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A HIGH SPEED TRIGGER SYSTEM FOR TOTAL DEPOSITED ENERGY MEASUREMENT IN A LIQUID ARGON CALORIMETER*

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Abstract

A system to produce trigger signals measuring the total energy deposited in the liquid argon/lead shower counters of the SPEAR Mark II Detector at the Stanford Linear Accelerator Center is described. The trigger signals are developed by summing, filtering, and discriminating the signals from several thousand preamplifiers connected to the liquid argon detector strips. The system requirement of trigger information 430 ns after a particle has entered the shower counter led to a special filter design in which a leading edge sampling technique was utilized. A filtered signal representing the total deposited energy is measured by a fast level discriminator that is strobed in synchronization with the e^+e^- beam crossings of the SPEAR storage ring. This sampling of the filtered waveform produces a digital output that is delivered to the trigger logic.

Introduction

The liquid argon shower counter system of the Mark II Detector at SLAC is comprised of 9 counter subassemblies; there are 8 barrel modules and one end-cap module.[1] These counters are composed of lead strips forming 362 detector channels per barrel module and 590 channels in the end-cap counter. Each channel has its own preamplifier, shaping amplifier, and sample and hold circuit. All channels are digitized every event to provide deposited charge data. The large number of individual channels provides positional information about showers occurring in the detector. The total energy deposited by an event in a counter can be calculated by summing the contributions from each channel. Although very accurate, this information is available only after all channels have been digitized and read into the data acquisition computer. In order to gain this total deposited charge information fast enough to be useful in making a primary event trigger decision, a separate and parallel charge measurement is necessary. The system for this measurement, which optimizes speed in the determination of total deposited energy in the shower counters, is the subject of this paper.

The Slow Channels

The preamplifiers of the liquid argon detector system are transformer coupled FET input, charge-sensitive amplifiers. These charge-sensitive amplifiers are followed by bipolar shaping amplifiers. These circuits, which produce approximately a 3 volt output pulse per picocoulomb of input charge, are packaged 8 channels to a printed circuit board. The boards are housed in card cages on the outside of the liquid argon counter modules. Their outputs are transmitted by twisted pair lines to Sample and Hold Analog Modules,[2] where the signals are sampled at their peaks. The peak voltage amplitudes are digitized and recorded for each trigger event.

These channels are termed 'slow channels' due to the relatively long time constants of the shaping amplifiers. For noise analysis a model of the slow channels is developed.

Figure 1 shows the parabolic charge signal from the detector strips. The parabolic signal is due to uniformly distributed charge drifting at a constant speed between the detector strips.[3] The total drift time, τ_d, is approximately 600 ns due to the electric field strength and the strip spacing of the 3 mm.

Figure 2 shows the model of the first amplifier stage. This charge-sensitive amplifier is a type often used in pulse preamplifiers. It is high impedance lossy integrator. The feedback time constant is long (0.1 millisecond) compared with the signal times, so it can be considered a lossless charge-to-voltage converter. The measured response to a step charge input is an exponentially rising voltage waveform with a 120 ns time constant. This is shorter than the input time, but not short enough to be neglected in the analysis. The convolution of the charge input and the charge sensitive amplifier's impulse response forms the input to the shaping amplifier. The convolution has a parabolic form, but is delayed almost 100 ns from the input.

The shaping amplifier, Figure 3, then processes the signal. Figure 4 shows the details of this amplifier's step response. The final output of the slow

