Structure and Properties of the Trigger-Time-Event System for the W7-X Experiment

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Abstract-- **The Trigger-Time-Event System (TTE-System) in the fusion experiment WENDELSTEIN 7-X serves the distribution of an experiment wide valid system time and facilitates the synchronisation of the control and data collection systems. The synchronisation requires an accuracy of < = 10nsec. Among other tasks the TTE-system also includes the distribution and recording of events and trigger signals under demanding real time conditions.**

The description of the TTI-system structure is followed by an explanation of the characteristic properties of the computer cards especially developed for this purpose.

A UML-based description of the driver for the TTE-cards exemplifies how TTE-card implemented devices, e.g. trigger, timer and pulse generator, are combined into user-specific real time tasks.

The utilization of the TTE-card is demonstrated with a sample application in which cycle clock signals of the segment control of WENDELSTEIN 7-X are generated by devices of the local TTE-cards.

I. Introduction

The Trigger-Time-Event System as described was specifically developed for the fusion experiment WENDELSTEIN 7-X (W7-X) which is presently being set up at the Max-Planck-Institut für Plasmaphysik in Greifswald. A description of the scientific tasks and the assembly of the stellerator-experiment is inter alia given in [1]. The control and data acquisition conceptions for W7-X are described in [2] - [4]. The properties of the implemented prototype of the TTE-system also allow the smooth use of the system in comparable control systems. Single components of the TTE-system, e.g. the all-purpose local computer cards of the local TTE-system, are also suitable for laboratory measurements or minor control tasks.

Various problems may arise if the time base in the varying subsystems of the complex control- and data processing systems of a fusion experiment is not generated with the required accuracy. The often required synchronised functioning of single components will not be ensured in this case so that complex synchronized control- respectively experimental processes cannot be carried out with the required accuracy. The correlation of data to a definite plasma event or control event and the comparison of data by means of timestamps will be considerably complicated with errors in the time synchronisation. Due to the multiple relationships of the synchronisation system with the control, monitoring and analyzing devices of large-scale fusion experiments, the development of a synchronizing device fulfilling the demands of all users requires great attention.

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II. Description of the Trigger-Time-Event System

A. The structure of the Trigger-Time-Event-System

Being an independent system, the TTE-system is associated to the central control system of the W7-X device. Its main components are: central TTE-system, local TTE-systems and TTE-networks. Figure 1 shows the structure of the TTE-system. The TTE-system is hierarchically structured with the central system on top and a quite arbitrary number of local TTE-systems subordinated. Synchronization signals, time information and event-messages are exchanged between the units of the system by means of a special network.

The synchronization signal is used for synchronizing the local counter's oscillators and time information is required for setting and verifying the local counter's content Event-messages carry information about changes of the state of the device or of the plasma . Each receiver can individually define its reaction to the event-message obtained. The unidirectional optical fibre-network connects the central TTE-system with all the subordinated local units.

This network distributes the synchronization signal, time information and event-messages from the central TTE-system. The event-messages mainly come from the central control system of the experiment. Alternatively they can be distributed through an Ethernet. The split up of the unidirectional network for the required number of local TTE-systems is put into effect by so called Switch-Repeaters. These devices amplify the received optical data signal with the synchronization and time information and pass it optically through each of the 12 ports to the following units.

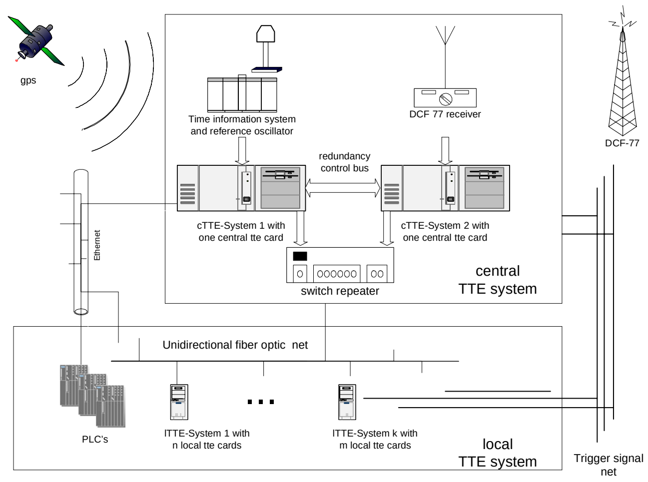

Figure 1: Structure of the TTE-system

A dedicated trigger signal network enables the quick processing of trigger signals. The central and local TTE-systems can feed electric trigger signals into the trigger signal network or receive trigger signals. The reaction to received trigger signals and event-messages can be configured by the user. The central TTE-system can broadcast predefined event-messages to all local systems upon receipt of a trigger signal from one of 8 input ports. The TTE-specific devices, e.g. the alarm timer, the delay- timer counter or the pulse generators, of the local TTE-systems can be controlled by trigger signals.

