# FAST TIMING CIRCUT FOR USE WITH CERENKOV COUNTERS* 

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#### Abstract

A timing circuit is described operating with Cerenkov counters of low light yield. Resolving times of $2 \times 0.8$ nsec were measured with two counters, each producing an average of $N=2.3$ collected photoelectrons. Light pulser measurements indicate that the resolving time decreases to $2 \times 70$ psee for 1000 photoelectrons. Desigu considerations, operating characteristics, and results of measurements with light pulser and with Cerenkov counters are discussed,


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## I. INTRODUCTION

In high energy physics experiments employing Cerenkov counters for time-of-flight measurements it is often necessary to obtain precise time determination when only a small amount of light is available. It has been shown ${ }^{1}$ that in order to recover the maximum timing information from the current pulse of the photomultiplier tube detecting the light, it is desirable that the centroid of the pulse be utilized for timing.

One realization of this principle is the vernier chronotron ${ }^{1}$ utilizing shockexcited resonant circuits where the timing information is stored in the phase of the decaying radio frequency signal. This circuit has been used successiflly to achieve resolutions ${ }^{2}$ of 0.4 nanosecond with deadtimes of a few microseconds. ${ }^{3}$ At high energy accelerators having low duty cycles, however, circuits having much shorter deadtimes are desirable in some experiments. The circuit described here sacrifices some of the available timing information in exchange for a shorter (< 50 nsec ) deadtime.

## II. PRINCIPIE OF OPERATMON

The centroid of a current pulse of the form $i(t)=t^{n} \exp (-t)$ can be determined by observing the time when the waveform $I \equiv \int\left[i\left(t-T_{0}\right)-K i(t)\right]$ dit crosses the zero current axis. The process is illustrated in Fig. I for the case of a symmetrical pulse, i.e., when $n \gg 1$ and $a K=1 / 2$ is chosen. ${ }^{4}$ The time of the centroid $T_{c}$, apaxt from the constant.delay $T_{o}$, is given by the zero crossing.

An "idcal" integrator, however, would imply infinite amplification and infinite deadtime. For a fixed finite amplification, the larger we choose the decay time constant $\tau$ of the intogrator, the slower the slope of the integratod pulse becomes
at the time of the zero crossing. If an "ideal" zero crossing detector were available, i.e., one which provides a timing signal precisely at the time of the zero crossing, we could choose $\tau$ very large, limited only by deadime considerations. Due to the presence of noise, however, the ideal zero crossing detector cannot be realized, and the time spread will become laxger for large values of $\tau .{ }^{5}$ Thus there exists an optimum value of $\tau$ with a concomitant optimum in $T_{0}$.

## III. DESCRIPTION

The basic circuit is shown in Fig. 2. The resistive divider network at the input attenuates the height of the signal at the base of Q1A to approximately half of that at the base of Q1B. The latter signal is delayed by $T_{o}$ by an external cable and subtracted from the former one by long-tail-pair Q1A-Q1B. Integration is performed at the collector of Q1A. Output transistor Q2 limits the positive output swing to +0.65 volts into a 50 -ohm load.

The zero-crossing time of the output waveform was measured as a function of the height of an input step function for $T_{0}=5 \mathrm{nsec}$ and $\tau=10 \mathrm{nsec}$ (Fig. 3). It can be seen that for input pulse heights of between -1 volt and -3 volts the change in the time of the zero crossing is less than the measurement error estimated at 50 psec .

A block diagram of the timing system is shown in Fig. 4. The signals from the photomultiplier tubes ${ }^{6}$ were processed by the timing circuits of Fig. 2. After a subsequent amplification ${ }^{7}$ of $\times 10$ (omitted for the light pulser measurements), the zero crossings were detected by the tumel diode discriminators of Fig. 5, followed by conventional trigger circuits. ${ }^{8}$ The time difference between the output pulses of the trigger circuit was converted to pulse height ${ }^{9}$ and recorded by a pulse height analyzer.

