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A Study on Electronic Circuits for Live-Time Correction in Multi-Channel Analyzer : Survey and Analysis

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방사선 스펙트럼 계측기(Multi-Channel Analyzer)의 Live-Time 보상회로에 관한 연구

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Abstract

This paper describes the counting-loss problem for radiation measurement. Multi-channel analyzers and spectrometers adopt various techniques for compensation for counting-losses in processing the radiation pulses from a detector. Researchers have tried to seek the best solution for the problem. However, any absolute solution has not been reached and vendors of radiation instruments use their own algorithms individually. This survey explains the various compensation algorithms with electronic implementation approach. Shortcomings and merits of each algorithm are also reviewed and a direction is suggested of the recommendable development strategy for counting-loss compensation.

요 약

방사선계측에서는 방사선검출기(detector)로부터 나오는 pulse를 처리하는 데 있어서 pulse의 counting 손실이 발생한다. 이 손실을 최소화하거나 보상하기 위한 여러가지 방법들이 제시되어 왔으나, 아직도 절대적인 해답이 확립되지 않은 실정이다. 본연구에서는 기 제시된 보상알고리즘들을 그 기능을 구현하는 전자회로와 함께 기술하고 특징을 분석하였다. 또한 본 연구를 통해 pulse의 counting 손실을 보상하는 한가지 알고리즘 개선방향을 제시하였다.

1. Introduction

Most of the measuring methods of radiation activity are based upon counting the number of events per unit time. Generally, counting just the number of pulses accumulated during a given time is the simplest method to measure the activity. However, there are some other factors to be considered to identify the activity more accurately in the multi-channel analyzer(MCA). Since the events of radiation are random, the pulses from the radiation detector also have a random nature. In MCA or spectrometer, all the pulses arriving to the analog-to-digital converter (ADC) are not counted due to the time taken for conversion and processing of the pulses[1].

Dead-time is defined as the time in which a spectroscopy system can not receive and process the input pulses properly to identify the event pulses[2,-5]. It includes detector dead-time and processing dead-time is considered mainly. Contrary to dead-timformance of radiation detector tubes; the latter occurs due to the electronic circuit processing the input pulses. In nuclear electronics, the processing dead-time is mainly considered. Contrary to dead-time, live-time is the time in which a system is actually available for accepting an event, i.e., the input gate is open. Fig. 1 illustrates a simple block diagram of the input part of analog-to-digital converter in MCA. If a Gaussian pulse arrives to the input gate of ADC, MCA begins A/D conversion after detecting the peak of the pulse. During the conversion time, the switch, *K1*, is closed to reject any input signal.

As a simple way, the "busy" signal from the ADC can be used for recording the live-time as Fig 2.

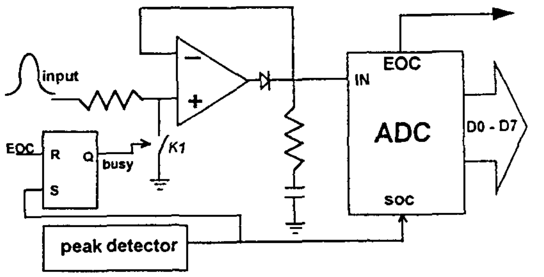


Fig. 1. Block Diagram of an Input Part of ADC in MCA

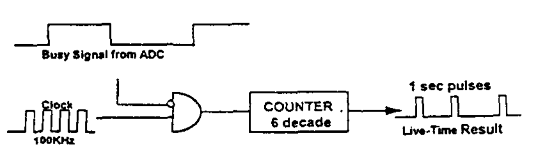


Fig. 2. Simple Live Time Recording Circuit in MCA

2. Representation of Live-Time

The basic live-time clock which accounts for the loss of the second pulse during the processing time of the previous pulse provides compensation for the following relationship[4, 6].

$$N_m = r \cdot t = \rho \cdot t \cdot e^{-\rho T_w} \, , \tag{1}$$

where N_m : measured count number,

t : elapsed real time,

r : rate of recorded pulse,

ρ : expected mean value of rate at the detector,

and T_w : time duration in which the amplifier pulse is above low level discriminator threshold or duration for processing of the pulse (dead-time).

