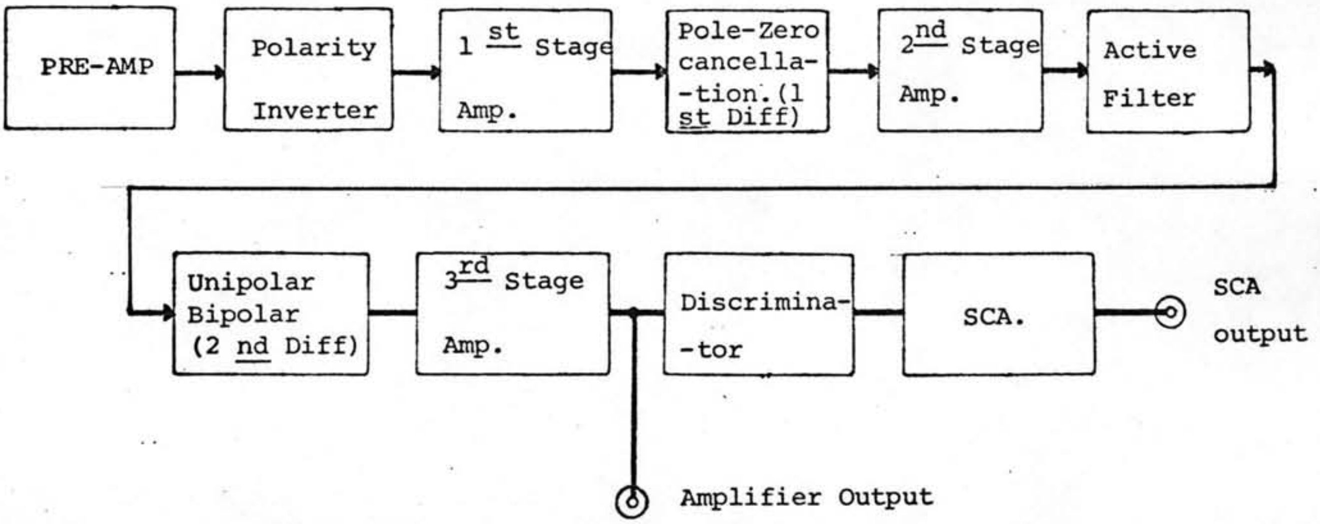
CHAPTER I

SYSTEM OF AMPLIFIER AND SINGLE CHANNEL ANALYZER



1.1 PREAMPLIFIER

A preamplifier is an amplifying element that is specifically designed to accept the signal from a detector and to amplify that signal with minimum shaping in a way that will preserve the maximum signal-to-noise ratio. In general, much attention must be focused on selecting and configuring the preamplifier's front end components to preserve the maximum signal-to-noise ratio. This selecting and configuring of components is very dependent on the detail characteristics of the particular detector being used and sometimes on the type of signal processing that follows the preamplifier. The types of detectors most frequently used in nuclear research are germanium planar, germanium coaxial, silicon charged particle, scintillator - photo multiplier, electron multiplier, and gas proportional counter. The germanium detectors are always operated at cryogenic temperature, whereas the silicon detectors and photo multipliers are operated at ambient temperatures for many applications and at cryogenic temperature for applications requiring the ultimate in resolution or sensitivity.

The three basic types of preamplifiers that are normally used with these detectors are charge sensitive, voltage sensitive and current sensitive. The charge-sensitive preamplifier is by far the most important type for spectroscopy applications.

