REVIEW OF THE DIAMOND LIGHT SOURCE TIMING SYSTEM

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Abstract

The Diamond Light Source timing system utilises a central event generator with distributed event receivers at the equipment being controlled for all accelerator and beamline subsystems. This provides distributed fiducials with resolution of 8 nsec and stability of 8 psec. It is based on commercial hardware from Micro-Research, Finland.

This paper describes the installed timing system and summarizes 5 years' operational experience of the system. It describes the hardware and software and the distributing network, and the achieved precision and stability of the system. Developments in the timing system to support additional operational functionality of Diamond, including top-up operation, are also discussed.

INTRODUCTION

Diamond Light Source is a 3 GeV third-generation light source with a 561 m storage ring (SR), a full-energy booster and a 100 MeV pre-injector Linac [1]. The photon output is optimised for high brightness from undulators and high flux from multi-pole wigglers. The current state includes 19 photon beamlines operational, with a further three beamlines in design and construction.

The Diamond timing system is based on commercial hardware from Micro-Research Finland Oy [2] and provides an integrated timing system across the three accelerators and the photon beamlines.

DIAMOND TIMING SYSTEM STRUCTURE

The Diamond timing system is based on a central event generator (EVG) which generates events from an internal sequencer and external sources. These events are distributed over fibre optic links to multiple event receivers (EVRs) [3]. The EVRs, which are located in the control system interface layer, decode the events as hardware triggers or software interrupts. Hardware triggers are connected directly to the equipment using copper or fibre optic connections or through a four-channel timer when greater timing resolution is required. For the Linac, the decoded events are further encoded by a gun transmitter and sent over a fibre link to the gun high voltage platform. The external event sources include astronomical time derived from GPS through a Symmetricom, XLi - Time & Frequency System and a 10 MHz clock from a rubidium generator, a 50 Hz trigger and a post-mortem trigger when the beam is lost. The event clock is derived from the 500 MHz master oscillator, so that it is locked to changes in the RF frequency. The structure is shown in Fig 1.

HARDWARE

Event Generator

The EVG issues event frames consisting of an 8-bit event code and an 8-bit distributed data bus, at a rate of 125 MEvents/sec. Events can originate from several sources which are: eight external trigger events, a sequence RAM, software events and events received from an upstream event generator. Events from different sources have different priorities which are resolved in a priority encoder. A block of RAM is used to store a sequence of events. The Booster revolution clock is used to count through the sequence memory, thereby transmitting events with a time resolution of ~500nsec The 8-bit distributed data bus signals are sampled simultaneously at the event clock rate and distributed to the event receivers. The EVG is realised as a VME module.

Event Receiver

The EVR recovers the event clock signal from the event stream and splits the event frame into the 8-bit event code and the 8-bit distributed data bus. The decoded events are mapped through RAM on to: four delayed pulse outputs, with programmable delay and width (16-bit pre-scaler from the event clock, 32-bit delay and a 32-bit width register), 14 pulse outputs with programmable delay and width (32-bit delay and 16-bit width) or seven set/reset flip-flop outputs. The processed events can produce hardware outputs or software interrupts and are time-stamped with a resolution of 1 μs. The hardware outputs are routed to connectors of the rear transition board, but any of them may also be multiplexed on to the front panel connectors. The EVRs are realised as both VME and PMC modules.

Linac Gun Driver

The Linac gun driver consists of two channels, providing single- and multi-bunch injection respectively, by driving separate gun triggers. It is realised as a gun transmitter in the Linac timing crate and a gun receiver which is placed on the gun HV platform. The gun transmitter accepts trigger signals from an EVR system, delays them with a resolution of 2 ns and generates modulated optical signals which are sent to the gun receiver, where they are decoded for driving the gun. A fine programmable delay is also available and allows adjustment of the triggering position with a resolution of 10 ps over a range of 10 ns.

