

# A progress report on the development and performance of OCTAVE-DAS and Correlator System




Tomoaki Oyama<sup>1</sup>,  
Yusuke Kohno<sup>1</sup>, Syunsaku Suzuki<sup>1</sup>, Masahiro Kanaguchi<sup>1</sup>, Takashi Nishikawa<sup>1</sup>, Moritaka  
Kimura, Noriyuki Kawaguchi<sup>2</sup>,  
OCTAE-team members

National Astronomical Observatory of Japan<sup>1</sup>,  
Shanghai Astronomical Observatory<sup>2</sup>,

# OCTAVE: e-VLBI array

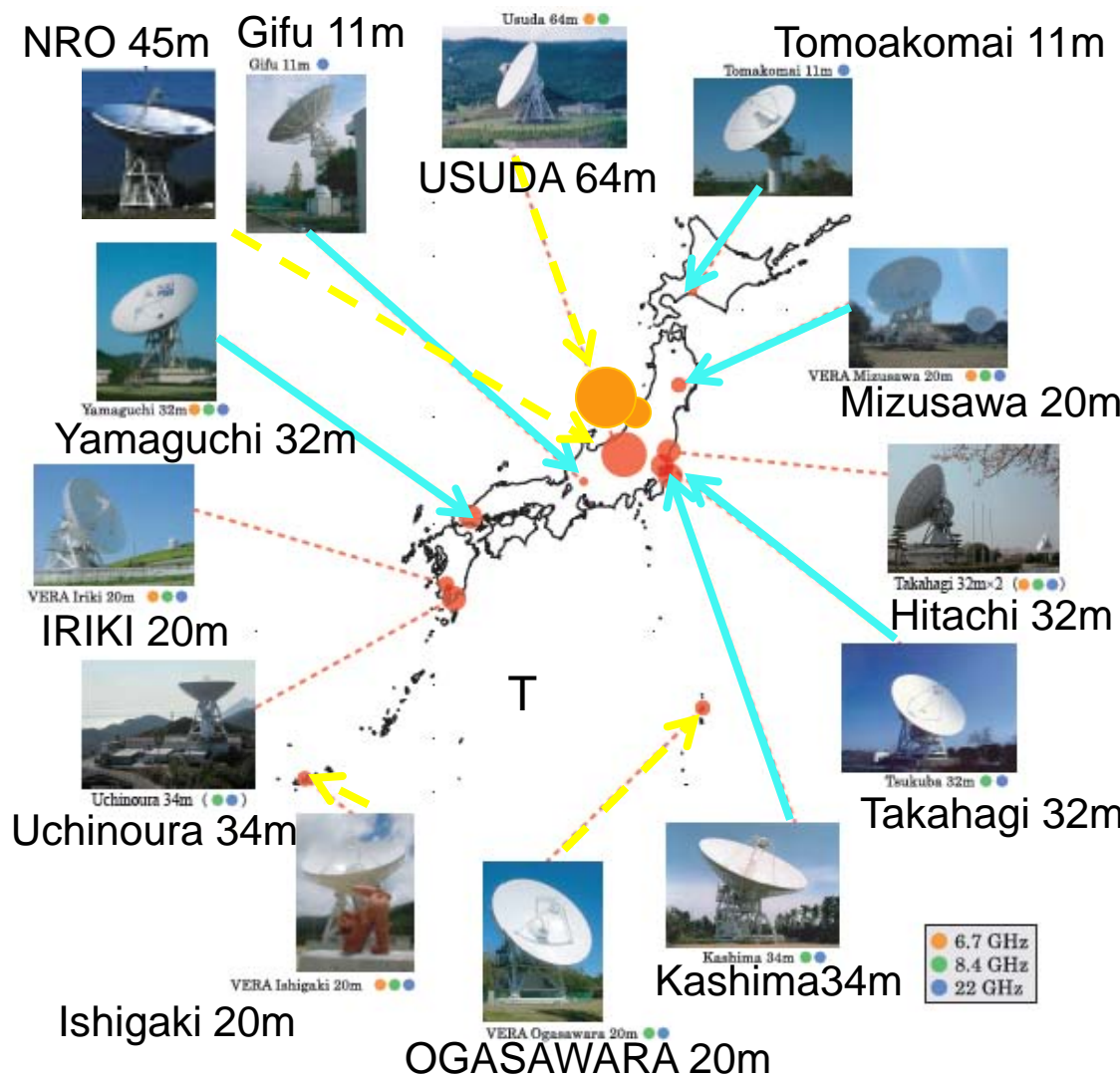
(Optically Connected Array for VLBI Exploration)

Subarray of JVN(Japanese VLBI Network)

-  Connected
-  not operated  
(Fiber is connected)
-  not connected

## Brief history of e-VLBI related to NAOJ

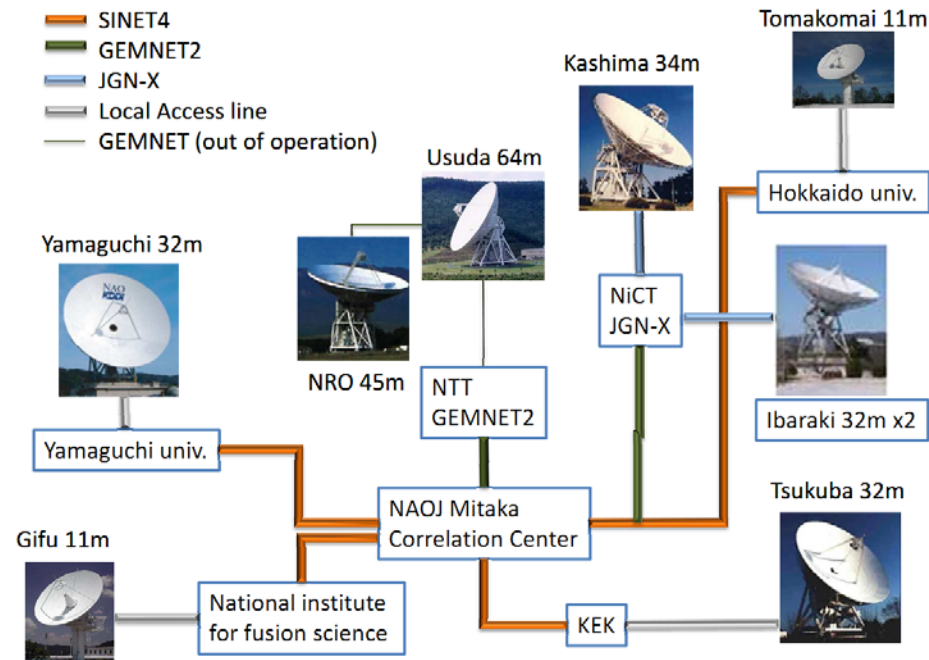
- 1998~ : Nobeyama45m-Usda64m  
(real-time fringe detected ATM, 256Mbps)
- 2004 : usuda64m, tukuba32m, gifu11m (2Gbps, ATM-IP)
- 2005 : Kashima34m, Yamaguchi32m, Nobeyama 45m(2Gbps)
- 2008 : several stations with10GbE
- 2011 : all connected station using 10GbE



# Communication lines

- lines Supplied by an academic network (SINET4/NII) and a test bed network(JGN-X/NICT) with 10GbE
  - Usuda and NRO are offline now
- SINET5 with 40 GbE in new future

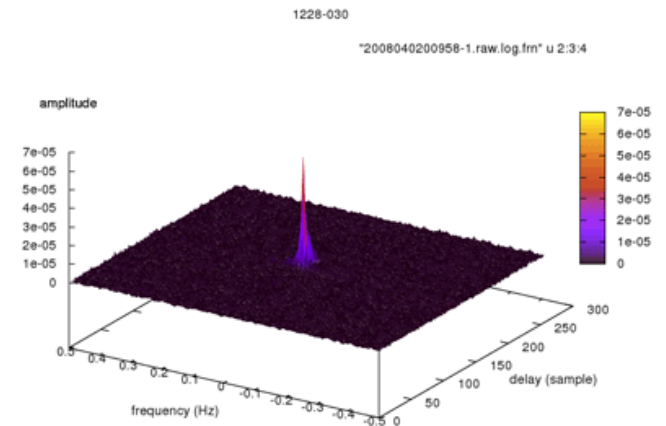
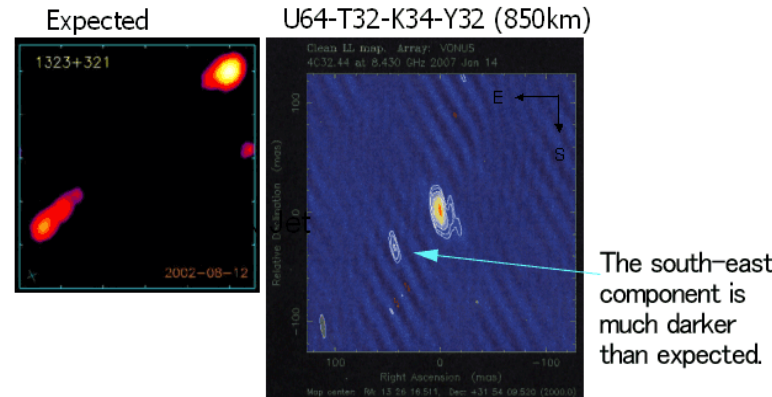
Local Disk Recording system were installed into non connected or at a slow bit rate station by 2013 (VERA, Usuda, NRO45m, Ibaraki and Tomakomai(for slow rate)) . Old system was replaced at all JVN stations .