1.2 CHARGE-SENSITIVE PREAMPLIFIER

The signal from a semiconductor detector or ion chamber is a quantity of charge. This charge amounts to a current pulse lasting from 10^{-9} to 10^{-5} sec., depending on the detector and its configuration. Most detector users are interested in measuring the quantity of charge and/or the time of occurrence of the events. The charge-sensitive preamplifier shown in Fig. 1.1 is well suited for measuring the quantity of charge. The signal produced by the detector as the result of a radiation interaction appears as a current pulse or a quantity of charge, and the output voltage produced by this quantity of charge is given by

$$V_o = \frac{Q}{C} \qquad \text{............ (1)}$$

Where $C = C_{in} + C_s$ (C_1 is coupling capacitor which is large in value

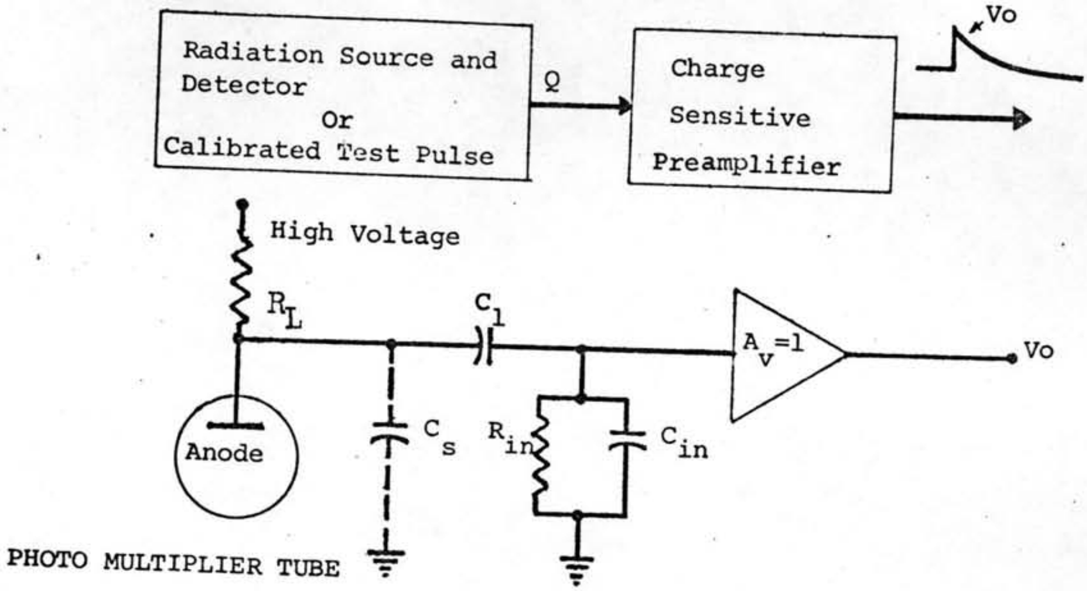


Fig. 1.1 Charge-Sensitive Preamplifier

compared to C, and therefore accumulate a negligible amount of voltage from the charge transferred). The voltage developed across C will decay with a time constant of $T_t = R_tC$

where $R_t = R_{in}//(R_L + R_s)$

$(R_s$ = High voltage supply output resistance)

Preamplifier is widely used as impedance matching between detector and amplifier, its gain is usually equal to one. Since, the unity-gain buffer circuit is used, the circuit gives the highest input impedance of any operational amplifier circuit.

1.3 AMPLIFIER

The principal function of an amplifier in a pulse analysis system is implied by its name : to expand the range of analog outputs from the preamplifier (normally 0 to a fraction of 1V) into a range that can be measured with greater ease and accuracy. The linear range of a NIM spectroscopy amplifier is usually 0 to 10V, the primary range for which nuclear signal analysis equipment has been designed. Shaping and filtering in the amplifier are used to improve the signal-to-noise ratio of the main amplifier and to shorten the response time required for each pulse. Pulse-shaping and processing considerations are of utmost importance in the design of a nuclear pulse amplifier.

1.4 RC PULSE SHAPING

The term RC pulse shaping applies to the use of resistors and capacitors as shaping networks. Because of developments in active-filter shaping methods, which also use only resistors and capacitors, RC shaping is now interpreted as referring to only passive CR differentiators and RC integrators. In the following descriptions of these circuits a step-function input is assumed.

A CR differentiation filter Fig. 1.2 affects the decay of the pulse and corresponds to a CR high-pass filter, which attenuates the low-frequency components of the waveform.