B. The central TTE-system

The main components of the central TTE-system are made up of two PCs each equipped with a central TTE-card, a Switch-Repeater for the splitting of the synchronization signal and time data to the unidirectional TTE-network and a highly stable reference oscillator. The control software for the central TTE-system functions under the real time operating system VxWorks (Wind River Systems). A highly stable, tempered controllable oscillator (OCXO) generates a reference clock signal which drives the master clock of the central TTE-system at a frequency of 50 MHz. The counter has a resolution of 64 Bit with Bit 2 being clocked by the oscillator. This results in an effective resolution of 20 ns. For future extensions, Bit 0 of the counter can be used to increase the resolution to 5 ns. In the non-synchronized mode, the central temperature-stabilized oscillator has a short term frequency stability of ±2.0*10-9/s and a the long term stability of ± 0.1*10-6/year. The oscillator can be synchronized by an external reference clock signal generated by a rubidium-oscillator. The utilized device “System 2000”from Datum Inc. is additionally equipped with a gps-receiver. By means of the gps-receiver, the rubidium-oscillator can be synchronized to improve the long term stability of its oscillator. Furthermore, the periodically received gps-time packets are used to synchronize the central counter with the internationally valid time on the basis of universal time coordinated (UTC). It was agreed upon that UTC shall be used as the effective time base for the control system of W7-X.

Conversions into local time formats have been made possible at any time by additional information given in the time-packets from the central control. The fault tolerance aspect of the TTE-system was very carefully considered. Both the redundant central pci-cards, which realize the essential functions of the central TTE-system, are designed to detect internal errors or errors with the redundancy partner and facilitate the switch-over of the signal source for the transmission through the unidirectional optical network. For this, status information is exchanged between the cards by means of a separate data bus (redundancy control bus) and the relevant time packets are analysed. Failures of the gps-system can be compensated at times by a DCF-77 based time information system. Many technical components of the experiment require for their control a resolution not better than a few milliseconds; and because of that a time server based on the simple network time protocol (sntp) was integrated for the components with reduced time demands. This time server distributes periodically time information by broadcast through an Ethernet or it sends the required time information on request. As against this, the components for hard real-time applications and data acquisition require resolutions up to the range of a few 10 ns which can be realized through the utilization of the specially developed TTE-cards. The synchronization signal and time data are transmitted with a data rate of 25 Mbit/s by means of the optical network in differential Manchester encoding**.**

Switch-Repeater devices represent the nodes of the optical network . Each Switch-Repeater has 12 output ports providing identical output and two input ports, one of them can be selected as source for the output. Within the redundancy control of the central TTE-system, this controllable signal input allows switching over from a faulty central TTE-card to a working one.

C. The local TTE-system

The local units of the TTE-system which are mainly used in the real time systems of the experiment and in the data acquisition stations have the following properties:

A local quartz oscillator drives a 64-bit counter that can be operated in three different modes: free-running, frequency synchronized with the central clock, frequency and time synchronized. Synchronization is effected through the unidirectional optical network that connects the local TTE-systems with the central TTE-system**.** The transit time on the fibre network can be compensated in the local units. A failure of the central synchronization can be bridged for a short time and without considerable loss of accuracy in the free-running mode.