Network configuration

# e-VLBI Observations

- Image of 4C32.44
  - 4/2007
  - X-band, BW512 MHz, 4stations
  - Real time correlator(OCTACOR)
- Fringe detection survey of Parsec-Scale Nonthermal Jets in Radio-Loud Broad Absorption Line Quasars, Doi et al., 2009
- Fringe detection survey of Fermi/LAT Un-associated Gamma-ray Sources, Niinuma et al.,2013, Fujinaga et al. submitted
- Science Obs. proposals are selected and operated by JVN-Consortium



# Octave family

We have developed several instruments for OCTAVE. We call them Octave family.

- **Octave series.**

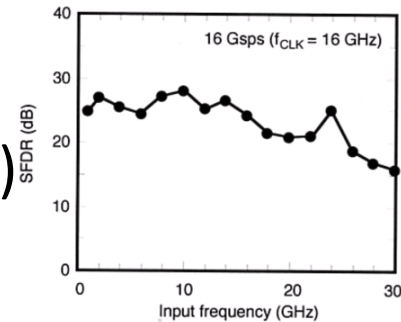
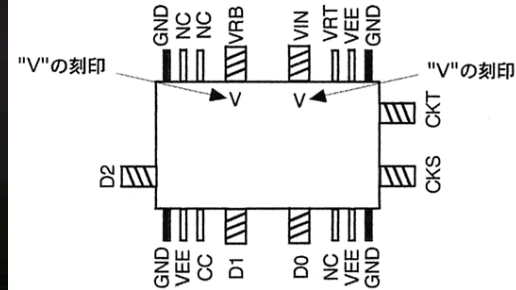
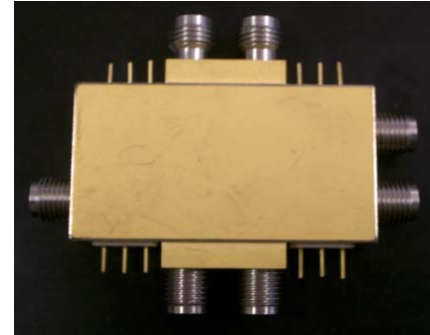
- **OCTAD** : **OCTA**ve **A/D** Converter
  - 16(max) Gsps high speed RF(~30GHz) direct A/D Converter
- **OCTAVIA1,2** : **OCTA**ve **VSI** Adapter
  - VSI-H  $\leftrightarrow$  10GbE (VDIF) converter
- **OCTADISK** : **OCTA**ve **DISK** drive
  - Disk recorder for VDIF (10GbE)
- **OCTADISK2(VSREC=VDIF Software RECorder)**
  - Commercial PC with 10 GbE-card and Raid Box
- **OCTACOR** : **OCTA**ve **COR**relator
  - Gbit realtime Hardware correlator (VSI-H)
- **OCTACOR2** : **OCTA**ve **COR**relator2
  - Software correlator system (10GbE, VDIF)

Many non-OCTAVE family instruments are also used in the array, such as ASD1000/3000, K5(NICT), Mark5B(Haystack).



# OCTAD : OCTAve A/D Converter (High speed sampler : RF(~30 GHz) Direct Sampling)

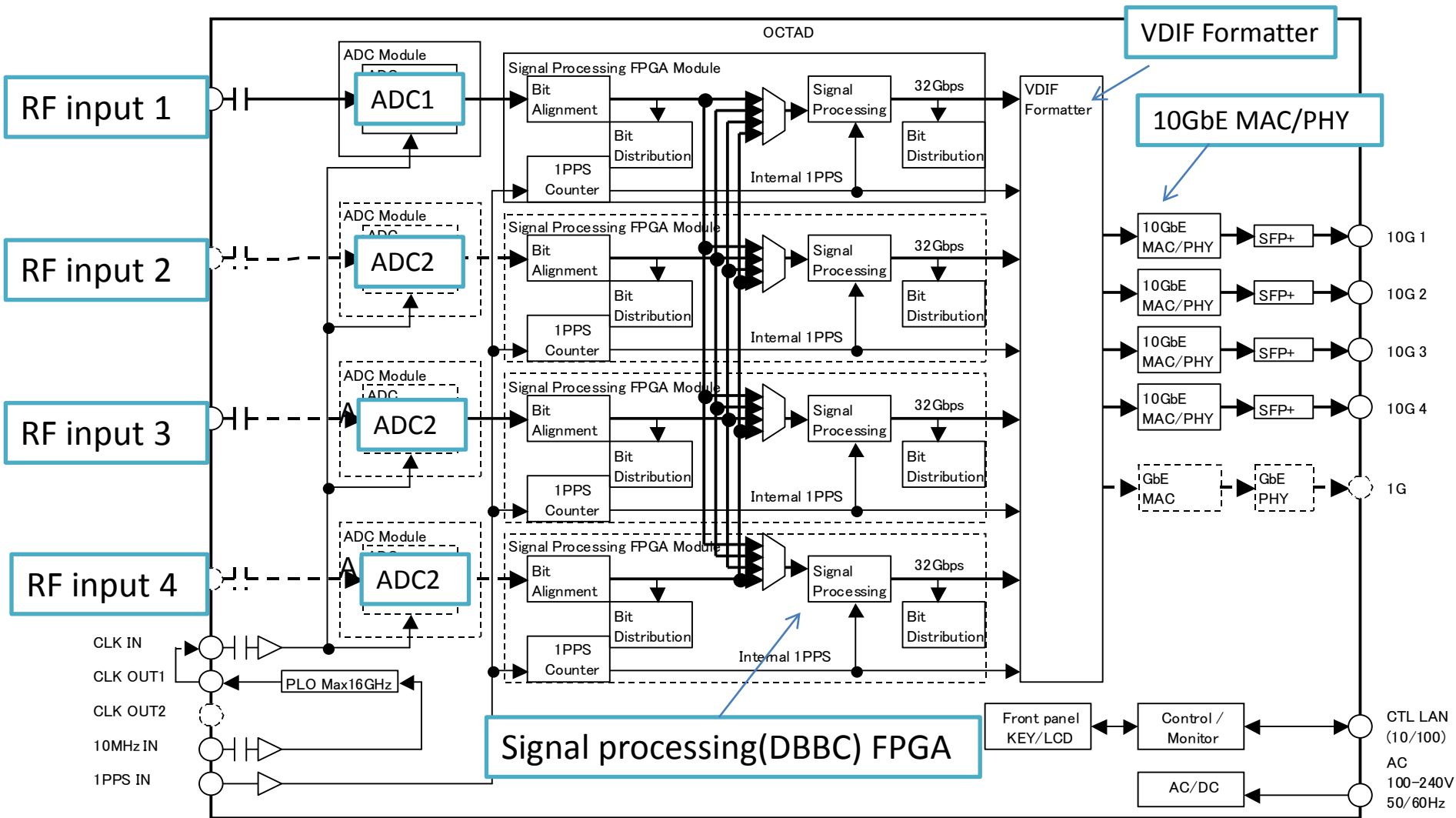
- A/D Chip
  - NTT Photonics/NEL/NAOJ
    - InP HBT ADC (~30GHz)
  - or
  - Hittait microwave (~20GHz)
- DBBC(Digital BaseBand Converter)
  - Two FPGA(Virtex7)
  - Firm : SuperH by Renesas



We do not need Down converter and base band converter using this simple system



# Block Diagram(OCTAD)





# Specification of OCTAD

<b>Input channel</b>	<b>4 Ch</b>	
Input frequency	~20 GHz(Hittite) or ~30 GHz(NEL)	
Sampling Frequency	16 GHz(Hittite), 8 GHz(NEL)	
Sampling bit	3 bit (10 bit under development)	
Output port	10 GbE X 4, 32Gbps(max rate)	
Transfer protocol	UDP、VDIF	

<b>DBBC</b>	<b>Out bit</b>	<b>Channels of out put</b>	
4096 Msps	2 or 3	2, 4	
2048 Msps	2 or 3	2, 4, 8	
1024 Msps	2 or 3	2, 4, 8, 16	
256,128,64,32,16 Msps	2 or 3	2, 4, 8, 16, 32	

OCTD has several DBBC modes to be conformable to VGOS and present VLBI system.



