Materials Science Forum Vols. 445-446 (2004) pp. 462-464
online at http://www.scientific.net

Linearity Tests of a Digital Positron Lifetime Spectrometer

R. Aavikko[1], K. Rytsölä[1] and J. Nissilä[2]

[1]Helsinki University of Technology, Laboratory of Physics, Otakaari 1M, FI-02015 HUT Espoo, Finland

[2]Centre for Metrology and Accreditation, Otakaari 7B, FI-02150 Espoo, Finland

Keywords: DPLS, Lifetime Spectrometer, Linearity, Positrons

Abstract. We present linearity test results for a completely digital positron lifetime spectrometer (DPLS) based on the 1 ch, 2 GS/s Acqiris DP210 digitizer. In general the performance of the apparatus is comparable to that of an analog spectrometer. A particular feature of the linearity of the digital apparatus is that one can observe "semidifferential" nonlinearity arising from the fact that the anode pulses are sampled with finite number of samples with discrete amplitudes and thus the number of different digitized anode pulses is finite. This means that also the possible time intervals measured by the apparatus are discretized. Our measurements show that in positron lifetime measurement setup this semidifferential nonlinearity is smoothed out even at 2 GS/s.

Introduction

Important characteristics for the performance of a positron lifetime spectrometer are time resolution, measurement rate and linearity. The resolution and throughput of DPLS have proven to be adequate [1, 2]. In this paper we present linearity measurements for DPLS.

In a conventional analog positron lifetime spectrometer two different nonlinearity types are distinguished [3]. *Differential nonlinearity* is variation of successive bin widths. *Integral nonlinearity* is "long range" nonlinearity, which appears as a trend of increasing or decreasing bin widths. The source of differential nonlinearity is usually attributed to the nonideality of MCA and the integral nonlinearity as arising primarily from TAC electronics.

The digital spectrometer has no fixed physical channels. A DPLS measures the time intervals of individual lifetime events directly in time units and the lifetime spectrum is then composed by histogramming these lifetimes. The histogram bin widths can be chosen arbitrarily, so the concept of differential nonlinearity is not meaningful in its typical interpretation. The DPLS has a crystal calibrated time base which gives very good integral linearity. Also the fact that the clock runs independently of the start- and stop events kills start and stop related transient effects.

The nonlinearities of the DPLS that we have observed are of "intermediate range" and we call them *semidifferential nonlinearities*. Our explanation for sources causing these phenomena are: The finite digitization accuracy leads to a finite number of different timing instants, which may not be evenly distributed. In our system start- and stop anode pulses are run on the same digitizer channel and ringing of the anode pulses can cause interference, which materializes as nonlinearity. The external gate module for detecting the coincidences can cause interference.

Experimental

The linearity of a positron lifetime spectrometer can be measured by introducing random start- and periodic stop signals [3]. This results in a uniform distribution of the time intervals. We obtain the start pulses from a radioactive source and the stop pulses from a pulser.

The linearity of DPLS can be measured with different setups: Firstly (i), both start- and stop pulses can be combined, separated by a cable delay and run on the same channel. The delays can be adjusted so that the stop pulse will be at the end of the sweep assuring that it will be interpreted correctly by the analyzing software. This setup yields much unneeded data which slows down the measurement, since the ratio of coincidences and triggered sweeps is low. Secondly (ii), a gate module for detecting the coincidences can be added to the previous setup. This speeds up the measurement by reducing unnecessary data. Thirdly (iii), the start pulse can be used for triggering the digitizer and only the position of the stop pulse is measured. This allows studying the effect of finite digitization accuracy, since the positions of the pulses are measured relative to the sampling points (whereas in other linearity measurements time difference of two pulses is measured).

In the measurements we have determined the positions of the anode pulses by first fitting smoothing splines [1, 4] to the leading edges of the pulses and then applying the constant fraction timing. The fitting method and the used parameters have an effect especially on the digitization nonlinearity.

