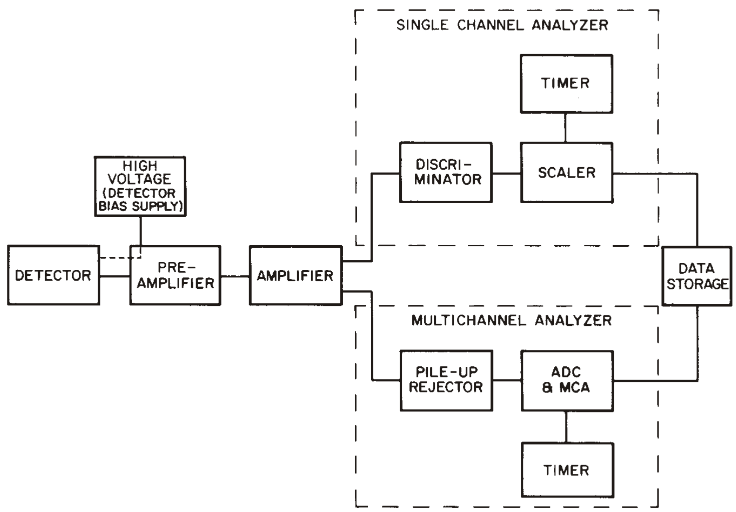
Chem 481 Lecture Material
3/25/09

Radiation Detection and Measurement

Gamma-ray Spectrometry

In order to obtain energy information from the output of gamma ray detectors, the output pulses must be processed by suitable electronics. A schematic diagram for a typical gamma counting system utilizing a NaI(Tl) or HPGe detector is shown below. Many of the individual components are built as NIM modules (Nuclear Instrumentation Methods modules) that fit into a standard bin that supplies power to the modules. Recently the trend has been toward the use of a stand-alone unit that contains all of the necessary pulse processing electronics. A description of the individual electronic components follows.

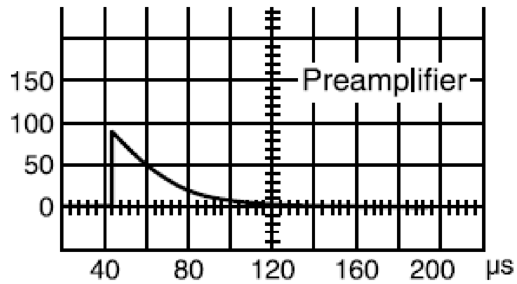


High Voltage Supply

For a NaI(Tl) detector this provides the necessary voltage to power the dynode stages in the photomultiplier tube. Typically a voltage of 900-1100 V is needed. In a semiconductor detector this supply provides the necessary reverse-bias voltage. Typically a voltage of 2000-3000 V is used.

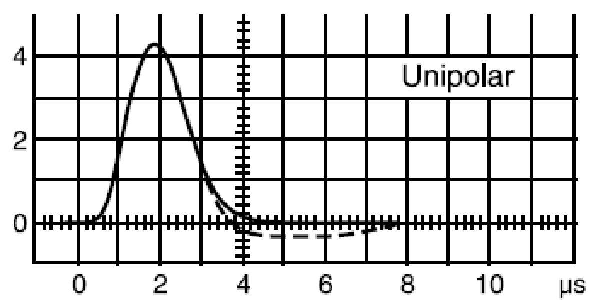
Preamplifier

A charge sensitive preamplifier generates a voltage pulse proportional in size to the integrated charge output of the detector. The preamplifier may also shape the pulse and provide signal amplification. Charge collection in a preamplifier is very rapid (see figure below). To maximize performance the preamplifier is located at the detector and is cooled to liquid nitrogen temperature to minimize noise.



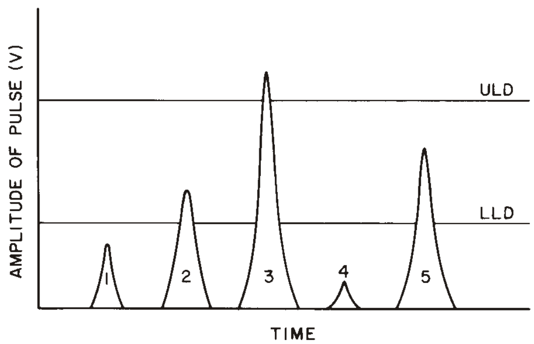
Amplifier

The amplifier further shapes and amplifies the output pulse. A unipolar pulse such as shown in the figure below is produced which is much shorter than the slowing decaying pulse produced by the preamplifier. The undershoot of the pulse (dashed line) will distort the amplitude of next pulse (resulting in photopeak broadening) if it occurs in close succession. The undershoot is compensated for by a process called pole/zero cancellation which quickly returns the unipolar pulse to zero baseline voltage.



