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New Development of EPICS-based Data Acquisition System for Millimeter-wave Interferometer in KSTAR Tokamak

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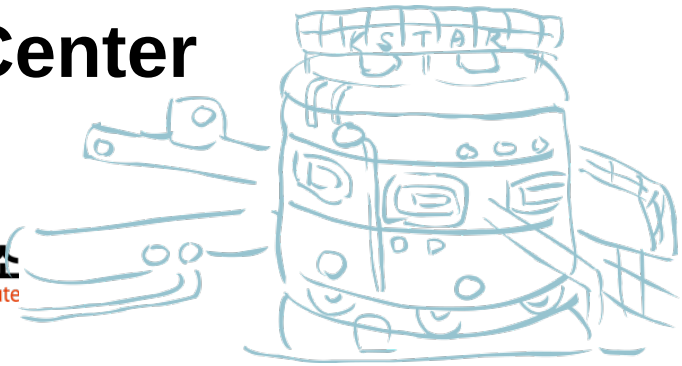


Outlines

- **Introduction**
  - KSTAR control system and diagnostic DAQ systems
  - What is Millimeter-wave Interferometer ?
  - First date acquisition system for the diagnostic
  - Why need new DAQ system ?
- **Upgrade DAQ system**
  - What are the considerations in design ?
  - Details about system hardware and software
  - How to calculate the density in real-time ?
- **Operation Result in the 4th Campaign**
- **Summary**

Features of KSTAR Control System

Structure	2 Tier		•Control --- Interlock+Safety
	2 Layer		•Central --- Local
Middleware	EPICS		
Operating system	Linux		•Plant monitoring & control
	VxWorks		•Feedback control
H/W Platform	Slow control		•PLC, cFP
	Fast control		•VME, PXI, cPCI, PCI, VXI, (ATCA)
Interface (Networks)	**M**achine	EPICS CA	•Plant monitoring & control •Operational data transfer
	Experimental Data	MDSip	•Shot-based data storing
	Real-time	Shared-memory	•Real-time feedback control
	Interlock	(ControlNet)	•Machine interlock & protection
	Timing	Home-made protocol	•Timing & synchronized operation
OPI	Qt (open source)		•Home made libraries
Data Managements	EPICS Channel Archiver		•Low rate continuous operational data
	MDSplus		•High rate shot-based experimental data

Diagnostics in KSTAR

Data Acquisition Systems for Diagnostics

- **Continuously increasing diagnostics campaign by campaign**
- **Almost 30 diagnostics operate in the 4th campaign**

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 VME crate with SBC •2 digitizers(max 100KSPS)
ECE_HR	ECE Heterodyne Radiometer	76	•1 VME crate with SBC •3 digitizers (max 100KHz)
TS	Thomson scattering Diagnostic	45	•Single Linux host and VME crate •Current charging digitizer
ER	Edge Reflectometer	4	PXI, max 200MHz
MC	Mirnov Coil	40	•VXI, Linux host •10 digitizers (1 ~ 800kHz)
SXR	Soft X-ray Array	64	•PXI, Linux host •8 digitizers (max 500KHz) •PSU control •Timing distribute board

First DAQ System for MMWI

What is Interferometer?

- Interferometry is a widely used diagnostic tool for measuring electron density which is a primary plasma parameter
- In KSTAR,
  - ✓ A 280GHz single-channel horizontal MMWI is installed
  - ✓ It is suitable for low line-integrated electron density
  - ✓ Electron density ~ about $10^{19}/m^2$

