An Overview of the Japanese GALA-V Wideband VLBI System

M.Sekido, K.Takefuji, H.Ujihara, T.Kondo, M.Tsutsumi, Y.Miyauchi, E.Kawai, H.Takiguchi, S.Hasegawa, R.Ichikawa, Y.Koyama, Y.Hanado, J.Komuro, K.Terada, K.Namba, R.Takahashi, K.Okamoto, T.Aoki, T.Ikeda (NICT)

K.Watabe, T.Suzuyama (AIST/NMIJ)

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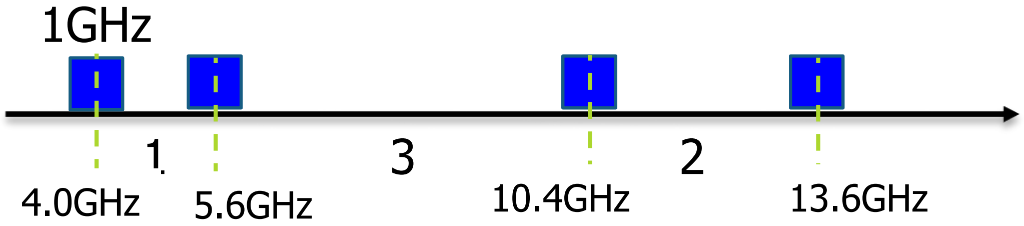
GALA－V Project Overview

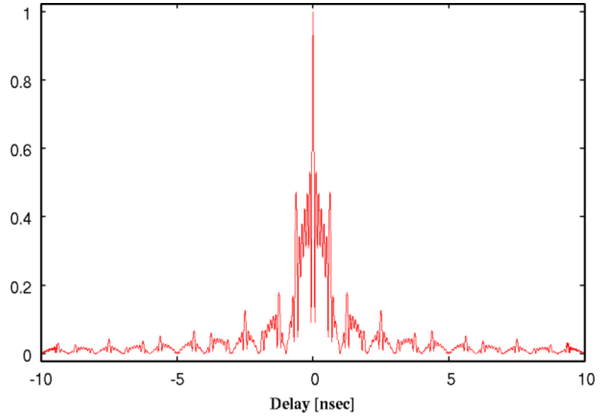
Frequency comparison by using Transportable Broadband telescopes

- VLBI Sensitivity :VLBI Sensitivity$=\propto D_1 D_2 \sqrt{BT}$

  B: 16MHz → 1024MHz (64 times)

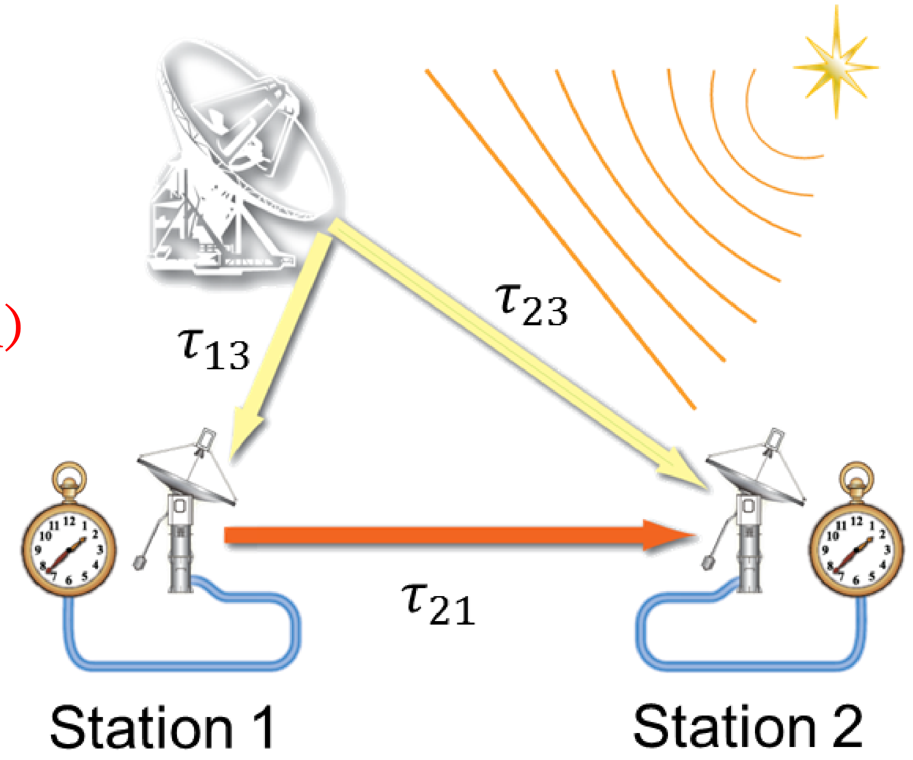
- Radio Frequency： **3－14GHz**
- Data Acquisition： 4 band (1024MHz width)
  - Fc＝4. 0GHz、5. 6GHz、10. 4GHz、13. 6GHz
  - Effective Bandwidth:3. 8GHz (10 times of Conventional)





Delay Resolution Function

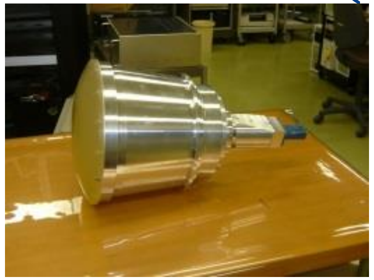
10 time higher resolution will be gained by broader bandwidth



$$\tau_{21} = \tau_{13} - \tau_{23}$$

Topics of our PROJECT

1. Broadband feed developed for Cassegrain Antenna(Kashima 34)
   - IGUANA-H: 6.5-15GHz
   - NINJA : 3-14.4GHz



2. Direct RF Sampling and Broadband Bandwidth Synthesis.
   A) Digitizing RF signal without frequency conversion.
   B) Broadband bandwidth synthesis without Phase-Cal system. ⇒ without Delay-Cal
3. Our Broadband VLBI Experiment shows, atmospheric delay changes order of 20 psec in hundreds seconds of timescale, thus quick switching short interval observation is required.

Broadband Antennas used in Gala-V Project

Kashima 34m

MARBLE1 1.6m @NMIJ(Tsukuba)

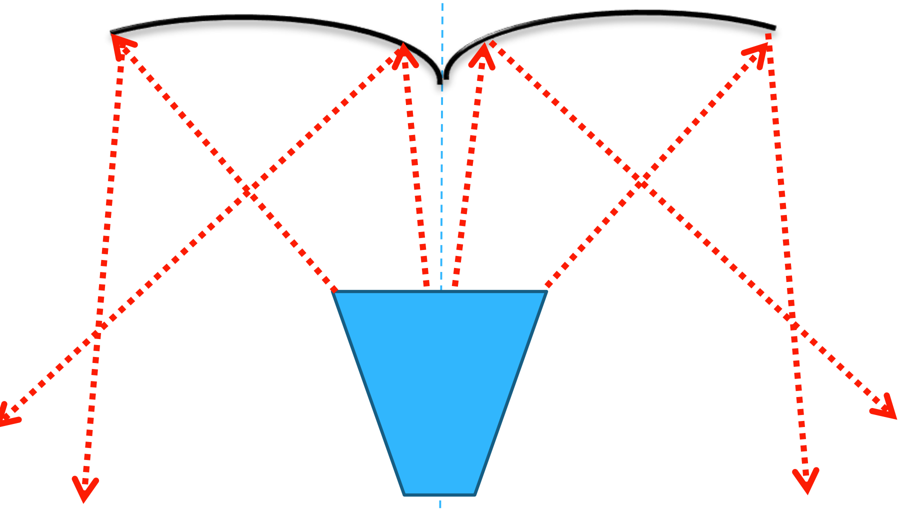
MARBLE12 1.5m
@Konganei

Original broadband Feed
NINJA, IGUANA-H

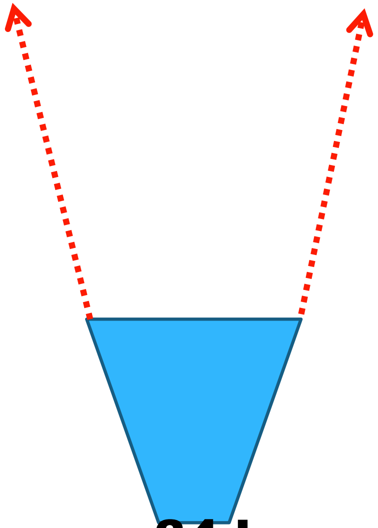
Rindgren
QRHA

Reason why NICT Developed Broadband Feeds

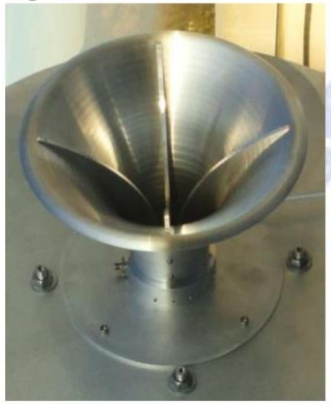
Requirement of
Broadband Frequency and
Narrow beam width

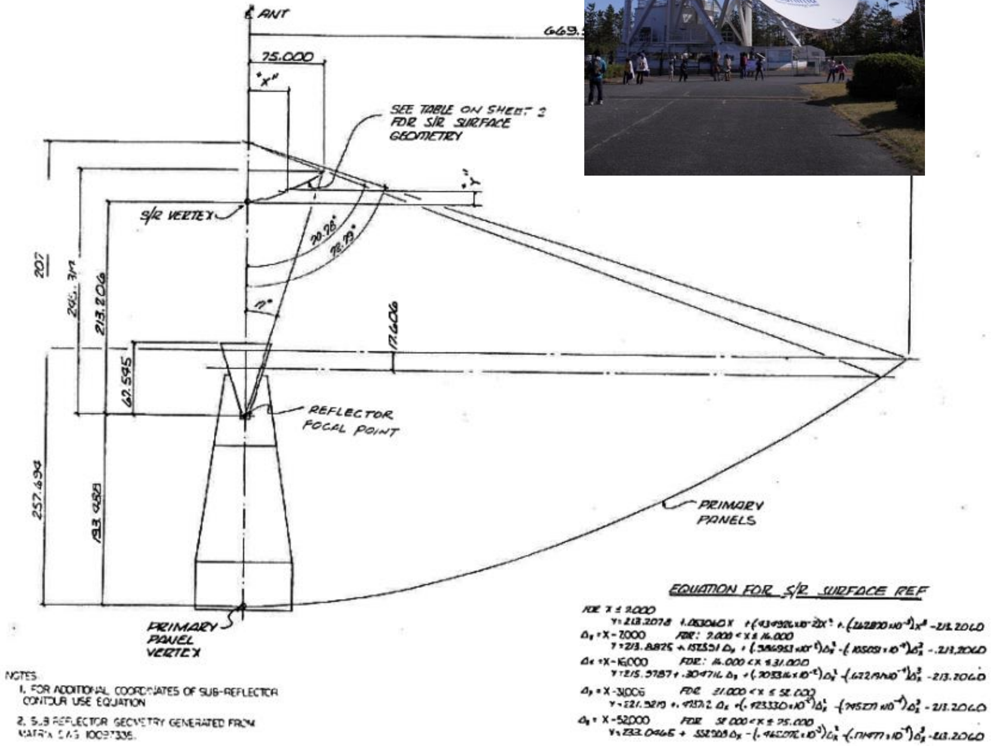


~120deg.



