

## FAST CONSTANT FRACTION DIFFERENTIAL DISCRIMINATOR FOR POSITRON LIFE-TIME SPECTROSCOPY

Paul ȘCHIOPU<sup>1</sup>, Dorin DUDU<sup>2</sup>, S. NITIȘOR<sup>3</sup>

*Lucrarea tratează aspectele legate de proiectarea și realizarea unei soluții practice pentru extragerea informației temporale din semnale analogice rapide cu amplitudini variabile pentru spectroscopia timpului de viață al pozitronilor în solid. Sunt prezentate principiul de funcționare și implementarea practică a acestuia împreună cu parametrii de funcționare obținuți și exemple de utilizare.*

*In this paper aspects related to design and realization of a practical solution for providing timing information from analogue signals with different amplitudes as used in life time spectroscopy of positrons in solids, are discussed. The operating principle is presented together with its practical implementation as well as obtained functional parameters and examples of use.*

### 1. Introduction

In solid state physics, a wide range of nuclear methods can be applied to provide structural information on atomic scale. Based on theoretical studies and the development of experimental techniques used in nuclear spectroscopy, the annihilation of positrons in solid states became a powerful instrument for their investigation [1], [2].

Positrons, diffusing into solids annihilate, depending on the electron density along their path [3]. They also can be trapped in locations of defects of the vacancy and/or of the dislocation type. Thus, the wave function of these positrons is localized there, until the annihilation with an electron from its vicinity occurs. Since the local density of electrons is smaller in these defects, the life time of the trapped positrons will increase [4]. Therefore, the overall decay will be slower according to the number of existing defects or consequently the number of trapped positrons, compared to the ideal crystal. The increased life times will be seen with different intensities in the overall life time spectrum for the positrons annihilation in the solid.

<sup>1</sup> Prof. dr. ing. Electronics Dept. University POLITEHNICA of Bucharest, Romania,

<sup>2</sup> Eng. National Institute of Physics and Nuclear Engineering “Horia Hulubei

<sup>3</sup> Ing. National Institute of Physics and Nuclear Engineering “Horia Hulubei

So, a possible way to investigate the defect concentration as well as their type, is to observe the number of positrons decaying in function of time, resulting in spectrum like:

$$D(t) = \sum_{i=1}^{k=1} I_i \exp\left(\frac{t}{\tau_i}\right) \quad (1)$$

With  $k$  for the number of different types of defects (+1 for the ideal crystal), having individual life times  $\tau_i$  and corresponding intensities of  $I_i$  for each component.

If positrons are not trapped at all, the spectrum reduces to:

$D(t) = I \exp(-t/\tau_b)$  where  $\tau_b$  is the life time of positrons in defect free crystal (and  $I=1$ ).

An experimental arrangement for life time measurements is shown in fig. 1, where the birth gamma ray (1270keV) of an emitted positron is detected with a fast scintillator-photomultiplier tube and one of the annihilation gamma ray (511keV) is measured by a similar detector. The corresponding signals feed two fast discriminators which give the start-stop signals for a time digitizer (TAC+MCA).

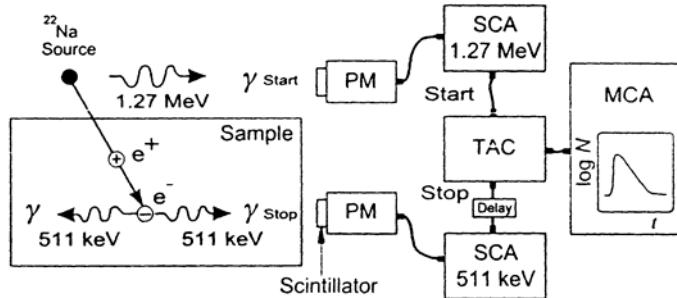


Fig. 1. Experimental arrangement for positrons life time measurement

In such experiments, the measured life time is a convolution of the real spectrum  $N(t)$ :

$$N(t) = \sum_{i=1}^{k=1} \frac{I_i}{\tau_i} \exp\left(\frac{t}{\tau_i}\right)$$

With the temporal resolution function  $F(t)$  of the system, which can be expressed (by replacing  $t$  with  $(t - t_0)$  of the delay) in good approximation with a Gaussian function as below:

$$D_f(t) = \sum_{i=1}^{k+1} \frac{I}{2} \exp\left[-\frac{t-t_0-\sigma_s^2/4\tau_i}{\tau_i}\right] \left[1 - \operatorname{erf}\left(\frac{1}{2\sigma_s\tau_i} - \frac{t-t_0}{\sigma_s}\right)\right]$$

