are a $3-\sigma$ level, 20%, 35%, 50%, 75%, and 98% of the peak brightness. *Right*: Beam pattern taken in the SiO $v=2$ line at $V_{\text{LSR}} = -29.5$ km/s. The $1-\sigma$ noise level is 0.31 K. The peak brightness is 15.9 K.

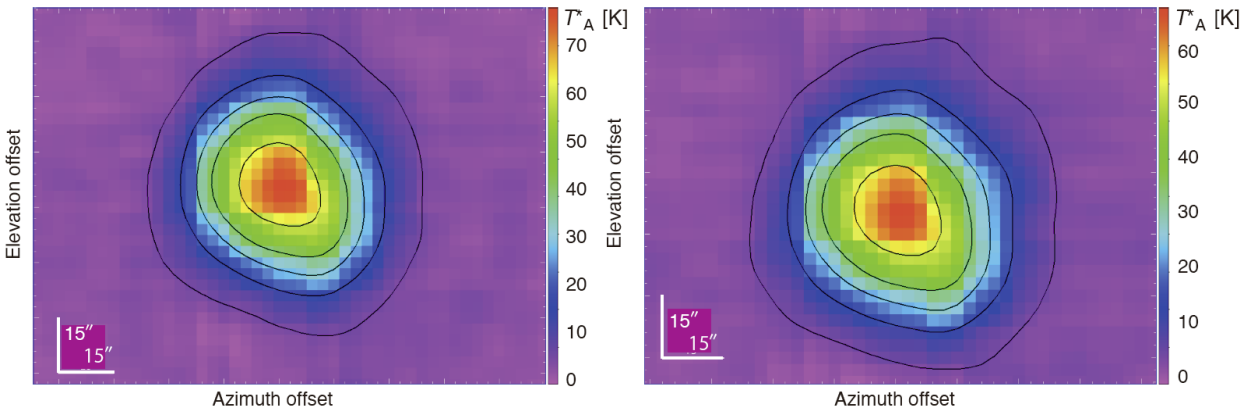


Figure 5: Same as Figure 4 but for VX Sgr (in southern sky) without the H22+Z45 filter in an elevation range of $29^\circ - 24^\circ$ (going down). The contour levels are 5, 20, 35, 50, 75, and 98% of the peak brightness. *Left*: Beam pattern taken in the SiO $v=1$ line at $V_{\text{LSR}} = 27.5$ km/s. The $1-\sigma$ noise level is 0.54 K. The peak brightness is 77.8 K. *Right*: Beam pattern taken in the SiO $v=2$ line at $V_{\text{LSR}} = 28.5$ km/s. The $1-\sigma$ noise level is 0.50 K. The peak brightness is 67.7 K. (The plots in Figure 4 and 5 were kindly provided by K.-Y. Shum and K. Nakashima.)

2.4 Aperture and main beam efficiencies

Table 1 gives the parameters of the observation system with Z45 and the H22+Z45 filter, which are obtained from the efficiency measurement conducted on 2022 September 1st to 2nd in night-time, low wind speed (<3 m/s) conditions. The aperture efficiency ($\sim 52\%$) is lower than that for H40 alone ($\sim 57\%$, see the status report by NRO in 2022—2023), but consistent with that for the system of H22+H40 simultaneous observations within 1% (Okada et al. 2020). Assuming the beam size to be $38.0''$ (Section 2.3) and citing the planet sizes and brightness temperatures from literature, we obtained the main beam efficiency to be 65—74%.

Table 1: Parameters obtained in the efficiency measurements in 2022 September.

	T_A^* [K]	θ_s ["]	T_B [K]	η_A [%]	η_B [%]
Jupiter (CH1)	77.5 ± 0.9	48.72	160.0 ± 10.0	48 ± 3	71.7 ± 5.4
Jupiter (CH2)	79.7 ± 1.0		160.0 ± 10.0	49 ± 3	73.7 ± 5.5
Saturn (CH1)	14.0 ± 0.2	18.606	142.0 ± 5.0	51 ± 2	64.6 ± 3.2
Saturn (CH2)	14.3 ± 0.2		142.0 ± 5.0	53 ± 2	66.1 ± 3.3

Columns (from left to right): Planet observed for the efficiency measurement; peak antenna temperature; size of the planet on the observed date; surface temperature of the planet assumed for the calculation; aperture efficiency; main beam efficiency. (This table was kindly provided by K.-Y. Shum and K. Nakashima.)

