Fusion Engineering and Design xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

The implementation of real-time plasma electron density calculations on EAST

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HIGHLIGHTS

- The real-time density calculation system (DCS) has been applied to the EAST 3-wave polarimeter-interferometer (POINT) system.
- The new system based on Flex RIO acquires data at high speed and processes them in a short time.
- Roll-over module is developed for density calculation.

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form 18 February 2016
Accepted 2 April 2016
Available online xxx

Keywords:
Real-time
Plasma electron density
Polarimeter-interferometer
FPGA

ABSTRACT

The plasma electron density is one of the most fundamental parameters in tokamak experiment. It is widely used in the plasma control system (PCS) real-time control, as well as plasma physics analysis. The 3-wave polarimeter-interferometer (POINT) system had been used to measure the plasma electron density on the EAST since last campaign. This paper will give the way to realize the real-time measurement of plasma electron density.

All intermediate frequency (IF) signals after POINT system, in the 0.5–3 MHz range, stream to the real-time density calculation system (DCS) to extract the phase shift information. All the prototype hardware is based on NI Flex RIO device which contains a high speed Field Programmable Gate Array (FPGA). The original signals are sampled at 10 M Samples/s, and the data after roll-over module are transmitted to PCS by reflective memory (RFM). With this method, real-time plasma electron density data with high accuracy and low noise had been obtained in the latest EAST tokamak experiment.

1. Introduction

In tokamak experiments, one of the most important quantities to measure is the plasma current density, which is not only closely relevant to plasma confinement and Magneto-Hydro-Dynamic (MHD) activity, but also plays an important role in advanced tokamak operation [1]. To measure the current density, polarimetry based on the Faraday-effect is widely recognized as one of the most reliable diagnostics [2]. There are many research achievements have been demonstrated on plasma electron density calculation by mean of polarimeter-interferometer system [3–5]. Recently, a Far-Infrared (FIR) laser polarimeter-interferometer has been established on EAST [6], and the phase shift information can be extracted from the signals after POINT system mixer. Since the electron density is proportional to the phase shift, electron density can be obtained for the plasma control system in real-time. The paper is organized as follows: the principle of this method is described in Section 2; the structure and the realization of the real-time density calculation system (DCS) are presented in Section 3; the application, including the bench test and experimental results are shown in Section 4; finally, the summary and future work are given in Section 5.

2. Principle

In the three-wave technique, two collinear laser beams with counter-rotating circular polarization are injected into the plasma to measure the Faraday angle, while an additional laser beam, employed as the local-oscillator (LO) beam, is mixed with the two probing beams to obtain the line-integrated density [7]. The three beams are slightly frequency offset (~1 MHz) for high temporal resolution measurement; therefore, the detected signal consists of three intermediate frequency (IF) carriers: one of them con-

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http://dx.doi.org/10.1016/j.fusengdes.2016.04.005
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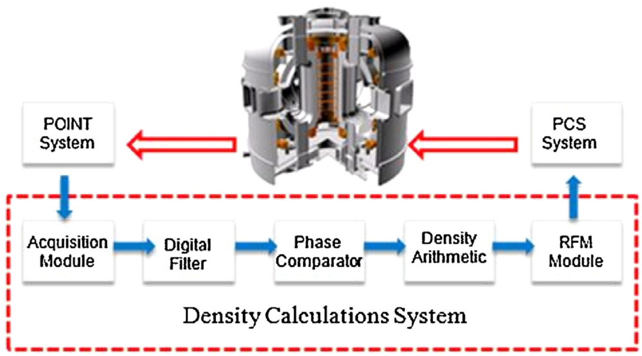

Fig. 1. Module design for density calculations system.

tains information of Faraday angle, while the other two contain information on the line-integrated density [8].

$$\phi = 2.82 \times 10^{-15}\lambda \int n_e dl \quad (1)$$

Eq. (1) expresses the relationship between density n_e and phase shift ϕ, λ is the wavelength of the beam, the unit is μm. So the DCS, aims at calculating the density, is designed to connect the POINT system with PCS for feedback control (Fig. 1).