Since the life time components are in the range of 160 ps up to few nanoseconds, it is necessary to provide an as good as possible temporal resolution [5], for the experimental setup. One of the most important requirements, to resolve such short life times, is the capability of the discriminators (SCA) to give their start-stop signals within errors smaller or in the range of the smallest expected life time component, to be measured.

In the following, a dedicated design for fast discriminators useable in positrons life time spectroscopy is discussed and the obtained results are presented.

## 2. Operation principle

Discriminators generate precise logic pulses in response to input signals exceeding a given threshold. There are two main types of discriminators, the leading edge discriminator and the constant fraction discriminator. The leading edge discriminator is the simpler of the two types. For a given input pulse, the leading edge discriminator produces an output pulse at the time when the input pulse crosses a given threshold voltage. This, however, can cause a problem in situations where the timing is important. If the amplitudes are different, but the rise times of the input pulses are the same, a sort of "time walk" occurs (fig. 1), because an input pulse with smaller amplitude but with the same rise time as a larger pulse will cross the threshold voltage at a later time. Thus, the timing of the output pulse is shifted due to the difference in amplitude.

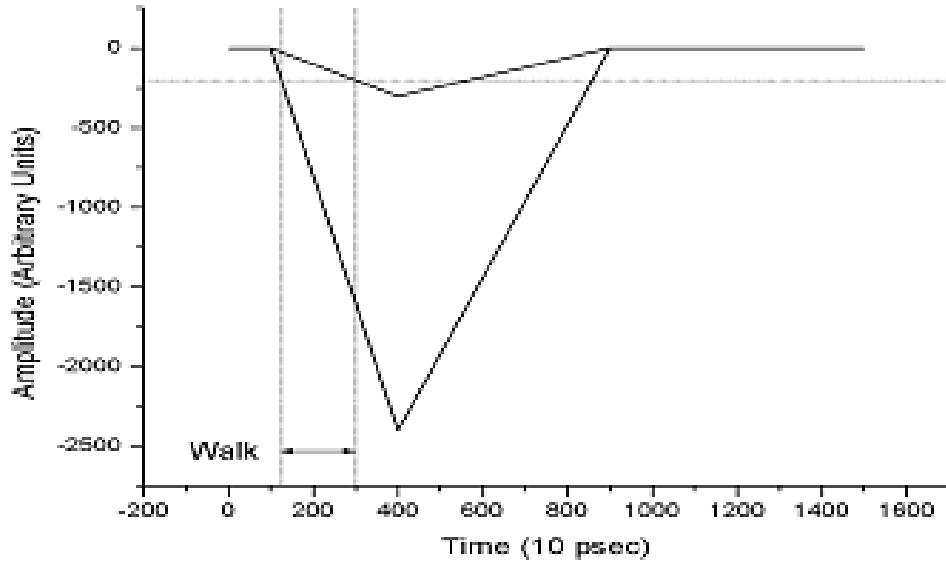


Fig. 2. Illustration of the time "walk" seen for different signal amplitudes when using a leading edge discriminator with a fixed trigger level

The constant fraction discriminator alleviates this problem [6] by using a constant fraction  $f$  of the input pulse to precisely determine the timing of the output pulse relative to the input signal. It does this by splitting the input signal in two, attenuating one, so that it is a certain fraction  $f$  of the original amplitude and delaying and inverting the other one. The attenuated pulse and the delayed/inverted pulse then are added together, and the zero crossing of the sum signal is computed (fig. 3).

