The master trigger board for the Daya Bay reactor neutrino experiment *

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Abstract: We have designed a master trigger board (MTB) for the Daya Bay Neutrino Experiment, which is aimed to precisely determine the unknown neutrino mixing angle θ_{13} using antineutrinos produced by the reactors of the Daya Bay Nuclear Power Plant (NPP) and the Ling Ao NPP [1]. MTB processes cross trigger request signals in three kinds of logics, and broadcasting calibration trigger signals to the local trigger board (LTB). All logics in MTB are implemented and tested in the Daya Bay neutrino experiment.

Key words: reactor neutrino experiment, master trigger board, cross trigger

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1 Introduction

The goal of the Daya Bay reactor neutrino experiment is to precisely determine the unknown neutrino mixing angle θ_{13} with a sensitivity of 0.01 or better in $\sin^2 2\theta_{13}$ at 90% confidence level, an order of magnitude than the current limit of direct measurements [1]. So this experiment places high demands in several points: the experimental site, detectors, electronics, and data analysis. The budget of systematic uncertainties assigned for the electronic trigger system is set far below 0.1% level. A careful design in both hardware and firmware is therefore required in the trigger system.

2 Signal signature and experimental layout

The basic experimental layout of Daya Bay consists of three underground experimental halls: one far hall and two near halls. In each hall, the detector has the same structure with two parts: antineutrino detector (AD) and Muon detector.

As shown in Fig. 1, four antineutrino detector modules in the far hall are shielded by a 1.5 m-thick water Cherenkov detector referred as the water pool inner (WPI). Surrounding this shield is another 1 m-thick water Cherenkov detector that can be called as the water pool outer (WPO). Above these detectors is resistive plate chambers (RPC).

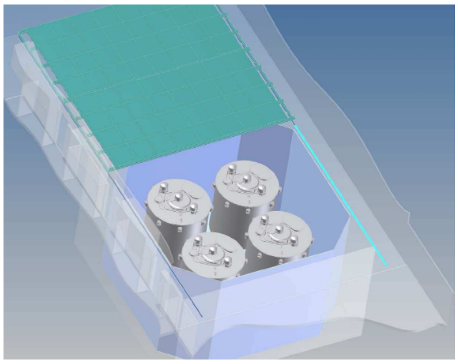

Fig. 1. Detector modules in the far hall [1]

The antineutrino detector is a three-concentric cylindrical structure. The innermost zone, filled with Gd-loaded liquid scintillator (Gd-LS), is the antineutrino target. The middle zone, filled with liquid scintillator (LS), is the γ-catcher. The outermost zone, filled with transparent mineral oil, shields against external γ rays that enter into LS from outside area. The reactor neutrinos will interact with the protons in the target, producing positrons and neutrons. The detection of neutrons is through the γ(s) released

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from the capture on either hydrogen or Gadolinium atom. All the neutrino reaction chains are shown as Eq. 1 to Eq.3.

$$\bar{\nu}_e + p \rightarrow e^+ + n \quad (1)$$

$$n + p \rightarrow D + \gamma(2.2MeV) \quad (Delayed\ 180\mu s)(0.3b) \quad (2)$$

$$n + Gd \rightarrow Gd^* \rightarrow Gd + \gamma' s(8MeV) \quad (Delayed\ 28\mu s)(50kb) \quad (3)$$

As shown in Fig. 2, the visible energy spectrum of prompt positrons is from 1MeV to 8MeV.

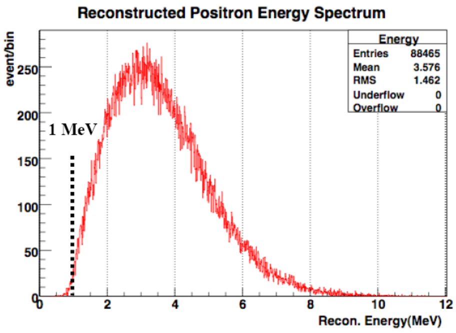

Fig. 2. Prompt signal energy spectrum [1]

The energy spectrum of delayed signals is shown as Fig. 3. When neutron is captured by proton (n-p), a 2.2MeV γ signal is released with a capture lifetime of 180 μs. While neutron is captured by gadolinium (n-Gd), an 8MeV γ cascade signal is released with a capture lifetime of 28 μs.

