Digital Pulser

Valentin T. Jordanov

labZY, LLC
E-mail: v.jordanov@labzy.com

ABSTRACT

The concept and the realization of the digital pulser are presented. The digital pulser is implemented as a functional block of a digital spectrometer. The digital pulser provides noise-free and distortion-free measurement of the inherent electronic noise of the entire spectroscopy system. The digital pulser is introduced at the end of the signal processing chain and allows separate evaluation of the individual spectroscopy blocks. It offers ability to characterize and diagnose problems of the digital pulse-height analyzers by grounding their inputs. The digital pulser does not interfere with the processing of the detector signals and does not contribute to the dead time and the pulse pile-up of the system. The digital pulser peaks are not affected by the presence of detector pulses and are stored in a separate histogram memory leaving the detector spectrum undistorted.

INTRODUCTION

Pulsers (test pulse generators) are used in radiation spectroscopy for estimation of the inherent electronic noise, correction of pile-up counting losses and dead time, calibration verification, gain stabilization and other characterizations of the spectroscopy systems [1-6]. Traditional pulsers are introduced at the beginning of the signal processing chain of the radiation spectrometers. They inject charge at the input of the detector preamplifier through a test capacitor or through the detector capacitance. Test capacitors increase the total input capacitance causing degradation of the noise performance of detector preamplifiers. Charge injection through the detector capacitance may create distortion and may require special high voltage circuitry. The analog pulsers are subject to their own electronic noise, ground loops and other unwanted electromagnetic interferences. In addition, the amplitude of these pulsers may drift with time and temperature.

One of the major shortcomings of the traditional pulsers is the interference of the test pulses with the detector pulses. The preamplifier pulse shape from the pulser injected charge is bipolar and differs from the unipolar pulse shape from the detector charge collection. This may affect the operation of the shapers (analog or digital), especially the base line restorers. As the test pulses are processed through the same signal chain as the detector pulses, the test pulses pile-up with the detector pulses and cause additional counting losses and distortion of the pulser and detector spectral peaks.

The use of the traditional pulsers may be limited ina portable system or in the field due to size requirements. Some detector configurations may not offer test input due to detector design, size or noise performance constraints.

With the introduction of the digital pulse processing some of the traditional uses of the pulsers have been replaced with new techniques. For example, the elimination of the ADC dead time and the employment of new digital shaping techniques allow estimation of the counting losses with much greater accuracy, and the need to use pulsers for pile-up correction and dead-time estimation diminishes. However, the use of pulsers to measure the inherent noise of the digital spectroscopy system remains important for optimal setting of the signal processing chain. This paper describes a digital pulser that allows for noiseless measurement of the electronic noise and evaluation of other characteristics of the digital spectrometers.

DIGITAL PULSER

In contrast to the traditional analog pulser, the digital pulser is introduced at the end of the signal processing chain. Fig. 1 depicts a simplified block diagram of a digital spectrometer utilizing a digital pulser. The digital pulser is fed by the output of the spectrometer's digital shaper. The digital pulser selectively processes sampled digital values. The digital pulser produces digital pulse heights with distribution that has variance equal to the variance of the digital shaper baseline distribution (inherent electronic noise). The mean of the baseline distribution, however, may be shifted by a digital offset generated by the digital pulser. The distribution of the digital pulse heights is recorded in a histogram memory.

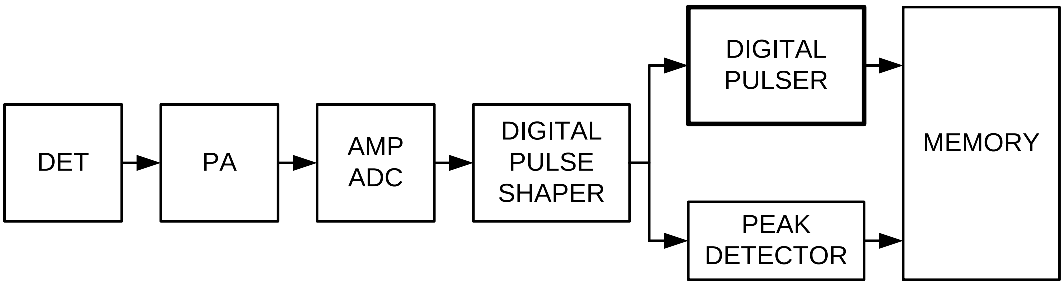


Fig. 1 Simplified block diagram of digital spectrometer using digital pulser.

