Current status and future view of VERA geodesy.

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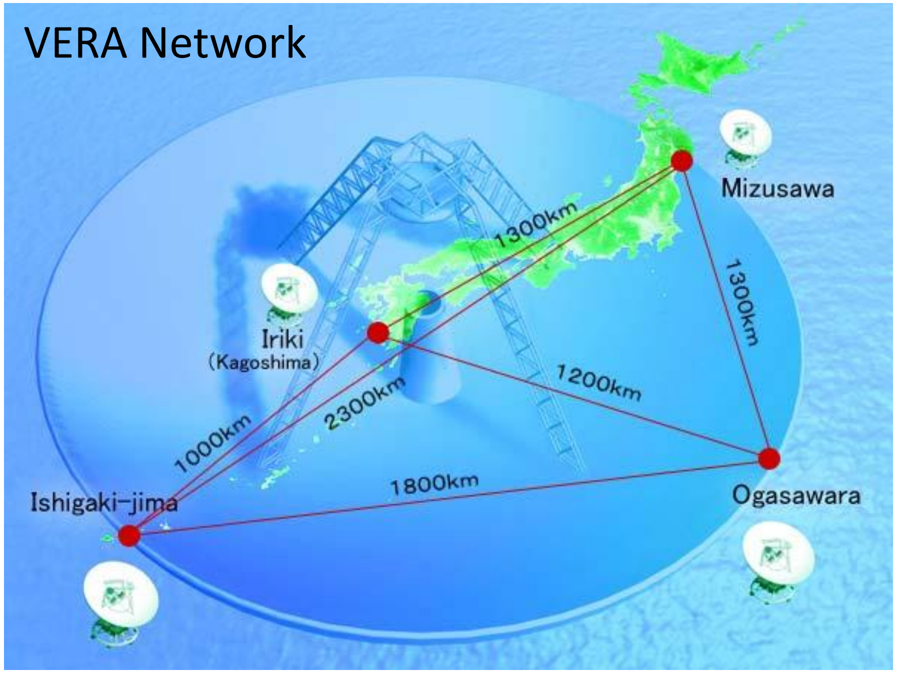
AOV Meeting @ UTAS, Hobart, AU on 19 Nov 2015



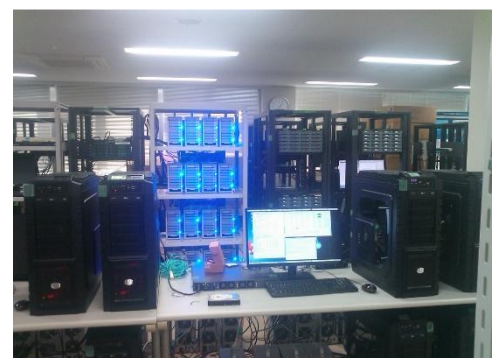
VERA is a Japanese VLBI array aimed for obtaining 3-dimensional map of our Galaxy. With phase-reference VLBI technique, VERA will measure distances and motions of radio sources in the Galaxy with -9th powers of 10 accuracy, unveiling the true structure of the Galaxy. The construction of VERA array was completed in 2002, and it is under regular operation since fall of 2003.

VERA monitors elongation (separation angle) between two radio emitting stars, maser-emitting molecule cloud and Quasar, for more than a year, and determines annual parallax and distance to the maser emitting sources.

Dual beam system
in upper cabin

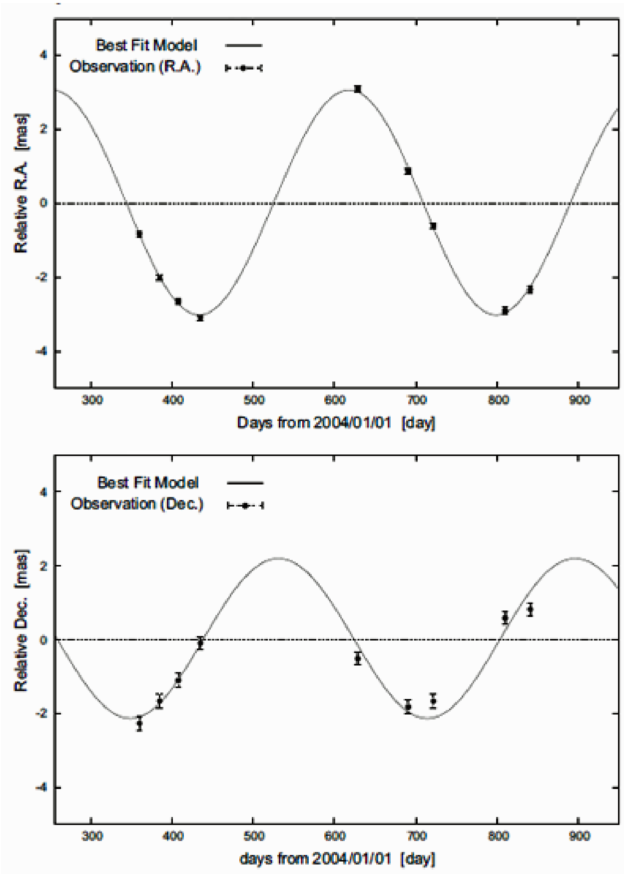
Two receivers move along the Cassegrain focus plane to observe two adjacent sources simultaneously.