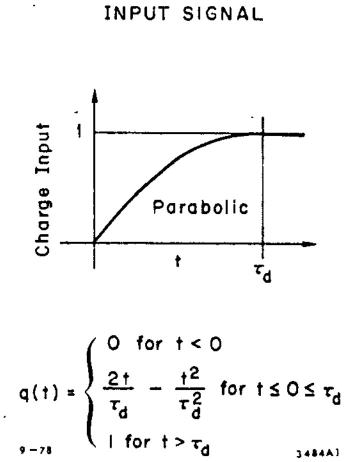

Fig. 1 Input Signal

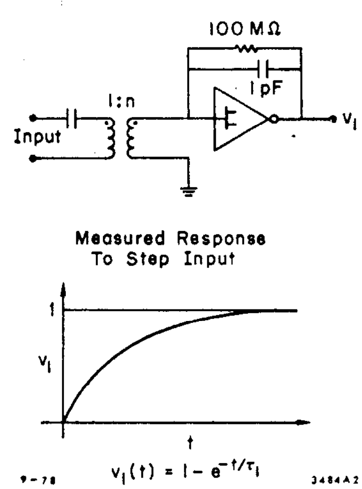

Fig. 2 Charge Sensitive Stage

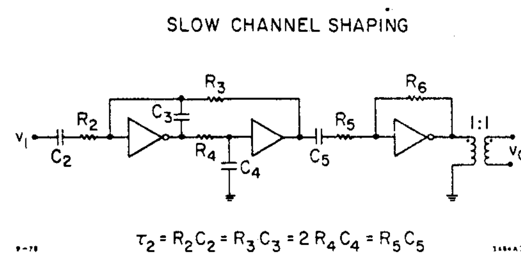

Fig. 3 Slow Channel Shaping

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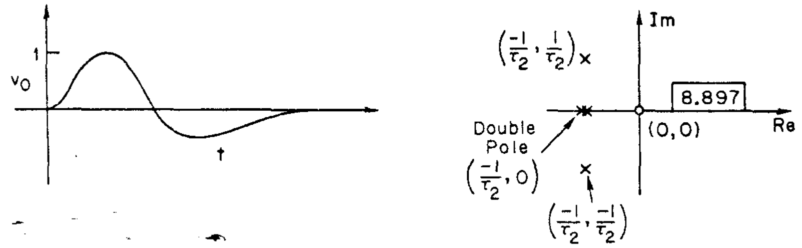

$$v_0(t) = 8.897\, e^{-t/\tau_2}\left[1 - \frac{t}{\tau_2} + \sqrt{2}\cos\left(\frac{t}{\tau_2} - \frac{3\pi}{4}\right)\right]$$

Fig. 4 Slow Channel Filter

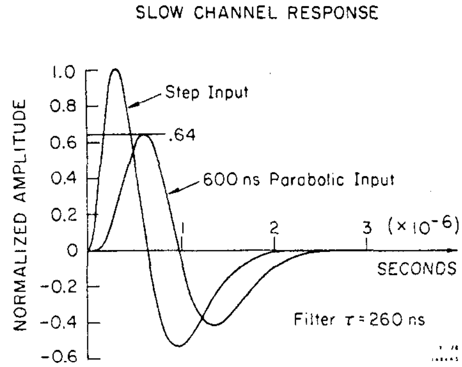

Fig. 5 Slow Channel Response

channels is shown in Figure 5, which contrasts the shaping amplifier's response to the detector/charge amplifier waveform and its step response. The peak amplitude of the response from the signal is only 64% as large as the peak of the step response. The loss in peak amplitude because the input charge is spread out in time, rather than being received all at once (as a step input), is termed "ballistic efficiency."

The Fast Channels

The purpose of a total deposited energy measurement is to recognize an event that would not be detected by other triggering systems. Neutral particles will cause showering in the lead and will therefore be detected in the calorimeter. In order to be useful, this type of event must be identified in time to cause a primary trigger which freezes the event data from all sections of the Mark II.

Timing Requirement

For maximum flexibility, a trigger signal is developed for each liquid argon module, and the total energy in all modules produces another signal. Due to the short interval between beam interactions at the SPEAR storage ring (780 ns), all trigger signals from the liquid argon system must be delivered to the trigger logic within 450 ns after each beam crossing. The cable delay between the preamplifiers and the subsequent electronics can be neglected, as all Mark II instrumentation has the same delay. Allowing 20 ns for forming and discriminating the grand sum of the filtered signals from the individual modules, and time for coincidence logic to process the module triggers, there is 430 ns in which to process the signals from each detector module. Of this time, 15 ns is required for a module level discriminator and line driver response, leaving a net time of 415 ns for signal filtering. Since the charge drift time in the argon is 600 ns for the 3 mm lead strip spacing, the energy determination must be made even before all the charge is collected.

Ballistic Efficiency

Due to the slow rise time of the signal from the detector compared with the required processing times, there is a loss in ballistic efficiency. As the time constants in the filter are shortened, the convolution of the slow input and the transfer function of the filter produce lower peak amplitude signals. Producing a bipolar filtered signal which peaks in 415 ns requires a filter with 155 ns time constants. This filter has a ballistic efficiency of 43%, which results in a 33% loss in signal compared to the slow channels. Figure 6 shows a comparison of the 260 ns slow channel response and this 155 ns filter. The loss of amplitude can be remedied with further amplification, but the noise will be correspondingly amplified.