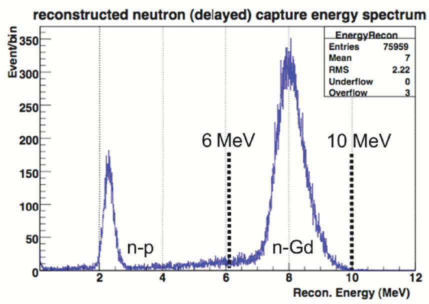

Fig. 3. Delayed signal energy spectrum [1]

Using these correlations in energy and time, the signal of antineutrino reaction chains can be identified.

3 The layout of the trigger electronics

In order to realize this detection requirement, a trigger system is designed for the Daya Bay reactor neutrino experiment. The electronics layout of the trigger system is shown as Fig. 4.

AD, WPI and WPO use the same readout electronics, including the local trigger board (LTB) and the front-end electronics board (FEE) [3]. RPC uses a special local trigger module due to the different detector structure.

To implement the cross trigger logic, a master trigger board (MTB) is shared by all the local trigger modules in each hall. In addition, MTB has a special function to broadcast the calibration trigger for calibrating the performance of detectors and electronics system.

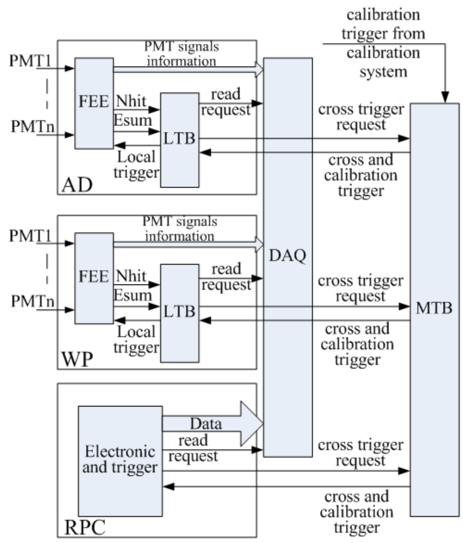

Fig. 4. The electronics layout of the trigger system for the Daya Bay experiment

For details, FEE in AD and water pool (WP) collect the analog signals from the photomultiplier tube (PMT) in the detector modules, and generates two kinds of signals for the LTB: the number of PMT hits (Nhit) and the energy sum of PMTs (Esum). The LTB processes these two kinds of signals to generate local trigger, which will be sent back to the FEE for recording PMT signals information, including time and charge data of PMT.

Accompanying the generation of the local trigger, LTB also sends data read request to the data acquisition system (DAQ), which will read out and record the local trigger information from LTB and the PMT information from FEE. LTB also generates the cross trigger request to MTB for cross checking other detector modules.

MTB collects cross trigger requests from all local trigger modules in the same hall, and processing them in multiple methods to generate the cross trigger which then will be distributed to the relevant local trigger modules. Together with the cross trigger, the trigger type and source are also distributed to the local trigger modules. LTB receives the cross trigger request, and generates a local trigger and packs the cross trigger information in the local trigger package for DAQ readout.

4 MTB logic design

MTB can generate the cross trigger in three kinds of logics meaning.

1) "Or" logic

In "Or" logic, when the MTB receives a cross trigger request from any sub-detector, it will generate a cross trigger and distribute it to the other sub-detectors.

For instance, when LTB in WP generates cross trigger for cosmic gay, MTB can transmit this cross trigger to LTB in AD which will record PMT signals information at same time.

This method can record as much data as possible, and cross check other sub-detector situation. But it will cause a high trigger rate in DAQ that may not afford. During the debugging period, the "Or" logic isn't recommended for use.

2) "Veto" logic

The cross trigger request generated by WP or R-PC is usually caused by the background radiation, which can possibly produce a fake anti-neutrino signal in AD. So the cross trigger request from WP or RPC can be used to veto the cross trigger request from AD.

In "Veto" logic, when a cross trigger request is issued by WP or RPC, MTB will open a veto window which consists of a pre veto window and a post veto window, as shown in Fig. 5. In the veto window, the cross trigger request from AD will be blocked, and no cross trigger is permitted to send out. This logic can be used to mask the radiation background online.