In 2014, the 1-Gbps recording system replaced to OCTADISK HDD data storage system. Recording time is 80 hours/unit.

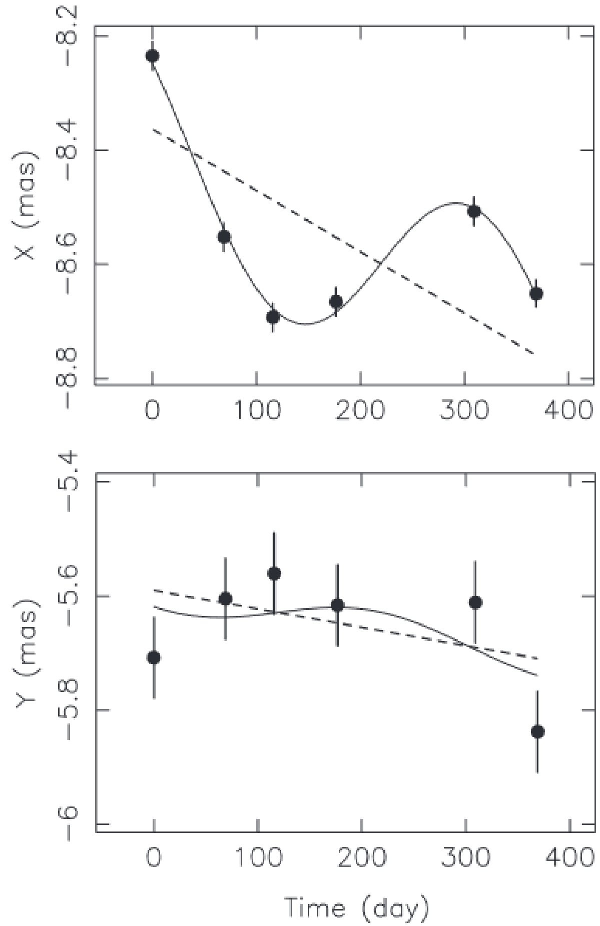


From 2015, the newly developed software correlator starts correlation operating in Mizusawa. Core engine of correlator is GICO3 developed by NICT.

Main target is a pair of Maser source and Quasar Maser freq.: C, K, Q



T-Lep (Mira Variable)
H_2O maser (22GHz)
Annual Parallax: 3.06-/+ 0.04mas
Distance: 327 -/+ 4 per-sec
(A. Nakagawa, et. al, 2014)



S269 (Star forming region)
H_2O maser (22GHz)
Annual Parallax: 0.189-/+ 0.008mas
Distance: 5.28 -/+ 0.24 kilo per-sec
(M. Honma, et. al, 2007)

Observation of over than 200 objects has already been performed. Then, annual parallaxes has been determined.

And, rotation speed and mass distribution (quantity of dark matter?) of our Galaxy are also modified. (Honma, et. al., 2007, Chibueze, et. al, 2015, etc.)

By the way, there is a cause-and-effect relationship between the result of VERA and Hobart.

The Antarctic VLBI Experiment in 1998

View of VLBI observation facilities in Syowa Station.

