A fast total energy trigger unit for a CsI calorimeter

C.A. Baker [a], N.P. Hessey [a,b,1], C.N. Pinder [a] and C.J. Batty [a]

[a] *Rutherford Appleton Laboratory, Chilton, Didcot OX11 0QX, UK*

[b] *CERN, CH-1211 Genève, Switzerland*

Abstract

A fast total energy trigger module for use with the CsI calorimeter of the Crystal Barrel experiment at LEAR is described. The unit intercepts and sums the data during the transfer of the digital output of the LeCroy FERA ADC's to the 1190 memory modules. Comparing the digital sum with two preset levels then generates outputs to the trigger logic in less than 40 μs from the start of the input gate signal to the FERA ADC's. This fast response allows the energy sum signals to be included in the level one trigger logic.

1 Introduction

The Crystal Barrel spectrometer for the measurement of charged particles (pions, kaons and protons) and photons, has now been in operation at the LEAR facility at CERN since 1989. The spectrometer covers almost 4π solid angle and is designed to investigate $\bar{p}p$ and $\bar{p}d$ annihilations at rest and in flight up to the maximum LEAR momentum of 2 GeV/c. The spectrometer, including the data acquisition [1] and trigger system, has been described in detail elsewhere [2]. The particular feature of the apparatus relevant to the present work is the calorimeter consisting of 1380 CsI crystals covering polar angles between 12° and 168° with full coverage in azimuth. Development of the crystal read-out system described in [2] has continued and in particular, re-configuring the read-out of the FERA ADC systems has given much improved reliability, the elimination of read-out errors and has simplified the diagnosis of faults. The arrangement described here is this improved version.

Shaped pulses derived from showers in the crystals are encoded zero-supressed (i.e. with pedestal subtracted) by both a fast and a slow ADC system. LeCroy

[1] Now at Universität München, D-85748 München, FRG

Preprint submitted to Elsevier Science *14 November 1997*

2282 ADC's [3] provide high resolution ($\approx$ 50 keV/channel) covering the dynamic range from 0 to 400 MeV with comparatively slow ($\approx$ 2 ms) read-out from the CAMAC data highway. The full dynamic range (0 to 2000 MeV) at lower resolution (1 MeV/channel) is measured in $\approx$10 μs by LeCroy CAMAC 4300B series ADC units [3]. About 25 μs after the start of the analogue signals from the CsI calorimeter the data from these ADC's are transferred in digital form via the ECL bus to LeCroy 1190 memory modules [3] housed in a VME crate. The present paper describes a hardware total energy trigger (TET) module housed in the same VME crate which during the transfer intercepts and sums the data words. A comparison of the final sum with two preset levels then generates outputs to the hardware trigger logic in $\leq$40 μs, at a similar time to outputs from other elements of the hardware trigger front end logic and before the output from the FACE (hardware fast cluster encoder) used to determine the number of shower clusters in the calorimeter. This quick response allows fast triggering on the total energy recorded in the CsI calorimeter.

Several other modules are housed in the same VME crate. A FORCE computer (based on a Motorola 68040 CPU) runs software for read-out and triggering on photon multiplicity, meson type and meson multiplicity. The interface to all CAMAC ADC's is provided by a CES CAMAC branch driver and computer control for the TET module is by an APAL-100 I/O module (See Section 3.3). The direct interface to the FORCE is via the Parallel Interface/Timer (PI/T) through a custom built module referred to as the Force Support Unit (FSU).

The hardware trigger decision at the first level, which now includes the decision of the TET, flags acceptance of the event to the read-out software by means of a bit set in the FSU. An additional bit in the FSU informs the software if it is to make a (second level) triggering decisions based on the decoded FERA data, for example, meson type and multiplicity identification. Following the read-out signal, and on completion of the strobing of the FERA data into the 1190 memory modules, four separate bits (one for each CAMAC crate containing FERA modules) are set in the FSU, and are sensed by the read-out software. These bits request the software to transfer all data words from the memory modules to the FORCE local memory. Following the transfer, if the 'software trigger' bit is set in the FSU, the data is calibrated from a look-up table and the search for the the specified photon multiplicity, meson type and meson multiplicity commences.