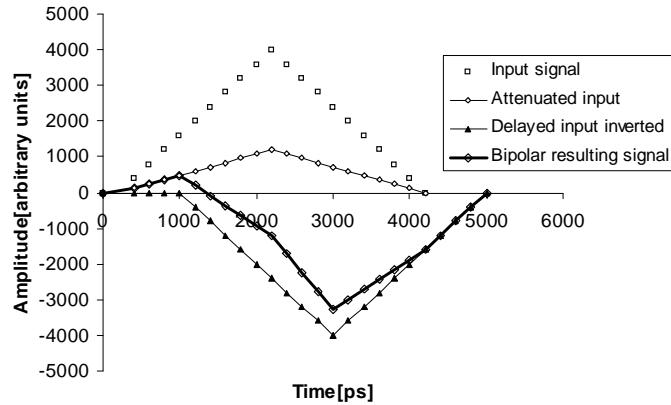


Fig. 3. Conversion of input signal in a bipolar pulse

The zero crossing point gives the time at which the CFD should create the output pulse which is independent of the signal amplitude (fig.4)

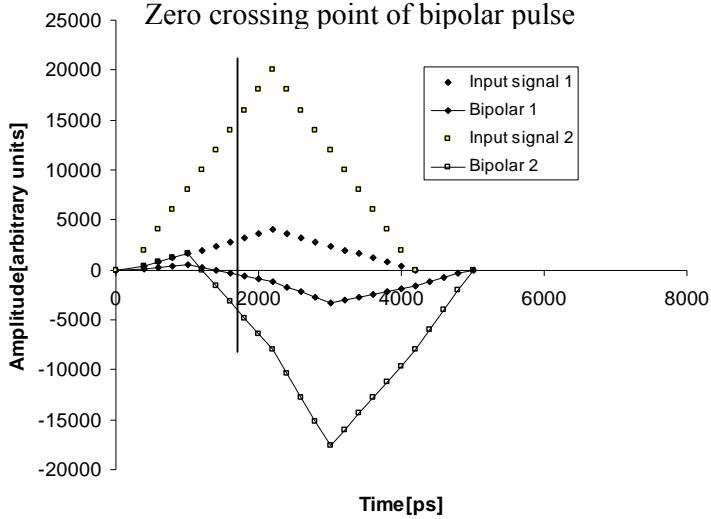


Fig. 4. Zero crossing of bipolar pulse is independent of input amplitude

For a simple linear ramp, like the one shown above, the equations for its input pulse, attenuated pulse, delayed and inverted pulse are as follows:

$$\text{delay} = t_d, \quad \text{fraction} = f, \quad \text{initial amplitude} = A,$$

$$\text{input pulse } V_i = -At,$$

$$\text{attenuated pulse } V_a = -fAt,$$

$$\text{delayed and inverted pulse } V_d = A(t - t_d).$$

The zero crossing  $V_a + V_d = 0$  resolved for  $t$  is:

$$0 = -fAt + A(t - t_d),$$

$$t_{\text{cross}} = \frac{t_d}{(1-f)}.$$

The amplitude fraction  $F$  in this general case can be found by calculating the ratio of  $V_d$  evaluated at the crossing time to the maximum value of  $V_d$ :

$$F = \frac{-m(t_c - t_d)}{-mt_r} = \frac{ft_d}{t_r(1-f)} \quad (2)$$

The structure of practical CFDD is shown as a block scheme in fig. 5. The input signal is split to directly feed a window discriminator (LLD and ULD) and to provide a delayed input for proper CF discrimination composed by a “Bipolar conversion” block and a fast discriminator (FD). The output of the window discriminator is enabling the GATE only if the input signal has its amplitude between lower and upper levels of individual discriminators LLD and ULD. Using this feature makes it possible to select the signals corresponding to a well defined energy range which is defining the START/STOP timing markers (see fig. 1). From GATE, the output pulse is directed to the output via a buffer to provide a matched output impedance and amplitude (50 Ohms and 2Vpp) for proper connectivity with other equipment.

