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IN THE OUTPUT OF A SINGLE CHANNEL ANALYZER
by G. W. Eakins, B. J. Loupee, W. A. Rhinehart, G. Schupp,
and E. N. Jensen

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A Method for Reducing Time Jitter in the Output of a Single Channel Analyzer

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ABSTRACT

An adapter for single channel analyzers has been built which reduces the time jitter in the output of an analyzer by a factor of approximately six. This reduction enables coincidence studies to be conducted using a correspondingly smaller $2\tau$ which results in an approximate sixfold increase in the true to accidental coincidence ratio. In addition the use of a smaller $2\tau$ permits the measurement of significantly shorter half-lives of metastable states than is possible without the use of adapters when only a simple coincidence circuit is utilized.

INTRODUCTION

Single channel analyzers have been used for a number of years in the study of gamma-ray spectra and in other experimental work where differences in pulse heights are utilized. The study of gamma-ray spectra will be discussed because it is of primary concern to this experimental group.

For gamma-ray spectra, a sodium iodide (thallium activated) crystal is used as the detector and the scintillation pulses from this crystal are collected by a photomultiplier tube whose pulses are then amplified before being fed into a single channel analyzer. The pulses into the analyzer are shaped approximately as illustrated in Fig. 1.

Time jitter is defined as the spread in the time output of a single channel analyzer as a result of the dependence of this time output on the pulse height input to the analyzer. A single channel analyzer can be designed to trigger on either the leading

Fig. 1 - Origin of time jitter in output of single channel analyzer.
or the trailing edge of a pulse; both methods give rise to time jitter in the output of the analyzer. Since the analyzers used in this study trigger on the leading edge, this method will be considered in illustrating the origin of time jitter.

A line has been drawn in Fig. 1 corresponding to an arbitrary window height setting of 20. If the analyzer is set to integrate, all pulses which rise above this line will be counted in the output, but the output for a high energy pulse will come out at an earlier time than the output for a low energy pulse because it will be triggered at time $t_1$ while the lowest energy pulse under the same conditions would be triggered at time $t_2$ or approximately $0.26 \mu\text{sec}$ later in time. Pulses of intermediate energy would be triggered at times between these two extremes. Time jitter of a slightly different type arises if the analyzer is set to give an output pulse only for input pulses within a certain energy region by differentiating. At a window height setting of 20, only the lowest energy pulse would be counted in the output of the analyzer and it would be triggered at time $t_0$ as before. If the window height is then moved to a setting of 800 in order to obtain the highest energy pulse in the output of the analyzer, it would be triggered at time $t_1'$ or approximately $0.21 \mu\text{sec}$ later in time than the low energy pulse under the same conditions. Again pulses which rise to intermediate window heights would be triggered at times between these two extremes but in this case the lower energy pulses would come out first.

If an analyzer is used to obtain only single channel gamma-ray spectra, the time output of the analyzer is unimportant. However, if the analyzer is used in conducting coincidence studies, the time output becomes a prime consideration. Coincidence studies are commonly conducted by feeding the outputs of two analyzers into a coincidence circuit with one analyzer set to give an output only for input pulse heights corresponding to a certain energy gamma ray and the other analyzer set at a certain window height and changed periodically in order to determine what gamma rays are in coincidence with the chosen gamma ray in the first analyzer. When each analyzer is set at a given window height, the electronic equipment can be adjusted to yield true coincidences in the output of the coincidence circuit. However, if the window height setting on one analyzer is changed, true coincidences would not be registered in the coincidence output if the time jitter between the two window height settings was enough to put the pulses from the new window height setting outside the $2\tau$ region of the coincidence circuit, where $\tau$ is the resolving time of the coincidence circuit.
The problem of time jitter in the taking of coincidence data can be partially alleviated if the output from one analyzer is fed into a variable delay and the delay adjusted to give a maximum coincidence counting rate for each window height setting. However, if one analyzer is set to integrate to obtain coincidence measurements, the variable delay could not simultaneously be set to account for the time jitter of all the pulses which lie above the integrating level and therefore the use of a variable delay is not a complete solution. The simplest method to solve the problem of time jitter is by using a large enough $2\tau$ so that even the maximum time jitter would not put any of the true coincidence pulses outside the $2\tau$ region of the coincidence circuit. The total time jitter in both analyzers is important in this consideration.