The Noise Problem

Short time constants also suffer from signal-to-noise (S/N) loss from the increased bandwidth. As described by Willis and Radeka,[3] the series noise is dominant at short time constants. Series noise is proportional to the reciprocal of the square root of the shaping time. Therefore, when changing from a 260 ns to a 155 ns filter, a 30% increase in noise would be expected. The result is a loss of 48% in signal-to-noise by changing the time constants from 260 to 155 ns.

Filter Type Comparisons

A loss of half the signal relative to the noise due to ballistic efficiency and bandwidth noise is quite undesirable when thousands of channels are going to be summed. The direct approach of using the same filter for both slow and fast channels, with only a change in time constants, may not be the best choice. It is necessary to evaluate other types of filters.

Bipolar

The bipolar filter, though unacceptable for the fast channels, is a good bench mark. Other filters will be compared to the 260 ns filter of the slow channels. Relative filter noise performance can be analyzed by the Goulding Method.[4] It is assumed that over our range of interest series noise completely dominates the parallel noise. Series noise (or Goulding's delta noise) indices for several filters are summarized in Figure 7. The triangular bipolar pulse is shown for comparison with the theoretical "equivalent noise charge" as calculated by Willis and Radeka.[3] The bipolar filter of the slow channels has lower noise than the triangular bipolar shaper, but is inferior to the unipolar shapers.

Unipolar

Unipolar shaping is acceptable because of the low count rate in the liquid argon system. The primary trigger rate of the Mark II is on the order of a few

