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TIMING DISCRIMINATOR USES LEADING-EDGE EXTRAPOLATION*

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ABSTRACT

A discriminator circuit uses dual current sources charging a capacitor to produce an output timing edge a fixed time after the starting corner of the input pulse, nearly independent of risetime and threshold setting. Performance with artificial and real pulses in the microsecond range is described.

Background

Obtaining a good timing information from slow-rising pulses is an old problem in pulse spectroscopy, and one of renewed interest in connection with high-energy calorimeters. In this type of detector the output pulse may have a long risetime for many reasons; for instance,

1. It may be derived from many proportional chamber wires ganged together, with varying drift times to the sense wires for any given particle trajectory.
2. The preamplifier is often deliberately designed to integrate the incoming charge.
3. Additional high-frequency rolloff may be used to stabilize the preamplifier, to reduce high-frequency noise, or to provide a pulse shape more suitable for sampling.

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Some of these factors (notably the first) also cause the overall shape to vary from pulse to pulse.

Any pulse carries timing information somewhat (perhaps considerably) better than its risetime. A "timing discriminator" is one which recovers this information while also imposing an amplitude requirement (threshold). Zero-crossing, constant fraction, and high/low techniques are in common use.

Another method that has been used - to our knowledge only in off-line data analysis - is to record the times at which the leading edge crosses two fixed levels, using this information to extrapolate to the corner or "true start" of the pulse. Obviously this will work to some degree even if the rise is not exactly linear. We discuss here an electronic implementation of this idea.

Principle of Operation

Figure 1(a) is a block diagram of the circuit. A comparator C fires when the input pulse exceeds the threshold V_T, setting a flip-flop; previously, comparators A and B have fired at 1/3 V_T and 2/3 V_T, respectively. Current sources i_1 and i_2 are controlled by A and B so that both are switched on by A and subsequently one is shut off by B. Accordingly the capacitor charges at a certain rate between the crossing of 1/3 V_T and 2/3 V_T and at a lower rate thereafter. Figure 1(b), drawn with the assumption of a linear rise and $i_1 = i_2$, shows that the capacitor voltage will eventually reach the same trajectory V(t) for a linear rise of whatever slope; the same holds true for a given slope and any threshold. It is only necessary to add a fourth comparator D which resets the flip-flop when this ramp reaches some fixed voltage (which is chosen with the slowest-rising pulses in mind and has nothing directly to do with V_T). The output trailing edge will then occur at a fixed time after the "true" start of the pulse; the leading edge, at the instant the pulse crosses V_T. The capacitor is discharged by a clamp controlled by D.

If the leading edge is not exactly linear, the trailing edge will "walk" somewhat with risetime and/or threshold changes. This can be mitigated, for any given assortment of pulses, by making i_1 and i_2 somewhat unequal.

Comparison with the timing techniques mentioned above would have to be done experimentally in any given case; however, we can make two general comments:

1. Unlike the zero-crossing and constant-fraction methods, the present method is not, to first order, shape-dependent.
2. Unlike the high/low technique it does not require any comparator set at a very low bias, which can be troublesome in the presence of baseline noise.

Circuit Description

Figure 2 shows a practical circuit for microsecond pulses. Though relatively complicated, it uses standard, inexpensive components. The current generators are transistors F and H switched on by the sharp positive-going 710 output via an inverter. At the 2/3 V_T level, transistor E is turned on harder than F, diverting one of the currents. The nonlinearity correction adjusts the ratio i_1/i_2.

The circuitry around the capacitor requires some explanation. It is desirable not only that the capacitor be clamped when the set level (typically 0.7 volt) is reached but that it be kept clamped until the input has again fallen below 1/3 V_T. Accordingly, identical clamps are applied to both the capacitor and the bias divider, and the divider standing current is deliberately chosen lower than i_1 or i_2, ensuring that pin 3 will remain more negative than pin 2 until both current sources are off. The bias potentiometer allows us to adjust for minimum delay for a given assortment of input pulses, and also to equalize several discriminators.

A typical input pulse spectrum will include some that manage to turn on the current sources but not long enough to fire the comparator. A leakage resistor must be provided to discharge the capacitor in this case; it must be large enough so that the departure from linearity of the exponential curve is small. This will be true if

$$\text{(resistance)} \times \text{(source current)} \gg \text{(ramp level)}$$

or, in our case

$$2.7\ \text{K}\Omega \times \frac{(12-5)\ \text{volt}}{3.6\ \text{K}\Omega} = 5.2\ \text{volt} \gg 0.7\ \text{volt}$$

The nonlinearity correction is made empirically using a pulser set to the longest risetime expected. Adjust the potentiometer until the trailing edge is at the same place with an input just above threshold as it is with a large input. At the correct setting, the trailing edge will wander back and forth slightly as the input amplitude range is swept out.