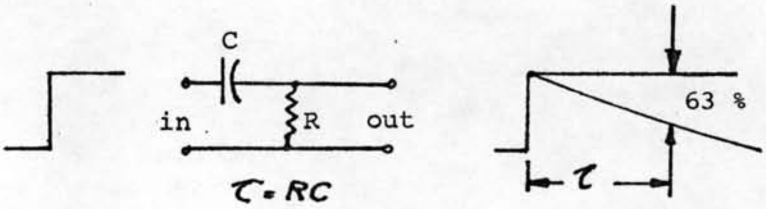


Fig. 1.2 CR Differentiation

An RC integration filter Fig. 1.3 affects the risetime of the pulse and corresponds to an RC low pass filter, which attenuates the high-frequency components of the waveform.

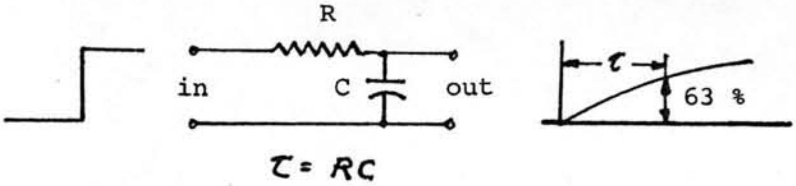


Fig. 1.3 RC Integration

Choosing a time constant best suited to the experiment will optimize the signal-to-noise ratio and minimize the pulse overlap. Time constants of 0.5 µs. are frequently optimum for surface-barrier semiconductor detector systems. Very low noise semiconductor detectors operating at low count rates, such as a Ge (Li) detector, may be served best by a 3 µs. time constant, whereas high counting rates may demand 1 - or even 0.5 µs. time constants for the best net resolution. Gas counters, with slow collection times, require longer time constants for optimum performance (For example 2 to 10 µs.).

There are two basic reasons for the pulse shaping manipulations (1) To prevent overlap, the effect of each detector event must be eliminated within a time that is short compared with the average spacing of the pulses, but its amplitude and time information must not be destroyed. If the response time is not shortened, pulses will overlap and create errors in amplitude measurements. Pulse-shortening methods, called clipping or differentiation, are utilized for this purpose.

(2) To enhance the signal-to-noise ratio, the unavoidable noise sources in the detector and first amplifying stages have a wide bandwidth compared with bandwidths of the useful components of the desired signal. Suitable pulse-shaping methods can enhance the desired signal while diminishing the noise, and this will improve the signal-to-noise ratio and the resolution of the system.

1.5 POLE-ZERO-CANCELLATION

The unipolar pulse of Fig. 1.4 shows an undershoot of the baseline at the completion of the pulse. If a second event is detected and processed by the shaping circuit before the undershoot has returned to the baseline, its amplitude will be destroyed by the amount of remaining undershoot and its subsequent measurement will thus be in error.

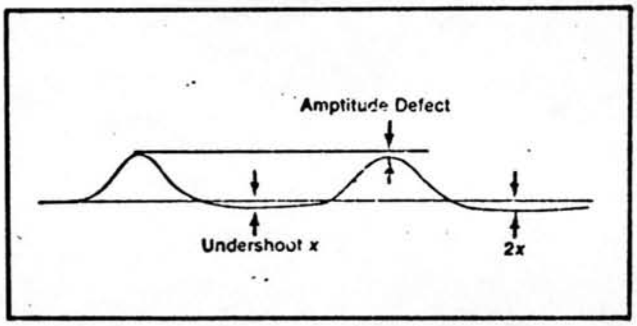


Fig. 1.4 Effect of Baseline Shift on Amplitude

The undesired undershoot can be cancelled by the addition of one resistor to the differentiating circuit and is called pole-zero cancellation. Fig. 1.5 shows a unipolar pulse to illustrate the contrast between an ordinary RC-coupled network and one with pole-zero cancellation.