Before the present total energy hardware trigger was constructed, the software trigger was also used to sum the decoded FERA data words during the read-out from the memory modules. This took $\approx$ 100 μs and was too late for the first level trigger, so that the present hardware solution is much preferred both for speed and to prevent unnecessary further processing by the read-out and trigger software. Events which are out of range in total energy can be rejected

Fig. 1. Overview of ADC system.

in ≤ 40 μs, the read-out abandoned and a fast hardware reset completed without processor intervention so that the apparatus is soon ready for the next event. The use of a fast trigger based on an analog sum of crystal signals was rejected due to difficulties with electronic noise, since all 1380 channels would contribute, even those where the associated crystal did not produce a signal pulse.

2 Overview of ADC and read-out system

The FERA data read-out system as used on the experiment is shown in figure 1. The FERA ADC's are contained in 4 CAMAC crates, with each crate containing 22 4300B FERA ADC modules and one LeCroy 4301 Driver module. Each FERA module contains sixteen 11 bit ADC's. After the crystal signal has been converted in the FERA ADC, the data word for each crystal is transferred, via the ECL bus and the 4301 driver, to the 1190 memory modules. These modules are housed in the local event builder VME crate [2].

When read out, each FERA generates a 'header word' containing a virtual station number, unique to that module, followed by 16 bit crystal words which contain the ADC data and also the address of the ADC within the FERA module. The data is transferred pedestal subtracted, so that only crystals containing data above threshold are read out.

Within each 4301 driver module a printed circuit board has been added containing a circuit which sums all the data transferred to the memory module during the transfer. At the end of the data transfer period, each modified 4301 contains the total sum of the data transferred to the memory module from that crate. These total sums are then transferred to the TET module which resides in the VME crate with the four 1190 memory modules. In the TET module the data from the four crates is added together to provide the total energy sum. After comparison of this sum with preset total energy levels, a logic signal is sent to the hardware trigger which manages the accept/reject of the current event.

Fig. 2. TET module. General arrangement

3 Total energy trigger hardware

3.1 General arrangement

The overall block diagram of the TET module is shown in figure 2. The FERA data for each crate is added in the modified 4301 before being transferred to the TET module. Here the data from all four crates is added into a 12 bit word. The output from the final adder is split two ways, one output going to the comparator circuits for comparison with the desired maximum and minimum levels, and the other to a multiplexer to be read externally. As shown in the lower part of figure 2 the maximum and minimum thresholds can be set either by switches on the front panel of the module or externally by the run control computer via the VME P2 connector on the rear panel of the module. This external control data is strobed into two latches, maximum and minimum, and then multiplexed with the setting from the front panel switches, the output of the multiplexer being selected by a Local/Remote switch on the front panel. These two twelve bit words are then compared with the total energy sum in two comparator circuits and also fed into a second multiplexer so that the threshold values can be read externally.

The comparator circuits compare the two set levels, maximum and minimum, with the total energy sum and generate separate output signals when the total energy lies between the two trigger levels, is greater than the minimum level and when the total energy is greater than the maximum level. The total energy sum and the maximum and minimum levels fed into the multiplexer circuit, can be read via the P2 connector by an APAL-100 forty eight channel I/O module [4] which is written to and read by the event builder [2]. These quantities are then written to the data recording tape as part of the trigger information for each event.

