ANIMMA 2021

Prague, Czech Republic

June 21-25, 2021

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Design of Real-Time Electronics System for Two-Dimensional Hard X-Ray Diagnostics with Intensity Imaging and Energy Spectrum in EAST

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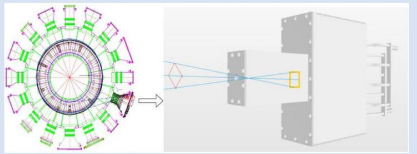
Abstract

Hard X-ray diagnosis is the most important diagnostic in Experimental Advanced Superconducting Tokamak (EAST) for studying low-hybrid wave physics and fast electrons, which helps to improve the operating performance and guarantee the operation safety of EAST Tokamak. The Hard X-Ray diagnostics used 16×16-channels pixel array Cadmium Zinc Telluride (CZT) detector which has the features of high resolution, large absorption coefficient, high detection efficiency, small size, and can work under normal temperature conditions. A charge-sensitive pre-amplifier card is designed which is electromagnetic shielding and easy to maintain, with low noise and low signal crosstalk. The card has 32 channels and the actual conversion gain can reach up to 1mv/fc. Then, a compacted pre-amplifiers module is built which is composed of 8 preamplifier cards and one back plane (transform signal from detector to pre-amplifier). Moreover, the multi-channel high precision data acquisition and signal process system based on FPGA (made in China) and PXIe bus is designed, which solves the problem of time synchronization during the acquisition of multiple boards. The direct memory access(DMA) mode is used for hardware programming to achieve high-speed data transmission. Meanwhile, a software driver has been developed based on the Windows platform, and through the QT framework. The real-time display of the two-dimensional intensity distribution of hard X-ray radiation over time and the three-dimensional curve of the pixel signal spectrum over time have been realized, and the data is stored quickly to facilitate further offline analysis and processing. The electronics system has been tested and the results show that it has reached the design performance.

Introduction

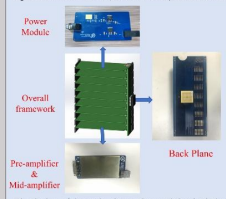


- In order to gain a comprehensive understanding of the plasma and enhance EAST performance, a two-dimensional CZT array detector has been installed in the D port of the EAST device to directly obtain the location of low clutter power deposition and to investigate the behaviour of fast electrons.
- Study of high-energy electron production and high-energy electron-unstable interactions under conditions of MHD, RMP, rupture, etc..
- Adjustment of plasma parameters and coupling of low clutter waves by obtaining energy deposition positions in real time improving heating efficiency and plasma confinement performance, in particular current profile control in long pulse advanced configurations

Electronics Design

The electronics system mainly contains the detector, pre-amplifier, mid-amplifier, signal-transfer module, National MCA and the EAST central control system. In this structure, pre-amplifiers and mid-amplifiers will be placed inside the D port. The CODAC system will be located in the cubicle area of the diagnostic building.

For electronics, the pre-amplifier is a charge-sensitive amplifier with a practical gain of up to 1mv/fc and time resolution 1us. The amplifier is spatially positioned next to the detector. The Mid-amplifier amplifies the voltage signal from the pre-amplifier by a factor of several tens and then connects it to the Signal transfer module via a signal transmission line (about 4 meters), which then sends the signal to the National MCA.



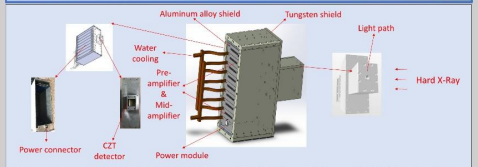
Due to the limited space available for the actual window installation, with a total space size of 150mm×180mm×65mm, a compact mounting structure was designed as shown in the diagram on the left. By mounting the detector on the back plane, the detector is powered by a separate - 1000V high voltage supply, which is introduced directly to the front of the detector; the 256 channel signal from the detector is amplified by 8 amplifier boards and processed by a power supply board to power the amplifier. And the multi-channel consistency, heat dissipation and crosstalk have been specially considered in PCB design.

The design of the main electronics card that includes acquisition and processing functions is based on the PXIe bus architecture. Moreover, the core chips that are used in the hardware circuit of the main electronics card, including the FPGA and ADC, are manufactured in China. This enables Chinese institutes to contact the manufacturing company to obtain information on the circuits and development tools with ease, as well as to carry out cross-development and collaboration. An ADC (type: YA16D80L) with an 80 Msps sampling rate and a 16-bit resolution was selected. A high-performance and irradiation-resistant FPGA (type: JFM7K325T) was used in the core logic processing and computing unit. The main electronics card typically contains four synchronized analog input channels and a hardware trigger input interface.