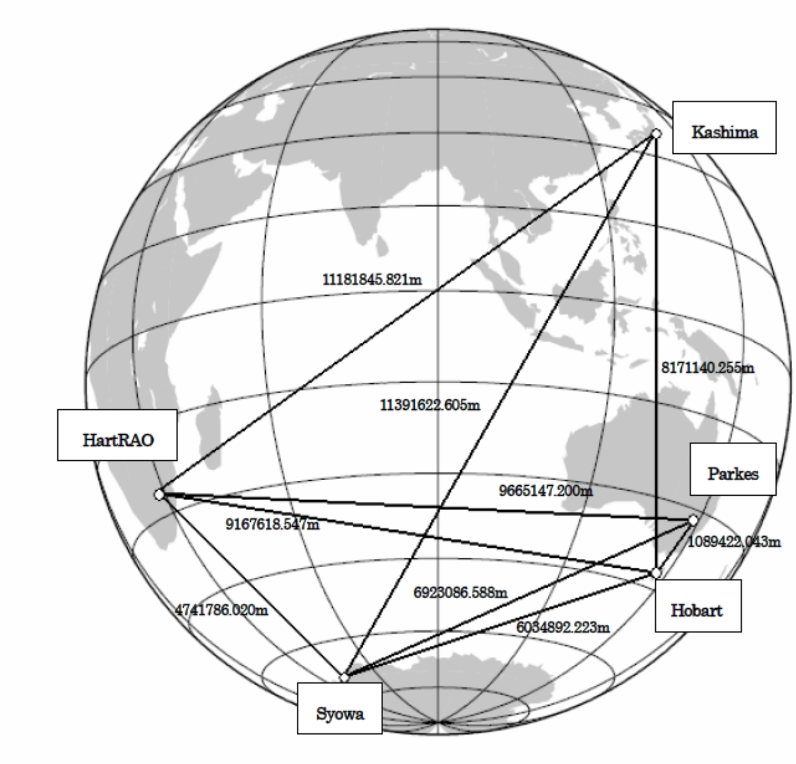
11m Multiple-purpose satellite receiving antenna in Syowa Station.

K4 back-end system installed in Syowa Station.

Carrying-in work of the hydrogen maser frequency standards in Summer Operation.

Operating in wintering.

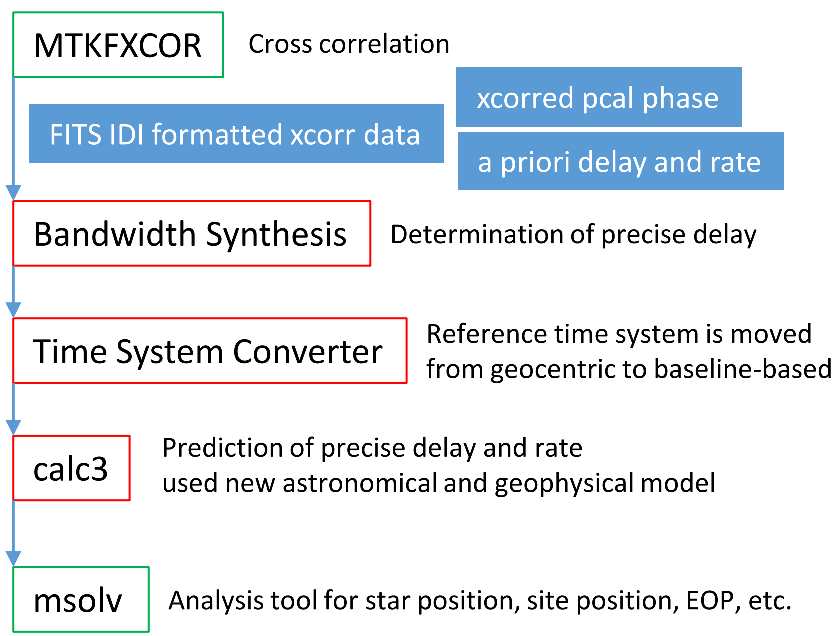
I stayed at Syowa Station in Antarctica for one year, during 1998.
The start of regular VLBI observation in Syowa Station is the purpose.
A set of VLBI observation systems was carried into Syowa Station.
And observations were carried out in the wintering period.



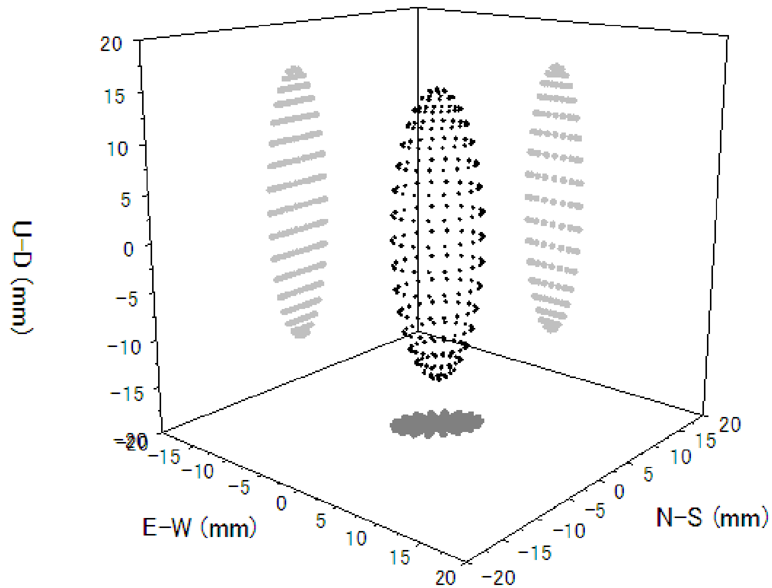
Core stations of the Antarctic VLBI network was consist of Hobart-26, HartRAO and Syowa.