The peak representing the distribution of the digital pulser output can be recorded independently from the detector spectrum. Therefore, the spectral interference between the detector spectrum and the pulser peak is eliminated without any additional means as it is in the case of the traditional analog pulsers [5,6]. It is clear that the digital pulser can not be used for calibration verification or gain stabilization because of its position at the end of the signal processing chain.

Fig. 2 shows a simplified block diagram of the digital pulser. *Pulser Strobe* is a digital pulse signal with width equal to the width of one cycle of the digital shaper clock. These short pulses may be generated randomly or at fixed frequency. The digital signal from the digital shaper (*Digital Shaper*) is added to a fixed *Digital Offset*. The result from the addition feeds the input of a data register (REG) which captures the adder's digital value at each *Pulser Strobe*. The captured digital value is held by the register until the next *Pulser Strobe*.

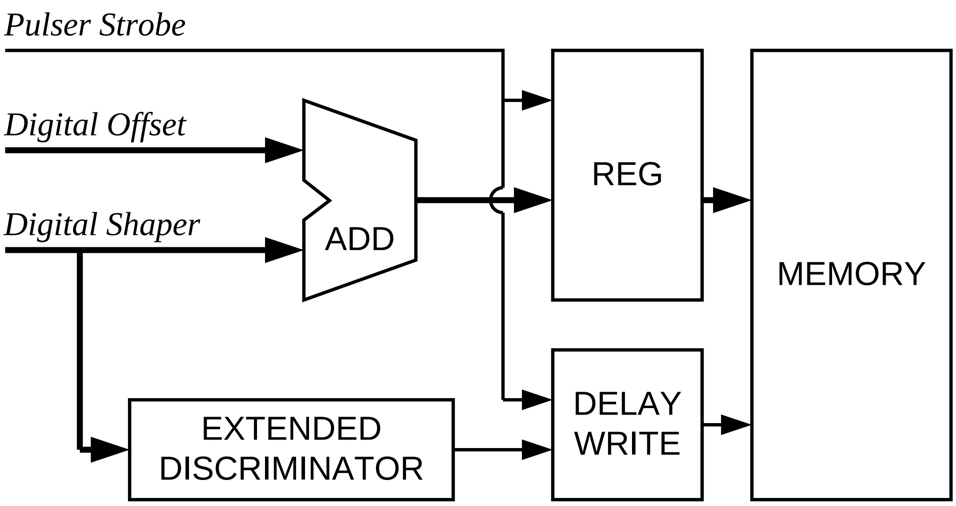


Fig. 2 Block diagram of digital pulser.

The *Digital Shaper* signal drives a discriminator with threshold set just above the noise envelope of the base line (EXTENDED DISCRIMINATOR). The discriminator pulse is extended in order to prevent capturing digital samples that represent superposition of the falling edge of the digitally shaped detector signal and the shaper's base line. A delay write technique is used to prevent memory storage of samples that are superposition of the leading edge of the shaped detector signal and the baseline. The delay write is triggered by the *Pulser Strobe* only when the extended slow discriminator is inactive. The delay write will be aborted if the extended slow discriminator becomes active during the delay period.

