VERITAS CFDs

J. Hall,[1] V.V. Vassiliev,[1] D.B. Kieda,[1] J. Moses,[1] T. Nagai,[1] and J. Smith[1]
(1) Utah High Energy Astrophysics Institute, Department of Physics University of Utah, Salt Lake City, Utah 84112-0830, USA

Abstract

The Level 1 (pixel) trigger of a VERITAS telescope is described. The trigger uses a constant fraction discriminator (CFD) to decrease VERITAS operation energy threshold by reducing the coincidence resolving time between neighboring pixels to ~ 5 ns. We discuss the optimization of the CFD design as well as unique requirements of the CFD application in a Imaging Atmospheric Čerenkov Telescope (IACT). We describe a novel feedback circuit to provide real time optimization of CFD performance under variable NSB conditions. Tests of the Level 1 trigger demonstrate jitter < 1 ns with background noise values up to 0.8 pe/ns.

1. Introduction

In an IACT, precise timing from the lowest level trigger is desirable in order to reduce the coincidence resolving time of the pattern trigger system [1] to the order of a typical Čerenkov pulse rise time, about $3 - 5$ ns. The smaller the coincidence resolving time, the lower the energy threshold of the IACT. One of the main scientific motivations for observations at lower energies is to increase the visibility horizon for variable/transient extragalactic objects such as AGN and gamma-ray bursts. Operating at lower energies will also allow an improvement in the absolute energy calibration with future GLAST data. This goal is achieved in the VERITAS design by the choice of the constant fraction discriminator (CFD) for our first level trigger on each channel of the telescope camera. This circuit was chosen because it theoretically eliminates slew time (the difference in the arrival times of scaled pulses,) which is an inherent deficiency of a simple threshold discriminator (TD).

2. CFD in IACT

The CFD works by splitting the input signal in two, delaying and inverting one, attenuating the other with fraction f, and summing them to create a zero-crossing discriminator (ZCD). It can be shown that, with no noise and with the same waveform of the input signal, scaling the pulse will have no effect on the

pp. 2851–2854

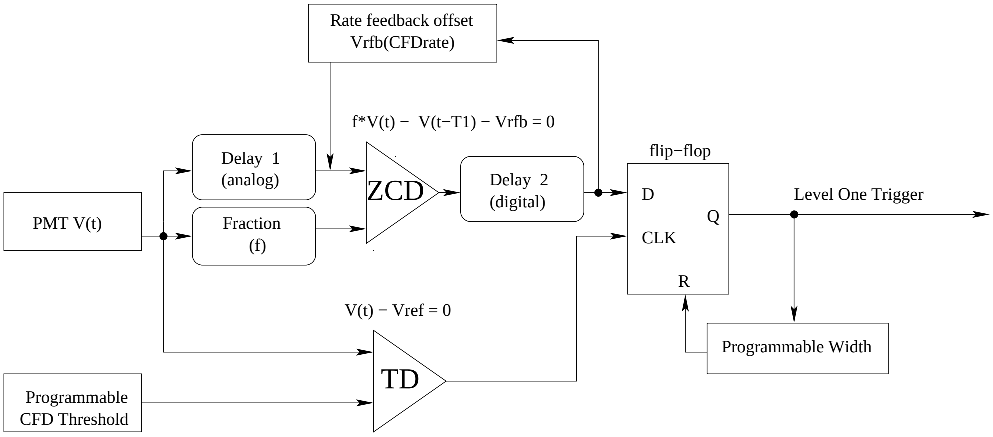

Fig. 1. A block diagram of the VERITAS Level 1 trigger.

trigger time (TT). The ZCD is sensitive to the noise conditions and when operated under the NSB influence will increase the jitter (the dispersion in the mean arrival times of the TT on an constant pulse) in the CFD. In order to reduce the jitter, a small, constant offset voltage is typically added to the ZCD suppressing its noise trigger rate. This works well in experiments where the background light conditions can be made negligible and the only small noise in the CFD that needs to be addressed is due to the electronics.

An IACT necessarily must operate under the night time sky with backgrounds from stars and human made light pollution that cannot be eliminated. In addition, NSB is expected to change up to a factor of four as the telescope points to sources in the direction of the Galactic center and normal to the Galactic plane. Noise in the CFD will increase the jitter of the ZCD. By applying a large offset to the ZCD, the jitter can be minimized, but at a cost of increased slew time. The offset will decrease the jitter by rejecting those pulses strongly distorted by the noise. Thus, a very large offset can also reduce the trigger efficiency (TE), the fraction of pulses that generate a trigger. Therefore, there is an optimum ZCD offset which balances jitter, slew time, and TE simultaneously and which is expected to vary substantially during real time IACT operation.