The recording system of the network was unique.
Syowa used K4 standard system, while Hobart and HartRAO used S2 system.

Thus it was necessary to consider compatibility of recording systems in the correlation processing.
When our Antarctic VLBI Project started, only the Mitaka FX Correlator was capable of cross-correlating the K4 data system with S2.
Correlations were made at the Mitaka FX Correlator



The Mitaka FX correlator had previously been used only for astronomical imaging. Several modification were necessary to translate raw correlators output into the standard delay and delay-rate used in the geodetic analysis.
I created the analysis system for VLBI geodesy expressed to right flow chart, investigating whether the output of Mitaka FX Correlator can be used for geodetic analysis (ex, the digit number of parameters, the guarantee of O-C, error estimation).



The left figure is the error ellipsoid of the estimated position of Syowa on 10th Nov. 1998.

This is the first geodetic solution of the Mitaka FX Correlator.
And this solution showed that the Mitaka FX correlator could be used enough for the analysis of the precise geodetic and astrometric VLBI.

VERA project adopted the Mitaka FX Correlator as a main correlator of VERA.
The result of the Antarctic VLBI has greatly affected this decision.

The Mitaka FX correlator. The main correlator of VERA till 2014.

VERA is carrying out the geodetic VLBI session with two purposes.

1, Fixing of the VERA network to TRF

Participation in IVS sessions (T2, AOV, JADE)

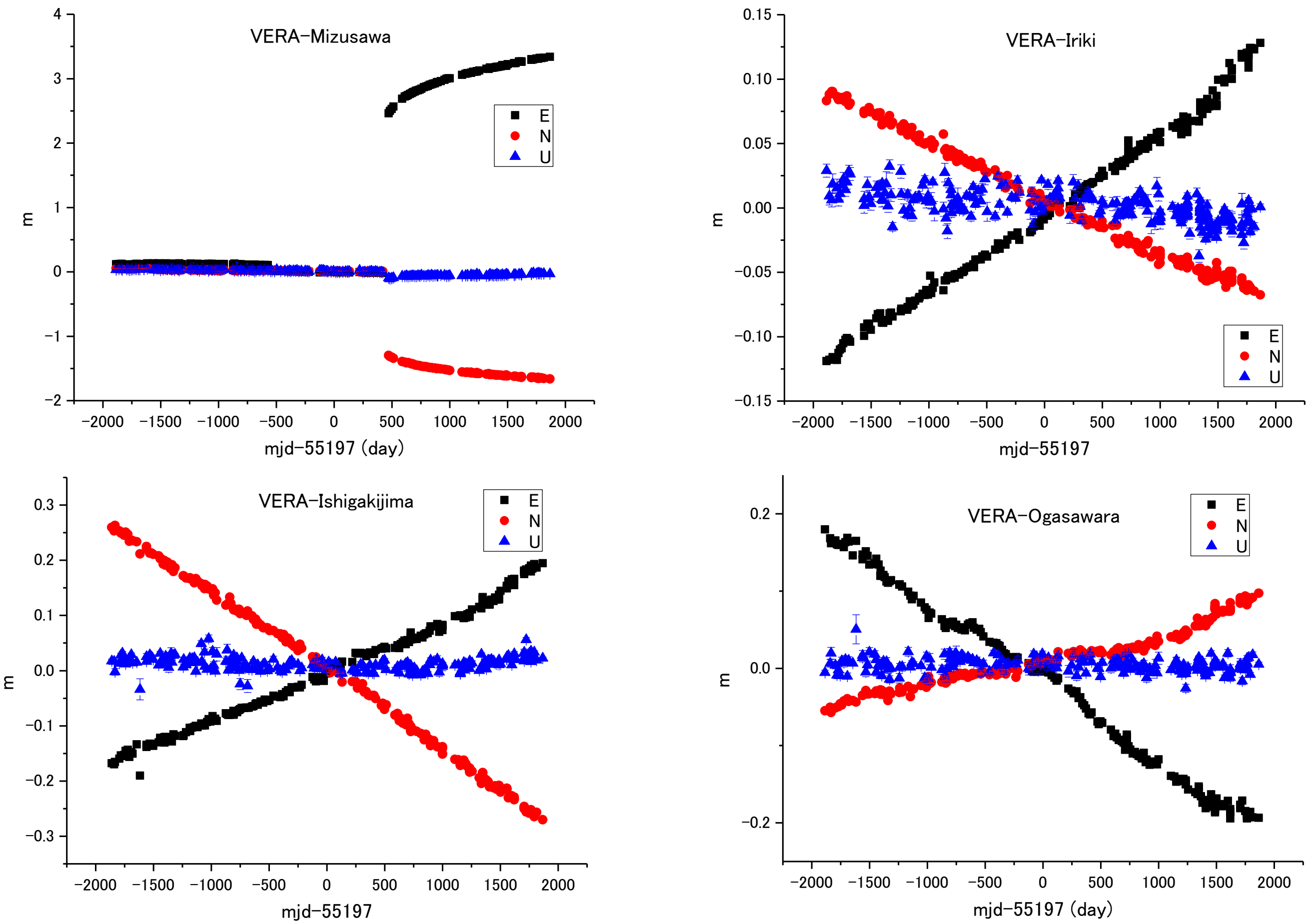
Specifications of observation	Traditional specification
Typical number of scan	200-300
Used Frequency band	S and X band
RF bandwidth	S: 2210-2320MHz, X: 8190-8610MHz
Number of channels	S: 6ch, X: 8ch
Analog baseband filter	K4 video convertor
Sampling mode	8MHz-1bit-16ch
Recorder	K5VSSP
Correlation	IVS correlation center (Bonn, Haystack, GSI)