2.5 Standing waves caused by the H22+Z45 filter

Standing waves generated by radio emission from the receiver have been observed when a perforated frequency band separation filter plate is inserted in the quasi-optics and the receiver emission is reflected by the filter to the receiver itself. Figure 6 shows the effect of such standing waves found on 2022 May 1, before installing a beam guide tube coated with absorbers on the inside of the tube. This effect is expected to be mitigated by installing the new beam guide tube and putting absorber films on the beam guide in the signal downstream of the frequency separation filter.

The effect of the standing waves is evaluated in terms of r.m.s noise level of the emission received with the continuum backend system. We found that the r.m.s noise level (median value) increased by a factor of $0.242/0.131 \sim 1.8$ when inserting the filter before the mitigation. Then we found that it does not change within 5% ($\{0.213-0.213\}/0.204$) between the noise measurements with and without the filter after the mitigation.

2.6 Operation with the H22+Z45 simultaneous observation system

One can create an observation table using the `nobs` program. A template of the device table (`.ndevice`) has been tested and provided for scientific demonstrations during 2021 December to 2022 September. All the 16 SAM45 arrays (spectral windows) are available with the observation system, as described in Section 3.

We obtained the data of system noise temperatures T_{sys} with this observation system during a period of 2022 November—2023 April. The system noise temperature was down to ~ 88 K in H22 and $T_{\text{sys}} \sim 121$ K in Z45 around elevations of $\sim 60^\circ$ (Figure 3).

