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A new pulse width signal processing with delay-line and non-linear circuit (for ToT)

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ABSTRACT

Traditional pulse-height-analysis systems suffer from the complexity arising from ADC circuits. In particular, it is difficult to be applied to a large format array of pixilated detectors. Each channel of such an energy resolving multichannel system must be low power consumption and therefore it must be composed of simple circuits. The time-over-threshold (ToT) method provides an inexpensive way in such a system. However, ToT method suffers from a poor linearity. We now propose a method to improve the linearity with the dynamic time-over-threshold method that relies on a dynamic threshold voltage and the trapezoidal shaping method.

1. Introduction

The time-over-threshold (ToT) method [1] is a pulse processing method, which compares input pulse signals with a preset threshold level and measures the time while the amplitude of input pulse signals is higher than the threshold level. As a result, the ToT method converts the pulse height into the corresponding time width. The ToT method is composed of a simple circuit and promising for front-end circuits in a multichannel system [2,3]. However, the ToT method suffers from poor linearity. We propose a new dynamic time-over-threshold (dToT) method with trapezoidal shaping [4] for improving the poor linearity of a conventional ToT method. Unlike the conventional ToT method that relies on a constant threshold voltage, the dToT method has introduced a dynamic threshold voltage.

2. Linearity analysis of the ToT method

The linearity of the time-over-threshold method is dependent on the shaping method. We have analyzed the non-linearity for several cases, the following example is sufficient to illustrate the issue. We define the pulse height h for fixed pulse duration of a for the triangular pulse. The pulse width obtained by a comparator of fixed threshold level d is:

$$a\left(1-\frac{d}{h}\right) \qquad (1)$$

as schematically shown in Fig. 1.

This causes highly non-linear relationship between the pulse height and the pulse width. Fig. 2 shows curves corresponding different threshold levels, where threshold levels are normalized by the maximum pulse height allowed in the system. At a lower threshold voltage, we observe strong non-linearity for higher amplitude. Higher threshold voltage shows better characteristics in terms of linearity; however, obviously the signal dynamic range is strongly limited at a higher threshold level. This simple analysis suggests the strong dependency of the non-linear and dynamic range characteristics on the threshold level for the conventional time-over-threshold method and it is very difficult to satisfy both the linearity and the dynamic range simultaneously.

3. The dynamic ToT method with a trapezoidal shaping method to improve the system linearity

As shown in the previous section, it is difficult to realize linearity with a conventional ToT method. In particular, we observe the strong dependence on the threshold level and the linearity. Therefore, we have developed an approach with varying threshold level for the ToT method. Here, we introduce a dynamic ToT method with a trapezoidal shaping method to realize, in principle, a perfect linearity.

3.1. The principle of a dynamic ToT method with trapezoidal shaping

A dynamic ToT method is a new ToT method where the threshold level is not constant but increased to catch up the input signal after signal detection. We need some delay time before sweeping the reference voltage. This delay time is made by

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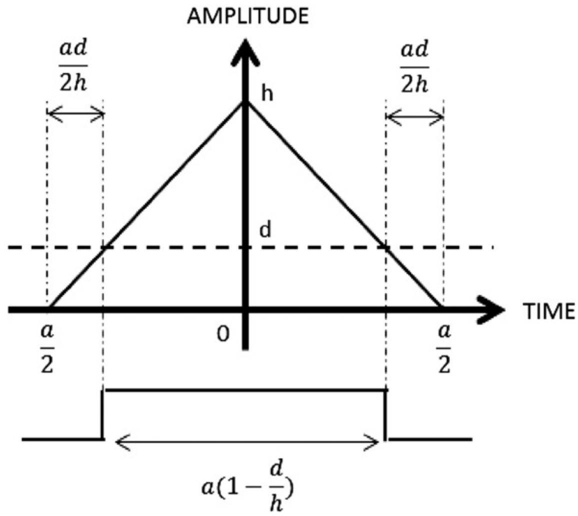

Fig. 1. The relationship between pulse height and pulse width for a triangular pulse shape.