Turning off the clock during T_w means measuring the elapsed live-time, t_L. Therefore, t_L is related to the elapsed real time t by the same factor as in Eq.(2), i.e.,

$$t_L = t \cdot e^{-\rho \cdot T_w} \tag{2}$$

Consequently, the recorded number of counts N_m divided by the live-time t_L gives:

$$\frac{N_m}{t_L} = \frac{\rho \cdot t \cdot e^{-\rho \cdot T_w}}{t \cdot e^{-\rho \cdot T_w}} = \rho \, , \tag{3}$$

which is the counting rate at the detector.

3. Methods for Live-Time Correction [3-12].

3.1. Manual Live-Time Correction

This method is used when an automatic feature is not available and the difference between recorded rate and expected rate is relatively small. If the dead-time for processing one pulse is always the same and generation of pulses is sufficiently random, Eq.(2) becomes[4, 6]

$$t_L = t \cdot e^{-\rho \cdot T_w} \cong t \cdot (1 - r \cdot T_w) \, , \tag{4}$$

and Eq.(3) becomes Eq.(5) It is

$$\frac{N_m}{t_L} = \frac{\rho \cdot t \cdot e^{-\rho \cdot T_w}}{t \cdot e^{-\rho \cdot T_w}} \cong \frac{r}{1 - r \cdot T_w} = \hat{\rho}\,, \quad (5)$$

where $\hat{\rho}$: approximated count rate.

The Eq.(5) is valid when the dead-time loss is less than 20%[3, 6].

3.2. The Philip's Dead-Time Corrector

This scheme of spectrometer uses a electronic box inserted between the pulse-height-selector output and the scaler input[6]. Fig. 3 shows the block diagram of the system.

From Eq.(5) the measured count rate can be

$$r \cong \rho - r \cdot \rho \cdot T_w\,. \quad (6)$$

A trigger signal is fed to the gating period generator from the output of the first decade of the scaler. Assuming that the corrector is working properly, the trigger pulse is generated every $10/\rho$ seconds. This pulse makes a gating pulse whose duration is $10T_w$. During this gating period, input pulses are counted in both counters and their values are summed to be fed to the scaler.

The pulses counted in counter 2 can be considered as the compensation pulses for the loss of pulses during the dead-time. The number of counts per unit time in counter 2 will be

$$r_{corr} = r \cdot \frac{\rho}{10} \cdot 10T_w = r \cdot \rho \cdot T_w\,. \quad (7)$$

From (6) and (7),

$$r + r_{corr} \cong \rho - r \cdot \rho \cdot T_w + r \cdot \rho \cdot T_w = \rho\,. \quad (8)$$

Therefore, the scaler output will represent the compensated counting rate, ρ.

The shortcoming of this system is the need to get the appropriate gating interval. It is necessary to readjust the gating period according to different sources and different detectors. Another weakness is that this scheme doesn't examine whether any real pulse has been reached or not during the dead-time.

However, this method is very simple and can become a real time application for the single channel spectrometer or radiation monitor. Also the detector dead-time can be considered in this method.

3.3. Live-Time Clock

Most of the automatic dead-time correction methods in the Multi-Channel Analyzer are based on the live-time clock that compensates the loss of real measuring time by adding the signal processing time [1, 7]. It is done by turning off the timer clock during the time in which an amplified pulse is above the MCA's low level discriminator threshold or the pulse is in process of MCA, and turning on when the amplifier output falls below the threshold and MCA's memory cycle is completed. Fig. 4 illustrates the block-diagram of the live-time clock circuit.

This method is very simple and effective when the generation of events is uniformly random in low counting rate. However, this does not compensate for the loss of the first pulse when a second pulse arrives before the height of the first pulse can be detected.