2, Monitoring of VERA network form with mm error (H:2-3mm, V:4-5mm)

VERA Internal geodetic VLBI

Specifications of observation	Specification peculiar to VERA
Typical number of scan	500-700
Sampling mode	1024MHz-2bit-1stream
Digital Filter mode	16MHz bandwidth - 16stream
Used frequency band	S/X (till 2006), K (2007 and after)
RF bandwidth	S: 2256-2384MHz, X: 8218-8608MHz, K: 22800-23328MHz
Number of streams	S: 4, X: 12, K: 16
Recorder	DIR2000H (till 2014), OCTADISK (2015 and after)
Correlation	Mitaka FX (till 2014), Mizusawa Software (2015 and after)

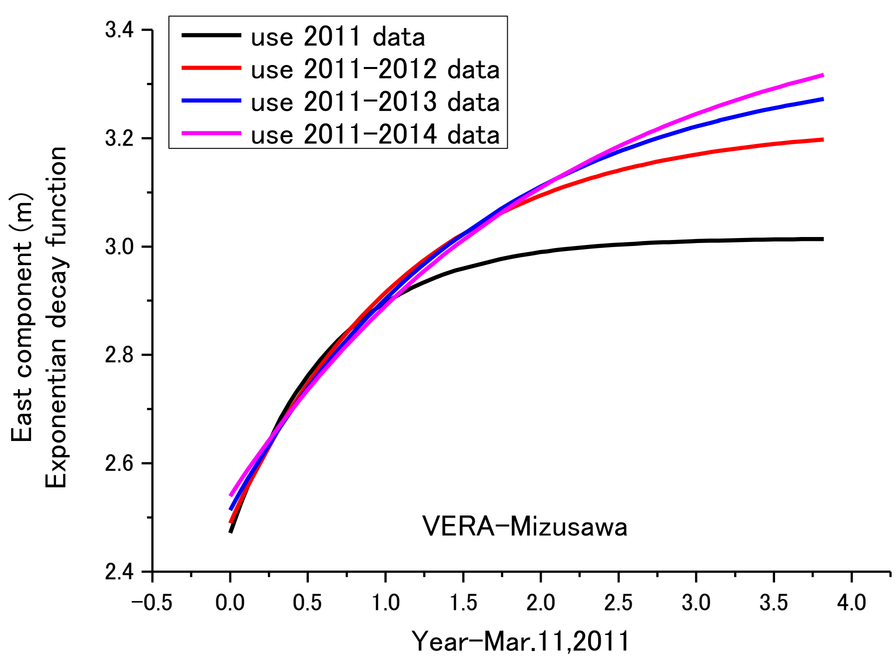
The result of VERA Geodetic VLBI Observations



- These plots are expressed on the H-V coordinates system and relative to the coordinate origin on Jan.-1, 2010.
- Linear movement velocity of Mizusawa is fixed to result of the global VLBI solution (GSI 2015a).
- Although the typical error of each result is 1mm in horizontal and 4mm in vertical component, the instability among the results is larger.
- Non-linear variations are seen in time series. Those phenomena are related with SSE, co-seismic crustal movement, and viscous alleviation of stress in the mantle, etc. Creeping after the 2011 off the Pacific coast of Tohoku Earthquake is especially remarkable. Mizusawa is a VLBI station nearest to the epicenter of this earthquake.