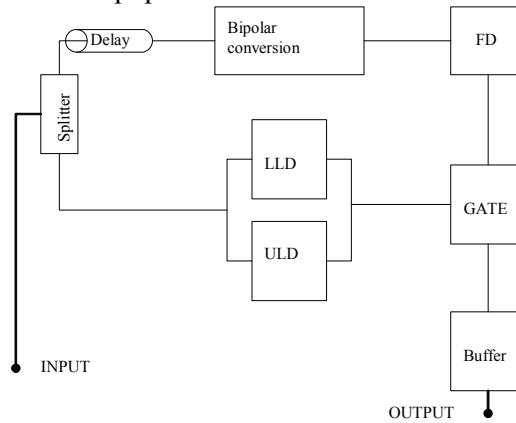


Fig. 5: Block scheme of CFDD

Since the whole design is based on usual high speed pulse electronics [3,4], only peculiar aspects related to the bipolar conversion of input pulse in connection to fast zero crossing discriminator will be discussed in details.

As mentioned above, the first step in designing a CFD is to transform the unipolar input pulse in a bipolar one, having the zero crossing point at a given fraction of the initial amplitude. This task is accomplished in our design, as is shown in fig. 6, by using a differential summing transformer, fed on one of the primary windings with the attenuated input signal and on the other one with the original, but delayed input signal.

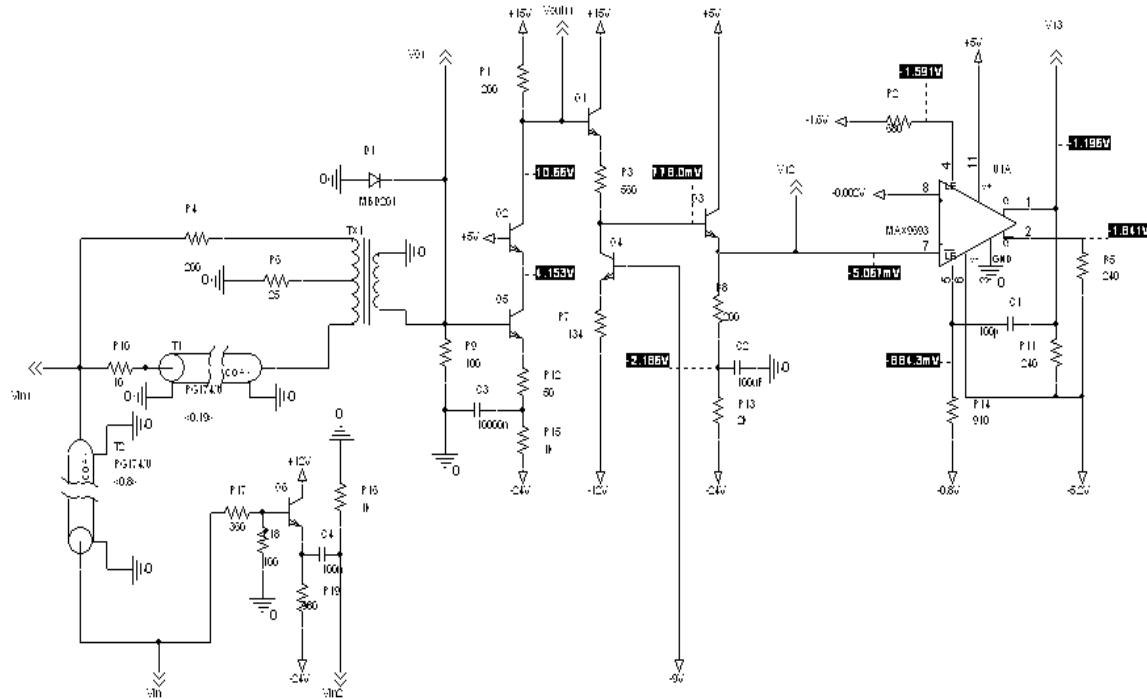


Fig. 6: Principle schematic of “Bipolar Conversion and FD” blocks from fig. 5

On the secondary winding the difference of the two input signals will be provided. This is a bipolar pulse, having the “zero crossing” point at a defined fraction of the original pulse.