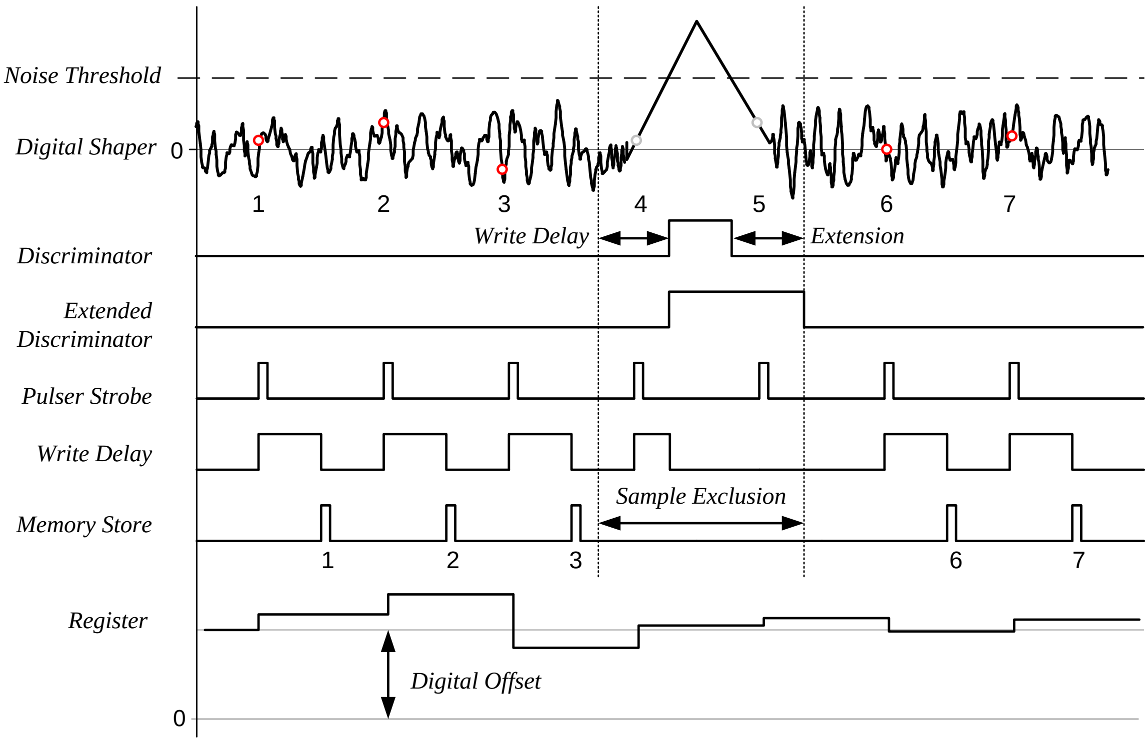


Fig. 3 Timing diagram illustrating the digital pulser operation.

To illustrate the operation of the digital pulser, a timing diagram is presented in Fig. 3. The *Digital Shaper* signal represents the baseline signal (electronic noise) and a single detector pulse with amplitude exceeding the *Noise Threshold*. When the detector pulse exceeds the *Noise Threshold*, the *Discriminator* becomes active. The *Discriminator* signal is extended by an *Extension* resulting in the *Extended Discriminator* signal. When active, the *Extended*

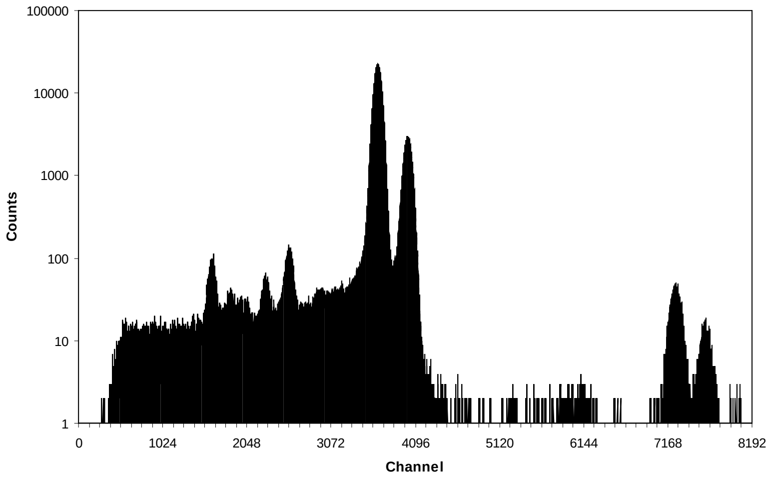
Discriminator prevents the *Pulse Strobe* from triggering the *Write Delay*, thus preventing the capturing of baseline samples that may be contaminated by the detector signal. When the *Extended Discriminator* is inactive, each *Pulse Strobe* pulse triggers the *Write Delay*. In this particular case, the *Write Delay* is just a fixed extension of the *Pulser Strobe*.