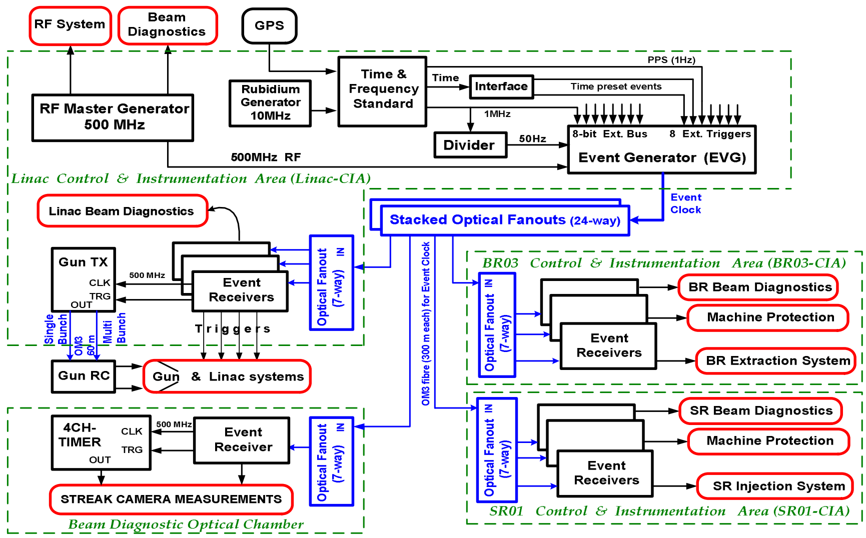

Figure 1: Structure of the Diamond Timing System

Four-channel Timer

The four-channel timer provides four independent timer channels with programmable delay and pulse width. The timer channels may be triggered individually, through a common input by PECL signals from the front panel or through a rear transition board by TTL levels. The delay and pulse width for each channel may be adjusted in a range of 8.5 sec with a resolution of 2 ns (one RF clock cycle). Further delay adjustment over a period of 10 ns with resolution of 10 ps is also provided.

Distribution

The timing distribution network delivers the event stream using OM3 multi-mode fibre. The network is structured as a two-level multi-star topology using 24 and 7 way fan-out modules. Simultaneous delivery of event messages to multiple EVRs is arranged by using fibres of equal lengths, 320m +/-0.2 m.

SOFTWARE

The timing system integrates into the EPICS based control system [4] through a number of EPICS records. The EG record configures and defines the options of a specific EVG module. These include choice of the EVG operating mode, selection of internally generated clock rates, optional transmission of software-invoked events and enable of event trigger inputs. The EGEVENT record is used to specify a single event to be placed into the sequence RAM. The ER record configures the options for the EVR, such as pulse delay, width and polarity, front panel output assignments and distributed bus enable. The EREVENT record specifies the desired actions to be performed upon receipt of a specific event code. Applications to control the timing system are built with the usual EPICS tools for databases and EDM for display panels.

Functionality to provide standard fill patterns is realised in the EPICS IOC for the EVG. This provides support for: single bunch single shot, multi-bunch single shot, single bunch fill, multi-bunch fill, period single bunch fill, arc fill and spread fill of the SR. In all of the “fill” cases the SR is filled to a predetermined charge.

EVENT GENERATION

The Diamond SR has 936 buckets and a revolution frequency of 533.8 kHz, and the booster 264 buckets and a revolution frequency of 1892.6 kHz. The coincidence of the SR and booster revolution determines a frequency for the coincidence clock of 48.529 kHz, based on the common factors of the two frequencies. The booster clock is used for counting through the EVG sequence RAM, and the coincidence clock is used to reset to the start of the sequence, thereby locking the cycles of all accelerators. Event entries are placed in the sequence RAM to generate the necessary sequence of triggers to accelerate the electrons through the Linac and booster into the SR, as shown in Table 1. Supplementary events are produced to provide control of the diagnostics in each of the accelerators and the transfer lines, gating signals during topup, and beam loss post mortem.

Events	Time/μs	Description
T-ZERO	0	Booster cycle trigger
BR-HW-TRG	44999.8	BR Magnets trigger
LINAC-PRE	49949.6	Linac Gun pre-trigger
BR-PRE-INJ	49950.1	BR Injection trigger
LINAC-HBT	49950.6	Linac Systems trigger
BR-INJ	58312.1	Booster injection
SR-INJ-SEPT	148973.8	SR Septum
SR-PRE-INJ	148999.6	SR Kickers
BR-PRE-EXTR	149000.7	Booster pre-extraction

Table 1: Events used to accelerate electrons

OPERATIONAL EXPERIENCE

The Diamond timing system has demonstrated a relatively high level of reliability. In all cases, the failures that have occurred have not led to the loss of stored beam in the SR. These failures have been associated with non-optimal driving current of optical transmitters in EVR transition modules, defective transceivers in fan-out modules and connection loss in optical fibres. In two cases individual EVRs lost their functionality and "refused" to process incoming events. Their functionality was restored after reflashing the Xilinx FPGA.

