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October 12, 1965

AN AMPLITUDE-INDEPENDENT NANOSECOND TIMING DISCRIMINATOR FOR FAST PHOTOMULTIPLIERS*

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Abstract

A circuit has been developed which reduces amplitude-dependent timing errors to less than 0.2 nsec over a dynamic amplitude range of more than 100 to 1. The anode signal is clipped, and a pedestal added, allowing adjustment of the discriminator to the true "zero-crossing" point. Tunnel diodes are used as threshold devices and pulse shapers.

A version of this circuit adapted to RCA-2067 photomultipliers is described which features a pulse-recognition threshold variable from < 1 to 10 mA and a pulse-pair resolution of < 15 nsec. In tests performed with a mercury-light pulser and in coincidence experiments with plastic scintillation counters, the time delay through this discriminator was found to be essentially independent of the signal amplitude over the linear range of the photomultipliers.

The Problem

In any attempt to time events with an accuracy considerably better than the width of the event-defining pulses, one must decide when the pulse occurred. This decision is easy if an obvious feature of the pulse occurs in a time shorter than the timing accuracy desired. A bipolar signal which crosses zero is easily generated in several ways and has the obvious feature that its polarity suddenly changes at the zero crossing. This index as to when the pulse occurred could be used for timing by any method in the absence of a better index.

Most zero-crossing detectors rely simply on a discriminator set to fire at low level on any signal that has the same polarity as the second half of a bipolar pulse. If, however, the discrimination level is set high enough to reject noise, small pulses require a significantly longer time after zero crossing to reach this threshold than large pulses, and systematic timing errors

are introduced. For fast photomultipliers and fast plastic scintillators, this threshold error may be as large as several nanoseconds for pulses near threshold. Two discriminators are thus often used -- one to detect the zero crossing and one which requires that the pulses be enough above threshold so that timing errors remain small. This method fails if pulses only slightly larger than noise pulses must be used. For fast-neutron spectrometry by time of flight it is indeed essential to use very small pulses. Scintillator saturation at low recoil-proton energy causes the pulse-height spectrum to peak at low amplitudes. It is also essential to use a wide-range of pulse amplitudes. Indeed, if a neutron-energy spectrum covers the range 1 to 10 MeV, a pulse-height dynamic range of 50 or greater is required. Timing errors, which vary systematically with pulse height, not only spoil timing resolution, but also produce systematic errors in flight-time measurement. The circuits described here are the results of an effort to eliminate systematic timing errors simply.

Method

If pulse recognition precedes the zero-crossing time, an offset in the zero-crossing signal can be produced by generating a pedestal after the pulse is recognized, and adding it to the bipolar signal. If the zero-cross discriminator bias is just equal to the pedestal height, the offset bipolar signals all cross threshold exactly at the zero-crossing time. The threshold timing error is thus eliminated. Both discriminators can be biased well above the noise level. On the other hand, all signals exceeding the recognition threshold may be used with no threshold timing error.

The zero-cross discriminator bias can be adjusted above or below the zero-crossing point, causing small pulses to fire the discriminator later or earlier than large pulses. This provides a means of first-order correction for other amplitude-dependent timing errors such as those due to pulse-shape variation or discriminator charge sensitivity.

For signals about the size of the pedestal, irregularities in the top of the pedestal become important. Since the pedestal is generated from the leading edge of the signal, variations of signal level near the recognition threshold cause a shift in the pedestal time with respect to the

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zero-crossing time. Any departure from a flat pedestal top thus causes timing errors.

Circuit Description

The circuit shown in Fig. 1 was built to test the method outlined above. Waveforms are shown in Fig. 2. The recognition discriminator and zero-cross discriminator are identical. The peak-current for tunnel diodes CR1 and CR3 is 10 mA. Each discriminator has a nominal input impedance of 50Ω . The recognition discriminator signal is strongly differentiated and the resulting 1-nsec spike is used to fire the pedestal generator, CR2. This generator is a 20-mA-peak-current tunnel diode with a transmission-line load to produce a flat-topped response. The pedestal which is fed to the zero-cross discriminator is about 0.5 mA and flat to within about $\pm 10\%$. The output tunnel diode, CR4, generates a standardized 0.4-V, 40-nsec output pulse with a 0.5-nsec rise time. A 7-in. clipping line connected at the anode of the photomultiplier forms a bipolar pulse that crosses zero about 6 nsec after the beginning of the pulse.

