COINCIDENCE TECHNIQUES

There are many applications that require the measurement of events that occur in two separate detectors within a given time interval, or the measurement of the time delay between the two events. These two approaches are used in gamma-gamma or particle-gamma coincidence measurements, positron lifetime studies, decay scheme studies and similar applications, and are titled coincidence or timing measurements.

A coincidence system determines when two events occur within a certain fixed time period. However, in practice it’s not possible to analyze coincidence events with 100% confidence due to the uncertainties associated with the statistical nature of the process. Statistical timing errors may occur from the detection process and uncertainties in the electronics resulting from timing jitter, amplitude walk and noise, which lead to statistically variable time delays between processed events. A simple coincidence circuit solves this problem by essentially summing the two input pulses, passing the resultant sum pulse through a discriminator level, and generating an output pulse when the two input pulses overlap. Figure 1.36 illustrates this process. Note that the period of time in which the two input pulses can be accepted is defined as the resolving time, which is determined by the width of the pulses, $\tau$, such that the resolving time is equal to $2\tau$.

The 2040 Coincidence Analyzer uses a more sophisticated scheme allowing analysis of several input signals. It produces a logic pulse output when the input pulses, on the active inputs, occur within the resolving time window selected by the front panel control.

Since detector events occur at random times, accidental coincidences can occur between two pulses which produce background in the coincidence counting. The rate of accidental or random coincidences is given by:

$$N_{\text{acc}} = N_1 N_2 (2\tau)$$

Where:

- $N_1$ = Count rate in detector number 1
- $N_2$ = Count rate in detector number 2
- $2\tau$ = The resolving time of the coincidence circuit

The number of counts in the detectors depends upon the experiment and the detectors, so the best way to reduce accidental coincidences is to make the resolving time as small as possible. However, the resolving time cannot be reduced below the amount of time jitter in the detector pulses without losing true coincidences, so the type of detector determines the minimum resolving time usable.

A coincidence setup with NaI detectors is shown in Figure 1.37. The unipolar pulse from the 2022 Amplifier is processed by a Model 2037A Constant Fraction Timing SCA to produce a standard NIM logic pulse for the 2040 Coincidence unit. The 814FP Pulser is used to set up delays and test operation.
In order to properly operate the system, a delay curve is obtained in which coincidences are measured as a function of relative delay between the two detectors. In the ideal case of no time jitter in either detector, the solid curve in Figure 1.38 is obtained. However, real detectors will produce the dashed curve, and the minimum resolving time setting is where there is a flat region (indicating all true coincidences are collected). Thus, the proper relative delay is the value for the center of the flat region.

Typical resolving times are 10 nanoseconds or better, for an energy range of 0.1 to 1 MeV. Shorter resolving times are possible for plastic scintillators and silicon charged particle detectors, even down to less than 1 nanosecond. In general, the shorter the rise time of the preamplifier pulse, the smaller the resolving time. This is discussed further with fast discriminators.

Another coincidence technique involves the direct measurement of the time delay between two pulses. A time-to-amplitude converter (TAC) converts a time difference between two input pulses to a 0 to 10 volt pulse. This analog pulse can then be used as an input to an SCA, or ADC and MCA. The Model 2145 TAC provides an integral SCA capability as well as an output pulse, gate delays and other features.

The use of a 2145 TAC with NaI detectors in exact analogy with the 2040 Coincidence unit is shown in Figure 1.39. There are several advantages to the use of a TAC. First, no delay curve needs to be taken since all relative decays occurring are recorded, and second, no resolving time setting is involved.

The natural time spectrum of the two detectors can be stored directly in an MCA, and if a window is set very narrow, as in Figure 1.40, then there are a minimum number of accidental coincidences recorded. The 2058 Nanosecond Delay is required to delay one detector pulse from the other so that a measurable time difference occurs.

**TIMING DISCRIMINATORS**

A crucial part of any coincidence system is the timing discriminator used to determine when a pulse occurs. There are two general categories:

- Slow (or energy) Timing
- Fast Timing

The timing single channel analyzers used in Figures 1.37 and 1.39 are examples of slow timing. The single channel analyzer operates with shaped pulses to select the range of energies involved in the coincidence, and produces an output logic pulse that is, ideally, independent of input pulse amplitude. Fast timing uses pulses directly from the detector, without regard to specific energy.