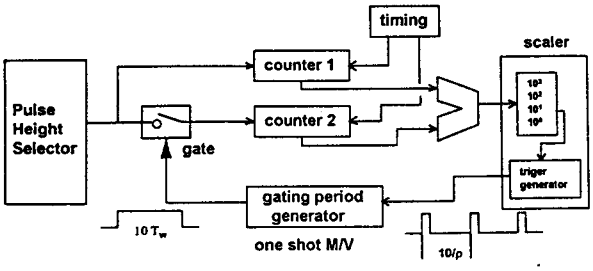


Fig. 3. Block Diagram of Philip's Dead Time Corrector

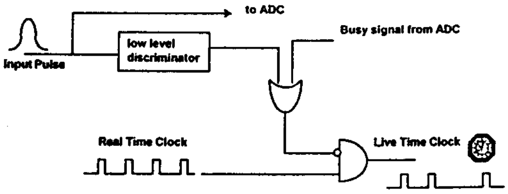


Fig. 4. Block Diagram of a Simple Live Time Clock

3.4. Lowe's Live-Time Corrector

An improved live-time clock is the Lowe's live-time corrector to compensate for the leading-edge file-up losses[6, 7]. In this scheme, when a second pulse arrives before the peak of the first pulse can be measured, the file-up rejecter or a circuit generates "INHIBIT" signal. Fig. 5 illustrates the block diagram.

The "INHIBIT" signal turns off ADC, and therefore the first pulse is discarded and no event is recorded in the memory. To compensate for loss of the pulse, another pulse of the same amplitude must be found and added to the memory. Lowe's method assumes that the next undistorted pulse is identical to the pulse which was lost. Therefore, until the next event is received and processed, the system turns off the live-time clock. This is one of the correction methods for the first pulse which was lost because of arrival of the second pulse before its peak.

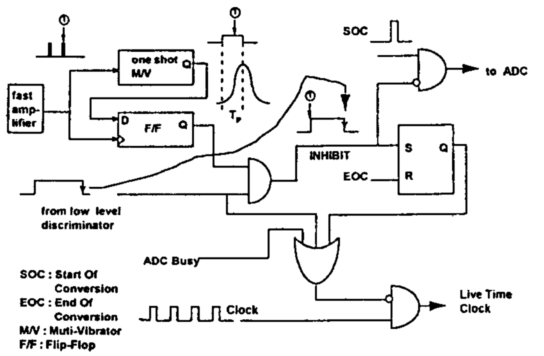


Fig. 5. Simplified Design for Lowe's Live Time Corrector

Although Lowe's method uses a ideal live-time clock for compensation of leading-edge pile-up, it is based on unjustified assumption that the next pulse would be identical to the first pulse which is lost. Also, the file-up rejecter dead-time is about 0.5μsec, so it can have a little deviation from the performance of an ideal corrector.

3.5. Gedcke-Hale Live-Time Clock

Another live-time clock for compensation for the leading-edge pile-up is the Gedcke-Hale live-time clock[6]. This method addresses the file-up compensation on the theoretical basis.

A simple live-time clock accounting for loss of the second pulse while the first pulse is in processing can be accomplished as Eq.(1), Eq.(2), Eq.(3). However, when a leading edge pile-up occurs, two pulses of the first and second become lost because of distortion of the first pulse as Fig 6[5].

Therefore, the leading duration should be compensated again, i.e. live-time should be shorter by T_p, rising time for normal pulse, than Eq.(2). That is

$$t_L = t \cdot e^{-\rho(T_w+T_p)}, \tag{9}$$

where T_p : rising time for normal pulse.

Also, the counting number, N_m, becomes

$$N_m = r \cdot t = \rho \cdot t \cdot e^{-\rho(T_w+T_p)} \tag{10}$$

Eq.(10) indicates that the effective dead-time per pulse with pile-up losses can be written as

$$t_d = T_p + T_w = 2T_p + (T_w - T_p) \tag{11}$$

Eq.(11) implies that the rising portion of the pulse, Tp, has double weighting for the dead-time interval.

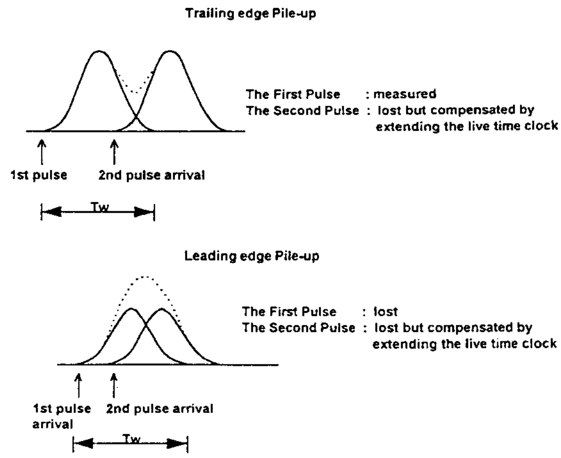


Fig. 6. Trailing Edge Pile-up vs. Leading edge Pile-up

The implementation of double weighting is achieved by decreasing the value of time from the clock during T_P and single weighting for (T_w-T_P) is done by holding the live-time clock during T_w-T_P. Fig. 7 illustrates the implementation of G-H live-time corrector. The operation sequences are: 1. pulse accepted, 2. down clock(T_P), 3. peak detection, 4. holding clock during(T_w-T_P), 5. processing complete, 6. up clock.