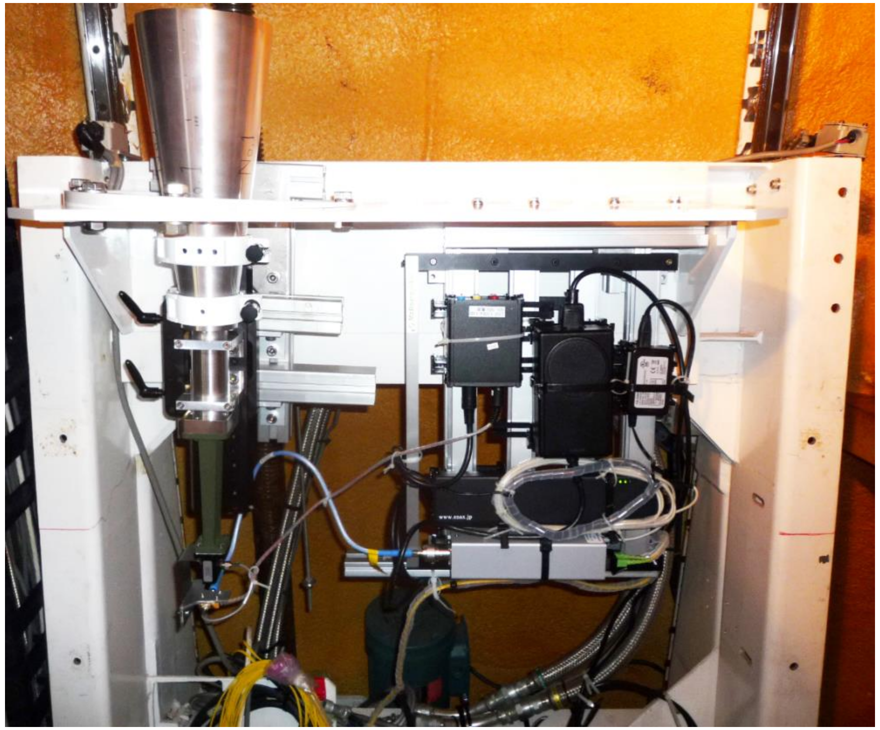
~34deg.





Broadband Feed for Cassegrain optics Kashima 34m antenna

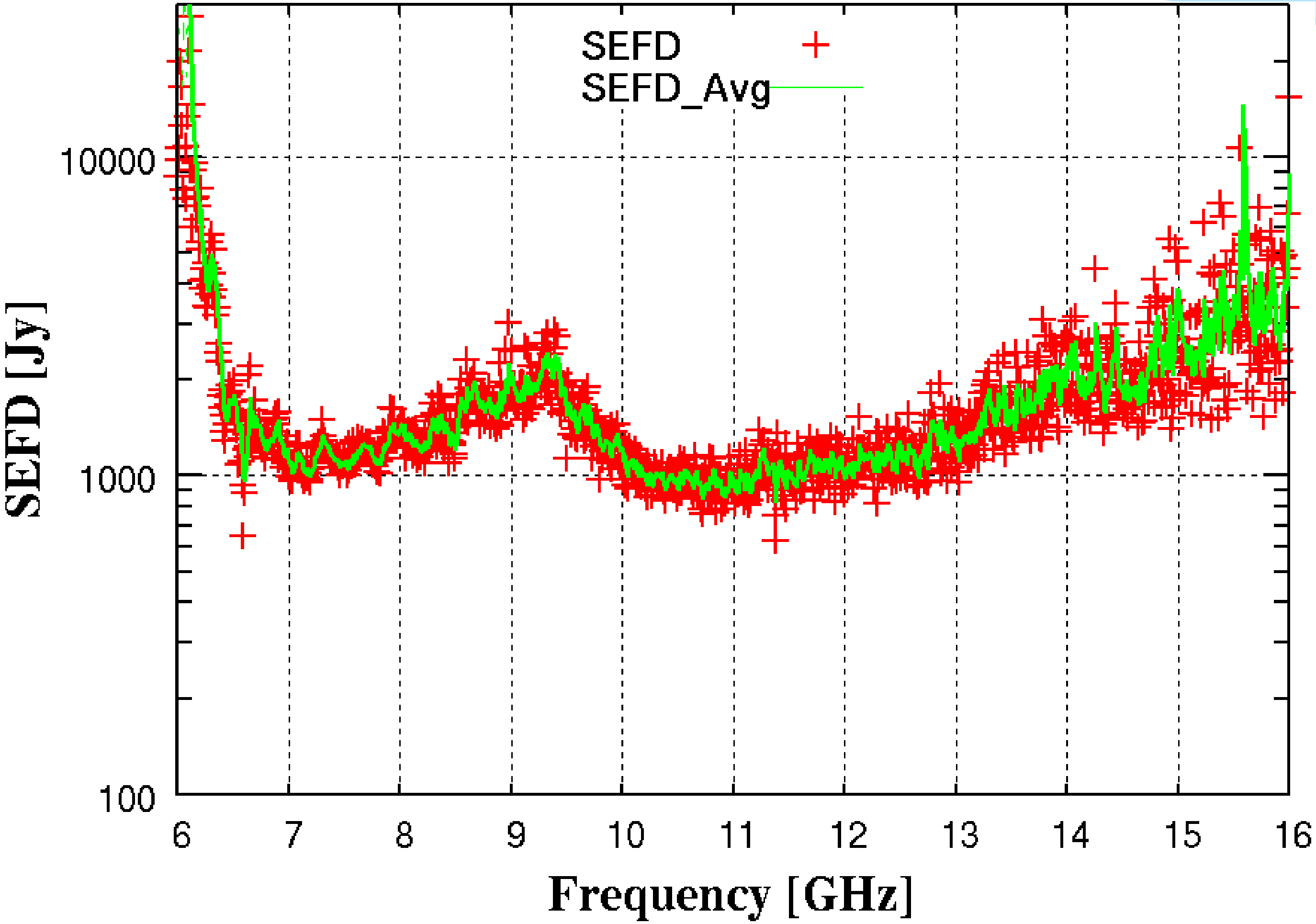
Planning change to Dual Polarization
Currently Single linear Polarization

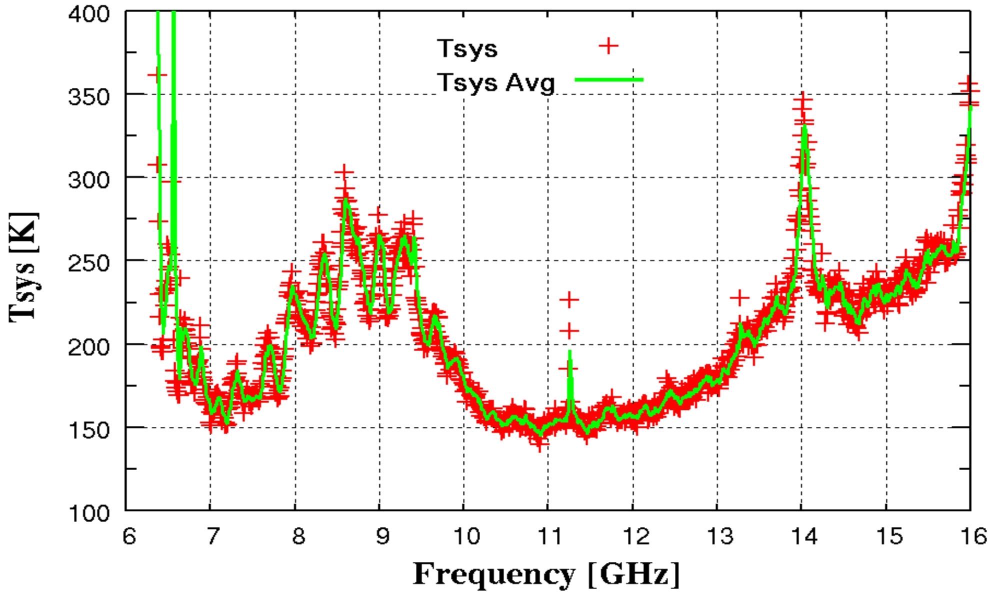


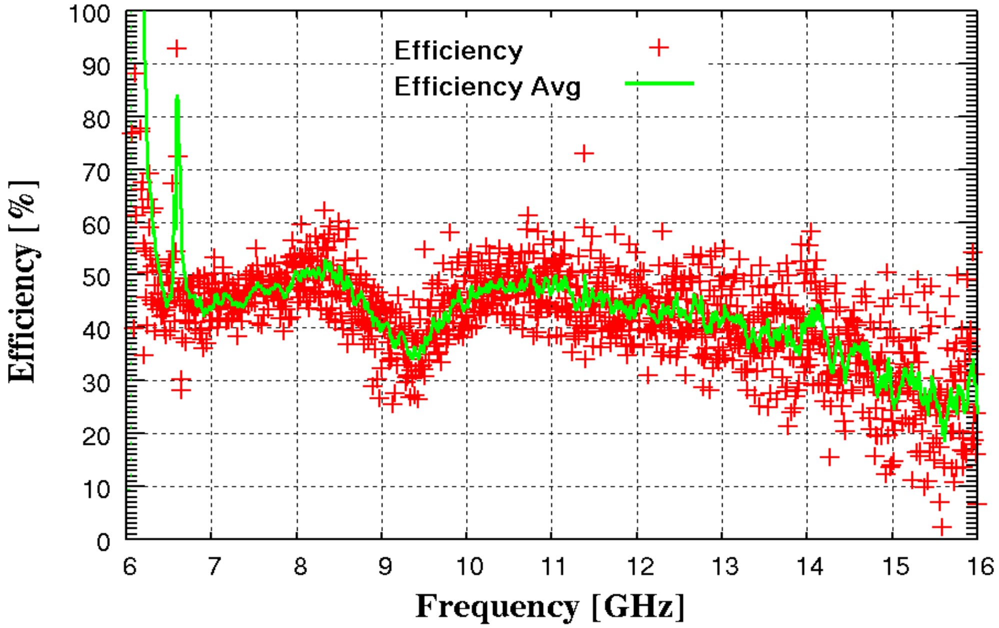
IGUANA-H Feed (6.5-15GHz)