The output may be used in a variety of ways. In our application, we wish to time several signals to an accelerator beam gate; accordingly the trailing edge is used to clock a D-type flip-flop to which the gate is applied as "data".

Performance

Figure 3 shows some tests with artificial pulses; all three photos were taken without changing the discriminator settings. The point here is that the timing edge walks by ~ 10 nsec for a range of risetimes and amplitudes giving a leading-edge variation of 350 nsec.

Two discriminators were used to detect cosmic ray coincidences between the top and bottom sextants of the MAC calorimeter at PEP. Figure 4 (a) and (b) show the pulse spectrum in one sextant, triggering the scope on the leading and trailing edges of the discriminator output respectively; this shows the timing action vividly. Figure 4 (c) shows time spectra obtained with a LeCroy qVT analyzer, one using the leading edges for start and stop, the other using the trailing edges. The vertical scale is logarithmic and the horizontal scale is 1 μsec. Although there is a significant improvement, the performance is not as brilliant as might have been hoped for from Fig. 3. In extenuation we note that this is a very large detector indeed; each sextant is about 1.5 meter deep and 2 meters long, and has 30 gaps containing 1350 wires read out in 90 groups. (The pulses shown are derived from two levels of summing amplifiers.) Obviously our method only partially corrects for various effects which are present. It should do much better for smaller detectors such as sodium iodide scintillators.

Acknowledgement

I wish to thank Prof. Frank Pipkin who brought the extrapolation method to my attention, and my collaborators on MAC (Experiment PEP-6) for general help.

Figure Captions

Figure 1 (a) Block diagram of the discriminator.

(b) Graphical construction showing how the circuit compensates for risetime differences.

Figure 2 Schematic diagram of the discriminator.

Figure 3 Performance with artificial pulses. (a) Pulse shaping circuit. (b) Pulse and output waveforms for R = 500 Ω (0.5 μsec risetime) and pulses from 1 (threshold) to 5 volts. (c) The same, for R = 250 Ω (0.25 μsec risetime). (d) Response to a fast pulse (R = 0). The sweep speed is 0.1 μsec per division.

Figure 4 Peformance with pulses from the MAC calorimeter at PEP. (a) Pulse spectrum with scope triggered on leading edge (pulse delayed in a transmission line). (b) The same, with scope triggered on timing edge (sweep speed 0.5 μsec per division) . (c) Time spectrum of cosmic ray coincidences deriving start/stop from leading edge (broad peak) and timing edge (narrow peak). The vertical scale is logarithmic and the horizontal scale is 1 μsec.