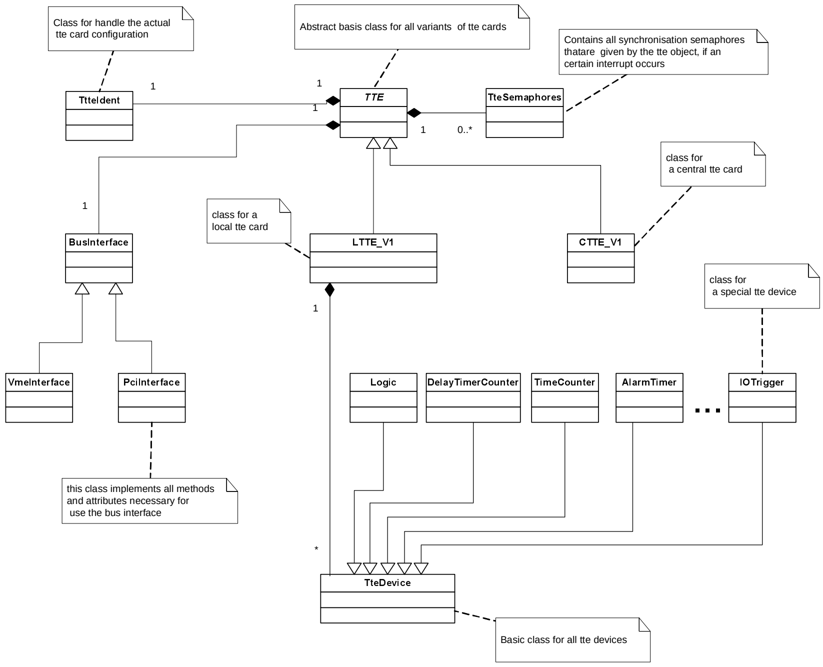

Figure 2: Diagram of a simplified class model for the driver programme

After re-synchronization of the oscillator the local clock can automatically set the counter value if the difference between local time and central time exceeds a preset error bar.

The local cards can specifically react to 1024 different event-messages by initiating programmable hardware and software reactions. Trigger signals can be distributed through a dedicated network. The local TTE-cards have various devices for signal processing. The interconnection of these devices can be flexibly programmed by software and configured in real time during operation of the card. All functions of the specific devices of the TTE-system are implemented in programmable logic circuits and facilitate a quick processing of signals at a scale of 1-3 FPGA-clock cycles consequently fulfilling demanding real time conditions.

The bus interface of the TTE-cards integrates the TTE-devices into the real time tasks running on the host computer. A comprehensive, universal function-library (TimeLib) describes the interface between the driver programmes of the TTE-card and the user programme. It simplifies the use of the TTE-devices on the TTE-cards in the application programmes and provides time-related functions (calendar functions, absolute and relative time functions). An extended description of the local TTE-card is given in [5].

D. The object orientated driver for the TTE-cards

An object orientated VxWorks driver has been developed for the TTE-cards. The modular hardware structure of the TTE-cards, which is basically made up of the bus interface and the TTE-devices, suggests the object orientated approach. Each device is considered as an instance of a specific class. Each class has the methods and attributes required for the initialization and operation of the device. Due to the possibility of different FPGA-programme versions for the individual TTE-cards, for example differing from each other by the number of implemented devices of a certain type, a special identification class was introduced. After booting the card first the number of the TTE-devices out of each type is determined by reading out a certain register range of the TTE-FPGA. Then the corresponding number of instances of a each TTE-device are being constructed. The user may access these objects through pointers which are allocated by the driver when creating the objects. The various TTE-card types are represented by an abstract class “TTE” serving as a base for the derived classes corresponding to different card types. Each special TTE-class has a defined number of different TTE-devices. The general properties of all TTE-devices are summarized in a super class “TTE-Device”. A simplified class model of the TTE-driver is shown in figure 2. The driver can be easily extended after adding new TTE-devices due to the class structure.

TTE-devices can release interrupts if a certain device status appears. All interrupt sources are summarized in a status register. This register is analysed by the Interrupt Service Routine (ISR). The assigned binary semaphore is given through the ISR when a flag is set in this register. A task of the user programme that was blocked before by this semaphore can then be transferred into the “running state”. This allows processing of interrupt states of the TTE-card with high priority.

III. SAMPLE APPLICATION

W 7-X generates pulses of up to 30 minutes length at full heating power. Therefore, it is useful to divide the available experimental time into individual sections called segments. A

