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AN AMPLIFIER-DISCRIMINATOR MODULE FOR VERY HIGH ENERGY γ-RAY ASTRONOMY

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An eight-channel amplifier-discriminator module has been developed for processing fast photomultiplier signals from a ground-based γ-ray imaging telescope. The module provides several outputs for recording pulse height, width and arrival time. Two-level discrimination provides the basis for a flexible, externally controlled trigger system.

1. Introduction

For a number of years, various groups have attempted to detect stellar sources of very high energy γ-rays by looking at the nanosecond Cherenkov light pulses generated by atmospheric air showers. Recently, experiments [1-3] employing imaging arrays of photomultipliers have shown that there is sufficient information in the Cherenkov light distribution to discriminate electromagnetic showers from the hadronic background. To enhance this technique further we have developed a fast pulse amplifier-discriminator module to permit the simultaneous measurement of pulse height, width and time of arrival from the 109 pixel elements of a photomultiplier camera. Input logic pulses for a two-level event trigger system is generated by dual comparator circuits with independent thresholds.

2. Experimental requirements

Observations of Cherenkov light produced by air showers in the night sky require the measurement of faint, fast pulses in a dc background of nearby urban illumination and fluorescent emission of air molecules in the upper atmosphere. Ambient light intensities of the order of 10^9 photons/s impose a gain limitation on photomultipliers: most phototubes will seriously degrade if operated continuously with anode currents in excess of 100 μA. This sets a limit of 10^5 to 10^6 on the gain of photomultipliers exposed to such an ambient background flux. Despite these restrictions, the unique time structure of Cherenkov radiation permits trigger thresholds corresponding to as little as five detected photoelectrons. Amplification by a factor of 10 is required to raise these pulses above the 20 mV threshold level of typical fast discriminator circuits. This amplification is also necessary to match the pulse amplitude to the input requirements of commercially available ADC modules. To preserve pulse shape information as well as possible, the amplifier must maintain bandwidths characteristic of the incoming photomultiplier pulses whose widths are as short as 3 ns. Dynamic range is also a consideration; the amplifier gain must remain constant for output pulses which range in amplitude from 0 to 1.5 V.

The principle purpose of this amplifier-discriminator module is to extract as much information from each photomultiplier pulse as possible. If all that is required is pulse amplification, several different commercially available modules would be more than adequate for our experiment. Unfortunately, this would ignore important information about the pulse time structure. It is expected that measurements of the pulse arrival times and widths will assist in the differentiation of γ-ray from hadronic air showers. The width measurements dictate the use of time-over-threshold discriminators whose output pulses remain at logic high as long as the input pulse exceeds preset threshold values. The discriminator output pulses must also constitute the input signals for event trigger decision logic. To obtain a more flexible and sensitive event trigger, two independent parallel threshold circuits are required for each channel. These discrimator logic pulses are also routed to scaler modules to monitor time variations in accidental rates. If all of these functions were performed by individual logic modules, the interconnection and fanout cost would be prohibitive. By packaging the amplification and discrimination electronics in a single module we have achieved significant cost savings as well as enhanced reliability. The result is a circuit with a single input and many outputs.

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3. Circuit description

A block diagram of a single channel is shown in fig. 1. The photomultiplier input signal is amplified by a factor of 10 using a Mini-Circuits MAN-2 hybrid rf amplifier selected for its high bandwidth, gain, and dynamic range. The output pulse drives three high-impedance circuits consisting of two comparators and one unity gain amplifier. The pulse is also connected to a 50 Ω output for amplitude measurement with an external ADC module. The comparators are LeCroy MVL407 monolithic time-over-threshold quad discriminators. These chips generate ECL logic pulses whenever the pulse amplitude exceeds preset dc levels. Two independent discriminator channels allow a more versatile trigger logic so that events can be captured which either produce relatively faint coincident pulses in two adjacent Cherenkov telescopes or a larger intensity of light in a single unit. The output of the comparators trigger three MC101098 ECL monostable multivibrators to generate fixed-width logic pulses, 25 ns long. These pulses are transmitted to external circuits via a set of five MC10192 ECL differential 50 Ω line drivers. By providing pulses initiated by both the leading and trailing edges of the photomultiplier waveform, external TDCs can independently measure the pulse arrival time and width. Two signals inform the event trigger logic whenever the input PMT pulses exceed the low and high threshold levels. The fifth signal output is routed to scaler modules to keep track of the singles counting rate for each phototube. The unity gain amplifier provides an independent buffered analog output pulse which may be used for diagnostic purposes or captured with a digital waveform recorder.