It should be noted that regeneration of CR1 or CR3 sends a pulse back towards the photomultiplier. This pulse is coupled to the opposite input line through the tube capacities. The signal lines must be long enough, then, to prevent recognition tunnel-diode regeneration from interfering with the zero-crossing signal.

Since the anode is loaded by the zero-crossing clipping line, it cannot be back-terminated. Therefore, the recovery time of CR3 and CR4 must be longer than the double transit time of the anode input line to prevent multiple firing. These features limit the circuit recovery time to about 100 nsec.

In addition, in order to avoid timing errors, the recognition discriminator must always be adjusted to fire at a lower current than does the zero-cross discriminator. If the zero-cross discriminator fires in the absence of a pedestal, an output will result with erratic timing information. Therefore, this circuit offers no convenient method of wide-range threshold variation.

In an effort to improve high repetition-rate performance and to provide a variable threshold, the modified discriminator shown in Figs. 3, 4, and 5 was constructed. This version differs significantly from the basic circuit in the following ways:

1. Transistor Q1 is inserted in the recognition input to reduce coupling from the recognition tunnel diode, through photomultiplier capacities, to the zero-cross input line.

2. In order to reduce input line lengths, the discriminator is constructed as shown in Fig. 5 for mounting on the base of the photomultiplier. The dead time is reduced to about 15 nsec. Threshold controls are connected re-

motely.

3. The output tunnel diode is arranged so that both the recognition tunnel diode and the zero-cross tunnel diode must fire in coincidence to produce an output pulse. This allows use of the recognition discriminator bias for variable threshold control.

4. Transistor Q2 is added to provide output buffering and amplification. Other modifications might be noted but their discussion is not germane to the purpose of this report.

The additional features of the modified circuit were gained at the expense of (a) circuit accessibility, (b) circuit simplicity, and (c) ease of adaptability to various photomultipliers. Point (c) affects this report, since the modified discriminators were constructed to fit an RCA 2067 photomultiplier. Therefore, even when deficiencies in this tube were suspected, it was not convenient to change types. Each version was found to have identical timing characteristics.

Performance

The discriminators were tested both with a spark-gap light source¹ and with plastic scintillators. The spark gap gives a fast, stable light flash whose time of occurrence is accurately determined by the electrical signal produced by the spark and whose intensity is adjusted with optical absorbers. Figure 6 shows the response of a type-2067 photomultiplier to the spark at light levels of 1000, 100, and 10 photocathode electrons respectively. The oscilloscope trigger for the left-hand set of photographs in Fig. 6 was obtained from the spark; that for the right-hand set was obtained from the discriminator. The increase of timing uncertainty caused by poorer photomultiplier statistics is apparent.

Figure 7, obtained with a Phillips 58 AVP photomultiplier, a 6.5-cm-diam Naton scintillator and a Na^{22} source shows the accuracy with which the discriminator fires at the zero-crossing point for a range in amplitude of a factor of sixty between threshold and maximum. For both Figs. 6 and 7 the multiplier anode signal was split (6-dB loss) so that both the oscilloscope and discriminators could receive signals. For Fig. 7 the discriminator recognition threshold of 10 mV corresponds to a Compton electron energy of ~ 17 keV. A dynamic range greater than 100 was easily obtained and only requires an output that remains linear to 40 mA.

Figures 8 and 9 show respectively the time shift and resolution of a type 2067 as a function of input light level. The solid line on Fig. 9 whose slope on the log-log plot is minus $1/2$ is the variation expected if the time resolution varies inversely with the square root of the number of photocathode electrons.