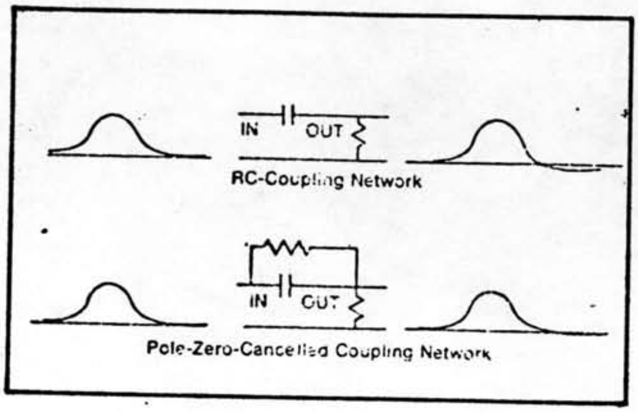


Fig. 1.5 Pole-Zero-Cancellation Circuit and Effect

This technique is used to cancel undesired differentiations in the preamplifier interstage circuits, the preamplifier decay time constant, and some of the amplifier coupling circuits.

1.6 ACTIVE FILTER

A pulse shape approaching the Gaussian distribution shape can be obtained if a large number of effective integrations follow a CR differentiation Active-filter feedback networks consisting of only resistors and capacitors can be used to simulate the performance of many passive RC integrators, but with fewer components. These active networks also allow for the possibility of deviations from the Gaussian shape toward responses similar to those of damped RLC networks (using resistors, inductors and capacitors for shaping), again using only resistors and capacitors, with their inherent simplicity and stability. Most current main amplifiers using active filter for pulse shaping are designed with damping factors that deviate slightly from the best Gaussian approximation in order to create a more sharply peaked pulse shape, as well as a larger percentage of negative amplitude when followed by a second differentiation.

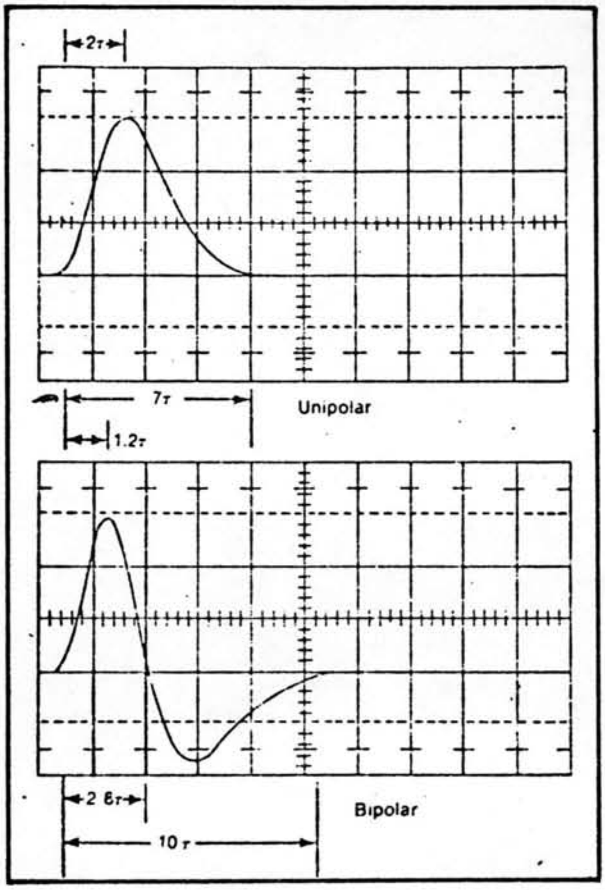


Fig. 1.6 Amplifier Output Pulse Shapes

Using Equal Integrate and Differentiate Time Constant.

Fig. 1.6 shows the unipolar (singly differentiated) and bipolar (doubly differentiated) output waveforms from the Amplifiers. The unipolar is used for optimum resolution and the bipolar pulse is used to satisfy gating and timing requirements.

1.7 FEEDBACK AMPLIFIER

Feedback amplifiers can be used to improve many areas of circuit performance. Negative feedback applied to an amplifier always reduces the gain of the amplifier, but it increases the bandwidth, change input and output impedance and lower distortion in the output signal. The performance of a feedback amplifier can be made to depend entirely on circuit element values rather than the active devices of the amplifier.