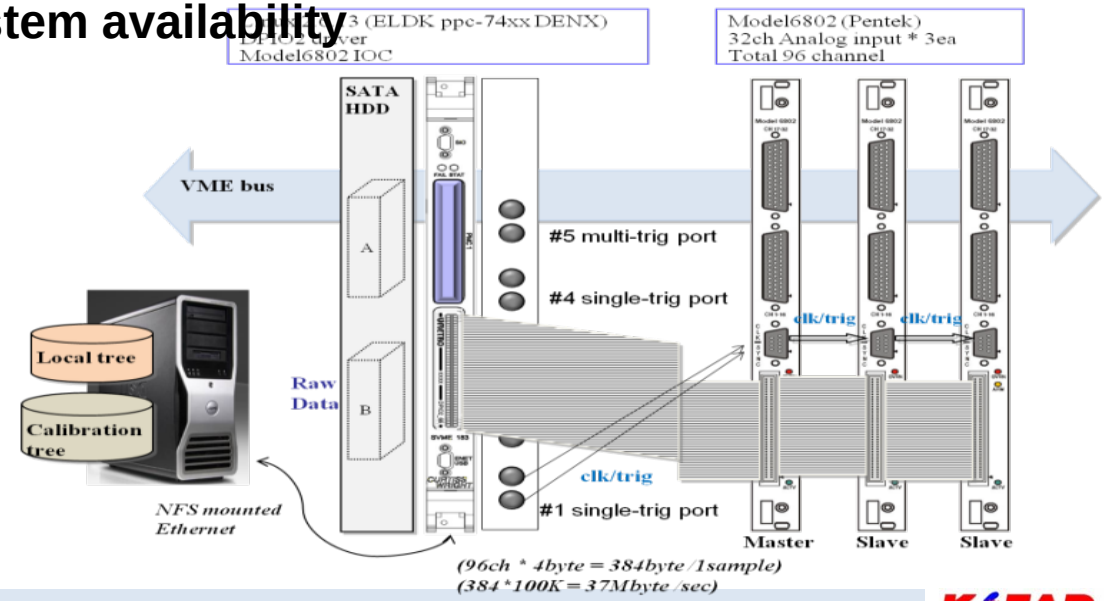
First DAQ system for MMWI

- The first DAQ system was developed for 3 difference diagnostics having similar channel characteristics for H/W utilization
  - ✓ MMWI, ECE Radiometer and H-Alpha monitor
- Features of DAQ System :
  - ✓ VME-form factor with 3 digitizers, totally 96 channels
  - ✓ CPU : SVME-183 (1.2GHz) (Curtis-wright)
  - ✓ Digitizer : Pentek M6802 (24-bit, 32CH, max 260kSPS)
  - ✓ O/S : Embedded Linux 2.6.20
  - ✓ Data stored in a local SATA disc thru FPDP
    - SATA HDD throughput : write (50.33MB/s)

First DAQ System for MMWI

Some Limitations of First DAQ system

- **Limitation in storing data** to local HDD
  - ✓ At 200KHz sampling, data rate = 200k*96CH*4Byte=74MB/s
  - ✓ At 100KHz sampling, it takes a long time for storing
- **Inefficient data management**
  - ✓ When one of three diagnostics obtains data at higher frequency, the others have to acquire unnecessary data
- **Un-isolated fault propagation** in operation
  - ✓ When a fault occurs in one diagnostic, it propagates to the others
  - ✓ Therefore, it reduces system availability



Upgrade DAQ System for MMWI

System Composition and Specification

- **Considerations in design :**
  - ✓ Does it support Linux OS? KSTAR standard OS is Linux
  - ✓ Is it stable for long-time operation without system reset?
  - ✓ Is it suitable for reducing development time and improving system reliability? Do we have experiences to develop?
  - ✓ Is the price reasonable?
- **We chose PXIe form-factor**

1) **Controller : PXIe-8108 (NI)**
   - ✓ 2.53GHz dual-core PXIe embedded controller with 4GB DDR2 RAM
   - ✓ up to 1GB/s system bandwidth and 250MB/s slot bandwidth
2) **Digitizer : PXI-6123 (NI)**
   - ✓ 8 simultaneously sampled analog inputs
   - ✓ 16-bit resolution, 500kS/s per channel, from ±1.25 to ±10 V input range
3) **Time synchronization : LTU (Local Timing Unit)(Home-made)**
   - ✓ Resolution and accuracy 5ns, output clock (1Hz ~ 100MHz)
   - ✓ Multi-triggering section : max. 8 (configurable)
   - ✓ 2Gbps optical communication using a dedicated Timing Network

