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 transient electric field measurement system for EAST device

Y. Wang[a,*], Z.S. Ji[a], C.M. Zhu[b], Z.C. Zhang[a], T.F. Ma[a], Z.H. Xu[a]

[a] Institute of Plasma Physics, Chinese Academy of Sciences, Hefei, Anhui, China
[b] The Experiment & Verification Center of State Grid Electric Power Research Institute (The Automation Equipment EMC Lab. of State Grid Co.), Nanjing, Jiangsu, China

ARTICLE INFO

Article history:
Received 19 June 2015
Received in revised form 14 June 2016
Accepted 15 June 2016
Available online xxx

Keywords:
Transient electric field
FFT
EMI
FPGA
Real-time processing

ABSTRACT

The electromagnetic environment around the Experimental Advanced Superconducting Tokamak (EAST) device is very complex during plasma discharge experiment. In order to fully monitor the changes of electric field around the EAST device during plasma discharge, a transient electric field measurement system based on PCI eXtensions for Instrumentation (PXI) platform has been designed. A digitizer is used for high-speed data acquisition of raw signals from electric field sensors, and a Field Programmable Gate Array (FPGA) module is used for realizing an on-the-fly fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT) algorithm including a beforehand identified antenna factor (AF) to achieve finally a calibrated and filtered electric field measurement, then these signals can be displayed and easily analyzed. The raw signals from electric field sensors are transferred through optical fiber by optical isolation to reduce electromagnetic interference (EMI). The high speed data streaming technology is used for data storage. A prototype of this system has been realized to measure the transient electric field strength, with the real-time processing and continuous acquisition ability of one channel of 14-bit resolution and up to 50 MHz sampling rate, and 6 KHz FFT frequency resolution.

1. Introduction

The Experimental Advanced Superconducting Tokamak (EAST) is a fully superconducting tokamak which comprises 16 D-shaped toroidal field coils, 14 poloidal field coils and its central magnet field is 3.5 T [1]. There are also some internal coils for fast control and many heating systems, such as the lower hybrid current drive system, ion cyclotron range of frequency system and neutral beam injection system, and the total heating power can reach to 40 MW [2]. These systems can generate high current or high voltage during plasma discharge experiment and may cause electromagnetic interference. While the transient electric field of rich spectrum is the most common interference and harmful to electric equipments, so it is important to measure the transient electric field, analyze its characteristics and make protection.

The research of transient electric field measurement always focuses on transient electric field sensors, for the electric field sensor is the key issue to transform the electric field signal into electrical signals. The typical transient electric field sensors are monopole sensors [3], asymptotic conical dipole sensors [4], and electro-optic crystal sensors [5,6]. The measurement system is usually realized by some sensors and oscilloscopes or spectrum analyzers, which can't continuously record for measurement of long period. EAST is aimed at high performance plasma for long pulse up to 1000 s or longer [1,2], so it is useful to record all the transient electric field signals during plasma discharges. The frequency characteristics of antenna factor AF of electric field sensor should be considered, for the AF is not a fixed value at a certain frequency band [7]. The development of the transient electric field measurement system with continuous recording and signal processing is quite important.

In this article, we aim to realize real-time processing on PXI platform for its numerous kinds of digitizer and FPGA modules and easy implementation with LabVIEW [8]. An ADC adapter and a FPGA module have been used to realize the measurement system, and the test and measurement analysis have been demonstrated.

2. Design

2.1. Architecture

The architecture diagram of the transient electric field measurement system is shown in Fig. 1. The raw signals from electric field sensors are transferred through optical fiber by optical isolation

* Corresponding author.
E-mail address: wayong@ipp.ac.cn (Y. Wang).

http://dx.doi.org/10.1016/j.fusengdes.2016.06.022
0920-3796/

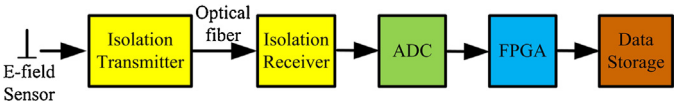

Fig. 1. Architecture of the measurement system.

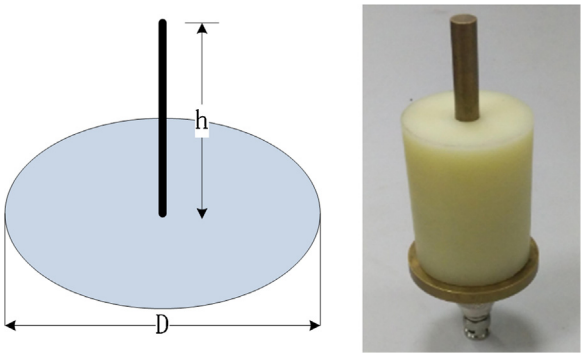

Fig. 2. Monopole antenna (a) schematic (b) sample.

to reduce electromagnetic interference (EMI), and then the isolated signals are sampled into digital processor by analog digital converter (ADC), then the acquired signals are calibrated into corresponding electric field signals by fast Fourier transform (FFT) and inverse fast Fourier transform (IFFT) algorithm. As we focused on real-time processing, the process is done on FPGA, and the calibrated data can be stored, displayed and easily analyzed.