In the taking of coincidence data it is desirable to have as small a $2\tau$ in the coincidence circuit as possible for two principle reasons. First, the accidental coincidence counting rate is proportional to $2\tau$ and therefore a small $2\tau$ is desirable to obtain the best possible ratio of true to accidental coincidences for a given source. Secondly, the smaller the $2\tau$ which is used the shorter the half-life that can be measured of any metastable state which lies between two gamma-ray transitions. One method of overcoming the handicap of time jitter is in the use of fast-slow coincidence circuitry. This method is effective but requires a great deal of additional electronic equipment and poses stability problems. Another method, to be discussed in this paper, is to actually reduce the time jitter a significant amount. Although time jitter cannot be completely eliminated, a time jitter adapter for single channel analyzers has been designed and built which has proven to be effective in reducing time jitter by a significant factor.

II. OPERATIONAL THEORY

It can be seen from Fig. 1 that the least amount of time jitter between pulses occurs when the integrating level is as far as possible below any of the pulse peaks. Therefore, it was decided to utilize this fact by building an auxiliary piece of electronic equipment which would have a reduced time jitter from that in a single channel analyzer by integrating on the pulses of interest in the analyzer at a very low voltage level as compared to the voltage peaks of any of the pulses. This piece of equipment, called a time jitter adapter for single channel analyzers, would then be used to determine the time output of an analyzer pulse.

\[^2\text{Porter, Freedman, Novey, and Wagner, Phys. Rev. 103, 925 (1956).}\]
This was accomplished by taking the amplifier output, which had previously gone to the analyzer, and feeding it simultaneously into both the analyzer and the adapter. The spectrum of pulses into the analyzer would be studied as before, but an output pulse would be fed onto one grid of a trigger circuit inside the adapter to effectively cock the trigger. The same pulse would come from the amplifier directly to the adapter and be amplified as much as possible, taking into account the effect of a high electronic noise rate if the amplification were too large. This pulse would then go through a delay cable and be fed onto the other grid of the trigger circuit, thus establishing the time output of the analyzer pulse to the coincidence circuit. The delay cable is necessary to insure that the cocking pulse from the analyzer actually arrives before the adapter trigger pulse. The output counting rate of the adapter under this arrangement would be the same as that of the analyzer except for a small percentage loss due to dead time in the trigger circuit. This dead time arises from the fact that once an analyzer pulse cocks the trigger circuit, the next analyzer pulse would not be counted if it arrived before the first pulse was triggered.

The one problem introduced using this technique is the probability that some pulse other than the pulse which gave rise to the cocking pulse might trigger the trigger circuit. This is a purely statistical consideration depending on both the total counting rate of the triggering pulses and on the time interval between the arrival of the cocking pulse and the arrival of the appropriate triggering pulse. The first points out the importance of having proper noise control by means of a variable gain in the adapter amplifier stage, and the latter shows the importance of the length of the delay cable in the adapter in minimizing the time interval between the cocking pulse and the triggering pulse.

III. CIRCUITRY

The system chosen for the time jitter adapter is a combination of well known circuits as shown in Fig. 2. The system was chosen because of its basic simplicity and ease of adjustment.

The output of the single channel analyzer is amplified, inverted and shaped by a single triode amplifier shown in the circuit diagram (Fig. 3). The output of this amplifier triggers one grid of an Eccles-Jordan trigger circuit.3 To prevent the trailing edge of the pulse from returning the trigger circuit to

Fig. 2 - Block diagram showing time jitter adapter elements and utilization with single channel analyzer.
Fig. 3 - Time jitter adapter circuit diagram (Continued on page 10).
Fig. 3 - Time jitter adapter circuit diagram
(Continued from page 9).
its original condition, the following device was used: a small capacitor was placed from the plate of the amplifier tube to ground. The amplifier tube was biased at cutoff. As the tube conducts, the capacitor is discharged to some voltage below B+ through the low plate resistance of the tube. At the end of the pulse the tube is again cut off and the capacitor must charge through the large plate resistor. This RC time constant is large so the trailing edge of the output pulse has a slow decay toward B+. Since the resolving time of the adapter only needs to be as good as the resolving time of the single channel analyzer, the relatively slow decay allows a sufficient resolving time of two to three µsec.

The second input is from the photomultiplier amplifier and is the same as the input to the single channel analyzer. Input pulses are amplified by a four tube, wide-band amplifier with cathode follower input and output. A gain control is provided by a variable resistor in the feedback loop of the amplifier.

The output of the amplifier drives a 2800 ohm delay line with a delay of approximately two µsec. (The exact length depends on the delay of the single channel analyzer used and the time jitter within the analyzer.) A cathode follower output is provided from the input of the delay line to monitor the number of noise pulses that are of sufficient height to trigger the trigger circuit.