NINJA Feed (3.2-14.4GHz, nominal)

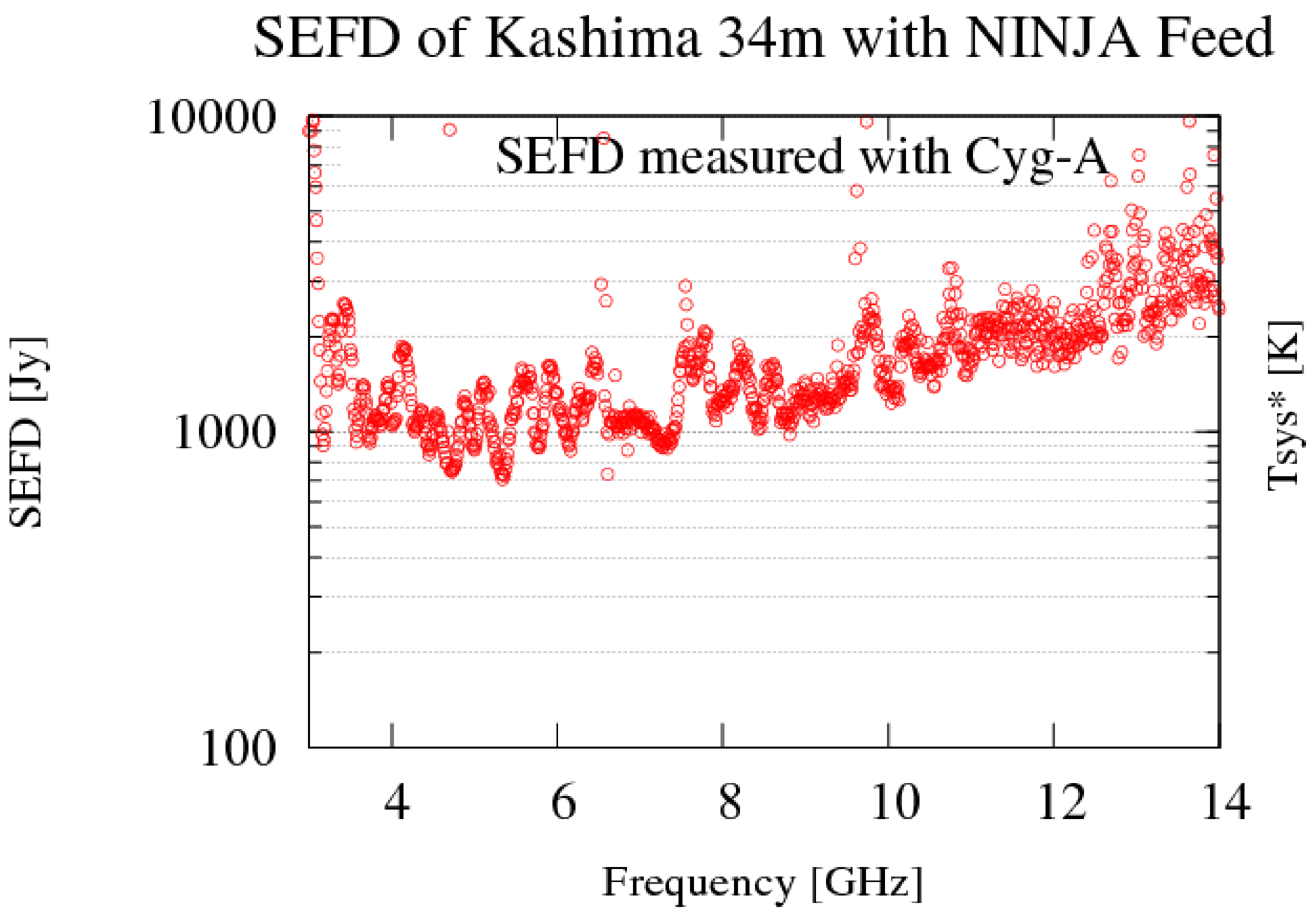
IGUANA-H Broadband Feed on 34m antenna

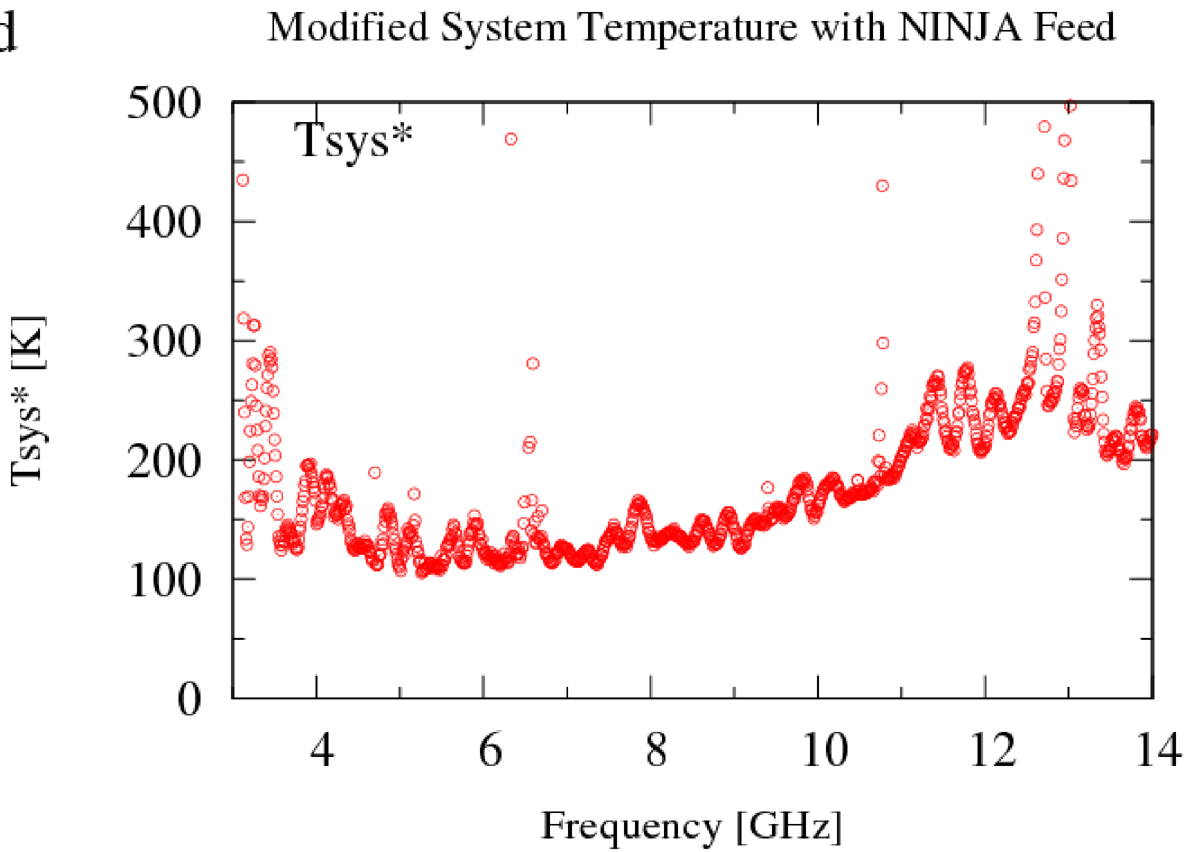




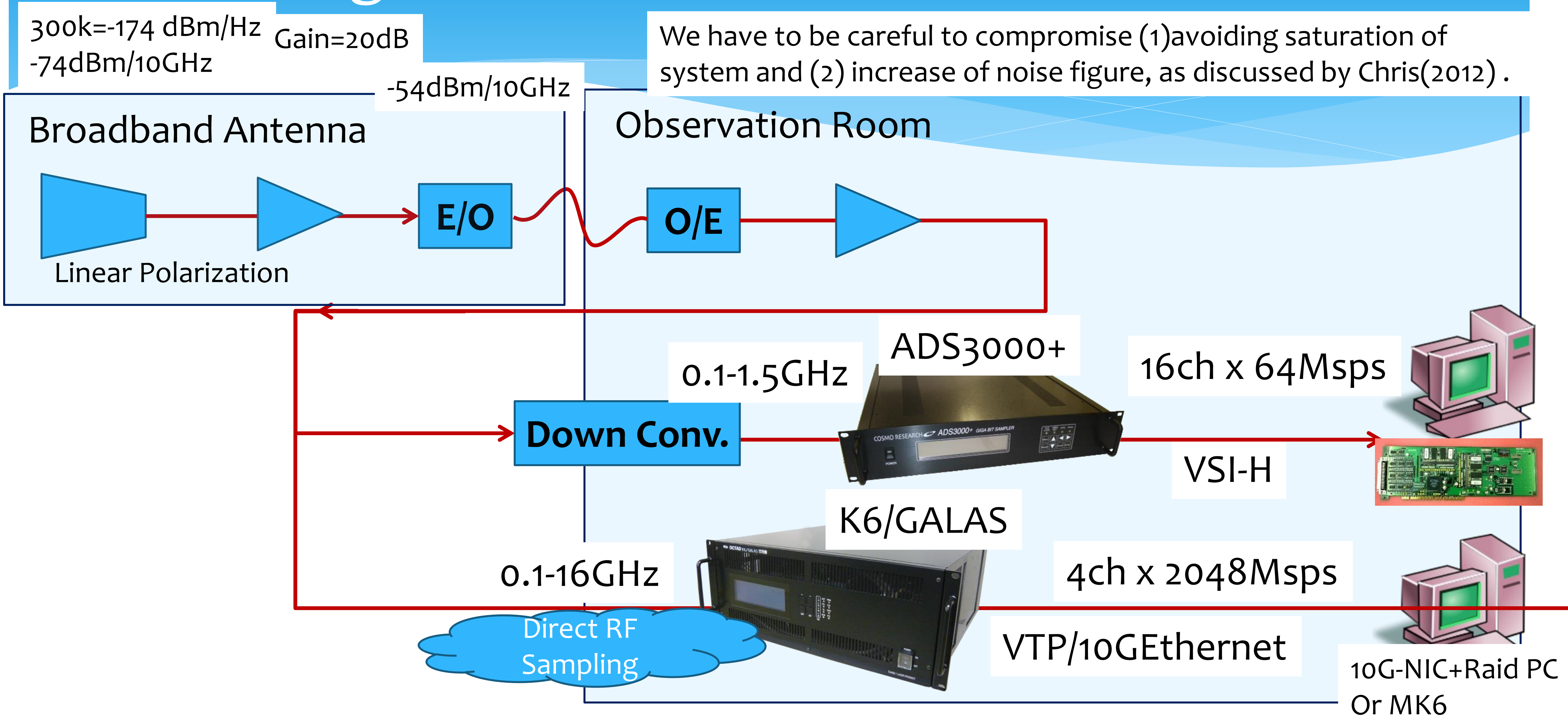


NINJA Broadband Feed on 34m antenna





Signal Chain From Feed to DAS



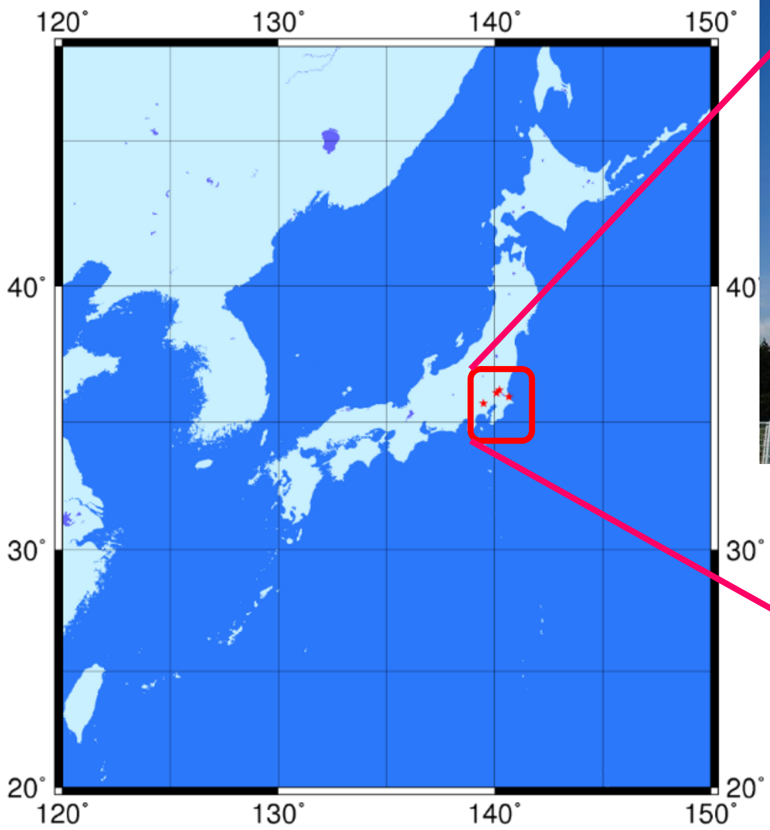
Direct Sampling of RF signal, Digital Filtering without Freq. Conv.

K6/GALAS

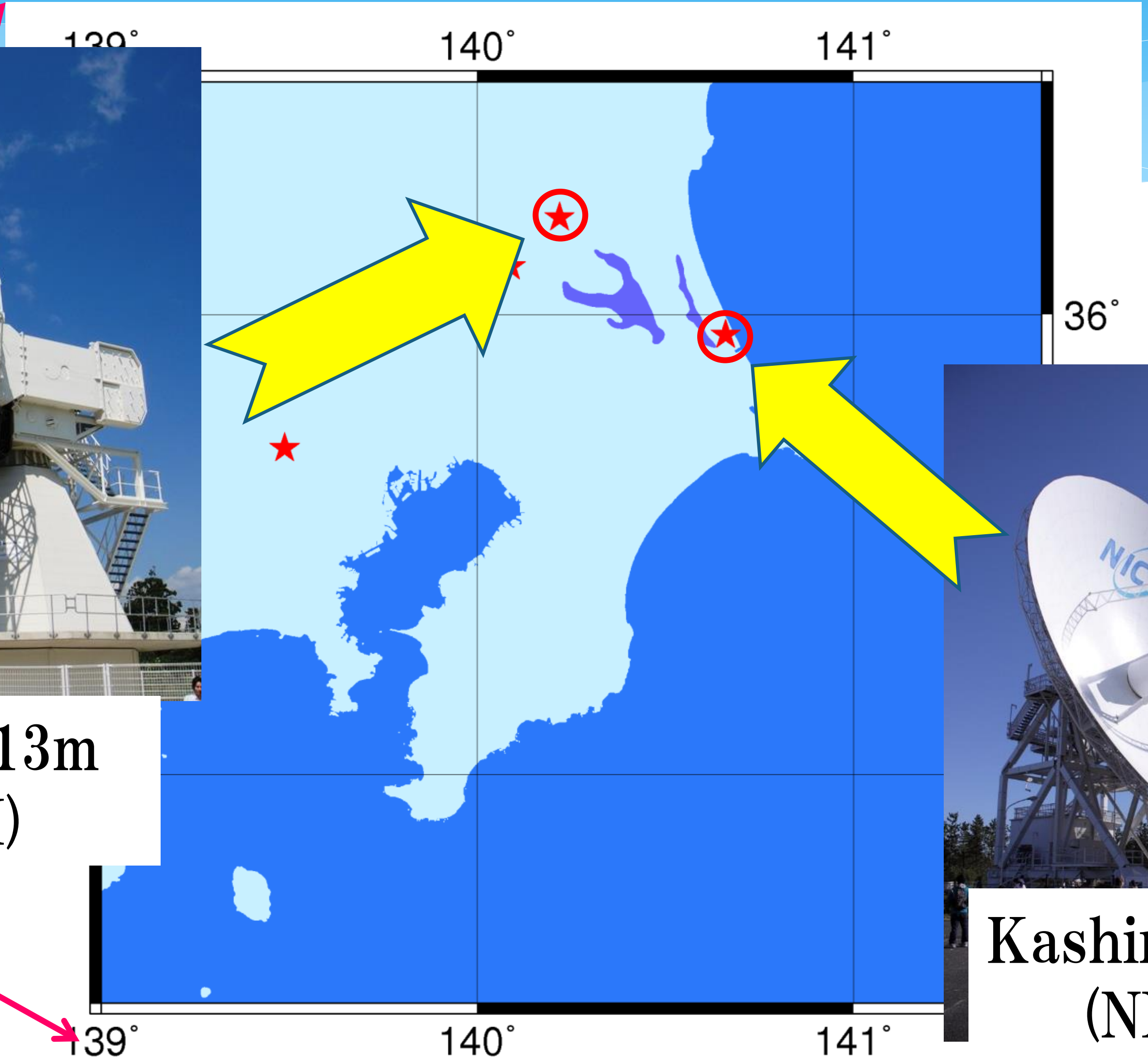
Basic Sampler system has been tested and developed by Porf. Kawaguchi, Dr.Kono, Dr. Oyama of NAOJ in collaboration with Elecs Co.Ltd.