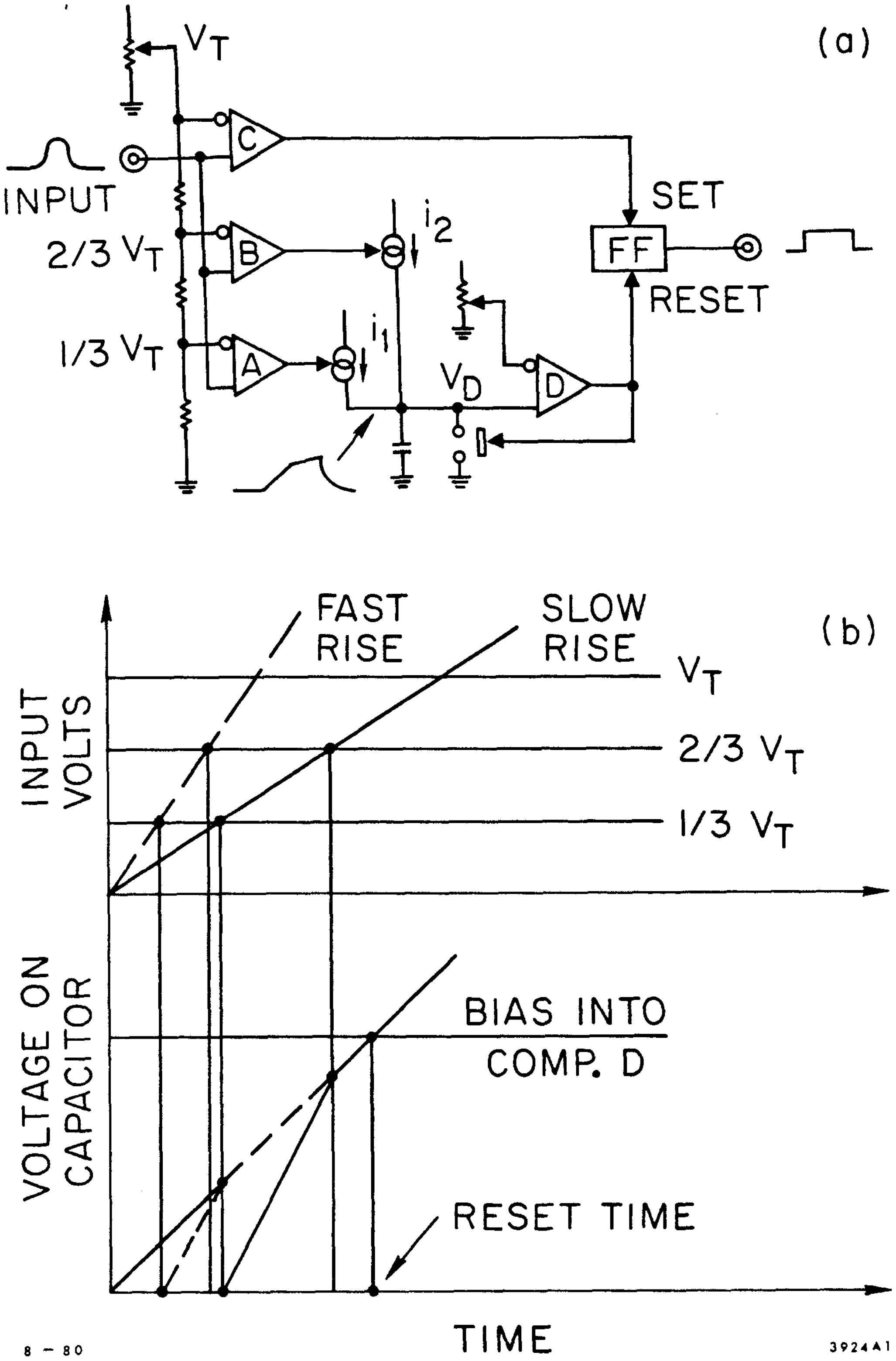
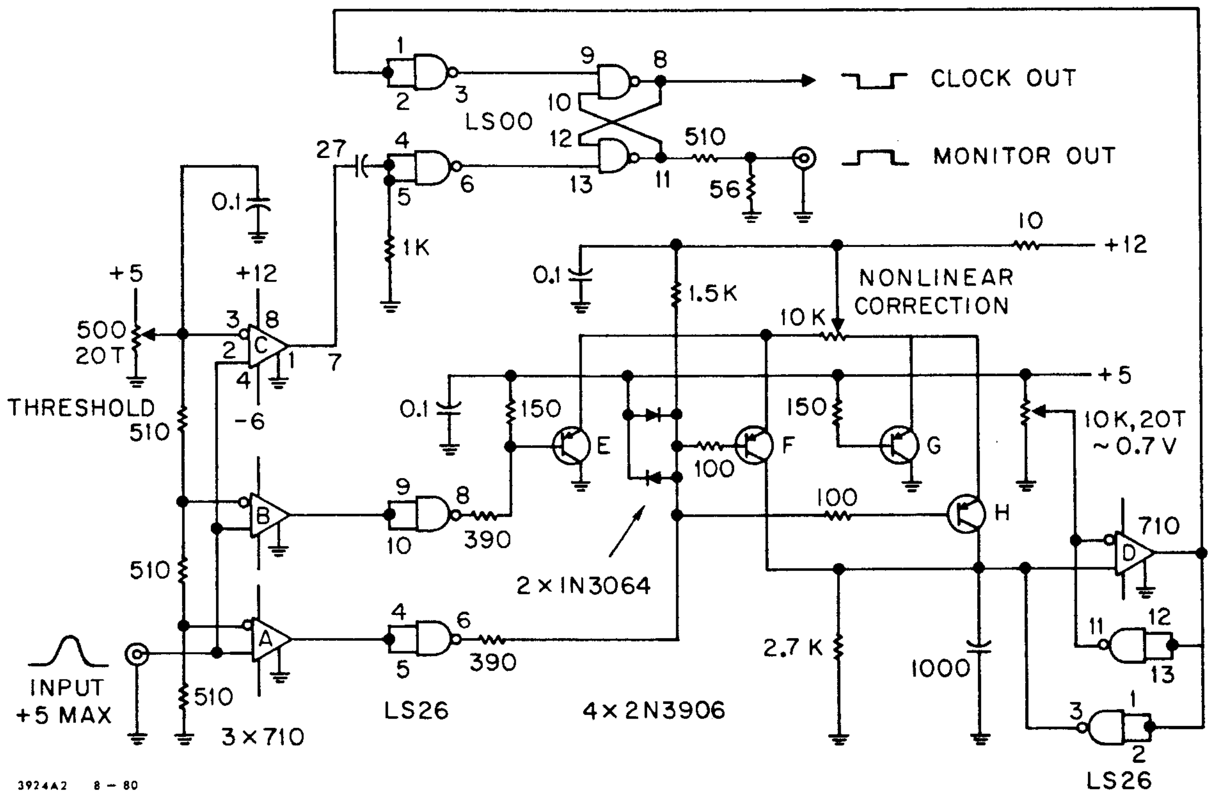