The delay line feeds the other grid of the Eccles-Jordan trigger circuit through another amplifier-shaper as described above. A negative pulse to the grid of a normally cut off tube produces no change so the operation is as follows: A random series of negative pulses from the amplifier and delay line is fed to one grid of the trigger circuit. This tube is then normally cut off. When a pulse falls in the window of the single channel analyzer a negative pulse is applied to the grid of the opposite tube causing a shift in conduction to the first tube. The first pulse applied to the first grid following the shift in conduction returns the trigger circuit to its original condition. With proper choice of delay line length the first pulse to reach the first grid will be the same in origin as the pulse that fell in the analyzer window. With the high gain of the adapter amplifier stage, the trigger circuit is triggered from a very low voltage level (less than 0.5 volt depending on gain setting) on the original pulse.

The negative pulse from the first plate of the trigger circuit is differentiated and the positive pulse from the trailing edge of the trigger circuit fires a blocking oscillator to give a constant output pulse that is approximately 180 volts high and
0.5 μsec wide. A cathode follower on the output gives a low impedance output for driving cables to other equipment.

The power supply is omitted from the circuit diagram. It is a 300 volt electronically regulated supply capable of delivering 175 mA. The + and -150 volt supplies are VR tube regulated and capable of 40 mA each.

IV. RESULTS

The effectiveness of the time jitter adapter in reducing time jitter can be seen in Figs. 4 and 5. Figure 4 was obtained by feeding one pulse from a double pulse generator into an analyzer with and without the adapter and looking at the output on an oscilloscope screen after the output had gone through a variable delay. The oscilloscope was triggered externally by the second pulse from the double pulse generator. The amplitude of the pulse generator input to the analyzer was adjusted to rise to the various window heights indicated by the abscissas of Fig. 4, but the analyzer output pulse was always obtained by integrating at a window height of 20. In each case the variable delay was adjusted to bring the pulse back to the position on the oscilloscope screen defined by the output pulse corresponding to an input pulse rising to a window height of 40. The amount the variable delay had to be changed for the various pulse height inputs was a measure of the time jitter between pulse heights. It can be seen from Fig. 4 that without the adapter the total time jitter in the analyzer, using pulse generator pulses, was 0.11 μsec over the range of input pulse heights investigated. This time jitter was somewhat smaller than would be predicted from Fig. 1 because the pulse generator pulses have a faster rise time than the pulses from the sodium iodide crystal. When the adapter was utilized this time jitter was reduced to 0.02 μsec with all of the jitter occurring for the smallest energy pulses as might be expected since the low-energy pulses are triggered nearer their peaks than are the high-energy pulses.

Figures 5a and 5b were obtained using a coincidence circuit with a 2τ of approximately 0.12 μsec. A Tb160 source was used because it yielded coincidences which were prompt within the restrictions of the 2τ used. For Fig. 5a both analyzers were set to integrate at a window height of 20 and delay curves were run with and without the use of adapters with the two analyzers. The reduction of time jitter is readily apparent from the reduction in half-width of the delay curve.
Fig. 4 - Time jitter in output of single channel analyzer.
Fig. 5 - Tb$^{160}$ delay curves demonstrating:

(a) Reduction of time jitter and

(b) Maximum time jitter with adapters.
Figure 5b was run to approximate the total amount of time jitter remaining in both analyzers with adapters. One channel was set to integrate at a window height of 50 for all three curves. The other channel was then set successively to integrate at 50 to obtain the total curve similar to that in Fig. 4a, to integrate at 1000 to obtain the high-energy gamma rays in coincidence with the low-energy gamma rays in the first analyzer and then to differentiate at a window height of 50 to obtain the reverse coincidences - low-energy gamma rays with high-energy gamma rays in the first analyzer. It can be seen from Fig. 5b that approximately 0.08 $\mu$sec time jitter still remains in each analyzer with adapter.

The decay of Yb$_{169}$ has been of interest to this group and two metastable levels in Tm$_{169}$ have been reported$^4$ in addition to the well established 0.66 $\mu$sec level. One of these two new metastable levels was reported to have a half-life of 0.04 $\mu$sec which could not previously be measured by this group using two single channel analyzers and a simple coincidence circuit. With the use of the adapters and a $2\tau$ of 0.12 $\mu$sec in the coincidence circuit, a preliminary determination was made to check the existence of the reported 0.04 $\mu$sec metastable state. One analyzer was set to window on the 63-kev gamma rays with the output from the time jitter adapter fed through a fixed delay line to the coincidence circuit. The other analyzer was set to window on the Tm$_{169}$ x-rays with the output from the adapter used with this analyzer fed into a variable delay which was calibrated in 0.01 $\mu$sec intervals. This delay was then varied over the time region indicated by the abscissas of Fig. 6. The delay curve of Fig. 6 indicates that when the x-ray is delayed with respect to the 63-kev gamma ray, a half-life close to 0.06 $\mu$sec is obtained after subtraction of the 0.66 $\mu$sec half-life fraction.

