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Pulse Height Analysis X-ray spectroscopy in the tokamak TCV

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Introduction

A PHA system has been successfully installed on TCV and used to measure the X-ray emission from a variety of plasma configurations. The preamplifier output from a Canberra model GUL0055P diode was shaped and pile-up inspected by a Canberra model 2024 gated integrator. The amplitude of the resulting pulse was recorded by an INCAA model TRCH CAMAC module with 12 bit signal amplitude resolution, 1 Msamples of on-board memory and a 1 μs cycle time. An Interface Amplifier and Time Generator, (IATG)[1] module, was integrated into the TCV timing system such that every 1-50 ms (user defined) a time tag was recorded into the acquisition memory, permitting the post-reconstruction of the arrival time of groups of events. The diode is fully depleted, (active area of 50 mm^2, active thickness 5 mm), by applying a bias voltage of 1000 V. The electric field thus generated inside is uniform and perpendicular to the detection surface, collecting charge from the whole detector volume. This large detection volume makes the diode sensitive to a wide range of x-ray energies ranging from a few eV to hundreds of keV and increases the probability that an incoming photon will loose all its energy in the diode. Since, in TCV, runaway electrons and hard X-rays [2] often present, the detector spends time processing unwanted pulses. Even though the electronics for signal processing and data acquisition have been optimised to improve the data throughput to match the high flux 2 s time duration of a TCV plasma pulse, the system is limited by pulse processing speed capability. The diode was mechanically coupled, via a high vacuum flight line ($<10^{-7}$ mbar), to TCV, and included the possibility of externally changing the viewing aperture and in line beryllium filters thickness. For calibration purposes, an ^{55}Fe radio-active source could be positioned in front of the diode. Four collimators of 0.3, 0.6, 1.0 and 1.15 mm diameter at the end of the flight tube limited the detector's étendue to the plasma to avoid saturation. The diode cryostat forced a horizontal mounting on TCV and the variety of plasma equilibrium that can be created in TCV made this geometry problematic as the plasma core is not always centred in the vessel so the diode is not always facing some plasma section. A centred configuration is not favoured on TCV since it does not benefit from the passive vertical position wall stabilisation.

The electron temperature deduced from PHA agrees better with the filtered diode and Thomson scattering system diagnostics, when the count rate did not exceed ~30 kHz. The values obtained were comparable to the Thomson measurement and 10 % higher than the filtered diodes, but all measurements agreed to within the error bars [3]. Line radiation was rarely observed.

The NEW PHA concept

An improved system must provide a higher count rate, to improve the diagnostic's time resolution and be vertically mountable on TCV. To meet the need for high throughput, mandatory in Tokamaks of short pulse duration and high-energy fluxes, the original detector was replaced by a Roentec XFlash Silicon Drifted Detector 1000B [4]. This detector consists of a very thin (~ 300 μm) fully depleted silicon wafer, making it only sensitive in the soft X-ray range and transparent to higher X-ray energies. An electric field, with a strong component parallel to the surface, drives signal electrons towards a small integrated collecting anode. The electric field is generated by a number of increasingly reverse biased field strips covering only one surface of the device. The radiation entrance side is a non-structured p+ junction, giving a homogeneous sensitivity over the whole detector's sensitive area (~5 mm^2). The extremely small value of the anode capacitance, which is almost independent of the active area, allows higher energy resolutions (FWHM<175 eV at 5.9 keV) even with short shaping times (<0.5 μs) compared to conventional photodiodes and Si(Li) detectors, making it suitable for high count rate applications (~1 MHz). These detectors also feature an integrated thermally stabilised thermoelectric cooler, which can operate the diode down to –10 ^oC. The power supplies for the cooler and the diode can be located far from the diode itself. To complement this system, a commercial Digital X-ray Processor (DXP) CAMAC unit, optimised for X-ray detector analysis, was installed. This unit has four integrated basic sections: a front-end Analogue Signal Conditioning; an ADC digitising at 40 MHz; a digital Filter, Peak detector, Pileup Inspector (FiPPI) to numerically filter the digitised signal stream generate triggers following an x-ray event; and a Digital Signal Processing (DSP) Unit for pulse height analysis, data corrections, surveillance of the other system sections (ASC and FiPPI) and communication with a host processor.

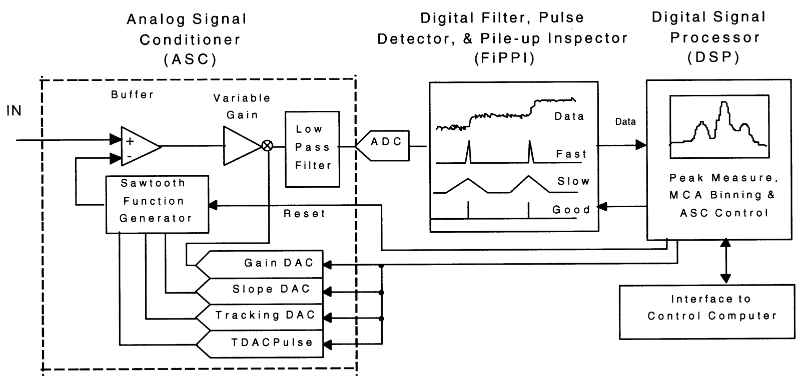


Fig.1: Block Diagram of the DXP channel architecture, showing the major functional sections

At present, data analysis is performed “off line” but only due to restrictions in the available software. Since basic data analysis of the PHA X-ray data, both for continuum and line radiation measurements, is straightforward, the final goal is to provide real-time data analysis with a temperature and impurity content monitor that can be used for machine feedback. A 4 DSP VME based card [5], is being programmed for fast data acquisition and simultaneous real-time data treatment with a view to providing very long pulse diagnostics for a machine such as ITER. The current goal is to obtain spectra with sufficient statistics every 10 ms, fit the data in real-time to evaluate the quality of the measurement and adjust remotely controllable X-ray PHA filters and apertures and finally provide the PHA data to the TCV control system. A separate DSP system could provide higher quality spectra with a reduced time resolution.

