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TIME RESOLUTION COMPARISON OF GENERAL PURPOSE PLASTIC SCINTILLATION DETECTORS FOR LOW-ENERGY BETA PARTICLES BY MEANS OF TIMING METHODS

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Abstract: The time spectrum of ^{14}C was achieved by using a BC 400 type general purpose plastic scintillation detector. Leading edge and constant fraction discrimination timing methods were used to obtain the time spectrum of the radioisotope. Obtained results from these methods were compared with each other.

1. Introduction

Timing in nuclear and particle physics refers the measurement of very small time intervals. For example, these are measurements of lifetimes of excited nuclear states or elementary particles, time-of-flight, etc. Therefore, the intervals range from a few pico-seconds to a few micro-seconds. Accurate measurements of very small time intervals require special techniques [1]. These special techniques are timing methods.

The time resolution of a timing system is defined as the full width at half maximum of amplitude [2]. A shaping time is defined at 61% of a peak value [3]. The time required for the shaped pulse to reach its maximum amplitude is called as the peaking time [2]. The peaking time is about 3-5 times greater than the shaping time. These quantities are shown in Fig. 1. The range between the noise level and the maximum output voltage is defined as dynamic range in a time-voltage graph (Fig. 2) [3].

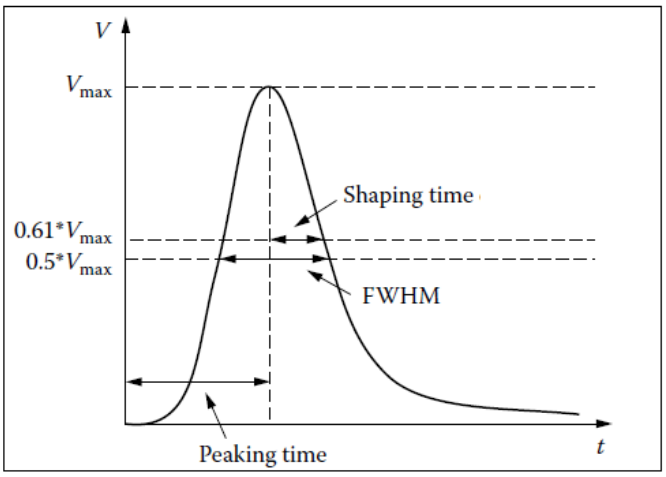


Figure 1: Shaping and peaking times [3].

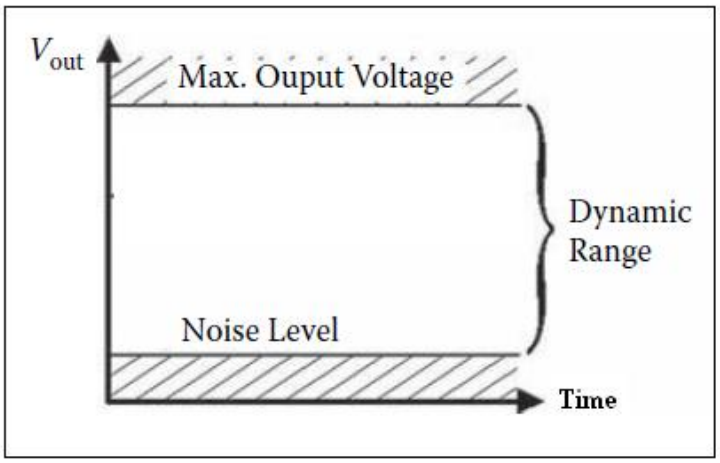


Figure 2: Dynamic range [3].

The most common and widely used plastics for the scintillation detectors are polyvinyltoluene, polyphenylbenzene and polystyrene. Plastics offer an extremely fast signal with a decay constant of about 2-3 ns and a high light output [1].

The basic problems encountered in timing methods are walk and jitter effects (Fig. 3). The walk effect is caused by variations in the amplitude or rise time of the incoming signals [1]. The rise time is the interval between the times at which the pulse reaches 10% and 90% of its final amplitude [2]. To minimize walk, a number of different triggering or time-pickoff methods have been developed [1].