The present problem and directivity of the solution

- Origin position which ties VERA network to TRF is instable, because a movement of each VERA station cannot be explained with only the plate motion. Therefore, in order to monitor the reference point of VERA, the continuous participation in the international VLBI network becomes important. It is requirements that the network includes the VLBI station which is in a stable landmass and where the position and velocity are obtained with high precision.
- Since the models of SSE or post-seismic creeping are not fixed, it is difficult to predict the station's position. In order to detect the perturbation (SSE, etc) more clearly, reducing of the variation among solutions is required.
- The average of the observed delay error is about 20-30 pico-seconds (7-10mm in light path length). The precision is restricted by the way to present VERA geodetic observation. However, in order to make the performance of the geodetic parameter estimation improve, it is necessary to make the observed delay error smaller.



The movement of Mizusawa station on and after March 11, 2011 which is fitted by exponential decay function. According to extension of the period of the data used for fitting, a damping time constant becomes large.

The future aim and prospection of VERA Geodesy

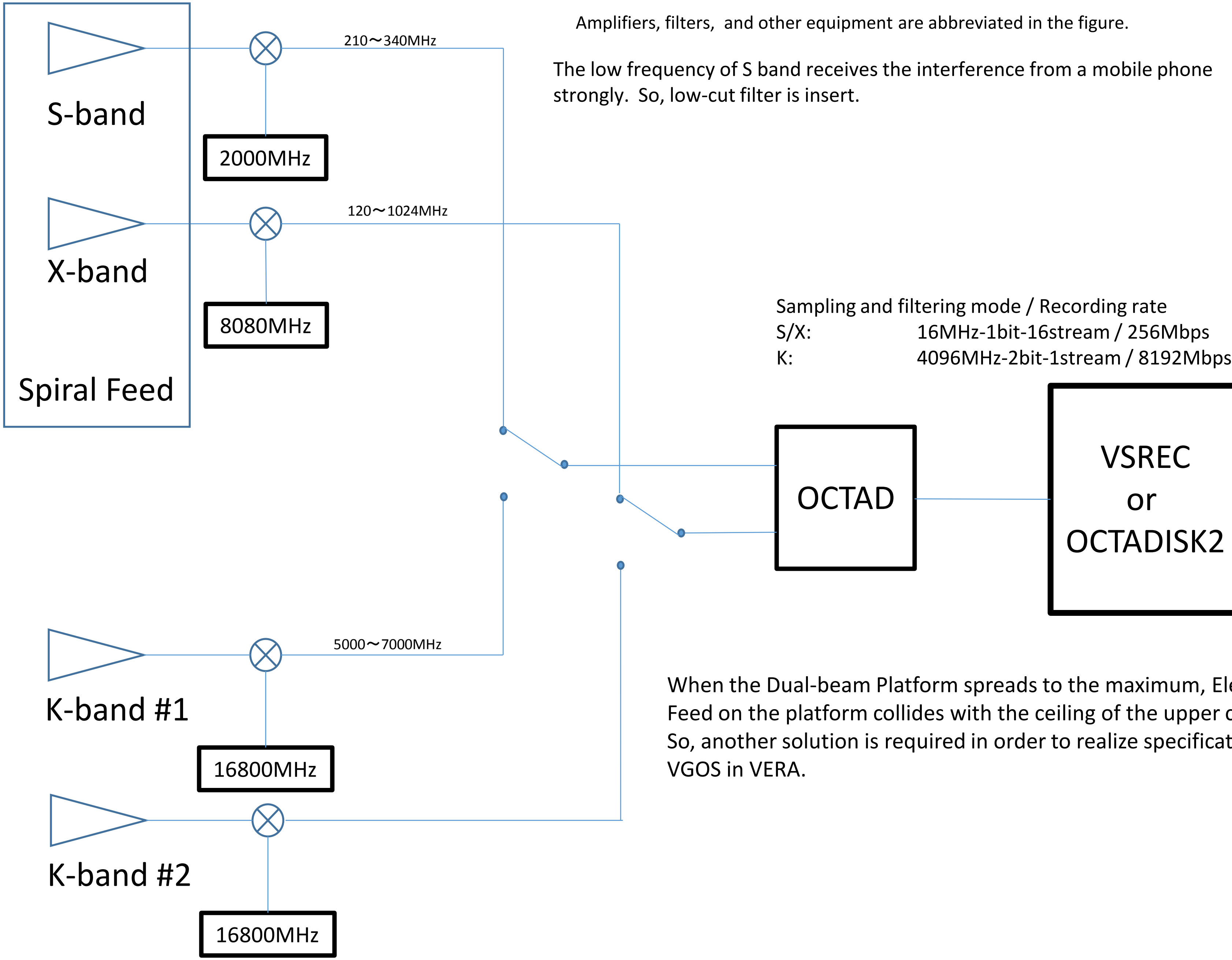
1. Participation of VERA station in international VLBI session continuously. The reference position of VERA and its long-term variation are defined in TRF steady by the international VLBI (AOV, T2, etc.).
2. Renewal of geodetic VLBI observation system. The purpose is increasing of a possibility that VERA can participate in the international geodetic VLBI.
3. Acquisition of more precise and more accurate observed delay. The error of observed delay aims to be a few millimeters (<5-6pico-seconds). It is an aim to improve the performance of parameter estimation.