3.2 Hardware in 4301 unit

The adder circuit shown in figure 3 is manufactured on a printed circuit board and mounted 'piggy back' inside each 4301. The ECL data signals from the

Fig. 3. Hardware in 4301 unit

4301 are converted to TTL levels using MC10125 level translators. These 11 bit data words are added (74283) to the previous value every time there is a strobe pulse from the 4301 and the 12 bit output is then stored in a 74174 latch. The WSO strobe pulse used to latch the data is the same pulse, shaped by 74123 shapers, that strobes the data into the 1190 memory modules. If bit 16 is set in the data word, this indicates that it is a FERA header word and is not required for the energy sum. In this case the strobe pulse does not reach the latches as it is negated by the 7400 NAND circuit. The latches are reset at the beginning of each FERA conversion by the gate pulse used to open the FERA ADC's. The 12 bit outputs from the latches are then buffered using 74128 drivers before being sent to the VME TET module (See figure 1).

3.3 TET module hardware

As already mentioned the TET hardware is constructed in a double width 6U VME module which resides in the crate together with the four 1190 memory modules and other units associated with the local event builder [2]. As well as the connectors for the inputs from the 4301 driver modules the front panel contains LED displays of the total energy sum and the maximum and minimum levels used by the comparator circuits. These maximum and minimum levels can be set via the dual in-line switches (DIL) on the front panel when the control is set to Local or via the P2 connector with the control set to Remote. In both cases LED's indicate the values of maximum and minimum levels used by the comparator circuits. Other LED's also indicate whether the total energy sum was between the minimum and maximum levels, greater than minimum level or greater than maximum level. In addition differential ECL output levels are generated for each of these three states.

The adder circuit inside the TET module is shown in figure 4. Four twelve bit words from each of the 4301 adder circuits are buffered using 7404's, into two pairs of 12 bit adder circuits, and these outputs are then summed in a third adder. The chip used for addition is the 4 bit adder type 74283. The output of the final adder circuit goes to the comparator circuits for comparison with the maximum and minimum levels, to a multiplexer for reading the total energy sum externally via the P2 connector on the rear of the module and also to the

Fig. 4. TET module adder circuits.

Fig. 5. TET module comparison and output circuits

LED indicators on the front panel.

Figure 5 shows the circuit for setting the minimum and maximum trigger levels required and comparing them with the total energy deposited in the crystals. The levels can be set either remotely via the P2 connector on the rear of the module, or by DIL switches mounted on the front panel of the module. External data from the P2 connector, is latched into two pairs of 74378 latches using control signals which are also obtained via the P2 connector. A strobe pulse is generated from the control bits using two 74123 dual mononstables, the outputs of which are fed in coincidence with the input control bit to suppress spurious noise signals on the input. The output from the coincidence (7408) then strobes the data into the latches. The latched outputs are fed into the 74157 quad multiplexer chips together with the levels from the front panel DIL switches. The output from these multiplexers is selected by the front panel Local/Remote switch. The output is then split three ways:-

(i) To LED indicators on the front panel of the module.
(ii) To a multiplexer circuit so that the minimum and maximum values can be read remotely.
(iii) To two sets of comparator circuits (7485) to be compared with the total energy sum from the adder circuits.

The comparator circuits, together with the 7402 NOR gate, then give signals for conditions when:-

(i) the total energy lies between the two trigger levels.
(ii) when the total energy is greater than the minimum level.
(iii) when the total energy is greater than the maximum level.

These levels are indicated by LED's on the front panel. The TTL levels are

Fig. 6. TET module monitor circuits.

Fig. 7. Structure of APAL module I/O ports.

then converted, in a MC10124 level translator, to differential ECL levels which are accessible on the front panel. One or more of these levels can then be incorporated in the hardware trigger logic, depending on which trigger conditions are required.

During data taking, the performance of the module can be observed on the front panel where LED's indicate the minimum and maximum set levels and also the total energy sum. These values can also be monitored externally via the P2 connector. The minimum and maximum values are multiplexed (figure 6) in a pair of 74857 hex universal multiplexers and the output is fed into a second pair together with the total energy sum. The output of this second pair then goes to the P2 connector. The states of these multiplexers are controlled externally and it is possible to read the minimum, maximum or total energy sum. In order to read these values and also set the minimum and maximum levels by computer control, the TET module is connected via the P2 connector, to an Eltec VME I/O module type APAL-100, sitting in the same VME crate.

