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The Timing System of the RFX Nuclear Fusion Experiment

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ABSTRACT

The RFX Nuclear Fusion Experiment [1] in Padova, Italy, employs a distributed system to produce precision trigger signals for the fast control of the experiment and for the experiment-wide synchronization of data acquisition channels. The hardware of the system is based on a set of CAMAC modules. The modules have been integrated into a hardware/software system which provides the following features:

- generation of pre-programmed timing events
- distribution of asynchronous (not pre-programmed) timing events,
- gating of timing event generation by Machine Protection System,
- automatic stop of timing sequence in case of highway damage,
- dual-speed timebase for transient recorders,
- system-wide precision of $\leq 3\ \mu s$, time resolution $\geq 10 \mu s$.

The operation of the timing system is fully integrated into the RFX data acquisition system software. The Timing System Software consists of three layers: the lowest one corresponds directly to the CAMAC modules, the intermediate one provides pseudo-devices which essentially correspond to specific features of the modules (e.g. a dual frequency clock source for transient recorders), the highest level provides system set-up support

The system is fully operational and was first used during the commissioning of the RFX Power Supplies in spring '91.

1. SIGMA

The Timing System is part of the fully computerized system for experiment control, monitoring, and data acquisition known as SIGMA (Sistema di Gestione, Monitoraggio ed Acquisizione Dati) [2]. SIGMA employs two distinct technologies: PLCs and CAMAC/VAX systems. Nine large PLCs, grouped into four subsystems provide slow control and continuous monitoring of the corresponding machine subsystems. Fast data acquisition and the generation of the precision trigger signals and of the fast reference waveforms is implemented by means of CAMAC equipment connected to a central VAXcluster via a fibre optic CAMAC Serial Highway implementation. All components of the system are connected to the same fibre optic Ethernet.

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2. Timing System Hardware Components

2.1. *THE TIMING HIGHWAY*

The CAMAC modules of the timing system are connected by a single optical fibre Timing Highway which carries the timing events in encoded form, imprinted on a 1 MHz carrier clock. Each timing event is encoded in a 10-bit frame. The fibre and connector are identical to the ones used both for the fibre optic Serial Highway and for the fibre optic Ethernet.

2.2. *CAMAC MODULES*

The system employs three types of CAMAC modules which provide the following functions:

The *Encoder Module* generates encoded timing events; it can be seen as the input device of the Timing system. Each Encoder can generate a maximum of seven events, of which six are produced by hardware inputs and one by software command. The event inputs are priority encoded. The code associated with each event is pre-loaded via the CAMAC interface.

The *Decoder Module* is the output device of the Timing System. The module can be divided in two sections: the code-recognizer section, which matches encoded events traveling on the Timing Highway to pre-loaded codes held by internal registers, and the counter-timer section. The module contains a crystal oscillator, which can be used as master clock. The module provides a rich set of options and operating modes

The *Timing Event Recorder* module can log up to 512 timing events together with their relative time of registration with reference to a start event (software or hardware defined).

Encoder and Decoder module have been developed for the Tokamak de Varennes [3]. The Timing Event Recorder has been added by RFX. All modules are commercially available [4].

3. HW System Description

3.1. *TIMING HIGHWAY STRUCTURE*

From an operational point of view, a clear distinction has been made between parts of the timing system which are required to be permanently 'on-line' and which are essential to produce a plasma shot and other parts which could be excluded, intentionally or unintentionally, without preventing normal operation. Hence, the timing system has been separated in two sections: *Machine Section* and *Diagnostics Section* (Fig. 1). The Machine Section delivers timing signals to all the essential machine components, i.e. converter units, gas injection control, essential data acquisition equipment. The Diagnostics