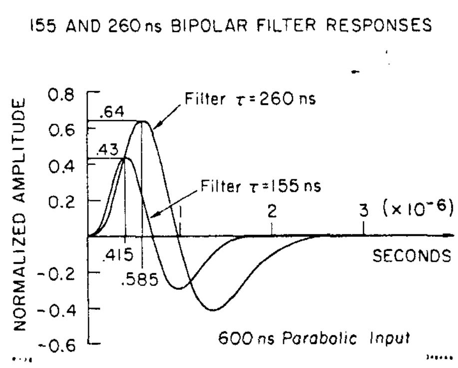

Fig. 6 Bipolar Filter Responses

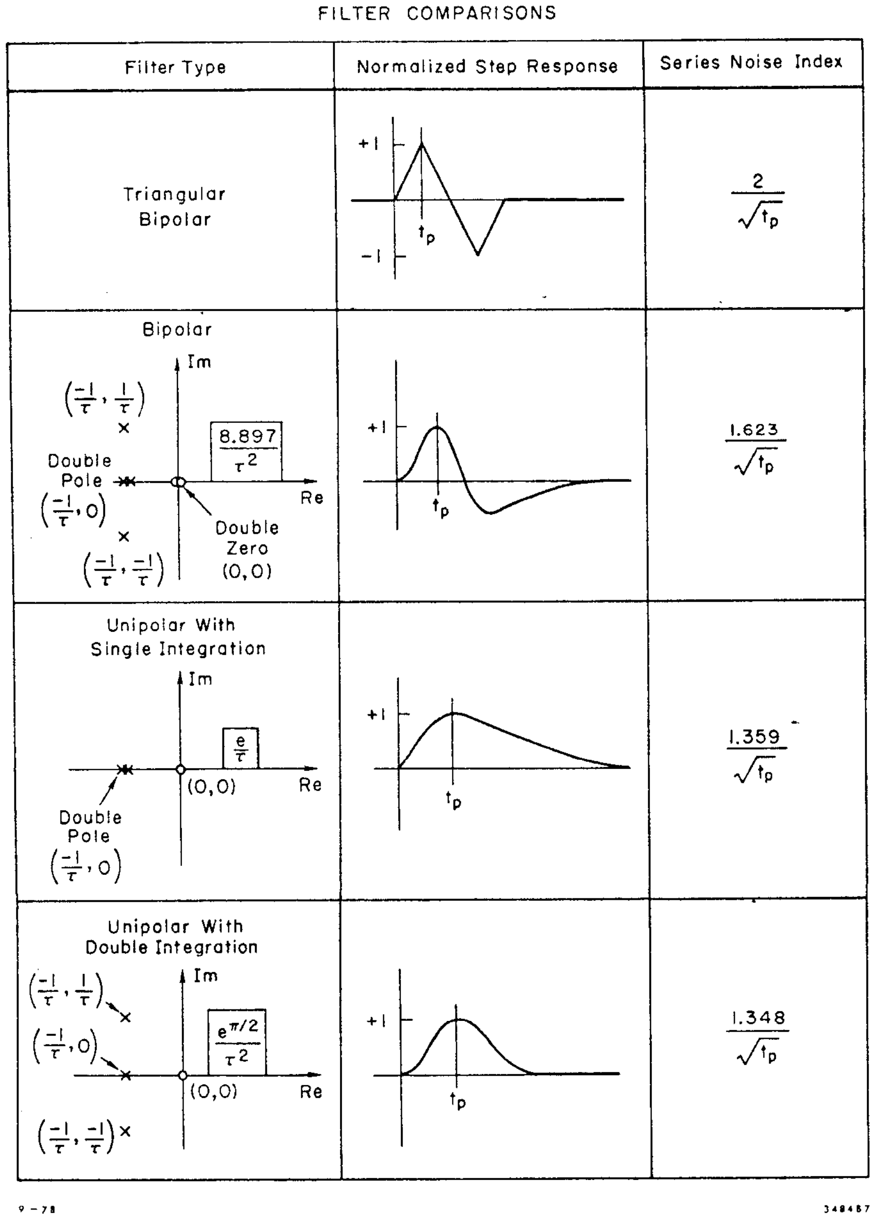

Fig. 7 Filter Comparisons

kilohertz, so the count rate in each individual counter module is indeed low. Peak amplitude shifting with count rate will therefore not be a problem: unipolar, AC coupled amplifiers can be used. Pole-zero cancelation of the first stage decay is also unnecessary for the same reason.

A significant gain would be expected due to the noise indices when using unipolar shaping instead of bipolar. A single differentiator followed by a 2-pole integrator has a good noise index, but offers no real improvement over the bipolar filter when a peaking time of 415 ns is required. The time constants of a unipolar filter are shorter than those of a bipolar filter for equal peaking times. This causes the ballistic efficiency of the unipolar filter to fall more rapidly than the bipolar filter as peaking times are shortened. The ballistic efficiency of a unipolar filter is 41% for a 415 ns peaking time (86 ns time constants) with the parabolic input. The resulting S/N ratio is 0.52 that of the 260 ns bipolar filter.

Leading Edge Sampling

The rapid fall in ballistic efficiency does however allow employment of a unipolar filter in a system that can improve the S/N ratio. Figure 8 shows the ballistic efficiency as a function of time constants. If the signal is sampled at 415 ns after the beginning of the input charge, the lower curve of Figure 8 is obtained. Using longer time constants and sampling the signal on its leading edge, instead of at its peak, can increase the ballistic efficiency by over 10%. Besides actually increasing the measured signal amplitude at

