Recent status of Daejeon hardware correlator and its functional expansion in future

Se-Jin Oh
Duk-Gyoo Roh, Jae-Hwam Yeom, ChungSik Oh, Dong-Kyu Jung, Ju-Yeon Hwang, T. Oyama, N. Kawaguchi, H. Kobayashi, K. Shibata
and staff of Correlator team of KASI/NAOJ

4th IVTW, Nov. 23~26, 2015, @ AUT, New Zealand
Contents

- Daejeon Correlator
- KJCC Operational Status
- Functional Expansion in Future
- Summary
We concluded that KASI & NAOJ join together for the best performance.

MOU between KASI & NAOJ (2005. 7. 7.) → Development of Korea-Japan Joint VLBI Correlator,
   → Common facility of correlation & data center

Joint Development Project was initiated respectively.
Japan : 5 years from April 2005, 2M$
Korea : renewed successional project,
   5 years from Jan. 2006, 8M$
## Specification (1)

KASI + NAOJ ➔ 2006~2010

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Antennas</td>
<td>16</td>
</tr>
<tr>
<td>Number of Inputs / Antenna</td>
<td>4</td>
</tr>
<tr>
<td>- Input Interface</td>
<td></td>
</tr>
<tr>
<td>- Maximum Data Rates</td>
<td>- 2Gbps VSI-H (32parallels, 64 MHz clk)</td>
</tr>
<tr>
<td></td>
<td>- 8,192 Mbps</td>
</tr>
<tr>
<td>Digitization for Each Inputs</td>
<td></td>
</tr>
<tr>
<td>- Number of Bits</td>
<td>- 2 bits/sample</td>
</tr>
<tr>
<td>- Quantization Levels</td>
<td>- 4 levels</td>
</tr>
<tr>
<td>- Sampling Rates</td>
<td>- 1,024 Msamples/sec</td>
</tr>
<tr>
<td>- Input Bandwidth</td>
<td>- 512 MHz</td>
</tr>
<tr>
<td>- Sub-stream Specification</td>
<td>- Logically Associated Sub-streams</td>
</tr>
<tr>
<td>Maximum Delay Compensation (Largest Baseline Length)</td>
<td>±36,000 km</td>
</tr>
<tr>
<td>Maximum Fringe Tracking (Fastest Phase Drift Cancellation)</td>
<td>1,075 kHz</td>
</tr>
<tr>
<td>Architecture</td>
<td>FX type, with FPGA and DSP chips</td>
</tr>
</tbody>
</table>
### Specification (2)

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FFT Processing</strong></td>
<td></td>
</tr>
<tr>
<td>- Freq. Resolution</td>
<td>- 0.05km/sec @ 22GHz</td>
</tr>
<tr>
<td>- Size of FFT points</td>
<td>- 256k/128k/64k/32k/16k/8k Adjustable</td>
</tr>
<tr>
<td>- Word length in FFT</td>
<td>- 20+20 bits fixed point for real &amp; imaginary</td>
</tr>
<tr>
<td>- Scaling</td>
<td>- Yes</td>
</tr>
<tr>
<td>- Re-quantization</td>
<td>- 16+16 bits fixed point for real &amp; imaginary</td>
</tr>
<tr>
<td><strong>W Correction</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Correlations</strong></td>
<td></td>
</tr>
<tr>
<td>- Number of Correlation Outputs/Input</td>
<td>- Max. 120 Cross- and 16 Auto-correlations</td>
</tr>
<tr>
<td>- Total Number of Correlation Outputs</td>
<td>- Max. 480 Cross- and 64 Auto-correlations</td>
</tr>
<tr>
<td>- Polarization Mode</td>
<td>- RR or LL ; Full Operation for 16 antennas</td>
</tr>
<tr>
<td></td>
<td>- RR and LL ; Full Operation for 16 antennas</td>
</tr>
<tr>
<td></td>
<td>- RR, RL, LR and LL : Full Op. for 8 antennas</td>
</tr>
<tr>
<td>- Data compression(Binning)</td>
<td>- Yes, 8,192 channels / correlation output</td>
</tr>
<tr>
<td>- Word length</td>
<td>- 32+32 bits Fixed Point for R &amp; I</td>
</tr>
<tr>
<td>- min. max Integration Time</td>
<td>- 25.6msec ~ 10.24sec</td>
</tr>
<tr>
<td><strong>Data Output to Archive (Max.)</strong></td>
<td>1.4 GBytes/sec</td>
</tr>
</tbody>
</table>
Target Array: EAVN

- For KVN, KaVA(w/ JVN), and EAVN(w/ Thailand VLBI Network), and also for Space VLBI
Daejeon Correlator Framework

- Mark5B
- Mark6
- VERA2000
- OCTADISK
- OCTADISK2
- Optical Fiber

Raw VLBI Data Buffer (RVDB)

VLBI Correlation Subsystem (VCS)

Correlated VLBI Data Buffer (CVDB)

Correlator Control & Operation S/W

- Yellow: NAOJ, Green: KASI
Mark5B playback → VSI compatible: KVN

DIR2000 was in use extensively at VERA.
  ▪ VERA 2000, which was modified by NAOJ according to DIR1000, used for playing back DIR2000 tape media for VERA.

