The Multichannel Pulse-Height Analyzer

The Multichannel Pulse-Height Analyzer is the primary tool used in nuclear science to record the energy or time spectra available from nuclear radiation detectors. It is often referred to as an MCA (MultiChannel Analyzer) or an MCB (MultiChannel Buffer). The former term was common when the function was totally contained in a stand-alone instrument. With the advent of the Personal Computer, the auxiliary memory and display functions were shifted to a supporting computer, and the specialized hardware for the pulse-height histogramming was incorporated on a card that plugged into the computer back-plane, or interfaced to the computer via a USB or some other interface cable. Thus, the computer-interfaced MCA is sometimes called a MultiChannel Buffer.

The basic function of the MCA can be understood as follows[1, 2, 3, 4]. Consider the case where a detector, offering a linear response to the energy of gamma rays, produces a pulse of electrical charge for every gamma-ray photon that is detected. In simplest terms, the amount of charge in the pulse produced by the detector is proportional to the energy of the photon. The preamplifier collects that charge, while adding as little noise as possible, converts the charge into a voltage pulse, and transmits the result over the long distance to the supporting amplifier. The amplifier applies low-pass and high-pass filters to the signal to improve the signal-to-noise ratio, and increases the amplitude of the pulse. At the output of the amplifier, each pulse has a duration of the order of microseconds, and an amplitude or pulse height that is proportional to the energy of the detected photon. Measuring that pulse height reveals the energy of the photon. Keeping track of how many pulses of each height were detected over a period of time records the energy spectrum of the detected gamma-rays.

The spectrum of gamma-ray energies could be laboriously recorded by using a single-channel pulse-height analyzer, a counter and a timer. This process would involve using a very narrow, voltage window on the single-channel analyzer (SCA). The window would be stepped through the entire 0 to 10-V pulse height range. At each step, the counts per unit time would be recorded with the counter and timer. Plotting the measured counting rate versus the lower level voltage of the window would generate the energy spectrum. Before the invention of the MCA, this is how nuclear physicists measured the energy spectrum. Compared to what can be accomplished with the MCA, it was a terribly inconvenient process.

There are a variety of electronic circuit designs employed in multichannel pulse-height analyzers[3]. But, the basic process can be understood as follows. The arrival of a valid input pulse (derived from the previously described amplifier output) must be recognized to start the process. To prevent wasting processing time on the noise that is always present on the baseline between pulses, the MCA uses a lower level discriminator with its voltage threshold set just above the maximum amplitude of the noise. When a valid pulse from a gamma ray exceeds the threshold voltage, the subsequent circuitry is triggered to search for the maximum height of the pulse. To protect against contamination from succeeding pulses, the linear gate* at the input to the ADC closes as soon as the maximum amplitude is captured. That maximum pulse height is presented to an Analog-to-Digital Converter (ADC) to be coded as a digital representation of the analog voltage. Essentially, the ADC compares the analog pulse height to a ladder of voltage levels. The ladder extends from 0 to 10 V with a uniform space between the rungs. Each rung represents a defined voltage. When a pulse arrives for measurement, the ADC looks at the voltage of the pulse, and decides which two rungs it belongs between. The intervals between rungs are numbered from zero to N_{max}. If the pulse falls in the N^{th} space between rungs, one count is added to the existing counts in the N^{th} memory location of the histogramming memory. Once the analysis of the pulse is completed, the MCA opens its linear gate and waits for the next available pulse to arrive. The process is repeated on a pulse-by-pulse basis over the counting time established by the instrument operator. At the end of the counting time, the histogramming memory contains a record of counts versus memory location that can be displayed to present the same energy spectrum that was plotted from the SCA in the process described in the previous paragraph.