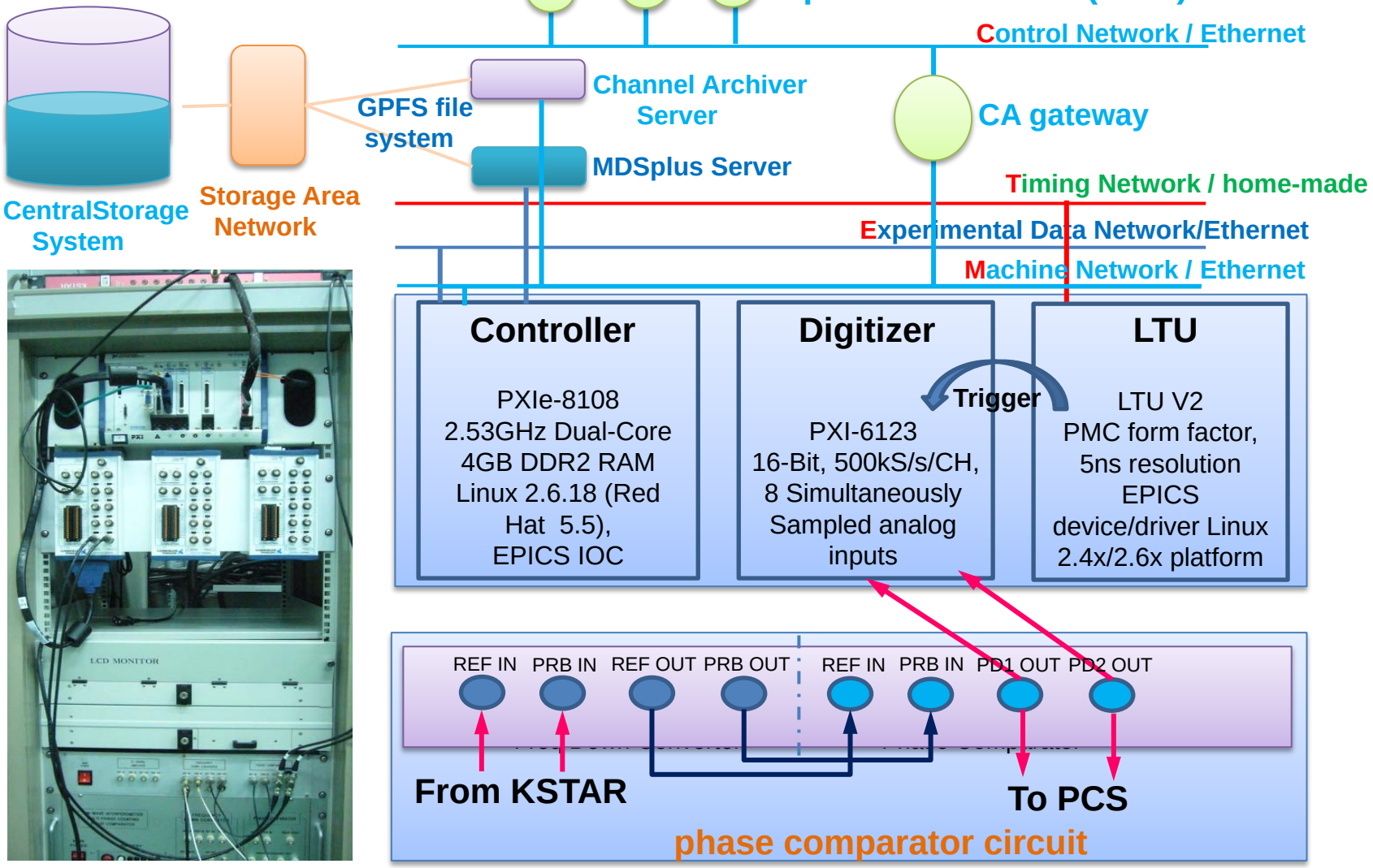
Upgrade DAQ System for MMWI

Development Environment

- **OS : RedHat Linux 5.5 (kernel – 2.6.18-194.e15)**
- **EPICS Base – 3.14.12.**
  - ✓ **Control application, device/driver for PXI**
- **MDSplus (2.3-0) : Pulse-based archiving of experimental data**
- **Qt 4.3.2**
  - ✓ **To develop operator interface panels**
  - ✓ **Use in-house developed Qt libraries, KSTAR Widget Toolkit (KWT)**
- **NI-DAQmx (8.0.2) : Hardware driver for PXI**
- **SFW (Software Frame-Work) :**
  - ✓ **in-house developed standard template**
  - ✓ **To reduce developing time and improve system reliability**
- **sysMonLib : To monitor system health status**
- **LTULib : Hardware driver for in-house developed local timing unit (LTU)**
  - ✓ **To synchronize with KSTAR experimental cycle**