The functions of DCS are shown above. It acquires the IF signals from the POINT system, separates the density information by digital filter, gets the phase shift after phase comparator, calculates the density, and transfers the results to PCS though RFM network.

3. Realization

3.1. Architecture

The DCS system should increase capability as well as improved extensibility by using Commercial Off-The-Shelf (COTS) components. NI PXIe standard devices are chosen, and the system platform is comprised by: (i) a 18-slot PXIe chassis features a high-bandwidth backplane; (ii) a controller equipped with an Intel Core i7 processors and 4 G DDR3RAM; (iii) PXIe-7966R Flex RIO device with a Virtex-5 SX95T FPGA on board. (iv) NI 5734 digitizer adapter modules are adopted with 16 bits analog-to-digital converter (ADC) resolution. (v) Reflective memory (RFM) card with 450–500 ns of latency between nodes. The software architecture of DCS is shown below (Fig. 2).

Since there are three Flex RIO modules in the system, one of these modules is selected as the master module to receive a trigger from central timing system [9]. The digitizer adapter converts the analog signal to digital data. After Flex RIO module, phase shift will be transferred to the host memory via Direct Memory Access (DMA) [10].

In the RT controller program, there is no user interface, when the power on, the system starts to work automatically. During the initialization, the FPGA and module parameters are configured; on

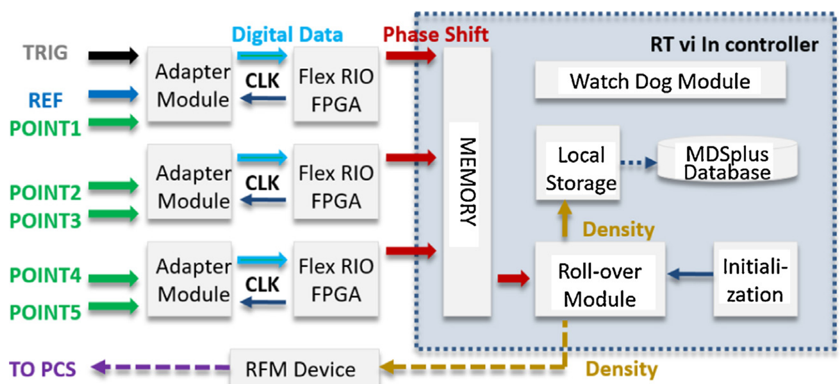

Fig. 2. Software architecture of density calculations system.

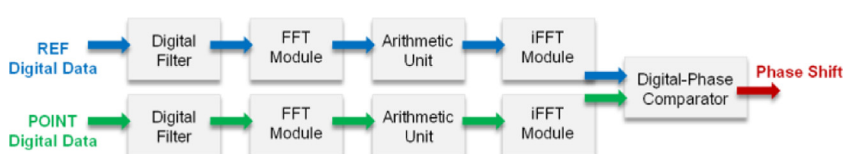

Fig. 3. Block diagram of Flex RIO FPGA.

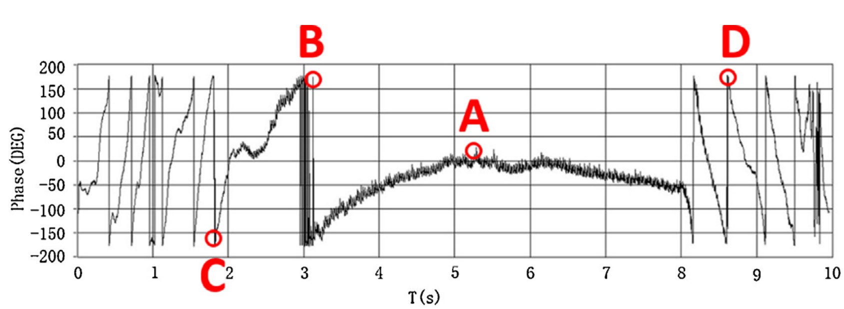

Fig. 4. Phase shift @ Shot NO.50650 on EAST.

Please cite this article in press as: Z.C. Zhang, et al., The implementation of real-time plasma electron density calculations on EAST, Fusion Eng. Des. (2016), http://dx.doi.org/10.1016/j.fusengdes.2016.04.005