At the falling edge of the *Write Delay* a *Memory Store* signal is generated which initiates the memory histogram function using the captured *Register* data. The *Write Delay* is terminated and no *Memory Store* is generated when the *Extended Discriminator* becomes active. Using this functionality, *Digital Shaper* samples that may be contaminated by the detector signal are excluded from capturing by the digital pulser. For example, in Fig. 3 only samples 1,2,3,6,7 (red dots) will be recorded in the digital pulser peak. Samples 4 and 5 (grey dots) will be excluded from the digital pulser peak.

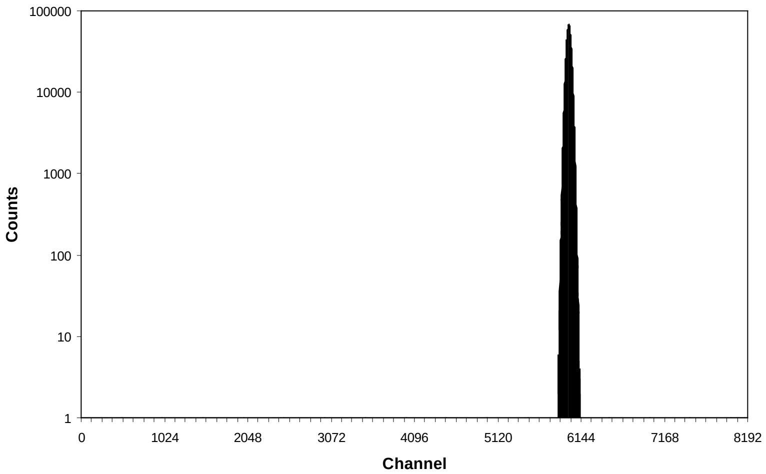
Other realizations of the digital pulser are possible, but they all should prevent capturing of data that may be contaminated by the detector signal. The *Pulser Strobe* may be generated at frequencies up to a few MHz. However, for efficient capture of the samples a more sophisticated registers may be used, e.g. FIFO register or circular buffer. As in the case of the traditional pulser, the digital pulser data is histogramed and stored in the memory. Therefore, the output of the digital pulser is a spectral peak and can be used for detailed analysis by existing spectral-data-processing software programs.

EXPERIMENTAL TESTS

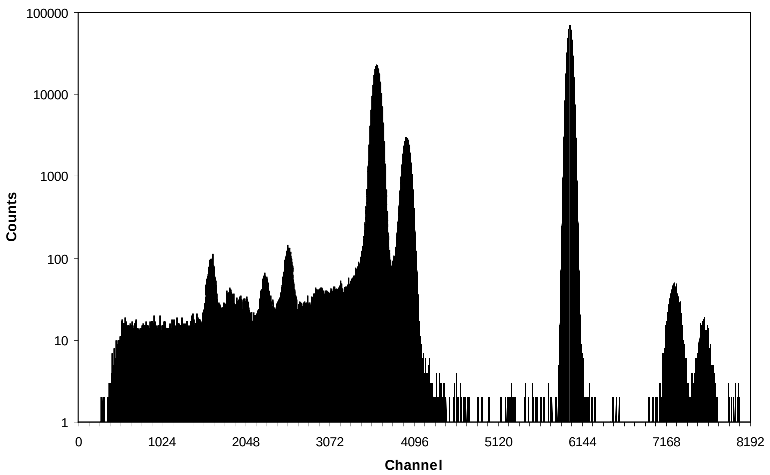
In the following examples, a digital pulser is used that is a part of nanoXRS. Fig. 4 shows Fe-55 spectrum and the digital pulser peak obtained simultaneously using thermoelectrically cooled silicon drift detector with resolution of 162eV@5.9keV. Fig. 4a shows the X-ray spectrum undisturbed by the digital pulser. The digital pulser is stored in a separate memory group depicted in Fig. 4b, and shows no signs of the X-ray spectrum. As illustrated in Fig. 4c, the digital pulser peak can be added to the detector spectrum if desired. This addition, however, will cause peak distortion if the digital pulser peak is added to a spectrum area with significant number of counts. In the case of Fig. 4c, the pulser peak is added to a part of the spectrum with few background counts. The FWHM of the digital pulser is 109eV and is direct measure of the system electronic noise.



a)



b)



c)

Fig. 4 Examples of x-ray spectrum and digital pulser peak.