As the amplitudes of the signals from the detectors can vary down to a factor 100, the ratio of the signal amplitude to the threshold of the trigger (usually in the range of 2-5mV) can cause timing problems in detecting the exact zero crossing point. To avoid the slight shift in trigger time of the FD, due to this

incertitude, an amplifier stage of cascode type (Q2/Q5) and the emitter follower Q3 is inserted between bipolar conversion and FD.

The operation of the bipolar conversion and fast discriminator block is shown in simulations, given by the PSPICE program in fig. 7 a, b, c, and d, (bottom to top) which is done with input signals for 0.05-5V (a). The corresponding bipolar signals at the input of the FD are shown, (b) and the same in expanded time scale, showing the zero crossing point in an enlarged scale (c). Finally the output pulses from the fast discriminator are shown (d). The timing incertitude from these plots can be evaluated to be in the range of 80 to 180 ps for th a) holds of the FD being in the range of 2-4mV.

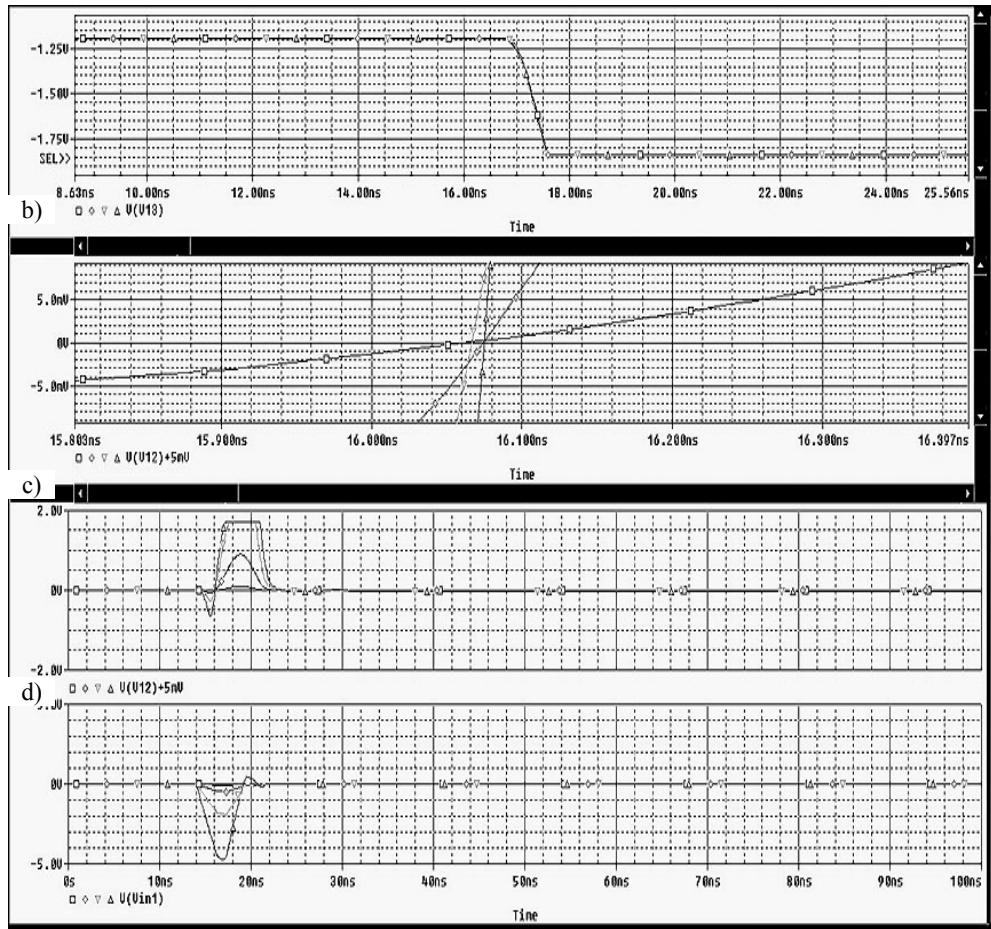


Fig. 7. Simulated operation of the circuit from fig. 6:a) Input signals with amplitudes between 0.05 and 5V; b) Bipolar signals at the input of the FD; c) The same bipolar signals at a expanded scale; d) Timing signals at the output of the FD

