THE MULTICHANNEL ANALYZER

PHYSICS 359E

INTRODUCTION

The multichannel analyzer (MCA) is an important laboratory instrument which can measure distributions of input signals consisting of pulses. It operates in two different modes: pulse height analyzer (PHA) mode, and multichannel scaler (MCS) mode. In PHA mode, the input pulses are sorted into bins (channels) according to their amplitude, while in MCS mode they are sorted according to the time when they arrive. The MCA provides a visual display of the resulting distributions and usually can output the data to a printer or computer for further analysis. Control in older MCA's was done by hard-wired logic, whereas all modern MCA's are microprocessor-controlled and have fairly extensive local arithmetic operation capabilities. Most microcomputers can function as MCA's with the addition of a specialized MCA board. In this experiment, the MCA will be used in PHA mode to investigate nuclear γ-ray spectra, and in MCS mode to study statistical distributions. These two modes are discussed in turn.

PHA mode

Recall that the scintillation detector produces a spectrum of pulse amplitudes corresponding to different energies lost by radiation interacting with the crystal. In Expt.1.1 on the scintillation counter, you used a single channel analyzer (SCA) to measure the pulse height distribution from a γ-ray source. Not only was this exercise tedious but it was inefficient since only a small range of pulse heights (determined by the window width) could be counted at one time. In PHA mode, the MCA is logically equivalent to an array of SCA's and counters. The amplitude of an incoming analog pulse (normally in the 0-10 V range) is digitized by the ADC (see Fig.1) and the digital value is used as the address of a memory location (corresponding to a given channel) that is incremented. Thus the screen display of the number of counts vs. channel number is really a histogram of the number of counts vs. pulse height, i.e. a pulse height spectrum. The range of pulse heights to be analyzed can be set via upper and lower level discriminators at the input (not shown in Fig.1).

MCS mode

In this mode, all incoming pulses are counted in one memory location (channel) for a given time (the dwell time) and then counting is moved to the next location for the same time and so on. The dwell time is determined by settings of switches on the front panel. The logic pulse which advances the channel number may also be used to step the value of some experimental parameter X; thus the MCA is effectively displaying the number of counts Y as a function of X. In this mode, the MCA is a sophisticated X-Y recorder. As an example, X might be the wavelength of a tunable laser and Y the number of fluorescent photons produced when the laser beam passes through some atomic vapour. The MCA display is the optical absorption spectrum of the vapour.
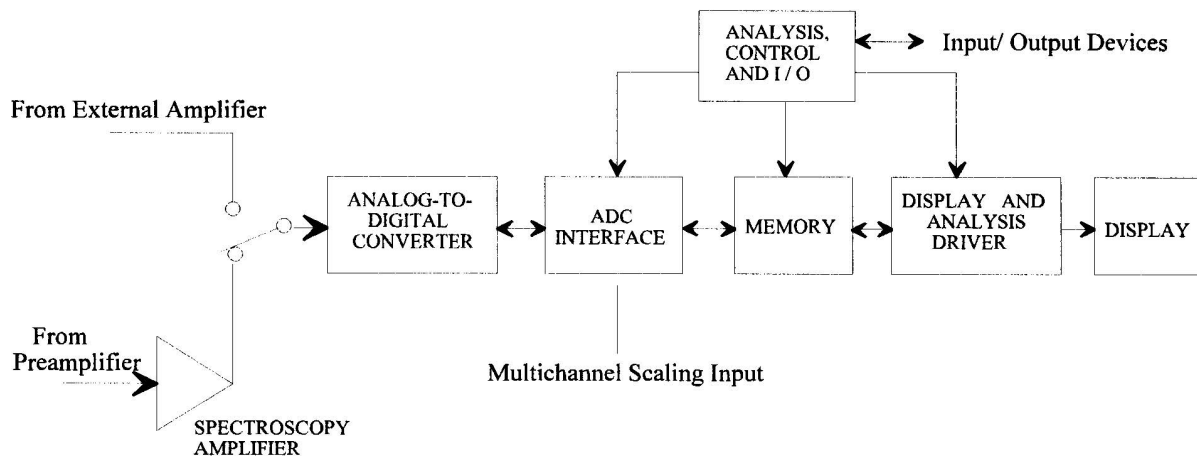
Figure 1: MCA functional block diagram

See the manual for the MCA that you are going to use for complete operating instructions. Find out the maximum value of input pulse height for your MCA ($V_{\max}$) and understand the function of the ADC gain control.

