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DESIGN OF DATA ACQUISITION AND CONTROL SUBSYSTEM OF THE KTM TOKAMAK MULTIFREQUENCY PULSE RADAR REFLECTOMETER

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A Kazakhstan Tokamak for Material studies (KTM) [1] is being developed by Russian and Kazakh scientists for modeling plasma-material interactions in the divertor region under conditions expected for ITER. The first results of designing a KTM radar reflectometer data acquisition and control subsystem (DACS) are presented. General requirements to the data acquisition and processing are defined. Problems of real-time processing and transmitting information to a Plasma Control System (PCS) are solved. A desirable time diagram of the DACS operation is shown and design approaches confirming it feasibility are given.

Keywords: Tokamak; Data acquisition system; Data processing; Radar reflectometer

INTRODUCTION

In experimental researches using advanced algorithms of plasma control in real time, it is required to determine an electron density profile with high time and spatial resolution. The level of fluctuations in the KTM plasma will allow us to research electron density with a spatial resolution of 1 sm and time resolution of 1 μs per point when radar reflectometer is used. As a result, a multifrequency pulse radar reflectometer with fixed frequency channels and its data acquisition and control subsystem (DACS) are being developed.

GENERAL REQUIREMENTS TO THE DATA ACQUISITION CHANNELS

An analysis of modern data acquisition systems of radar-reflectometers [2, 3] has allowed us to determine the requirements to the data acquisition channels and their structure. The channels have to include: a video-amplifier with a passband of (0.1–1.5 GHz); a constant fraction discriminator providing binding to the leading edge of a reflected pulse with a

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precision of ±50 ps, a Time Amplitude Converter (TAC) with a time resolution of about ±50 ps; ADC consecutively sampling all frequency channels for less then 10 μs. Data acquisition have to be made by DACS in conjunction with global time of experiment, assigned and distributed to the DACS by synchronization system of KTM tokamak with precision of ±10 ns. Also it is necessary to carry out the synchronization of the microwave pulses launching into the plasma and the moments of starting of the TAC and ADC operation.

Data acquisition channels have to satisfy the listed above requirements during the plasma discharge when there is a strong electromagnetic noise. Modern techniques allow us to provide full galvanic isolation and electromagnetic immunity by transmitting of a wideband (0.1–1.5 GHz) analog signal from an experimental hall through a fiber-optic link. This technical approach was used at conceptual designing of data acquisition channels (Fig. 1) (E/O and O/E are the electro-optical and opto-electrical converters respectively).

CONCEPTUAL DESIGNING

At researches of density profile evolution, it is desirable to have as high accuracy and time resolution of measurements as possible while plasma control requires lower accuracy but high speed of real time processing and transmitting of information to control system. Designed subsystem should solve both these tasks.

For researches, the requirements to the data acquisition depend on spatial and time resolution of radar-reflectometer. The plasma control system imposes additional requirements. Hence, data acquisition cycle T_{daq} depends on control cycle T_{cs} (Fig. 2). According to this diagram, cycle duration T_{daq} have to be less than 100 ms. It requires to estimate whether it's possible to perform data acquisition, preliminary processing, density profile reconstruction and data transmission to PCS during T_{daq} cycle.

Estimation of DACS performance

Data sampling period is defined by radar reflectometer itself. Its duration is 1 μs per channel. Hence all ten channels are sampled for 10 μs.

Preliminary processing is used in order to increase measuring information accuracy. For reduction of preliminary processing time it is possible to start processing when data from the first channel is received and realize parallel calculation for all channels on hardware level. Thus, estimated time of the preliminary processing will be less than 10 μs.

Information stream dividing is required for transmitting the measured information to the PCS and to the 3rd level of the general Data Acquisition System (DAS). Thus it is desirable to divide these two information streams right after the data sampling, for which purpose the following is offered. The data acquired from ADC is written in a shared dual-ported memory. Cells of the memory are simultaneously read out in two ports without additional delays. Data from the first port are transferred to the 3rd level of DAS. The second port supplies data for density profile reconstruction.

The density profile reconstruction time depends on an applied algorithm and a way of its realization in real time. High accuracy of reconstruction is not necessary for the PCS, but very high speed of processing is required. A simple algorithm of reconstruction [4] was used in order to get high speed of calculations.

