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Time-stamping system for nuclear physics experiments at RIKEN RIBF

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ABSTRACT

A time-stamping system for nuclear physics experiments has been introduced at the RIKEN Radioactive Isotope Beam Factory. Individual trigger signals can be applied for separate data acquisition (DAQ) systems. After the measurements are complete, separately taken data are merged based on the time-stamp information. In a typical experiment, coincidence trigger signals are formed from multiple detectors to take desired events only. The time-stamping system allows the use of minimum bias triggers. Since coincidence conditions are given by software, a variety of physics events can be flexibly identified. The live time for a DAQ system is important when attempting to determine reaction cross-sections. However, the combined live time for separate DAQ systems is not clearly known because it depends not only on the DAQ dead time but also on the coincidence conditions. Using the proposed time-stamping system, all trigger timings can be acquired, so that the combined live time can be easily determined. The combined live time is also estimated using Monte Carlo simulations, and the results are compared with the directly measured values in order to assess the accuracy of the simulation.

1. Introduction

Event time-stamping is becoming common in the field of nuclear physics with radioactive isotope (RI) beams [1]. A time-stamp provides absolute timing information to event data, and allows the use of individual triggers for separate data acquisition (DAQ) systems. After the measurements are complete, a variety of physics events can be identified by analyzing the time-stamps. This approach is suitable for β-decay experiments because the trigger rates for beam and β-ray detectors are very different like about 100 and 500 events/s respectively. To maintain a consistent time frame, clock synchronization between separate DAQ systems is necessary. Such time-stamping systems have already been implemented in the γ-ray detector arrays of EXOGAM [2], RAISING [3], AGATA [4] and SeGA [5]. In the RIKEN Radioactive Isotope Beam Factory (RIBF), a new time-stamping system has been developed for nuclear physics experiments. One of the remarkable features is that it can attach the time-stamp information to an existing CAMAC/VME based DAQ system. In this system, time-stamp information is equivalent to the absolute time of the trigger. Since developed time-stamping system is compliant with the CAMAC and VME specifications, time-stamp information can be taken together with other CAMAC/VME read-out modules. The timing resolution of the time-stamping system is 10 ns and this is enough to find the event correlation between separated DAQ systems. This specification enables us to merge separately taken data on an event-by-event basis, after the measurement.

RIBF produces intense RI-beams and a variety of nuclear physics experiments are performed. The length of the beam line is over 100 meters. Since detectors are placed at distant places, a network-distributed DAQ system (RIBF DAQ) has been introduced [6]. RI-beams are measured by a beam line detector set on an event-by-event basis. The beam line detector set consists of plastic scintillators, parallel plate avalanche counters and ionization chambers. These detectors measure information of time-of-flight, position and energy. There are about 500 signals in the beam line detector set. These signals are acquired by about 50 read-out modules distributed in 10 CAMAC/VME front-end systems. However, these CAMAC/VME front-end systems run in parallel, the same trigger signal is applied to all. Because all beam line detectors are fired by incoming beams at the almost the same timing. This trigger timing is also recorded as a time-stamp datum. The RIBF DAQ system merges data from multiple CAMAC/VME front-end systems in online. CAMAC/VME front-end systems have different transaction times, i.e. the dead time. Each front-end system generates a busy signal which corresponds to the dead time for one event. In the RIBF DAQ system, the longest busy signal from multiple CAMAC/VME front-end systems is adopted as the veto signal to the trigger. This insures that each CAMAC/VME front-end system can accept all

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generated trigger signals. This measurement condition is called "the common trigger" and "the common dead time" configuration.

In many cases of nuclear physics experiments, the common trigger configuration is applied to measure desired physics events efficiently. For the measurement of γ rays from in-flight RI-beams, the coincidence signal of the beam line detector and the γ-ray detector is generated. This coincidence signal is applied as the common trigger for both of beam line and γ-ray front-end systems. In RIBF, a typical coincidence trigger rate of γ rays from in-flight RI-beams is about 1 kHz. In this case, the live time of the RIBF DAQ system is about 80%. In case of β-decay experiments, it is better to apply individual triggers for different detectors. RI-beams are implanted to a silicon detector array. After implantation, β decay will occur after a few milliseconds or more. Event timings of beam implantation and β decay are asynchronous. Therefore, the beam single trigger and the silicon single trigger should be applied to separate DAQ systems. Developed time-stamping system can synchronize the time-stamp information of separate DAQ systems with 10-ns time bins. The life time of the isotope can be determined by the time-stamp difference between the beam implantation timing and the β-decay timing. If the implantation rate is much higher than its life time, the β-decay event rate will be too high. For β-decay experiments in RIBF, the RI-beam implantation rate is limited to 100 particles par second. Therefore, the live time of the DAQ system is sufficient even if the single trigger is applied. To determine the reaction cross-section, it is necessary to know the live time of the DAQ system. However, the combined live time, that denotes the live time arises from separate DAQ systems, is not clearly known. This combined live time issue will be discussed in Section 3.