Single Channel Analyzer (SCA)

When a single gamma energy is being counted, such as in a biological assay involving ^{125}I, it may be convenient to use a gamma counter that employs a single channel analyzer (SCA) and scaler. The SCA has a lower and an upper level discriminator so that only input pulses with a size that falls between the discriminator levels will generate an output logic pulse that is counted by a scaler (see figures below).



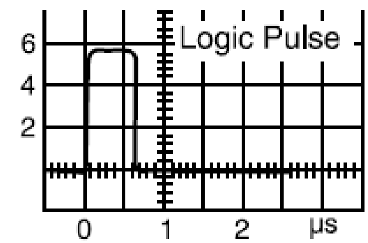


Figure 8.27. Utilization of a single-channel analyzer (SCA) for energy discrimination.

Multichannel Analyzer (MCA)

If a sample emits many gamma rays of interest, a full spectrum of pulses (energy spectrum) can be obtained with a multichannel analyzer (MCA). One can think of a MCA as a series of SCAs with incrementing narrow windows, each with it own memory location to store data. The output from the amplifier is first digitized by an analog-to-digital converter (ADC) which converts the pulse into a number proportional to the energy deposited in the detector by the gamma ray. This number will correspond to the address of a particular memory location (channel) and one count is added to this channel The MCA can process pulses over the entire output voltage range and display the spectrum in real time. A computer program analyzes the spectrum to provide specific information such as photopeak energy and area and even radionuclide present.

Unlike the other components of a gamma-ray spectrometry system, the ADC is a gated device. That is, while it is busy digitizing an input pulse, it closes and will not accept additional input until the digitizing is complete. The digitizing time interval is known as ADC dead time and information will be lost during this period. To compensate for this, one counts for a specific amount of 'live time', the time when the ADC is available. The analyzer simply extends the counting time until the sample has been counted for a specific amount of ADC processing time. For example, if the ADC is busy 5% of the time, a 1000-second live-time count will be extended to a total of 1050 seconds of actual clock time (real time). This method to correct for dead time losses works fine except when the activity being counted is decaying significantly during the counting interval. Extending the counting time will not correct for dead time losses in this case because there may not be anything left to count.

In a traditional Wilkinson ADC, the time to digitize a pulse is proportional to the energy (amplitude) of the pulse; higher energy means longer conversion time. The digitizing process is illustrated in the figure below. First,the amplitude of the incoming signal is stored on a capacitor. When the peak of the signal is detected, the capacitor is linearly discharged back to zero volts. When the discharge process is started, a counter begins counting upward from zero. When the capacitor is fully discharged, the counter is stopped and the number it contains is the digitized amplitude of the pulse. The clock rate of the counter is typically 100 MHz (as in the lab) but can be as fast as 450 MHz.

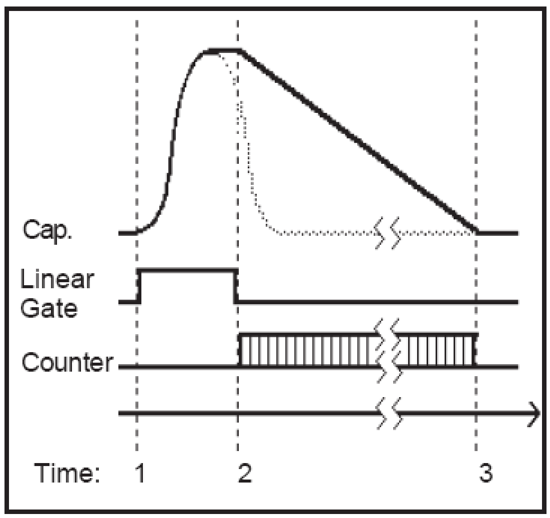


Figure 16
Wilkinson ADC Operation

For many counting systems the ADC is the slow throughput component because it takes 10s of microseconds to digitize pulses. Newer, fixed conversion time ADCs (for example, 0.9 μs conversion time irregardless of pulse size), which operate on a system of successive approximations, are much faster (can handle higher count rates) than the Wilkinson type.

Modern, high performance MCAs use digital signal processing techniques which start with digitizing the preamplifier signal. This digital signal is then further processed using high-speed digital calculations.