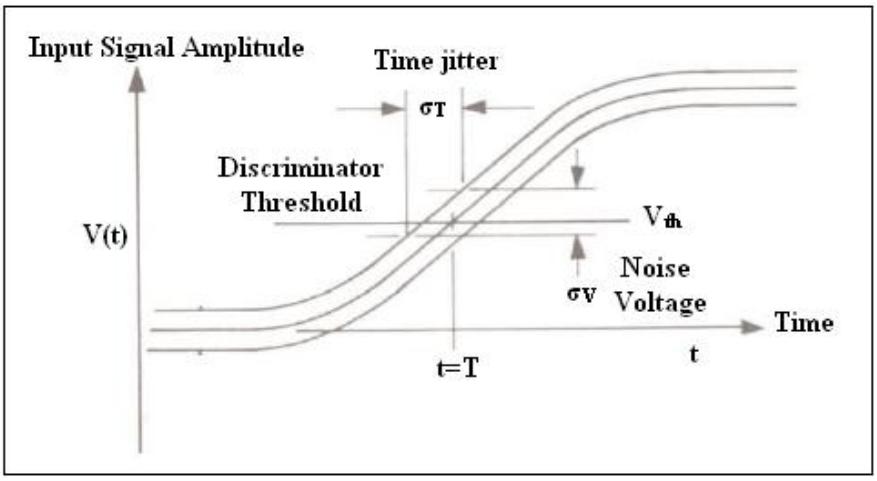


Figure 3: Time jitter and noise voltage [4].

Many studies were acquired by various authors. For example, Cho et al. [5] reduced the noise by using leading edge timing method. Moszynski and Bengston [6] published an article about timing methods. In addition, the authors investigated the time resolutions of scintillation detectors besides the timing properties of the photomultiplier tubes and scintillators. Time resolution values of CdTe and CdZnTe detectors were improved by using timing method by Okada et. al. [7]. Aykac et. al. [8] compared the results obtained by the digital timing method with those of the analog timing method.

The time spectra of ^{14}C via the timing methods pointed out above were obtained by using the spectrometer which is consisted of a BC 400 type plastic scintillation detector in this study.

2. Experimental Procedure

A point ^{14}C radioactive source with the activity of 100 μCi by which it emits beta particles with the maximum energy of 156 keV was used in present work. It was placed in 2 cm far away from the detector surface. A plastic scintillation detector in the dimensions of 9 mm by 3 inch was used. Since ambient light intensity and high room temperature cause to detector noise [1], all measurements were carried out in a dark medium and at a constant room temperature (22 ^{0}C). Data acquisition time was chosen of 300 s in the study.

The leading edge timing method determines the time of arrival of a pulse with the help of a discriminator as shown in Fig. 4. A discriminator threshold is set and the time of arrival of the pulse is determined from the point where the pulse crosses the discriminator threshold [9].

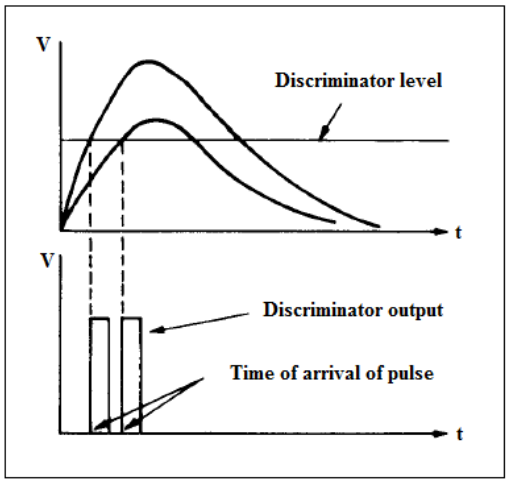
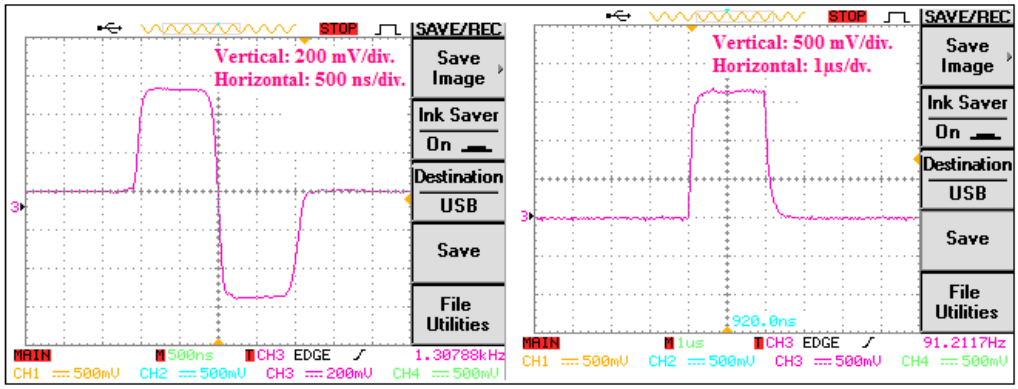


Figure 4: Principal of the leading edge timing method [9].