Two coincidence measurements were performed using identical counter assemblies con-

sisting of RCA 2067 photomultipliers, 10-cm semicylindrical light pipes, 1.3-by 2.5-by 2.5-cm Pilot B scintillators, and the discriminators shown in Fig. 5. Unfortunately, the photoelectron collection efficiency of the photomultiplier varies widely over the face of the tube. A semicylindrical light pipe coupled to the sensitive part of the photocathode was used in an attempt to improve the number of collected photoelectrons.

In the first set of measurements, a Na^{22} sample was used as a source of 0.5-MeV coincident gamma rays. The discriminator outputs were used to drive the start and stop inputs of a Lawrence Radiation Laboratory time-to-height converter.² Figure 10 is the result of a multi-channel pulse-height analysis which shows the time resolution and line shape that resulted when both detector thresholds were set at 20 keV. The nongaussian line shape results from the superposition of gaussians of different widths. Figure 11 shows the results of using 30-keV side-channel windows set just above tube noise and just below the annihilation radiation Compton edge. The shift in the line centroid was less than 0.1 nsec for all settings of the side channel windows. An asymmetry still appears, however, when one side-channel window is set high and the other low. This indicates that some timing error remains at low levels.

In the second experiment a beam of minimum-ionizing (~ 1 BeV/c) pions from the Bevatron was passed through both scintillators. Energy loss was about 1.3 MeV in each scintillator. About 20 000 particles arrived per 50-msec burst, so the time-to-height converter could not be used. The measured time between the 5 and 50% points on the side of a fast-coincidence curve was 0.25 nsec. This corresponds to a time resolution of 0.35-nsec full width at half maximum for the two-detector system.

Acknowledgments

Several of the discriminators, including that shown in Fig. 5 were capably built and tested by Tom T. Shimizu. The discriminator used for Fig. 7 was built and tested by John Binney at the University of Oregon. One of us (H. W. L.) would like to thank Dick A. Mack and his staff for their hospitality and advice during a summer at Berkeley.

References

1. Q. A. Kerns, F. A. Kirsten, and G. C. Cox, Rev. Sci. Instr. 30, 31 (1959).
2. Donald L. Wieber, Nucl. Instr. Methods 24, 269 (1963).

Figure Legends

- Fig. 1. Circuit diagram of basic pedestal-type discriminator.
- Fig. 2. Waveforms for circuit of Fig. 1 showing addition of pedestal to zero-crossing signal.
- Fig. 3. Block diagram of modified pedestal-type discriminator.
- Fig. 4. Circuit diagram of modified pedestal-type discriminator.
- Fig. 5. Photograph of modified pedestal-type discriminator.
- Fig. 6. Photographs of RCA 2067 photomultiplier anode signal. A spark-gap trigger is used as the source. In a, b, and c, the 661 sampling oscilloscope is triggered by the electrical signal from the light source. In d, e, and f, the oscilloscope is triggered by the discriminator.
- Fig. 7. The anode signal obtained from a Phillips 58 AVP, a Naton scintillator, and a Na^{22} gamma-ray source. The annihilation radiation and 1.27-MeV gamma-ray Compton edges are apparent. The oscilloscope trigger was obtained from the discriminator and shows a timing accuracy better than 0.3 nsec over a dynamic range of 60.
(a) 100 mV/div, 4 nsec/div. — (b) 20 mV/div, 1 nsec/div.
- Fig. 8. Output time shift as a function of signal amplitude.
- Fig. 9. Time resolution (full width at half maximum) as a function of signal amplitude.
- Fig. 10. Na^{22} coincidence line shape with no side-channel selection, and discriminator thresholds at 20 keV.
- Fig. 11. Na^{22} coincidence resolution with slow-coincidence side-channel correction (a) 30-keV windows centered about 80 keV, (b) 30-keV windows centered about 320 keV.

Fig. 1

MUB-8047

Fig. 2

MUB-8038

Fig. 3

MUB-8039

ZN-5204

Fig. 5

ZN-5208

Fig. 6

ZN-5200

Fig. 7

Fig. 8

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Fig. 9

MUB-8042

Fig. 10

MUB-8045

Fig. 11

MUB-8046

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