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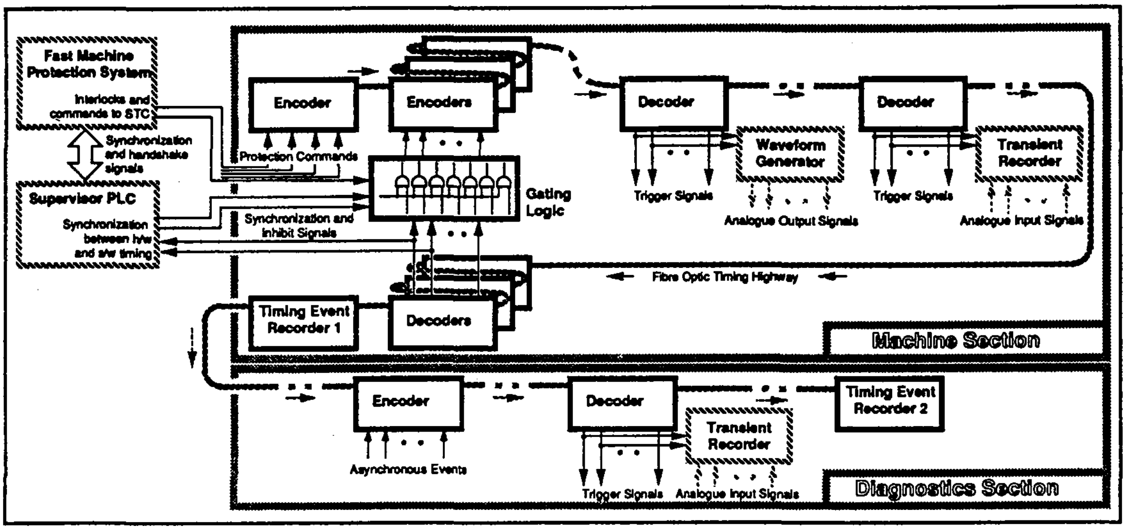

Figure 1: Hardware Structure of the RFX Central Timing System

Section delivers timing signals to all the equipment which is not essential for machine operation, typically the diagnostics. The two sections use one Timing Highway. The highway serves first the Machine Section and afterwards the Diagnostics Section. A timing Event Recorder is placed at the end of each section.

3.2. *FEATURES*

3.2.1. PRE-PROGRAMMED TIMING EVENTS

A number of pre-programmed timing events are released sequentially after an initial software start command or hardware start pulse. The start signal is fed into an Encoder event input channel. The corresponding event then travels in encoded form along the Timing Highway; it can be used by any downstream Decoder module. It returns to a Decoder module placed at the "end" of the highway (physically near to the Encoder module). This Decoder produces another timing pulse after a pre-programmed delay after receiving the encoded Start event. This pulse is again fed into an event input of the Encoder, from where it travels along the highway as second encoded event. All further timing events are generated in the same way as delayed events after the start signal. This structure has the effect of interrupting the timing sequence in case of interruption of the Timing Highway. In this case the clock signal is missing which is used to count down the delays for the delayed events.

At the local CAMAC crate, one decoder channel is required per event in order to "reproduce" the event as local timing pulse. This reproduction includes a programmable delay, the possibility to invert the output signal, and to program the duration of the local timing pulse.

3.2.2. ASYNCHRONOUS TIMING EVENTS

Encoders which are placed anywhere on the Timing Highway may be used to encode asynchronous external signals. Such events are encoded in exactly the same way as pre-programmed events. They can be decoded and used by any decoder downstream from the position of the encoder module on the highway. At RFX this mechanism is used to record interventions of the independent Fast Machine Protection System and to trigger automatically data acquisition channels in case of such intervention.

3.2.3. GATING OF TIMING EVENTS

Timing events produced by the central part of the timing system are subject to gating by the fast machine protection system. This intervention is part of the machine protection strategy of RFX. The gates are placed at the inputs of the Encoder Modules of the event generation circuits.

3.2.4. TIMEBASE FOR A/D AND D/A MODULES

A large number of A/D Converter CAMAC Modules need to be synchronized during the plasma shot both in terms of sampling repetition rate and acquisition time window. An equivalent requirement exists for the generation of fast, pre-programmed reference waveforms, which are produced by D/A CAMAC modules with local memory. Among the many possible configurations two 'standard' configurations have been selected: The *Gated Single Speed Clock Generator* configuration produces clock pulses of programmable frequency and on/off ratio for a time window which starts at a programmable delay after a selected timing event and ends after a programmable time. This configuration occupies two Decoder channels. The *Dual Speed Clock Generator* configuration produces clock pulses of programmable frequency f1, switches to programmable frequency f2 after a selected timing event, and switches back to frequency f1 after a programmable delay. This configuration occupies two Decoder channels.

3.2.5. PRECISION AND TIME RESOLUTION

The system guarantees an overall precision of less than

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3 µs between any two events in any two locations of the system. Time resolution, i.e. the minimum time between two different, programmed or recorded events, is 10 µs which are due to the frame length of the encode timing event on the Timing Highway.

3.2.6. SELF-TEST

Automatic Stop of the Timing Sequence: In case of interruption of the Timing Highway the generation of further timing events downstream from the interruption is inhibited because the internal counters of the downstream decoders are stopped due to the missing highway clock which is used to increment these counters. As the Decoder modules which produce the highway events are placed at the"end" of the highway any such interruption has the effect that no further events are produced.

