VGOS Related Developments in Japan

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1 Overview

Development of VGOS compliant broadband VLBI observation system is being conducted by GSI (Geospatial Information Authority of Japan) and NICT (National Institute of Information and Communications Technology).

GSI has constructed a fully VGOS-compliant 13m diameter antenna at Ishioka, which is located about 30 min. drive from Tsukuba station. The ring focus 13m antenna became ready for observation in Oct. 2014 and the first VLBI fringe was detected with broadband feed (Eleven feed[3]) in Dec. 2014 on Ishioka 13m - Kashima 34m baseline. A new data acquisition system named K6/iDAS is being prepared for broadband VGOS observation.

NICT Kashima group is developing a broadband VLBI system for application to distant frequency comparison project named GALA-V. The GALA-V project is composed of a pair of transportable small diameter antennas and a large diameter antenna. A new broadband feed was originally developed for Cassegrain focus type 34m radio telescope. Two ways of data acquisition systems are prepared for the broadband observation. One way is using conventional analog frequency conversion for feeding signal to sampler ADS3000+. The ADS3000+ has digital baseband conversion function of 16 narrow bandwidth channels output via VSI-H interface. Another way is acquiring 4 x 1024 MHz bandwidth signals at once without frequency conversion (direct sampling) by using high speed sampler K6/GALAS. In both cases, correlation processing is performed by fast software correlator GICO3[2] developed by NICT.

Sharing these information on Japanese developments of new VLBI antennas, feed systems, data acquisition systems will be useful for IVS community for collaboration and coming VOGS observations.

2 GALA-V Project — NICT Kashima

2.1 VLBI Application for distant frequency comparison

In the GALA-V project, a pair of transportable small diameter antennas are used for precise frequency comparison of atomic standards located remote sites. Disadvantages of sensitivity due to smaller collecting area are compensated by expanding observation bandwidth and using large diameter antenna as counterpart for boosting the signal to noise ratio (SNR) in the observation(Fig. 1). Development of this system has been conducted with keeping in minde that the system become compatible with VGOS specification by minimum modification. Currently these small antennas (named MABRLE1 and

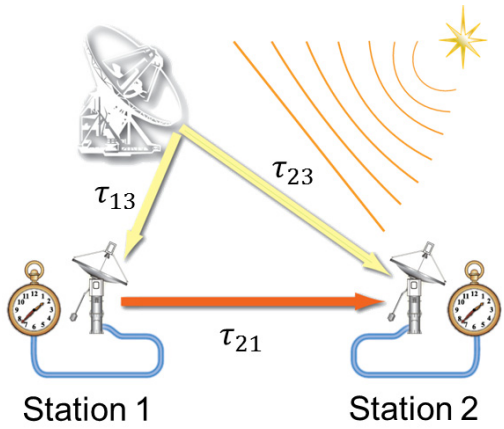

Fig. 1 Concept of GALA-V project for distant frequency comparison.

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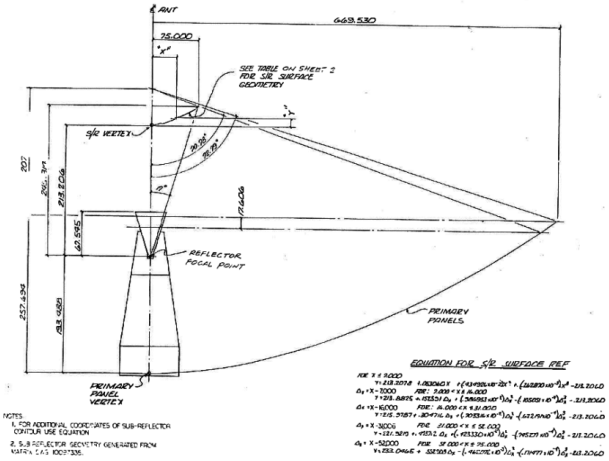
2) are equipped with broadband feed (Rindgren Quad Ridge Horn, hereafter referred as 'RQRH') with prime focus optics. Although existing large diameter antenna (Kashima 34m) designed with Cassegrain focus optics requires narrow beam for the feed, thus we had to develop original broadband feed with narrow beam width. And successfully we have developed such feed system.

