Data processing in the data acquisition system of the vertical neutron camera plasma diagnostics at the ITER tokamak

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Abstract. The vertical neutron camera (VNC) diagnostic system’s role is the study of the plasma physics and plasma pulse control at the ITER tokamak. The VNC provides neutron flux measurements and the neutron and alpha source profile across the plasma. The VNC is composed of two neutron cameras: an upper one and a lower one. The upper VNC is located in upper port plug 18 and contains 6 fan-shaped collimators to observe the inner part of the plasma. The lower VNC is located in lower port plug 14 behind the diverter cassette and contains 5 fan-shaped collimators with the line of sight (LoS) focused on the outer part of the plasma. Each collimator has a detector unit composed of two diamond detectors and two fission chambers. The electrical signal is transmitted from the neutron detectors to the data acquisition system by a triaxial cable with mineral isolation. The signal from the neutron detectors is preliminarily amplified by current pre-amplifiers, digitized with a sampling rate of 250 MHz and transmitted from the port cell zone to the diagnostic building under normal environmental conditions by digital optical lines. In the diagnostic building, signal is preliminarily processed and transmitted to the ITER central control system. The data acquisition system was designed according to the following ITER guidelines: the Radiation Hardness Policy (RHA), the Electrical Design Handbook (EDH), the Plant Control Design Handbook (PCDH), and the Annex B for VNC Procurement Arrangement (specifies the special requirements for measurement procedures and results).

1. Data acquisition system architecture

The VNC data acquisition system architecture is shown in Figure 1.

The DAQ (data acquisition) system is composed of two parts: a remote part, which is located close to the detector units in the port cell under strong radiation and electromagnetic fields, and the main part, which is located in the diagnostic building under normal environmental conditions.

The remote part consists of current pre-amplifiers and measurement modules that digitize the output signal from the pre-amplifiers and transmits data to the main part of the DAQ system via digital optical lines. Optical lines implement the function of galvanic isolation between the remote and main parts of the system to provide electromagnetic compatibility of the neutron detectors with the DAQ system.
Figure 1. VNC data acquisition system architecture.
The main part of the DAQ system consists of processing modules that acquire digitized data and process it into three modes: a count mode, an ADC mode and a spectroscopic mode. The processed data are transmitted to the interface node of the DAQ system via an optical line.

The interface node role is integration of the measurements to the ITER control system, CODAC. It consists of an industrial PC and PXIe chassis with the following installed modules: NI FlexRIO with an adapter for the optical lines and a NI 6683H synchronization board to synchronize with the ITER clock and for time-stamping the measurements.

2. Registration and preliminary amplification of the signal

The neutron detectors are powered by a 400 V offset voltage when the detector captures a particularly low current produced in the signal chain. The current for the fission chamber is 1–2 μA, and for the diamond detector, it is 300 nA. A signal with such a low amplitude cannot be transmitted over a long distance and should be preliminarily amplified. In our case, a current pre-amplifier was chosen for signal amplification, and it was correctly integrated to the detection system. The pre-amplifier generates a voltage pulse with an amplitude in proportion to the energy of the detected particle.

For calculation of the spectrum of registered particles, the output signal from the current pre-amplifier should be produced with the following characteristics:

- A maximum pulse amplitude is 2 V;
- An output pulse duration on the pulse base of no more than 75 ns, and for the middle level amplitude, no less than 25 ns;
- A noise level that should not exceed 200 keV for a neutron energy of 5 MeV.

The output signal from the current pre-amplifier may have deformations that are caused by internal noise from the electronics, external electromagnetic noise, non-compatibility of signal chains and non-linearity of the pre-amplifier. The oscillograms of the output signals from the pre-amplifiers are shown in Figures 2 and 3. The signal in Figure 3 has a deformation for the reflected signal due to non-compatibility of the input resistance.

3. Analog to digital conversion of the signal

The amplified signal is transmitted to the differential input of the scaling amplifier with a working bandwidth of 0–50 MHz and an input signal range from –1 to +1 V, and then it goes to the low-pass filter. The differential input reduces the common-mode noise in the signal lines from the pre-amplifiers, and the low-pass filter reduces the high frequency modes of the input signals, which are out of the bandwidth for the measurement channels (0–50 MHz).