IF Input Port	2
Input Freq. Range	0.1-16.4 GHz
Sampling mode	**DBBC Mode** **Nch/unit=1,2,3, or 4** 2048 Msps/ch Qbit=1, or 2 bit
Output Port	10GBASE-SR, 4port
Max Data rate	16384 Mbps/port

Domestic Broadband Experiments
14-15 Aug. 2015



Ishioka 13m
(GSI)



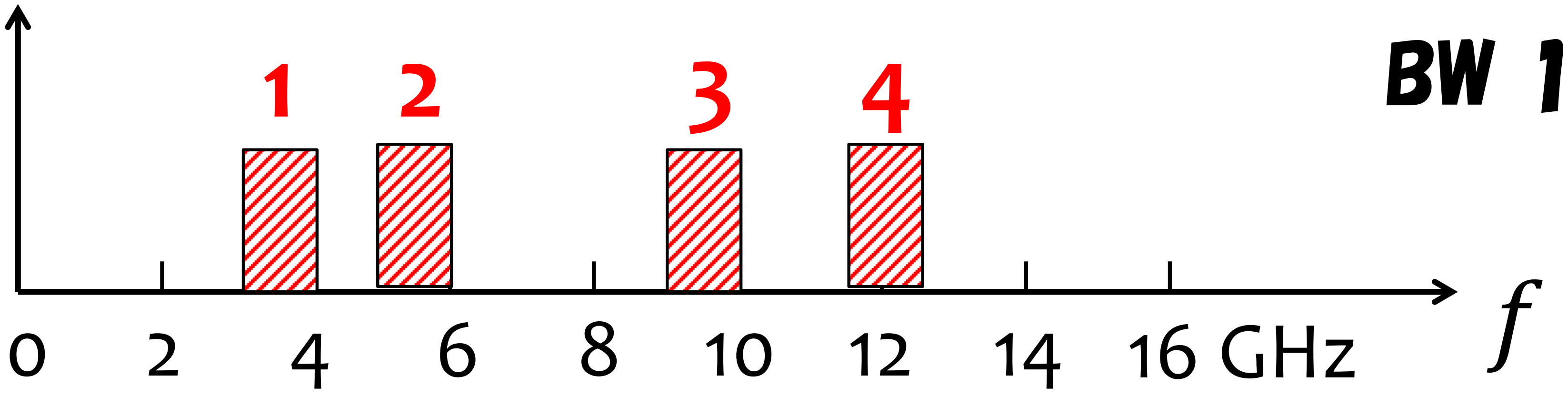
Kashima 34m
(NICT)

As close as Zero Redundancy

Frequency allocation

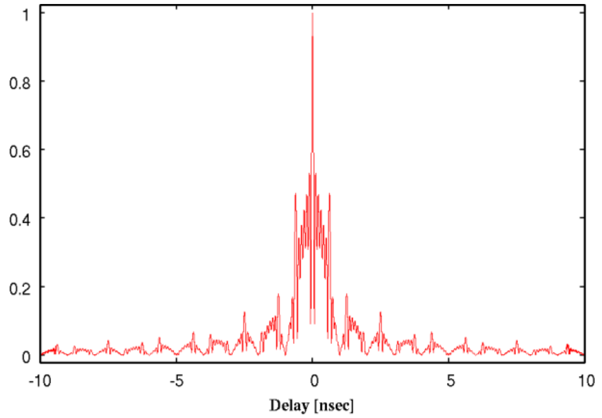
Fine Delay Resolution
Without Ambiguity

Direct Sampling (K6/GALAS)