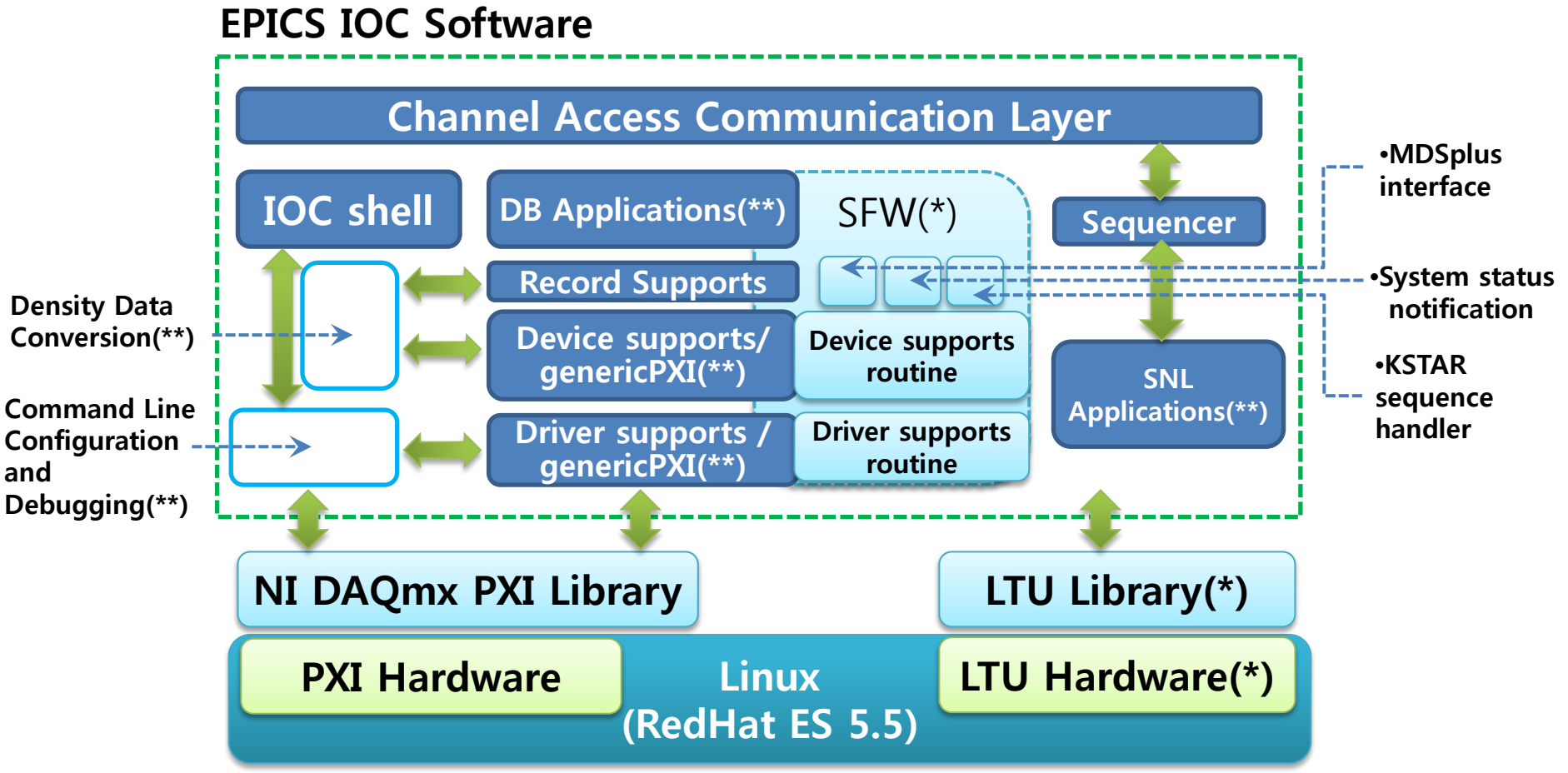
Upgrade DAQ System for MMWI

Configuration



Upgrade DAQ System for MMWI

Functional Block Diagram of IOC

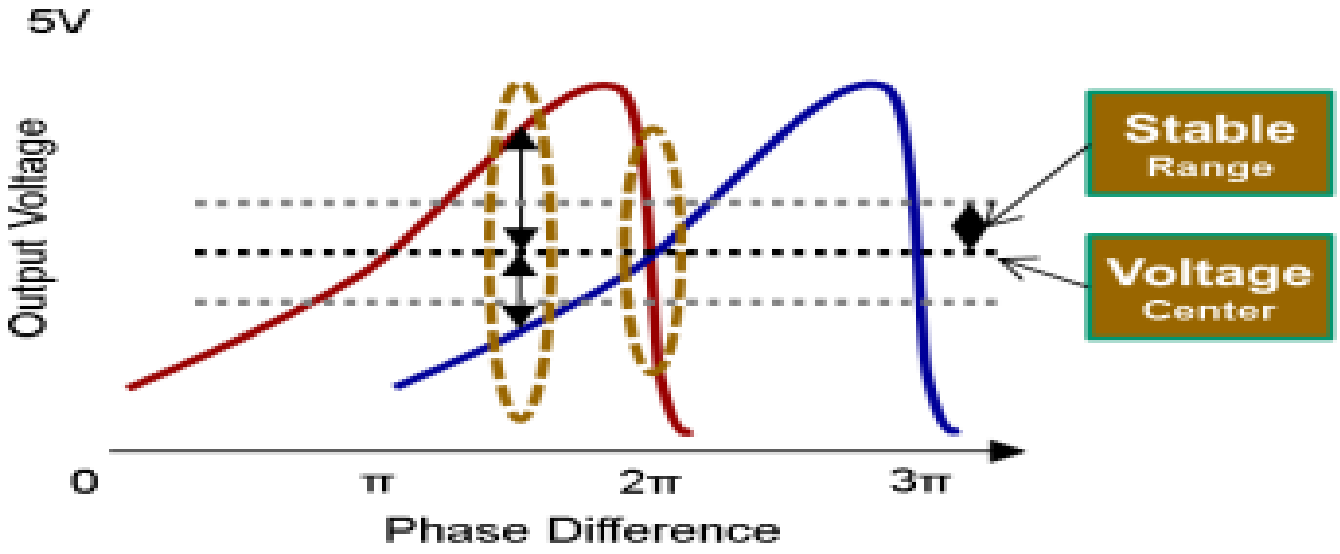


( ) EPICS native features
(*) Developed for every DAQ system
(**) Developed for MMWI

How to Measure Plasma Density?

Features of Interferomenter Signals