A novel circuit is added to the standard CFD design to create a coupling of the ZCD offset to the ZCD trigger rate. This rate feedback loop (RFB) is introduced to the CFD in order to automatically adjust ZCD offset when the noise level changes. The strength of this coupling is programmable and the RFB responds to changing observation conditions on the scale of ~ 1 second.

3. Implementation

The VERITAS CFD is integrated with an fADC board with 2 ns resolution [2]. Figure 1 shows a block diagram of the VERITAS CFD design. The photomultiplier tube (PMT) is buffered and can be assumed as a time dependent voltage source, V(t). This signal is divided three ways. One channel is fed to a TD. The two other channels form the ZCD with the delay line, τ_1. The ZCD output is then delayed by a delay line, τ_2 and clocked into the flip-flop by the TD signal.

The RFB signal is generated by a frequency to voltage converter at the ZCD output with integration time of ~ 1 second. The RFB coupling constant between ZCD offset and ZCD rate is programmable with a dynamic range of ~ 1000. The RFB design was tested and optimized with simulations.

We optimized CFD performance, jitter, slew time and TE, with respect to f, τ_1, and τ_2. It can be shown from CFD timing analysis that the optimum is reached on a two dimensional surface of these parameters:

$$f = 1 - \frac{\tau_1 + \tau_2 + \tau_\epsilon}{\tau_{rt}}, \tag{1}$$

where $\tau_\epsilon = 0.5$ ns is the delay time of the electronics, a flip-flop and AND gate, and τ_{rt} is the 1-100% rise time of the PMT photoelectron (pe) pulse. This fraction ensures the ZCD trigger occurs at the peak of the single pe pulse so the threshold of the trigger is the TD reference voltage.

The values of τ_1 and τ_2 were experimentally optimized by varying them in the range [0,5] ns. The best performance achieved was found along the curve $\tau_2 = 0$ for all combinations of fraction and τ_1 satisfying equation (1). This finding is fortuitous since a change in the pe pulse shape can be compensated by readjusting f without changing τ_1.. This experimental result was later checked computationally and found to agree with simulations.

4. Performance

The resulting VERITAS Level 1 trigger meets the following specifications. The output width is 12-bit programmable between 4-25 ns. The output width dispersion is less than half a nanosecond. The jitter of the CFD is less than 1 ns (including the $\sim$ 300 ps jitter of the test apparatus) for the majority of the expected night sky background, about $[0.2, 0.8]$ pe/ns. For a large NSB noise of 1.2 pe/ns, the jitter is of the order 1.2 ns. The RFB effects the jitter and efficiency as shown in Fig. 2 for a 6 pe input pulse with a 5 pe threshold. Low values of RFB coupling, about 5-20, lead to a $5-10\%$ reduction in the timing jitter of the CFD on pulses at the threshold. The TE increases by about 5% for small values of RFB, but large values will cause up to a 50% reduction in efficiency for large

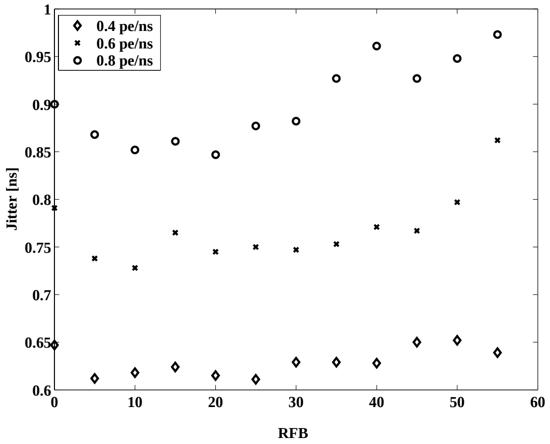

Fig. 2. Jitter of a CFD vs RFB coupling at three levels of NSB.

NSB. The slew time is estimated to be 0.6, 0.8, and 0.9 ns for NSB values of 0.4, 0.6, and 0.8 pe/ns respectively.

5. Conclusions

A CFD with a novel coupling of the ZCD rate to its dc offset, which automatically adjusts the ZCD to the noise in the field of view, has been developed for the VERITAS observatory. The implementation of the first level trigger in the VERITAS design will enable operation of the telescope pattern triggers with a programmable coincidence resolving time down to 4 ns. This capability will substantially increase the VERITAS trigger aperature at sub hundred GeV energies.

Acknowledgments

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References

1. Bradbury, S.M. et al., 1999, Proc 26th ICRC (Salt Lake), OG 4.3.21
2. Buckley, J. et al., 2003, these proceedings