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A CALORIMETER SOFTWARE TRIGGER FOR THE MARK II DETECTOR AT SLC*‡

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ABSTRACT

A new FASTBUS-based calorimeter software trigger for the upgraded Mark II at the Stanford Linear Collider (SLC) is presented. The trigger requirements for SLC and a short description of the hardware used for this purpose are given, followed by a detailed description of the software. Some preliminary results are presented [1].

1. MARK II AT SLC

The new SLC was designed and built both to test linear collider technology [2] and for the production of Z^0 bosons for physics analysis [3, 4]. The beam-crossing frequency at SLC is sufficiently low that only a single level of triggering is required for an event logging rate of a few Hertz.

2. THE HARDWARE

The upgraded Mark II detector [5] uses a lead-liquid argon sampling device as the barrel calorimeter and a lead-proportional tube device as the endcap calorimeter. A brief summary of the relevant facts is given here. Figure 1 shows the components of the trigger hardware.

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2.1 Liquid Argon Calorimeter

The liquid argon calorimeter [6] consists of eight independent liquid argon cryostats forming a barrel around the central part of the detector with strip readout geometry. Each module comprises seven layers of 2 mm lead sheets interleaved with 3 mm gaps filled with liquid argon. The strips have orientations parallel, perpendicular and at 45° to the beam. There are 362 channels per module and the total thickness of lead and liquid argon is 14 radiation lengths.

2.2 Endcap Calorimeter

The endcap calorimeter [7] forms the end parts of the barrel and consists of 36 layers of proportional tubes interleaved with 0.5-radiation-length layers of lead. The tubes in the layers are oriented in a plane perpendicular to the beam vertically (4 X-layers/side), hori zontally (4 Y-layers/side), and diagonally at +45° (2 U-layers/side) and at −45° (2 V-layers/side). There are 1276 channels of electronics for each end, with preamplifiers and shaping amplifiers located on the endcap. The angular range covered by the endcap calorimeter is between approximately 15° and 45°.

2.3 Readout

To reduce the number of electronics channels in the trigger, sets of eight adjacent channels are summed on the detector resulting in 42 sums of eight channels per module, or a total of 336 channels for the entire liquid argon calorimeter system (Fig. 2) and in 180 channels per module (per side) or a total of 320 channels for the entire endcap calorimeter system (Fig. 3). These signals are sent to the Sum/Buffer & Formatting circuits in the electronics house where the signals are reformatted, transformer-coupled to the ADCs, and summed (Fig. 1). From there, these signals are fed into eight FASTBUS ADC modules for digitization. The FASTBUS ADCs are LeCroy 1885N 96-channel 12-bit ADCs with an equivalent dynamic range of a 15 bits and a conversion time of 750 μm. A SLAC Scanner Processor (SSP) [8, 9] performs front-end data acquisition, including data reduction and gain-offset corrections, and forms the trigger decision. The hardware components of the software trigger have been in place and working reliably for more than one year.

2.4 Calibration

The system is calibrated by measuring the noise (pedestal) and the response (gain) to stepwise increasing amounts of charge injected into each of the preamplifiers of the liquid argon and endcap readout systems. The liquid argon and the endcap systems are equipped with independent calibration systems, and are calibrated simultaneously. The entire dynamic range of the ADCs is calibrated by injecting 10 different values of charge into the preamplifiers with 20 iterations of each value. The calibration program on the VAX calculates the gain, pedestal and noise for each channel based on summary information from the SSP. These results are stored and downloaded to the SSP at the beginning of the run. Also calculated are a readout threshold for data reduction and a set of three trigger thresholds for each channel. Long-term monitoring of calibration constants have shown very good stability over a period of one year.

3. THE SOFTWARE

The SSP can be programmed in IBM system/370 assembly language or FORTRAN. Code development for the SSP is done on an IBM mainframe. After compilation and cross-assembly, the code is sent to the VAX 8600 online computer. At the start of data acquisition, the code and the calibration constants are downloaded to the SSP.

A series of test programs exercise all functions of the ADCs and of the FASTBUS system at the beginning of every data and calibration run.

