Look-up table concept for trigger generation*

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Abstract

Proton decay experiments are being conducted at Kolar Gold Fields in Karnataka since 1980, by the Indo-Japanese collaboration. These experiments employ finegrain tracking calorimeter type detectors using a large number of proportional counters. Measurements are made on the ionisation of charged particles as they traverse through the detector. Data acquisition system comprises of several slave processors connected in a network controlled by a Personal Computer. Each slave processor supervises event and monitor data collection as well as control for a logical block of detector.

One of the major tasks of the data acquisition system is, to generate a trigger signal whenever a cluster of proportional counters is activated due to the traversal of a charged particle through them. A dedicated trigger system which is configured as a special station in the network executes this task. Since the number of channels are quite large, and the conditions for the trigger generation are complicated and interdependent, it is impracticable to design the system using conventional hardware based logic.

To reduce the complexity and cost of the system as well as to introduce flexibility into the design, *look-up table* concept is employed. Various types of probable trigger patterns are loaded into EPROMs. Processed

*Proceedings of the National Symposium on Nuclear Electronics & Instrumentation, BARC, Bombay, 1989.

pulses from the proportional counters are used to address these EPROMs. Trigger signal is produced when any one of the patterns is identified. To reduce the chipcount further, a twotier procedure is adopted in trigger generation.

This paper discusses various issues involved in the design as well as technical aspects of the whole system in detail. It also presents various other features of the system, such as centralized services, on-line trigger rate monitoring systems.

Introduction

Experiments are being conducted by the Indo-Japanese collaboration in the mines at Kolar Gold Fields in Karnataka, to look for signals of Grand Unification Theory like proton decay and magnetic monopole. Detectors employed for these experiments are also useful to study among many other interesting phenomena, high energy atmospheric muons and neutrinos.

First in the series of experiments(Phase I), which is incidently also the first of its kind in the world, was operational since 1980. It is located at a depth of 2300m, the deepest experimental site in the world. Latter of the two are situated at a depth of 2000m. Data acquisition and control systems employed for these experiments are significantly different from that of the first experiment. This paper brings out salient features of the trigger systems in use in the new experiments(Phase II & III).

Detectors are built using a few thousand proportional counters and a few hundred tons of iron. Each of the phenomena of interest activates a cluster of channels in a typical configuration. To detect these phenomena when they occur is an important task of the Data Acquisition System(DAS). A dedicated trigger processor equiped with a front-end controller and hardware modules carries the task of generating trigger, employing the concept of *look-up tables* rather than the conventional hardware methods.

1 The detectors

The detectors are classified as fine-grain tracking calorimeters. The larger of the two(Phase-II), which has been in operation for more than three years, comprises of 3480 proportional counters, arranged in 60 layers of 58 each. A proportional counter (hereinafter called channel) is 6m long with cross section 10cm x 10cm.

The channels of a layer are othogonal to those of the next. A veto-jacket of 6 layers surrounds the detector on three sides, with 2 layers to a side. The other detector (Phase-III) which is in operation for a year, comprising of about 1600 channels, forms the fourth side of the veto-jacket.

A channel gives a pulse of amplitude of a few millivolts with a rise time of about 500 ns, when a charged particle passes through it. When a charged particle traverses the detector it leaves a track of activated channels. Typically a particle traversing the detector at near vertical angles pass through all 60 layers hitting atleast one channel in a layer, whereas a particle travelling with large zenith angles may cross a few layers, hitting several channels in each. Besides the particles have different velocities; muons have *beta* of nearly 1 while that of magnetic monopoles of our interest are between 2 X 10-4 and 1 X 10-3.

Since the number of channels is large, the DAS is designed to record data from all channels parallelly. The DAS consists of a host PC controlling a network of 10, Z-80 based Front- End- Processors (FEP). Nine of the FEPs record data from 8 layers each independently. The tenth FEP is a dedicated Trigger Processor. Figure 1 gives block diagram of the DAS.

Typical configurations (trigger criteria) are stipulated, which have to be detected for the events of interest. It is required of the trigger system to detect these predetermined configurations efficiently and initiate the event recording process in the host and all other FEPs.

Phase-III detector differs significantly from Phase-II in topology as well as purpose, but not so in design of DAS. There are differences in the trigger criteria of Phase-III, and these will be described in a later section as an example of the flexibility the trigger system affords. The trigger system of Phase-II is taken in detail.

2 The trigger criteria

The criteria can be logically defined in three levels.