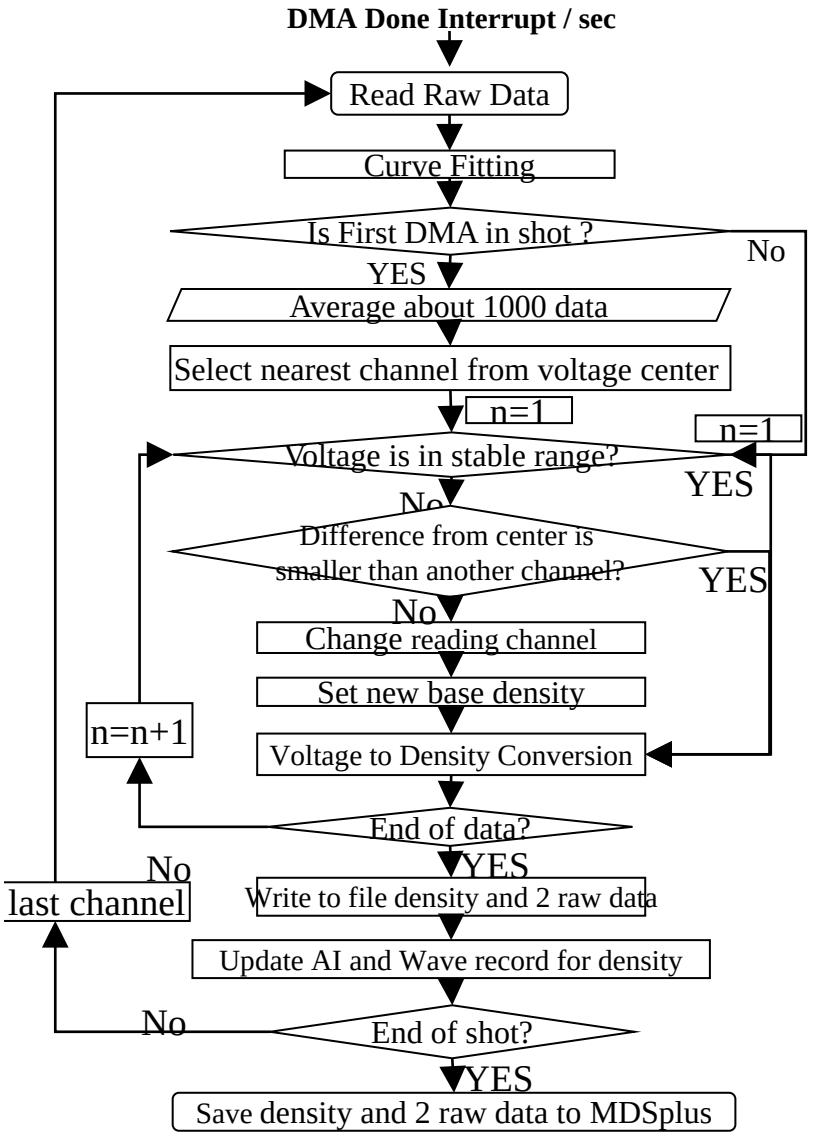
- When millimeter-wave travels through plasma, its phase is changed in proportional to the plasma density
- A phase comparator measures the phase difference and outputs a voltage signal
- If the measured phase difference exceeds 2π, the fringe jump occurs and the output voltage goes back to zero.