The program flow of the trigger SSP software is shown in Fig. 4. The program has one entry point and two main branches. The SSP program is started on every beam crossing, or every 8.33 ms at a beam crossing rate of 120 Hz. On each beam crossing, the trigger branch is executed. A Master Interrupt Controller (MIC) module forms the overall trigger decision, based upon the software trigger and other detector subsystems, according to the trigger criteria downloaded at the beginning of the run. The data-acquisition branch is executed for each candidate beam crossing triggered by the MIC module.

Execution of the trigger branch causes all ADCs to be read out. The raw ADC counts are mapped into the four bins of energy defined by the three trigger thresholds, and the trigger algorithm is executed. The results of this algorithm are communicated to the MIC via the special purpose FASTBUS module MM in Fig. 1.

For a triggered event, the SSP is started a second time by the MIC module to execute the branch called DAQ in Fig. 4. Pedestal and gain corrections are made for channels which surpass their readout thresholds. The remaining data is then formatted into a buffer and sent to the VAX. The MM module contains a timer which is controlled and read out by the SSP. Detailed timing information is written into the output buffer together with the rest of the data, allowing for offline studies of execution times of the readout and trigger code.

3.1 Trigger Algorithm

The goal for this trigger algorithm is to achieve a high efficiency for selected events down to very low energies while remaining insensitive to beam-related backgrounds. The granularity of the trigger data for the calorimeters is fine enough to exploit the difference in topologies between annihilation events and background.

The algorithm identifies localized energy towers within each module pointing back to the interaction point (IP). This is accomplished by comparing each channel's raw ADC value against the set of thresholds calculated for every channel at calibration time, based on the channel's offset, gain and mapping in the calorimeter. A summary of these three threshold comparisons is stored in a compact array. This array is then systematically searched for combinations of calorimeter channels representing contiguous, projective "towers" of energy. The searching algorithm consists of assembling threshold information for each channel in successive layers within a single calorimeter module into a single 32-bit word. This word serves as an index into a predefined tower definition array, whose contents indicate the presence or absence of a tower. The sensitivity of the software trigger can be modified by altering coherently the sets of three thresholds for each channel or by changing the number of towers which have to be found.

Initial construction of the tower definition array resulted from an analysis of energy deposition patterns produced by Monte Carlo Z^0 events. Additional tuning was made by examining beam-related backgrounds produced during the past year. The studies of these beam background events revealed significantly different sensitivities of the various layers to beam background events. For example, layers in the beam direction are very sensitive to beam background events, while layers measuring the polar angle are not.

Since such tower finding algorithms can consume a significant number of CPU cycles, it is very important to limit the searching to meaningful combinations and to terminate any looping which can no longer be considered promising. This technique yields execution times well within the required range given by the time interval between beam crossings. The execution time for the trigger processing is in the range of 4–6 ms, of which 1 ms is needed for the digitization and ADC readout. The completion time of the trigger code strongly depends on the occupancy in the liquid argon calorimeter and the endcap calorimeter.

4. RESULTS

Cosmic ray and beam background data have been recorded for the software trigger and have been analyzed offline. The cosmic ray data provides a clean sample of single-muon particles going through the detector. Events were selected if they contained a reconstructed track from the central drift chamber extrapolated out into the calorimeter modules. A single muon deposits approximately 15 MeV/layer on average, representing a signal 2.5–4.0 σ above equivalent noise charge in the liquid argon calorimeter and 10 MeV/layer on average, representing a signal 15 σ above equivalent noise charge in the endcap calorimeter. These results show a high sensitivity to minimum ionizing particles. The endcap calorimeter trigger data have turned out to be a very important commissioning tool for SLC due to its ability to differentiate and measure muons from sources far upstream in the beamline from electromagnetic debris originating near the IP. Muons originating upstream traverse the entire endcap calorimeter while electromagnetic debris from the IP is absorbed in the first few layers of the endcap calorimeter on either side. These observations have inspired an analysis routine which assesses sources of background on an event-by-event basis and is used online for beam tuning. Offline, the same information is used to find and understand correlations between background measurements from other parts of the Mark II detector.