The data in the histogramming memory breaks up the energy scale of the spectrum into discrete, digital intervals. These intervals are typically called channels, in analogy with the use of the single-channel analyzer described above. If the ADC has 1000 channels, the 0 to 10 V pulse-height range is digitized into channels that are 10 mV wide. ADC resolutions are commonly available from 500 to 32,000 channels. Detectors that have a finer energy resolution require more channels, while it is more productive to use a lower number of channels with detectors having coarser resolution[6].

MCAs that are supported by computers generally use the computer to display the spectrum, analyze the spectral content and select the operating parameters for the MCA. It is important to develop familiarity and agility with those controls. Because the channel number is proportional to the energy of the gamma ray (to first order), the horizontal scale can be calibrated to read in the appropriate units of energy. Typically, the computer mouse can be used to click on the top of a gamma-ray peak in the spectrum to identify the energy of the gamma ray. The mouse can also be employed to set a region-of-interest (ROI) across a peak. This enables convenient summing of the total number of counts in a peak, and the subtraction of the background under the peak. ROIs can be used with embedded software to obtain a more accurate estimate of the peak energy for energy calibration purposes[6].

One of the more useful features of an MCA is the live time clock. This is a scheme that counts elapsed time only when the system is not dead to accepting an additional pulse[2, 3, 5]. Thus, if the experiment is run for a preset live time, there is an automatic correction for the dead time. The observed counts divided by the elapsed live time represents the true counting rate at the input to the detector. Collecting counts for a preset live time not only compensates for the systematic error caused by dead time, but it also eliminates the dead time distortion of the counting statistics[2, 3, 5]. Consequently, the square root of the number of counts obtained in the preset live time can be used to estimate the expected standard deviation in the counts.

Other significant features are controls for starting/stopping data acquisition, a button for clearing the contents of the memory, the ability to select the digital resolution (number of channels full scale), upper and lower level discriminators to limit the pulse heights that are accepted, and a linear gate function. The linear gate incorporated in the MCA allows the user to apply a logic pulse to the gate control input to preferentially select which analog pulses will be processed and which pulses will be rejected. This is a useful function for coincidence experiments.

MCAs and MCBs generally have the ADC closely coupled to the histogramming memory. This histogramming mode is an efficient configuration when the instrument is used to analyze the spectrum from a single detector. More sophisticated experiments in nuclear science involve multiple detectors measuring various aspects of the decay of an excited nucleus. In this case, it is more productive to separate the ADCs from the histogramming memory[3]. The ensemble of coincident events from all the detectors for the decay of a single nucleus must be concatenated as an isolated, multiparameter event for more complicated data processing. For that situation, the concatenated ADC outputs are saved as sequential, multiparameter events in a list in the computer memory[3]. This is referred to as the list mode. Mining useful data from the list mode requires complicated, special purpose software.

For further information on the operation of the MCA, consult the manufacturer's data sheet and instruction manual, or peruse the references listed below.

References

1. Glenn F. Knoll, Radiation Detection and Measurement, 2nd Edition, John Wiley & Sons, New York, 1989.
2. Ron Jenkins, R. W. Gould and Dale Gedcke, Quantitative X-Ray Spectrometry, Marcel Dekker, Inc., New York, 1981.
3. See the Introduction to the CAMAC ADCs on the ORTEC web site at www.ortec-online.com/Solutions/modular-electronic-instruments.aspx.
4. See the Pulse-Height, Charge or Energy Spectroscopy topic on the ORTEC web site at: www.ortec-online.com/Solutions/scientific-research.aspx.
5. D. A. Gedcke, ORTEC Application Note AN63, Simply Managing Dead Time Errors in Gamma-Ray Spectrometry, available at http://www.ortec-online.com/Library/index.aspx?tab=1.
6. D. A. Gedcke, ORTEC Application Note AN58, How Histogramming and Counting Statistics Affect Peak Position Precision, available at http://www.ortec-online.com/Library/index.aspx?tab=1.

*A linear gate transmits the analog signal when the gate is open, and blocks the analog signal when the gate is closed. The timing and durations of the open/closed states are controlled by the width of a logic pulse.

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