The power-on sequence and power consumption of different voltage rails for the FPGA are considered in the design of the power supply module for the main electronics card. By controlling the power-on sequence, the FPGA can operate more stably and its service life can be increased.

Hardware architecture	pxie 3u4hp standard hardware structure
Channel number	single card 4 channels
Sampling rate	80MHz 16bit
Time resolution	1ms
Total read address	512/1024/2048
Measurement accuracy	better than 0.3%
Inherent noise: $V_{noise\ (RMS)}$	< 5mv

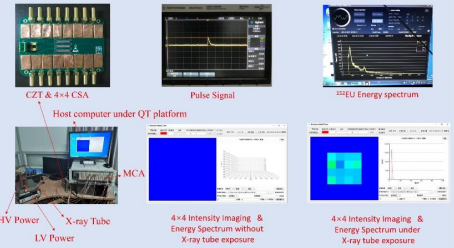
Internal and external shield and water cooling design



The overall structural design of the chassis consists mainly of the inner shield, outer shield, light path and water cooling. The advantages of the chassis are that it provides a reliable and stable integrated structure, EMC shielding, heat dissipation and efficient maintenance.

EU-125 Radiation source experiments

The selected 2D CZT detector is 25.4×25.4×5mm³ with a pixel array of 16×16 and a single pixel size of 1.5×1.5mm². The energy resolution is 90%pixels<6.5%@122keV (room temperature) and the detection range is 20kev~700kev, which can be used to measure the energy spectrum of plasma in the hard X-ray radiation energy band (20-200 keV).



- A 16-channel charge-sensitive pre-amplifier was designed and combined with the ^{152}EU radioactive source to perform preliminary validation experiments for this system. The particle pulse signal was successfully captured by oscilloscope, and then the energy spectrum of ^{152}EU was measured in combination with National MCA.
- The intensity map shows the signal strength of the time-divisional spectrum through a colour interval from blue to red, and the user can choose to display the time-divisional and total energy spectra directly by clicking on a pixel. The difference in intensity imaging can be clearly seen experimentally whether there has X-ray tube exposure. The feasibility of this system was initially verified through the above experiments.

Summary and Prospect

A two-dimensional hard X-ray real-time intensity imaging and energy spectrum measurement system has been designed on Windows platform, using national core chips (ADC and FPGA) and the open source platform Qt. The main electronic card was tested to verify the capabilities of the electronic system. The system will then be combined with the EAST for comprehensive performance verification, real-time intensity imaging and energy spectrum measurement of 16×16 arrays, and eventually give the location of low clutter power deposition and feedback phase control to achieve effective performance enhancement of the device.

Reference

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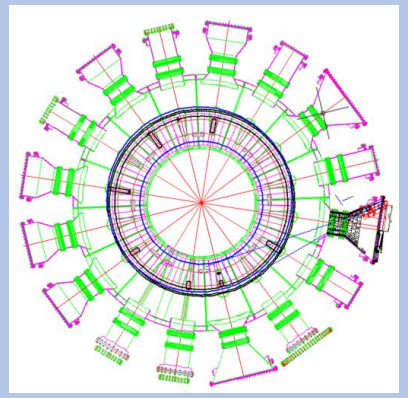
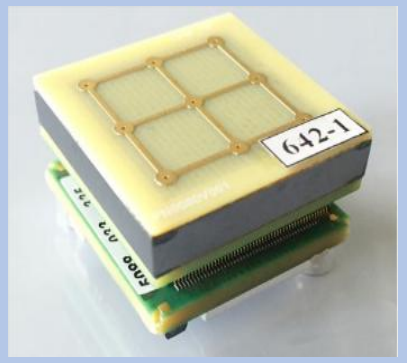
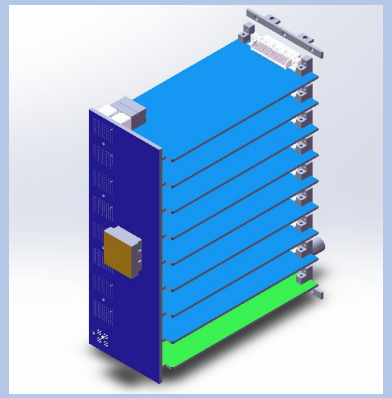