As of March 1989, about 30,000 events were triggered by the software trigger during beam background runs showing a working general triggering scheme. Since the beams and their backgrounds were very unstable, we have been unable to make a direct measurement of the trigger efficiencies.

5. CONCLUSIONS

All components of the new calorimeter software trigger have been installed. The hardware is reliable and the triggered data have been used extensively for beam background studies. The intrinsic flexibility of a software trigger will aid in the implementation of new algorithms as they are developed during the evolving needs of the Mark II experiment.

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FIGURE CAPTIONS

Figure 1: Trigger hardware components.

Figure 2: (a) ϕ projection of liquid argon calorimeter; (b) Single module liquid argon calorimeter segmentation.

Figure 3: Single module endcap calorimeter segmentation.

Figure 4: Flow chart for the trigger software.

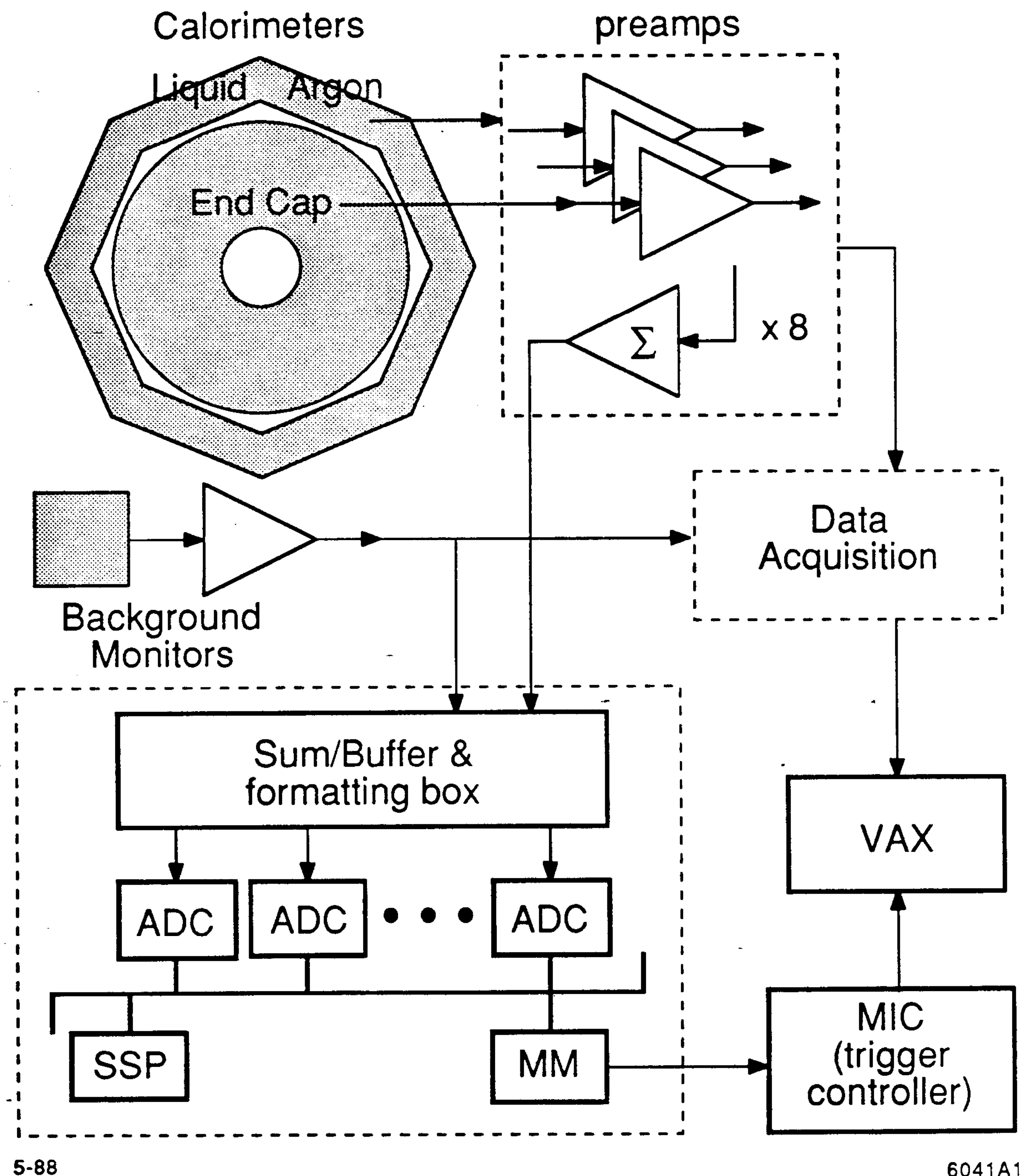
Calorimeters
preamps
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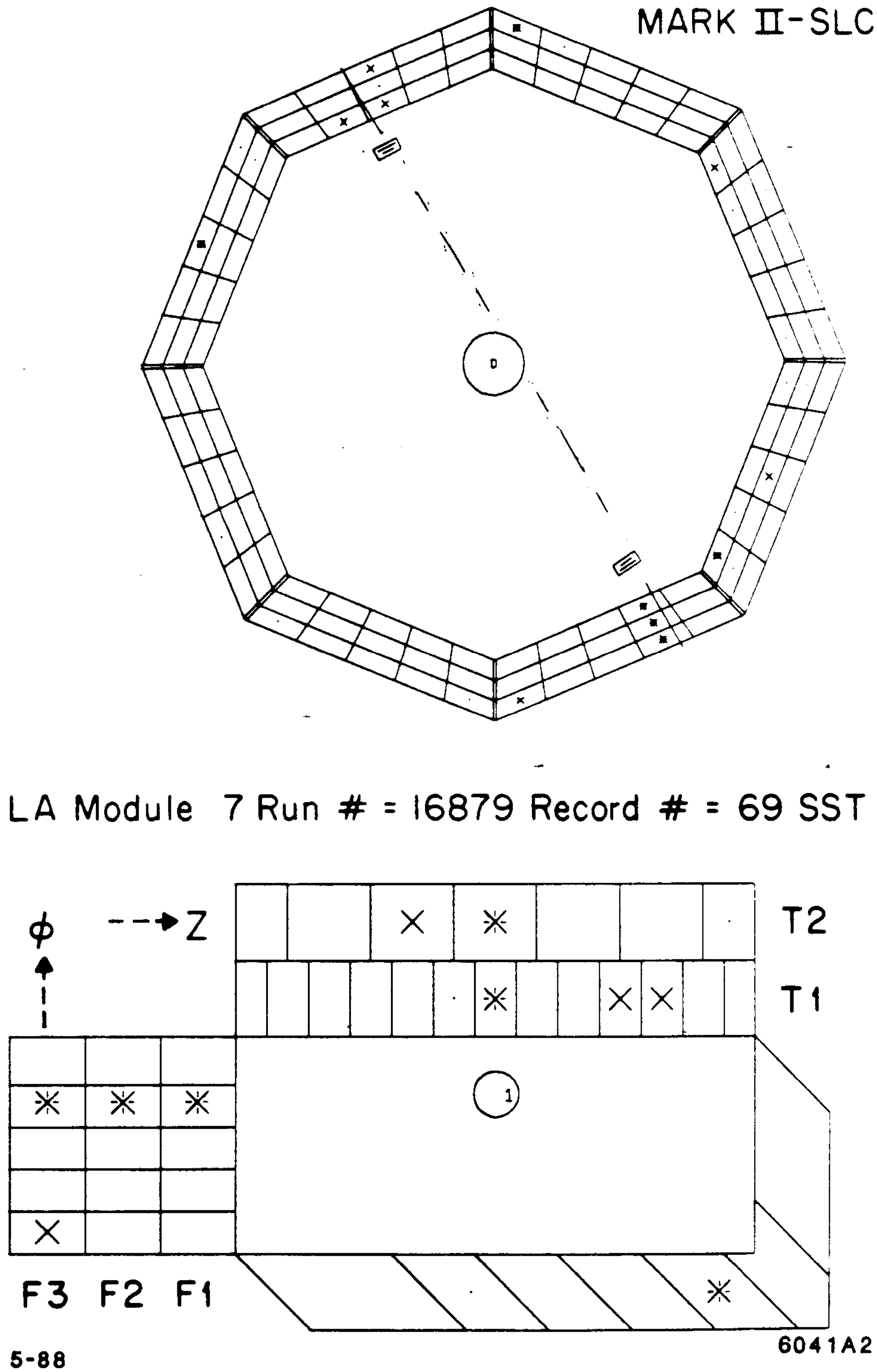
Fig. 1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LA Module 7 Run # = 16879 Record # = 69 SST
φ
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Fig. 2