Three basic techniques are used in both fast and slow modes for acquiring timing information:

- Leading Edge
- Crossover
- Constant Fraction

CANBERRA provides electronic modules for performing any of these techniques, and the proper choice depends upon the detector and application, as discussed below.
The most fundamental timing circuit generates a logic signal when the leading edge of an input pulse crosses through a discriminator level as shown in Figure 1.41.

The main problem is that the time of the output pulse varies markedly with amplitude, as can be seen by comparing the two signals shown. This effect can be reduced by setting the discriminator at a very low level, such as just above noise. The Model 2037A Timing SCA sets the discriminator up to a maximum of 200 millivolts.

Crossover timing relies on the fact that the zero-crossing point in a bipolar pulse is very nearly independent of pulse amplitude. (See Figure 1.42). The Model 2037A Timing Single Channel Analyzer offers a crossover mode of operation for bipolar input pulses. The crossover technique has some limitations in that there is still time dependence or “walk” for different amplitudes, and that signals with varying rise times from the same detector (such as occurs with germanium detectors), will produce walk.

The constant fraction technique will eliminate most of the shortcomings of the two former methods of timing. The constant fraction timing technique is similar to a discriminator, but with a threshold that is a constant fraction of the signal amplitude. A discussion of the constant fraction technique, as implemented in the Model 2126 Constant Fraction Discriminator, is given in the Timing Section.

This module can be connected to NaI or fast plastic detectors with negative amplitude output signals ranging from –5 mV to –5 V, and rise times down to 1 nanosecond. The 2126 performs no signal processing on the input and is very often attached directly to the anode of a photomultiplier tube. As mentioned above, constant fraction discrimination is a method that offers a timing output signal when a constant ratio of the pulse height is reached. This ratio, once set, is consistent from pulse to pulse, thus removing the amplitude and rise time errors that arise. The main problem with this method is that it is still sensitive to pulse shape distortion, exhibiting poor time resolution for energies less than 200 keV and for poorly shaped or noisy pulses.

Whenever noise or low amplitude is a significant characteristic of a detector, a filter network is required between the signal source and amplifier to alleviate the noise distortion. The Model 2111 Timing Filter Amplifier has a built-in filter that attenuates the noise component before amplification of a low signal. When used with a constant fraction discriminator such as the 2126, a stable time reference can be derived. The 2111/2126 combination has widespread application in gamma-gamma coincidence and lifetime studies, offering excellent time resolution, which in connection with the high resolution of large germanium detectors, increases the rate of useful data collection.

The 2111 Timing Filter Amplifier is applicable for both surface barrier and germanium timing applications. Both of these detectors produce signals of low amplitude, distorted with noise, and in the case of germanium detectors, poorly shaped rise times. A gamma-gamma coincidence system with NaI and germanium detectors is shown in Figure 1.43. This is an example of a “fast-slow” coincidence system in which Model 2111 and 2126 constant fraction discriminators are used to indicate the presence of a pulse, and an energy range on the NaI detector is selected. The energy spectrum of the germanium detector is stored in the MCA if the ADC gate is opened by a coincidence pulse representing a combination of proper NaI-germanium timing and the selected NaI energy. A Model 2145 TAC is used to set the true coincidence range because of the set-up convenience offered, as described above. The TAC SCA output and the Timing SCA output of a Model 2015A Amplifier/Timing SCA are placed in coincidence with Model 2040 Coincidence unit. If desired, an energy requirement could be placed on the germanium detector by adding a Model 2037A Timing SCA on the 2025 amplifier’s bipolar output, and feeding the 2037A’s output to the Reset/Inhibit input on the 2145 TAC.

Anticoincidence systems are occasionally required, as mentioned above for Compton suppression in germanium detectors (see Figure 1.24) or cosmic ray suppression in alpha/beta counting.
Figure 1.43 NaI-Ge Fast-Slow Coincidence Electronics