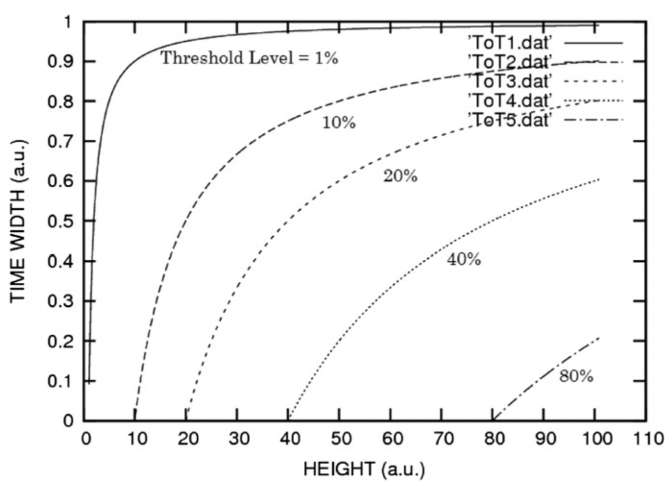

Fig. 2. The relationship between the pulse width and the pulse height for the triangular pulse case.

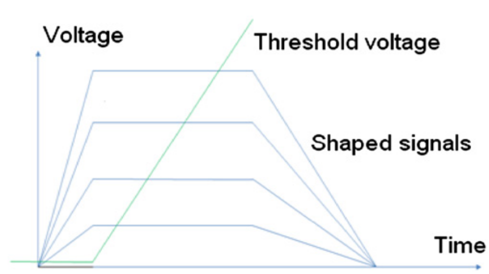

Fig. 3. Dynamic threshold method with a trapezoidal shaping method: linear pulse width change is expected for a linear threshold voltage sweep after signal detection.

a mono-stable multi-vibrator in timing with a rise of comparator output after the signal pulse arrival. In fact, this is realized by a small modification to the conventional ToT. If the trapezoidal shaping method is combined with the dynamic ToT method with a linear threshold voltage sweep, the linearity is drastically improved as shown in Fig. 3.

The advantage of such a system lies in its flexibility in shaping time selection, since the modification of the system suitable for the shaping is only applied to the reference voltage. The disadvantage of the system lies in how to realize a trapezoidal response with reasonable time constant. Usually we need a SMD type delay line, however, the implementation of delay line in Application Specific Integrated Circuit (ASIC) is somewhat difficult.

3.2. Trapezoidal shaping

As shown in Fig. 4, input pulses from a charge sensitive amplifier are clipped by a delay line and sent to a integrator and clipped by another delay line one more time and then changed into a trapezoidal shape.

3.3. Dynamic threshold

The dynamic threshold voltage is output from the capacitor charged by a constant current circuit in the timing with the output from a mono-stable multi-vibrator. As shown in Fig. 5, a comparator compares the trapezoidal shaped pulse with this dynamic threshold voltage and outputs the pulse with a certain time width corresponding to the input pulse height.

3.4. Time to digital conversion

Digital pulse width signals are processed with a time-to-digital converter. A simple solution with a reasonable circuit is to use an

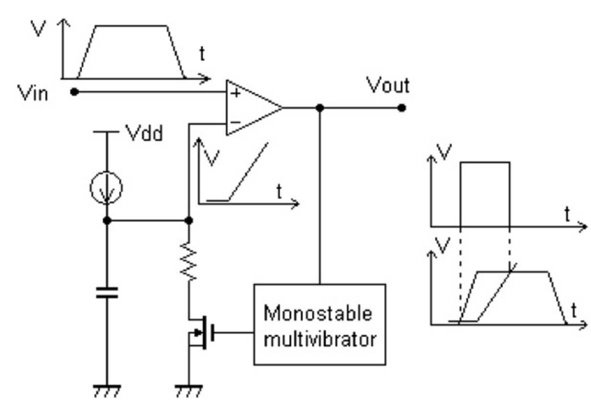

Fig. 5. Circuit diagram of dToT.

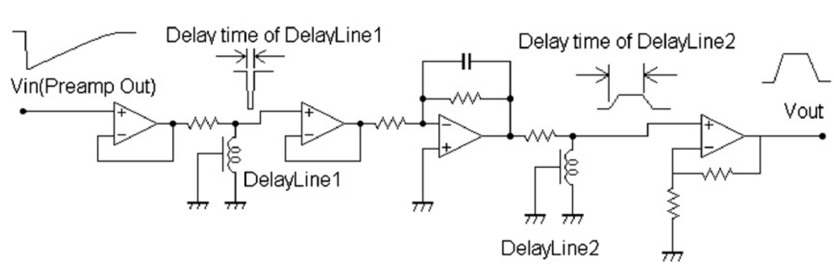

Fig. 4. Circuit diagram of trapezoidal shaping.