New development of EPICS-based data acquisition system for Electron Emission Diagnostics in KSTAR Tokamak

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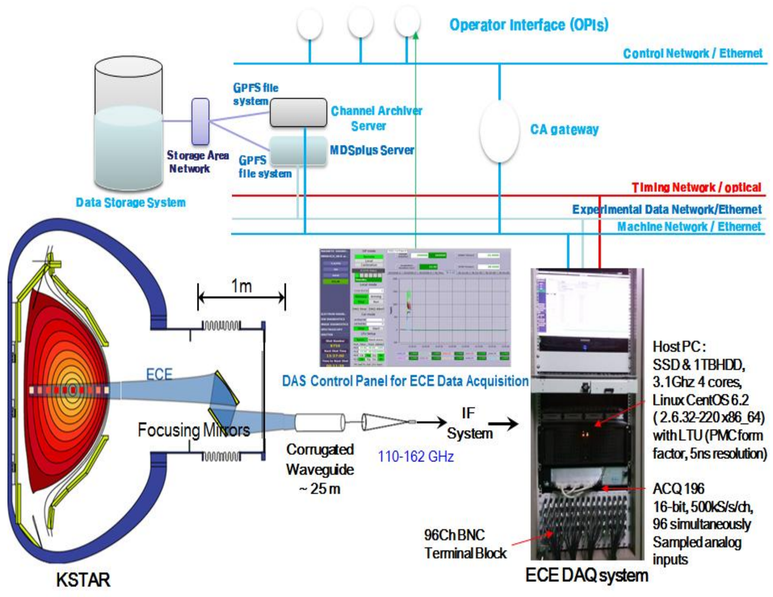
Korea Superconducting Tokamak Advanced Research (KSTAR) has operated and installed various diagnostic devices from the first campaign, and has executed to add, change and upgrade the devices according to KSTAR upgrade and installation plan every year. A data acquisition system of Electron Cyclotron Emission (ECE) Heterodyne Radiometer (HR) has been operated to measure the radial profile of electron temperature in KSTAR tokamak. At first, Linux OS platform was set up to VME-form factor with DAQ unit to measure ECE diagnostics. At the first campaign, 8 channels were measured and stored, DAQ system was developed as EPICS middleware in the Linux OS platform like other diagnostic and control devices of KSTAR. To store data, MDSplus DB was used, and Qt was used with DAQ Control UI. This system measured 2 other diagnostic devices as well as ECE at the same time (H-Alpha, millimetre-wave interferometer). ECE was increased to total 40 channels at the second campaign and 48 channels at the third campaign, and VME unit as the same farm-factor was newly set up to operate. At the fourth campaign, 76 channels were extended to operate. But, there were some limitations in the new VME DAQ. First, sample rate was limited to 100 kHz, and loss of test data was increased every year due to the instability of embedded DAQ system. For ECE electron temperature diagnostic data, over 100 kHz was required to measure and store, so cPCI-form factor was newly set up to operate the unit stably in 2012. And there's, in the existing system, disadvantages that data was stored to local HDD, and could be identified after long time with shot-off. DAQ system was newly set up to compensate the disadvantages. It was realized with a function to measure and store data to MDSplus and to display raw data in real-time in 2012, and in 2013, the other function to display and calculate electron temperature according to each position by channels depending on change of TF magnetic field in run-time and another function to calibrate a factor of radial profile with Electron Cyclotron Emission Heterodyne Radiometer prior to testing were set up. As a result of operating the device in 2012 and 2013, it was stably operated and increased the availability of system. Also, by using ECE real-time data, the real-time plasma control was successfully tested through Ethernet.

➢ Data Acquisition Systems for Diagnostics

- Continuously increasing diagnostics campaign by campaign
- Almost 30 diagnostics has been operated in the 6th campaign [1]

DAQ System	Diagnostic System	CH	Description
MD	Rogowski Coil	3	•1 cPCI crate with 2 independent backplane •2 Linux servers with PCI expansion •Total 576 channels on 6 digitizers •max 500KSPS (digitizer itself) •Streaming data acquisition •Full EPICS and MDSplus integration
	Flux/Voltage Loop	45	
	Magnetic Field Probe	232	
	Diamagnetic Loop	8	
	Saddle Loop	40	
	Vessel Current Monitor	3	
	Halo Current Monitor	32	
	Probe system	12	
MMWI	MMW Interferometer	2	•PXI, Linux host, max 500kHz
HALPHA	H_Alpha Monitor	30	•1 cPCI, Linux host •1 digitizers(max 500KSPS)
ECE_HR	ECE Heterodyne Radiometer	76	•1 cPCI, Linux host •1 digitizers (max 500KHz)
TS	Thomson scattering Diagnostic	45	•Single Linux host and VME crate •Current charging digitizer
ER	Edge Reflectometer	6	PXI, max 200MHz
MC	Mirnov Coil	40	•2 VXI, Windows host •10 digitizers (1 ~ 800kHz)
SXR	Soft X-ray Array	64	•PXI, Linux host •8 digitizers (max 500KHz)