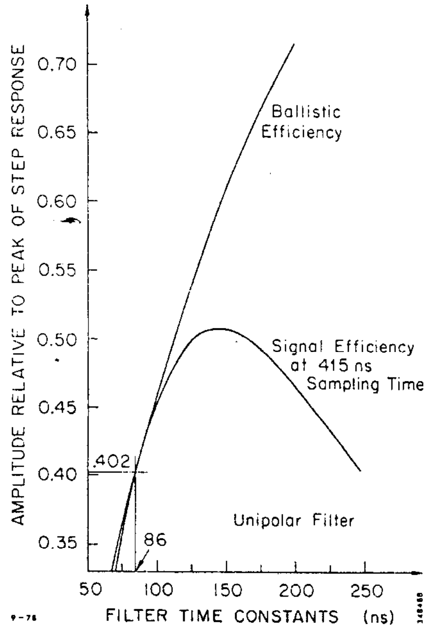

Fig. 8 Ballistic Efficiency

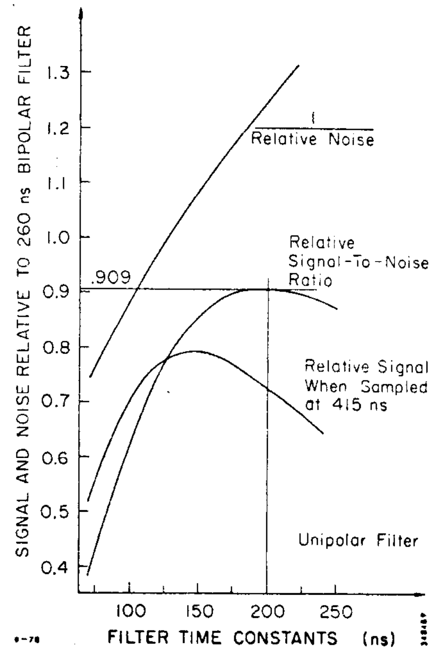

Fig. 9 Signal-To-Noise Ratio

LEADING EDGE SAMPLING WAVEFORM

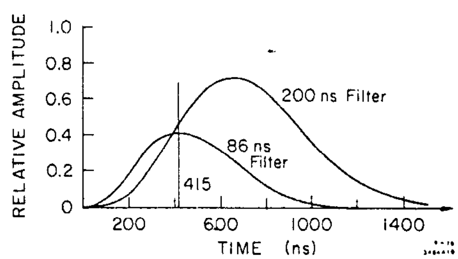

Fig. 10 Leading Edge Sampling

415 ns, using longer time constants also decreases the series noise. Figure 9 shows the reciprocal of the relative noise, normalized to the 260 ns bipolar filter noise. By multiplying this curve with the signal amplitude sampled at 415 ns, the Relative Signal-to-Noise Ratio curve is obtained.

The optimum unipolar filter uses approximately 200 ns time constants to produce a S/N ratio that is only 9% less than the 260 ns bipolar filter. Leading edge sampling can achieve a 78% increase in S/N over peak measurement in this instance. Figure 10 compares the 415 ns peaking waveform with the optimum leading edge sampling waveform.

Hardware Realization

The speed requirements of the system necessitate wideband amplifiers in the filter. In order to minimize the system cost and power consumption, the signals from each LA module were first summed and then filtered. With this arrangement, only 10 active filters are needed for the Mark II.

Preamplifier Circuit Boards

In addition to the eight slow channels on each preamplifier circuit board, a ninth signal path is used for the fast total energy measurement. The output of eight charge-sensitive stages are summed and amplified without shaping by this path. The resultant output signal waveform from this summation is the parabolicly rising charge signal. This signal is transformer coupled and transmitted via twisted wire pairs to CAMAC packaged instrumentation located next to the experimental area.

The Ladar Modules

The remainder of the electronic units developing the trigger signals are single-width CAMAC modules. The module type receiving the signals from the preamplifier printed circuit boards is the Liquid Argon Dual AddeR (LADAR). The LADAR, shown in Figure 11, is a dual 16 input linear fan-in CAMAC module. All input signals are accepted via a 32-signal pair card edge connector on the front panel. The output signals from the LEMO connectors are scaled linear sums of the inputs. The output impedance is very high (a current source) to drive terminated 50 ohm cable. Propagation delay through this module is approximately 5 ns.

The LAFD Modules

The outputs from the LADAR's are connected to Liquid Argon Filtering Discriminators (LAFD's). The LAFD, Figure 12, has two identical independent sections in a CAMAC module. Three LADAR section outputs are added by each LAFD section. This level of summation is 384 detector channels, which is sufficient to include all channels from one barrel module or half of an end cap. The sum is filtered using a differentiator followed by a two-pole active integrator to produce a semi-Gaussian unipolar pulse. This filter is the same as shown in Figure 3 without C_5. The filtered signal is then compared to a front panel adjustable reference voltage by a fast voltage discriminator. The comparison is sampled to produce a NIM fast negative logic output signal. The time at which the filtered waveform is sampled is controlled by a strobe input signal.

The Total Deposited Energy

Scaled linear outputs are available from the LAFD's. These signals represent the energy deposited in the individual detector modules. The linear outputs can be summed and discriminated for a measurement of the total energy in the liquid argon system. Commercially available linear fan-in and discriminator CAMAC modules are adequate to process this final trigger signal. The NIM outputs from the LAFD's and total deposited energy discriminator are then combined with other trigger sources by the Mark II trigger logic to make primary

