## Glossary of important terms

This document defines some of the more important terms which are used in nuclear instrumentation and in X-ray spectroscopy. It is not an exhaustive glossary but is intended as a quick reference.

**Activity** (of a radioisotope)**:** The number of nuclei in a sample undergoing radioactive decay in each second. It is commonly expressed in curies (Ci), where 1 Ci = $3.7\times10^{10}$ disintegrations per second. Today, the preferred (SI) unit is the becquerel (Bq), where 1 Bq = 1 disintegration per second = 27 pCi.

**Baseline** (of a pulse): The instantaneous value that the voltage would have had at the time of the pulse peak in the absence of that pulse. In nuclear electronics, pulse heights are measured relative to the baseline, which is not necessarily zero. See Figure 1.

**Baseline restoration**: A method used to keep stabilize the baseline of a shaped pulse. Baseline restoration (BLR) typically uses active feedback, where an error amplifier samples only the baseline (the shaped output between valid signals) and produces the correction signal needed to hold this constant.

**Baseline shift**: Changes in the pulse baseline. These usually occur due to changes in count rate or to other long term drifts, ie with temperature.

**Bias** (voltage): The voltage applied to a detector to produce the electric field to sweep out the signal charge.

**Bipolar pulse**: A pulse that has two lobes about the baseline. See Figure 2.

**Charge collection time**: The time interval, after a radiation interaction, during which the signal current flows between the terminals of the detector.

**Charge sensitive preamplifier:** A preamplifier in which the output voltage signal is proportional to the input charge. Since charge is the time integral of current, a charge sensitive preamplifier provides the time integral of the input current.

**Conversion gain**: The ratio of output signal to input signal in which the units differ between output and input. In nuclear electronics, the preamplifier (charge amplifier ) has an input in units of energy (eV) or charge (pC) and the output in units of volts. The multichannel analyzer has an input in units of volts and output in units of channels.

**Dead time**: The duration of time following a valid event during which a subsequent event will not be measured by a particular electronic system.

**Decay time constant**: The time for a true single exponential waveform to decay to a value 1/e of the original height.

**Detector**: The radiation sensor, producing an electrical signal when ionizing radiation interacts within it.

**Dose**: The quantity of radiation absorbed, specifically in energy per unit mass. It is commonly expressed in rads, where 1 rad is 100 ergs/gram. Today, the preferred (SI) unit is the gray (Gy), where 1 Gy=100 rad = $10^4$ ergs/gram

**Dose equivalent**: A measure of the biological damage to living tissue from radiation exposure. It is the product of absorbed dose in tissue multiplied by a "quality factor" which depends on the type of radiation. It is expressed numerically in rems or sieverts

**Electron volt**: A unit of energy, the kinetic energy gained by an electron through an electrostatic potential difference of 1 volt. Commonly used in radiation instruments because its multiples, kiloelectron volts (keV) and megaelectron volts (MeV), are in the range of characteristic ionizing radiation. 1 eV = $1.6\times10^{-19}$ joules.

**Electronic noise**: Spontaneous fluctuations in the output voltage of a system resulting from the physics of the devices and materials making up the system.

**Energy resolution**: The minimum separation between two peaks in the energy spectrum at which the peaks are resolved.

**Energy spectrum**: The distribution of the intensity of the radiation as a function of energy.

**Equivalent noise referred to input**: The value of the noise at the input of an electronic system that would produce the same value of noise at the output as does the actual noise source (regardless of its origin). Also called Equivalent Noise Charge (ENC).

**Fast Channel**: The "fast" and "slow" channels are two parallel signal processing paths inside many shaping amplifiers, operating at different shaping times and optimized to obtain different information about the incoming pulse train. The "slow" channel, which has a long shaping time constant, is optimized to obtain an accurate pulse height. The "fast" channel, which has a short shaping time constant, is optimized to detect pulses which are closely spaced in time and so overlap (or pile up) in the slow channel.

**Flicker Noise**: Also known as 1/f noise, pink noise, low frequency noise, or excess noise, this is electronic noise with a spectral density that varies as $1/f^{\alpha}$ with $\alpha$ near unity. Its physical origin is not as clear as shot noise or thermal noise, the other fundamental noise sources: it is clearly associated with the details of fabrication of electronic devices rather than their intrinsic properties. In radiation detector, 1/f noise is independent of shaping time constant and therefore often dominates electronic noise at the noise corner.