OCTADISK: modified using RVDB with 4Gbps recorder/playback developed by NAOJ.

Optical Fiber: Capable of dealing with the full data rate of 8 Gbps.
OCTADISK2 (removable storage) by NAOJ/Elecs

- Record / **playback** VDIF data stream via 10/40G Ethernet at 8Gbps (standard), 16Gbps (high-end), 32Gbps (flagship)
- Realizing direct analysis of data stream without file format conversion by adopting Linux file system for the storage
- It will be installed at 2016 in KJCC for supporting VERA.
Purpose:

- Different recording systems are operated in each country
- Adjust data format as like # of bits per sample, and so on
- Easily synchronize the data while playback (heterogeneous recorder models)
- Maintain the buffering between recorder speed (1 Gbps) and correlation speed (8 Gbps)
Raw VLBI Data Buffer (RVDB)

Basic configuration

4 C-ports
2Gbps, nominal
8Gbps=2G x 4

To Correlator Input Ports

VSI Optical Adapter (OCTAVIA)

4 D-ports
2Gbps, nominal
8Gbps=2G x 4

From Playing Back Units

10Gbe Switch

OCTADISK

Control PC

OCTADDDB

OCTADDDB

OCTADDDB

VDIF
Daejeon Hardware Correlator (KASI/NAOJ)
2011.07~Joint Operated by KASI/NAOJ
<table>
<thead>
<tr>
<th>Mode</th>
<th>#IF</th>
<th>Bandwidth [MHz]</th>
<th>Max. #Chan</th>
<th>#Bits</th>
<th>Max. Data Rate [Mbps]</th>
<th>Recorder</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>1</td>
<td>256</td>
<td>1</td>
<td>2</td>
<td>1,024</td>
<td></td>
<td>Test Obs</td>
</tr>
<tr>
<td>C2</td>
<td>1,2</td>
<td>128</td>
<td>2</td>
<td>2</td>
<td>1,024</td>
<td></td>
<td>Test Obs</td>
</tr>
<tr>
<td>C3</td>
<td>1,2,3,4</td>
<td>64</td>
<td>4</td>
<td>2</td>
<td>1,024</td>
<td></td>
<td>Test Obs</td>
</tr>
<tr>
<td>C4</td>
<td>1,2,3,4</td>
<td>32</td>
<td>8</td>
<td>2</td>
<td>1,024</td>
<td>Mark5B [KVN]</td>
<td>Open Use</td>
</tr>
<tr>
<td>C5</td>
<td>1,2,3,4</td>
<td>16</td>
<td>16</td>
<td>2</td>
<td>1,024</td>
<td>VERA</td>
<td>Open Use</td>
</tr>
<tr>
<td>C6</td>
<td>1,2,3,4</td>
<td>8</td>
<td>16</td>
<td>2</td>
<td>512</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C7</td>
<td>1,2,3</td>
<td>64/128</td>
<td>2/1</td>
<td>2</td>
<td>1,024</td>
<td>OCTADISK [VERA]</td>
<td></td>
</tr>
<tr>
<td>C8</td>
<td>1,2,3,4</td>
<td>32/64/128</td>
<td>2/1/1</td>
<td>2</td>
<td>1,024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C9</td>
<td>1,2,3,4</td>
<td>32/128</td>
<td>4/1</td>
<td>2</td>
<td>1,024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C10</td>
<td>1,2,3,4</td>
<td>16/32/128</td>
<td>2/3/1</td>
<td>2</td>
<td>1,024</td>
<td>Mark6 [KVN]</td>
<td></td>
</tr>
<tr>
<td>W1</td>
<td>1</td>
<td>512</td>
<td>1</td>
<td>2</td>
<td>2,048</td>
<td></td>
<td>Test Obs</td>
</tr>
<tr>
<td>W2,3</td>
<td>1,2,3,4</td>
<td>512</td>
<td>4</td>
<td>2</td>
<td>4 x 2,048 = 8Gbps</td>
<td>OCTADISK2 [VERA]</td>
<td>To be tested Obs soon</td>
</tr>
</tbody>
</table>