As a conclusion, the expected input radiation rate is obtained by Eq.(12) as

$$\frac{N_m}{t_L} = \frac{\rho \cdot t \cdot e^{-\rho(T_p+T_w)}}{t \cdot e^{-\rho(T_p+T_w)}} = \rho \qquad (12)$$

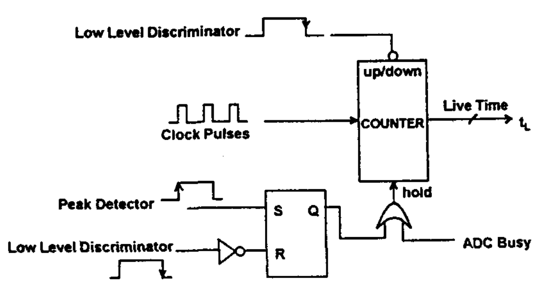


Fig. 7. Block Diagram of the G-H Live Time Corrector

3.6. Harm's Dead-Time Correction

A method to compensate the dead-time loss by real-time application is Harm's dead-time correction method[6, 7, 12]. It depends on counting the events lost during the dead-time. The output pulses of fast discriminator are counted in a correction scaler during the processing time. The number of scaler plus one is fed to an adder to make summation with the content of memory whose address is determined according to the current pulse amplitude.

In Harm's method, it is assumed that events stored in the scaler would have the same amplitude and that the number of events equals to the number of pulses output of the fast discriminator. Therefore, the performance of this algorithm mostly depends on the resolution of the fast discriminator. The most valuable benefit of this implementation is that it can be applied in real time. Fig 8 illustrates the block diagram of Harm's method.

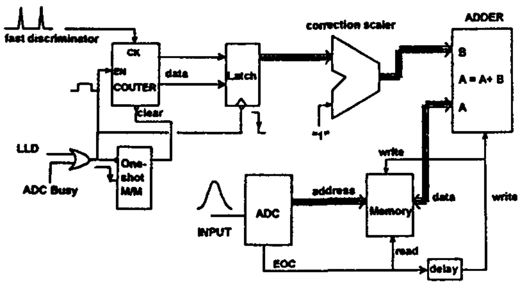


Fig. 8. Block Diagram of Harm's Deadtime Correction

3.7. Barnhart's Method

Using a similar idea to Harm's method, the Barnhart dead-time correction method achieves another counting loss compensation depending on fast-discriminator output. It employs a different implementation of compensation for loss of pulses[6].

Two operation modes, real counting mode and compensation mode, are the key features. In the real counting mode, the elapsed real-time is recorded while the output pulses of the fast discriminator are counted into an up/down counter. On the other hand, one count is subtracted from the counter when an event is gathered from the pulse shaping amplifier and stored in the memory. The content of the counter is the difference in counts between the fast discriminator and the total number of MCA memory. It makes the number of lost pulses.

When the number of counts in the counter reaches a preset value, the compensation mode is initiated. The circuit stops the live-time clock and disables the up-counting function of the counter, until the subtraction in the counter due to the arrival of the normal Gaussian pulses during this mode causes the counter to reach zero. The electronic functional block-diagram is shown in Fig 9.

This method seems to be simpler than Harm's method, but has a drawback that it is not a real-time

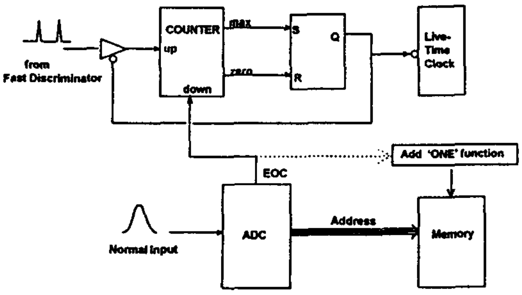


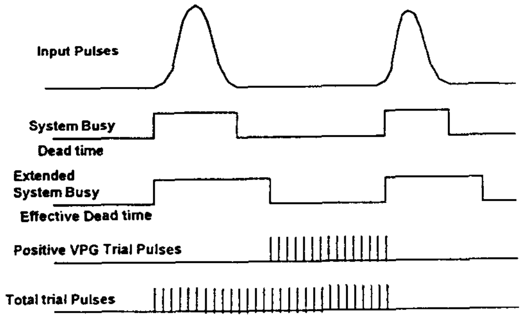
Fig. 9. Block Diagram of Barnhart Approach

compensation.

