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Time Pick off Circuit for Nuclear Timing Spectroscopy Applications

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ABSTRACT: In this paper, different techniques of time pick- off circuits are reviewed. This shall also review the constant fraction discriminator and its two cases (Constant Fraction discriminator and Amplitude Rise Time Compensation). Time pick off circuit is implemented using CFD technique. The input signal to the circuit is delayed, and a fraction of the un-delayed pulse is subtracted from it. A bipolar pulse is generated and its zero crossing is detected and used to produce an output logic pulse using Comparator andMono-stable Multi-vibrator.

KEYWORDS: Time Pick off circuit, Discriminator, Nuclear Timing Spectroscopy, Constant Fraction Discriminator, Amplitude Rise Time Compensator.

I. INTRODUCTION

Time interval measurement have remarkable importance in modern science and in its applications such as low and high energy nuclear physics, solid state physics, high energy particle physics, neutron physics, etc. Many attempts are dedicated in developingadvanced time interval measuring instruments across the world. Many techniques have been introduced for time interval measurement. A Time to amplitude converter (TAC) converts time interval to a corresponding analog voltage, which is again converted to digital signal with an Analog to Digital Converter (ADC). Time interval measurement systems are an integral part of most collider detectors. Although many of these systems require modern timing performance. In some cases very accurate time of flight measurements for interpretation of data is required. In suchapplications the timing performance of the discriminator must be carefully considered.

II. TIMING- SPECTROSCOPY

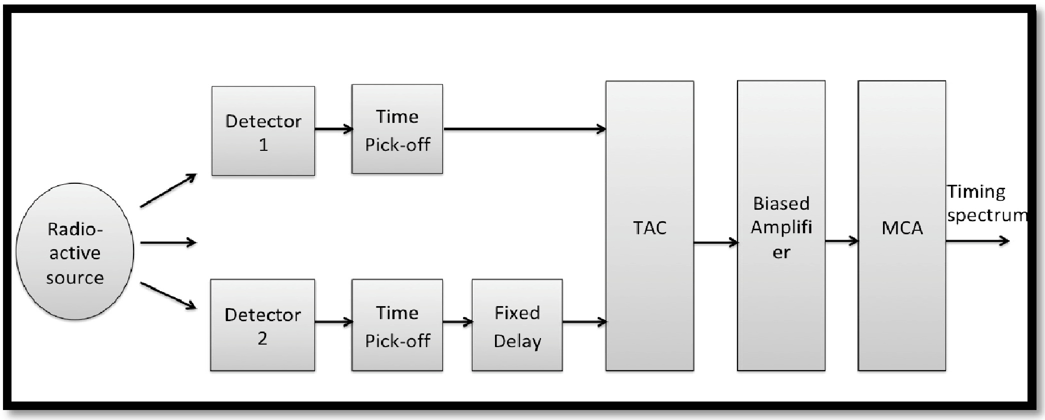

Fig 1. Simplified Block Diagram of a Nuclear Timing Spectroscopy System

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Time spectroscopy involves the measurement of the time relationship between two events. Its simplified block diagram is shown in fig. 1. A time pick-off circuit is employed to produce a logic output pulse that is consistently related in time to the beginning of each input signal. A time- to-amplitude converter (TAC) can be used to measure the time relationship between correlated or coincident events seen by two different detectors that are irradiated by the same source. Figure 1 is a simplified block diagram of a typical timing spectrometerused for making this type of timing measurement. Time pick-off circuits are used to generate START and STOP pulses which are provided to TAC.The amplitude of the voltage on the capacitor at the end of the charging interval is proportional to the time difference between the two signals. The amplitude information from the TAC is often applied to an MCA for accumulation of the data and display of the probability density of the start-to-stop time intervals, commonly called a timing spectrum.

A. TIME PICKOFF TECHNIQUE

A time pick-off element is vital in all timing systems. An ideal time pick-off produces a logic pulse at its output that is exactly related in time to the occurrence of an event. Three important sources of error can occur in time pick-off measurements: walk, drift, &jitter. ([1])

Walk is the time movement of the output pulse from the pick-off element, relative to its input pulse, due to changes in the shape and amplitude of the input pulse. Drift is the long-term timing error introduced by component aging and by temperature variations in the time pick-off circuitry. Jitter is the timing uncertainty of the pick-off signal that is caused by noise in the system and by statistical fluctuations of the signals from the detector.

In semiconductor detector systems timing properties are obtained primarily by time slewing (walk) resulting from the shape of the detector output pulse.Other sources ofvariations in charge collection time are charge trapping, which is due to crystal defects or impurities, and the plasma effect.