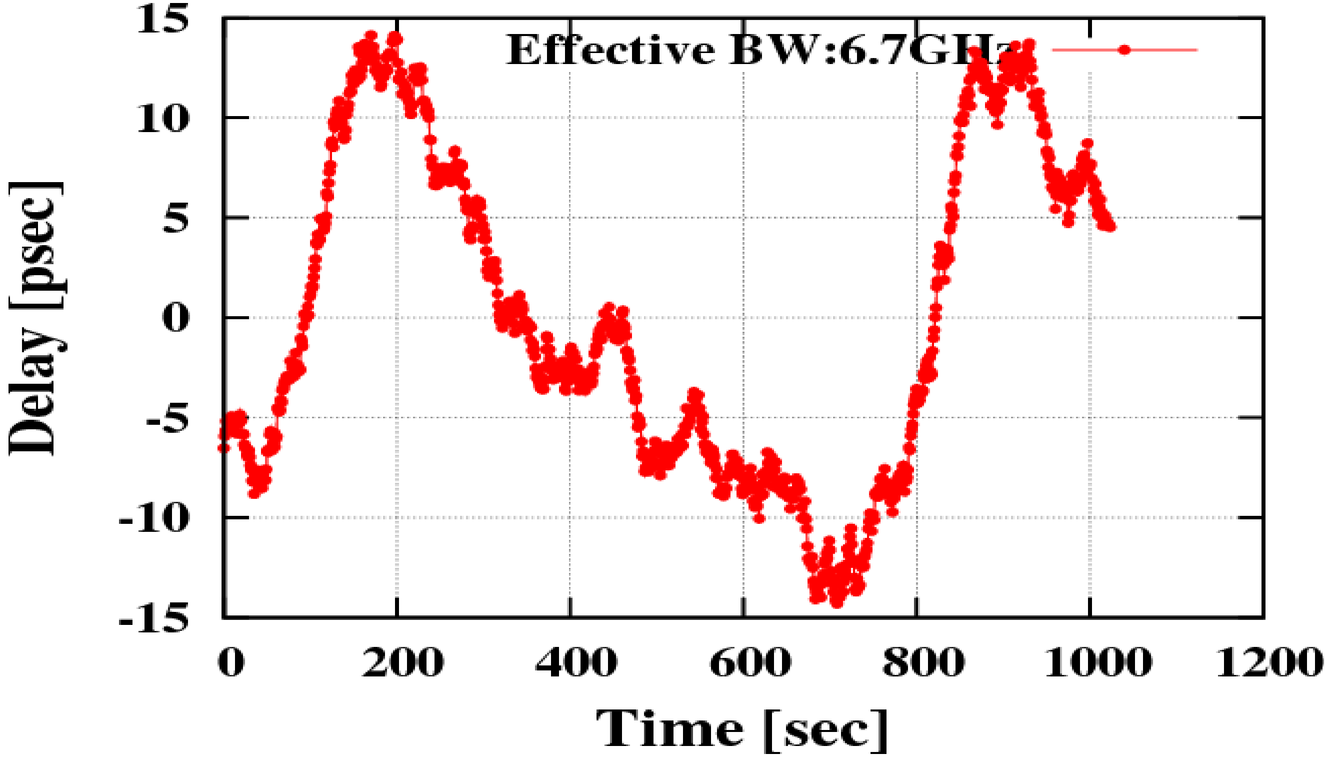


BW 1024MHz each

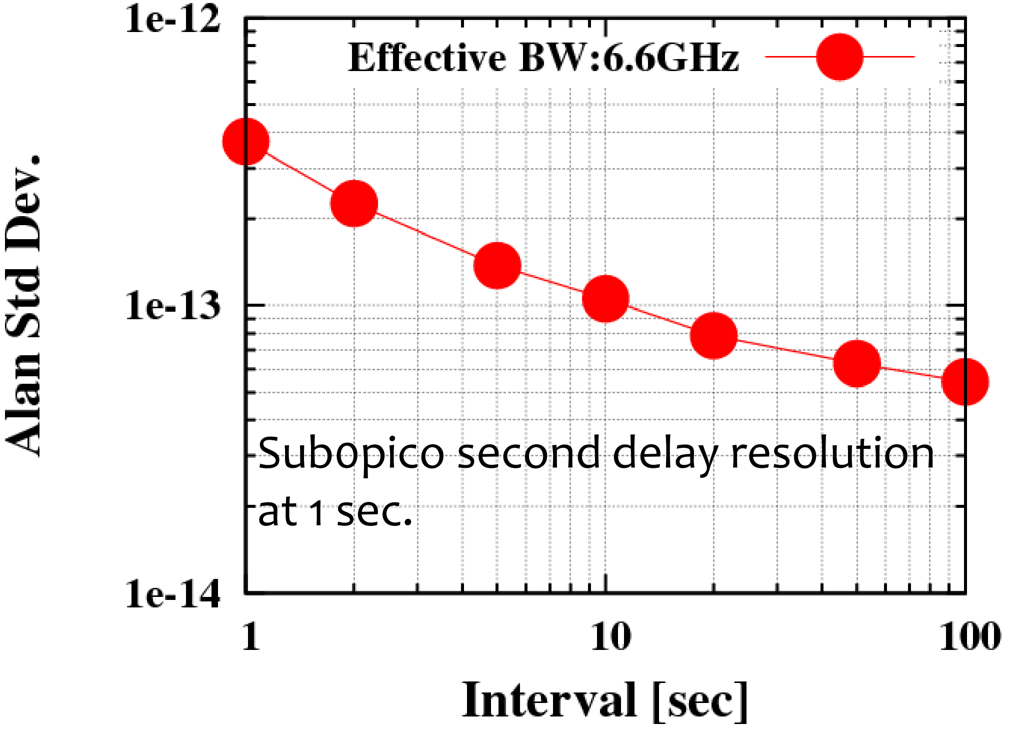
Lower Edge= 3.2, 4.8, 8.8, 11.6GHz



Delay Behavior Broadband Delay (3.2-12.6GHz) Kashima34 – Ishioka 13m

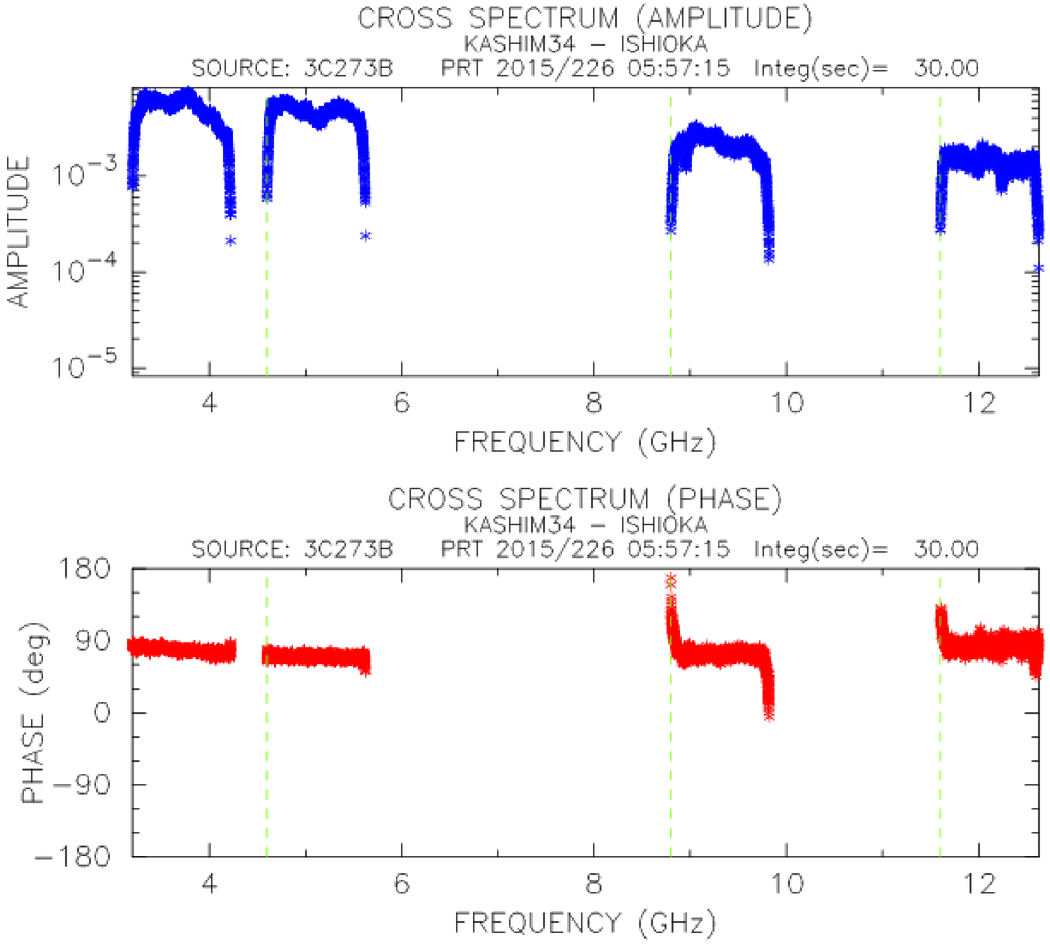


Alan Standard Deviation

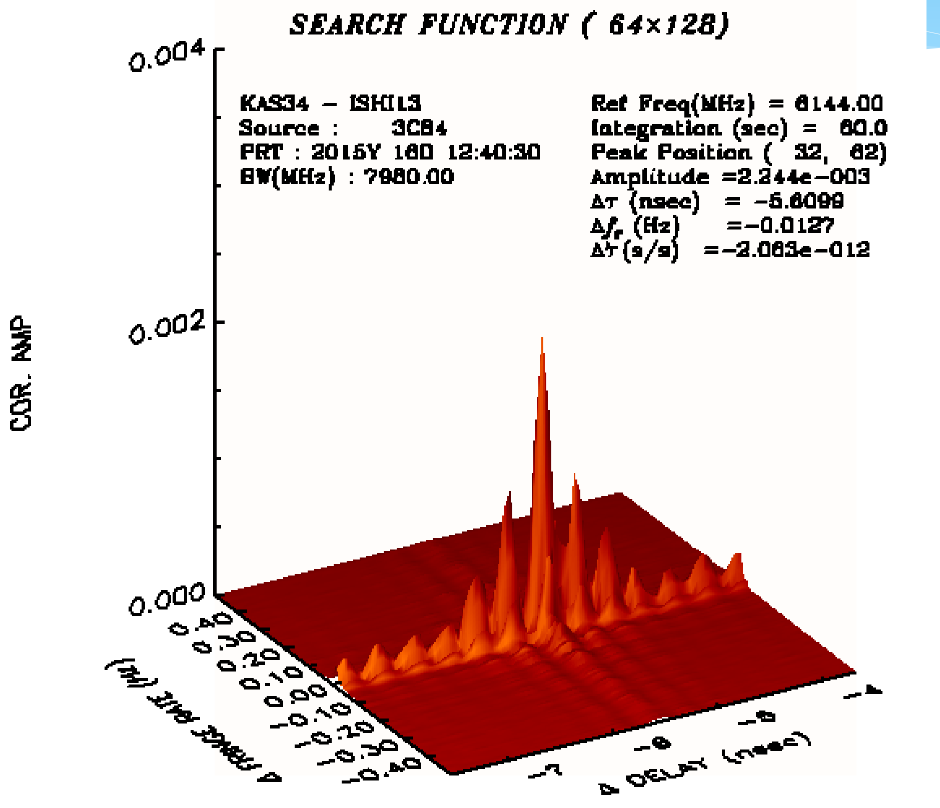


Full Bandwidth Synthesis #1-#(6-14GHz) by Phase Calibration with Radio Source

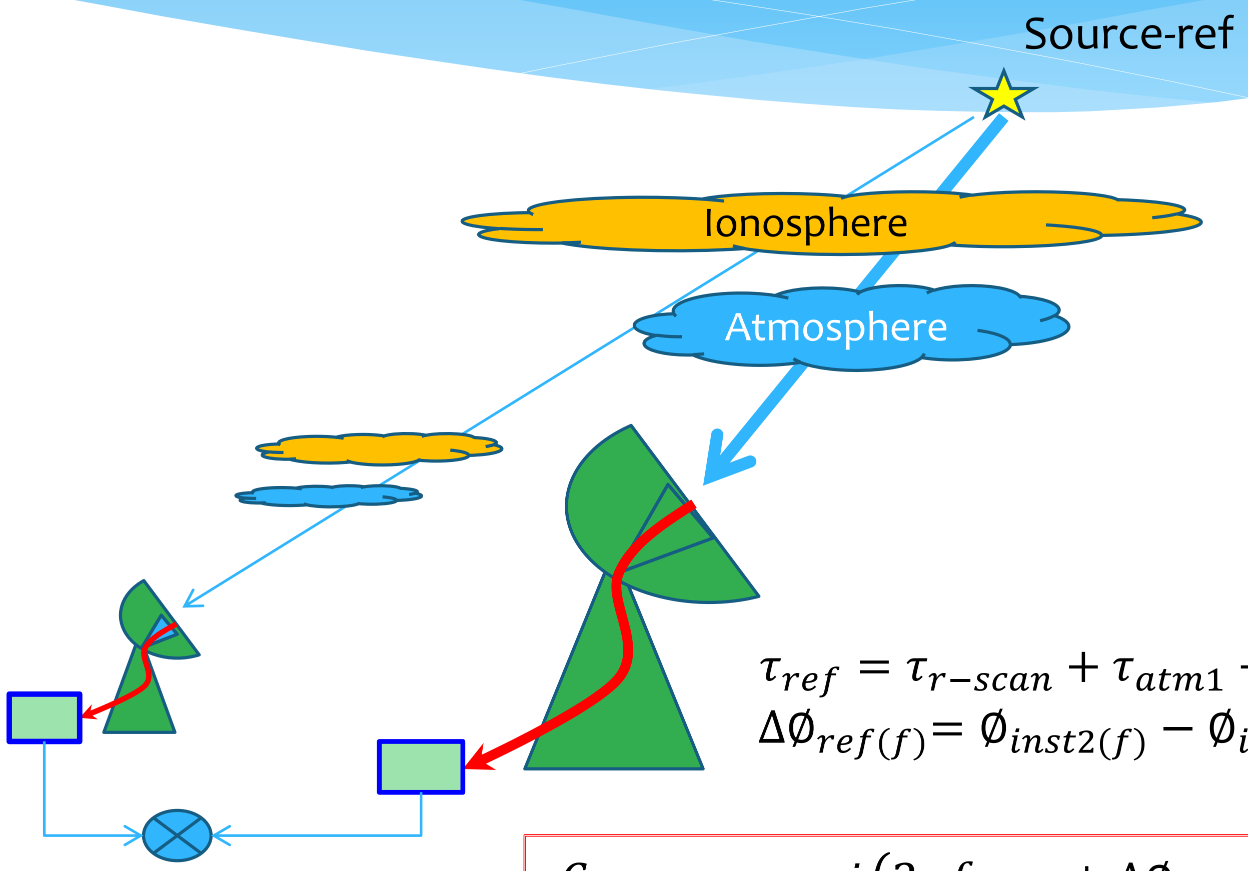
Cross Spectrum



Delay Resolution Function



Procedure of Broadband Phase Calibration with radio source



$$\tau_{ref} = \tau_{r-scan} + \tau_{atm1} + \tau_{inst}$$

$$\Delta\emptyset_{ref(f)} = \emptyset_{inst2(f)} - \emptyset_{inst1(f)}$$