3.8. VPG(Virtual Pulse Generator) Method

The VGP method was developed by Westal in 1981. This is one of real-time correction[7]. However, instead of using any discriminator it uses a mathematical weighting factor approach based on escape-acceptance probability calculation. It is shown in Fig. 10.

The weighting factor can be the inverse of the escape-acceptance probability which is calculated by the ratio between the positive VGP trial pulses and the total trial pulses. The escape-acceptance probability represents the probability that this system can catch input pulses without losing. Some extension is added to the system busy in order to compensate the leading-edge file-up.



Acceptance Probability = 15/29 = 0.51
Weighting Factor = 1 / 0.51 = 1.95
Compensated Count Rate = Measured Count Rate * Weighting Factor

Fig. 10. Principle of the Virtual Pulse Generator Method

4. A Proposal for the Direction on Live-Time Correction Circuit

Most of the live-time clocks assume that pulses at a detector are randomly generated. However, it can not be assured that all the events of radiation are completely random. The probability of a little periodicity could exist depending on the situation. If events of a radiation source have even a little periodicity, most live-time correction algorithms will result in an over-correction.

Therefore, the real-time compensation methods such as Ham's method with pile-up rejection circuits are preferable. Fig. 11 illustrates a simple real-time application which is come from the modification of Ham's circuit to which a pile-up rejection circuit is added for taking out the leading-edge pile-up.

5. Conclusions

Various techniques and problems concerning counting loss of radiation pulses in the Multi-channel Analyzer have been described. Characteristics of the compensation techniques are presented briefly in Table 1. Any absolute solution has not been defined yet. In the case of low counting rate, the simple live-time clock can be applicable without large error. But at high rate or for short lived nuclides, the

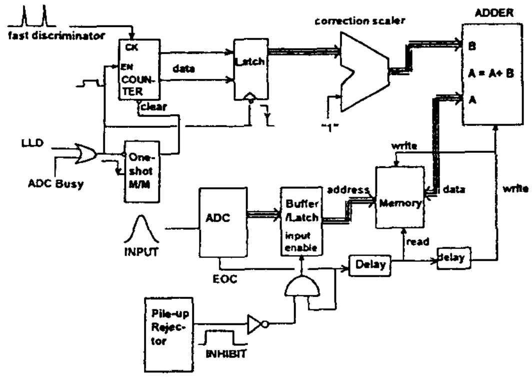


Fig. 11. A Proposed Modification of Harm's Deadtime Correction

Table 1. Summary of Characteristics of Live-time Correction Methods

Characteristics / Methods	Automatic correction	Capable to compensate detector dead-time	Real conting	Simplicity of algorithm and impleimentation	Real-time application	Consider leading edge file-up	Remarks
Manual live-time correction	No	Yes	No	Simple	No	No	valid at low couting rate
Philip's dead-time corrector	Yes	Yes	No	Simple	Yes	No	can be used for single channel spectrometer
Live-time clock	Yes	No	No	Simple	No	No	typical method for MCA
Lowe's live-time corrector	Yes	No	No	Not simple	No	Yes	includes file-up rejector
Gedcke-Hale live-time clock	Yes	No	No	Medium	No	Yes	double weight on the leading edge
Harm's method	Yes	No	Yes	Not simple	Yes	No	real counting and real-time correction
Barnhart's method	Yes	No	Yes	Not simple	No	No	real counting mode and compensation mode
Virtual pulse generator method	Yes	No	No	Not simple	Yes	No	calculation of escape probability

live-time clock which simply delays the clock can produce a big deviation. For these reasons, real-time application is strongly recommendable for the common use of pulse counting-loss compensation algorithm. In addition, improvement on the performance of the fast discriminator should be done because it plays the most important role that distinguishes the two close pulses of radiation event.

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