III. **CONSTANT FRACTION DISCRIMINATOR**

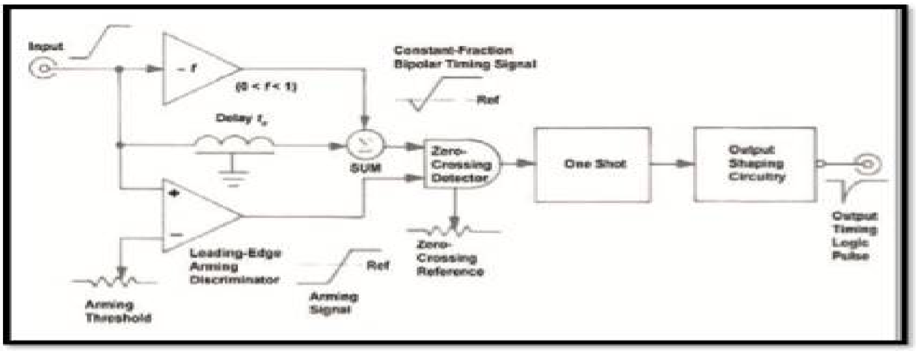

Fig. 4. Constant Fraction Discriminator

A functional representation of a constant-fraction trigger is shown in Fig. 4. In this method the input signal to the circuit is delayed, and a fraction of the un-delayed pulse is subtracted from it. A bipolar pulse is generated and its zero crossing is detected and used to produce an output logic pulse. A leading- edge arming discriminator provides energy selection capability and prevents the sensitive zero-crossing device from triggering on the noise on the constant-fraction baseline. A one-shot multi-vibrator is used to prevent multiple output signals frombeing generated in response to a single input pulse. With this technique, walk due to risetime and amplitude variations of the input signals isminimized by proper selections of the shaping delay-time. Jitter is also reduced for each detector by proper selection of the attenuation fraction that determines the triggering fraction.Two cases must be considered in determining the zero-crossing time for the constant-fraction bipolar signal. The first case is for true-constant-fraction (TCF) timing, and the second is for the amplitude-and- rise-time-compensated (ARC) timing. ([3])

A. True Constant Fraction Timing

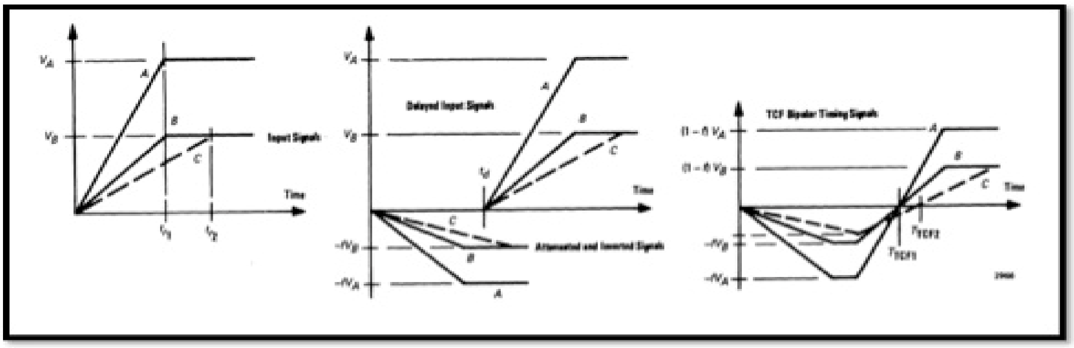

Fig. 5. Timing Signal formation in a constant fraction discriminator for TCF

In TCF case the zero crossing takes place while the attenuated input signal is at its full amplitude. Fig illustrates the signal formation in an ideal CFD for TCF timing with linear input signals. Here, the time pick-off signal to be generated at the same fraction of the input pulse height regardless of the amplitude.