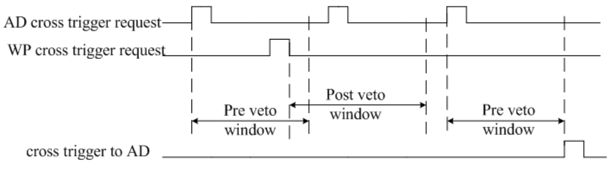

Fig. 5. Veto cross trigger logic

3) "Look back" logic

The reaction formulas from Eq. 1 to Eq.3 indicate the prompt positron signal and the delayed γ signals have a certain energy spectrum and time relation. The MTB can check this relation online to help find out the antineutrino signal.

Firstly, LTB should send cross trigger request with amplitude information of PMT signal to MTB. Secondly, all cross trigger request signals in AD should be vetoed by WP and RPC signal. Thirdly, MTB check the amplitude and time information of these cross trigger request signals, then generate look back trigger and send back to relevant LTB.

Shown as Fig. 6, when a small signal is followed by a large signal, it is like a prompt positron signal is followed by a delay γ signal released by n-Gd reaction. If the time interval between them is less than 28 μs, MTB will generate loop back type 1 trigger and send back to LTB in AD.

When a large signal is followed by a small signal, it is like a prompt positron signal is followed by a delay γ signal released by n-p reaction. If the time interval is less than 180 μs, MTB will generate loop back type 2 trigger and send back to LTB in AD.

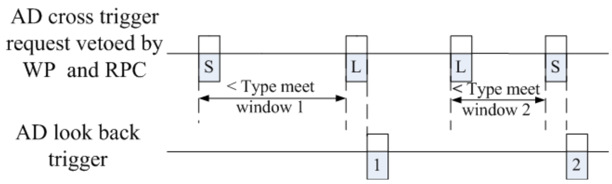

Fig. 6. Look back trigger logic

Besides these three kinds of cross triggers, the MTB can also broadcast the calibration triggers to the local trigger modules as mentioned above.

In total, the MTB can generate 5 types of trigger outputs: "Or" logic cross trigger, "Veto" logic cross trigger, "Look back" type 1 cross trigger, "Look back" type 2 cross trigger and calibration trigger. To each local trigger module, only one twisted-pair cable is used by the MTB to transmit these five types of triggers and even the trigger source in serial code.

In near and far hall, there are 5 and 7 sub-detectors respectively. To accommodate the maximum requirement, the MTB has 8 cross trigger request input channels, 12 calibration trigger request input channels and 8 cross trigger output channels. The 8 cross trigger output channel can work independently.

Since there are many input channels, a prescale logic is implemented in the MTB to reduce the input trigger rate when it is necessary. This is a useful function during the debug period of the electronics system.

5 MTB hardware and test

The MTB hardware consists of 8 parts: clock circuit, cross trigger request input circuit, calibration trigger input circuit, trigger output circuit, VME bus interface, FPGA and online configuration circuit and power supply circuit as shown in Fig.7. FPGA in MT-B is XC4VLX40-10FF668C of Virtek4 family which produced by Xilinx [4].

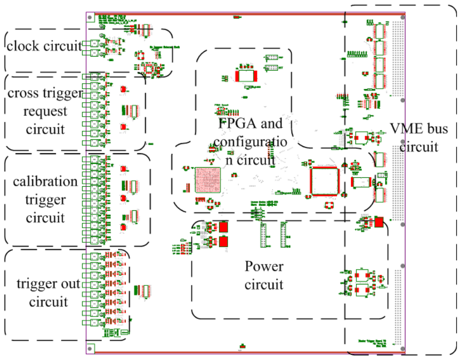

Fig. 7. Display of MTB hardware

The MTB hardware and logics have been tested in the Daya Bay near hall. No failure is found.

For instance, LTB of AD2 and WPI send different frequency of periodic cross trigger request to MT-B, which process these signals by using "Veto" logic. Then DAQ checks the trigger rate of AD2 cross trigger. The test result is shown in the Table 1. The trigger rate of AD2 can be reduced by "Veto" logic due to WPI cross trigger request signals.

Table 1. Test result of MTB "Veto" cross trigger

AD2 cross trigger request rate	WPI cross trigger request rate	AD2 cross trigger rate
2.5kHz	1.25kHz	1.25kHz

6 Conclusion

We have designed and produced MTB for the Daya Bay reactor neutrino experiment. Multiple cross trigger logics and a calibration trigger broadcasting logic have been implemented in MTB to achieve the experimental goal. MTB has been installed and tested in Daya Bay near hall and proven to work well.

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