DESIGN AND IMPLEMENTATION OF A FULL-FEATURED DISTRIBUTED SYNCHRONIZATION SYSTEM USING COMMERCIAL HARDWARE

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Abstract

In large scale facilities like accelerators, synchronization is not only about triggering. Other aspects of synchronization, namely synchronous data-acquisition and/or collection and data time-stamping are equally important. In this paper we first discuss the general synchronization requirements of modern accelerators and then describe our approach to address such requirements in SwissFEL project. In our FEL test stand we have implemented a full-featured synchronization system by integrating off-the-shelf hardware into a distributed control system (EPICS). By full-featured we mean a unified mechanism which addresses all aforementioned synchronization requirements (triggering, synchronous data acquisition/collection, time-stamping). We describe in detail our method to achieve this and explain what software components we had to develop in addition to available control system software.

INTRODUCTION

Many experimental and industrial control systems have to deal with synchronization issue in some ways. Synchronization problems differ for different facilities and systems but nearly all of them fall into one or a combination of the following categories:

a. Distributed triggering
b. Distributed time stamping
c. Distributed, synchronous information exchange (distribution/collection or command/control)

Due to their complexity and often very stringent requirements, large scale experimental physics facilities are the meeting point of all these synchronization problems in their most stringent form. Depending on the requirements, budget, chosen technology and existing infrastructure, these problems can be addressed differently although they are all closely related. Sometimes they involve in-house development of hardware and software systems. IEEE-1588 standard [1] was defined to solve the abovementioned problems in networked control systems based on Ethernet. Unfortunately the commercially available IEEE-1588 compliant systems and devices cover at the moment only a narrow range of applications. Another limitation is that the network components (mainly switches and routers) have to comply with IEEE-1588 while there is very little support for that on the market. Furthermore, although the synchronization quality of this standard is in general very good, it still cannot satisfy the requirements of many complex physics facilities.

These requirements have brought some physics facilities to collaborate with each other and with industry to search and merge solutions for their common synchronization problems in a single system. The result is the Global Event System which has evolved incrementally during several years towards a full-featured synchronization system. The first implementation of such a system (known to us) was developed at APS (Advanced Photon Source) synchrotron radiation facility. The ideas of this system became the basis of a new system for the SLS (Swiss Light Source) [2] which was developed in collaboration with Micro Research Finland (MRF) Company [3]. The implementation had a lot of new features which together with the commercial availability of the system made it attractive for other projects. The system went through another major revision when it was adopted by the Diamond Light Source project. The evolution has happened in a close collaboration with Micro Research Finland and its customers [4]. The event system has evolved to its current state thanks to the ideas and requirements brought in by the various projects [5, 6].

In the following sections, we first describe briefly the major features of this system and finally we describe an example of its application which utilizes all abilities of such a system to address almost all synchronization issues we have discussed so far.

GLOBAL EVENT SYSTEM

In a global event system, a central event generator (EVG) gathers and generates necessary timing information and distributes it via high speed links to interconnected event receivers (EVR). As many EVR's as required are connected to the central event generator in a star topology. This topology guarantees a deterministic (although not necessarily equal) propagation time. All EVRs in the network receive the complete timing information from the link.

The timing information is transmitted as 16-bit frames. These frames are divided in two parts: 8 bits for transmitting the events, namely numeric codes with a predefined meaning. Events are transmitted by the event generator upon detecting a signal edge, expiration of a hardware counter or upon a software request. Upon receiving a code, EVR can decide to react or ignore it. The reaction can be triggering hardware, software or both. The remaining 8 bits can be used to send status of up to 8 sampled signal bits or a byte of raw data or both multiplexed in time.

Maintaining synchronized timestamps is assisted by generation and distribution of a clock tick in form of a specific event code or a specific status bit and having

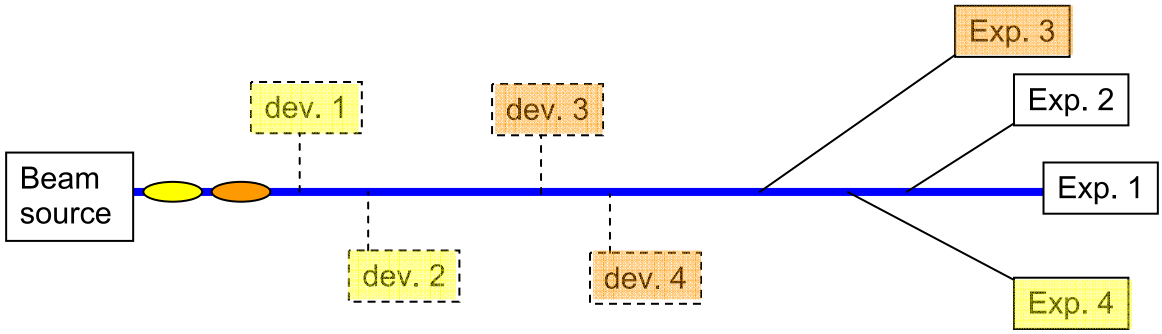

Figure 1: Very simple illustration of an FEL facility.

receivers count them synchronously. To distribute synchronous data, the raw data are written to a dedicated data buffer on the EVG and transmitted synchronously and parallel to the trigger events. Currently there are some developments on the same hardware by the manufacturer to provide full-duplex communication for data and a possible extension where events can be used to synchronize data transmission in a system with a ring topology as well.