How to Calculate Density in Real-time?

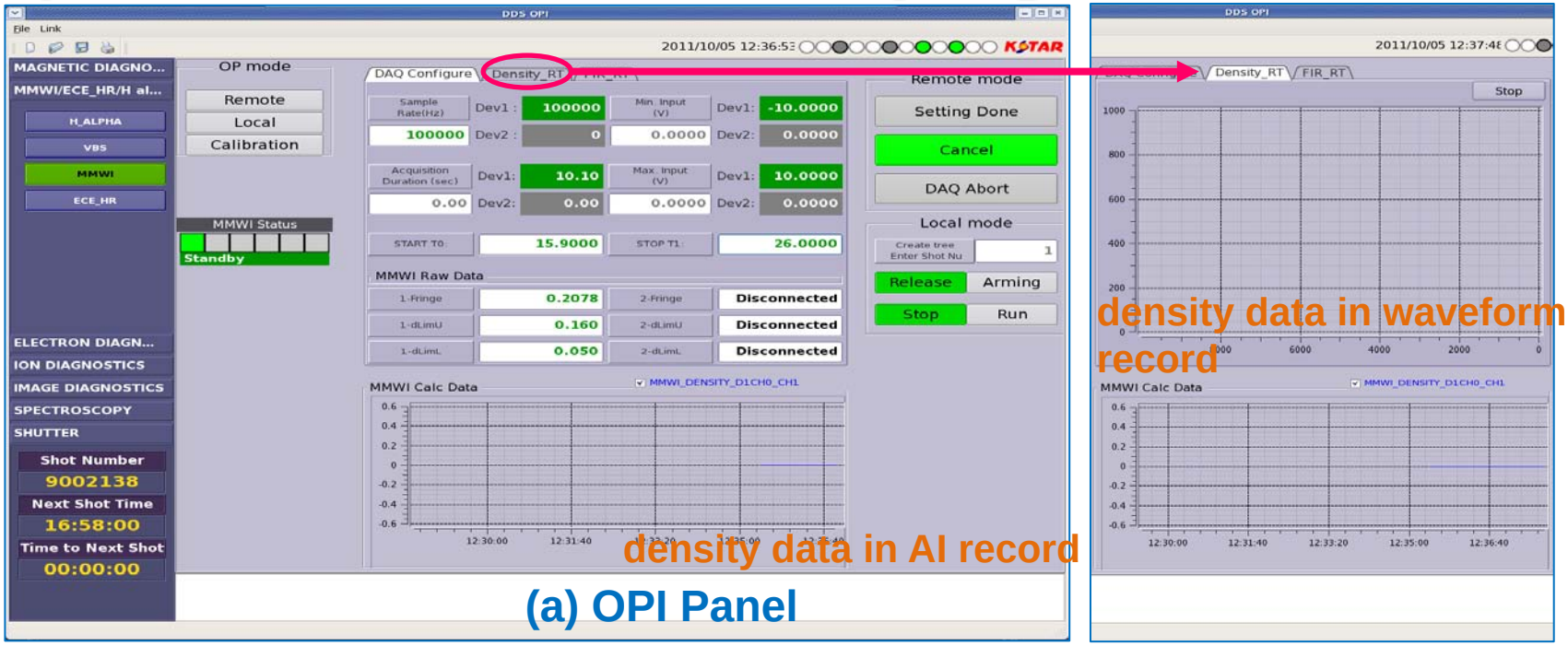
Data Processing Sequence

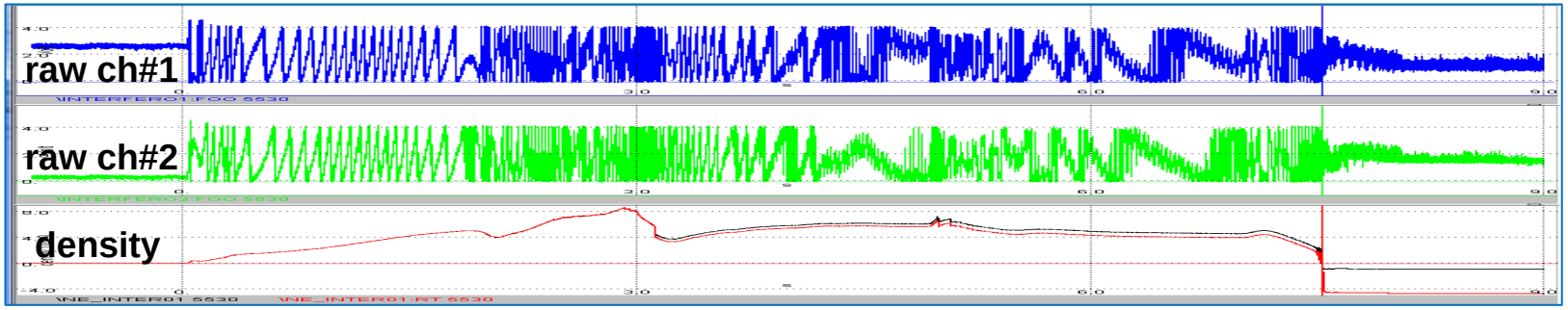
- DMA done Interrupt / sec
- Fitting to compensate for a slight curvature of the phase comparator circuit
- Select nearest channel from voltage center
- Density conversion with the selected channel
- End of data process in buffer
- Write data to file : density and 2raw data
- Update AI/Waveform record with density data
- This sequence is repeated at every DMA interrupt
- 2 Raw & density data transmitted from local HDD to MDSplus DB in the central storage



Operation result in the 4th campaign?

Operation Panel and Density Signal





(b) Plasma density

Operation Results in the 4th campaign?

What are improved ?

- Increase data sampling frequency
- Improve system stability and reliability
  - ✓ system fault has occurred just one time
- Optimize data size
- Implement additional function
  - ✓ Displays density data on real-time
- Enhance density calculation procedure

Campaign	Fault counts	Lost-shot counts	Total shot
1st 2008	23	23	1283
2nd 2009	4	2	1059
3rd 2010	14	17	2126
4th 2011	1	2	2002

What will be modified next?

- A small number of data points displayed in run-time during a shot
  - ✓ One density data at every 1sec, 10 points for a plasma pulse in 2011
  - ✓ It will be increased to 10 data at 1 sec

Summary

- In the 4th operation of KSTAR in 2011, the newly developed MMWI DAQ system operated as an independent system.
- Add to the solving the problems of the previous system, the new DAQ system has a few advantages in the views of hardware and software
  - ✓ Improved performance in data acquisition by adopting the standardization
  - ✓ More accurate synchronized operation with a new timing board
  - ✓ Run-time calculation and displaying of density data
- Also, there was a progress in the efficient data management
- The MMWI DAQ system will be modified to meet requirements arising in operation such as;
  - ✓ Increasing the DMA event counts for the effective run-time displaying
  - ✓ Real-time data archiving to reduce the waiting time in MDSplus DB