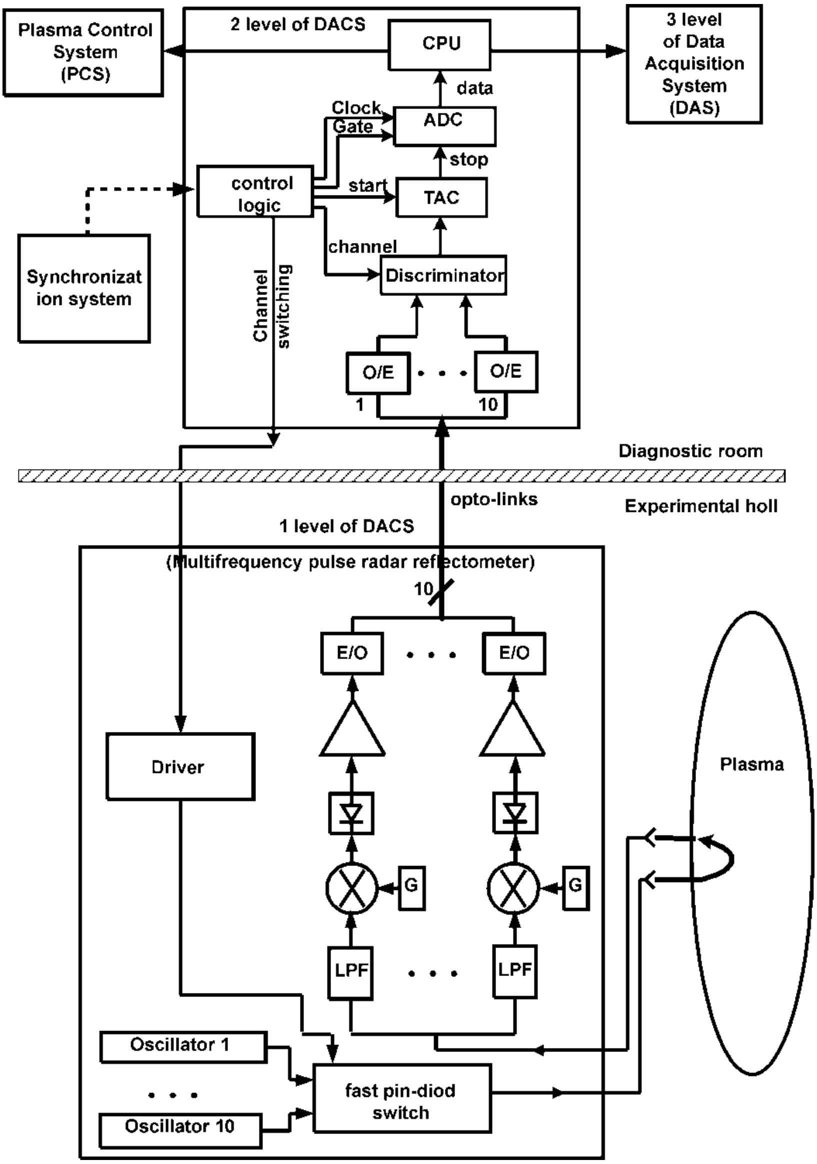

FIGURE 1 Data acquisition channels.

At the first part of algorithm, the calculation of integral equation (1)

$$\varphi(\omega) = 2\frac{\omega}{c}\int_{x_0}^{x_c} N(w, x)\,\mathrm{d}x + \varphi_0(w) \tag{1}$$

is executed by replacing integration by summation and making substitutions $\mathrm{d}x = x_j - x_{j-1}$, $N_i = (N_{i,j} + N_{i,j-1})/2$, $\phi_0(w) = 0$. Hence:

$$\varphi = \sum_{j=1}^{j=i} A_{i,j}(x_j - x_{j-1}) \tag{2}$$

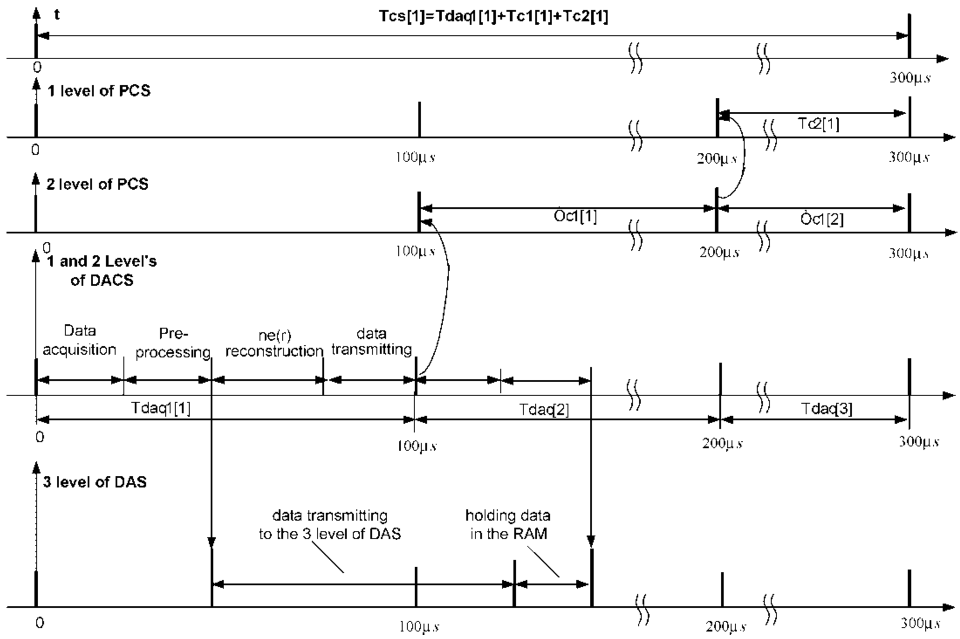

FIGURE 2 Time diagram.