Test Obs soon
## KJCC Operational Status

**Korea-Japan Correlation Center**

http://kjcc.kasi.re.kr

### 2015B Correlation List

<table>
<thead>
<tr>
<th>Season</th>
<th>#Observation</th>
<th>Corr Finished</th>
<th>Remain Corr</th>
<th>Remark</th>
<th>Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>KaVA 2015B</td>
<td>26</td>
<td>18</td>
<td>5</td>
<td>3</td>
<td>2015.11.13</td>
</tr>
</tbody>
</table>

**Finished** | **Doing** | **Not yet** | **Suspend** | **KJCC evaluation** | **Not related in KJCC**

---

**Please click the observation code for more detail procedure!!**

<table>
<thead>
<tr>
<th>Observation Date</th>
<th>Observation Code</th>
<th>PI &amp; SWG</th>
<th>Frequency Band</th>
<th>Corr Mode</th>
<th>Objective</th>
<th>Media POS</th>
<th>Copy Status</th>
<th>Fringe Detection</th>
<th>Correlation Status</th>
<th>FITS release Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015.10.30 (15303k)</td>
<td>r15303k</td>
<td>T. Jike</td>
<td>K</td>
<td>GEO1K(C5)</td>
<td>Geodetic Experiment</td>
<td>STN</td>
<td>NY</td>
<td>NY</td>
<td>1:15...</td>
<td>NY</td>
</tr>
<tr>
<td>2015.10.30 (15303a)</td>
<td>k15hi01d</td>
<td>H. Imai/ES</td>
<td>K,Q,W,D</td>
<td>VERA7(C5)</td>
<td>ESTEMA</td>
<td>KJC</td>
<td>NY</td>
<td>NY</td>
<td>1:15...</td>
<td>NY</td>
</tr>
<tr>
<td>2015.10.29 (15302b)</td>
<td>k15hi01c</td>
<td>H. Imai/ES</td>
<td>K,Q,W,D</td>
<td>VERA7(C5)</td>
<td>ESTEMA</td>
<td>KJC</td>
<td>NY</td>
<td>NY</td>
<td>1:15...</td>
<td>NY</td>
</tr>
<tr>
<td>2015.10.29 (15302a)</td>
<td>k15hi01b</td>
<td>H. Imai/ES</td>
<td>K,Q,W,D</td>
<td>VERA7(C5)</td>
<td>ESTEMA</td>
<td>KJC</td>
<td>KVN Done</td>
<td>NY</td>
<td>1:15...</td>
<td>NY</td>
</tr>
<tr>
<td>2015.10.28 (15301b)</td>
<td>k15hi01a</td>
<td>H. Imai/ES</td>
<td>K,Q,W,D</td>
<td>VERA7(C5)</td>
<td>ESTEMA</td>
<td>KJC</td>
<td>NY</td>
<td>NY</td>
<td>1:15...</td>
<td>NY</td>
</tr>
<tr>
<td>2015.10.28 (15301a)</td>
<td>k15mk04b</td>
<td>M. Kino/AGN</td>
<td>K</td>
<td>GEO1S(C5)</td>
<td>KaVA Observation of PKS1510 at K-band</td>
<td>KJC</td>
<td>KVN Done</td>
<td>All</td>
<td>Finished (15.11.13)</td>
<td>1.2015.11.16</td>
</tr>
<tr>
<td>2015.10.27 (15300a)</td>
<td>k15mk01i</td>
<td>M. Kino/AGN</td>
<td>Q</td>
<td>VERA7SIOS (C5)</td>
<td>KaVA AGNWG Sgr A* Q-Band Monitoring (151027)</td>
<td>KJC</td>
<td>KVN Done</td>
<td>All</td>
<td>Finished (15.11.13)</td>
<td>1.2015.11.16</td>
</tr>
</tbody>
</table>
## Correlation Status

<table>
<thead>
<tr>
<th>Season</th>
<th>Observation</th>
<th>Corr Finished</th>
<th>Remain Corr</th>
<th>FITS release</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015B</td>
<td>26[~208hrs]</td>
<td>18</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>2015A</td>
<td>42[~336hrs]</td>
<td>42</td>
<td>0</td>
<td>42</td>
</tr>
<tr>
<td>2014B</td>
<td>30[~240hrs]</td>
<td>30</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>2014A</td>
<td>56[~448hrs]</td>
<td>56</td>
<td>0</td>
<td>56</td>
</tr>
</tbody>
</table>

- For KaVA, 500hrs observations are planned in every year. It will be increased to 1000hrs from next year.
- The 1Gbps correlation for KaVA is now conducted normally.
- Test 2Gbps correlation for KaVA was finished without any trouble. → So, next year 2Gbps correlation will be also conducted.

