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Development of new data acquisition system at Super-Kamiokande for nearby supernova bursts

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The observation of supernova neutrinos is anticipated to research the detailed mechanism of the core collapse supernova. Super-Kamiokande (SK), a 50-kton water Cherenkov detector, can detect supernova neutrinos effectively and reconstruct their direction and energy. However, the expected event rate from nearby-supernova may exceed 60MHz and exceeds the capacity of the current DAQ system. Therefore, we developed a new DAQ system.

This new system records the number of PMTs which detect photons with 17 nsec and 17 μsec time binnings. This system is also capable to generate a signal to pre-scale the charge and the timing data to minimize the data loss in the existing DAQ system.

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1. Introduction

The supernova neutrinos provide important information to understand the detail mechanism of the core collapse supernova. This is because 99% of its energy is predicted to be emitted as neutrino and neutrinos are promptly released even from the core part of supernova. Until now, the neutrinos from supernova were detected only once, from 1987A, which is 50 kpc from the earth, by two water Cherenkov detectors. Though the observed neutrino events were as few as 11 at Kamiokande[1] and 8 at IMB[2], these data highly contributed in the research of the supernova. Now more precise observation with larger statistics is highly anticipated.

Super-Kamiokande (SK) is a ring imaging water Cherenkov detector with 32,000-ton photosensitive volume, 11,129 20-inch photomultiplier tubes (PMTs) for inner and 1,885 8-inch PMTs for outer detectors, respectively[3]. The energy threshold is as low as 4 MeV and it is possible to reconstruct neutrino direction and energy. Therefore, it is possible for SK to detect supernova neutrino with high efficiency. It is expected to observe about 8000 neutrinos from a supernova at the galactic center, ~10 kpc from the earth. The current DAQ of SK is capable to record a neutrino burst from a supernova as close as 1 kpc without any loss. However, a possibility of a supernova in 1 kpc is discussed recently[4]. In such a case, fair amount of data will be lost due to the limitations of the current DAQ system. Therefore, we developed an independent DAQ system dedicated to such extremely high rate neutrino events.

2. Main DAQ system

Current main DAQ system in SK uses the software trigger. PMT signal above the threshold of 1/4 photoelectrons (p.e.) is converted to a digital value in the front-end module so-called QBEE[5]. In QBEE, chrage-to-time converter (QTC) and time-to-digital converter (TDC) are employed to digitize the PMT signal. All the QBEE modules are synchronized with a 60 MHz master clock in order to keep the relative timing of each TDC in different modules. One TDC count corresponds to 0.52 ns and the width of the TDC counter is 15 bits, which corresponds to full time window of 17 μsec. Also, all the hit information are tagged with shared 60-kHz 32-bit counter, which is also used to reset TDC count when this counter is incremented. As a result, effective width of TDC is 47 bits, corresponding to ~20 hours.

After each conversion, the charge and the timing information are stored in the local buffers on the board until the data are transferred to the readout computer. All the timing and the charge information are sent to the readout computers via Ethernet. The computers receive data from QBEE, sort them in the order of the time, identify the events by the software trigger, and record the hit information associated with the events. In case of rather low energy event bursts, including supernova neutrino bursts, it is possible to keep ~6 million events in 10 seconds. We have to take the speed of data transfer into consideration and the practical limit is ~2 million events. This corresponds to a supernova burst occurred at ~1 kpc. However, the data just after or during the burst will be lost when the location of the supernova is closer than 1 kpc. The data loss in case of this kind of event burst is found to be caused by the limited size of the data buffers in each QBEE board.