- Broadening of the observed frequency bandwidth by using new high speed sampler – recording system.

OCTAD (High speed sampler and DBBC)

Specifications
Maximum sampling rate: 10384Mbps
Quantifying bit number: 2bit or 3bit
Output: 10GbE
10GbE channel number 4ch (max)
10GbE application layer protocol: VDIF

Plan of VERA Geodetic Observation System



Amplifiers, filters, and other equipment are abbreviated in the figure.

The low frequency of S band receives the interference from a mobile phone strongly. So, low-cut filter is insert.

Sampling and filtering mode / Recording rate
S/X: 16MHz-1bit-16stream / 256Mbps
K: 4096MHz-2bit-1stream / 8192Mbps

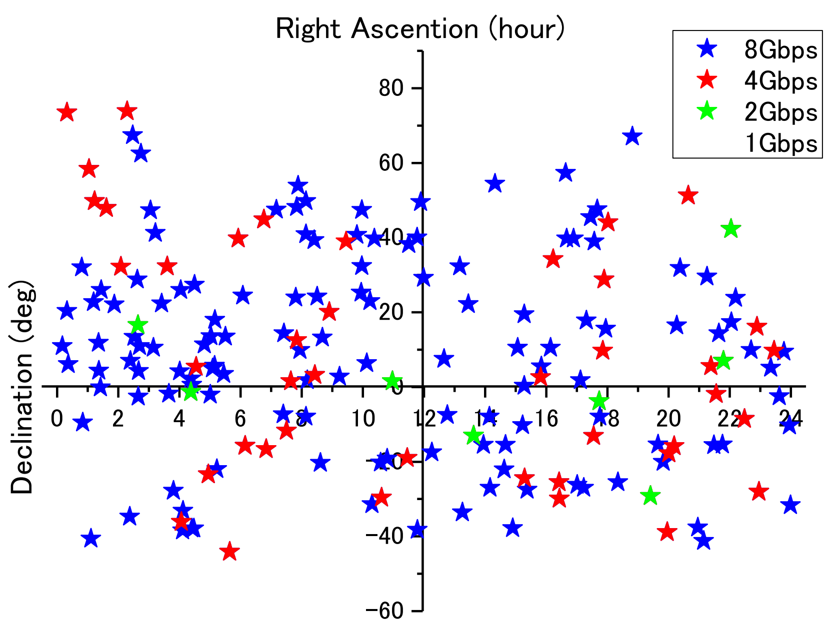
When the Dual-beam Platform spreads to the maximum, Eleven Feed on the platform collides with the ceiling of the upper cabin. So, another solution is required in order to realize specification of VGOS in VERA.

Performance prediction by broadening of recording bandwidth

Sampling mode/ Recording rate	Minimum SNR	Minimum flux density (Jy) necessary to fringe detection	Number of fringe-detectable stars (Even if EL <= 6 degree / in a total)
512MHz-2bit/ 1Gbps	280	4.54	0/4
1024MHz-2bit/ 2Gbps	170	2.02	8/21
2048MHz-2bit/ 4Gbps	65	0.78	44/79
4096MHz-2bit/ 8Gbps	45	0.25	170/219

Performance of present VERA observation system

Star list: P. Charlot, et.al: The celestial reference frame at 24 and 43GHz. Ⅱ.Imaging, Astronomical Journal, 139:1713-1770, 2010 May, doi:10.1088/0004-6256/139/5/1713