To package eight channels in a single module requires a relatively high component density. The VME standard was chosen to define the mechanical specifications of the printed circuit board and module hardware. The board has eight conducting layers; two for signal traces, two for corresponding signal ground return lines, one power ground plane and three power distribution planes. The board dimensions are 233.4 mm × 280.0 mm, corresponding to a VME 6U module. Although the PC board is somewhat more complex to fabricate, the multiple layers considerably eased the problem of providing clean 50 Ω transmission lines between components and input and output connectors. A detailed circuit diagram is shown in fig. 2.

4. Performance

The performance of the analog amplifier is the most crucial aspect of the entire circuit. In most of the measurements to be described below, the input signals were provided by a Hewlett-Packard 8082A 250 MHz pulse generator and the output was recorded by a 1 GHz sampling rate Hewlett-Packard 54111D digital oscilloscope. The digital measurement facilities of the HP scope considerably simplified obtaining gain and rise-time data.

The gain was measured for input pulses with widths of approximately 15 ns and pulse heights varying from 23 to 450 mV. The variation in gain for a single channel

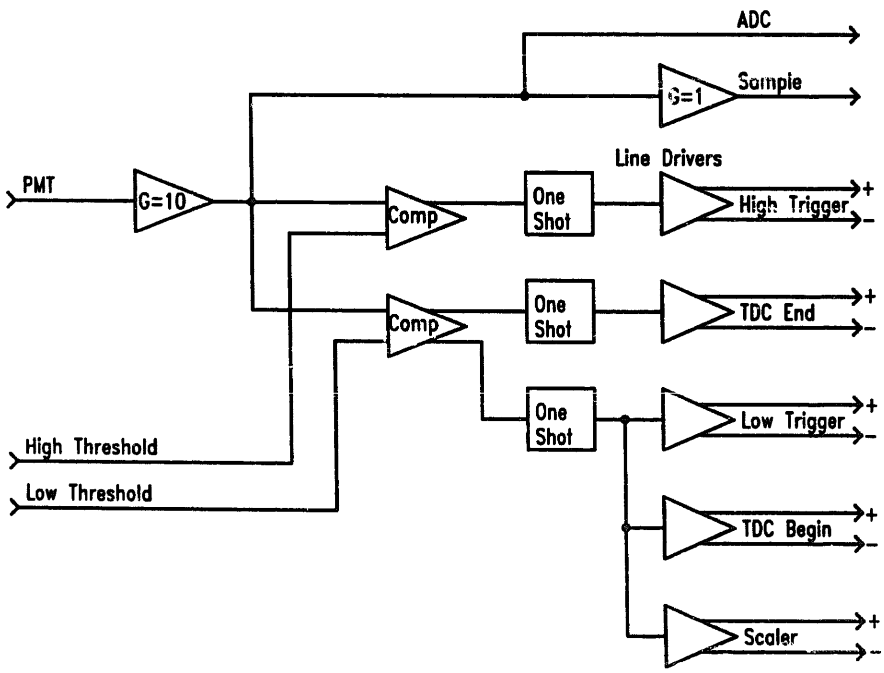

Fig. 1. Block diagram of a single amplifier–discriminator channel.