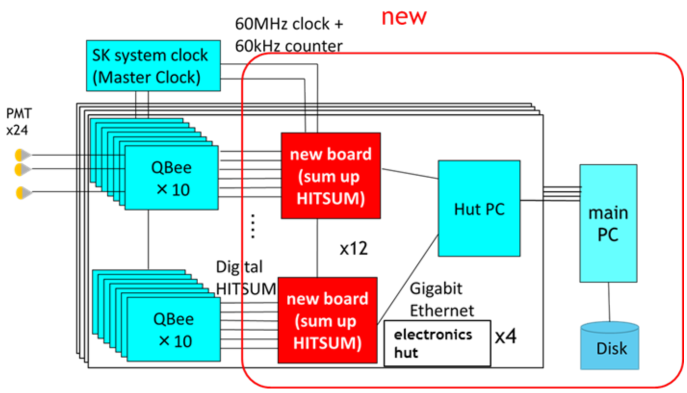

Figure 1: The SN modules and QBEEs, data flow of hitsum

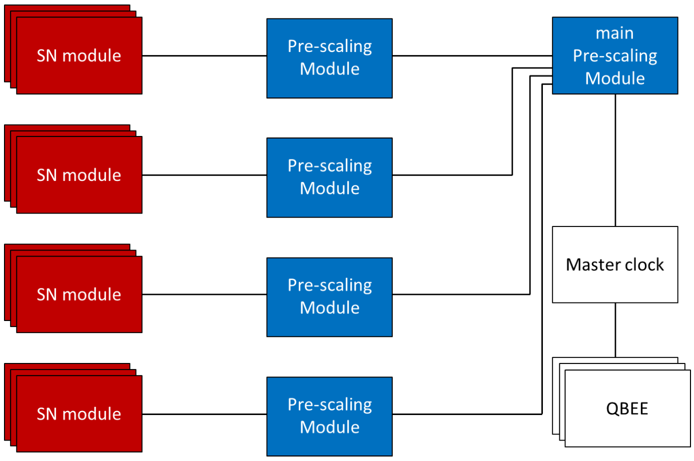

Figure 2: The SN modules and the pre-scaling modules

3. SN burst DAQ system

In order to solve the problem of QBEE for nearby supernova a SN burst DAQ system was newly developed. The SN burst DAQ system has two functionalitiess, one is to record the number of PMTs that detect photons using the so-called digital hitsum from QBEE, and the other is to generate signal for pre-scaling the normal QBEE data steam. This system consists of 48 SN modules, 5 pre-scaling modules and 5 computers for readout as shown in Figs. 1 and 2.

Each SN module has 10 inputs of digital hitsum, two NIM level digital signal outputs, two NIM level digital signal inputs. The module is equipped with a FPGA (Xilinx Virtex-5) to process the data, 4 GB of DDR2 memory for local data buffering and two individual Ethernet ports for the data transfer.

3.1 Recording digital hitsum

The system uses digital hitsum signal from QBEE. This is a 5-bit LVDS signal and provides the number of hit PMTs in each cycle of 60 MHz. As 24 PMTs are connected to one QBEE, digital hitsum ranges from 0 to 24. This signal is generated by the QTC in QBEE and not affected by the status of the local buffer. The total number of hit PMTs in the detector for low energy events has good linear correlation with the total energy deposit in SK. Therefore, it is possible to estimate the total energy deposit in SK by recording the sum of digital hitsum from all the QBEEs.

However, the amount of the data is still too big if we try to record the sum of hitsum at 60MHz. Therefore, we decided to sum up the 'sum of hitsum' 1024 cycles and store this 60-kHz sum constantly. Because typical number of hits for a single supernova burst neutrino is ~120 PMTs for a 20-MeV neutrino event and the nominal 60-kHz sum due to the dark hits is just ~750, the number of hits from one supernova neutrino event is expected to be larger than the fluctuation of the dark hits. This means that it is possible to identify a single event using the 60kHz-sum data. The total data rate to be stored is 576 GB/day and the stored 60-kHz sum is deleted after 1 week if there is no supernova.

Even though it is possible to identify single event in the stored data, we would like to keep as much detailed information as possible around the supernova burst. Therefore, we decided to keep 60-MHz sum for 1 minute in the local buffer memory on each board and read them out by the computer when supernova like burst is detected.

