

NEW EVENT TIMING SYSTEM FOR DAMPING RING AT SuperKEKB

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Abstract

We utilize the Event Timing System to perform the operation of injector for the SuperKEKB accelerators. We construct the Sub-timing Station to manage two kinds of triggers for the Damping Ring devices. We developed new Event modules, VME-EVO and VME-EVE, to deliver triggers to the beam monitors at Damping Ring. The triggers for 84 beam position monitors can be provided with only 5 new Event modules. The timing accuracy of outputs from the new Event modules is ~ 15 ps. It well satisfies the requirements from the beam monitors at Damping Ring.

INTRODUCTION

SuperKEKB [1, 2] is the electron-positron collider which targets the world's largest record of luminosity. This is the upgrade machine of KEKB [3, 4] and one of the most important projects at KEK. SuperKEKB is designed to achieve 40 times larger luminosity than that of KEKB – it is realized from two times larger storage current and 20 times smaller vertical emittance.

The control system of injector linac (LINAC) [5] is extremely important for both KEKB and coming SuperKEKB. One of key technologies for the LINAC control is Pulse-to-Pulse Modulation (PPM). This injector “simultaneously” performs the top-up filling operations into four independent rings – two rings of SuperKEKB and two light sources [6, 7]. Therefore more than 150 of parameters to operate the LINAC beamline should be changed, pulse-by-pulse, typically in 50 Hz.

The Event Timing System of LINAC [8–10] works for not just the delivery of timing-triggers to the beamline devices but the above-mentioned PPM operation. It forms star topology optical network. The Event Generator (EVG) [11] is placed at Main Timing Station¹ – it is the focal point of optical network. The EVG controls the LINAC devices by delivering various kinds of Events. The Event Receivers (EVRs) [11] are placed at the individual edges of the optical network. The EVRs work for the beamline devices in the two kinds of ways when they receive the Events. One is the launching of triggers, like NIM or TTL, for indicating the timing of injection process. The other is the CPU interruption to switch the parameters of devices for the PPM.

We develop Sub-timing Station on one edge of Event network for the newly constructed Damping Ring (DR). The several Event modules including the newly developed modules are installed at DR Sub-timing Station since the delivery

of timing-triggers towards the DR devices during the storage of beam-pulses is complicated.

In this report, we introduce the timing system at DR with the newly developed Event modules.

TRIGGER REQUIREMENTS AT DR

In this section, we explain the requirements to the timing system at DR. We need the special treatments to the triggers for the beam monitors since they are not synchronized with the LINAC operation. We explain the triggers for the beam position monitors (BPMs) as an example.

Operation Scheme of DR

DR is constructed for SuperKEKB. It is utilized in the injection of positron-pulses at LINAC. The frequency of RF cavity at DR is 508.89 MHz and it is same as that at MR. The harmonic number is decided to be 230 for making Bucket Selection of Main Ring (MR) [12, 13] efficient. The positron-pulses are stored at least 40 ms for damping their emittance.

In each positron injection, two of RF-buckets are occupied by the beam-pulses. The RF-buckets to be occupied are changed depending on the Bucket Selection in pulse-by-pulse.

Triggers for BPM

There are 84 BPMs at DR. They work during the storage of positron-pulses and measure the orbit. The timing of trigger for BPM is set by the delay value from the DR revolution as a reference and is independent from the LINAC operation.

The delay value is determined from two components. The individual BPMs have their own delay which are related with the installed positions along the DR beamline. In addition to these individual delays, there is the common delay which is related with the RF-buckets occupied with beam-pulses. The common delay must be set in the 508.89 MHz step since it is the frequency of RF cavities at DR. It should be adjusted, in pulse-by-pulse, because of Bucket Selection.

To validate the certain performance of BPMs, the accuracy (jitter) of the total delay values should be < 2 ns.

Summary of Requirements to the Timing System

Here we summarized the requirements to the timing system for the DR operation.