PROCEDURE

Pre-laboratory preparation

Read Chapter 10, Secs 2 and 5, in Reference 1. (You will probably not be able to do the lab exercise correctly without understanding this material.)

Computer connection

The MCA output should be connected to a lab microcomputer so that spectra can be transferred, stored as data files, plotted, and analyzed.

If you are using the Canberra MCA, the software for file transfer is located on device G: in subdirectory \MCA. A program called CANREAD will ask you for the memory segment being used and the channels to transfer. It will then command the MCA to transfer data and inform you when it is finished. You should run the program from your own directory (e. g. F:\JONES). Once the file is stored on the micro as ASCII, you can use all of the usual software for plotting, curve fitting, etc.

If you are using the Tracor MCA, use program TRACOR in G:\MCA. Data is transfered via a serial connection from the MCA. The program will ask you for a filename and then ask you to press the I/O button on the MCA.

If you are using an MCA built into a microcomputer, use the mouse and the menu system to store the spectrum to disk. The saved file will have to be processed through a conversion program to put it in a form usable by the plotting and analysis programs.

Part I: Nuclear γ-ray spectra

The experimental setup used in this part is similar to that used in the study of scintillation detectors, with the output of the amplifier going to the MCA rather than the SCA and scaler. Using this

arrangement, you should make the following measurements:

1. Connect the pulser to the input of the linear amplifier and adjust the pulse height and amplifier gain to give an output pulse near the maximum input for the MCA you are using (determine this using your pulser). Then connect to the MCA and measure the channel number as a function of pulse height using the ten-turn potentiometer on the pulser to change the pulse height. You should find a linear relationship between channel number and pulse height; ideally the intercept should be zero but there is usually an offset, which must be known when converting a channel number to a voltage or γ-ray energy.

2. Connect the scintillation detector to the amplifier input, set the high voltage at the normal operating value and adjust the amplifier so that the pulses from the ^{137}Cs source have a maximum amplitude of about 40% of $V_{\max}$. Use the MCA to measure the pulse height distribution from the ^{137}Cs source and use this to provide a calibration of γ-ray energy vs. channel number for the rest of the experiment.

3. Using the calibration from 2., **measure the energies** of the γ-rays from the ^{60}Co, ^{133}Ba and ^{22}Na sources. Also, obtain γ-ray spectra from the sample of uranium ore and the luminous watch dial in the lab. At the end of this series of measurements, repeat your measurement of the spectrum of ^{137}Cs to make sure your calibration has not changed.

4. Connect the large NaI scintillation detector to the amplifier input. Place the jar of potassium chloride on the crystal and accumulate a spectrum for about 15 min. You will have to adjust the gain of the amplifier so that the spectrum fits on the display. You should observe a peak (what energy?) arising from the decay of the ^{40}K (0.01% abundance) in the KCl. Since this is a rather weak source, you should remove the source, put the MCA in SUBTRACT mode, and count background for exactly the same time that you used for the source. This procedure is known as background subtraction and should always be used when the background is appreciable. Save the spectrum and calibrate the detector using the ^{137}Cs source.

5. In part 4. you will have observed some very large pulses arising from the interaction of cosmic ray muons with the crystal. To study these, recalibrate the MCA with ^{137}Cs using a gain which places the Cs photopeak in a high channel. Then, using the click switches on the amplifier, reduce the gain to a value which will put pulses of 60 MeV in the highest channel. Accumulate data overnight to obtain a spectrum from the muons. Note that the energy spectrum of muons will not show a peak. This spectrum may however show the ^{40}K γ-ray peak arising from the potassium in walls and floor of the lab (what energy should this peak have?).