The zero crossing time is depicted for input signals A and B, which has same rise time but different amplitudes. From signal A and B the zero crossing time is seen to be dependent on the rise time of the input signal. For linear input signals that begins at time zero the constant fraction zero-crossing time for TCF case, T_{TCF}, is

$$T_{TCF} = t_d + f.\ t_r \qquad (1)$$

Where tr is the input signal rise time. Two criteria for td must be observed to ensure TCF timing. The shaping delay must be selected so that

$$t_d > t_r\,(1-f) \qquad (2)$$

This constraint ensures that the zero-crossing time occurs after the attenuated linear input signal has reached its maximum amplitude. TCF timing is most effectual when used with input signals having a wide range of amplitudes but having a narrow range of rise times and pulse width. These restrictions favor the use of TCF timing in scintillator/PMT systems. Walk effect can be assigned to the charge sensitivity of the zero crossing detector and the slew limitations of the devices used to form the constant fraction signal. ([3])

IV. AMPLITUDE AND RISE-TIME COMPENSATION

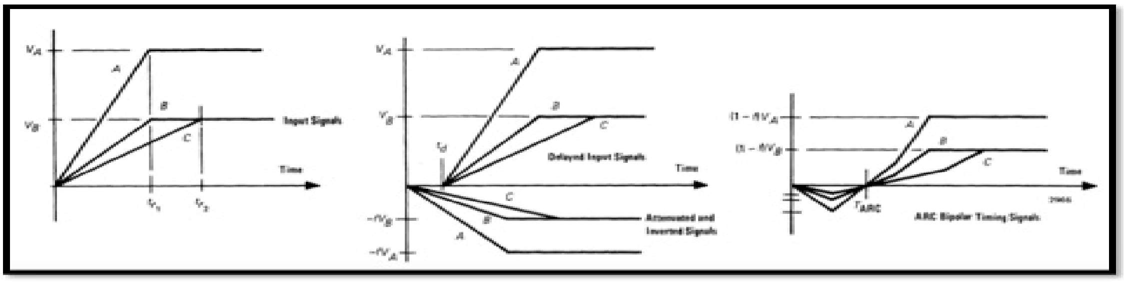

Fig. 6. Signal Formation in a Constant Fraction Discriminator For AFC Timing

In ARC timing, when the time of zero crossover occurs before the attenuated input signal has reached its maximum pulse height. This condition eliminates the rise time dependence of the zero crossing time that was found in TCF technique**.** The fig. 6 illustrates the signal formation with linear input signals. The amplitude independence of the ARC is depicted for input signals B and C, which have the same amplitude but different rise times. For linear inputsignals that begins at the zero crossing time, T_{ARC} is

$$T_{ARC} = t_d \,/\, (1 - f) \qquad (3)$$

When the input signals have a wide range of amplitudes and rise times making it especially suitable for use with large volume germanium detectors that have wide variations in charge collection, AFC timing is used. Jitter is a limiting factor in ARC timing with a narrow dynamic range of input signals. An additional problem is encountered with the ARC timing technique, the constant-fraction discriminator can produce leading-edge time walk.

A leading-edge discriminator is commonly used in the zero-crossing detector in a constant-fraction discriminator. To provide ARC timing the zero-crossing detector must be armed during the time interval between the initiation of the constant-fraction signal and its zero crossing. If the sensitive crossover detection device is armed before the bipolar timing pulse begins, random noise is generated by the time pick off circuit on the constant-fraction baseline. If the leading edge occurs after zero crossing time, the unit produces leading edge timing. This type of timing error occurs most often in ARC timing for signals with exceptionally long rise times and for signals with peak amplitudes that exceed the threshold level by only a small amount. ([1])