# Evaluation of OCTAD

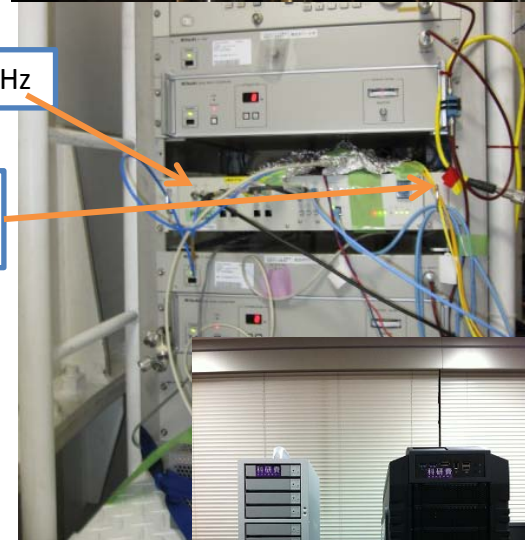
- Lab. test of sampling jitter
  - 0.17 psec ( $L_c < 1\%$  @43GHz)
- Zero baseline fringe test observation
  - 9/2012, 12/2013
  - Mizusawa 10m x 20m BL=30 m
  - K-band, 16Gbps x OCTAD, OCTADproto



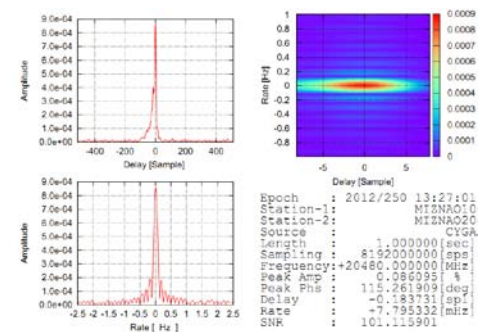
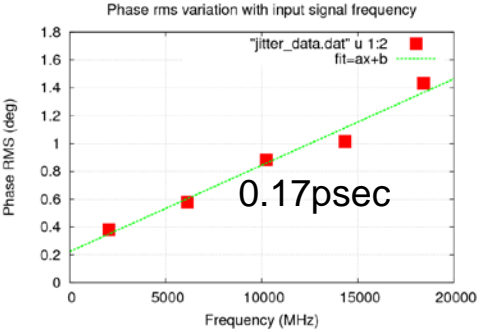
RX output 20-24GHz

OCTADp(A/D) input 20-24GHz

A/D output using 10GbE Optical fiber, VDIF format

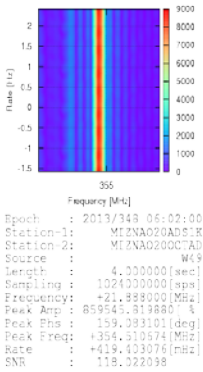
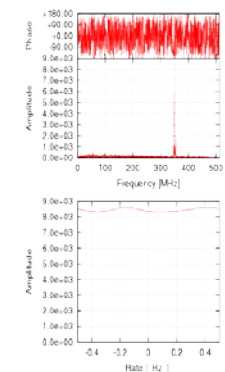


Software recorder VSREC(OCTADISK2)



Sampling jitter

Fringe of CygA (4GHz band width)

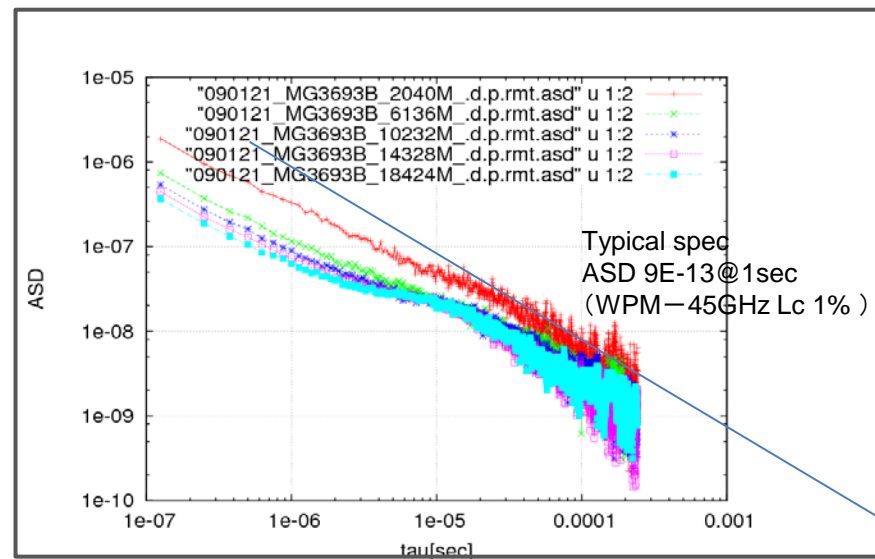
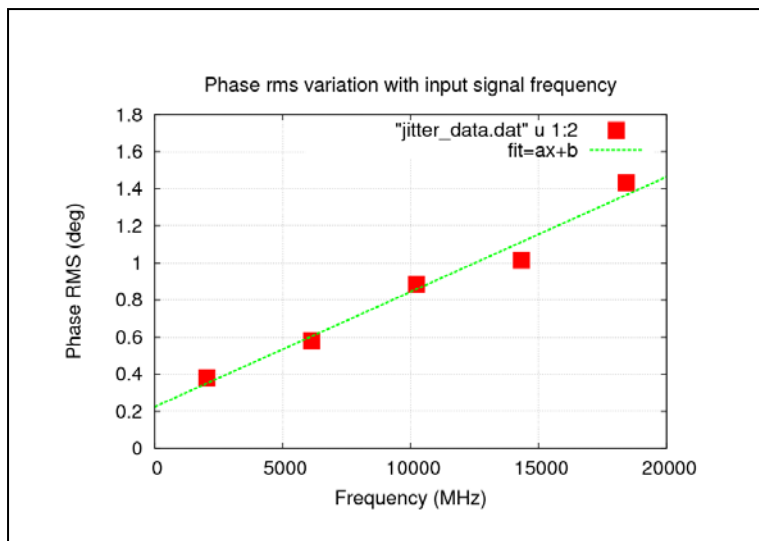
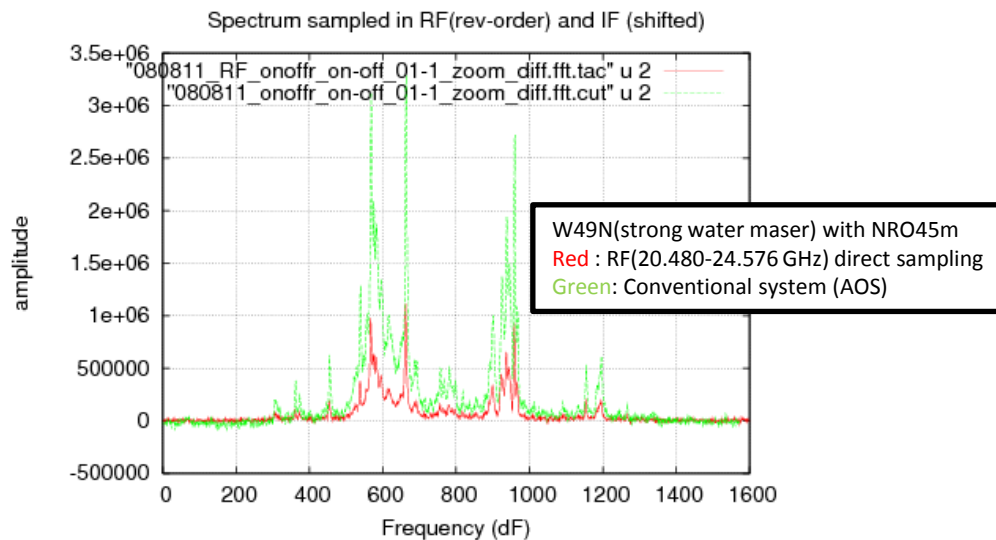
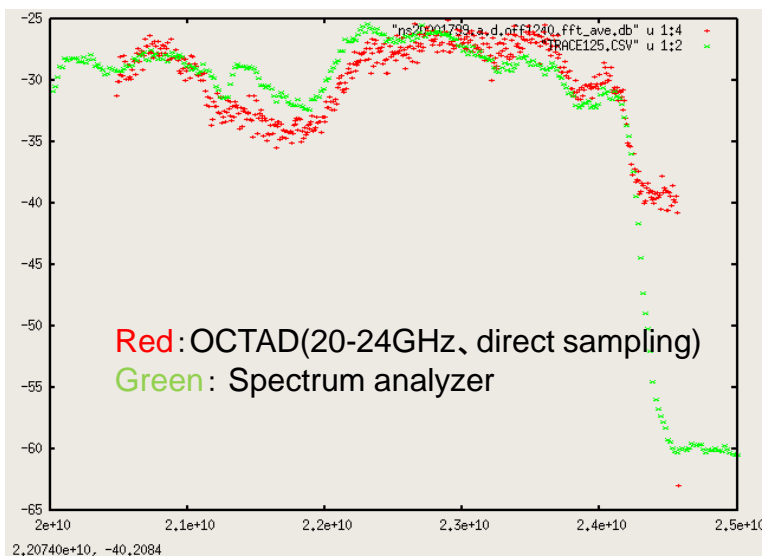


XS of W49 (512MHz BW)

AS of W49 (512MHz BW)

# Evaluation of OCTAD

## RF(~24 GHz) Direct Sampling



# VSI-Adapter (OCTAVIA1,2) Disk recorder (OCTADISK)

- OCTAVIA1,2(Octave-VSI-Adapter)  
( VSI-H $\leftrightarrow$ 10 GbE Converter, bi-directional)
  - 4 VSI I/O ports (1 or 2 Gbps)
    - OCTAVIA2 : reduced version , have only 4 port (I or O)
  - One 10 GbE I/O port (VDIF Format)
  - VBR Function for the traffic jam for e-VLBI
  - Multicast
  - Originally developed and operated for Korea Japan Joint vlbi correlator , 2007~
- OCTADISK (Octave-disk-drive)
  - Implemented on FPGA
  - One 10 GbE I/O port (VDIF Format)
  - Total Recording and playing rate is 4.5Gbps , 4 stream, simultaneous operation for KJJVC,
  - 12 hard disk drive per 1 module
  - Originally developed and operated for Korea Japan Joint vlbi correlator , 2007~