2.2 Broadband Feed for Cassegrain Antenna

Instead of constructing a new telescope, we decided to upgrade Kashima 34m antenna to enable broadband observation. The first prototype of multimode horn antenna (IGUANA-H) for Kashima 34m antenna was designed and manufactured by NICT in the 2013. After installation of the feed with room temperature LNA, the first light observation was made for Methanol maser emission at 6.7 GHz and 12.2 GHz simultaneously from radio source 'W3OH' on 17 January 2014 (Fig.3). Received signal amplified by LNA is transferred to observation building via broadband (1-18 GHz) signal transmission system E18000[1] through optical fibers. System equivalent flux density (SEFD) of the 34m antenna with this feed system is below 2000 Jy, and its aperture efficiency is 30 - 50 % for the 6.5-15 GHz frequency range (Fig. 4).

Since the prototype IGUANA-H is not sufficient for full VGOS observation, the second feed design (named 'NINJA') targeting for 3.5-14.4 GHz frequency range is under development, and will to be mounted on 34m antenna in 2015. The NINJA feed is composed of multimode horn and dielectric lens system. The third candidate feed design for the 34-m antenna is coaxial horn antenna (IGUANA-FULL), which is composed of wider outer horn for lower frequency (mother feed) and inner horn (daughter feed) inside it. Current IGUANA-H feed is actually inner daughter feed as a part of IGUANA-FULL feed.

The NINJA feed design is not only for 34m antenna, but also going to be used for upgrading the MARBLE-1 and 2 antennas. The upgrade plan includes exchanging dish size from current 1.5m/1.6m to 2.4 m, and improvement of the aperture efficiency. Current poor efficiency of MARBLE1/2 antennas are caused by mismatching of beam size/shape with the main dish. By exchanging feed system with own designed NINJA feed adjusted for new main reflector, we are expecting improvement of the efficiency. In accordance with exchanging the feed system, antenna optics is going to be changed from current prime focus to Cassegrain focus.



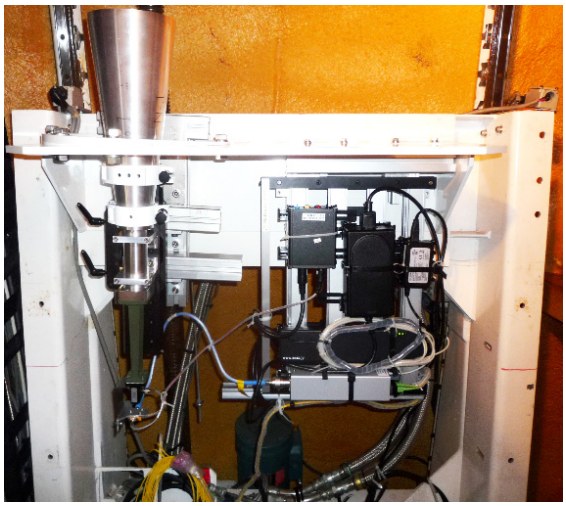


Fig. 2 Drawing of 34m antenna reflector configuration (upper panel). Viewing angle of sub-reflector diameter from focal point is 34 degrees. Broadband feed system (IGUANA-H) with room temperature LNA mounted on Cassegrain type Kashima 34m antenna (lower panel).

2.3 Data Acquisition System (DAS)

Preliminary selection of observation frequency was made by taking into account (1) minimum redundancy array for fine delay resolution function, and (2) radio frequency interference (RFI) survey around Kashima, Tokyo, and Tsukuba region. Selected frequency has been used for designing fixed frequency down converter (Table 2). By combination of the down converter and

[1] http://www.toyo.co.jp/page.jsp?id=14347

Table 1 Broadband feeds originally designed by NICT.