where $A_{i,j} = (N_{i,j} + N_{i,j-1})w_i/c$, φ is the phase shift, N is the refraction index, x is the position of cutoff layer.

Calculation of Eq. (2) gives cutoff layer positions $\{x_i\}$, $i = 1, 2, \ldots, 10$. In the second part of algorithm, these points are used at plasma density profile approximation by the least-squares method.

For the estimation of processing time of the algorithm, the programmable logical device of FPGA type Altera Flex10K FPGA was used. The time of processing is less than 40 μs in this case. It shows that the proposed technical approach provides acceptable performance.

Data transmitting to PCS have to be made during about 10 μs. In each T_{CS} cycle the information about a new calculated density profile $n_e(r, t_k)$ has to be passed to the control system. Among widespread serial interfaces an Ethernet 100BaseT has been chosen. It allows to pass mentioned above data for 7.5 μs when operating at point-to-point topology. Reduction of data transmitting time should not lead to increasing of data processing time. Hence, neither transmitting raw data to PCS and then processing, nor data compression in real time before transmitting are effective decisions. In both cases we have to reserve time and computational power that is inadmissible or leads to a more complicated and expansive system.

While data transmitting to the third level of DAS, an Ethernet 100BaseT interface is also used.

DACS ARCHITECTURE

Described above requirements have been satisfied at the DACS architecture designing. The following requirements have also been taken into account:

– High functionality, reliability and flexibility;
– Complete set of required functional modules;

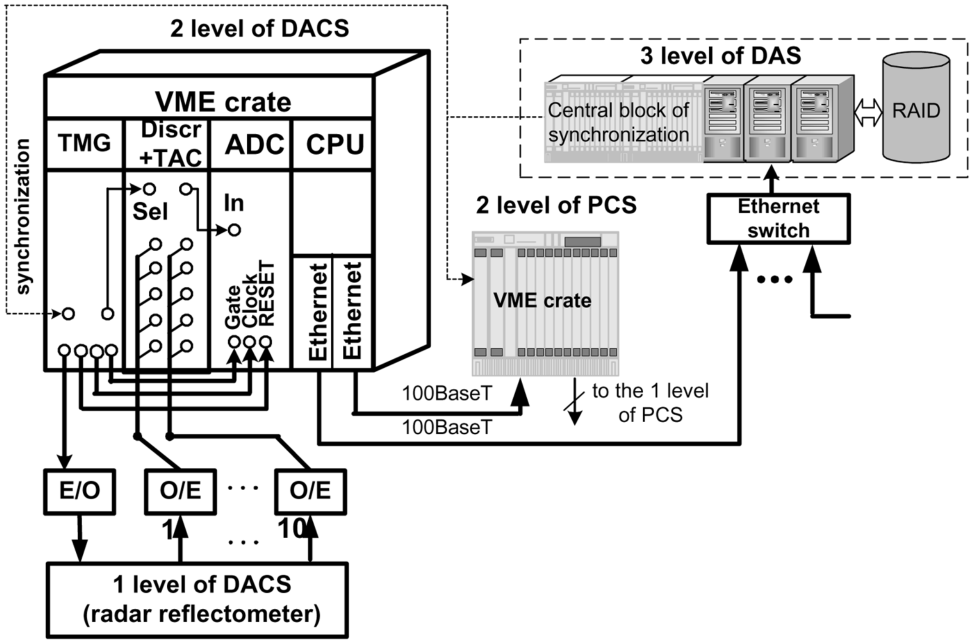

FIGURE 3 DACS architecture.

– Technical support of hardware by manufacturers;
– Widened opportunities for integration with other systems (PCS, DAS and synchronization system).

The VME-based system completely meets all these requirements. There is a wide choice of discriminator and TAC VME modules, single board VME-based computers and required communication interfaces are supported, and a lot of synchronization modules are supplied. The architecture of DACS and its interfacing with proper systems are presented on Figure 3.

CONCLUSIONS

The preliminary design decisions have shown an opportunity to realize all required functions during a cycle of measurement $T_{\mathrm{daq}} = 100\,\mu\mathrm{s}$. The next design tasks include creation of an advanced algorithm, DACS prototyping and testing.

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