# OCTADISK2p (Octave-disk-drive 2)

- OCTADISK2p(Software recording system)
  - VSREC(Software) + Commercial PC customized by requirement
  - Customized PC  
(ex, for OCTAD, >8 Gbps recording )
    - CPU: Core i 7 3.2 GHz
    - Memory: 24 Gbyte
    - Raid : Areca ARC-1882-ix-24
    - Raid box : STARDOM ST8-U5X2(SAS)
    - 10 GbE card : Neterion X3110SR
    - Cent OS 5.6
  - VSREC(Recording software)
    - Code: Standard C
    - Input : UDP, TCP/IP, (VDIF)
    - Output : Linux standard format (xfs, ext4)
  - >8 Gbps recording @1 pc+ 1 or2 raid box(8 HDD)
  - Have playing function to OCTAVIA for KJJVC
  - Installed at VERA, NRO45, 3/2012



## Current status of OCTADISK2

OCTAVIA to OCTADISK2(PC) using this software

Raid	HDD	ARC-1882 ix
Raid 0	8 disks	10.201 Gbps
Raid 6	8 disks	4.337 Gbps
Raid 0	8 disks	10.447 Gbps

Completely COTS system  
(include shipping media and raidbox)



# Correlators for OCTAVE and JVN

- Real time correlator(OCTACOR) for e-VLBI
  - FPGA correlator
    - FX and XF type
    - 2Gbps/station
    - 5 stations
    - Installed and operated at Tokyo-Mitaka-correlation center from 2001
- Post processing Correlator(OCTACOR2)
  - Software correlator
    - Engine(GICO3) by NICT and NAOJ
    - Integration and post-processing software developed by NAOJ
    - Out put format : CODA for VEDA, FITS
    - Speed of processing is about 1900Mbps for 4 stations with 2048 Mbps data, 2k (Core I 4.6GHz, 6 core) > upgrade using GPU

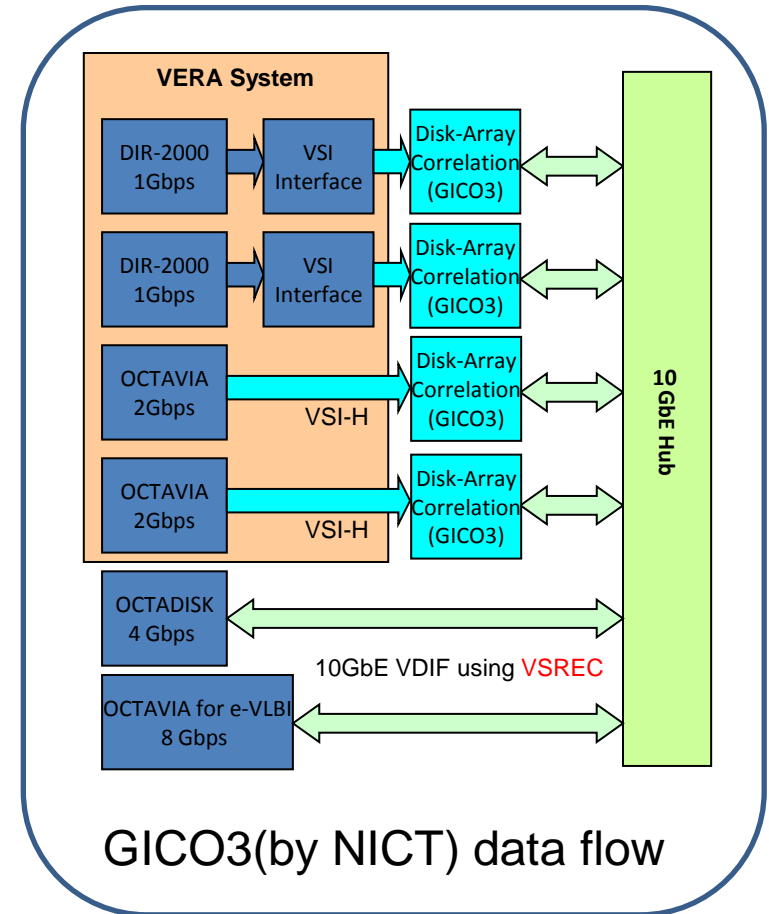
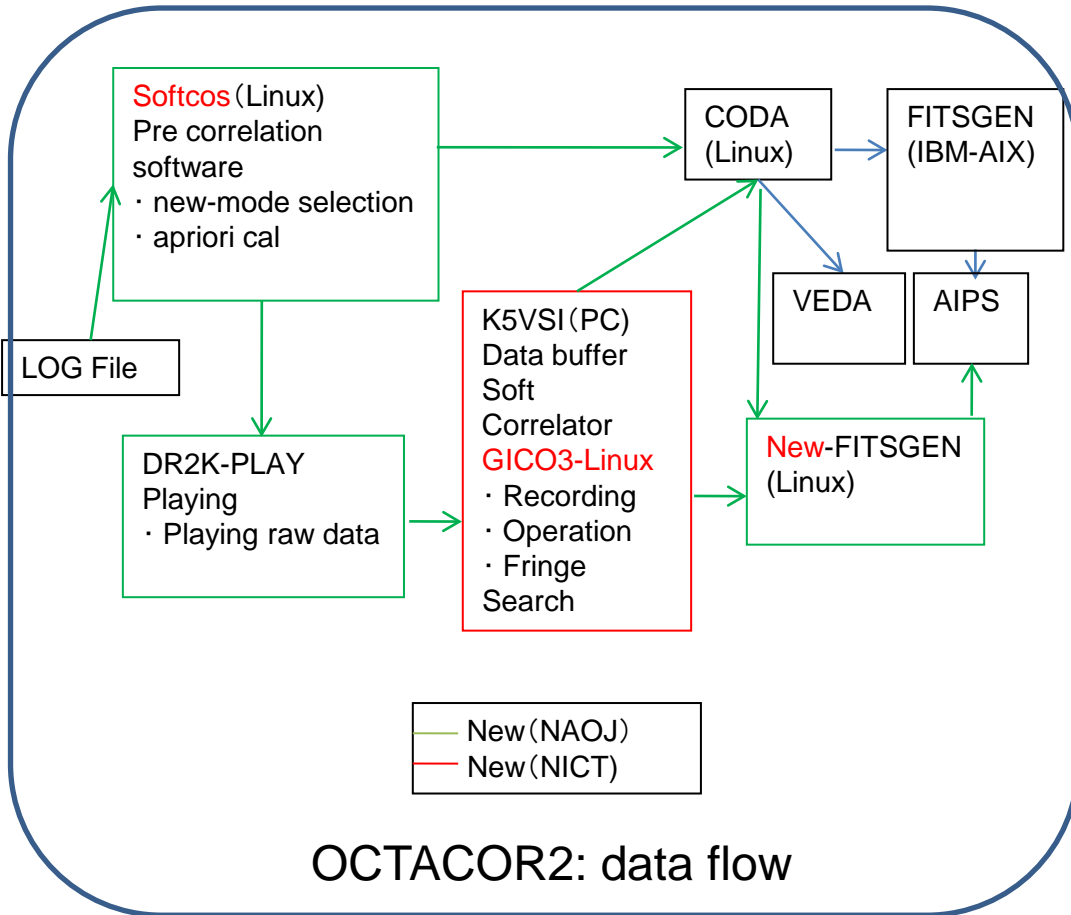
We use 4-5 PCs to correlate 8 Gbps 4stations data.  
Correlation time is same as observing time.



Soft Correlators    Hard Correlators

# OCTACOR2 : OCTAve CORrelator 2

Software Correlator system at Mitaka(Tokyo)



- To overcome restrictions of present VERA correlator system
- Can correlate various new systems, (ex 512 MHz broad band data)
- each components are separately developed.

# Correlation mode of OCTACOR2

(Mitaka software correlator system)

Speed	IF numbers	Bandwidth (MHz)	Sampler, DSP
1 Gbps	1, 2, 4, 8, 16	256, 128, 64, 32, 16	VERA, KVN, VLBA
2 Gbps	1, 2, 4, 8, 16	512, 256, 128, 64, 32	ADS1000, OCTAVE
4 Gbps	1, 2, 4	1024, 512, 256	ADS1000, ADS3000+
8 Gbps	1, 2, 4	2048, 1024, 512	OCTAD
16 Gbps	1, 2, 4, 8	4096, 2048, 1024, 512	OCTAD
32 Gbps	1, 2, 4, 8, 16	8192, 4096, 2048, 1024, 512	OCTAD(pair)
64 Gbps	1, 2, 4, 8, 16, 32	8192, 4096, 2048, 1024, 512	OCTAD(pairs)

- Quantization: 1, 2 bit
- FFT point : 4M/1 IF ← (16k)
- Stations : arbitrarily ← (5 stations)
- Polarization : Full Stokes ← (none)
- Hybrid Correlation (512MHz × 256 , 128 MHz) for JVN, EAVN
- Speed of processing : **200 Mbps for 7 stations** with 1Gbps recording using one PC (Xeon 3.4 GHz Hexa core dual).