Feed Name	IGUANA-H	NINJA	IGUANA-FULL
Feed Type	Multi-mode Horn	Horn Lens Antenna	Coaxial Horn
Frequency Range	6.5-15 GHz	3.2-14.4GHz (nominal)	2.2 - 18 or 22 GHz (plan)

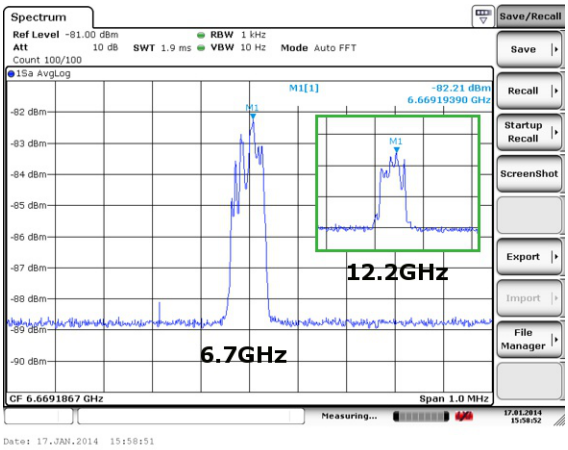


Fig. 3 Methanol maser emission at 6.7 GHz and 12.2 GHz from W3OH were observed simultaneously with broadband feed (IGUANA-H) of the 34m antenna.

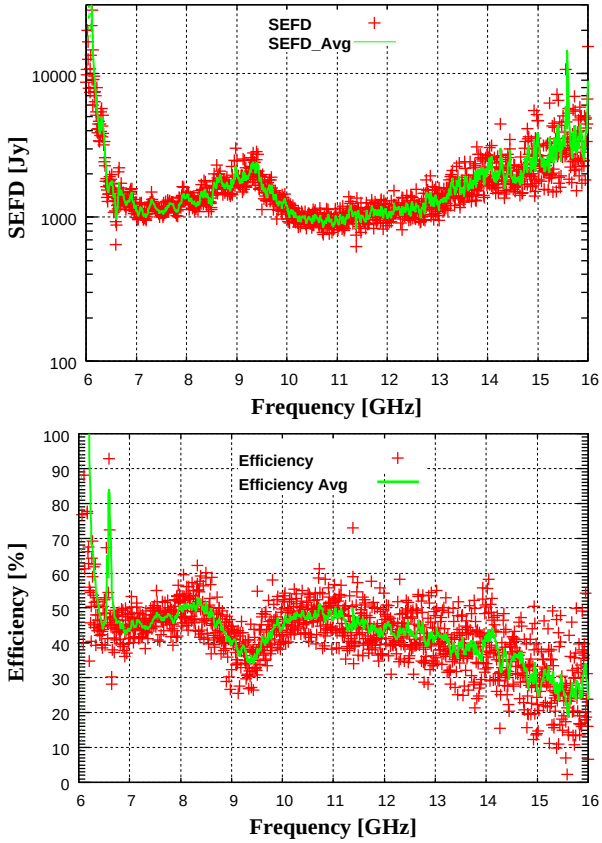


Fig. 4 SEFD(upper) and aperture efficiency(lower) of 34m antenna with IGUANA-H feed.

ADS3000+ sampler, VGOS compatible multiple channels of 32 MHz bandwidth data acquisition is available. In addition to the conventional down converter system, direct sampling technique [1] (sampling signal at radio frequency) was employed as an alternative data acquisition method.

Since our down converter is not capable of flexible selection of frequency band, frequency choices are limited as listed in the table2 for common VGOS-compatible multi-channel observation. However adding some more frequency bands is not significant problem. We can prepare fixed frequency down converter by just purchasing additional band pass filters if needed.

2.4 Correlation Processing and Analysis

Fast software correlator GICO3 [2] has been used for processing the GALA-V project data. Observed delay data has been compiled to Mk3DB and analyzed by CALC/SOLVE software. X-band single band observation have been made several times on GALA-V network (Kashima34 – MARBLE1(Tsukuba) – MARBLE2(Koganei)) from Aril 2014. Since the maximum baseline length is no more than 100km, ionospheric delay was not significantly affected in single band

Fig. 5 Outlook of ADS3000+. One set of sampler is capable of "64Msps x 2bit x 16ch" observation.

observation. Obtained station position repeatability was less than 5 mm, and 5 cm for horizontal and vertical position, respectively.

Table 2 Two observation modes are used in the GALA-V project. Combination use of IF down converter and ADS3000+ can be used both **Wide** and **Narrow** channel observation. Direct sampler K6/GALAS is used only for **Wide** channel obseravtion.