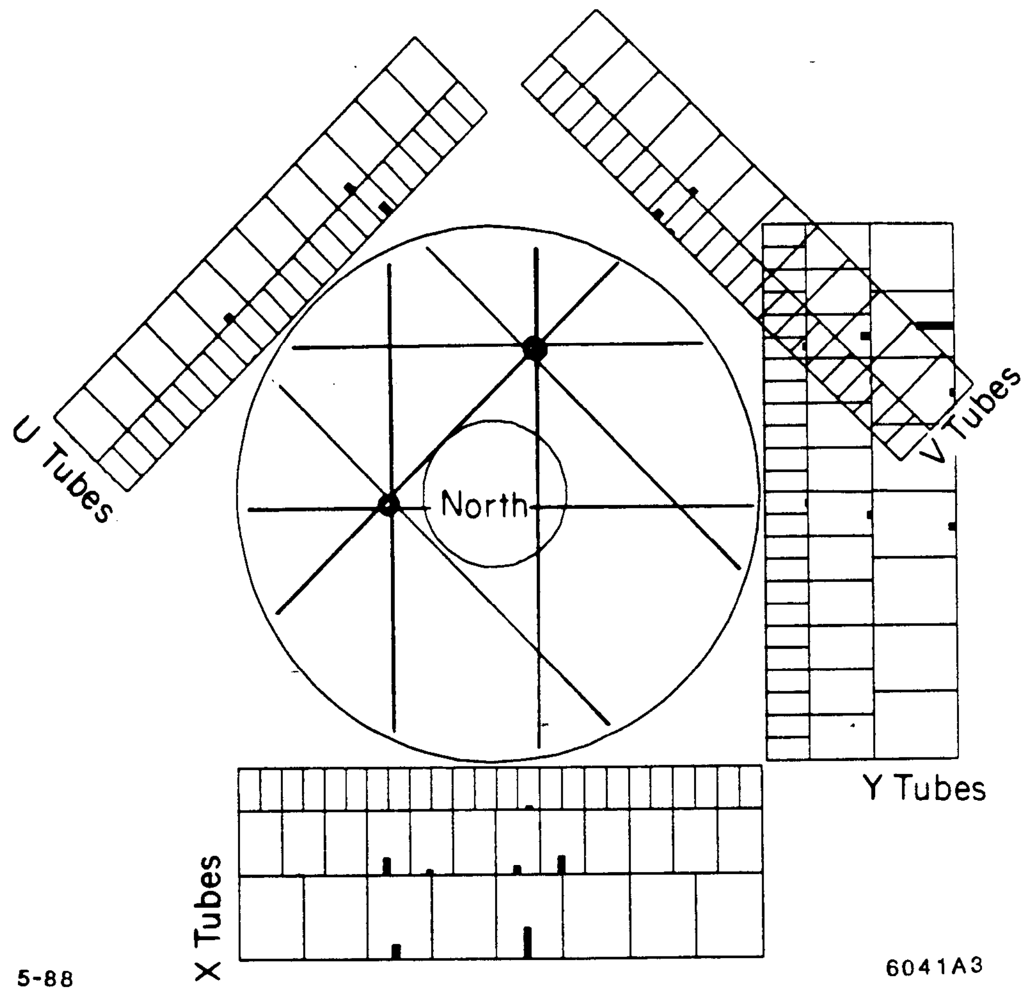
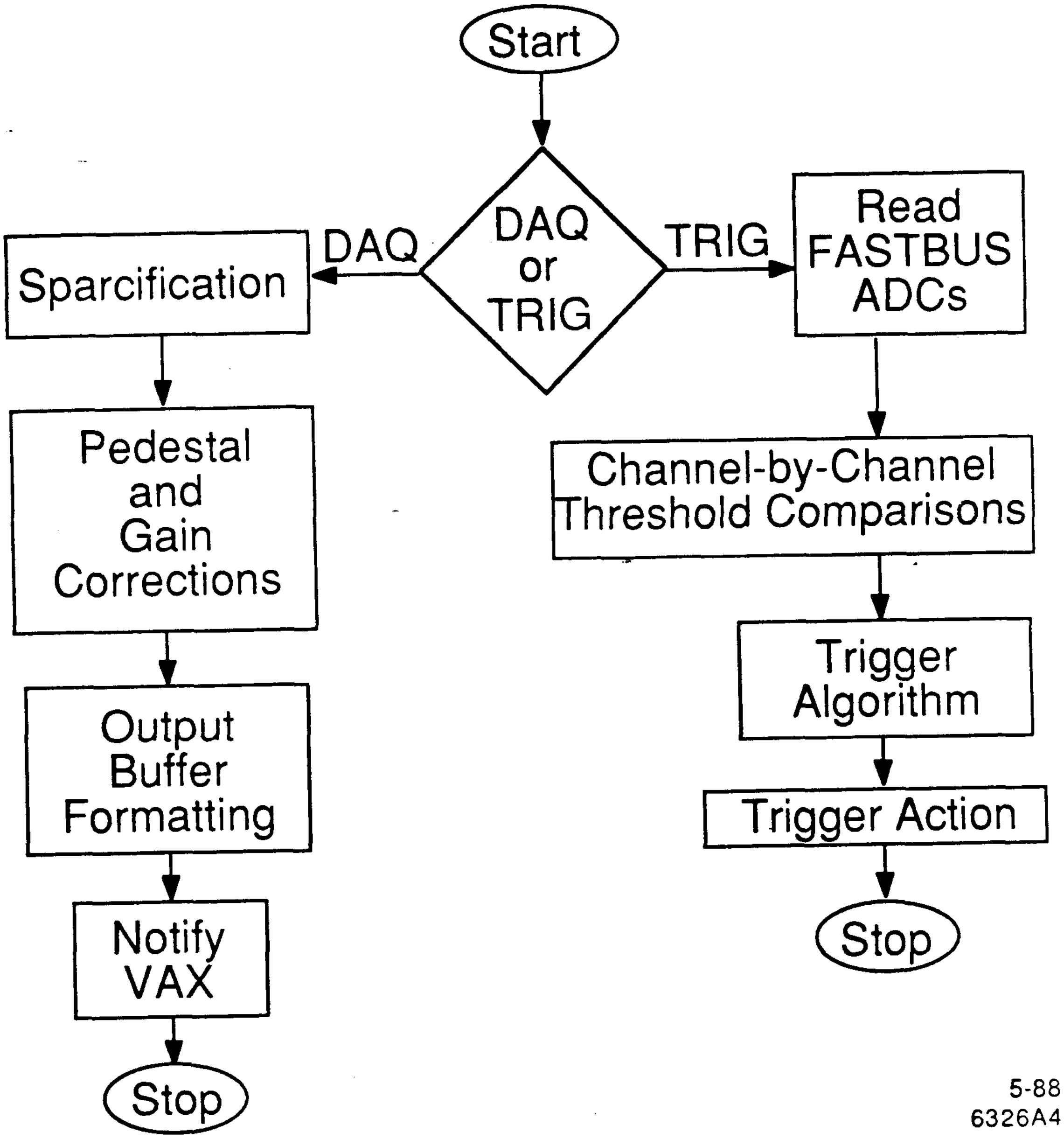


Fig. 3



Start
DAQ
or
TRIG
DAQ
TRIG
Sparcification
Pedestal
and
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Corrections
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Notify
VAX
Stop
Read
FASTBUS
ADCs
Channel-by-Channel
Threshold Comparisons
Trigger
Algorithm
Trigger Action
Stop
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Fig. 4