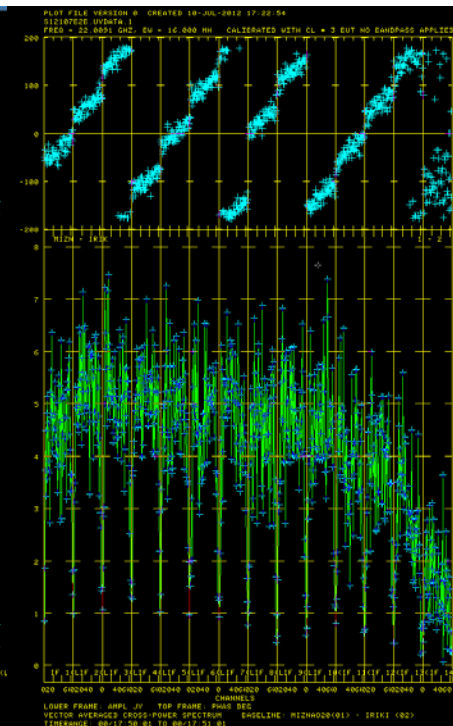
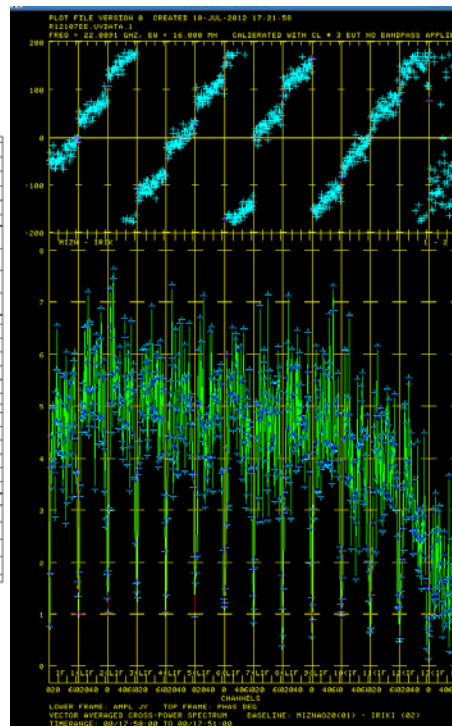
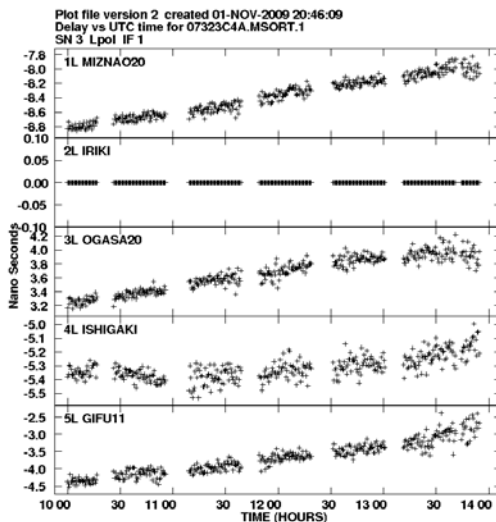
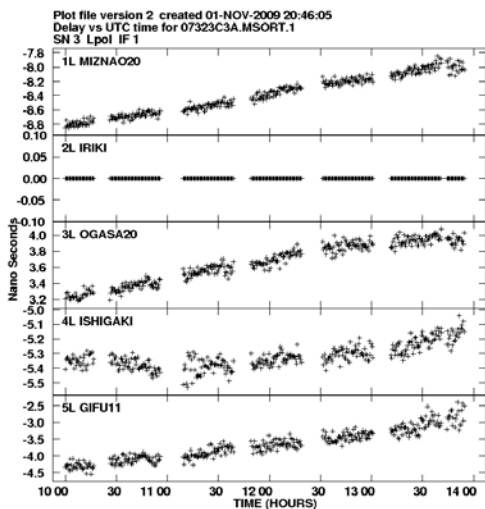


# Mitaka-FX-Corr(Hardware Corr) VS OCTACOR2(Soft corr system) Delay and Cross Power Spectrum(AIPS)

Array : VERA4 stations

Objects : 3C446, BLLAC

Observing mode : 256Msps/2bit X 1ch、32 Msps/2bit X 15 ch )



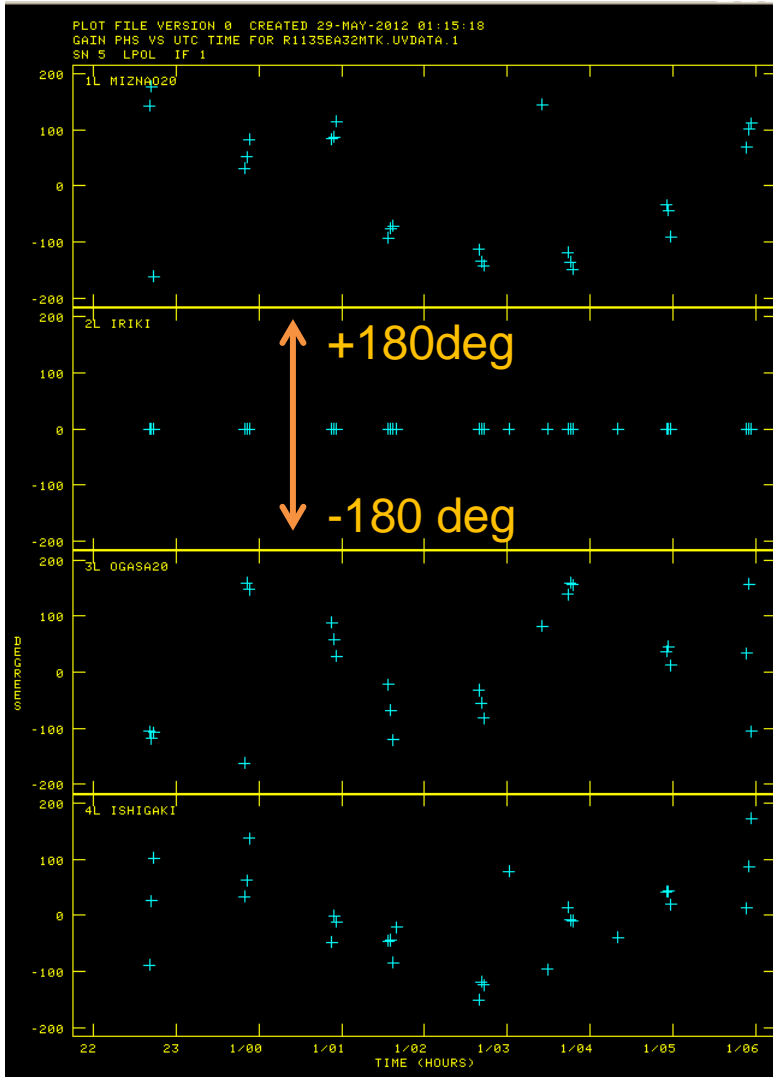
Mitaka-FX(Hard correlator)

Software correlator(OCTACOR2)

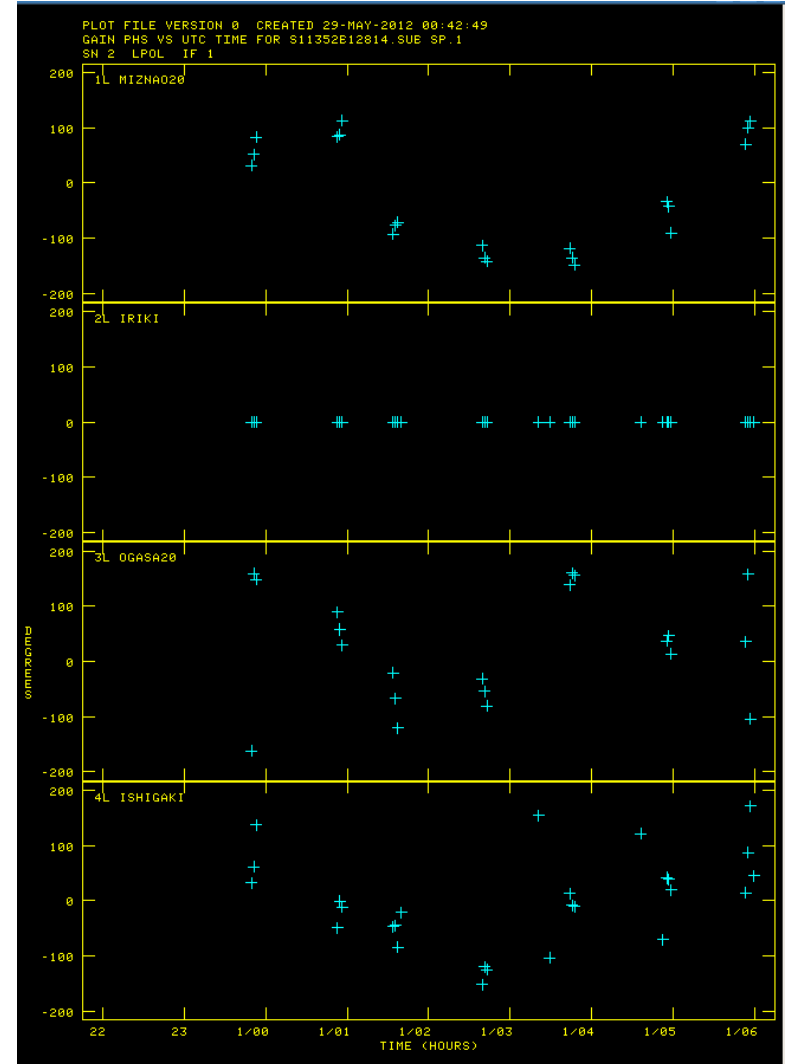
Mitaka-FX(Hard correlator)