In the setup for this timing method, the detector output was first sent to a preamplifier (PA, Ortec 113) then a delay line amplifier (DLA, Ortec 460). The output of the DLA was split into two branches. Each branch was connected to a timing single channel analyzer (TSCA, Ortec 420A). One of the output signals of the TSCAs was directly sent to start input of a time to amplitude converter (TAC, Ortec 566), the other output was connected to stop input of the TAC through a delay unit (D, Ortec 425A). TAC is a device which converts a time period between its two input pulses into a logic output pulse whose height is proportional to this duration [1]. The output of the TAC was finally connected to input of a multichannel analyzer (MCA, Ortec Trump 8K). Consequently, the time spectrum of the used radioactive source was obtained.

The output signal shapes of the DLA and the TAC are shown in Fig. 5.



(a) (b)

Figure 5: Output signal shapes of (a) DLA (b) TAC.

In Fig. 6, time jitter and noise voltage were determined from the TSCA output.

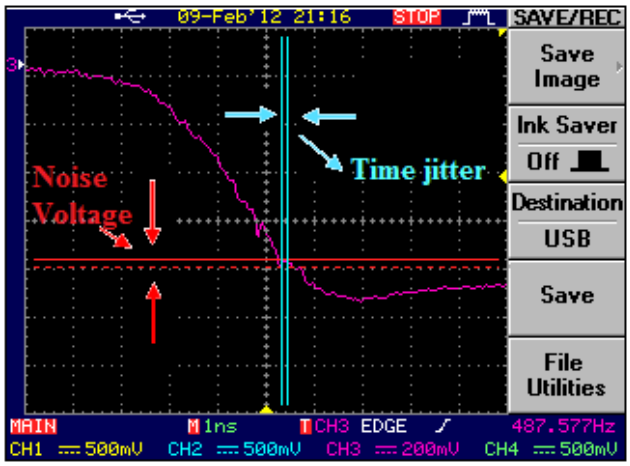


Figure 6: Time jitter and noise voltage.

Time jitter and noise voltage values with the dynamic range of 2:1 for the used detector were determined as 120 ps and about 24 mV, respectively.

The constant fraction timing method was used in the second part of the study. The most efficient and versatile method available today is the constant fraction timing method. In this method, the logic signal is generated at a constant fraction of the peak height to produce an essentially walk-free timing signal. The basis for this idea arose from empirical test which showed the existence of an optimum triggering level for the best timing resolution [1].

The principle of constant-fraction timing method is shown in Fig. 7. First, the original pulse (7a) is attenuated by a factor f equal to the fraction of the pulse height on which the timing will be based (7b). The original pulse is inverted and delayed (7c) for a time longer than its rise time. Finally, the signals in Fig. 7(b) and 7(c) are added to give the signal in 7(d). The time pick-off, taken as the zero-crossing point, is thus defined by the preselected fraction of the pulse height and independent of the pulse amplitude. It can be shown that pulses with the same rise time always give the same zero-crossing time [9].

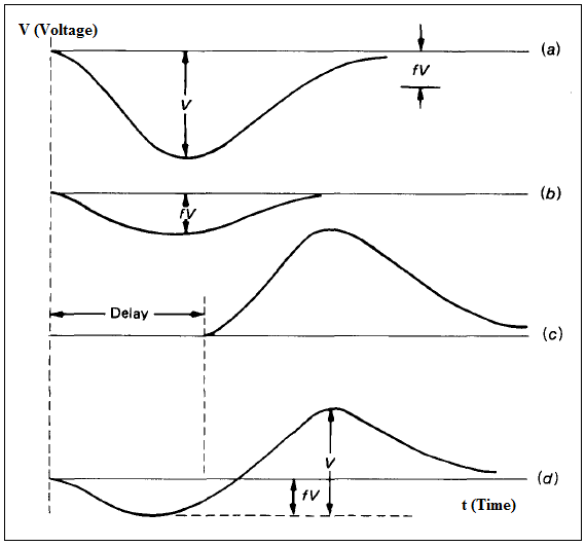


Figure 7: Timing by the constant fraction timing method [9].