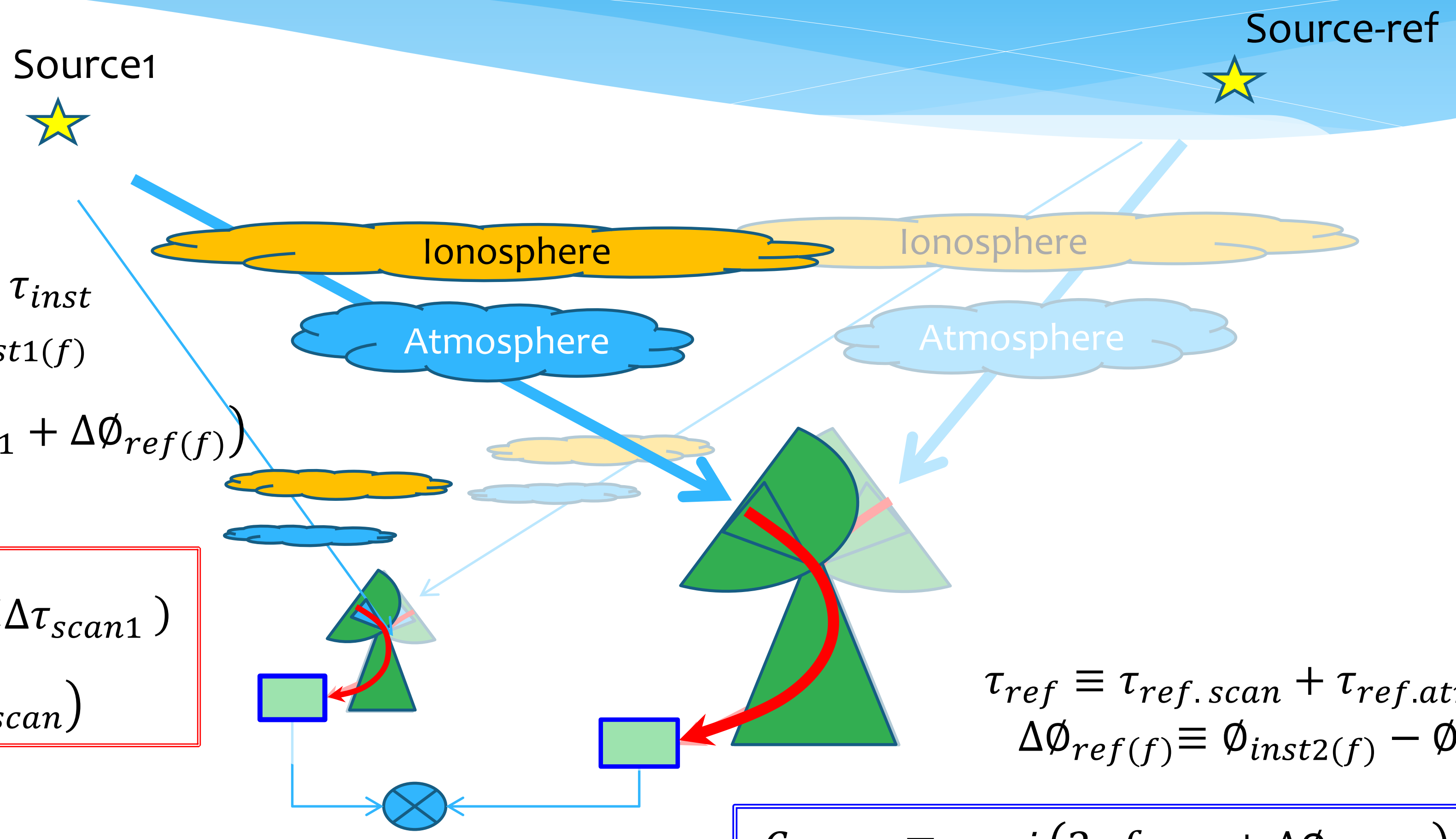
$$C_{ref(f)} = \exp j\left(2\pi f\tau_{ref} + \Delta\emptyset_{ref(f)}\right)$$

Procedure of Broadband Phase Calibration with radio source

$$\tau_{scan1} \equiv \tau_{scan1} + \tau_{atm1} + \tau_{inst}$$
$$\Delta\emptyset_{ref(f)} \equiv \emptyset_{inst2(f)} - \emptyset_{inst1(f)}$$

$$C_{scan,1(f)} = A_{scan1(f)} \exp\left(i2\pi f \tau_{scan1} + \Delta\emptyset_{ref(f)}\right)$$

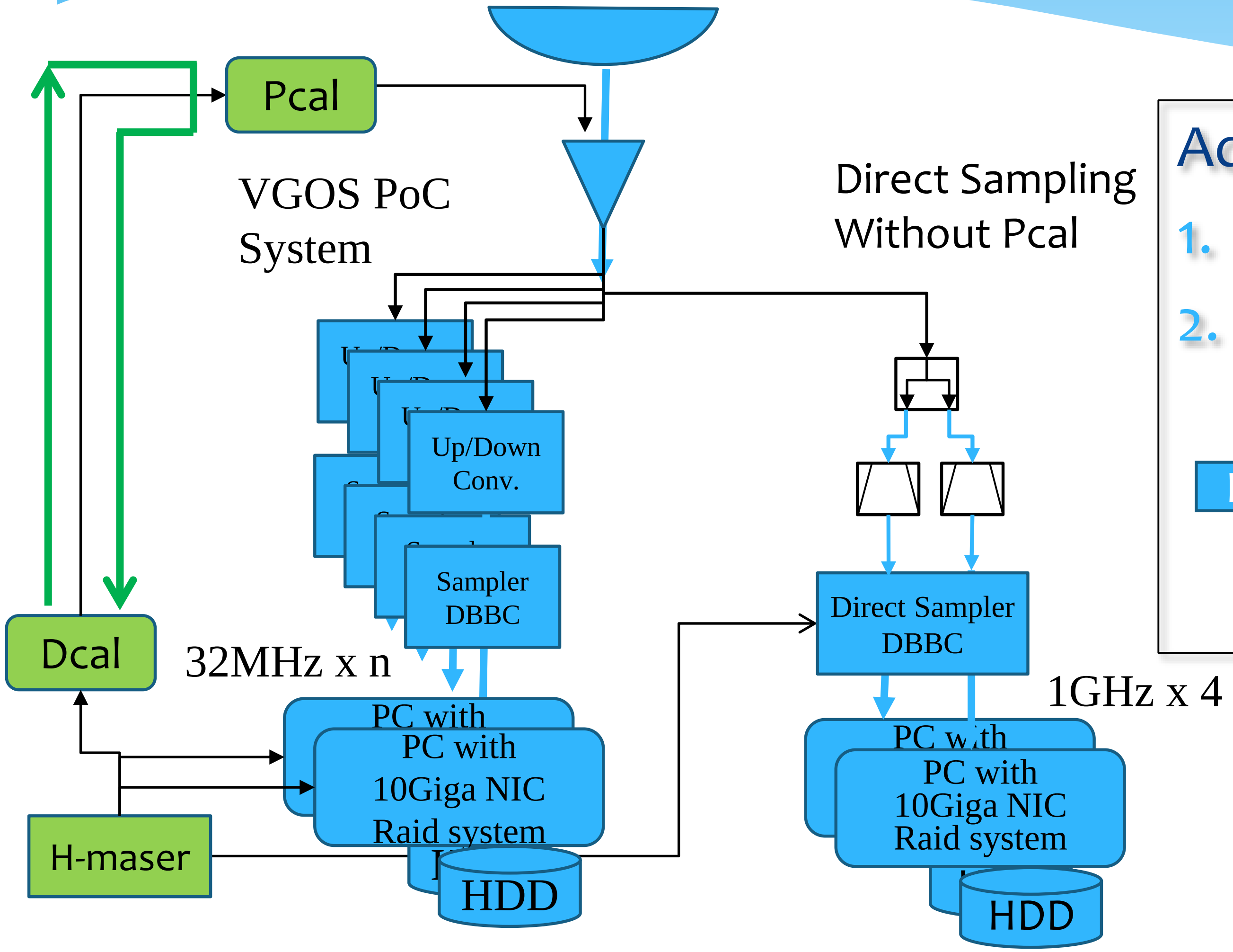
$$\frac{C_{scan1(f)}}{C_{ref(f)}} = A_{scan1(f)} \exp(2\pi f i \Delta\tau_{scan1})$$
$$\Delta\tau_{scan1} \equiv \left(\tau_{scan1} - \tau_{ref.scan}\right)$$