We do not go to further details of the system design and rather dedicate the rest of this paper to description of an application of such system in a large scale physics facility where the all functionalities of such synchronization system is fully and nicely exploited. More details of the system can be found in [3].

SWISSFEL TIMING SYSTEM

SwissFEL is a compact Free Electron Laser (FEL) facility planned to be built at Paul Scherrer Institute [7]. It is a linear accelerator of about 1 Km length which will provide femto-second pulses of high intensity for several experiments. The produced beam is time-shared between several experimental station (beamline) located at the end of the linear accelerator [see Fig. 1]. Such facility requires all three synchronization aspects we have mentioned: distributed-, triggering, time stamping, and synchronous data exchange. We have chosen a commercial hardware that we have briefly described to fulfill synchronization requirements of this facility* without any need for in-house hardware development.

Requirements

As the devices and subsystems which require triggering, are distributed over a long distance the need for a distributed triggering system is self-explained. The diagnostic devices, pulsed magnets, power supplies, RF subsystems and Laser systems are examples of such subsystems. Most but not all of the required triggers form a cyclic sequence of events with repetition rates in the range of 10 Hz to possibly 400 Hz. Due to complexity of the accelerating machine and beamlines a precise synchronized time stamping is critical to perform data correlation studies.

In addition to timestamps, we also use a bunch-marking technique that enables us to precisely distinguish between the data collected from different bunches even if synchronized time stamping is not available [see Fig. 2]. In this technique every pulsed beam is marked with a unique identification number which is distributed as a synchronous data in parallel to the trigger information to all subsystems equipped with timing hardware. Because the beam is time-shared, important beam parameters have to be sent in advance (before beam generation) to the experimental stations to inform them about the coming beam and let them decide for example to enable or disable their subsystems. In some cases, especially for machine studies and developments, single-shot synchronous measurements are required as well. This is also implemented by combination of sequencing of trigger events and synchronous (command) data distribution and provides with synchronous data collection from many subsystems for a single pulse of the beam upon user request. In this mode a command data (e.g.”Ready”) is distributed upon user’s request which enables triggering the set of devices and sensors of interest only for the next coming beam and disables them right after that until the next (Ready) command and the collected measurements are assured to belong to this specific beam.

Integration to Control System

SwissFEL will use EPICS [8] as its major control system component. The hardware technology is chosen to be based on VME. We use therefore MRF timing hardware mostly in the VME format. Programming and configuration of the EVG and EVR are done by a number of EPICS records and corresponding device drivers. At each beam generation cycle a sequence of programmed event with relative delays are distributed to the receiver systems. Each frame of information can be transmitted in a rate of up to 125 MHz. The required synchronization information embedded in these frames includes trigger event codes, timestamps and synchronized data. The detected events at the receiver side cause generation of local triggers with programmable local delay and pulse-width which can be adjusted by means of EPICS records.

* The femtosecond-level synchronization of subsystems (reference frequency distribution) is designed in an independent scheme which we do not discuss here. The two different level of synchronization are locked to the same master oscillator.

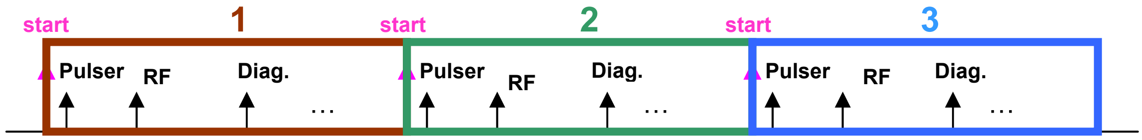

Figure 2: Demonstration of periodic sequence of trigger events together with bunch numbering (marking).

The synchronized timestamps that are maintained with the assistance of EVR at each system, are attached to each EPICS record whenever the get processed. There is a time-stamping management module in EPICS which provides fallback mechanisms in case of timing hardware failure. This time management module guarantees a monotonic increasing time function under all conditions.

CONCLUSION

They will be added when the final proceedings are produced. In this paper we have discussed the general synchronization requirements of complex experimental physics facilities. We have then illustrated such requirements by describing SwissFEL timing as a real-world example. We have presented our approach to solve almost all of our timing related problems by exploiting a commercial timing system without any need for in-house developments.

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