- Interface : RTM-T
  - ✓ PCI-Express on cable x 1
  - ✓ Streaming data is transferred over 200 Mbyte/sec to a host PC
- Other : BNCPANEL
  - ✓ 2U rack-mount steel panel
  - ✓ 32 isolated BNC connectors x 3
- DAQ system receives signals from ECE detector module
- OPI displays the real-time data and changes parameters to control the DAQ system through Machine Network
- The DAQ system archives raw data saved in a local SSD disk to MDSplus DB in central storage system through Experimental data Network



➢ Some limitations of before DAQ system

- Performance limitation in storing data to local HDD
  - ✓ It could not store data to local HDD sufficiently (data rate, 200kHz * 96ch * 4Byte =74MB/s)
  - ✓ It takes a long time for storing after shot
  - ✓ It could not display raw data during shot
- DAQ system fault during the shot
  - ✓ The system often caused fault during shot
  - ✓ It could not store data when a fault is occurred

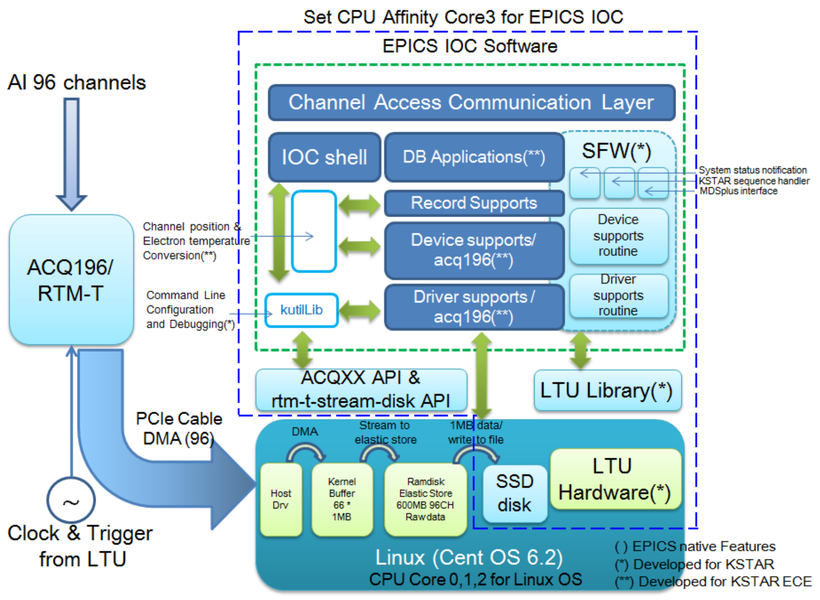
➢ Requirement of the New DAQ system

- Reliability and long term stability
  - ✓ Running digitizer in KSTAR
  - ✓ The DAQ should operate without system fault
- Real-time ability – control and data monitoring on real-time
- Acquire high sample data over 500 kHzS/s per channel
- Long time data archive over 300 sec per shot

➢ S/W development for ECE DAQ system

Classification	Name / Version	Remarks
Operating System	Cent OS 6.2 Kernel 2.6.32-220. x86_64	
EPICS	Base 3.14.12 and Extensions	Control application
MDSplus	MDSplus 3.0-1	Pulse-based archiving of experimental data
GUI	Qt 4.3.2	To develop OPI with in-house KSTAR Widget Toolkit (KWT) [4]
Digitizer driver & API	ACQ2XX_API 1.11 RTM-T hostdrive	Hardware driver and application
EPICS Device/Driver	drvAcq196 for acq196 digitizer drvCLTU for the TSS drvKutil for debug drvSFW for sequential operation	In-house development SFW – to reduce development time and to improve system reliability [5]

- Standard software framework(SFW) composed of an EPICS library(sfwLib)
  - ✓ Provides essential functions to support common records
- Streaming data (1MB) archiving from ACQ196 to host kernel buffer(1MB * 66)
- Extraction of 1 point data per each channel from 1MB data for raw and Te data to display on real-time
- Storing data in local SSD during a shot
- After shot, DAQ system archives raw data from Local SSD to MDSplus DB