The APAL-100 module is a general purpose parallel input/output module containing four 8 bit registers which can be used either as output or input in blocks of 4 bits. In order to communicate with the TET module the I/O has been structured as shown in figure 7.

Port A is used to write the data into the maximum and minimum level registers, the top two bits in channel 2 being used as control bits which determine which of the two registers are written into. Bit 7 is used for data being strobed into the 'maximum' register and bit 8 for the 'minimum' register. Before writing to the maximum and minimum registers, PORT A channels 1 and 2 are reset to zero.

Table 1
Truth table

Bit 7	Bit 8	Out
0	0	Maximum
0	1	Minimum
1	x	Total Energy

Port B is used to read the maximum, minimum and total energy values with again the top two bits in channel 2 being used to determine which words are accessed. Table 1 shows how the bits are used.

4 Performance

When studying $\bar{p}p$ annihilations 'at rest' the maximum energy which can be deposited in the crystals is 1880 MeV. At 1940 MeV/c antiproton beam momentum, the highest available from LEAR, the maximum energy deposited in the crystals is 3090 MeV. The total energy sum in the TET module is contained in a twelve bit number which with a calibration of 1 MeV/channel gives a full scale of approximately 4000 MeV. With the present data acquisition system there are four unused channels with their pedestal output set high to ≈ 280 in order to force each FERA crate to read out some data with each gate pulse. [2] For these channels the pedestal value to be subtracted from the data in the FERA modules, is set to the maximum of 255, so that the equivalent of 25 MeV is transferred to the memory modules for each of these crystals. This gives an additional contribution of (4×25) 100 MeV to the total energy sum in the TET module so that its effective range is reduced by this amount. However the thresholds on the FERA ADC's are set at 5 MeV, to reduce the number of ADC's which trigger on noise, so that the total energy recorded is reduced by $5\times$n MeV, where n is the number of ADC channels which are read out. With a typical value of 40 for n, the total energy recorded is reduced by about 200 MeV.

These two factors, due to the four high pedestals and the 5 MeV threshold, have to be taken into account when setting up the maximum and minimum threshold levels. In practice an on-line monitoring program samples events recorded by the calorimeter and, using pre-set tables, calibrates the output from each crystal. This allows the energy scale of the TET to be calibrated very easily and the appropriate energy thresholds to be chosen.

[2] This feature is required so that the FERA 4301B driver always initiates some transfer of data from the FERA ADC's to the 1190 memory modules.

The total time taken for the operation of the module to perform the additions and to generate a trigger level is as follows:-

(i) 6 μs gate which opens the FERA ADC's
(ii) + 8.5 μs conversion time of the ADC's
(iii) + 2.5 μs pedestal subtraction and data compression
(iv) + n$\times$0.2 μs transfer time to the 1190 memory module where n is the number of ADC channels read out
(v) + approximately 1 μs settling time.

Hence for an event transfer with energy deposited in 60 crystals the total time from the beginning of the event to the time when the trigger pulse is available is approximately:-

$$6 + 8.5 + 2.5 + 12 + 1 = 30 \ \mu\text{s}.$$

The above calculation is a 'worst case' and assumes that all the ADC's read out were from the same FERA crate. In fact data is usually read out from all four crates in parallel so reducing the operational time. For example with a maximum of 20 crystals read out from one FERA crate, and with fewer than 20 from each of the other three crates, the time is reduced to 22 μs.