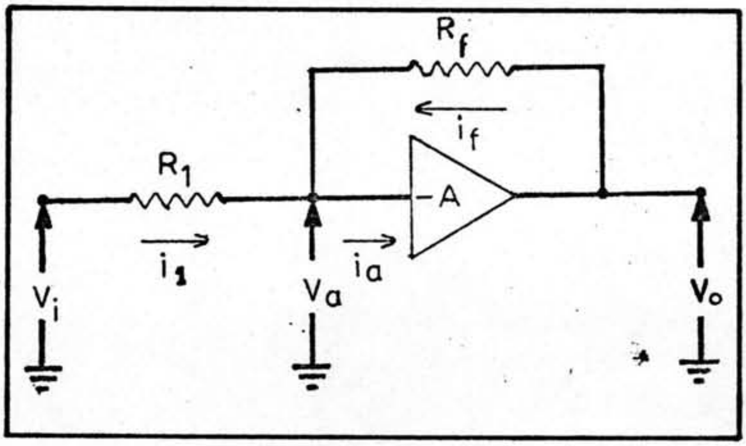


Fig. 1.7 Ideal Negative Feedback Voltage Amplifier

$(R_{in} = \infty , \quad R_{out} = 0)$

A is the open loop gain (positive number $A \gg 1$)

$$i_1 + i_f = i_a \quad \text{................} \quad (2)$$

$$i_a = 0 \quad \text{(high input impedance)}$$

$$i_1 = -i_f$$

$$\frac{V_i - V_a}{R_1} = -\frac{(V_o - V_a)}{R_f} \quad \text{..............} \quad (3)$$

$$V_o = -AV_a$$

$$\therefore \quad V_a = -\frac{V_o}{A}$$

Substituting V_a in Eq. (3)

$$\frac{V_i + \frac{V_o}{A}}{R_1} = -\frac{V_o + \frac{V_o}{A}}{R_f}$$

$$\frac{V_i}{R_1} + \frac{V_o}{AR_1} = -\frac{V_o}{R_f} - \frac{V_o}{AR_f}$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_f} - \frac{V_o}{AR_f} - \frac{V_o}{AR_1}$$

$$\frac{V_i}{R_1} = -\frac{V_o}{R_f} - \frac{V_o}{A}\left(\frac{1}{R_f} + \frac{1}{R_1}\right)$$

Since $A \gg 1$

$$\therefore \quad \frac{V_i}{R_1} = -\frac{V_o}{R_f}$$

The closed loop gain $A_f = \frac{V_o}{V_i} \simeq -\frac{R_f}{R_1}$

1.8 BASELINE RESTORATION (BLR)

Baseline restoration is used to compensate the effect of baseline shift on a unipolar signal caused by uncancelled RC interstages in the amplifier. This will restore the signal quickly to the baseline when an undershoot occurs. Fig. 1.8 shows the effect that baseline restoration would have on the two closely spaced pulses shown in Fig. 1.4. There are a variety of circuits that can be used to restore the baseline. Fig.1.9 shows one possible configuration for active baseline restoration.