2.1 Level-1 triggers

Level-1 triggers comprise of the horizontal multi-fold coincidence of channel hits, within a 3 μsec time window. The following are the level-1 trigger criteria.

1. Single fold coincidence (1-F): The OR-ed output of all but the extreme channels of a layer.
2. Two fold coincidence (2-F): Atleast two in any set of five consecutive channels of a layer are hit.
3. Three fold coincidence (3-F): Atleast three in any set of five consecutive channels of a layer should be hit.

2.2 Level-2 triggers

Level-1 triggers are used to detect more complex configurations of level-2 triggers as described below. As mentioned earlier, these configurations are derived from the possible types of phenomena we are interested in studying using the detectors. Whenever it is possible interms of total trigger rate, shallow trigger patterns and lower thresholds are specified. This is done in order to enable the system to be able to identify the phenomena such as proton decay more efficiently for which the corresponding trigger patterns can not be stipulated precisely.

Level-2 triggers, except the monopole trigger are defined in a coincidence window of 3 μsec. The window is 20 μsec for the monopole trigger.

1. Vertical 5-fold trigger: At least one channel hit in 5 different layers in a set of 11 consecutive layers. This configuaration is aimed at detecting atmospheric muons, showers and nucleon decay events.
2. 3-F + 3-F trigger: In a set of 3 consecutive layers, atleast two should have a horizontal 3-F coincidence separately. This along with the following two criteria are useful in identifying neutrino interactions in the surrounding rock and air, proton decay and any other unknown phenomena.
3. 3-F + 2-F + 1-F trigger: In a set of 4 consecutive layers, a 3-F, a 2-F and a 1-F coincidence should occur in three different layers.
4. 2-F + 2-F + 2-F trigger: In a set of 4 consecutive layers, atleast 3 different layers should have a horizontal 2-F coincidence each.
5. Monopole trigger: Atleast 8, in a set of 20 layers should have atleast a horizontal 1-F coincidence.

In deciding the coincidence windows and number of layers specified for the coincidence, the considerations were the velocities of the particles of interest and chance coincidences due to the background satisfying the criteria. For magnetic monopoles moving at one hundredth of the velocity of light, 20 μsec is optimal; but to offset the greater possibility of chance coincidence because of large time window, stipulation of larger number of layers is specified.

Typical trigger rates of various modules are listed in Table 1.

2.3 Master trigger

Master trigger is formed when any one or more of the level-2 triggers are generated. But it is accepted only when the main gate which is controlled directly by the host is open.

3 Hardware implementation

Level-1 trigger generation circuitry is designed as sub-modules in Digital Data Storage Modules (DDSM), which are one for a layer. DDSMs handle second level of digital pulse processing for different modules of DAS such as event recording, trigger genration and monitoring modules. Level- 1 triggers are driven on signal buses and terminated with 140 Ohm resistances on Trigger Generation Modules (TGM) for further processing. TGMs operate under control of Trigger Control Module (TCM), which in turn is controlled by the Trigger Processor (TP). Schematic of the trigger system is shown in Figure 2.

3.1 Level-1 trigger generation

Processed pulses from all the channels of a layer are driven to the respective DDSMs. These pulses are shaped to 3 μsec. on their leading edges and OR-ed to get the 1-F output of the layer.

The shaped pulses are simultaneously given as address (negative logic) to a bank of eight EPROMs of 4KB capacity. They are loaded with look-up tables, which have FE hex in locations whose binary address has horizontal 2-fold coincidence of 0's, and FD hex where there is 3-fold coincidence. The EPROMs generate 2-F on the first and 3-F on the second data line. The EPROMs are permanently read enabled. Thus their output is held as long as a valid coincidence exists on the address lines [Figure 3].

Overlapping of address lines is done to include all combinations. The 2-F and 3-F outputs of the EPROMs are OR- ed seperately to get 2-F and 3-F pulses of the layer.

3.2 Level-2 trigger generation

This task is distributed on four identical TGMs. Schematic of Trigger Generation Module is shown in Figure 4. The generation of level-2 triggers on one of the modules is described.

3.2.1 Vertical 5-fold trigger

One 8 KB EPROM and an AND gate suffice to detect all possible combinations of 5-fold coincidences in 14 consecutive layers [Fig. 5]. Level-1 1-F lines of first 13 layers are used to address the EPROM. It is loaded with a look-up table with FE hex at locations whose address has a 5-fold coincidence and FD hex at addresses that have 4- fold coincidence on the most significant 10 address lines. Thus the EPROM generates vertical 5-F on the first and 4-F on the second data line. Second data line is AND-ed with 1-F signal of 14th layer for a possible 5-fold. A flow chart for the generation of look-up tables for vartical 5-F is outlined in Figure 6.