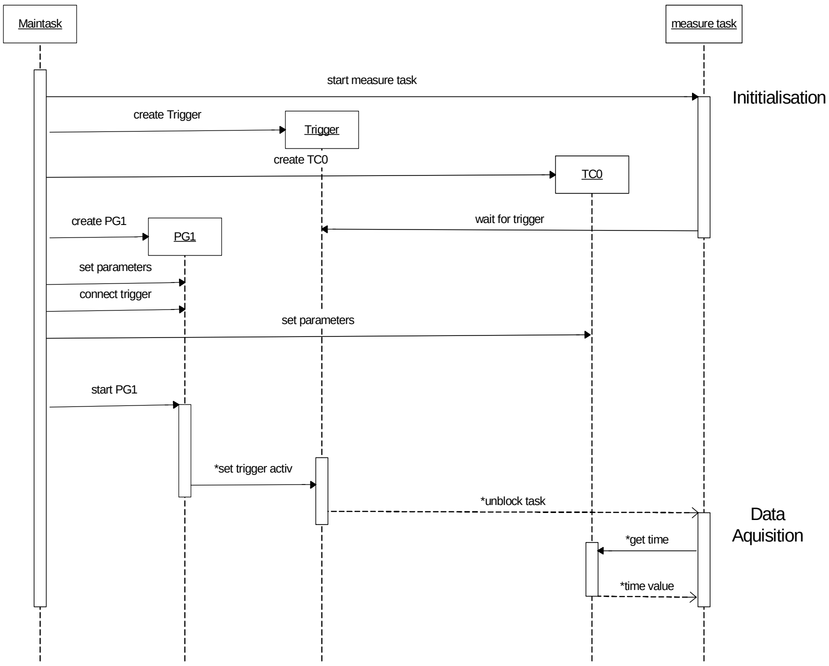

Figure 3: Sequence diagram of the sample application

segment programme defines the state of the entire experiment when a segment is being realized. [3, 4]**.** This segment control requires various clock signals which have to be generated synchronously in the segment control units of all components of the experiment. The following example shows a simplified model for the generation and processing of clock signals when controlling the segment: A primary clock cycle (*primClk)* with a frequency of f=1kHz generates a time grid. By definition, a change of segments may only be put into effect with the signal *primClk.* The signal *primClk* is generated by a properly initialised pulse generator (PG0) on a ltte-card of each segment control unit. The hardware-output signal of this pulse generator is delayed by a Delay-Timer-Counter (DTC0) on the TTE-card by 500µs. This signal is called the secondary clock cycle secClk. The time for the occurrence of primClk is recorded by a Time-Capture Unit. With an active *primClk* and *secClk,* in each case an interrupt is released. In the primary cycle within the Interrupt Service Routine (ISR) tasks waiting for the primary cycle will be put from the “pended” to the “ready” state. The secondary cycle divides the primary into two phases, the first of which is used for data acquisition and the second for data processing. For example, data measured during phase 0 can be used in phase 1 for the calculation and output of a control point. The sample application has additionally a measuring sensor (ADU). The ADU might need a certain number of pulses at a given interval beginning with the primary clock pulse. The clock pulse *Clk3* is generated by the pulse generator PG1 on the TTE-card, conditioned and output to the ADU through the I/O-Trigger 2 programmed as an output device. A Delay-Timer-Counter-Device (DTC1) is operated in counter mode and counts the ADU-counter pulses from the pulse generator PG1. Having reached the programmed number of pulses, the DTC1 signal *DTCactiv* stops the pulse generator over its input Start/Enable until a new primary cycle starts.

Figure 3 shows a sequence diagram describing a part of the activities in the course of the sample application. The task *maintask* causes initialising of the measure task by the message “start measure task”. Then, a software trigger is generated that can be started by giving the semaphore of the TTE-pulse generator PG0. The semaphore is given whenever the TTE-pulse generator PG0 generates an active output signal and releases an interrupt. The trigger release causes all the tasks which were blocked to become ready. After the trigger has been created the objects for the pulse generator PG1 and the Time Capture TC0 remain to be created and initialized.