Part II: Statistical distributions

In the measurements above you should have noted fluctuations in the number of counts recorded in unit time, especially for the weaker sources. This illustrates a fundamental characteristic of radioactive decay which can be easily investigated with this apparatus.

Radioactive materials can be characterized by a decay constant with the following significance: the probability that any given nucleus will undergo decay in time interval dt is just λdt. For a source containing N nuclei, this can be written as

$$\frac{dN}{N} = -\lambda dt \tag{1}$$

or

$$\frac{dN}{dt} = -\lambda N \tag{2}$$

leading to the famous exponential decay law $N(t) = N_0 \exp(-\lambda t)$, where $N(t)$ is the number of nuclei remaining at time t and N_0 is the number at time 0. For observations made at times t such that $\lambda t << 1$, N hardly changes and the expected mean number $\langle \nu \rangle$ decaying in unit time, given by $\langle \nu \rangle = \lambda N$, is approximately constant. Nevertheless, there will be statistical fluctuations in the actual number of counts per unit time, and it can be shown (Refs. 1 & 2) that the probability of observing exactly ν counts per unit time is given by the Poisson distribution:

$$P(\nu) = \frac{\langle \nu \rangle^\nu \exp(-\langle \nu \rangle)}{\nu!}. \tag{3}$$

This distribution is difficult to use if ν and $\langle \nu \rangle$ are large, because all the terms in the expression become *very* large or *very* small (try evaluating Equation (3) for $\nu = \langle \nu \rangle = 100$ with your pocket calculator). In this circumstance $P(\nu)$ can be approximated by the Gaussian (normal) distribution

$$P(\nu)d\nu = \frac{1}{\sigma\sqrt{2\pi}} \exp[-\frac{(\nu - \langle \nu \rangle)^2}{2\sigma^2}]d\nu \tag{4}$$

with the standard deviation given by $\sigma^2 = \langle \nu \rangle$.

Now we want to accumulate some data that can be described by the two distributions. This can be accomplished by obtaining a long series of repeated measurements of ν from a radioactive decay.

Put the MCA in MCS mode, adjust the MCS dwell time and the source to detector distance such that you have approximately 1 count per channel. You can use the **Region of Interest** integral to verify this. Copy the contents of the MCA memory to a disk file on the computer for later analysis. This will include writing a short program to type out the number of times that each value of $\nu = 0, 1, 2, ...$ is observed, and comparing the resulting distribution with that predicted by the Poisson distribution. (Normalize your experimental distribution – multiply it by a constant – so that the areas under the experimental and Poisson distributions are the same.)

Now increase the count rate by a factor of about 100 and repeat the measurement. Again, save the data and count the number of times that each value of ν occurs. For the Gaussian distribution, you may find it useful to sum the data in 3 or 4 adjacent columns when plotting the histogram to reduce the statistical fluctuations in the number of occurrences of a given value of ν. Using the values of the mean and standard deviation obtained from your data, plot a Gaussian distribution on the same graph as your histogram. Comment on how well the Poisson and Gaussian distributions fit your data.

REPORT

Your report should include the following:

- the calibration curve from Part I, a).

- plots of the pulse height spectra labeled appropriately with an indication of the number of counts on the Y-axis and the γ-ray energy on the X-axis. The energies of any prominent features should be noted. Compare your deduced peak energies to tabular data (e.g. from Reference 3) for the decays you observe.

- histograms of the statistical distributions of counts in the two datasets you acquired in Part II, with the predicted distributions (Eqns. 3 and 4) superimposed.

- listings of any computer programs you wrote to analyze the data in Part II.

REFERENCES

1. Melissinos, A. C. and Napolitano, J., Experiments in Modern Physics, 2nd Ed. (San Diego, CA: Academic Press 2003), Secs. 10.2 and 10.5.

2. J.R. Taylor, An Introduction to Error Analysis (University Science Books 1982) Ch.11.

3. Handbook of Chemistry and Physics (CRC Press; available in the lab).