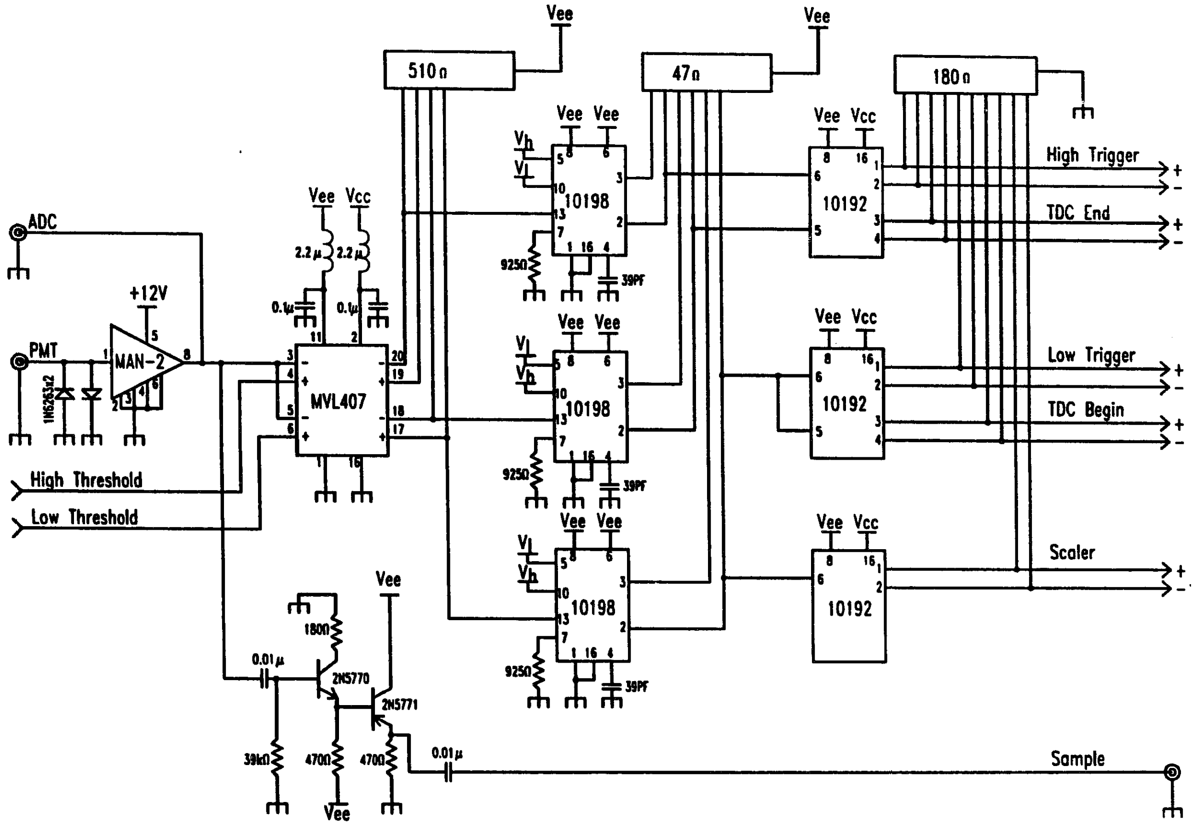

Fig. 2. Detailed schematic diagram of a single amplifier-discriminator channel.

is shown in fig. 3 as a function of input pulse amplitude. As can be seen from the graph, the amplifier delivers almost constant gain for output pulses up to two volts and degrades relatively slowly beyond this limit. For constant input, the gain variation was measured to be ±5% from channel to channel within a prototype module. The pulse rise time is 3.2 ns, determined between 10

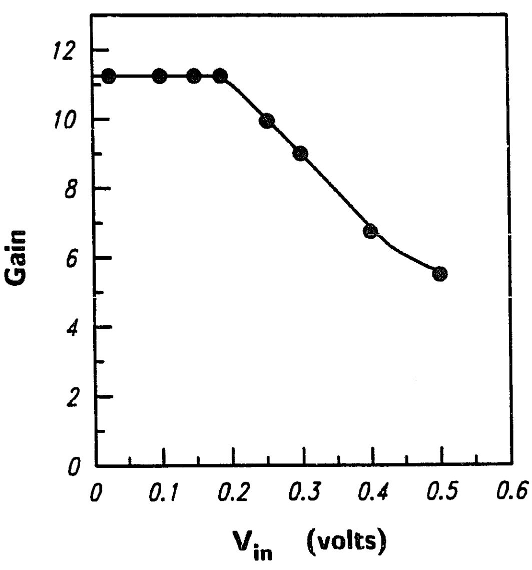

Fig. 3. Amplifier gain as a function of input pulse amplitude.

and 90% of peak pulse height. This is completely adequate for Cherenkov light signals from air showers. The Mini-Circuits MAN-2 rf amplifier is internally ac coupled so that dc levels are blocked. The low frequency roll-off is characterized by a pulse decay time of 200 ns. This far exceeds the requirements of VHE γ-ray astronomy. The response of the amplifier to typical photomultiplier scintillation pulses verified the measurements made with the HP signal generator.

Cross talk between channels was determined by injecting 25 mV signals in one amplifier and measuring the outputs of all other channels. The cross-talk amplitude was typically 2 mV or 1% of the amplified signal. With the amplifier input terminated in 50 Ω, the output noise is approximately 1 mV rms.

The sharpness of the response of LeCroy MVL407 discriminators was checked by plotting the logic transition curve as a function of the comparator dc reference voltage. The input voltage transition width of 3 mV is similar to the performance of commercial fast pulse discriminators. The minimum permissible threshold voltage for the MVL407 is 20 mV. The unity gain buffer amplifier rise time is slightly slower than the main amplifier output. Rise times of 3.6 ns were observed.

The eight-channel module requires three dc voltages for operation: +12.0, +5.0, and −5.2 V. The corresponding supply currents are respectively 0.6, 0.15, and

4.0 A. A large fraction of this power (35%) is consumed by the ECL monostables.

5. Conclusions

The eight-channel amplifier–discriminator module described above provides a compactly packaged multiplicity of functions for characterizing the signals encountered in Cherenkov air shower γ-ray astronomy. By incorporating discriminators and pulse shaping circuits with a decade amplifier, an economical module has been designed which minimizes the need for expensive coaxial connectors. This circuit will be incorporated in the electronic data acquisition system for the GRANITE γ-ray detector [4] at Mt Hopkins in Arizona.

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