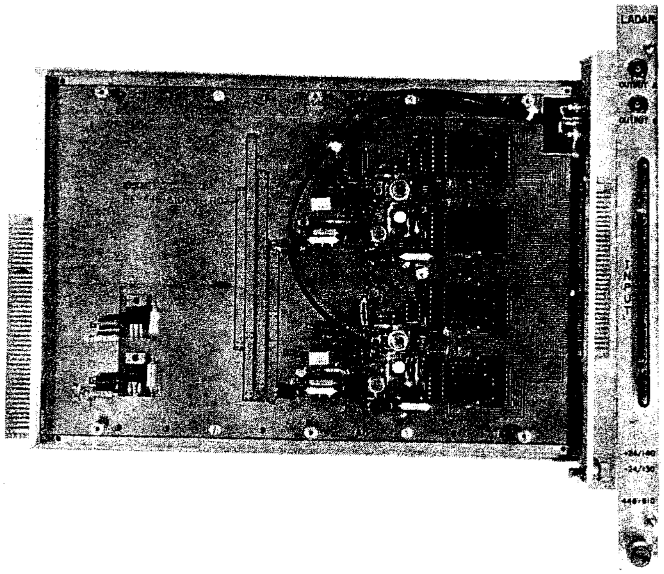

Fig. 11 LADAR Module

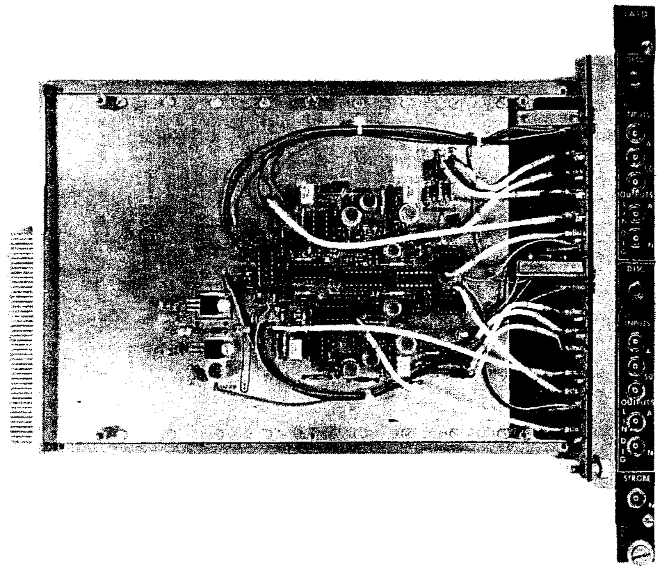

Fig. 12 LAFD Module

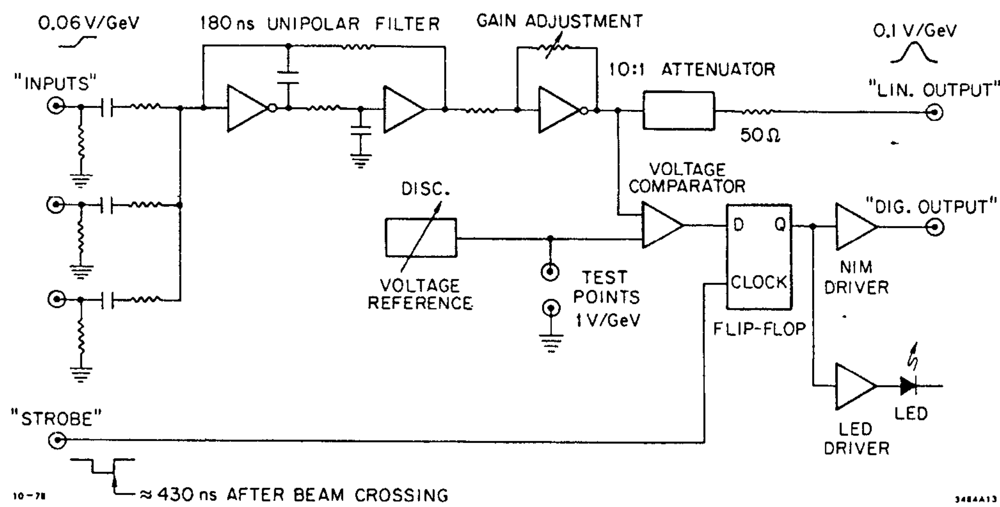

Fig. 13 LAFD Block Diagram

and secondary trigger decisions.

Conclusion

Improvement in signal-to-noise ratio is achieved by not measuring the signal at its peak as is normally done. Longer time constants than those which produce 415 ns peaking times, actually result in an increase in signal amplitude when the output is sampled at 415 ns due to the ballistic efficiency increase. Longer time constants also can reduce noise because the series noise is dominant. The technique of leading edge sampling can be used to increase the signal-to-noise ratio when fast signal processing is required from relatively slowly rising detector signals, and when the timing of the input signal is known.

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