There are 48 SN modules (12 modules are set upin each electronics hut). A SN module calculates 60-MHz and 60-kHz sums of 240 PMTs. Both data contains 32 bit event number and the data taken by the main DAQ system can be easily associated. 60-kHz sum is constantly sent to the readout computer.

As explained, the latest 1 minute of 60MHz-sum is stored in the DDR2 memory on each module. When the external trigger is issued, the recorded data in the DDR2 memory are sent to the readout computer via dedicated Ethernet port. This external trigger is generated by a pre-scaling module based on the outputs from SN modules. The 60-kHz sum is monitored in FPGA to identify possible event burst in the detector and to generate the SN trigger for the pre-scaling of QBEE data.

In order to check whether the firmware of this module is correctly working or not, we compared the 60kHz-sum to the data recorded by the main DAQ for 24 hours. With the first version of the FPGA firmware, both 60-kHz and 60-MHz sums are consistent with main DAQ data except for a fixed timing shift. The observed timing shift was about 520ns. This does not make any serious issue in analyzing the recorded data by this module but increases the probability of fake SN trigger, which is explained in the next section, from each module. This is because the internal QBEE calibration data are split into two blocks and easy to mimic an event burst in the SK detector. Therefore, we revised the firmware to adjust the timing shift and it became less than 17 ns. As a result, the latest firmware largely reduces the possibility to make fake SN trigger.

3.2 Pre-scaling

The SN burst module generates a SN trigger. SN triggers are gathered by the sub pre-scaling modules in each electronics hut and then transferred to the main pre-scaling module in the central electronics hut. The main module issues a veto signal and sends it to the master clock module, which send a veto signal to inhibit TDC conversion in all the QBEEs. In addition, the main module generates a trigger to start the readout of 60-MHz sum in the DDR2 memory.

The criterion to issue a SN trigger in each SN burst module is 4 consecutive 60kHz blocks that have more than 100 hits. 100 PMT hits/24PMT/17μs corresponds to ~1 MHz supernova events in

SK. On the other hand, the main DAQ system can accept 6 MHz burst without any loss and thus, it is possible to send veto signal before filling up the buffers in QBEE.

The condition of 4 consecutive blocks is required to exclude possible fake triggers issued by high energy muons, which causes signal reflection between PMT and QBEE. In the beginning, 3 consecutive blocks were required to have 100 hits to generate a trigger. However, there were 6 fake triggers in 24 hours with this condition, while there was no fake trigger for the same data if we require 4 consecutive blocks. Therefore, we revised the condition.

The pre-scaling modules are equipped with FPGA (Spartan 6) and it is necessary to optimize the logic to pre-scale the main DAQ data. The pre-scaled condition must be set not to fill up entire QBEE buffers. On the other hand, we have to record as much data in the main DAQ system as possible. In order to satisfy these requirements, we are planning to tune the following parameters; the number of SN triggers for starting pre-scaling and the way to change the pre-scaling rate with time or SN trigger rate. For the optimization work, we are planning to flash laser diode in the SK detector at high rate to mimic the event bursts and also, perform simulation studies and finalize the condition as the next step.

4. Summary

We developed a new DAQ system in order to avoid uncontrolled data loss by extremely high rate neutrino events from a nearby supernova. The new system constantly records PMT hits at 60 kHz and the system record 60-MHz sum of 1 minute around a neutrino burst candidate. The system also generate a veto signal to inhibit TDC conversion of main DAQ.

The timing between hitsum data and QBEE data was adjusted in 17ns and the condition to generate a SN trigger in each SN board was decided. SN modules with the revised firmware started taking hitsum data in June, 2015. Since then, the system has been successfully running. The firmware of the pre-scaling module is going to be developed after optimizing the logic. We have plans to flash laser diode in the SK detector at high rate and to perform simulation studies for the optimization work.

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