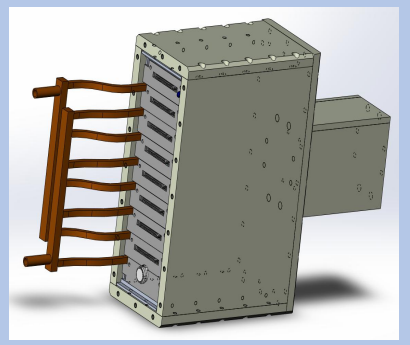
Installation position & light path range



CZT Detector



Pre-amplifier & back plane

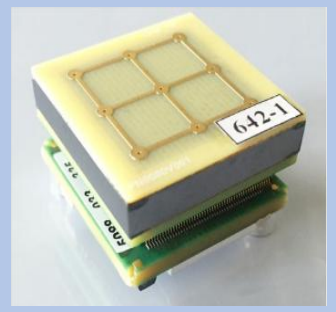


Internal and external shield &water cooling design

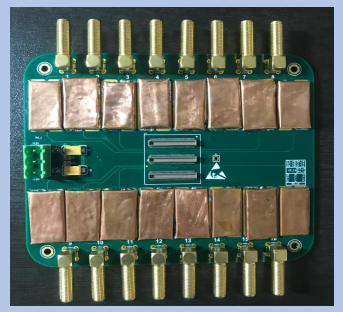
National MCA

Host Computer

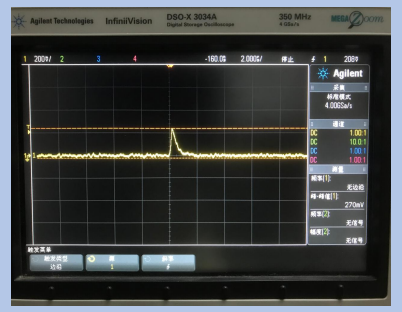
Preliminary Verification Experiment



16×16 CZT



4×4 Pre-amplifier



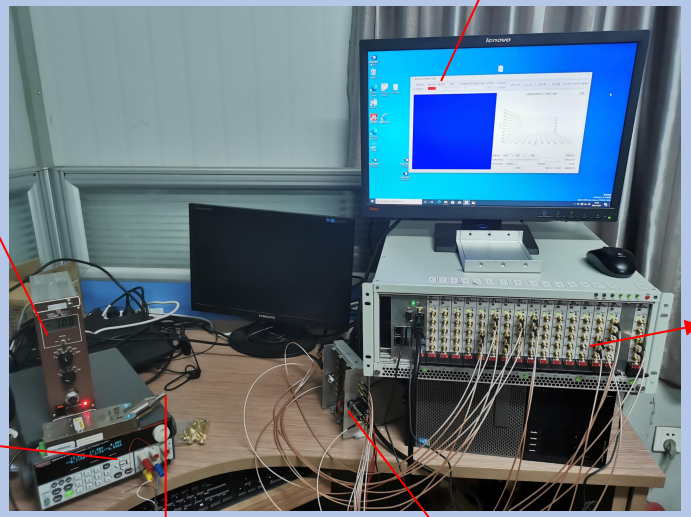
Pulse Signal

^{152}EU Energy spectrum

Host computer under QT platform

HV Power

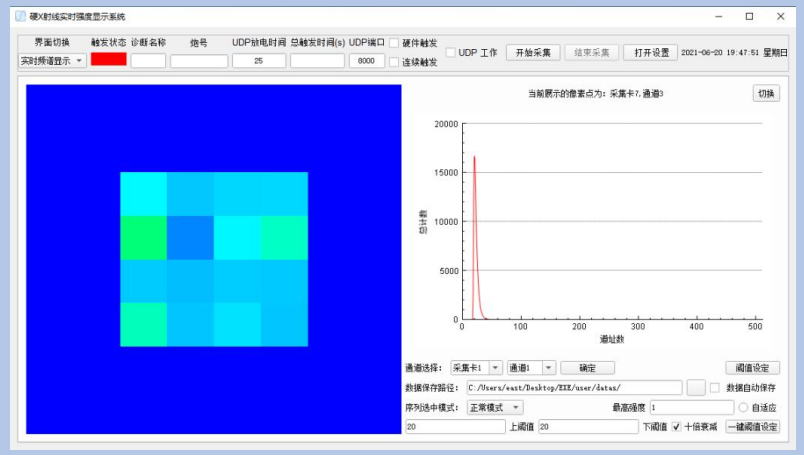
LV Power



National MCA

X-ray Tube

CZT & Pre-amplifier



4×4 Intensity Imaging & Energy Spectrum under X-ray tube exposure