**Full Width at Half Maximum (FWHM)**: The width of a shape at 50% of its peak amplitude. Can refer to the width of a peak in the energy spectrum or to the shape of a pulse or to any other peaked shape. For a Gaussian, the FWHM is 2.35 times its $1\sigma$ value.

**Gamma-Rays**: Electromagnetic radiation generated by transitions within nuclei. Usually corresponds to wavelengths <0.1Å (>120 keV). In astronomy, where the origin of the photons is not known, gamma-rays are often considered to be photons $\geq$511 keV.

**Incoming count rate** (ICR): The true rate of radiation interactions in the detector. Because electronics have a dead time and radiation interactions occur at random time intervals, the rate of measured events (or output count rate, OCR) is always less than the ICR.

**Multichannel analyzers (MCA)**: A multichannel analyzer measures the distribution or spectrum of incident events. Its output is a histogram containing the number of events occuring within each data channel. Most commonly, the MCA measures the energy spectrum and each channel corresponds to an energy range. The histogram then represents the number of events within each energy range, which is the energy spectrum. MCAs can also measure a timing spectrum or other distribution.

**Output count rate** (OCR): The rate of events measured by the electronic system.

**Parallel noise**: Electronic noise arising from components in parallel with the detector, the signal sources. This is generally equivalent to current noise into the preamplifier and arises primarily from shot noise in the detector and thermal noise in parallel resistances.

**Peaking time**: The time required for a shaped pulse to go from the baseline to the peak. It is related to the shaping time constant the shaping amplifier, usually approximately 2.4 times as long. See Figure 1.

**Pile-up**: An event in which two (or more) pulses overlap in time. See Figure 3.

**Pile-up detector**: Circuitry to detect the overlapping or partial coincidence of two pulses.

**Pulse duration**: The time during which the pulse amplitude is non-zero. Because of the difficulty of defining "zero" accurately (in analog systems), it is usually specified as FWHM (full width at half maximum), the time during which the pulse amplitude is greater than or equal to half the peak height. See Figure 1.

**Pulse height**: The height of a pulse measured from its peak to the instantaneous baseline. Also called peak height. See Figure 1.

**Pulse height analyzer**: Circuitry to categorize pulses according to heights. There are two main classes, single channel analyzers and multichannel analyzers.

**Pulse height distribution**: The distribution of the frequency of pulse heights. Usually a histogram, in which the horizontal axis represents the pulse height (in a certain number of pulse height bins, or channels) and the vertical axis represents the number of events with pulse height in each channel. Most often, the pulse height corresponds to deposited energy so the pulse height distribution (PHD) is the energy spectrum. However, the pulse height may also correspond to timing or other properties.

**Pulse pair resolving time**: The minimum time between two pulses at which they can be recognized by the electronics as two distinct pulses.

**Radiation:** Energy traveling through space. Nonionizing radiation is common and includes light, radio waves, and sound waves. Ionizing radiation includes both electromagnetic radiation (X-rays and $\gamma$-rays) and particles such as alpha and beta particles and neutrons.

**Radioactivity**: The spontaneous emission of radiation from a nucleus decaying to a lower energy state.

**Semiconductor detector**: A semiconductor device that utilizes the production and motion of excess charge carriers to detect and measure incident ionizing radiation.

**Sensor**: A device which produces an electric output from some energy input or stimulus.

**Series noise**: Electronic noise arising from components in series with the detector, the signal source. This is generally equivalent to voltage noise into the preamplifier and arises primarily from noise in the input channel of the JFET used at the preamp input.

**Shaping amplifier**: An amplifier that accepts the output pulses from a charge-sensitive preamplifier and shapes them in order to improve the signal-to-noise ratio and to minimize pile-up. In nuclear electronics, this usually consists of some form of differentiator (or high pass filter), a voltage amplifier, and some form of integrator (or low pass filter). See Figure 2.

**Shaping time constant**: The time constant $\tau$=RC of a semi-Gaussian shaping amplifier with equivalent noise bandwidth. The complete performance of a shaping amplifier depends on many time-related parameters, including peaking time, pulse width, noise bandwidth, and top duration. The relationship between these quantities and the "shaping time" depends greatly on the shaping amplifier implementation, so using only the shaping time constant to specify shaping is not recommended [see IEEE Std 301-1976, p 15] but it remains common practice.

**Shot noise**: Electric current is the flow of discrete, quantized electric charges. Shot noise is electronic noise arising from statistical fluctuations in the current through a junction, such as that in a semiconductor detector, where it forms a current or parallel noise source.