## IV. PERFORNANCE

Light pulser measurements were conducted using a $14-\mathrm{kV}$ discharge in an 80 -psi oxygen atmosphere as a light source. ${ }^{10}$ The amount of light per pulse was varied by the insertion of neutral filters. ${ }^{11}$ The optimum values of the delay and of the integrating time constant were found empirically to be $T_{0}=5 \mathrm{nsec}$ and $\tau=10 \mathrm{nsec}$, respectively.

Measurements were also performed using two gas Cerenkov counters with 12-cm photomultiplie: tubes at the Mark III linear accelerator of Stanford University. ${ }^{12}$

Results are shown in Fig. 6. The number of photoelectrons $N$ collected by the first dynode was measured by using the statistics of the anode pulse height distribution; no correction was made for variances contributed by the emission statistics of the dynodes. The rosults of the light pulse measurements are consistent with a measured light pulser time spread of $\sigma_{\text {PULSER }}=0.4 \mathrm{nsec}$, a photomultiplier tube time spread of $\sigma_{\text {PMT }}=0.35 \mathrm{nsec}$, and a contribution of $\sigma_{\text {CIRCUIT }}=0.055 \mathrm{nsec}$ by the circuit, resulting in a

$$
\begin{aligned}
2 W & =2.36\left(\sigma_{\text {PULSER }}^{2} N^{-1}+\sigma_{\text {PNT }}^{2} N^{-1}+\sigma_{\text {CIRCUTT }}^{2}\right)^{1 / 2} \\
& =\left(1.77^{2} \mathrm{~N}^{-1}+0.127^{2}\right)^{1 / 2} \mathrm{nsec} .
\end{aligned}
$$

## FOOTNOTES AND REFERENCES

1. C. Cottini and E. Gatti, Nuovo Cimento 4, 1550 (1956).
2. Here, and in the following, resolution is defined as the full width at half maximum (FWHM) of the timing curve of counts vs. time.
3. R. L. Anderson and B. D. MeDaniel, Nucl. Instr. and Methods 21, 235 (1963).
4. In reality, current pulses of photomultiplier tubes are not symmetrical. For $\mathrm{n}=1$ (a good approximation for the tubes used here), the optimum valuc of $K$ is in the vicinity of 0.6 .
5. A. Barna, "A subnanosecond coincidence circuit," SLAC Report No. 52, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1965).
6. RCA Types 8575 were used for the measurements with the light pulser, Amperex Types 58 AVP with the Cerenkov counters.
7. Hewlett-Packard Type HP460 AR amplifiers were used.
8. Edgerton, Germeshausen and Griex Type TR 104S.
9. An Edgerton, Germeshausen and Grier Type TH 200A time to height converter was used:
10. L. Hundley, T. Coburn, E. Garwin and L. Stryer, Rev. Sci. Instr, 38, 488 (1967).
11. These measurements were performed with the assistance of R. Baggs, W. Flansburg and C. R. Carman.
12. This data was takon by Robert Simonds in collaboration with one of the writers (B.R.).

## FIGURE CAPTIONS

Fig. 1. Principle of operation illustrated for the case of symmetrical current pulse.

Fig. 2. Schematic diagram of the timing circuit.
Fig. 3. Zero-crossing time of the output waveform of the circuit of Fig. 2 vs. the height of a negative step-function input pulse. The integrating time constant at the collector of Q1A was set to $\tau=10 \mathrm{nsec}$, the external delay to $T_{0}=5 \mathrm{nsec}$.

Fig. 4. Block diagram of the timing system. The $\times 10$ amplifiers were omited in the measurements with the light pulser.

Fig. 5. Tumel diode discriminator. Tumel diode is G. E. Type SMTD 715.
Fig. 6. Resolving time $2 W$ (full width at half maximum) as a function of the average number of photoelectrons $N$ collected by the first dynode of the photomultiplier tube. The measurement with the Cerenkov counter is denoted by o. Light pulser measurements are marked by + . The solid line is a fit $2 W=\left(1.77^{2} N^{-1}+0.127^{2}\right)^{1 / 2}$ nsec. (See text.)


FIG. 1


FIG. 2


FIG. 3


FIG. 4

$\overline{67845}$

FIG. 5


FIG. 6


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