(a)
V_T
C
INPUT
SET
FF
RESET
$2/3\ V_T$
B
i_2
$1/3\ V_T$
A
i_1
V_D
D
(b)
FAST RISE
SLOW RISE
INPUT VOLTS
V_T
$2/3\ V_T$
$1/3\ V_T$
VOLTAGE ON CAPACITOR
BIAS INTO COMP. D
RESET TIME
TIME
8 - 80
3924A1

Fig. 1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2
3
9
8
10
12
LS00
CLOCK OUT
27
4
5
6
13
11
510
56
MONITOR OUT
0.1
1K
10
+12
0.1
1.5K
NONLINEAR
CORRECTION
+5
+12
500
20T
THRESHOLD
3
8
2
C
4
1
7
-6
510
10K
+5
0.1
150
E
150
F
G
100
10K,20T
~0.7V
B
9
8
10
390
100
H
2×IN3064
710
D
510
A
4
6
5
390
2.7K
1000
11
12
13
3
1
2
INPUT
+5 MAX
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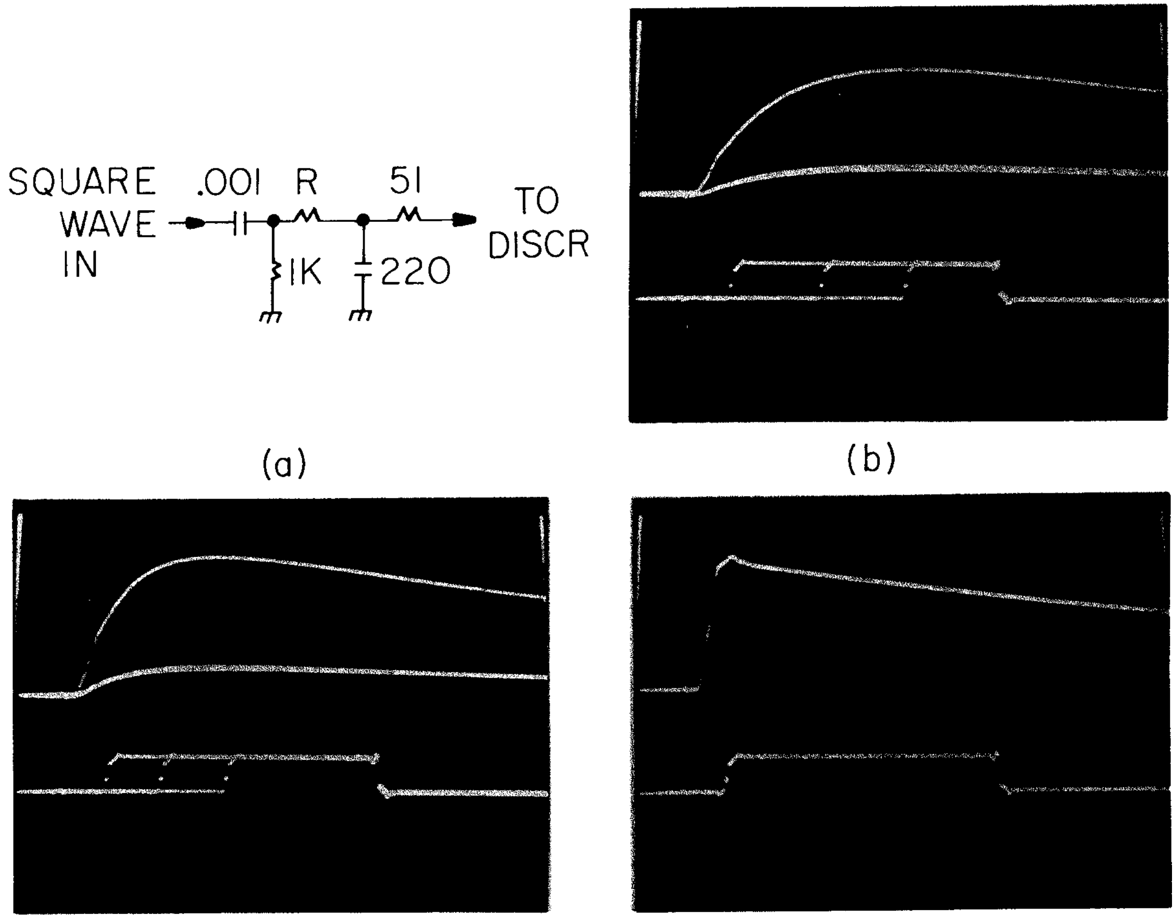
LS26
4×2N3906
LS26
3924A2 8-80