Data Acquisition Mode	**Wide channel observation**	**Narrow channel observation**
observation mode unit	2048 MHz : 1 bit :1ch	64 MHz : 2bit : 16 channel
Frequency conversion (from RF to IF)	Direct Sampling	Analog down conversion
Down Converter	–	Required.
Available RF Frequency	Any 1024MHz bandwidth within 0.1-16 GHz range.	3500-4524 MHz 5100-6124 MHz 9900-10924 MHz 13100-14124 MHz Additionally 6419-6919 MHz, 11930-12430 MHz
Sampler	K6/GALAS	ADS3000+
Input Frequency	0.1 - 16 GHz	0.01- 1.5 GHz

Table 3 ADS3000+ Sampler specification parameters.

Input	
Number of inputs	2
Input Freq. Range	0.01-1.5 GHz
Output	
Sampling Mode	Broadband Mode(∗) 128Msps :8 bit 512Msps : 2,4 bit 1024Msps: 2 bit 2048Msps: 1 bit
	DBBC Mode Nch: 16 Sample rate: 4, 8,16,32,64 Msps Quantization bit: 1, 2, or 4 bit
Max data rate/port	4096 Mbps
Number of output port	4
Interface port	VSI-H
Data format	VSI-H(raw)
Control	telnet /1000BaseT

(*) Typical observation modes are indicated.

Fig. 6 Outlook of K6/GALAS direct sampler. One set of sampler is capable of “2048Msps x 1bit x 4ch” observation.

Table 4 K6/GALAS Sampler specification parameters.

Input	
Number of inputs	2
Input Freq. Range	0.1-16.4 GHz
Output	
Sampling Mode	Broadband Mode 3200 Msps :1,2 bit 6400 Msps : 1,2 bit 12800 Msps: 1 bit
	DBBC Mode Nch: 1,2,3,4 Sample rate: 2048 Msps Quantization bit: 1,2bit
Max data rate/sampler	16384 Mbps
Number of output port	4
Output Interface port	10GBASE-SR (SFP+)
Data format	VDIF/VTP over UDP/IP
Control	telnet /1000BaseT

Under the collaboration between NICT and GSI, the VLBI experiments between Ishioka 13m and Kashima 34m were conducted during December 2014 - January 2015. The first fringe of Ishioka 13m station was detected in December 2014 and super broadband VLBI with 8 GHz bandwidth was successfully performed in these experiments. The experiments were performed by ”Wide channel observation” mode with both direct sampler K6/GALAS and fixed-frequency down converter and ADS3000+ sampler. Figure 9 shows the fringe and cross spectrum of the 8 bandwidth synthesis. A K6/GALAS sampler was used for acquiring 6-10 GHz frequency bands, and two set of ADS3000+ sampler was used for observation at 10 -11GHz and 13 -14 GHz. The differences on signal characteristics clearly seen in cross spectrum is caused by the difference of the