Software correlator(OCTACOR2)

# DR2K → Mitaka-FX (Hard-corr) VS OCTADISK → OCTACOR2 (Soft-corr) Phase(r11352b、Calibrator)



Mitaka-FX

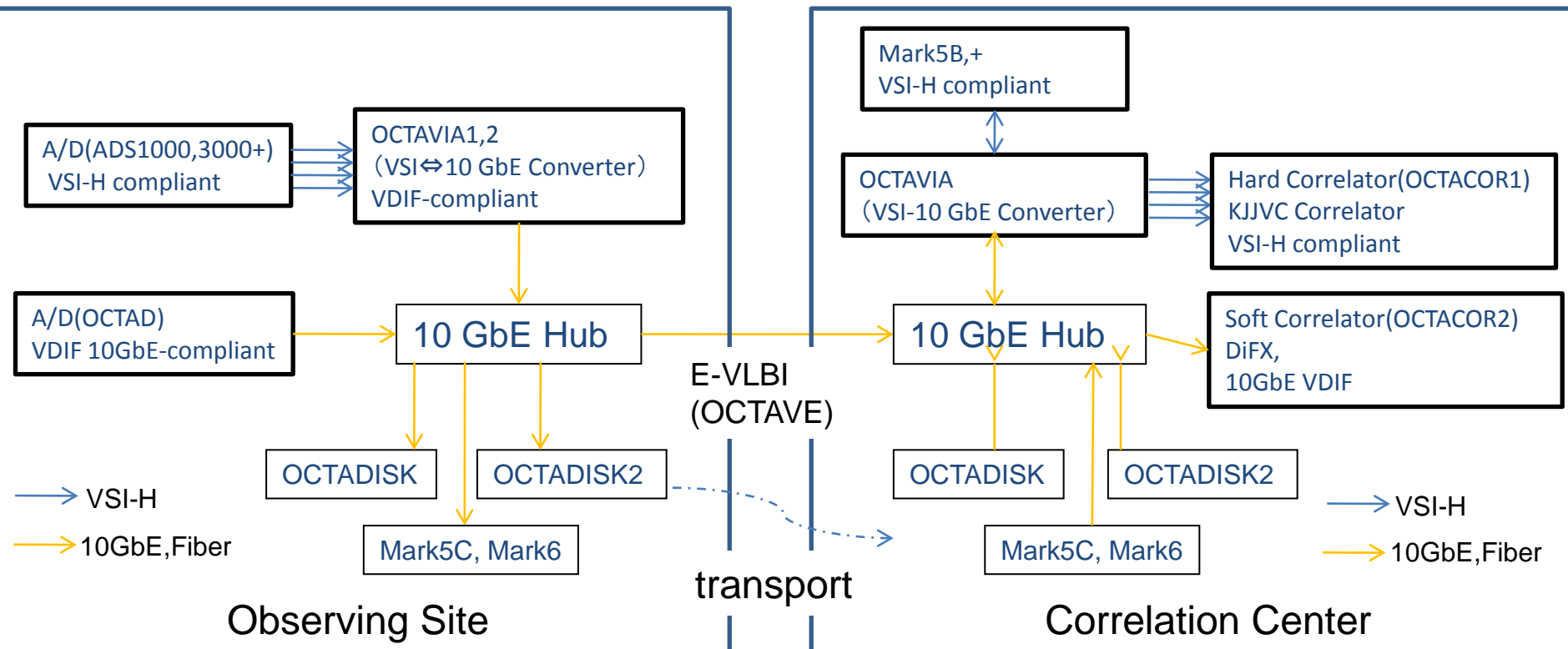


OCTACOR2

# Example of configuration for OCTAVE-DAS & Correlator



Removable Storage (with 2 storage-cartridges)



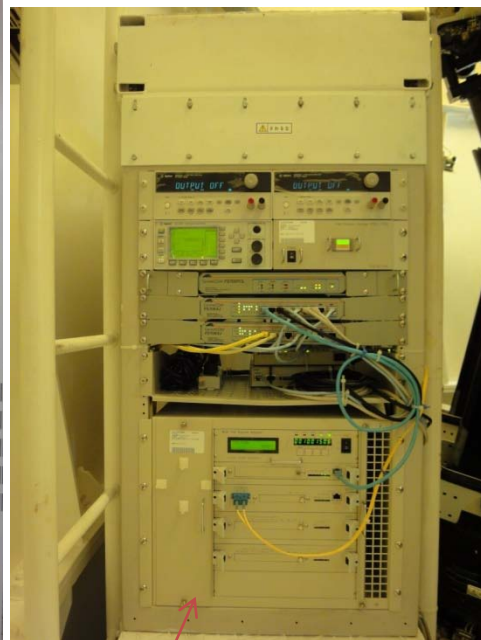
# Replace VERA terminal for New wide band observing system using OCTAVE-DAS

Octavia/Octadisk were installed at all VERA stations (2010/7)

- Duplicate recording (DIR2000 , OCTADISK)
- 4-8 Gbps recording is available now



Observing room  
OCTADISK  
10GbE Hub

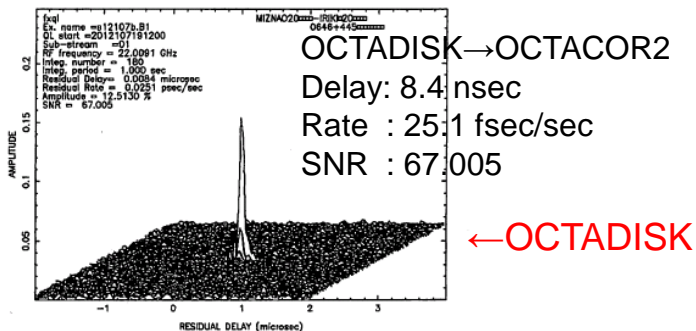
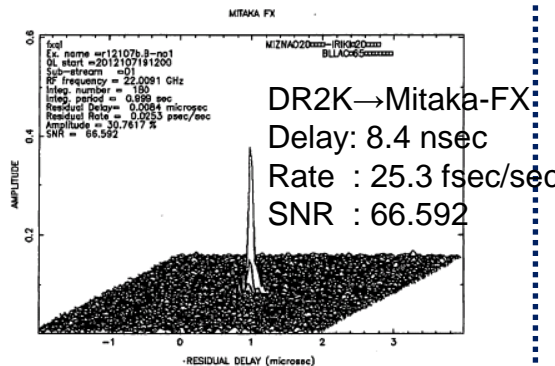


Vertex room  
OCTAVIA

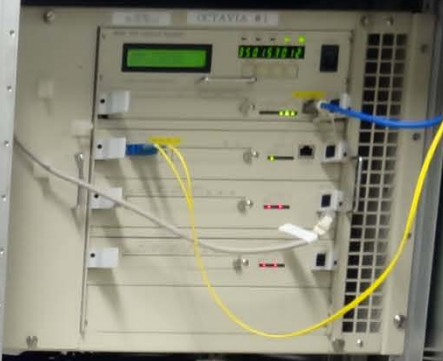
## Correlation test

- Tape→Mitaka FX  
OCTADisk →OCTACOR2
- Results of evaluation  
> Coincidence

DIR2000⇒







# VLBI Calibrator survey for VERA using wide band (8Gbps) system

## Purpose :

- Evaluation of new system
- Calibrator survey for VERA

Data : Jan 8/2013.(6:00~18:00)

Band : K

target : VCS X band (petrov et al.,2012)

30° <DEC<55° , total 193 target sources

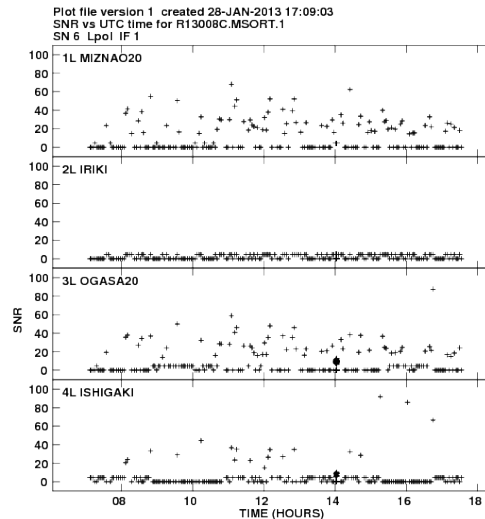
Freq :