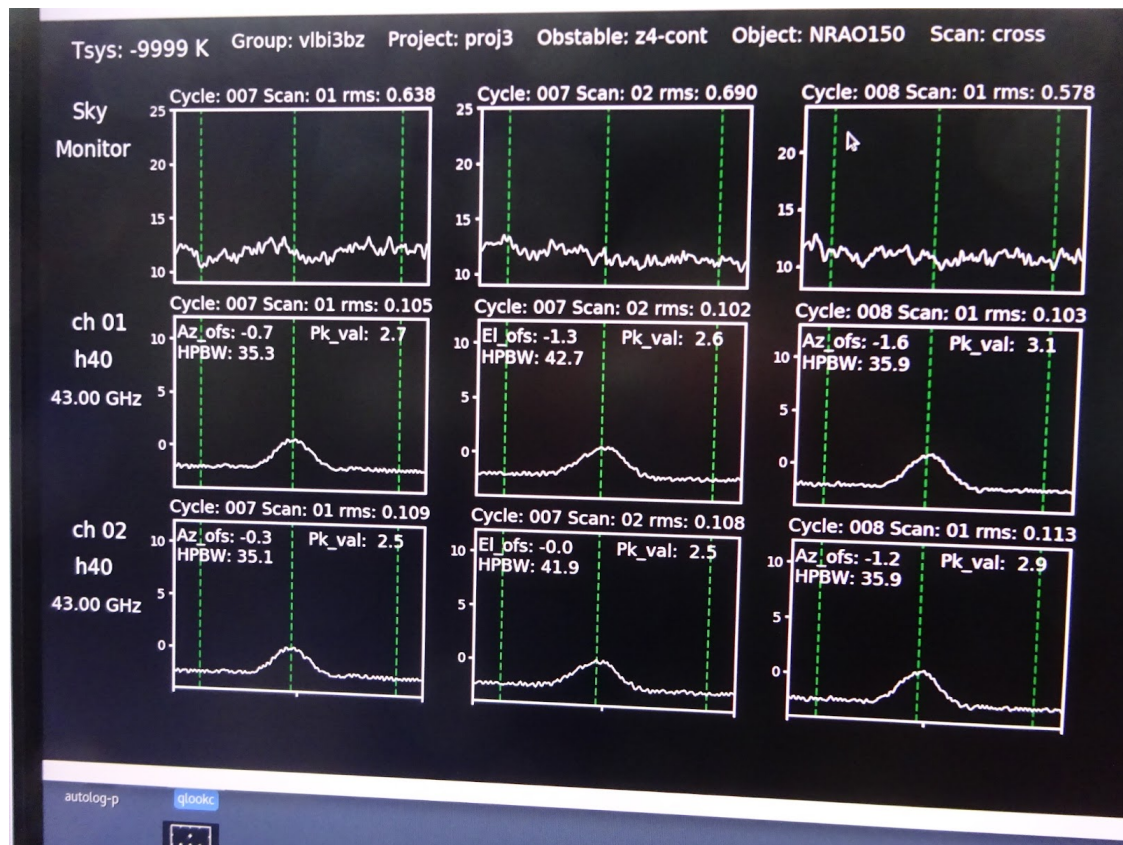
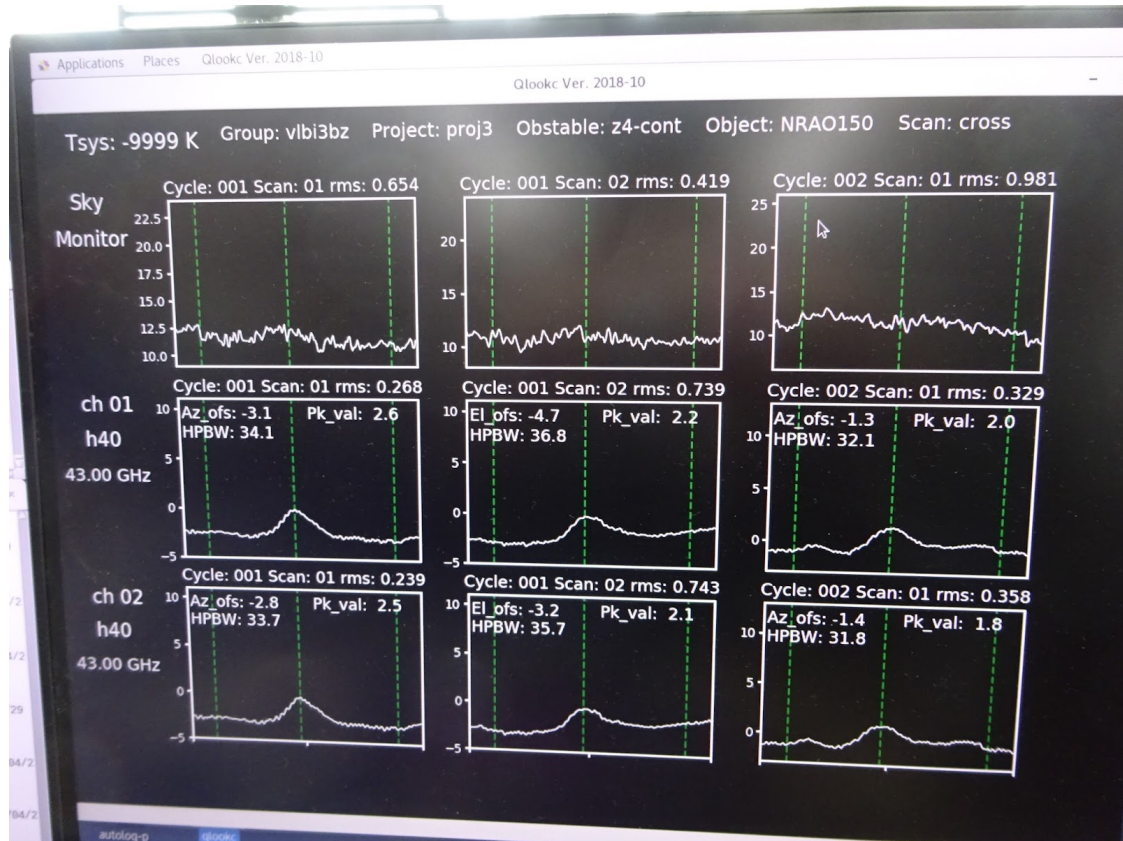


Figure 6: Brightness variation when scanning NRAO 150 using Z45 and the continuum backend system, which were observed on 2022 May 1, before installing a beam guide tube coated with absorbers on the inside of the tube. *Top*: Case with the H22+Z45 filter. *Bottom*: Case without the filter.