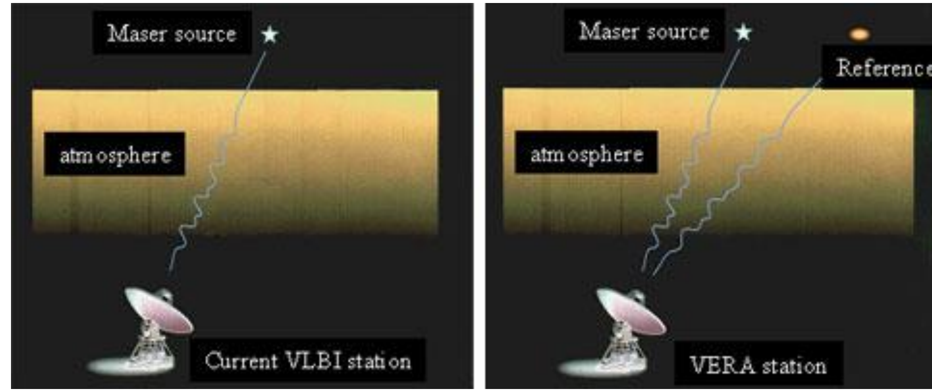
Distribution of fringe-detectable stars in the Celestial sphere

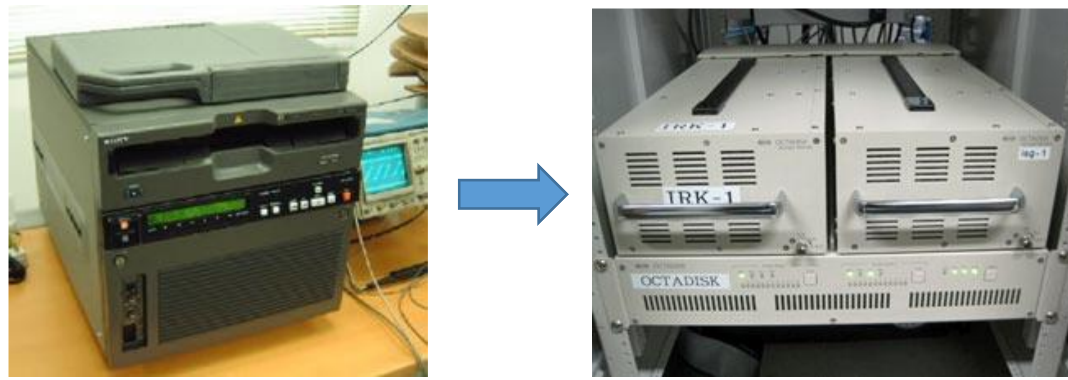
Simulation Setting:
Four VERA stations observe a radio star simultaneously.
Maximum Observed Delay Error = 6 ps (2mm length)
Cutoff Maximum Duration Length = 120 sec
Structure Effect: 0 <= variation of delay < 10 ps
structure index = (always 1) or (1 and sometime 2)
Cutoff Lower Angle of Elevation = 5 degree

Broadening of the recording bandwidth is indispensable in order to secure the number of stars which can be used for Geodetic VLBI.
When the recording rate is 4Gbps, the number of stars is secured enough, but distribution of the stars is partial.
We schedule K-band geodetic VLBI experiment using OCTAD in this winter.

Thank you

Most unique aspect of VERA is `dual-beam' telescope, which can observe two nearby sources at the same time. VERA's dual-beam observations effectively cancel out the atmospheric fluctuations, and then VERA can measure relative positions of target sources with respect reference sources with high accuracy. Such VLBI observation technique is referred to as 'phase-



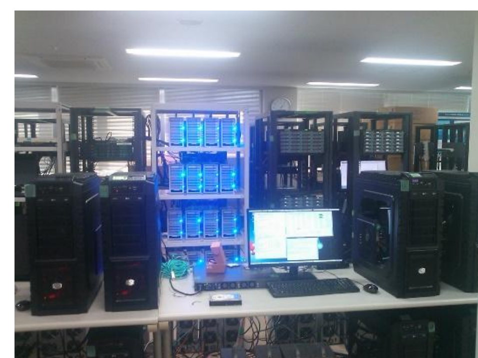


Till 2014, the 1-Gbps recording system adopted DIR2000H tape recorder, and replaced it with OCTADISK HDD data storage system from 2015.

The dual-beam receiving system in upper cabin

Two receivers are installed at the Cassegrain focus to observe two adjacent sources simultaneously.

Correlation was performed by the Mitaka FX correlator till 2014.



From 2015, main correlator is replaced with the newly developed software correlator operated in Mizusawa.