V. DESIGN AND IMPLEMENTATION OF TIME PICK-OFF CIRCUIT

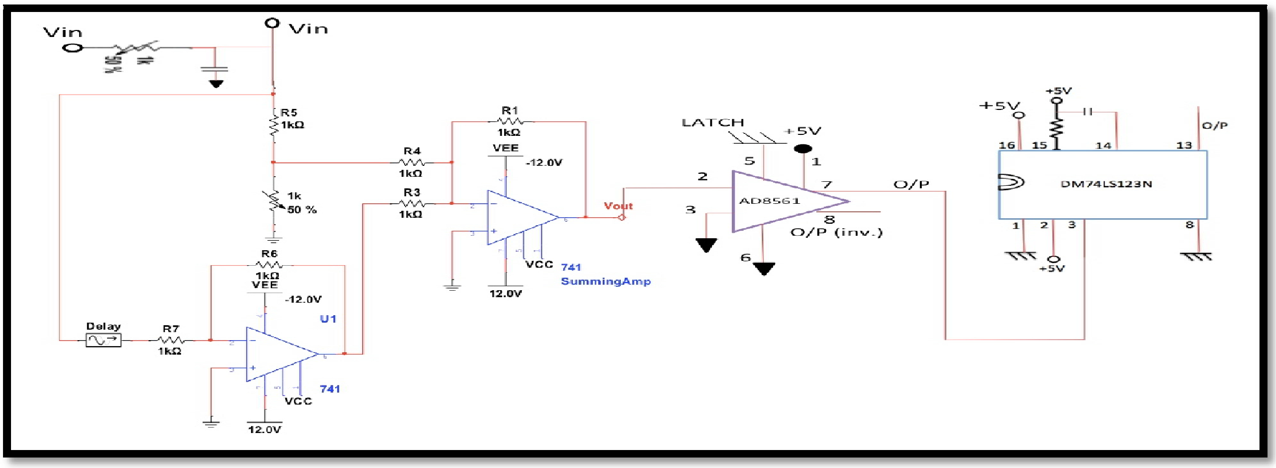

Fig. 7 Functional Representation of Constant Fraction Trigger

Fig.7 belongs to the circuit, which is practically been achieved, and delay has been introduced with the help of analog delay cable. In this method the input signal to the circuit is delayed, and a fraction of the un-delayed pulse is subtracted from it. This bipolar pulse is further given to AD 8561 Comparator IC which triggers the wave by single output pulse. This pulse is then passed to DM74LS123N Monostable multivibrator to get the desired output.

VI. MATHEMATICAL REPRESENTATION OF MONOSTABLE MULTIVIBRATOR

The basic output pulse duration is essentially determined by the values of external capacitance and timing resistance. For pulse duration when $C_{ext}$is < 1F, use the following formula:

$$t_W = K.R_t.C_{ext}$$

where, k=0.33 ; R=100kohms ; C=100pF (as per the data sheet) ([8])

We get t_w= 173.9 µsec□.   ... (i)

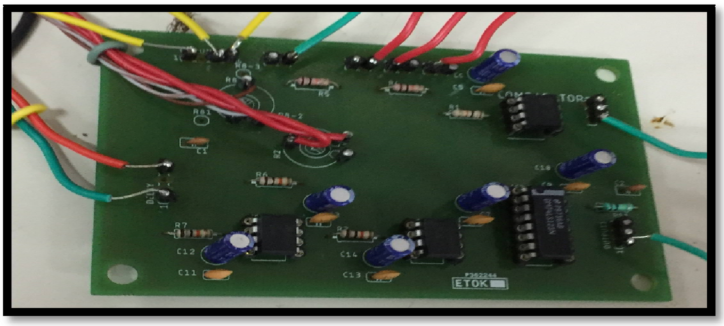

Fig. 8. Circuit Implementation of Constant Fraction Trigger

Fig.8 refers to the circuit practically achieved identical to the diagram shown above. All the test have been completed and successfully achieved the desired output. Step-by-step representation of the output is shown below.

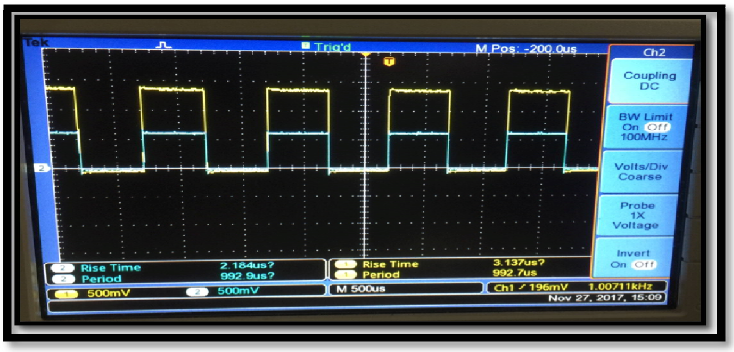

Fig.9 Attenuated Output Pulse

This image displays the output received on CRO as the attenuated pulse. As seen above the pulse is attenuation factor for input pulse 0.5.

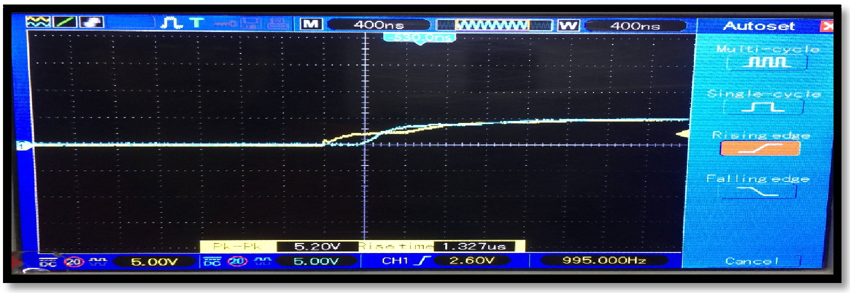

Fig. 10 Delayed output pulse

Fig.10 shows the output received after the analog delay cable is introduced to get a delayed output. The blue signal represents delay output of 350 nanoseconds.