Event Recording Function: In order to record the time of occurrence of events, the timing system comprises Timing Event Recorder modules which register timing events. The same function is used for recording asynchronous events and for the verification of the generation of the synchronous events.

Missing Clock Detection: The Timing Event Recorder Module which is placed at the end of the Timing Highway can be programmed to produce an interrupt request to the computer in case of missing highway clock.

Watchdog Function: A software controlled watch-dog function can easily be implemented. At regular intervals a specific software generated event is produced and sent down the highway. A Decoder channel placed at the end of the Timing Highway is programmed to detect this event.

4. SW SYSTEM DESCRIPTION

4.1. MDSPLUS

The Timing System Software is embedded in MDSplus [5], the model driven data acquisition system jointly developed by IGI Padova, MIT Plasma Fusion Laboratory and the Fusion Group of Los Alamos National Laboratory. It works in a VAX/VMS cluster environment. It is based on the concept of an "experiment model" which contains a hierarchical, tree-structured representation of the experiment. The experiment model contains the description of the parameters to be loaded, of the data to be acquired, of the devices used for acquisition, of the set-up of those devices, of the data acquisition and analysis "actions" to be executed during the experiment shot cycle.

4.2 TIMING SYSTEM SOFTWARE

The software support for the timing system has been organized in a three-layer approach: module-related devices, functional pseudo-devices which regroup frequently-used functionalities of modules into easy-to-handle software devices, and one system-wide device.

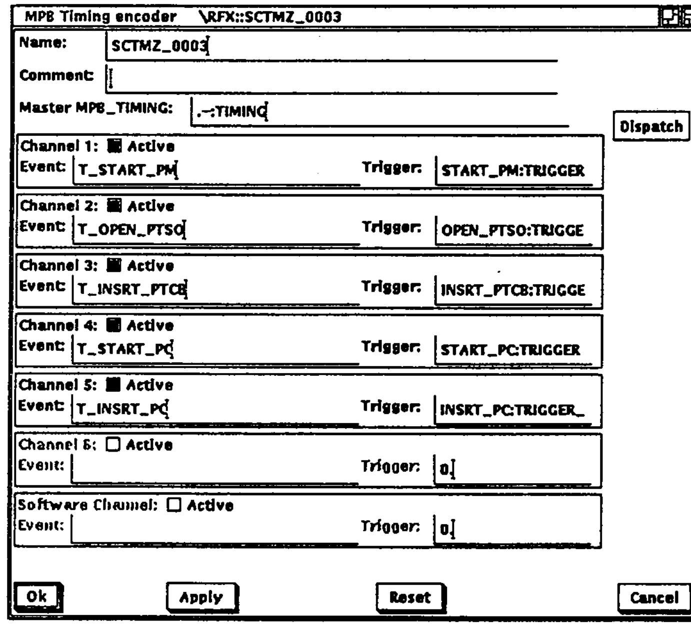

Figure 2: User Software Window for Encoder Module

4.2.1 MODULE-RELATED DEVICES

One such software device exists for each type of CAMAC module, which make all functions and settings of the actual CAMAC modules available: MPB_DECODER, MPB_-ENCODER, and MPB_RECORDER respectively. These are the only software devices which have a direct hardware counterpart. Their fields reflect the hardware registers of the modules. Fig. 2 shows, as an example, the set-up window for the Encoder module.

4.2.2. FUNCTIONAL PSEUDO-DEVICES

The functional pseudo-devices have been provided in order to provide an easier interface for the Decoder module. They do not correspond directly to any hardware. Rather, the contents of their fields are translated by their initialization operation into the appropriate values and stored in the "target" MPB_DECODER device. The pseudo-devices do not support all features of the module, only the more commonly used configurations are supported.

MPB_PULSE provides the software support for the generation of pre-programmed timing events at local CAMAC crates (see 3.2.1 above). It provides the generation of a pulse after a programmable delay from a timing highway event. Optionally a second pulse may be generated on the same output channel after a second delay. Pulses can be substituted with level toggles.

MPB_CLOCK is a continuous single speed clock generator, with programmable frequency and duty cycle.

MPB_GCLOCK provides the software support for the Gated Single Speed Clock Generator (see 3.2.4. above)

MPB_DCLOCK provides the software support for the Dual Speed Clock Generator (see 3.2.4 above). Fig. 3 shows, as an example, the corresponding set-up window.