PERFORMANCE

The main performance measure of the installed system is the stability (jitter) of the decoded event with respect to the RF clock, which is 8.0 ps for the VME EVRs and 22.0 ps for the PMC EVRs [5]. The differential error of decoded events between EVRs is +/-1 ns; this is defined by lengths of fibres in distribution network. The seasonal stability (drift) is within 25-30 ps, and the drift over a 24 hour period does not exceed 10 ps. In both cases the dominant factor is the temperature stability in the experimental hall.

DEVELOPMENTS

The major development that has taken place on the Diamond timing system has been changes to support the operation of the accelerators in top-up operation, which commenced in October 2008[6]. Top-up involves injecting charge into the SR on a periodic basis, every few minutes, with photon shutters open, to maintain the fill pattern, constant current, higher overall current, constant heat load on components and hence better stability of the photon beam. The changes were: the addition of a new mode to control the EVG, the separation of triggers for the SR kickers and septum to different events, the addition of a 4 hour periodic event and the provision of new events to the photon beamlines.

The new EVG mode provides a mechanism to define a sequence of shots to take place and for the electrons to end up in the specified bunches in the SR. This enables a client application to control the top-up process by checking which bunches require charge and directing the injected charge into those bunches. This makes it possible to maintain an arbitrary bunch structure in the storage ring. An example of this is 250mA hybrid mode where there are 685 buckets filled to 0.68 nC, 125 empty buckets, 1 bucket filled to 5.6 nC and further 125 empty buckets, see fig 2. The larger bunch has a much shorter lifetime than the other bunches and so requires more frequent filling.

Originally the SR kickers and septum shared a common event; however the septum power supply requires a number of cycles before it achieves the required field. By assigning the septum to a separate event a number of pre-cycles of the septum can take place, as part of the topup cycle, without triggering the kickers and so without disturbing the stored beam.

The four-hour periodic event is used to reset the integrators on all radiation monitors, which provide an interlock based on the integrated dose over that time period and so are sensitive to ongoing lower level radiation losses. To generate this event, an EVR local to the EVG is programmed to give an output four hours after the event. This output is then connected back into the EVG to generate the four-hour periodic event. The event is started and synchronised to the shift boundary when the IOC is restarted. To increase the reliability of this, an interface module has been developed that continues to produce the reset, every four hours, when the event from the timing systems is not produced; thus a failure of the timing system or maintenance on the timing system such that events are not produced does not result in false alarms from radiation monitors as a result of integrating the natural background radiation.

Asymmetry of the SR kicker pulses results in beam disturbance which lasts up to 12 ms. This affects the brightness of the photon beam and hence some of the beamline experiments. Two additional events were introduced for topup operation (TOP-UP-ON and -OFF) to enable the beamlines to mask the periods when the injection takes place. These events are decoded as “Short” and “Long” gate signals from the EVRs, and mask either each injection shot, or all of the multiple injections of a top-up cycle, and are provided to each photon beamline.

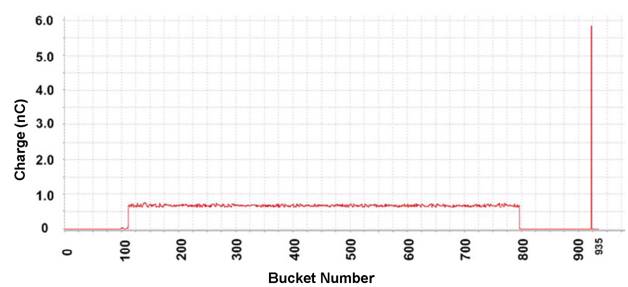

Fig 2: 250mA hybrid fill pattern

CONCLUSION

The installed timing system has functionally met the requirements for the initial operation of the accelerator and beamlines on Diamond Light Source. The system has further proved to be very reliable in operation and has proved to be flexible to accommodate additional functionality for top-up operation.

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