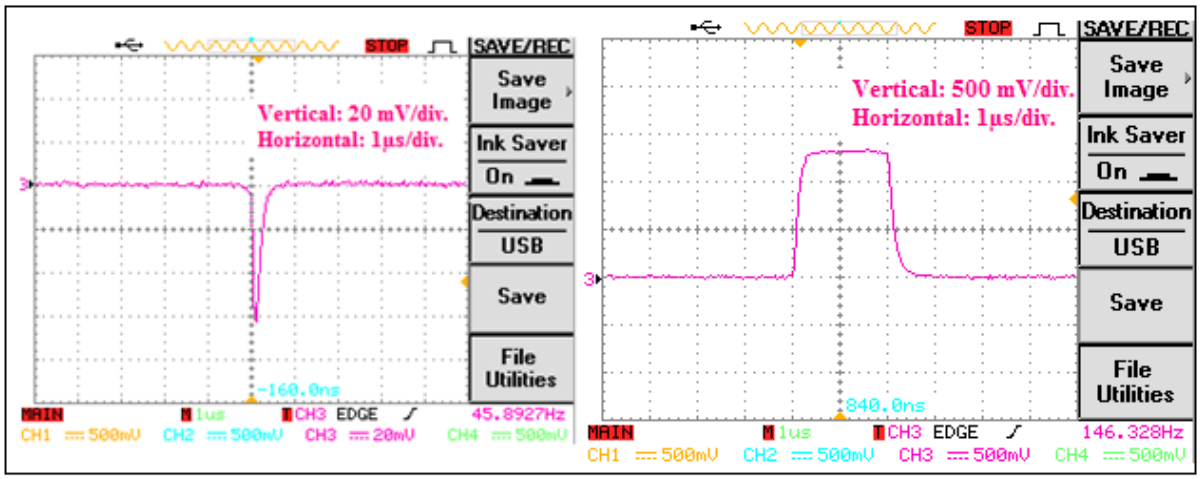
In the constant fraction timing setup in this study, the detector output was split into two branches again, and these outputs were forwarded to two timing filter amplifiers (TFA, Ortec 454). The outputs of the TFAs were then connected to two constant fraction discriminators (CFD, Ortec 463). One of the output signals of the CFDs was directly sent to start input of the TAC, the other output was connected to stop input of the TAC through the D. The output of the TAC was connected to input of the MCA. Thus, the time spectrum of the used radioactive source was obtained.

The output signal shapes of the TFA and the TAC are shown in Figs. 8.

The shaping and peaking times were determined for the used detector by using the information given in the previous section. Shaping and peaking times were found as 80 and 440 ns, respectively. It can be realized that the peaking time was about five times greater than the shaping time for the used radioisotope. The obtained result was in accordance with the rule depicted in the reference [3].

It was stated that the walk effect was lower than ±150 ps in the constant fraction timing method [10]. Time jitter and noise voltage values from the CFD were obtained as 120 ps and about 12 mV for the used detector.

Before acquiring the time resolution results, we calibrated the channels of the MCA. Time calibration graph is shown in Fig. 9. The inverse of the slope of the obtained time calibration graph gives corresponding time value per channel of the MCA. This value was calculated from this graph as 195.3125±0.0051 ps.



(a) (b)

Figure 8: Output signal shapes of (a) TFA (b) TAC.

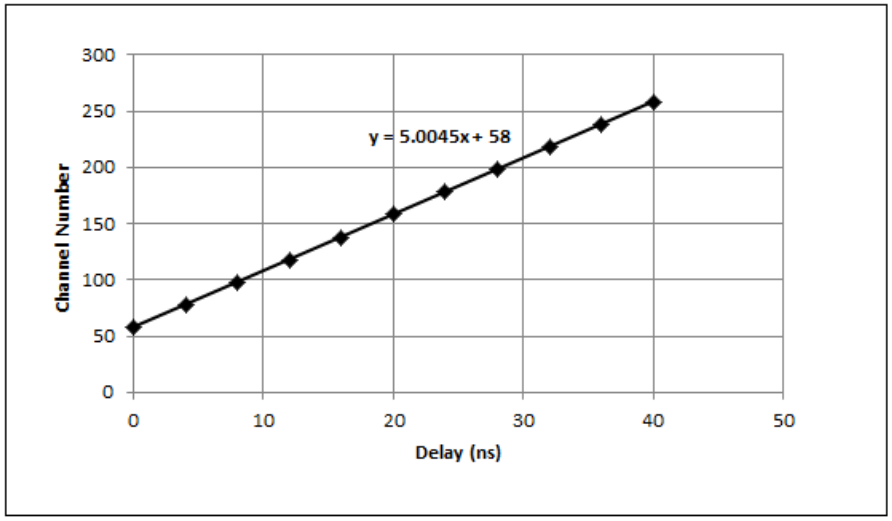


Figure 9: Time calibration graph (fitted time calibration=195.3125±0.0051 ps/ch).