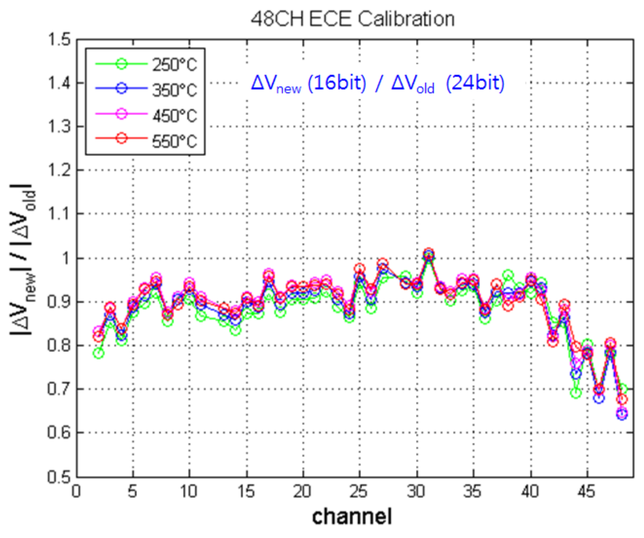


➢ H/W upgrade for ECE DAQ system

- Selection of the cPCI-form factor digitizer and development of a new ECE DAQ system with ACQ196 digitizer
- Controller : Host PC
  - ✓ Intel® Xeon CPU E31220 @ 3.1 GHz 4 cores with 8 Gbyte RAM
  - ✓ 160 GB SSD and 1TB HDD
- Digitizer : D-Tacq ACQ196
  - ✓ 96 simultaneously sampled analog inputs
  - ✓ 16-bit resolution, 500kS/s per channel
  - ✓ ±10 V input range
- Time synchronization : LTU (Local Timing Unit) [2][3]
  - ✓ Resolution and accuracy 5ns
  - ✓ Output clock : 1Hz ~ 100MHz
  - ✓ Max 50 multi triggering sections
  - ✓ 2Gbps Optical communication speed
  - ✓ Extension : Configurable 8 channels (Trigger or Clock)

➢ Calibration with new digitizer

- Calibration had been performed with a new DAQ system before campaign
- Calibration with old DAQ, VME form-factor 24-bit resolution
  - ✓ 100 kHz/S/s, 1 second measured per a shot
  - ✓ 4 temperatures x 1000 shots = 4000 shots
- Calibration with new DAQ, cPCI form-factor 16-bit resolution
  - ✓ 500 kHz/S/s, 15 seconds measured per a shot
  - ✓ 5 temperatures x 200 = 1000 shots
- The calibration result with new DAQ system showed data missing in 2 of 1000 shots
  - ✓ These were caused by delay of deleting buffer space in ramdisk (other API overuse of CPU and memory)
  - ✓ Data missing was solved by isolation of 1 CPU for EPICS IOC of 4 CPUs
- Comparison of calibration factor between new and old DAQ
  - ✓ Calibration with two different digitizers showed almost same results

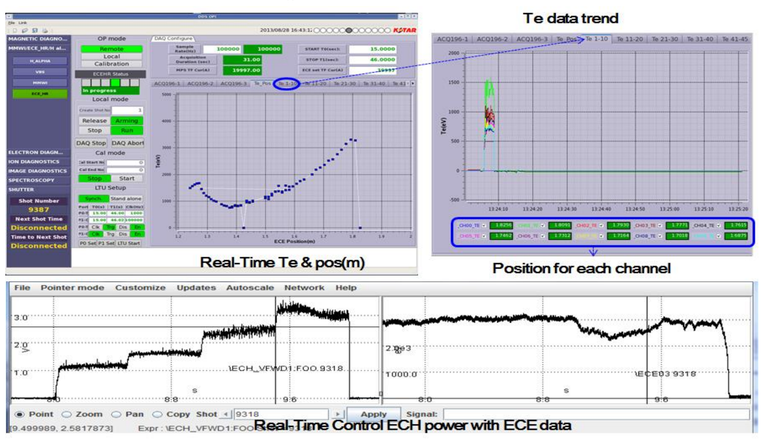


➢ Operation Results

- A new ECE DAQ system improved stability and reliability of system
  - ✓ system fault has not been occurred
  - ✓ data loss was caused by user's mistake
- Higher data sampling frequency
- Implementation of additional functions
  - ✓ displays electron temperature in real-time
  - ✓ displays data of Te trend and position of channel
- Enhance of electron temperature calculation procedure

Campaign	DAQ fault counts	Lost shots	Total shots
1st 2008	23 (VME)	23	1283
2nd 2009	4 (VME)	2	1059
3rd 2010	14 (VME)	17	2126
4th 2011	1 (VME)	2	2002
5th 2012	0 (cPCI)	3	1822
6th 2013	0 (cPCI)	5	1071

- OPI panel has been developed by using in-house KWT
  - ✓ to control cPCI DAQ
  - ✓ to display electron temperature and raw data in real-time
- Result of ECH power control using ECE data in real-time
  - ✓ through CA (Channel Access) in 1G Ethernet
  - ✓ successful control of plasma



➢ Summary and Future Plan

- A new developed ECE DAQ system has been upgraded and successfully operated during KSTAR experimental campaigns.
- A new 500kS digitizer was used for measuring ECE signals
- Calibration results with two different digitizers were almost same.
- Successful plasma control by using ECE real-time data and display of electron temperature data on OPI panels in real-time
- In future, segments data will be stored to MDSplus DB without delay

➢ References

[1] Mikyung Park, et.al.., "Data acquisition system implemented with various platform for KSAR diagnostic systems", Fusion Eng.Des. 85 (2010) 350-355.
[2] Mikyung Park, et al.., "Development of a Prototype Time Synchronization System for KSTAR with a VME-bus System", Fusion Eng. Des. 81 (2006) 1817-1821
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[5] Woongryol Lee, Other, "Design and implementation of a standard framework for KSTAR control system", 9th IAEA TM on Control., (2013).

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