$$\tau_{ref} \equiv \tau_{ref.\,scan} + \tau_{ref.atm} + \tau_{inst}$$
$$\Delta\emptyset_{ref(f)} \equiv \emptyset_{inst2(f)} - \emptyset_{inst1(f)}$$

$$C_{ref(f)} \equiv \exp i\left(2\pi f \tau_{ref} + \Delta\emptyset_{ref(f)}\right)$$

Advantages of Direct RF Sampling Technique proposal of Pcal-free system



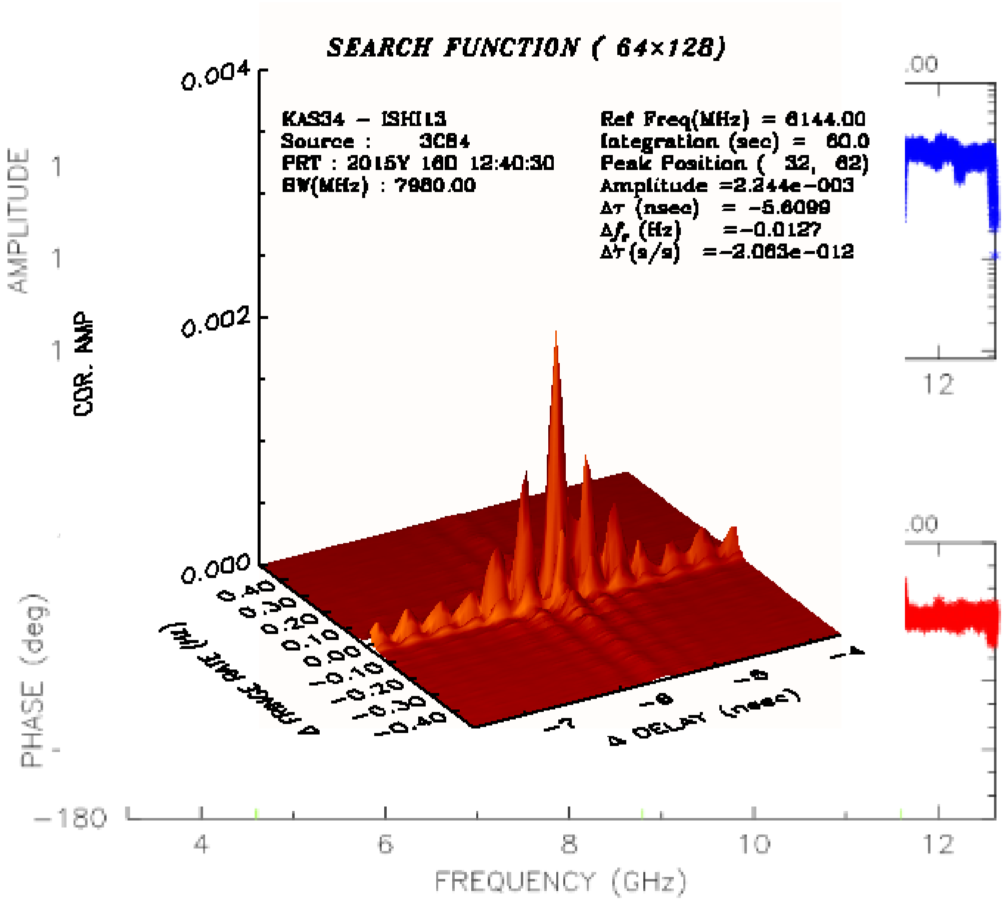
Advantages of Direct sampling

1. Simple and less system components.
2. Stable phase/Delay relation between band gives possibility of BWS without P-cal device

If verified → Delay-Cal device is not necessary, too.

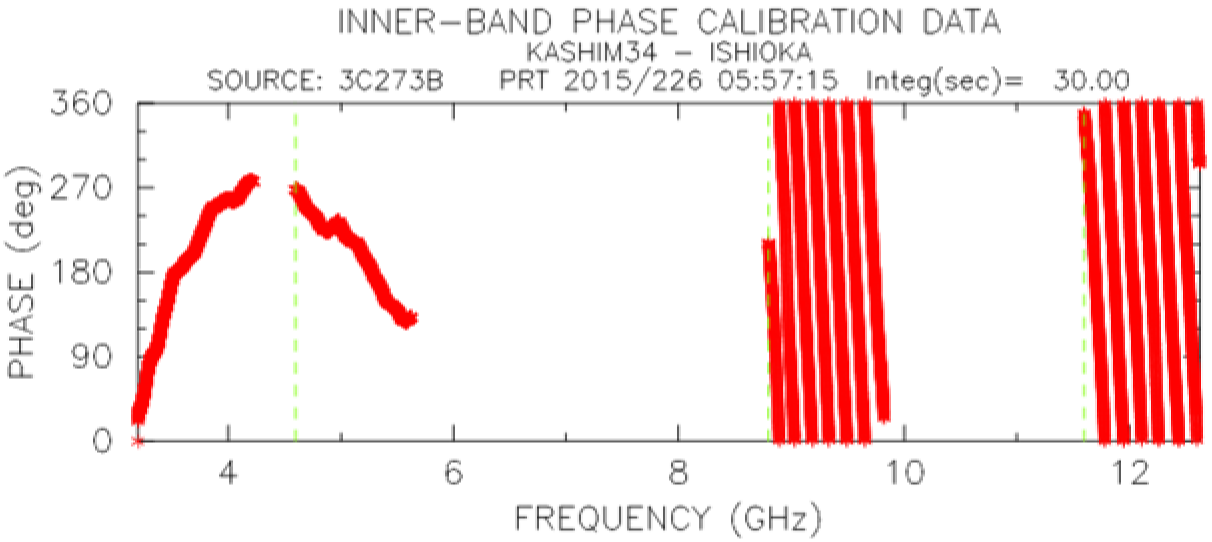
Full Bandwidth Synthesis #1-#4 (3.2-11.6GHz) by Phase Calibration with Radio Source

Cross Spectrum after calibration



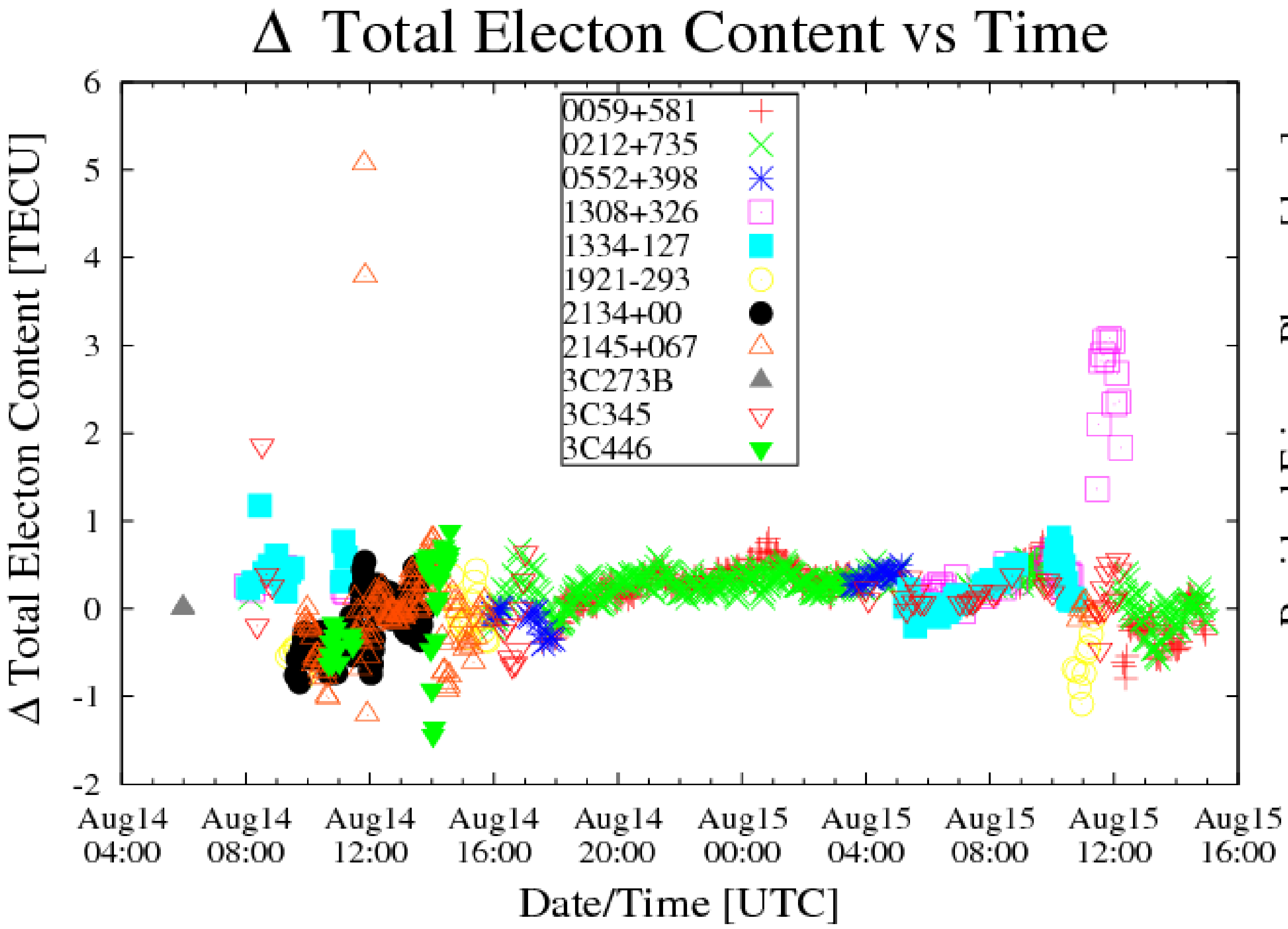
Phase/delay characteristics for calibration