There are the triggers only for the DR devices like the beam monitors. They are delivered during the storage of

¹ We call it as Main Trigger Station in the KEKB era.

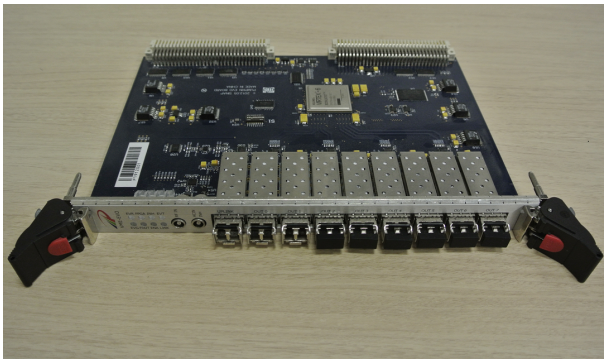


Figure 1: Picture of the VME-EVO module.

positron-pulses. The timing is independent from the LINAC operation and synchronized with the DR revolution.

The timing of triggers for 84 BPMs at DR should be set with the accuracy of < 2 ns. The delays for the individual BPMs consist of their own delays and the common delay which are adjusted in the 508.89 MHz step.

In addition to above “DR specific” triggers, of course, we deliver triggers for indicating timing on the injection (extraction) of beam-pulse to (from) DR. They are utilized for the septum magnets and so on and can be realized by simply connecting EVRs with the EVG at Main Timing Station.

EVENT TIMING SYSTEM AT DR

In this section, we explain the configuration of Event Timing System at DR. We introduce the new Event modules which are utilized for delivering the triggers towards BPMs. They are the VME type modules originally developed for the proton therapy machine at SINAP [14] and customized for the SuperKEKB project. We confirmed also the new modules are compatible with the KEK’s current standard modules, VME-EVG-230 and VME-EVR-230RF [11].

New Event Generator

Figure 1 is a picture of the VME-EVO module. Its specification is summarized in Table 1. The sequence for delivering Events can be triggered by the TTL input or the up-link Event. The operation clock (Event clock) can be set independently from the upstream module when its up-link channel connects with the EVG. The VME-EVO module has 8 TX channels (outputs) so that it does not need the dedicated fanout module.

It is also worth noting, VME-EVO can be utilized also for the EVR or fanout modules. It depends on settings.

New Event Receiver

Figure 2 is a picture of the VME-EVE and VME-TTB modules. Its specification is summarized in Table 1. The VME-EVE module has 8 outputs which launch the TTL level triggers. The output channels can be increased by installing the VME-TTB module on the rear slot of VME sub-rack. The VME-TTB module has additional 16 output channels.

Table 1: Specifications for New Modules

	VME-EVO	VME-EVE
Type	EVG/EVR/fanout	EVR
Event Clock	60-135 MHz	60-135 MHz
Clock Sync.	RF input	Up-link
Trigger	TTL, Up-link Event	Up-link Event
Output	Optical $\times 8$	TTL $\times 8$ ($\times 24$)
Precision	Event Clock	Event Clock/20

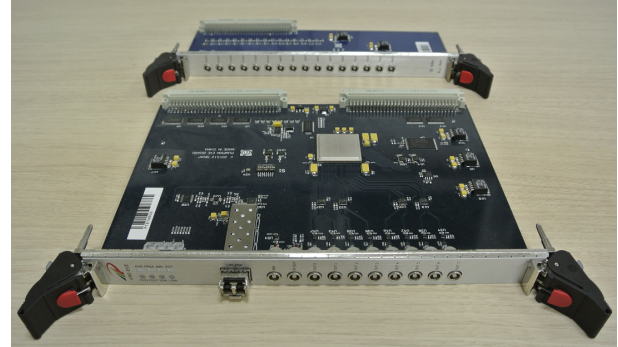


Figure 2: Picture of the VME-EVE and VME-TTB modules.

