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Development review of transient recorders with onboard isolation on JET

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Abstract

The JET tokamak is currently using about 7000 transient recorder channels for data acquisition, mainly sampling at 5 kHz but including a few at 1 MHz or higher. Nearly half of the channels are provided by module designs with front ends that are galvanically isolated to over 1000 V. Performing analogue-to-digital conversion before isolation provides many benefits. This paper reviews three such designs that have been commissioned or developed by control and data acquisition systems (CODAS) personnel over the past 10 years and examines the trends.

Keywords: Transient recorder; Isolated; ADC; DAQ

1. The advantages and disadvantages of isolation

In the early days of JET it was realised that measurement equipment attached to the torus vessel could reach dangerously high voltages due to an earth fault on the poloidal field coils. It was calculated [1] that, to be safe, connections to the vessel should be protected from voltages of 1000 V dc. These voltages must not damage the transient recorder modules and they must not result in large currents, which could damage the wiring. The inputs could satisfy these requirements without isolation, but they would need high common mode input impedance.

The three transient recorders described here are summarised in Table 1. They all have analogue inputs that are individually isolated to over 1000 V. As well as satisfying the safety requirements, isolated inputs provide other system benefits. Because there is no dc path, and a high impedance ac path, there are no ground loops and many noise problems are avoided. In principle there is an infinite common mode input impedance and common mode rejection ratio.

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[1] See the appendix of J. Pamela et al., Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004) IAEA, Vienna (2004).

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Table 1
Comparative specification

	UXD1	BAD2	UXD7 (provisional data)
Sample rate	10 ksamples/s (fixed)	2 Msamples/s (max)	200 ksamples/s (max)
Isolation	1500 V dc	1000 V ac	1500 V dc
Number of channels	8	4	8
Input configuration	Single ended	Differential	Differential
Input ranges	±100 V to ±50 mV	±10 V to ±125 mV	±10 V to ±50 mV
Input range control	Component selection	Programmable gain amp	Programmable gain amp
Basic resolution	16 bit	14 bit	16 bit
Memory/channel	64 ksamples	64 Msamples	8 Msamples
Timing and trigger	JET clock	JET clock or external	JET clock
Approximately cost per channel	€120	€700	€200
First used on JET	1994	2003	2006

The biggest disadvantage in requiring each channel to be separately isolated to 1000 V is that JET cannot use Commercial-Off-The-Shelf modules. So the isolated transient recorders used on JET are specially commissioned and cost more. However if the costs are low enough, the modules can be used even when isolation is not essential; quantities go up and costs come down.

2. System architecture

Measuring the voltages on magnetic sensor coils is a major use for all these modules. As the sensor coils are inside the torus, the designs include isolated front ends. In all the modules described here, isolation comes directly after a serial ADC as this is the easiest and cheapest way to provide it. Before the UXD1, ADCs consumed too much power to be supplied with isolated power within the module; so either external (isolated) power was required or analogue isolation was used, resulting in problems of linearity and stability.

When the UXD1 was designed, memory was expensive and it was not possible to store the whole pulse, so timing was complicated, using 'importance sampling windows' and variable-speed sample clocks. The newer designs benefit from cheap, small memory devices; they capture the whole pulse and timing is much simpler. All that is now required is the central synchronisation clock and a start (of pulse) trigger.

As components continue to get smaller and more powerful, more of the transient recorder system can be built on a single module. A major contributor to this trend is the low-cost microprocessor; so in the case of the UXD7, the entire system fits a single board and includes an embedded microprocessor with Ethernet interface.

3. Timing system

The JET timing system distributes a 'start of pulse' trigger and a 'JET clock', a 1 MHz reference clock for synchronising subsystems. This allows correlations to be made between different diagnostics. All three ADC's use these two signals to keep in step with the JET clock and to trigger sampling at a pre-set time in the pulse. The 2 MHz basic sampling rate of the BAD2 is generated by frequency multiplication of the 1 MHz reference. Simple frequency division is sufficient for the slower designs and the dc/dc convertors are synchronised to the clock, removing most of the coupled noise from the power supplies.

The UXD1 system has provision for recording windows around JET 'event triggers', also distributed by the JET timing system. However, pre-programmed sampling sequences must leave memory storage available for recording an event, like a JET disruption. This complication is not required in the later designs because their larger memories enable the whole JET pulse to be recorded. Provided the time of the event is known, the data around it can be recovered after the pulse.

4. Data outputs

In all three designs, the module simultaneously handles data in two different ways, as a transient recorder