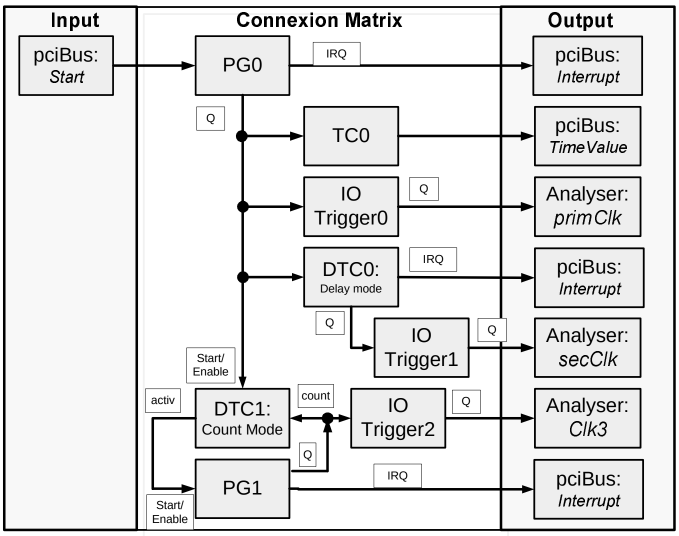

Figure 4: Interconnection of LTTE-devices for the sample application

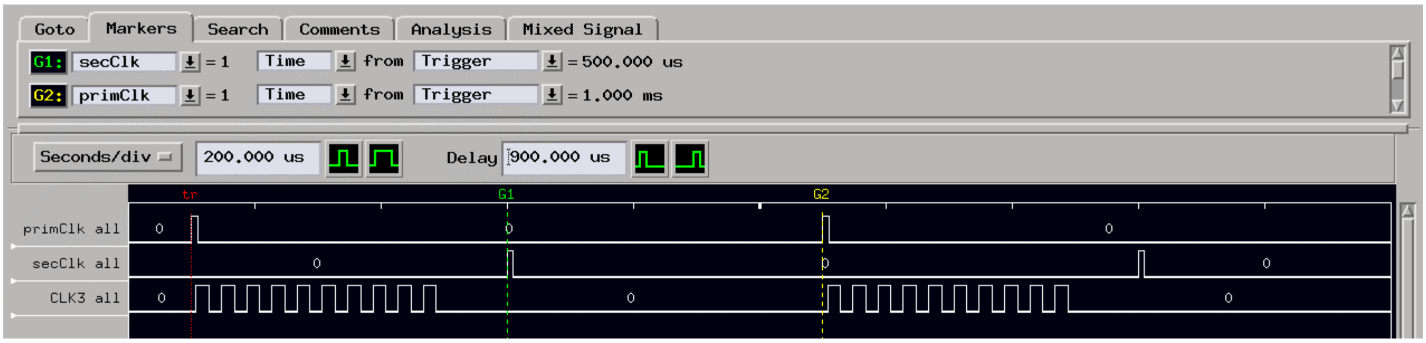

Figure 5: Analyzer plot of generated clock pulses

The measure task, which is connected with the trigger, can only receive data and read out the time from the Time-Capture-Device when the trigger was released.

Figure 4 shows the necessary interconnection of the TTE-devices that is carried through during the initializing phase of the ITTE-card in the sample application. The TTE IO-Triggers 0-2 were introduced into the application for outputting conditioned pulses. A logic analyser-plot in figure 5 shows the hardware signals *primClk* and *Clk3* generated on the ITTE-card. The triggers G1 and G2 which were used in the analysis show that the clock signals appear exactly at the expected time (tr->G1=500µs, tr->G2=1ms).

IV. Summary

The technical components of the fusion experiment W7-X have been developed for plasma discharges which may last for up to 30 minutes with full heating power. Since all control and data acquisition systems have to be perfectly synchronized for the tasks stipulated in the segment programme, a special Trigger-Time-Event-System (TTE-System) was developed. Along with the distribution of a system-wide valid time and the synchronization of the components, the TTE-system distributes and processes event-messages and trigger-signals.

The TTE-system has a hierarchical structure. The central TTE-system is the head of the structure with all local TTE-units subordinated. The number of the connected local units is not restricted and may be extended according to requirements. A unidirectional optical fibre network connects the central unit to the local systems. This network distributes synchronization signals, time information and event-messages. A dedicated and individually configurable trigger- signal network is designed for the fast distribution of trigger signals. The hardware for the central and local TTE-systems was developed as PC-cards. The high demands on the time resolution, the precision of the synchronization and the speed of processing are be met by using Field Programmable Gate Arrays (FPGA) of the type XILINX Virtex 1000E.

The connection to the real time tasks on the host computer is effected by a pci-bus interface. Structural changes, which for example include the number of implemented components for a designated type, can be quickly realized when loading a new

programme into the FPGA without calling for a new PC-card-design. The short signal paths between the components in the FPGA ensure minor delays for the signal processing.
It is the main task of the central TTE-system to provide an extremely precise system clock pulse that drives the central clock. A driver written in the programme language C++ was developed for the real time operating system VxWorks (Wind River Systems). The object oriented approach permits using the driver for several card variants.

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