2. Time-stamping system

To realize event time-stamping for general nuclear physics experiments, a new time-stamping module has been developed, and is referred to as a logic unit for programmable operation (LUPO). There are two types of LUPO, based on CAMAC and VME buses (Fig. 1). CAMAC/VME LUPO modules are installed on DAQ systems at RIBF. Each DAQ system acquires detector data together with the time-stamp information of the trigger. The time bin of the time-stamping system is 10 ns, and the dynamic range is 48 bits which corresponds to 1 month duration. The 10-ns time bin is sufficient to identify coincidence events between separate DAQ systems and to measure the life time of RI beams. The components of a LUPO are listed below:

- Components:
  - User FPGA (Spartan 3E 500)
  - CAMAC/VME interface CPLD
  - 50-MHz crystal oscillator
  - 8 LEDs
  - 4 NIM inputs
  - 4 NIM outputs
  - 16 LVDS inputs/outputs

The time-stamping firmware is implemented in a field programmable gate array (FPGA). A complex programmable logic device (CPLD) is used to simplify the bus communication protocols, allowing almost the same firmware to be used for both CAMAC and VME LUPOs. In time-stamping firmware, 4 NIM input connectors are used for a trigger input, a time reset input, an external clock input and an interrupt input. Pulse, level and clock signals are generated via 4 NIM output connectors. Pulse and level signals are used for indicating busy time. The clock signal output is a through

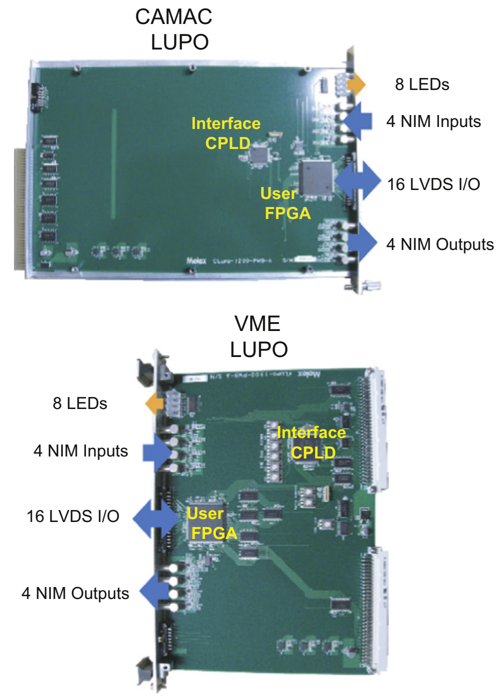

Fig. 1. Photographs of CAMAC and VME LUPO boards.

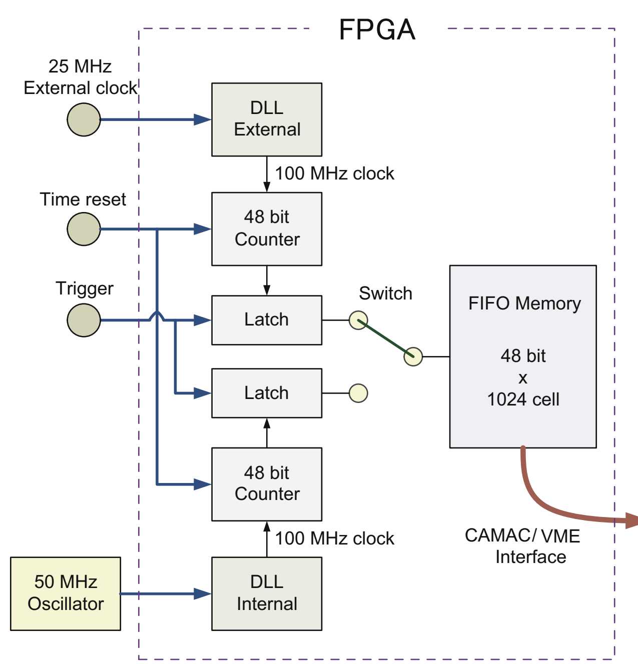

Fig. 2. Block diagram of time-stamp circuit implemented in FPGA.

output of internal or external clock. It can be distributed to other LUPOs as an external clock. The FPGA has 4 digital clock managers including a delay-lock-loop (DLL) circuit, which provides functions for clock-skew elimination and frequency synthesis. A block diagram of the time-stamping circuit in a LUPO is shown in Fig. 2. In response to a trigger signal, the counter value is latched and stored in the FIFO memory. The FIFO uses the built-in FPGA block RAM, and can store up to 1024 time-stamps with a length of 48 bits. In order to synchronize the time-stamp information, the signals of the external clock and the time reset are required. The DLL circuit generates a 100-MHz clock signal from a 25-MHz external clock or