DIR2K : 21.459-21.971GHz , BW=256MHz

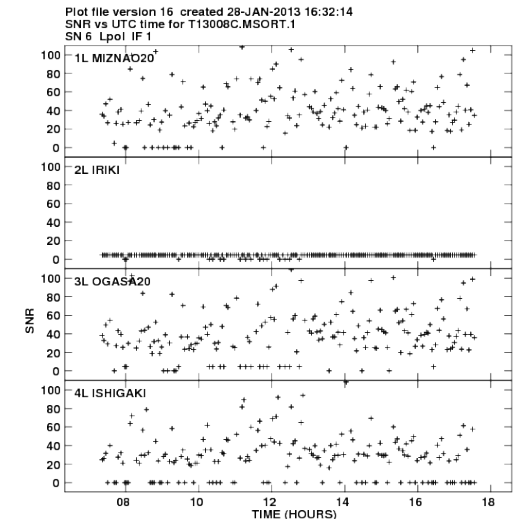
WIDE-BAND : 21.459-23.507GHz, BW=2048GHz

Recorder:(Simultaneous recording )

- DIR2K 1Gbps
- 2 Gbps(OCTADISK) + 6Gbps (OCTAVIA2 + OCTADISK2)
- total : 8 Gbps (512 MHz X 4 ch)



DIR2K 256MHz



WIDE-BAND 2GHz

## Results

- 1, 176/193 sources were detected between MIZ-IRK baseline using OCTAVE-DAS (8Gbps).
- 2, SNRs were increased to 3-3.6 times higher than present observing system.

## Discussion

1, The number of Candidates

- VCS( -30 to 90 ) : 3228
- Average number of VCS sources within 2 degree circle : 1.35 (3228 / 2383)
- Sufficiency rate is
  - 113 % in case of Tsys 140K, 8 Gbps
  - 43 % in case of Tsys 140K, 1 Gbps
  - 15 % in case of Tsys 600K, 1 Gbps

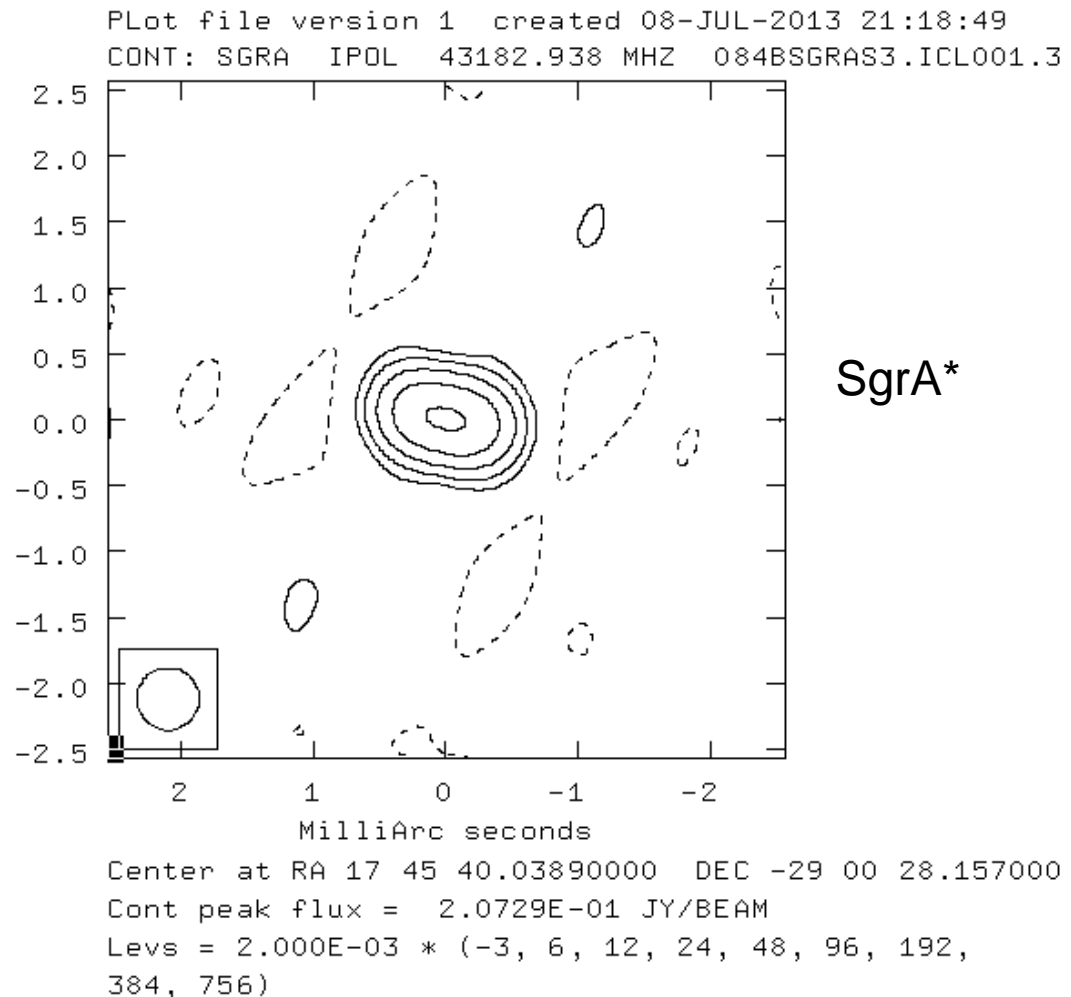
- In case of Tsys 400K, 8 Gbps recording, there is at least one vlbi calibrator source within 2 degree circle.

	Detection rate(1Gbps)	Detection rate(8Gbps)	Increasing rate(numbers)	Increasing rate(SNR)
MIZ-IRK (Tsys 140K)	43% (83/193)	92% (176/193)	2.12	3.21
IRK-OGA	34% (66/193)	87% (167/193)	2.53	3.60
IRK-ISG (Tsys 600K)	15% (28/193)	74% (142/193)	5.07	3.01

	X band(VCS)	C,S band	Total	Candidate/ need number
-30<DEC<90	2193	1035	3228	135% (3228/2383)
Tsys140K, 1Gbps =43%	943(2193 X 0.43)	194	1137	48% (1137/2383)
Tsys600K, 1Gbps =15%	329	91	420	18% (420/2383)
Tsys140K, 8Gbps = 92%	2018	665	2683	113% (2683/2383)
Tsys600K, 8Gbps = 74%	1623	347	1969	83% (1969/2383)

# Broad band (8Gbps) scientific observations for VERA

Date : 3/2013/  
Antenna : VERA (4 stations)  
Band : Q-band(43GHz)  
Target : Sgr A\*  
A/D : ADS3K+OCTAVIA2  
  
Recorder : OCTADISK2(VSREC)  
  
Recording rate: 8 Gbps(512MHz X 4)  
  
Correlator: OCTACOR2  
(software correlator)  
  
First image of 8 Gbps obs



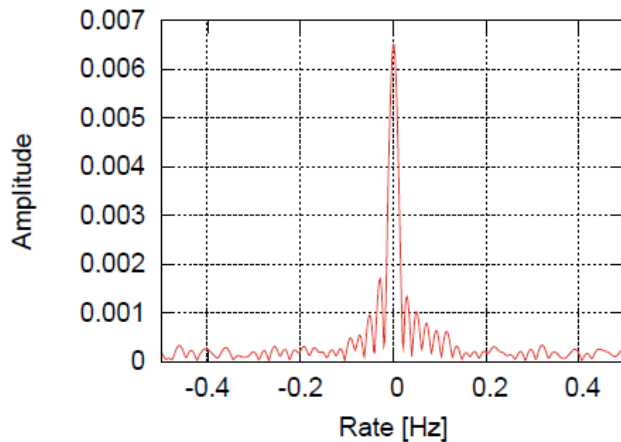
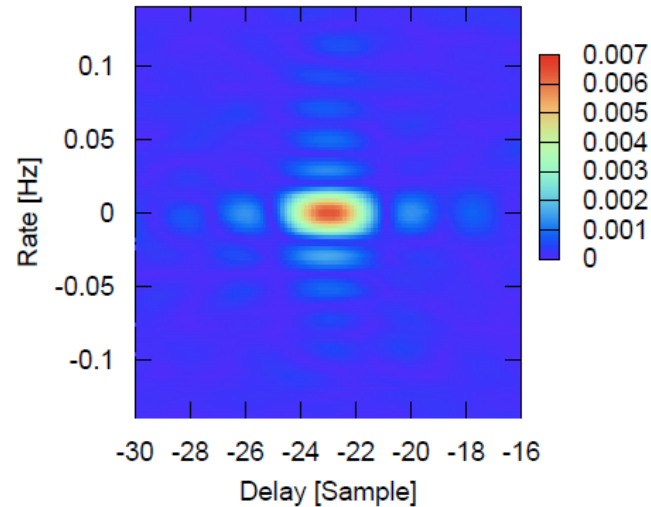
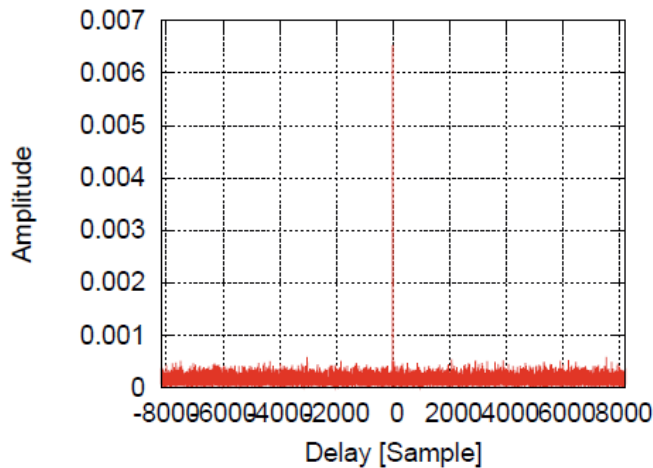