The total energy trigger has been used in studies of a number of channels for $\bar{\text{p}}\text{p}$ annihilations at rest, including $\pi^0\eta\eta$, $\pi^0\eta\eta'$, and $\pi^+\pi^-\pi^0\pi^0\eta$. The latter reaction was used for measurements of the $\eta\pi^+\pi^-$ and $\eta\pi^0\pi^0$ decay modes of the E/ι meson [5]. The level 0 trigger used information from the wire and jet drift chambers [2] to select events with 2 long charged tracks. The total energy trigger described here, together with the fast cluster encoder (FACE), were then used in the level 1 trigger to select events with 8 clusters (6 photons and 2 charged tracks) and total calorimeter energy in the range 950-1700 MeV. Finally the software trigger at level 2 calculated the energies and angles of the crystal clusters, formed all possible invariant masses and checked if these matched the desired hypothesis. The time taken for this latter process was 1 - 2 ms and the function of the level one trigger was to reject events which clearly would not satisfy the selection criteria. Further details of this special trigger system have been given by Urner [6].

The total energy trigger has also been used extensively for running in flight [7]. Here the events can be strongly peaked at forward angles leading to the possible 'loss' of one or more photons or charged particles down the exit beam pipe. There are also a relatively large number of forward peaked elastic scattering $\bar{\text{p}}\text{p} \rightarrow \bar{\text{p}}\text{p}$ and charge exchange $\bar{\text{p}}\text{p} \rightarrow \bar{\text{n}}\text{n}$ events. All these events give less than the full $\bar{\text{p}}\text{p}$ total energy in the CsI calorimeter and are rejected by the total energy trigger. This enables the processing of a larger number of front-end triggers per second without invoking the read-out software.

Fig. 8. Spectrum of summed ADC channel contents.

Fig. 9. Total CsI energy spectrum for same events as in figure 8.

As an example we show in figure 8, the spectrum obtained with the on-line monitoring program, showing the summed FERA ADC channel contents obtained at a beam momentum of 1050 MeV/c with the TET module in operation. The selection of events due to the limits set at 1500 and 2800 channels is clearly seen. Figure 9 shows the measured total CsI energy spectrum for the same events. The low- and high-energy cut offs are now not so sharp. This is due to the differing energy calibrations of the ADC's and the varying effect of the 5 MeV ADC thresholds (See section 4) due to the differing numbers of crystals associated with each event. The selection of 'wanted' events in the total energy peak is however clearly evident.

5 Conclusions

A fast total energy trigger module for use with the CsI calorimeter of the Crystal Barrel experiment at LEAR has been described. The unit sums the data during the transfer from the LeCroy FERA ADC's to the 1190 memory modules. Comparing the digital sum with two preset levels then generates outputs to the trigger logic in less than 40 μs from the start of the input gate signal to the FERA ADC's. This fast response allows the energy sum trigger signals to be included in the level one trigger logic [2]. The method described could be adapted to a variety of needs in experiments using FERA or other similar ADC systems.

Acknowledgement

We wish to thank Bruce Barnett for his work in the incorporation of the TET remote set-up and read-out into the data acquistion system, Hartmut Kalinowsky for his contribution in incorporating the TET into the Hardware Trigger Logic, Marcel Kunze and many other members of the Crystal Barrel collaboration for helpful discussions. This work was financially supported by the British Particle Physics and Astronomy Research Council.

References

[1] M.Merkel, IEEE Trans. Nucl. Sci. **NS-39** (1992) 159.

[2] E. Aker et al. (Crystal Barrel collaboration), Nucl. Instr. and Meth. **A321** (1994) 69.

[3] Manufactured by LeCroy Research Systems, Chesnut Ridge, NY 10977-6499, USA.

[4] Manufactured by ELTEC elektronik GmbH, Galileo-Galilei-Straße 11, W-6500 Mainz 42, Germany.

[5] C. Amsler et al. (Crystal Barrel collaboration), Phys. Lett. **B358** (1995) 389.

[6] D. Urner, Study of E/ι decay to $\eta\pi\pi$ in $\bar{\mathrm{p}}\mathrm{p}$ annihilation to $4\pi\eta$, in: *Proceedings of the Third Biennial Conference on Low-Energy Antiproton Physics. LEAP94* (Bled, Slovenia, 1994) World Scientific Pub. Co., Singapore (1995).

[7] J. Adomeit et al. (Crystal Barrel collaboration), Z. Phys. **C71** (1996) 227.