Four units of 8KB EPROM + AND gates suffice to cover all the combinations of vertical 5-fold trigger generation for 26 layers.

3.2.2 The other level-2 triggers

The single fold, 2-fold and 3-fold horizontal coincidences from Level-1 are used to address an 8 KB EPROM as shown in Figure 7. Look-up table for the EPROM contains 3F+3F coincidences in 3 layers, 2F+2F+2F coincidences in 4 layers and 3F+2F+1F coincidences in 4 layers. Possible partial coincidences are checked by AND-ing separately to make a complete unit.

3.2.3 Monopole trigger

Four EPROMs of 4 KB capacity are used to detect a monopole [Figure 8]. The 1-F signals, after being stretched to 20 μsec are used to address the first set of two EPROMs, which function as an adder. The EPROMs output on the first four data lines, in binary, the number of pulses on the address lines. These two numbers are given as address to an EPROM that is loaded with a table that functions as an adder-cum-comparator. This EPROM gives an output if the sum of the two binary numbers given to it as address is equal to 8 or more.

3.3 Master trigger

Each of the TGMs produces a pre-master trigger when one or more of its sub modules produce a level-2 trigger. Pre-master trigger signals from all the 4 TGMs are wired- ORed and fed to TCM. The wired-ORed pre-master trigger is gated with a veto signal from the host. The gate will be kept open by the host when the system is ready to accept the master trigger. In otherwords, it will be kept closed when the system is busy recording the data initiated by an earlier master trigger.

The final master trigger is shaped to the required width, and distributed to the host and to all the FEPs using 50 Ohm cable drivers.

4 Trigger control module

Trigger control module shares back plane with TGMs. It is designed as an hardware front-end executive to the Trigger processor. This module executes the following additional tasks under control of the Trigger processor.

1. Setting the *trigger enable latches* on the four TGMs, to selectively enable any or all the triggers generated by their level-2 trigger modules for participating in the generation of pre-master trigger. Choice of selecting the trigger modules is left to the operator at the time of starting the *run*.
2. Reading the trigger type (trigger mark), whenever a master trigger is formed, to determine which of the individual triggers have caused the master trigger. It is possible that more than one trigger criteria is satisfied in the process of master trigger generation. The trigger type information is very useful at the time of detailed analysis of data to ascertain the efficiency of various trigger generator modules as well as to find out the topographical characteristics of data.
3. Since the Front-End Processors operate autonomously, a common clock is necessary for the FEPs to synchronise the data recording process whenever

an interesting (global) phenomenon occurs in the detector. A master clock (5MHz) is generated for the purpose and transmitted to all the FEPs using a 50 Ohm cable drivers.

5 Trigger processor

A Z-80 microprocessor based trigger processor forms an vital station in the DAS network controlled by the host PC. It performs the duties of a liason system between the trigger system and the host. It receives commands and control data from the host for system initialisation, enabling trigger latches, for trigger rate monitoring and so on. It also sends data collected regarding trigger type and trigger monitoring to the host. Trigger processor also provides software infrastructure necessary for various modules upstream in executing their functions.

6 Trigger rates monitoring

Once the positions of proportional counters are fixed in the topology of the detector, they respond consistantly to the dominated radio active radiation surrounding the detector. They do so by a constant pulse rate if taken for sufficiently long durations. Hence this rate of a proportional counter is a good parameter to check its performance. Monitoring the level-1 trigger rates is done as routine check on the detector as well as level-1 trigger system performance.

The 1-F signal lines of the layers are multiplexed on the TGMs and carried to the TCM, where they are scaled using a software controlled counter.

2-F and 3-F trigger rates are monitored using a pseudo-FIFO method using priority encoder chains on the TGMs and software counters on the TCM. This is possible because of the low rate of 2-F and 3-F.

7 Phase-III detector

Phase-III detector is designed to track low energy magnetic monopoles more efficiently than Phase-II detector. The major changes in Phase-III are:

1. It has only 20 layers of proportional counters and no veto-jacket.
2. Four layers, two at the top and two at the bottom are of 118 proportional counters each. These counters have 5cm x 5cm cross section.
3. Of the 16 layers in between, the upper eight are of proportional counters filled with helium + methane mixture and the other eight are of argon + methane mixture (as in Phase-II). Each of these layers have 59 proportional counters each.