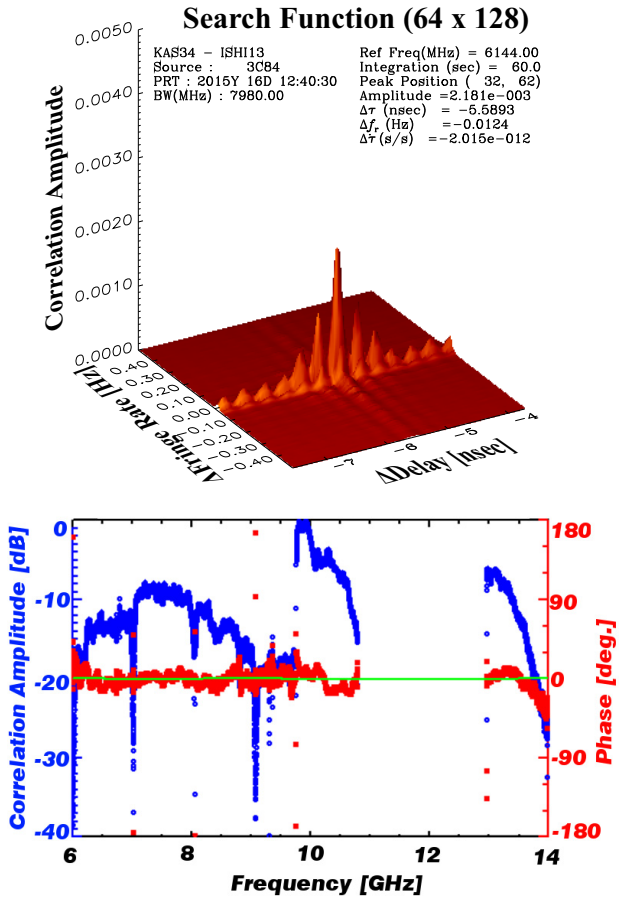


Fig. 7 A fringe obtained by 8GHz bandwidth synthesis (upper panel) and phase and Amplitude of the cross spectrum (lower panel). Amplitude variation over the frequency is caused by differences of data acquisition systems and signal paths. Inter-band and Intra-band phase characteristic correction has been applied.

data acquisition systems. It is notable that inter-band variation in phase and amplitude is small in case of direct sampling.

Additionally the first international VLBI observation with broadband feed was made between Westford, GGAO and Kashima 34m on 20 January 2015. Kashima 34m station participated the Westford – GGAO VGOS experiment by tagalong with ”narrow channel observation” mode (see Table 2) at 10 GHz band. We are going to make further domestic and international broadband experiments in 2015 for research and developments of broadband VLBI system.

3 Ishioka VGOS Station – GSI

3.1 Ishioka 13m Antenna

Ishioka 13m station was constructed with fully VGOS-compliant specification in 2014. Eleven feed [3] was mounted until end of January 2015. The first VLBI observation was conducted between Ishioka13 – Kashima34 baseline, and the first fringe was detected in December 2014. Additionally broadband observation with 8GHz bandwidth over 6 - 14 GHz frequency range was successfully performed on this baseline.

Fig. 8 Ishioka 13m Radio Telescope.

Table 5 Antenna parameters of Ishioka 13m VGOS Station

Diameter	13.2 m
Mount Type	AZ-EL mount
Azimuth range	± 270 degrees from the south
Elevation range	0-90 degrees.
Slew Rate	Az:12deg./sec., El: 6deg./sec.
Feed system	Eleven feed, Triband Feed, QRFH
Optics	Ring focus

3.2 K6/iDAS data acquisition system

Fully VGOS compatible data acquisition system has been developed by GSI. Flexible up-down converter is used for selecting the observation band. Signal is converted to 1-2GHz frequency range, then fed to a new VGOS compatible sampler named K6/iDAS developed by GSI. The up-down converter and K6/iDAS have been tested on Tsukuba32 - Ishioka13 baseline, and fringes have been detected successfully.

Fig. 9 K6/iDAS VLBI Sampler.

Table 6 K6/iDAS Sampler specification parameters

Input	
Number of Input	2
Input Freq.Range	0.1 – 3 GHz
Output	
Sampling Mode	Broadband Mode 256Msps : 1,2,4,8 bit 512Msps : 1,2,4,8 bit 1024Msps:1,2,4 bit 2048Msps:1,2 bit
	DBBC Mode Nch: 4,8,16, 32 Sample rate: 8,16,32,64,128 Msps Quantization bit: 1,2,4,8,bit
Max data rate/port	4096 Mbps
Number of output port	2
Interface	10GBASE-SR(SFP+)
Data format	VDIF over UDP/IP

3.3 Near Term Schedule

Eleven feed of Ishioka 13m station was replaced to Tri-band feed[5] in the early Feb. in 2015. Then geodetic S/X-band VLBI experiments including Tsukuba32 and Ishioka13 have been intensively conducted for accurate station position transition from Tsukuba32 to Ishioka13, because Ishioka 13 m station will succeed the reference coordinates of Japanese datum from Tsukuba 32 m station. Exchanging the feed from Tri-band to Eleven feed may happen at the end of this year. Ishioka 13m station has another broadband Quad Ridge Flared Horn (QRFH)[4], but it is not ready yet. After re-design of Cryo-Dewar for the QRFH, this feed may become candidate to be used.

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