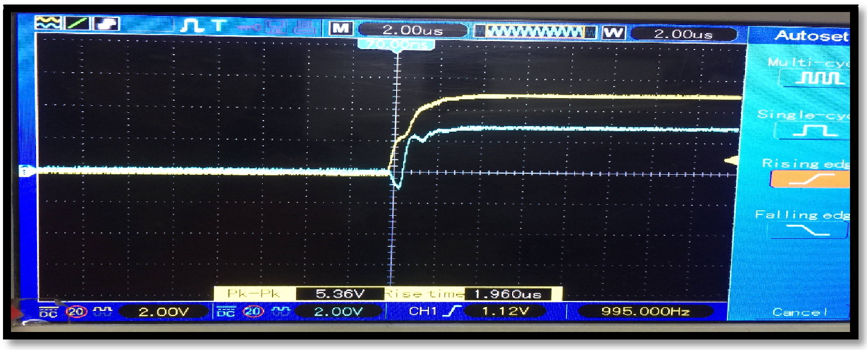

Fig. 11 Bipolar signal

After delay and inverting the signal we achieve a bipolar pulse as seen in Fig.11. This signal is obtained at the output pin of the second fast response IC LF356. This signal is further passed to AD 8561 Comparator to trigger the output signal.

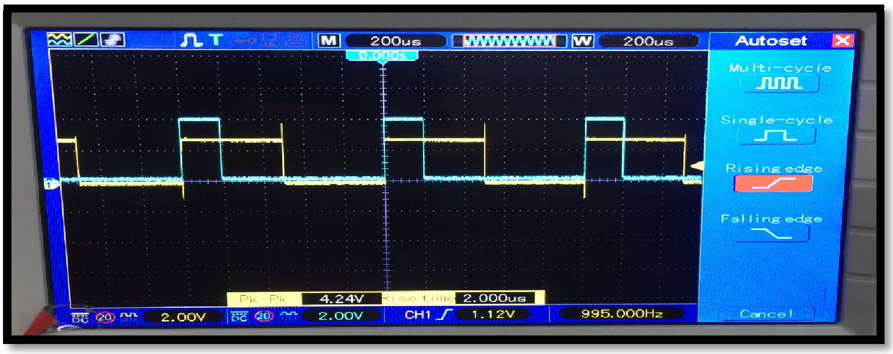

Fig. 12 Output of Monostable Multi-vibrator

This output belongs to the final output of the circuit when we get a single triggered output pulse with respect to the output pulse.
From (i) we get tw=173.9 µsec□ and by the readings we get 200µsec.By the above results we can say that the monostablemultivibrator gives appropriate results.

VII. CONCLUSION

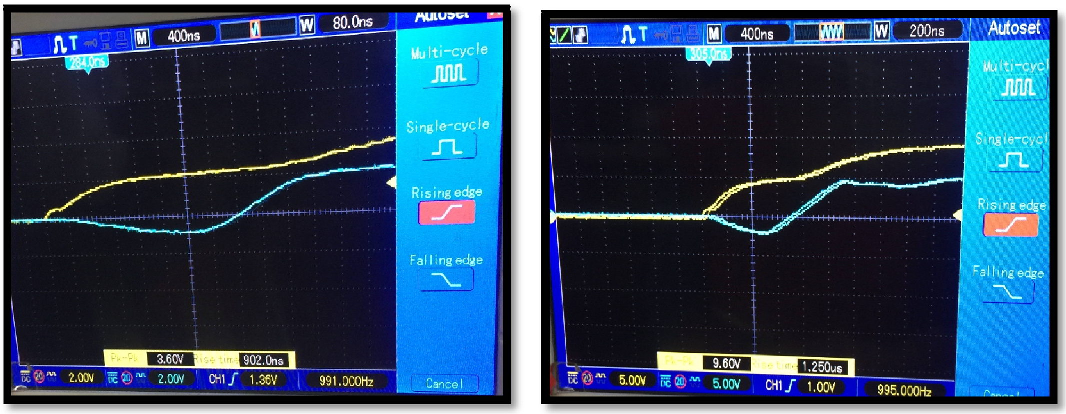

Fig. 13 CFD output with Same Rise Time But Different Amplitude.

Fig 13 shows output of a constant Fraction Discriminator with same rise time but different amplitudes. Bipolar pulse crosses zero almost at the same time instant irrespective of amplitude variation at the input. This circuit plays an important role in Timing Spectroscopy and has application in nuclear devices like SPECT and PET etc.

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