# A history of fringe test observation btw other systems and OCTA system

- Mark5B : Mark5B format > Cutting header is needed for our soft correlator
  - First fringe test
    - btw SMA and SMT0 for submm VLBI on Oct 2010.
  - Second fringe test
    - btw KVN and VERA for KJJVC evaluation on Jan 2011.
  - Third
    - Btw CVN and VERA leaded by Hachisuka, hagiwara and china-team from 2012
  - Fourth
    - Btw Italy and VERA leaded by Hagiwara-san and Italy-team,
    - Could get fringes btw SRT and NOTO on Sep 2014 using OCTA software correlator  
We will try again btw Italy and Japan
- Mark5C : VDIF >
  - First
    - Tidbinbilla and VERA leaded by Hagiwara-san and Horiuchi-san in 2014
  - Others
    - EAVN test leaded by Hagiwara-san , tiger-team
    - Btw LBA and VERA leaded by Sugiyama-san , and LBA team

# Fringe btw Iriki and Ulsan

## @2011 Jan



```

Epoch      : 2011/028  04:21:00
Station-1  : IRIKI
Station-2  : KVN-US
Source     : 3C454.3
Length     : 50.000000 [sec]
Sampling   : 32000000 [sps]
Frequency  : +22098.000000 [MHz]
Peak Amp   : 0.652696 [%]
Peak Phs   : -20.224761 [deg]
Delay      : -22.997986 [spl]
Rate       : +0.736389 [mHz]
SNR        : 40.908203
    
```

# Fringe test observation between VERA-IRKI 20m and Tidbinbilla 70m

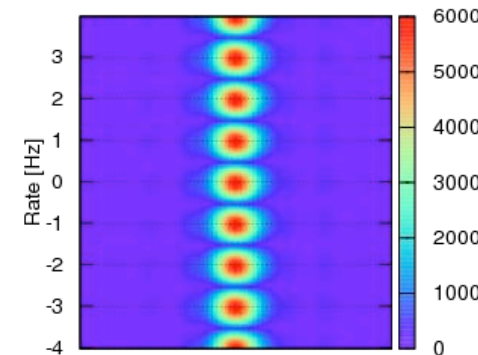
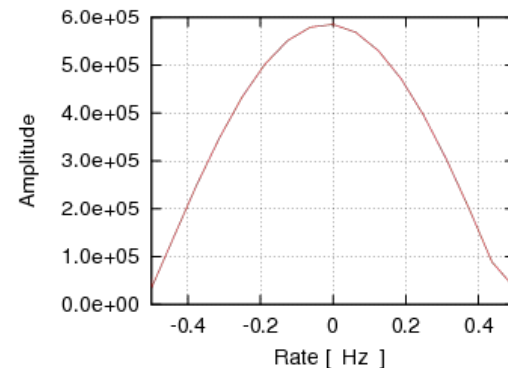
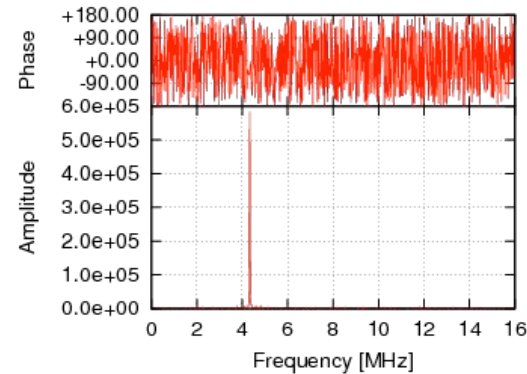
2014/2/23 Orion-KL

Date : 2014/2/23  
Antenna : Tidbinbilla 70m  
VERA-IRK 20m  
Target : Orion-KL  
Recorder: OCTADISK2@VERA  
Mark5C@Tidbinbilla

Recording rate: 1Gbps

Correlator: OCTACOR2  
(software correlator)

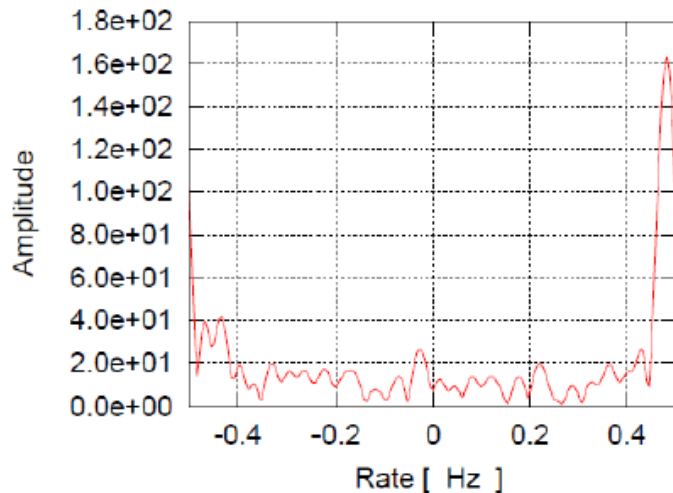
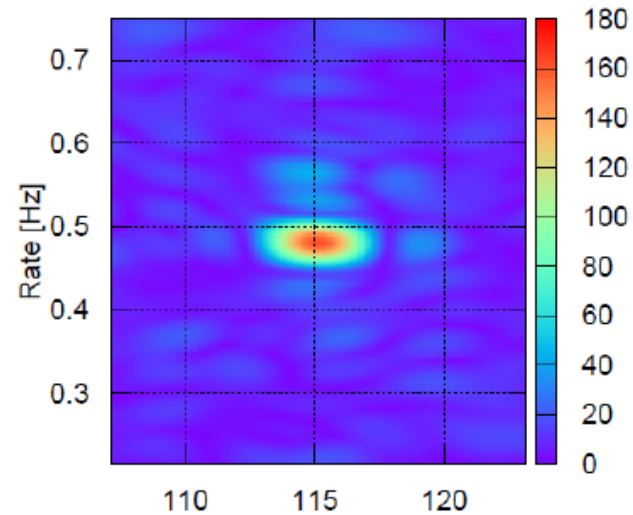
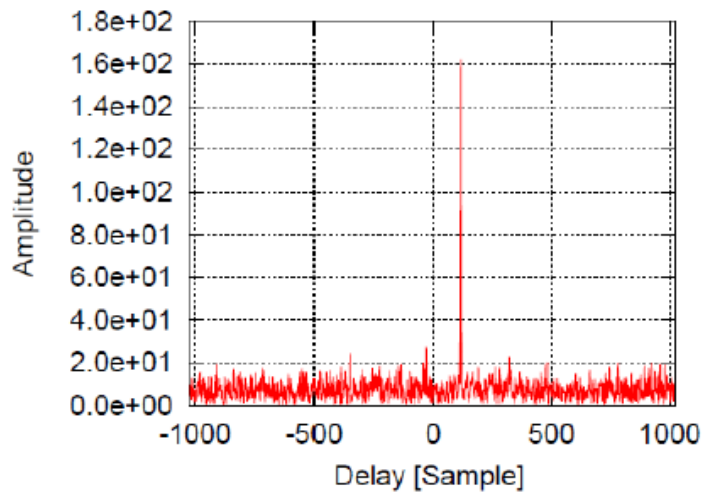
Because of using the VDIF format,  
so it is easy to correlate  
the data from different recorders.



Epoch : 2014/055 11:20:4  
Station-1: MIZNAO2  
Station-2: TID70  
Source : ORIO  
Length : 2.000000 [sec]  
Sampling : 32000000 [sps]  
Frequency: +22227.000000 [MHz]  
Peak Amp : 58577623.404280 [  
Peak Phs : -49.941642 [deg]  
Peak Freq: +4.327064 [MHz]  
Rate : -15.335083 [mHz]  
SNR : 434.121939

VERA IRIKI 20m-Tidbinbilla 70m

# Fringe btw NOTO and SRT using OCTACOR on Sep 2014



```

Epoch      : 2014/171 11:20:02
Station-1  : NOTO
Station-2  : SARDINIA
Source     : 3C84
Length     : 30.000000 [sec]
Sampling   : 32000000 [sps]
Frequency  : +22155.490000 [MHz]
Peak Amp   : 16297.575715 [%]
Peak Phs   : 120.657502 [deg]
Delay      : +115.145081 [spl]
Rate       : +482.181803 [mHz]
SNR        : 21.211012
    
```

# Summary

- Japanese E-VLBI (OCTAVE) is now operated
- Have developed new broad band VLBI system, named “OCTAVE-DAS”
- JVN old(Tape) back-end system have been replaced with new broad band system(> 2 Gbps) conformable to VDIF and VGOS