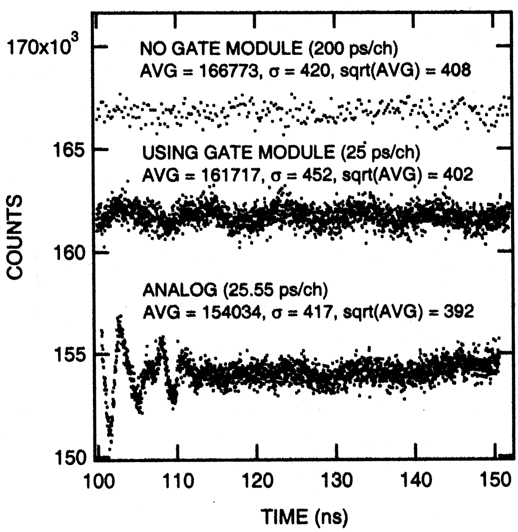

Figure 1: Linearity measurements of digital and analog positron lifetime spectrometers. The gate module is seen to cause ≈10 ns "oscillations" (ii). The data obtained without gate module (i) has much wider bin widths in order to obtain similar statistical accuracy as with other methods. The averages and standard deviations presented in the figure are calculated between 115–145 ns.

Results

Results from linearity measurements are presented in figure 1: basic measurement without the gate module (i) shows good linearity. Using the gate module to speed up the measurement (ii) introduces "oscillations" with $\approx$ 10 ns periodicity. We have not found an explanation for these oscillations. The amplitude of these oscillations is approximately of same magnitude as the nonlinearities of the analog spectrometer (which is being used routinely in our experiments). These oscillations remain constant independent of the cable delays used in the measurement setup. They seem to have $\leq$ 2 ps effect on the average positron lifetime.

Since the number of sampling points in the leading edge and the number of different sampled voltage levels are finite, the number of different anode pulses digitized by DPLS is finite. At 2 GS/s the number of sampling points at the leading edge of the anode pulse is approximately 5. Voltages are sampled with 8-bit precision, but since the samples represent a leading edge of an anode pulse, they are highly correlated. Thus the number of different digitized leading edges is much lower than the theoretical maximum $(2^8)^5 = 10^{12}$.

A particular timing algorithm is a deterministic mapping from the sampled voltage values to time. Since the number of different inputs (sampled anode pulses) is finite, also the number of outputs (different timing values) is finite. Timing values can be expected to be nonevenly distributed. This was also observed in practice: in figure 2 is depicted a measurement of position of the pulser pulse when the digitizer is triggered with the detector pulse (iii). In this setup the digitization nonlinearity with one sampling interval periodicity (0.5 ns $\triangleq$ 20 ch) is prominently visible. Introducing smoothing ($p < 1$) [1, 4] has an expected effect of lowering the amplitude of the variations.

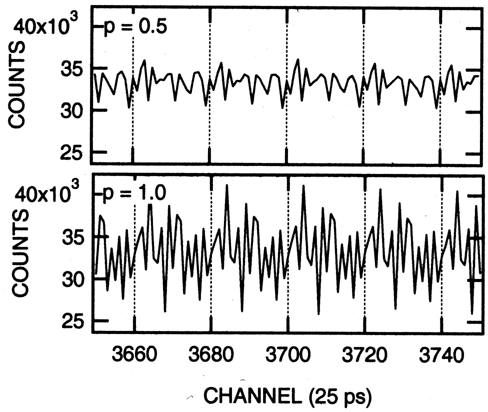

Figure 2: Measurement of the position of a pulser pulse, triggered by detector (iii). The same original data is analyzed with different spline smoothing parameters p ($p = 1$ corresponds to no smoothing) [1]. Each p value produces its characteristic periodicity. The positions of digitizer samples are marked with vertical lines. The digitization nonlinearity with one sampling interval (20 ch) periodicity is prominently visible: standard deviation predicted by Poisson statistics for the data is 180.

We do not observe the effect of digitization nonlinearity in a typical positron lifetime measurement. The explanation for this is that the time intervals are measured between two anode pulses. This smooths up the nonlinearity for two reasons: unlike the pulser pulses used in this experiment, anode pulses have varied amplitudes and different amplitudes have each their own characteristic digitization nonlinearity curves. Also, in positron lifetime measurement the time intervals are measured as the difference of the two pulse locations. The anode pulse locations and the sampling points are not directly correlated and since the digitization nonlinearity is related to the sampling points themselves, the nonlinearity smooths out. This effect is presently being studied by simulations.

Conclusions

In this paper we have covered linearity measurements of our DPLS. The linearity of the apparatus is fully adequate for routine positron lifetime measurements. Unlike in analog spectrometers, the nonlinearities of DPLS manifest themselves primarily as "semidifferential" nonlinearities in the intermediate range. A particular feature of the semidifferential nonlinearites is the digitization nonlinearity, which can be observed as having a periodicity of one sampling interval. This arises due to the fact that the number of different digitized anode pulses is finite. However this nonlinearity smooths out due to the inaccuracy of the triggering and variations in anode pulse amplitudes.

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