3. Results

The time spectra of ^{14}C obtained from leading edge and constant fraction discrimination timing methods can be seen in Figs. 10 and 11.

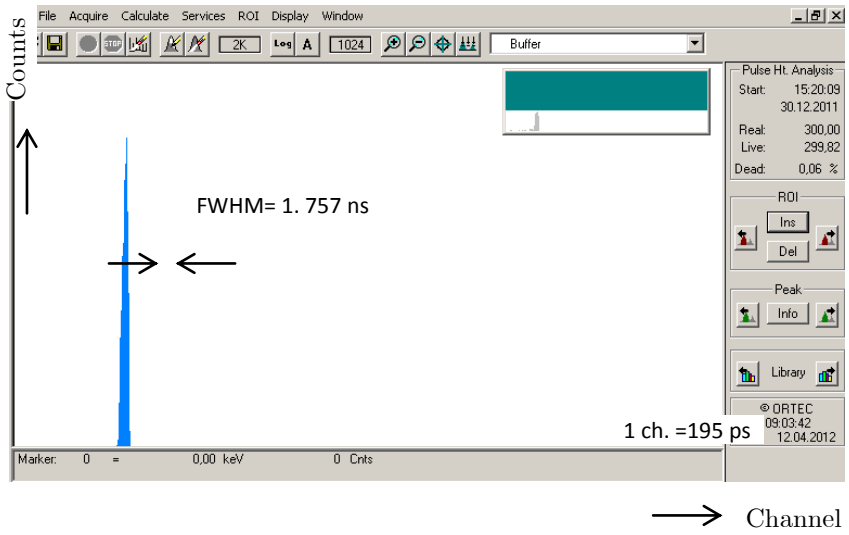


Figure 10: The time spectrum of ^{14}C by means of leading edge timing method.

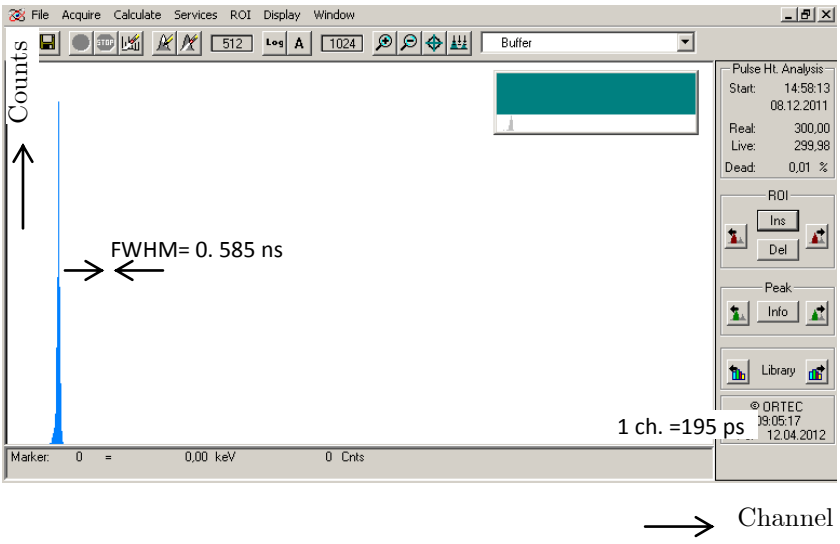


Figure 11: The time spectrum of ^{14}C by means of constant fraction discrimination timing method.

In these figures, channel and counts were represented in horizontal and vertical axes.

It can be concluded that these time spectra did not involve any pile-up effect and spectrum distortion because of the lower dead time of the MCA (lower than 30-40%) [1, 2].

Time resolution values from leading edge and constant fraction discrimination timing methods were obtained as 1.757 and 0.585 ns, respectively.

4. Discussion

In this study, time spectra of a pure low-energy beta emitter (^{14}C) were determined by means of leading edge and constant fraction discrimination timing methods. Since no information about the timing properties of this isotope was encountered, this study was performed for this need.

The time resolution value which was obtained by using constant fraction discrimination timing method was lower than that of leading edge timing method. This means that the obtained time resolution from constant fraction discrimination timing method was better than that of leading edge timing method. This situation was emphasized in various studies [1, 6, 11]. Because the changes of the signal amplitude are excessive in leading edge timing method than constant fraction discrimination timing method, walk effect is more significant in leading edge timing method and this case should be compensated. Therefore, constant fraction discrimination timing method provided better time resolution values than leading edge timing method [6].

Consequently, it is recommended that constant fraction discrimination timing method should be preferred in time measurements for the low-energy betas.

Acknowledgements

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