### 3. Results and discussion

Practical CFDD were made according to the presented solution and used in a time spectrometer as shown in fig. 1 with which the life times of positrons in a super conductive sample was measured. The experimental data has been analyzed with a dedicated program (RESOLUTION) and the results are shown in fig. 8

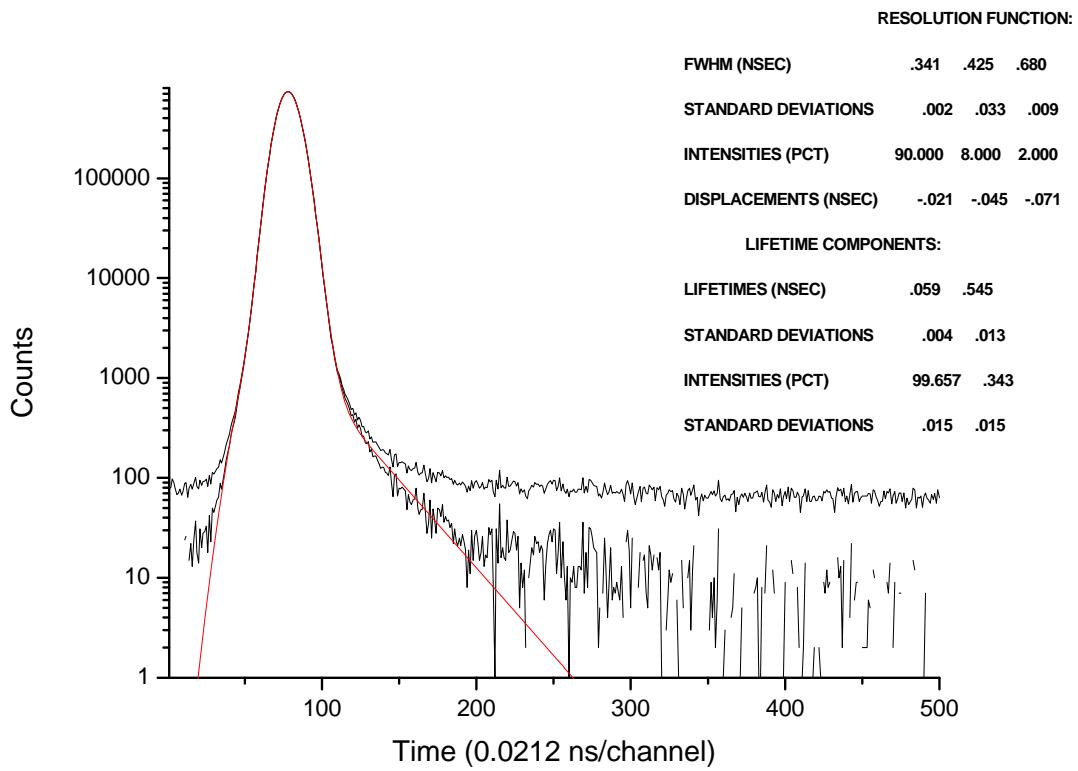


Fig. 8 Time resolution for designed CFDD.

The obtained overall resolution of 341 ps can be explained by the independent contributions from individual resolutions of the CFDD, the detectors and the time to amplitude converter (TAC). As the resolution of the TAC, which is about 60 ps, can be neglected, the time resolution of the spectrometer is given only by the CFDD and the detectors according to the relationship:

$$[(200\text{ps})^2_{\text{cfdd1}} + (200\text{ps})^2_{\text{cfdd2}} + (200\text{ps})^2_{\text{D1+D2}}]^{1/2} = 200 * 3^{1/2} = 346\text{ps}$$

In which the time resolution of detectors were measured in other experiments before.

#### 4. Conclusions

A practical fast constant fraction differential discriminator has been designed and realized for a high resolution time spectrometer, used for positron life time measurements. The individual resolution of less than 200ps is admissible with such experiments and could be further improved by using fast discriminators having threshold incertitude less than 2mV.

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