Experimental Performance

The best energy resolution for the combination Germanium detector with the traditional analogue signal treatment was 202 eV, for the 5.9 keV x-rays at a rate of 30 kHz. Above this limit, the spectral lines are still observed but the resolution is increasingly degraded until 50 kHz where the spectrum is useless. Trials with the SDD plus the analogue pulse conditioning showed that it was possible to improve the system energy resolution to ~180 eV and the throughput by a factor of 1.5, but pileup events are still fatal above 50 kHz, as the analogue modules saturate. With the CAMAC DSP unit, the energy resolution and the throughput were considerably improved for both detectors.

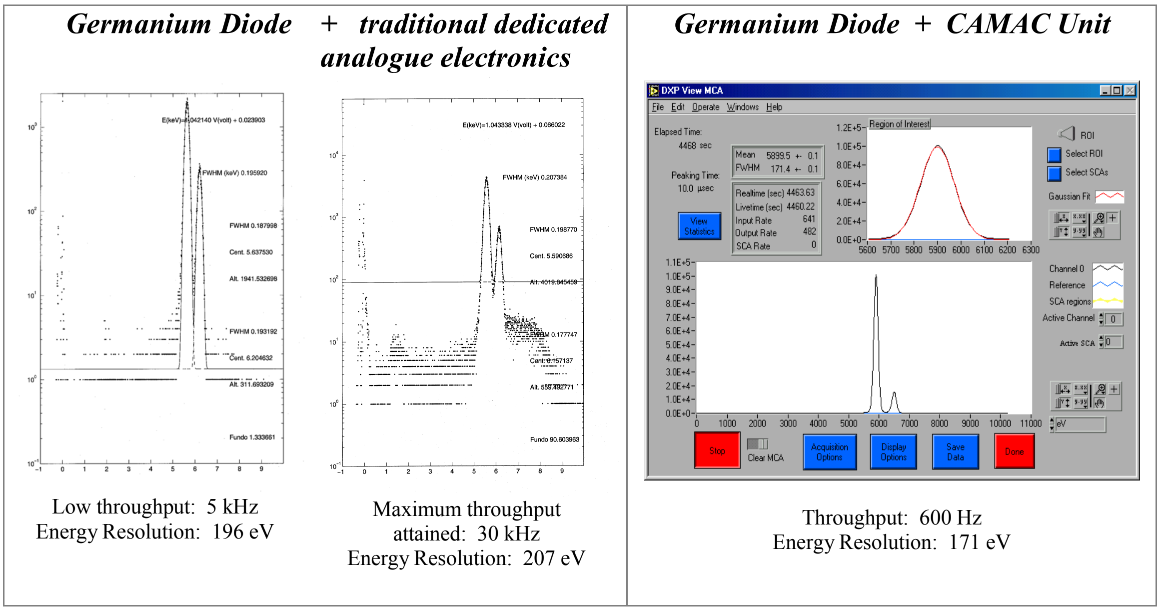
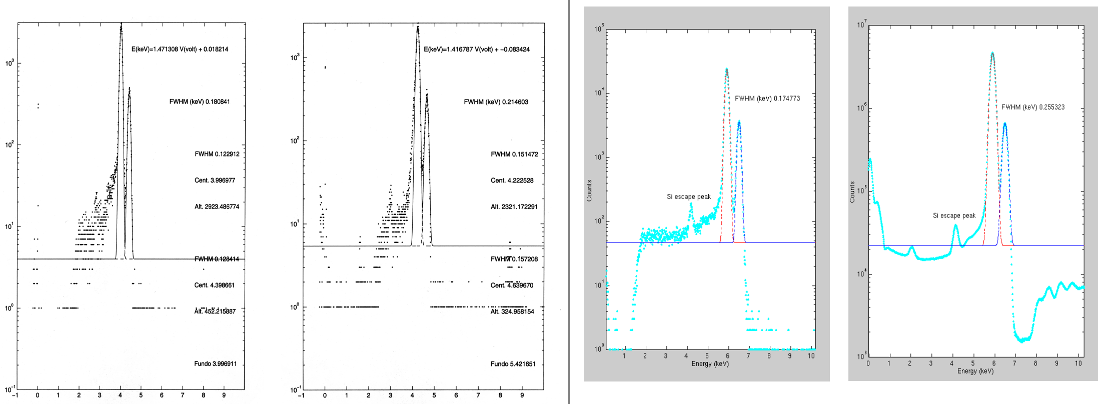


Fig 2.1: Results obtained with an ^{55}Fe radioactive source

SDD + traditional dedicated analogue electronics		***SDD + CAMAC Unit***	



Low throughput: 5 kHz Energy Resolution: 181 eV	Maximum throughput attained: 50 kHz Energy Resolution: 214 eV	Low throughput: 3.7 kHz Energy Resolution: 175 eV	**Throughput: 110 kHz** **Energy Resolution: 255 eV**

Fig 2.2: Results obtained with an ^{55}Fe radioactive source

Conclusions

The results obtained show that a “modernised” PHA system with an electronically cooled diode and state of the art DSP signal treatment can result in greatly improved performance over traditional analogue components. The simplicity of the data analysis, the high quantum efficiency and the very low étendue required to a high intensity source, like a Tokamak plasma, could make this diagnostic very suitable for routine observation and control of a burning plasma.

Aknowledgements

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