Therefore one set of VME-EVE and VME-TTB can manage totally 24 kinds of TTL level triggers².

The trigger delivery is implemented when VME-EVE receives an Event from up-link. The delay can be set on the individual outputs, independently. The individual channels have two kinds of delay functions. One is the Event clock delay. The other is the 20 times more precise step than the Event clock and named “RF delay”. The RF delay is provided with the GTX technology.

Overview of Event Timing System at DR

Figure 3 is the schematic view of module configuration for the DR timing system. We install two VME-EVR-230RF modules and one VME-EVO at DR Sub-timing Station.

Two EVRs are connected with two lower-level EVGs of Main Timing Station, respectively. Therefore, one EVR is synchronized on the timing of the positron-pulses injection while the other EVR is synchronized on that of extraction. Their Event clocks are 114.24 MHz and phase-locked by the up-link EVGs.

The VME-EVO module is operated with the Event clock of 127.2225 MHz. The 508.89 MHz clock for the RF cavities at DR is put into the RF-IN channel. It is 4 times divided on the inside circuit and utilized as the reference clock. We put the DR revolution into the AC-IN channel of VME-EVO.

There are 4 local IOCs for the BPMs. In each IOC, the VME-EVE modules are installed with VME-TTB. The individual IOCs manage the triggers for the 21 BPMs. The up-link channels of VME-EVEs are connected with VME-EVO at Sub-timing Station.

² Note, now we are developing also the module with the NIM level outputs.

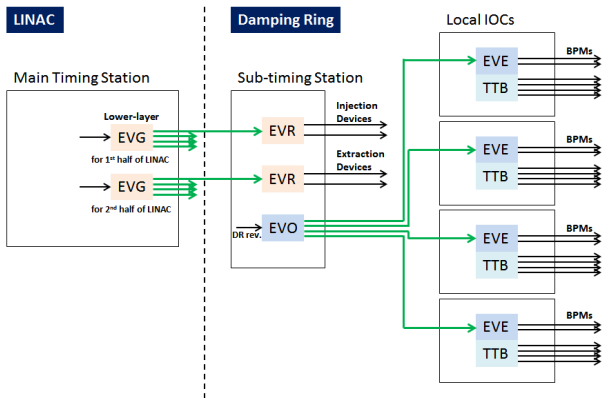


Figure 3: Schematic view of configuration of Event Timing System: the right part from dashed line is the configuration for Damping Ring. We configure DR Sub-timing Station with the three Event modules.

The entire “VME-EVO+VME-EVE” system can provide the triggers with the timing reference of the DR revolution and the arbitrary delays. They are utilized as the triggers for the beam monitors. The two components of delays for the BPM triggers are realized in the following way.

The delay adjustments for individual BPMs are needed to compensate the difference in their installed positions. They are implemented by the Event clock delay of individual VME-EVE channels.

The common delay is needed to fit the timing of triggers to the storage bunches and adjusted by the Event scheduling on the sequence RAM of VME-EVO. However the Event clock of VME-EVO is 4 times coarser than the required precision, 508.89 MHz, for setting the common delay. Therefore we additionally utilize the RF delay of VME-EVE (and VME-TB) channels. The RF delay can manage 4 times more precise delay since its intrinsic precision is 20 times more than the Event clock.

The module configuration of Event Timing System for the beam monitor at DR is simple even though the complicated timing adjustments are required to the triggers. We can manage the triggers for the 84 BPMs with only 5 Event modules. The triggers for other beam monitors, like the synchrotron radiation monitor, also can be delivered from the similar system.

PERFORMANCE OF NEW MODULES

Here we introduce the timing accuracy (jitter) of TTL outputs from the new Event modules as an example of their basic performance.