Helium is more ionized than argon by low energy particles like monopoles. Besides, ions drift slower in helium resulting in pulses of rise time of about 1500 ns. Hence part of the detector has different timing characteristic.

The DAS employed in Phase-III is identical in design to Phase-II, except that it has four Front-End Processors with a fifth one as the trigger processor. The trigger sub- systems too are similar. The trigger criteria are redifined because the different purpose of the detector and also larger rise times of helium channels.

Level-1 triggers (1-F, 2-F and 3-F) are defined in a coincidence window of 9 μsec for the helium-filled channels, while for the other layers it is 3 μsec. Level-2 triggers are as follows:

1. 3F + 3F, 3F + 2F + 1F, and 2F + 2F + 2F triggers are defined with the same format as in Phase-II but in a window of 9 μsec.
2. Muon Trigger-I: Atleast 5 of the bottom 10 layers should have a 1-F in each. This is defined in a window of 3 μsec because the bottom 10 layers are *argon* layers.
3. Muon Trigger-II: The above trigger is modified to conform with the larger rise times of the helium-layers. Atleast 6 out of 10 consecutive layers taken from the top 14 layers should have a 1-F in each, in a window of 9 μsec.
4. Monopole Trigger-I: Atleast 7 out of *helium* layers should have a 1-F in a window of 40 μsec.
5. Monopole Trigger-II: Atleast 10 layers in the entire detector (20 layers) should 1-F coincidences within a 35 μsec window.
6. Phase-II Trigger: It is of interest to record the data in Phase-III detector when master trigger is generated in Phase-II. Also, particles like parallel muons may pass througn both detectors. Hence the master trigger of Phase- II is carried to Phase-III and included as one of the trigger criteria.

These combinations were acheived by adopting the design of Phase-II trigger system and loading the EPROMs with the modified look-up tables. The other changes are the addition of appropriate pulse stretchers.

8 Critical evaluation of the trigger system

The major advantage of the concept of look-up table is the great reduction of chip-count. The EPROMs may be described as Programmed Logic Arrays with the added advantage of re-programmability by the user. Thus allows for flexibility in trigger criteria, by reprograming. In fact, this was well demonstrated in the process of adopting the design of Phase-II trigger system to that of Phase-III.

8.1 The problem of spikes

Spikes, of width varying from make to make were observed at the outputs of EPROM's. In fact, spikes on the data lines of EPROMs during switching of the address lines are inherant(with outputs permanantly enabled). But this is of little consequence in a microprocessor based system where EPROMs are used to store programs. But the same can produce adversable results in the trigger system drastically degrading its performance. For example, under simulated 4-fold coincidence, the EPROM's were observed to give output indicating a 5-fold.

To eliminate the spike, an auto-correlation method is used. The output of the EPROMs is delayed and AND-ed with itself.

8.2 Delay in master trigger generation

Mention must be made that each EPROM in the generation of a trigger adds its access time (typically about 200 ns) to the delay in master trigger generation. In these detectors, the time between the start of pulse formation to the leading edge of the master trigger is about 1000 ns. The contribution to the delay by the electronics is constant. But the response of the proportional counters themselves varies, other conditions being equal, because of the actual path and path-length of the particle inside the proportional counter. This response may range upto 800 ns. Because of these inherent properties of the detector, the timing of 1000 ns does not result in loss of data.

8.3 Efficiency of the system

It is utmost important to confirm that various trigger modules are performing the tasks with maximum efficiency under worst or unknown conditions. Firstly, detailed analytical methods were employed in estimating the efficiency of the system. During design, the prototypes of various trigger modules were subjected to a lot of simulated events to study their performance. Finally, experimental data is accumulated and analysed frequently to arrive at exact figures regarding the overall efficiency of the system.

At all these stages it is found that the efficiency is quite satisfactory in a broad domain of detecting many intersting phenomena.

Acknowledgements

The authors wish to thank Messers R P Mittal, T Ravindran, K Sampurnanand for their contributions during the course of the experiments. The co-operation of the officers and other staff of Bharat Gold Mines Limited at all stages of our experimental activity is gratefully acknowedged. The authors are thankful to the Ministry of Education, Japan for partial financial support to these experiments.

Captions for figures

1. Block diagram of the DAS
2. Schematic of the Trigger system
3. Level-1 trigger generation
4. Schematic of Trigger Generation Module
5. Generation of vertical 5-F trigger
6. Flowchart for generation of vertical 5-F trigger
7. Generation of Level-2 horizontal triggers
8. Generation of Monopole trigger

Caption for table

1. Typical trigger rates