When a positive signal is present, the output from comparator A_1

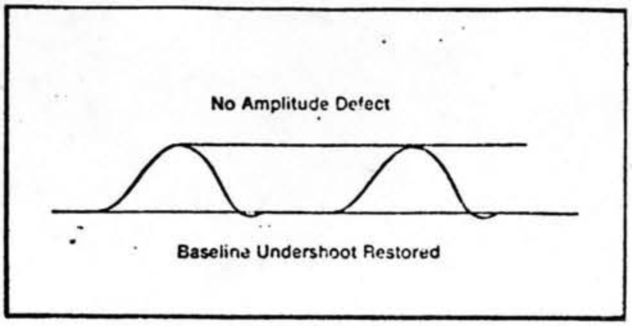


Fig. 1.8 Effect of Baseline Restoration

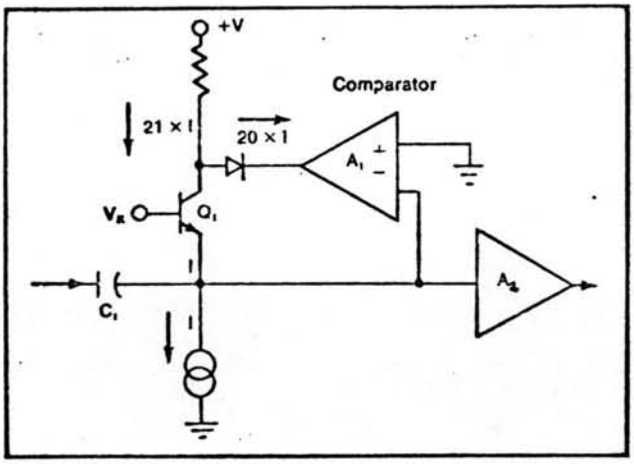


Fig. 1.9 Typical Baseline Restorer Circuit

goes negative. Since this takes all the current from Q_1, the signal is not affected. When undershoot caused by the coupling capacitors occurs, the A_1 output goes to a positive value, causing a large current through Q_1 until the undershoot is driven back to the baseline. The relative values of restoring current and capacitance determine the speed at which the baseline restoration occurs and thus control the amount of baseline restoration required for various count rates. Although the BLR stabilizes the baseline, it introduces some minor undershoot and rectifies noise which results in a slight degradation in resolution when high restoration rates are used.

1.9 DISCRIMINATOR AND SINGLE-CHANNEL ANALYZER

The application of voltage constraints on the output signals from an amplifier is the same as applying energy constraints on the nuclear events being detected and processed. The application of these constraints is accomplished by employing single-channel analyzers and discriminators in a nuclear instrument system. The purpose of using a discriminator or a single-channel analyzer may be to limit the counting of events to those of interest and to exclude all other detected events, or to reduce the incoming data so that further processing and analysis are performed only on selected events. Discriminators mark the occurrence of pulses that exceed a predetermined minimum amplitude level. If an event does not reach the discriminator level, no output is generated. Fig. 1.10 shows three pulses as they might appear at the output of a main amplifier.