**Single channel analyzer** (SCA): Circuitry which produces a logic output pulse indicating the presence of an input pulse with peak amplitude in a specific range. The time of the logic output bears a specific relationship to the time of the input pulse, and there are several different time relationships which are commonly used in different classes of SCAs.

**Slow Channel**: See Fast Channel.

**Spectrometer**: An instrument for obtaining spectra.

**Spectroscopy**: The study of spectra.

**Spectrum**: The distribution of a characteristic of a physical system or phenomenon, or a graphic representation of such a distribution. In most nuclear applications, the energy spectrum is of interest, ie one measures the distribution of emitted energies. The timing spectrum, mass spectrum, charge state spectrum, and other spectra are also measured.

**Tail pulse**: A pulse having a short rise time and a long, exponential decay.

**Thermal Noise**: Electronic noise arising from the random thermal vibrations of charge carriers in a conductor. In radiation detection, thermal noise is most often due to the channel of the input FET, where it is a voltage or series noise soure, and to the feedback resistor, where it is a current or parallel noise source.

**Unipolar pulse**: A pulse which is predominantly single sided with respect to its baseline.

**X-ray**: A type of electromagnetic radiation with wavelength below 10 angstroms ($10^{-9}$ m), or energies above 1.2 keV. Hard X-rays, with shorter wavelength and higher energy, overlap the range of lower energy gamma rays. The distinction between the two depends on the source of the radiation, not its wavelength: X-ray photons are generated by energetic electron processes, gamma rays by transitions within atomic nuclei.

**X-ray fluorescence**: A method for identifying the elements in a sample from the spectrum of characteristic X-rays emitted by the atoms in the sample when excited by radiation.

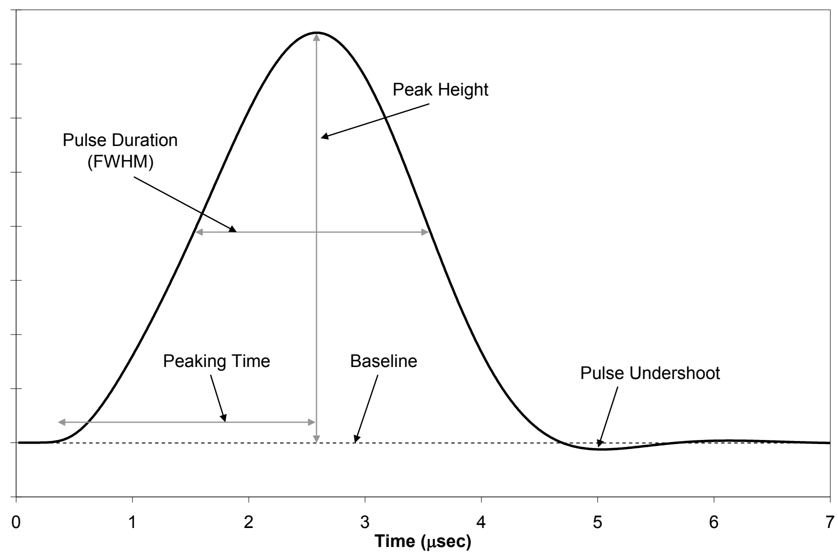


Figure 1. Illustration of typical unipolar shaped pulse, defining the critical quantities.

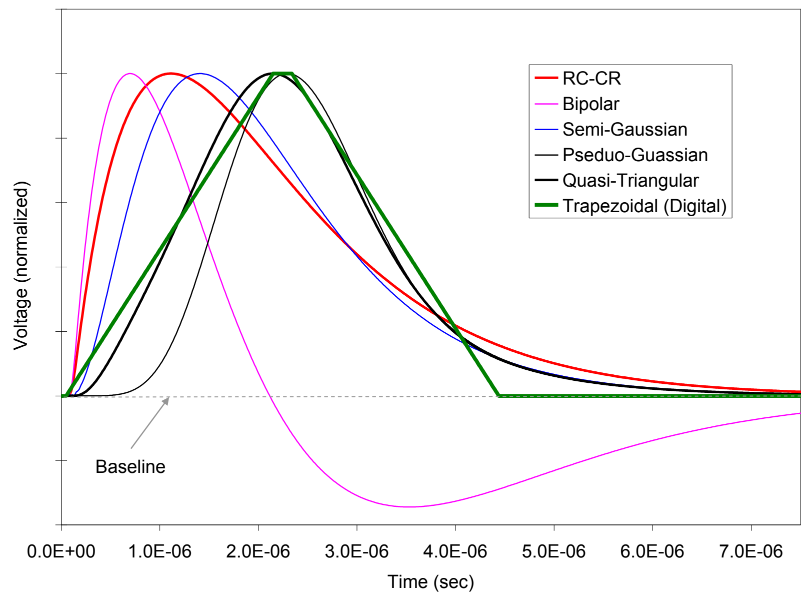


Figure 2. Illustration of pulse shapes obtained with different shaping amplifiers. Each of these has a “shaping time constant” of 1 μsec but with different transfer functions. The general properties are as follows:

- RC-CR: Very simple to implement but usually exhibits poor performance (noise, dead time, stability).
- Bipolar: Simple to implement and negative lobe makes for good baseline stability, but long pulse duration so poor dead-time characteristics and poor noise characteristics
- Semi-Guassian and Pseudo-Gaussian: Implemented using active filters (complex pole pairs). When used with active baseline restoration, these provide good performance using analog components.
- Quasi-Triangular: Also implemented using active filters in analog components. This is very close to the “ideal” transfer function, for optimum performance, but is relatively complex.
- Trapzoidal: Implemented using digital processing. Has the best performance, combining excellent resolution, stability, and dead time.

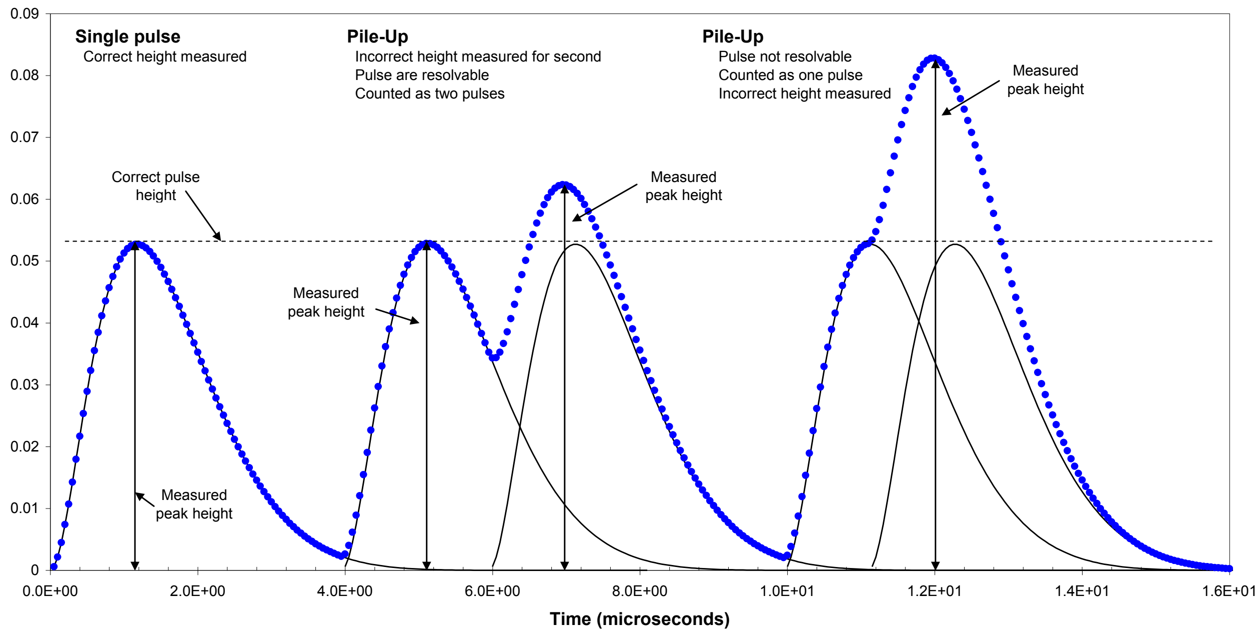


Figure 3. Illustration of pulse pile-up. This plot shows five incident pulses, which occur at random time intervals since nuclear decay is a stochastic process. The individual pulses are the black lines, while the blue dots represent the sum, which is what is measured.

The first pulse, on the left, is isolated in time and so is counted at the correct pulse height measured. The next two overlap partially, with a valley between the peaks. Two pulses will be recorded, and the first will have the correct pulse height, but an incorrect amplitude is measured for the second. The final two overlap enough that there is no valley. This looks like a single pulse to the electronics (they are not resolvable) with an incorrect height. If the two occur close enough in time, the resulting amplitude is the sum of the individual pulses.