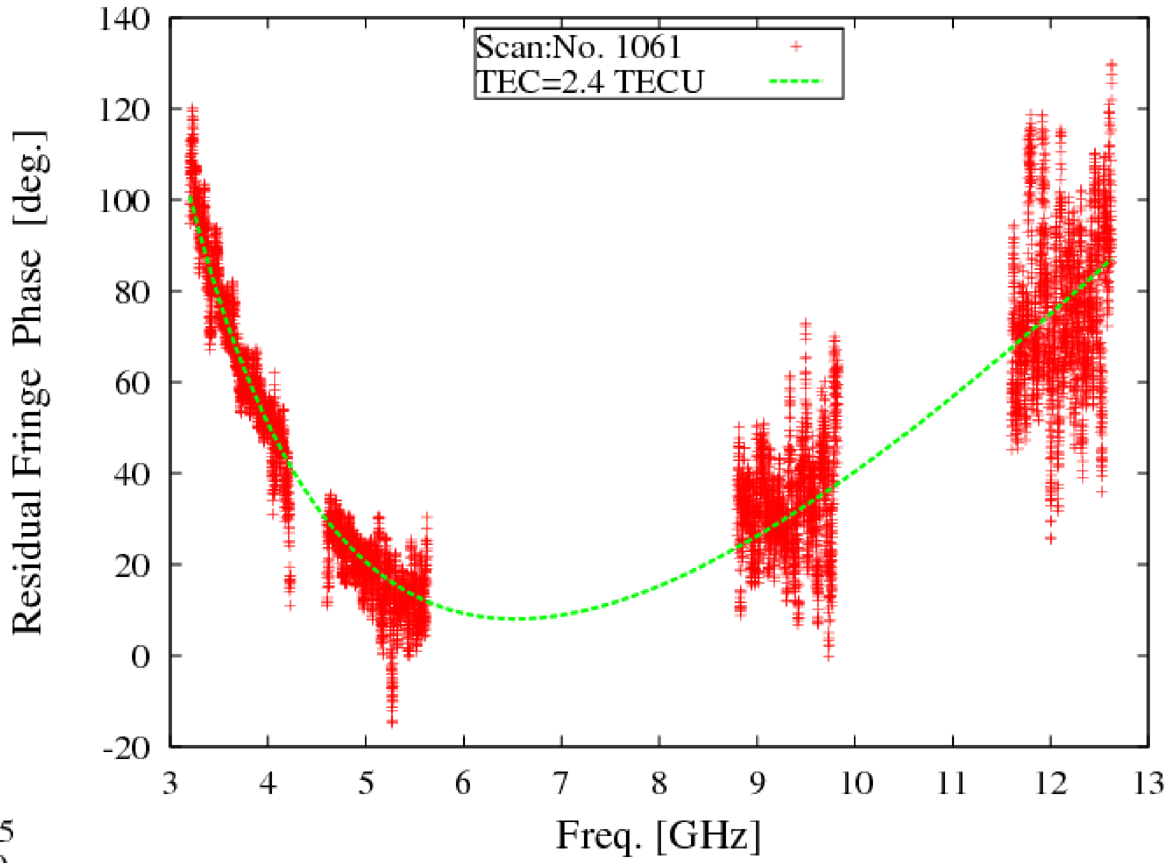
Calibration Cross Spectrum Phase



Least Square Estimation of δTEC and $\delta\tau$

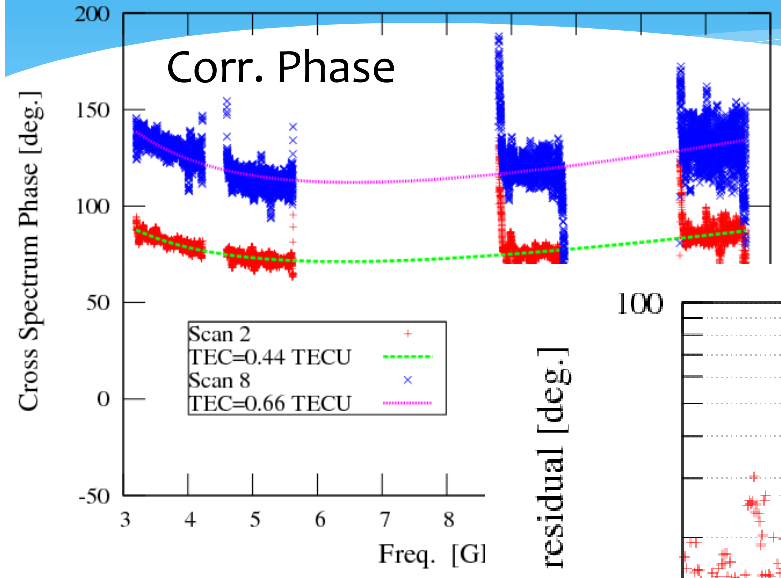
$$\emptyset[deg.] = \alpha\frac{\delta TEC}{f} + 360 \times \delta\tau \times f + c$$





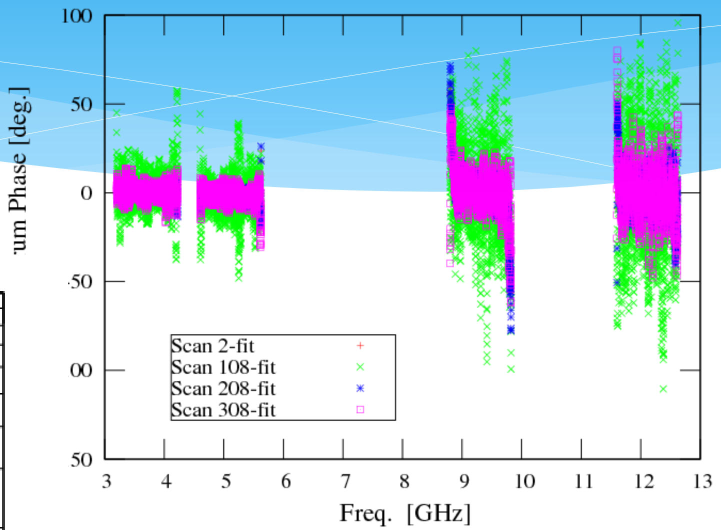
How much this calibration strategy will be stable?

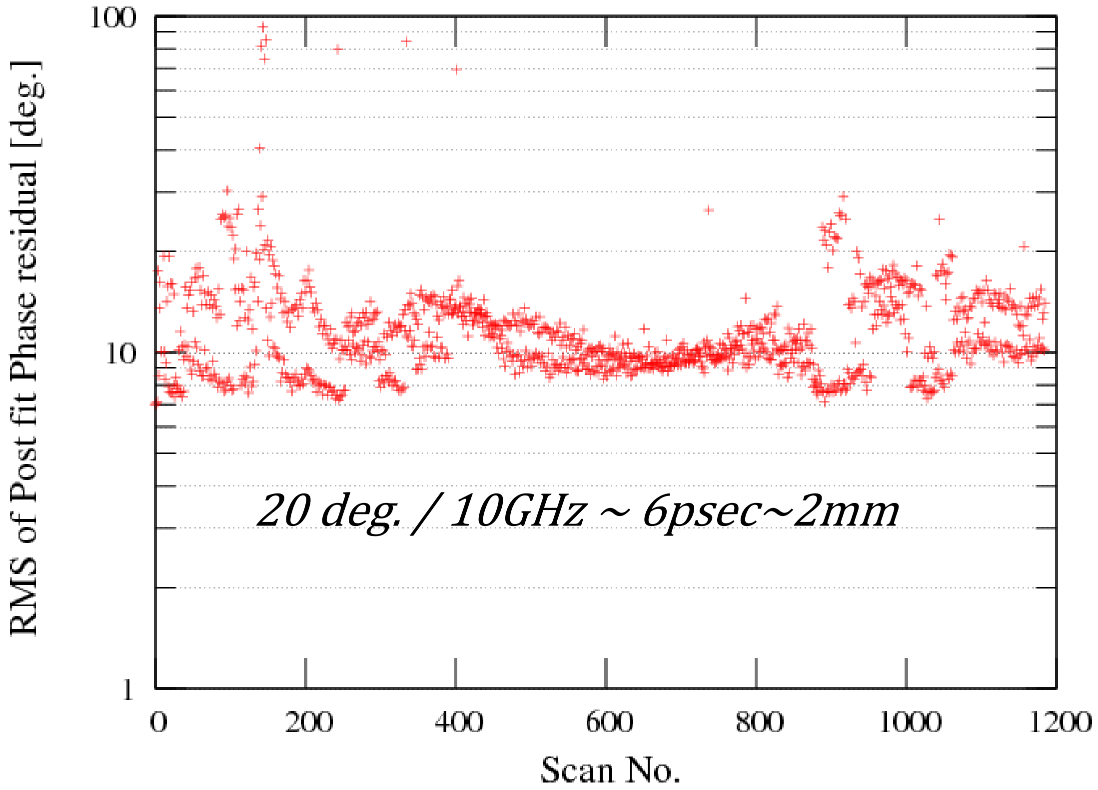
⇒ One evaluation with existing data…



After Removing known phase curve by fitting

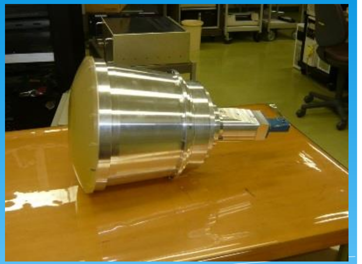
$$\delta\emptyset = \alpha\frac{\delta TEC}{f} + 360 \times \delta\tau \times f + c$$





Standard deviation of phase were computed over whole bandwidth or each scans of 24 hours experiment.

Summary



1. We developed Broadband feed for Cassegrain focus telescope to enable VGOS compatible observation with existing 34m telescope.
2. The Broadband BWS software started to work.
   * We need long baseline VLBI data for testing/improvement.
3. Direct RF sampling technique is quite useful especially in case of broadband Pcal device is difficult.
   * Un modeled phase variation rms was evaluated to be less than 20 deg. For 24 hours on Kashima34 - Ishioka 13m.

Acknowledgements

* Development of Broadband Feed is was supported by a grant (2013-2014) of Joint Development Research from National Astronomical Observatory of Japan(NAOJ).
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Thank you for attention.