Then, the signal values are transformed to 14-bit digital samples with a sampling frequency of 250 MHz in the real-time mode and transmitted to optical transmitters-receivers (OTR). The functional scheme of the measurement line for one channel is represented in Figure 4.
4. Digitized data acquisition and preprocessing on FPGA

Digitized samples are transmitted from the measurement modules to the processing modules by optical lines with a 5 Gb/s rate in the real-time mode. Data acquisition is performed by an aggregator, which acquires data from two transmission lines from the measurement module at a rate of 10 Gb/s. The aggregator divides the input data stream by eight output streams via a 2.5 Gb/s rate in the real-time mode. The output streams are divided into two groups by four channels and transmitted to the transceivers. The transceivers decode the data and transform them from the serial to parallel format. Data are represented on transceiver outputs as four 2-byte samples with service information.

The final digital samples are processed and produce the measurements, which occur in the data processing node based on FPGA. Each node processes data in three modes:

- Count mode
- ADC mode
- Spectroscopic mode

The data processing node includes:

- A digital filter to reduce noisy high frequency modes of the input signals;
- A module of relevant event localization and determination of its maximum;
- A logical block and auto-incremental memory element that produces an amplitude spectrum, threshold logic and an event counter array with programmable discrimination levels by signal maximum values;
- An ADC registration channel with control logic.
- The functional scheme for the data processing node based on FPGA is shown in Figure 5.

The data processing results in each channel mode are transmitted to the crate controller every 20 ms. The results are transmitted by the crate controller by their generation rates via a serial optical link to the next system level, which is the interface node of the VNC DAQ system. The interface node includes a NI FlexRIO module installed in the PXIe chassis, which is connected to a 3-channel optical link adapter.

The NI FlexRIO module was chosen from the ITER I&C hardware catalogue, which is mandatory to use in the ITER project and performs an interface function of determining the electronics integration with the ITER data acquisition and CODAC control system.

![Figure 4. Functional scheme of the measurement line for one channel](image-url)

![Figure 5. Functional scheme for the data processing node based on FPGA.](image-url)

The process of integration to the ITER EPICS-based SCADA system CODAC core system is described below.
5. Data transmission to the ITER CODAC control system

The interface node for the data acquisition system (Fast Controller) consists of a combination of an industrial PC and a NI PXIe chassis with installed boards that have different functionalities. This node performs data acquisition, additional data processing and calculations of physical plasma parameters, time-stamping and synchronization with ITER clocks with a defined accuracy. Representation of the results is done in proper data format for data exchange with CODAC and data transmission to CODAC, the Central Archive and Plasma Control System.

The hardware interfaced to the CODAC have different levels of integration. These schematic levels are shown in Figure 6.

Figure 6. Hardware integration levels.

The Linux operational system drivers are located on the lowest level. At this level, interfacing with the hardware device is performed via API functions. The next level has the EPICS device support. This level is represented by the EPICS IOC (Input Output Controller) program application. At this level, data exchange with the device can be performed via EPICS PVs (Process Variables).

The EPICS PVs database is located in the EPICS IOC. The measurements from the input/output devices (e.g., NI FlexRIO) are associated with records in the EPICS database. They acquire timestamps and are transmitted to the CODAC via the PON (Plant Operation Network) and channel access protocol.

Transmission of the raw measurements from the input/output device for buffering is performed by DMA (Direct Memory Access) technology. The EPICS IOC reads the raw data from the buffer and transmits them to the central archive via DAN as an EPICS PV array.

After data publication, the PON results become available for viewing and analysis on HMI (Human Machine Interface) screens. The test operator’s screen of the VNC data acquisition system is shown in Figure 7.
The measured signals from 6 processing modules are shown on the HMI. Additionally, it is possible to select one of four channels for each module. Data from every channel are available in the ADC mode or spectroscopic mode. Discrimination levels and the duration of the working cycle are also available in the configuration tabs.

6. Conclusions
The VNC data acquisition system should provide measurements that fully correspond to the ITER requirements for accuracy and time resolution for safe ITER operation and for the study of the physical plasma parameters in the real-time mode. The described data acquisition system was designed according to environment conditions and ITER requirements and guidelines. The measurement process consists of signal registration and its pre-amplification, digitization and transmission via optical lines to processing modules in the diagnostic building where the acquired signal is processed in three modes – the count mode, ADC mode and spectroscopic mode. The measurements are transmitted to the interface node of the DAQ system for final processing and transmitted to the ITER central control systems in a defined data format and with a defined accuracy. The described design resolves problems related to operating the electronics under certain environmental conditions for integration of galvanic isolation between the port cell and diagnostics building. Additionally, the high cost of the FlexRIO module was taken into account, and usage of a signal concentrator module led to DAQ system optimization due to cost.

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