3. Description of the User Guide

HINOTORI team hopes that NRO can present the description of the User Guide given as follows in a rectangle block

Instruction for observations with the H22+Z45 system

1. Preparation of the device (.ndevice) table
h2z4_1.ndevice is provided as a template device table.
Signals from H22 and Z45 shall be provided to A01—06 and A07—16, respectively.
Check the polarization: H22R in A01—04, H22L in A05—06, Z45V in A08, 10, 12, 14, 16, and Z45H in A07, 09, 11, 13, 15.
Spectral resolutions shall be set separately for A01—08 and A09—16.
2. Change the mirror to “H22+Z45”
3. Start your observation. Push the “LD1-OPEN” in the “MMC control” window when the telescope elevation goes below 80 degrees.

Figure 7 shows the device table h2z4_1.ndevice loaded in nobis for this observation mode.

4. Operation plan

HINOTORI team shall have the responsibility for maintaining the H22+Z45 filter plate. If the plate might have some difficulty in scientific operation or be considered to be updated, another plate will be fabricated in Osaka Metropolitan University and tested by the team.

There exist only two modes of 2:1 switch selection patterns of the New IF Switch Box, for single-dish and VLBI observations, respectively. No further upgrade of the switch patterns is considered.

The new observation system with H22+Z45 will be operated until Z45 will be decommissioned by NRO. Maintenance of Z45 is out of scope in this document and should be discussed with the user community in the future.

ProjectSourceReferenceScanDevice

Obs. Type : Line

Device Table

h2z4_1

Choose

Load

Samples

Save

Check

Note (optional) H2O,NH3, SiO v=0, 1, 2, 3, CH3OH

FrontendBackendSummary

Please use a sample device table.

Frontend

	Frontend	IF	Track freq. (GHz)	IF freq. (GHz)
FE01	H22R	USB-L	22.8	6
FE02	H22L	USB-L	22.8	6
FE03	Z45V	USB-L	43.2	6
FE04	Z45H	USB-L	43.2	6
FE05		USB-H		
FE06		USB-H		
FE07		USB-H		
FE08		USB-H		

IF-Backend

sub-Array1

	Frontend	Att.
IF01	FE01	5
IF02	FE01	5
IF03	FE01	5
IF04	FE01	5
IF05	FE02	5
IF06	FE02	5
IF07	FE04	5
IF08	FE03	5

sub-Array2

	Frontend	Att.
IF09	FE04	5
IF10	FE03	5
IF11	FE04	5
IF12	FE03	5
IF13	FE04	5
IF14	FE03	5
IF15	FE04	5
IF16	FE03	5

Parameter Config File

Choose

ProjectSourceReferenceScanDevice

Obs. Type : Line

Device Table

h2z4_1

Choose

Load

Samples

Save

Check

Note (optional) H2O,NH3, SiO v=0, 1, 2, 3, CH3OH

FrontendBackendSummary

sub-Array1

sub array mode

Disable

Enable

SpW mode

Disable

Enable

sub-Array1 Spectral Window1

	Rest Freq. (GHz)	Resolution (kHz)
A01	23.121024	30.52
A02	23.6945	
A03	22.316	
A04	22.23508	
A05	22.316	
A06	22.23508	
A07	43.267	
A08	42.82053	

sub-Array1 Spectral Window2

	Rest Freq. (GHz)	Resolution (kHz)
A17		
A18		
A19		
A20		
A21		
A22		
A23		
A24		

sub-Array2

sub-Array2 Spectral Window1

	Rest Freq. (GHz)	Resolution (kHz)
A09	42.82053	61.04
A10	43.267	
A11	44.06941	
A12	42.51934	
A13	43.122027	
A14	43.122027	
A15	42.51934	
A16	44.06941	

sub-Array2 Spectral Window2

	Rest Freq. (GHz)	Resolution (kHz)
A25		
A26		
A27		
A28		
A29		
A30		
A31		
A32		

Figure 7: Device table h2z4_1.ndevice loaded in nobS for this observation mode.