- KVN only observation data is correlated by DiFX.
2Gbps test correlation

- 7 stations (KaVA(6) + Sejong)
- 22GHz, 512MHz BW x 1IF, 2Gbps
Correlator Functional Expansion in near Future
KVN plans to introduce RF Direct Sampler next year.
Sampling
- 20Gsps x3bit, Max freq. 24GHz
- 4Gsps x10bit, Max freq. 10GHz (Opt 18G)
- 2Gsps x12bit, Max freq. 3GHz (Opt 18G)

DBBC
- Output bandwidth : 16~2048 MHz
### RF Direct Sampler DBBC output mode

<table>
<thead>
<tr>
<th>DBBC Output bandwidth [MHz]</th>
<th>Bit/sample</th>
<th>DBBC CH 1 x DSP</th>
<th>DBBC CH 2 x DSP</th>
<th>DBBC CH 3 x DSP</th>
<th>DBBC CH 4 x DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2048</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1024</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>512</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>128</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>64</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>32</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>16</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

- When FIR Tap number of LPF is 63, the above list is applied.
- The number of DBBC channel changes by the number of FIR Tap.
New terminal for ultra wide band at VERA

- Simultaneous Multi-Frequency
- Dual-Pol
8Gbps operation (current, 16 stations)

RVDB 8Gbps

Antenna Unit 1 (8Gbps)

Antenna Unit 2 (8Gbps)

Antenna Unit 3 (8Gbps)

Antenna Unit 4 (8Gbps)

... (Antenna Units 5 to 16)

Antenna Unit 16 (8Gbps)

Corr. & Accumul. Unit (CAU)

Data Archive System

VCS

4 VSI

10GbE

optical

optical

optical

optical

optical
**Needed equipment**

- **Hardware**
  - For KaVA 7 or 8 stations, 4 sets of RVDB2 system are needed. In this case, small costs are expected.
  - It will be simply to implement by introducing RVDB2 system.

**RVDB2 : OCTAVIA2 + OCTADISK2**
Conceptual considering phase for upgrade (16~32Gbps)

- **How to upgrade**
  - By modifying current equipment?
  - Introducing new design concept?
  - Introducing software correlator?

- **How long take to implement**
  - Planning

- **How much budget will be needed**
  
  briefly introduce the focus on hardware by modifying current system or adopting new design.
16Gbps operation (considering design, 8stations)
Considering item for 16 Gbps

Needed equipment

- Hardware
  - For KVN 3stations, 2 sets of RVDB2 system are needed.
  - For KaVA 7 or 8 stations, 12 sets of RVDB2 system are needed. In this case, big costs are expected.
32Gbps operation (considering design1, 4stations)

- RVDB2 8Gbps
- Antenna Unit (8Gbps)
- Antenna Unit (8Gbps)
- Antenna Unit (8Gbps)
- Antenna Unit (8Gbps)
- Corr. & Accumul. Unit (CAU)
- Data Archive System

- 32Gbps Synch playback
- 4 VSI
- Optical
32Gbps operation (considering design2, 7~8stations)

By changing Antenna unit input 4 VSI to VDIF

[Diagram showing connections between OCTDSK2 32Gbps, Antenna Unit (VDIF), VCS, Corr. & Accumul. Unit (CAU), and Data Archive System.]
Basic Standard Module by Elecs

- Proposed by Elecs industry Ltd.
- Requirement for Correlator Hardware
  - Flexibility
    - Easy to modifying function for scientific needs.
  - Scalability
    - Small start up, and expansion to a full large scale system.
  - Usability
    - Minimum down time in failure

- Basic Standard Module, BSM
  - FPGA based multi purpose hardware
  - 40GbE base general I/O ports

- Combination of BSMs completes a large scale hardware correlator
  - Small basic blocks form a complex large scale system
  - If one basic module is failed, other module substitute the function

BSM concept
Basic Standard Module

Diagram showing the interconnections between different components including:
- Memory > 1GB
- FPGA1 with 40GbE or 4x10GbE
- FPGA2 with 40GbE or 4x10GbE
- 100Base-T for control
- Control CPU ARM/LINUX
- Power source
32Gbps operation (considering design3)

- OCTDISK2 or Storage-based Playback (32Gbps)
- Storage-based Playback (32Gbps)
- OCTDISK2 or Storage-based Playback (32Gbps)
- OCTDISK2 or Storage-based Playback (32Gbps)
- OCTDISK2 or Storage-based Playback (32Gbps)

VCS

Corr. & Accumul. Unit (X)

Data Archive System

By using Storage-based plybak, By introducing BSM(F) part

Storage-based Record/ploybk develop will be started in 2016
E-shipping is now conducting for KVN
eVLBI by using the KREONET, OCTAIVA2 and OCTADISK2
- 2, 4, 8 Gbps/station @ KJCC in near future
Daejeon correlator
- is now normally operating with 1Gbps for KaVA.
- Will be normally operated with 2Gbps soon.
- Will conduct 4 or 8Gbps correlation.

For functional upgrading of Daejeon correlator
- how to make a plan
- How to implement: design and development
- How to get the budget