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4.2.3. SYSTEM DEVICE

The system pseudo-device MPB_-TIMING has three distinct functions: system initialization, system configuration assistance, highway monitoring.

A typical *initialization* sequence is the following: First, the table of association between timing event codes and the corresponding times (in seconds relative to the start of the experiment pulse) is calculated from the user input to the MPB_-ENCODER and MPB_TIMING devices. Next, initialization operations are performed on all declared pseudo-devices by loading the necessary parameters into the MPB_-DECODER devices (no CAMAC command is issued in this phase !). If event times are required (e.g. to record the correct pulse time in a MPB_PULSE device), they are retrieved from the MPB_TIMING system-device. Last, initialization operations are performed on the MPB_DECODER and MPB_-ENCODER devices and set-up data are loaded into the Decoder and Encoder module registers.

The second function of the system-device MPB_TIMING is the *assistance with system hardware configuration.* In large systems, as RFX, events are generated by an Encoder whose trigger input is the output signal from a Decoder channel which is used as a delayed pulse generator which in turn is using an event produced by another Encoder channel. In addition, gated and dual speed clock generators require two Decoder channels to work: the first channel is used as a gate for the second one. Keeping track of all necessary connections and of the times associated to events and pulses, as well as frequency switches, may become very difficult when a large set of signals is involved. MPB_TIMING supports this

- by calculating the times associated with each event following the cascade of hardware triggers and timing events;
- by providing a graphic display of the set of the programmed signals;
- by listing the required hardware connections.

The third function of MPB_TIMING is the *display of the timing highway events* as recorded by the timing event recorder modules(s). As shown in Fig. 4 the time of arrival of each event is displayed alongside the time at which the event had been programmed.

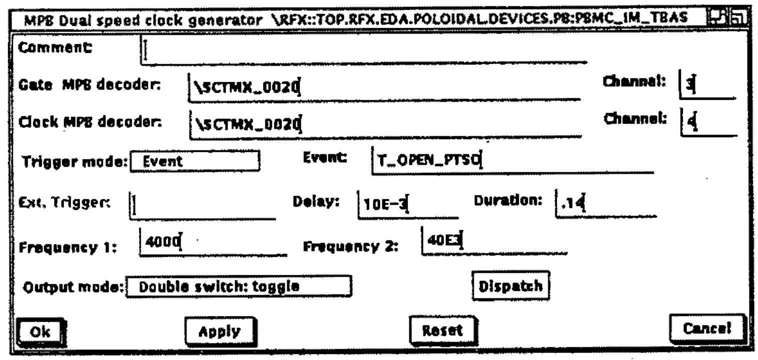

Figure 3: User Software Window for Dual Speed Clock Generator Device

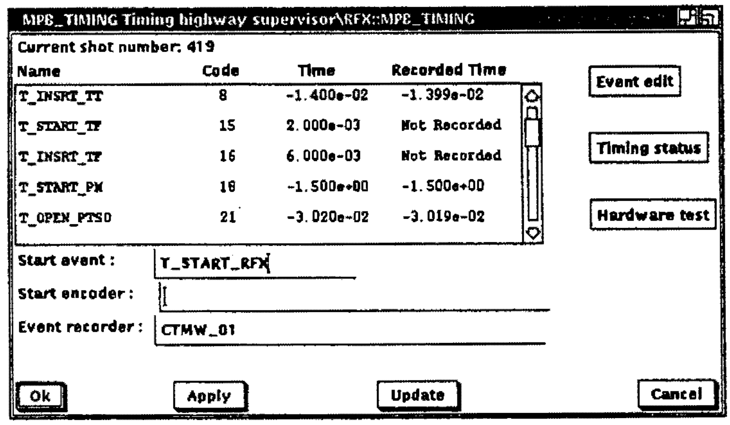

Figure 4: User Software Window for Timing Event Recording

5. OPERATION EXPERIENCE

The system is now fully operational. It was successfully used during the integrated commissioning of the RFX Power Supplies from April to October 1991. It is now being used for the start-up phase of RFX which should lead to first plasma before the end of 1991.

The actual installation comprises of 5 Encoders, 24 Decoders, and 2 Event Recorders. About 20 different timing events are being produced during a normal RFX pulse cycle which are used as trigger signals in different parts of the plant. 5 asynchronous events (from the protection system) are actually recorded and distributed. Time base signals are generated for 52 CAMAC transient recorders providing 391 data acquisition channels, 58 of which use the dual frequency clock feature, and for 10 D/A converter modules which provide 42 fast reference waveforms.

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