Fig. 2



(a) (b)

(c) (d)

Fig. 3

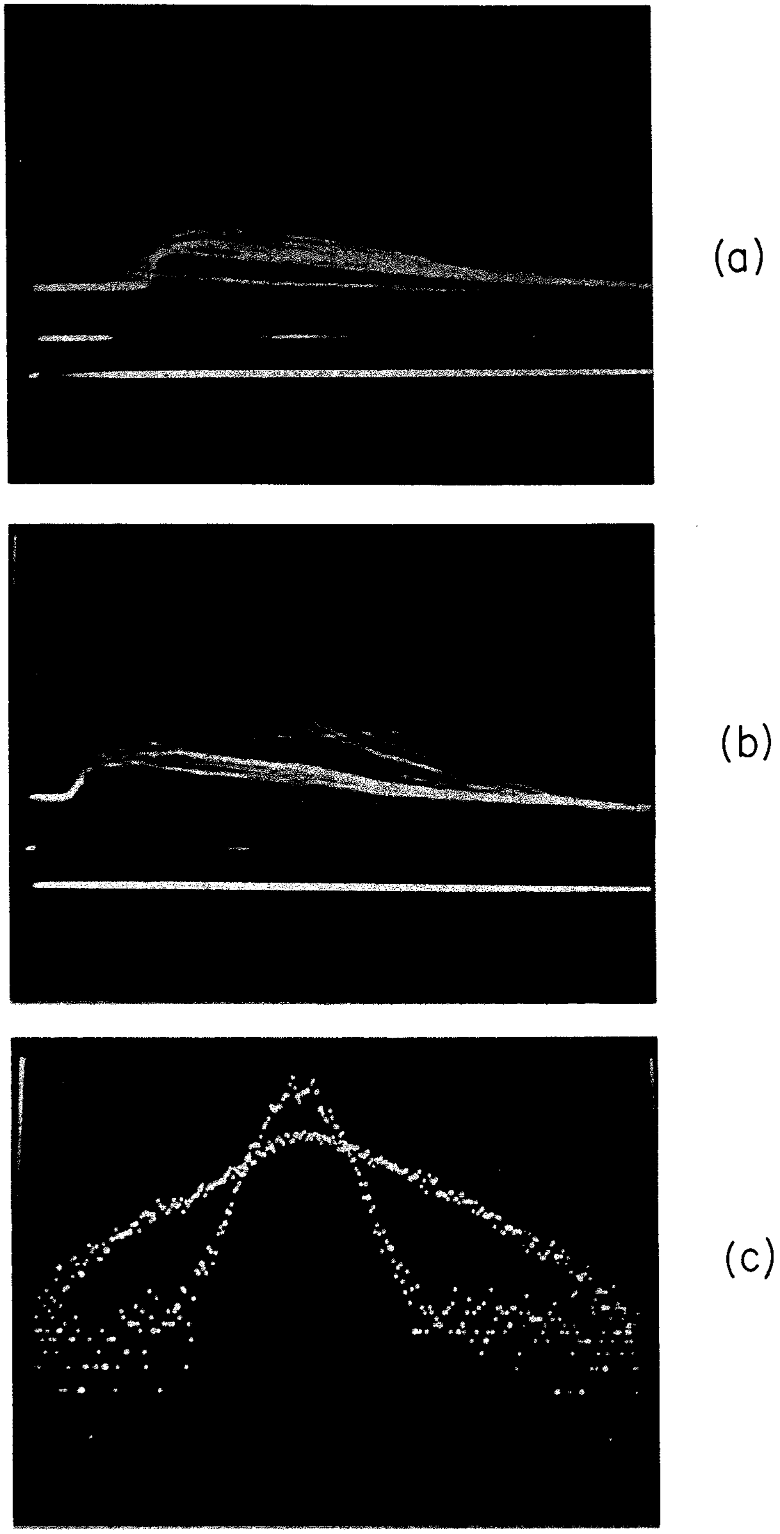


Fig. 4