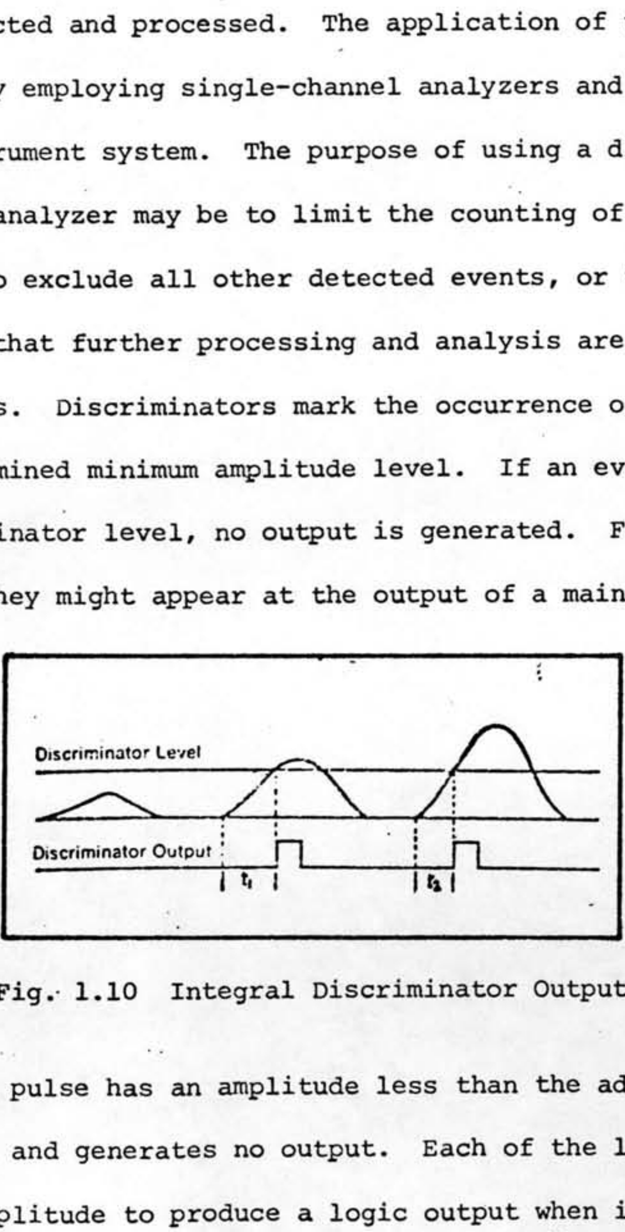


Fig. 1.10 Integral Discriminator Output Triggering

The first pulse has an amplitude less than the adjusted discriminator threshold and generates no output. Each of the last two pulses has sufficient amplitude to produce a logic output when its amplitude crosses the threshold.

Single-channel analyzers (SCA) mark the occurrence of pulses that meet certain restrictions placed on their amplitudes. These instruments have both lower-level and upper-level discriminators that can be set to define a certain amplitude range in the main amplifier output. The region between the lower-level and upper-level discriminator settings is called the SCA window.

Pulses whose amplitudes fall within the window are marked by a logic output from the SCA. Pulses with amplitudes less than the lower-level or greater than the upper-level do not meet the window requirements and therefore do not produce output pulses. The three pulses shown in Fig. 1.11 are the same as those shown in Fig. 1.10, with the horizontal lines indicating the settings of the lower-level and upper-level discriminators in the SCA.

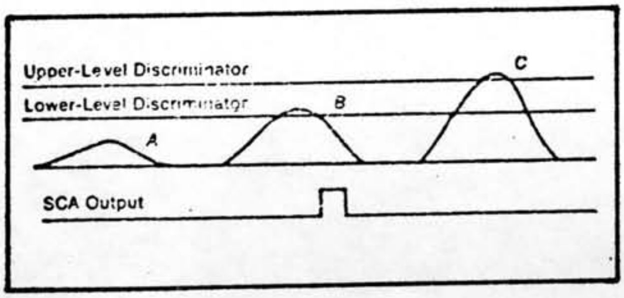


Fig. 1.11 Single-channel Analyzer Function

As can be seen, only pulse B meets the window requirements and produces a logic output from SCA.

Removal of the upper-level-discriminator restrictions from the single-channel analyzer makes its function as an integral discriminator. If the upper-level restrictions were removed from the unit whose output is shown in Fig. 1.11, both pulse B and C would be marked by logic outputs.

There are two basic types of single-channel analyzers :

1. Standard nontiming SCA
2. Timing SCA

The timing SCA, such as the designed SCA produces its logic signal output at a time that is related to the occurrence of the event measured. Fig. 1.12 shows two similar pulses from a main amplifier and the response in a peak detection single-channel analyzer.

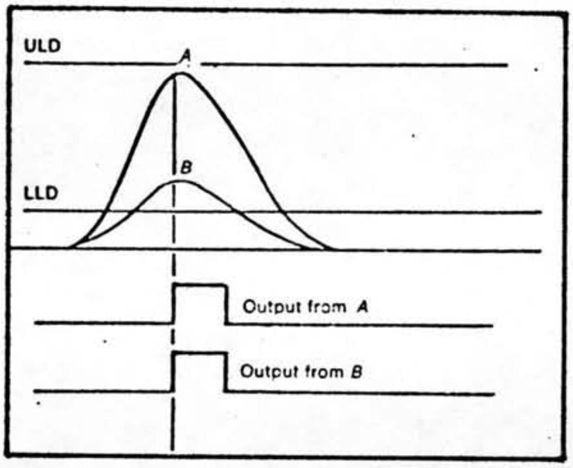


Fig. 1.12 Peak SCA Output Triggering

Even though the amplitudes are different, the pulse peaks occur at the same time and the outputs are produced after the peak is detected. Thus these outputs are produced at the same time with respect to the occurrence of the event. This is well suited to gating and coincidence applications.

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