The electric field sensor is developed in-house, whose bandwidth is 10 KHz–20 MHz and measurement range is 0.2–3000 V/m.

The fiber-optic isolation ISOBE5600 offers nine measurement ranges from ±100 mV to ±50 V and 20 MHz bandwidth, which can fully satisfy demands for safety, bandwidth and measurement accuracy [9].

For ADC and FPGA processing, we selected the NI 5751 digitizer adapter module and NI PXIe-7966R FlexRIO FPGA Module. NI 5751 has 16 simultaneously sampled channels of 14-bit resolution and 50MS/s each channel and 2 V peak-to-peak input range [10], while PXIe-7966R features a user-programmable Virtex-5 SX95T FPGA chip and 512 MB DDR2 DRAM for onboard processing [11]. These modules with a 2.3 GHz quad-core PXI express controller NI PXIe-8135 [12] can be installed in one 8-slot 3U NI PXIe-1082 chassis [13].

NI HDD-8265 external hard-drive redundant array of inexpensive disks (RAID) enclosures expands high-speed data streaming solutions by offering higher data streaming rates and storage capacities, which offers 24 TB storage capacity and 750 MB/s of sustained data read and write rates in RAID 0 mode for 80% of the total storage capacity, and can satisfy the requirements of this system [14].

2.2. Electric field sensor

A kind of electric field sensor called monopole antenna has been designed. Fig. 2 (a) is the schematic of this monopole antenna [3], in which a monopole element of length h, which is located in free space at the center of an infinitely thin, circular ground plane of diameter D. The maximum sampling rate of this system is 50 MHz, so the bandwidth of measured signal is about 20 MHz and the corresponding minimum wavelength is

$$\lambda_{\min} = \frac{c}{f_{\max}} = \frac{3 \times 10^8}{20 \times 10^6} = 15\text{m}.$$

The actual length of h is 0.15 m, which is much less than 3.75 m ($\lambda_{\min}/4$), so it can be considered as an electrically small antenna.

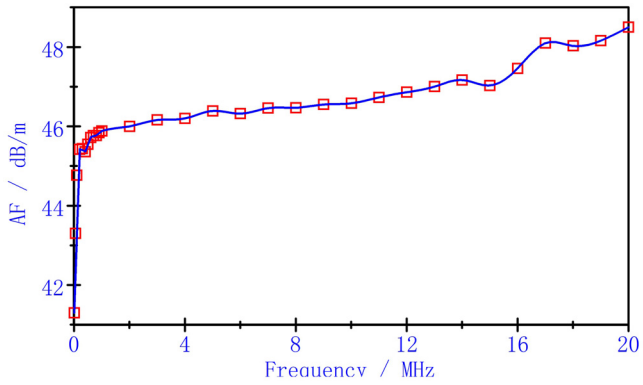

Fig. 3. The AF curve fitting.

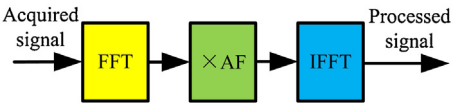

Fig. 4. Algorithm of signal transforms.

The diameter D of ground plane is 0.06 m for size consideration. Fig. 2(b) shows a sample of the actual monopole antenna.

The antenna factor AF can be found by spline fit to the calibrated AF in discrete frequencies, as shown in Fig. 3.

2.3. Algorithm

The signal acquired by the monopole antenna is a kind of electrical signal, so it should be changed into electric field signal. This algorithm is used to calibrate the acquired signal into real electric field signal. While the AF value of the monopole antenna is different at different frequency, so FFT and IFFT are necessary for this transformation.

The acquired signal is processed by FFT, then the spectrum result is multiplied by the corresponding AF, and IFFT transforms the signal from frequency domain into time domain, as shown in Fig. 4.

The number of FFT and IFFT is 8192, so the FFT frequency resolution is

$$f = \frac{F_s}{N} = \frac{50\text{ MHz}}{8192} \approx 6\text{ kHz}.$$

The pipeline technique is adopted to increase the speed of sampling and processing. The point-by-point FFT of 8192 samples costs a delay of 20534 clock cycles on FPGA by LabVIEW [15], and so is delay of IFFT. The clock cycle is 20 ns, so the inherent latency is almost about

$$t_d = 2 \times 20534 \times 20ns \approx 800us$$

2.4. Software structure

The program of this measurement system contains two parts, as shown in Fig. 5:

(a) Program on Host, providing users interface and transferring sampling settings and AF to FPGA, receiving data from FIFO and writing data to high-speed storage.
(b) Program on FPGA, receiving parameters from host, processing the sampling signal, including FFT and IFFT, and then writing the processed data to FIFO.

Please cite this article in press as: Y. Wang, et al., The transient electric field measurement system for EAST device, Fusion Eng. Des. (2016), http://dx.doi.org/10.1016/j.fusengdes.2016.06.022