V. DISCUSSION

Three definite gains can be seen with the use of the adapters. Without the adapters a $2\tau$ of approximately 1.0 $\mu$sec would be needed in order to insure against the loss of true coincidences as the window height settings are changed. The use of adapters makes it possible to reduce $2\tau$ to less than 0.2 $\mu$sec with a resulting effective gain in the ratio of true to accidental coincidences for a given source. In addition it can be seen from Fig. 5a that when using the $2\tau$ of 0.12 $\mu$sec, the adapters concentrate the true coincidences into a shorter period of time and

$^4$Mihelich, Ward, and Jacob, Phys. Rev. 103, 1285 (1956).
Fig. 6 - Yb$^{169}$ Delay Curve - X-ray vs. 63-kev gamma ray.
therefore higher counting rates are obtained at the peak of the prompt coincidence curve with a corresponding gain in the true to accidental coincidence ratio. Probably the most striking contribution of the adapters, as a result of making it possible to utilize a coincidence circuit with a smaller $2TT$, is in the measuring of shorter half-lives of metastable states. Previously a coincidence circuit with a $2TT$ of approximately 1.0 $\mu$sec was used in coincidence studies and the resulting half-life slope of a prompt coincidence curve was approximately 0.1 $\mu$sec, where the half-life slope is defined as the interval of time necessary for the coincidence counting rate to decrease by a factor of two. With this limitation the shortest half-life of a metastable state which could be measured reliably was in excess of 0.20 $\mu$sec. With the adapters and the shorter $2TT$ of Fig. 5 it can be seen that the prompt coincidence curve falls off with a half-life slope of approximately 0.02 $\mu$sec, making it possible to measure half-lives as short as perhaps 0.03 $\mu$sec. This fact made possible the obtaining of the data in Fig. 6.

Since the time jitter adapter determines the time output of any analyzer pulse, a given energy pulse will come out at a time independent of how that pulse was triggered in the single channel analyzer. Using the illustration of Fig. 1, the high energy pulse would be triggered at time $t_1$ or $t_1'$ depending on whether the single channel analyzer was set to integrate at a window height of 20 or differentiate at a window height of 800. This amounts to time jitter of as much as 0.47 $\mu$sec on a single pulse depending on where it is triggered by the analyzer. The effect of this time jitter when using the adapter is to have a variable time interval between the arrival of the cocking pulse from the analyzer and the arrival of the trigger pulse through the adapter. This type of time jitter is therefore completely eliminated with the use of the adapter independent of the extent to which time jitter between pulses of different voltage heights is reduced.

Since a noise pulse may trigger the trigger circuit within the time jitter adapter in the time interval between the arrival of the cocking pulse from the analyzer and the appropriate trigger pulse through the adapter, these noise pulses may register as true coincidences either inside or outside the region of prompt coincidences in a delay curve. The result of this is to destroy the fast fall-off of the prompt region of a delay curve near the edge of the prompt region and to introduce a false half-life curve of weak intensity. This problem can be overcome by considering two facts. First, the noise pulses trigger the analyzer pulses earlier in time than the appropriate pulses would. Therefore, the use of an adapter with only one of the two analyzers introduces the false half-life on only one side of the prompt curve.
Secondly, the use of an adapter with only one of the analyzers causes a sharp fall-off on only one side of the prompt curve and this is the opposite side from which the noise pulses from this adapter would give the false half-life. Therefore, short half-lives free of the noise pulse problem can be measured on one side of the prompt curve using an adapter with only one analyzer, while short half-lives can be measured on the opposite side of the prompt curve by using an adapter only with the other analyzer, thus eliminating the problem of noise pulses on that side. As a result, delayed coincidence data can be taken free of the problem of noise pulses on the side of the prompt curve which is of interest by proper use of only one time jitter adapter, and the advantage of the sharp fall-off of the prompt curve due to the use of the adapter can still be utilized. For prompt coincidence work where one analyzer is periodically set at different window heights, an adapter should be used with each of the analyzers in order to reduce the time jitter in the output of both analyzers so that advantage can be taken of as small a 2\(\tau\) as possible in the coincidence circuit.

Although the time jitter adapter was originally designed for use with single channel analyzers, it can be used effectively to reduce the time jitter in any piece of electronic equipment which introduces time jitter in its output as a result of triggering on pulses of different voltage heights.

The amount of time jitter from a single channel analyzer is dependent on the rise time of the pulses in the detector crystal as well as the electronic circuitry preceding the analyzer. Whatever the time jitter might be for a given experimental setup, a time jitter adapter used with a single channel analyzer will reduce this time jitter by a factor of approximately six. When a correspondingly smaller 2\(\tau\) is utilized, this reduction constitutes a significant gain in the true to accidental coincidence ratio as well as an effective increase in the ability to measure the half-lives of shorter-lived metastable states.