The test system is configured by connecting the VME-EVO and VME-EVE modules. The VME-EVE is equipped with the VME-TTB. The RF clock of 508.89 MHz are put into the RF-IN channel of VME-EVO and the test system is operated with the Event clock of 127.2225 MHz. They are same condition as the real operation.

We measure the timing accuracy of TTL outputs from VME-EVE and VME-TTB with the oscilloscope. The same

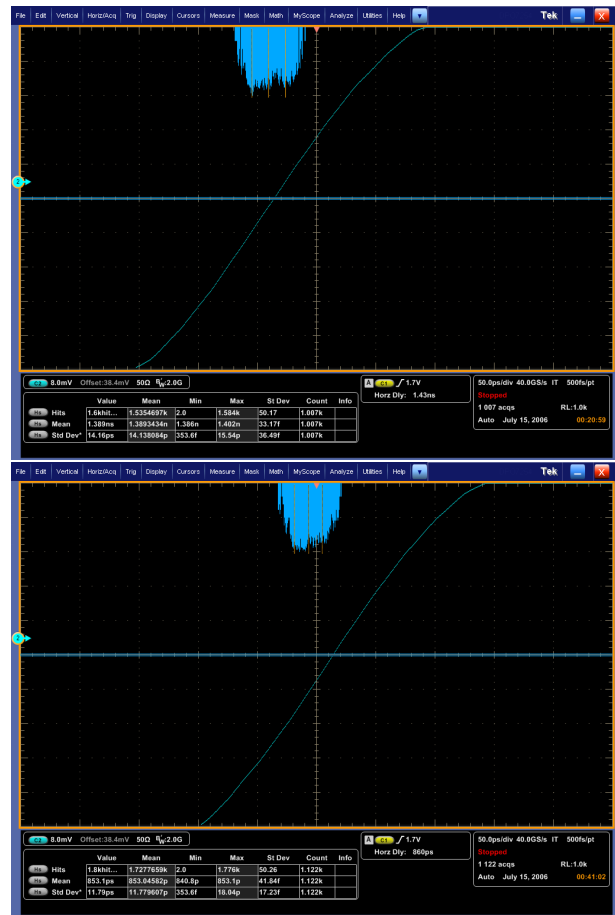


Figure 4: Results of timing accuracy measurements: results for CH1 of VME-EVE and CH0 of VME-TTB are shown in the upper and lower figures, respectively.

508.89 MHz clock is put into this oscilloscope as the reference of measurements. The oscilloscope is triggered by the TTL outputs and operated in the sampling mode. The trigger resolution and sampling step of oscilloscope are 100 fs and 500 fs, respectively. Therefore the capability in this timing measurement is enough to discuss following results.

The examples of results are shown in Figure 4. The upper picture is the result of CH1 of VME-EVE. The accuracy of output is determined from the standard deviation of histogram to be ~15 ps. The resultant accuracies of all other channels of VME-EVE are similar with this result. The result of CH0 of VME-TTB is shown in the lower picture. The accuracy of output is ~12 ps. This example picture also well represents the accuracy of all other channels of VME-TTB.

Note our results are a little bit worse than the same measurements performed at SINAP. One of the reasons is the quality of the reference signal. The RF clock which we use is a little bit noisy so that it affects the measurement.

CONCLUSION

We develop Sub-timing Station to manage two kinds of triggers for the DR devices. One is the triggers for indicating timing on the injection and extraction of beam-pulses.

The other is those for the beam monitors. The three Event modules are configured at Sub-timing Station.

The newly developed Event modules are adopted for the triggers to the beam monitors. They are implemented by inputting the DR revolution. Their Event clocks are 4 times division of the 508.89 MHz frequency which is for the RF cavities at DR.

The triggers for 84 BPMs at DR can be managed by the only 5 modules and it is one of the advantages of newly developed modules.

The timing accuracy of outputs from the VME-EVE and VME-TTB modules are determined to be ~ 15 ps and ~ 12 ps, respectively. They are quite better than the requirements for the BPM operation.

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