One of the major applications of the digital pulser is to estimate precisely the electronic noise of the digital spectroscopy system in a very short time. To optimize the performance and the settings of the digital pulse shaper, a noise profile of the entire signal processing chain was measured. The FWHM of the pulser peaks were recorded for different rise times of the digitally shaped triangular pulses. The digital pulser operated at frequencies between 1MHz and 20kHz depending on the rise time of the triangular pulses. More than one million counts were recorded in each pulser peak. The intrinsic electronic noise is measured as FWHM of the recorded digital pulser peak. Fig. 5 shows the electronic noise dependence on the rise time of the digitally shaped triangular pulse. All data shown in Fig. 5 were manually taken in less than 5 minutes. The process can be automated and will allow "noise optimization" of the system in less than one minute.

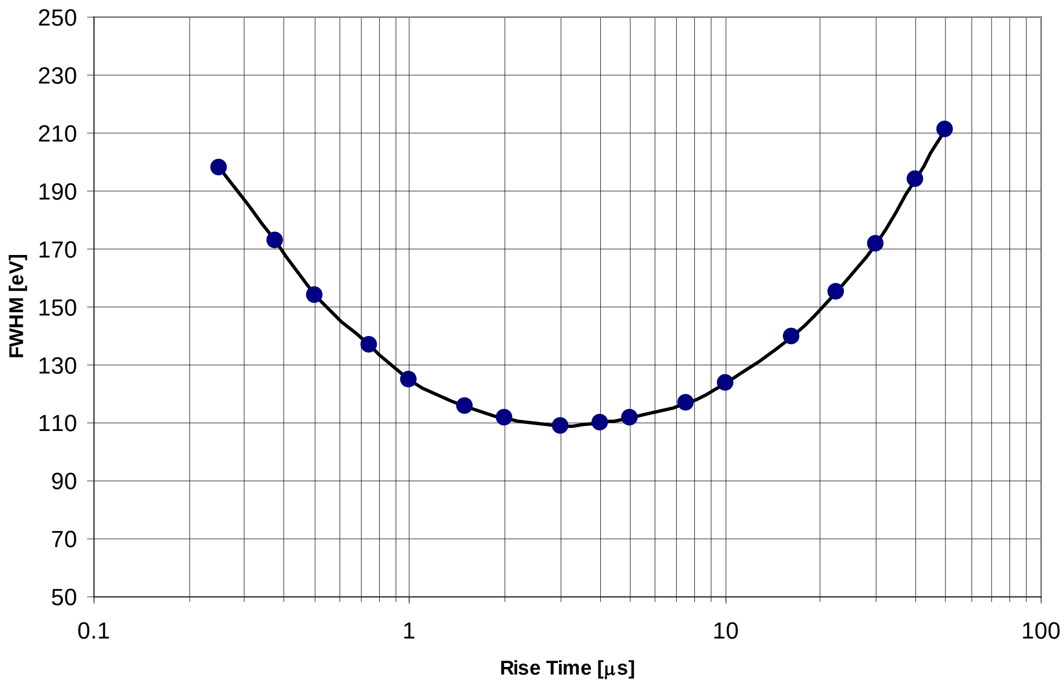


Fig. 5 Electronic noise profile of digital spectroscopy system.

The digital pulser is also a powerful diagnostic tool. As stated earlier, the digital pulser is connected at the end of the signal processing chain. This allows diagnostic of the individual modules comprising the spectroscopy system. For example, the preamplifier response can be eliminated by disconnecting the preamplifier and grounding the input of the amplifier that follows the preamplifier. This connection is shown in Fig. 6.

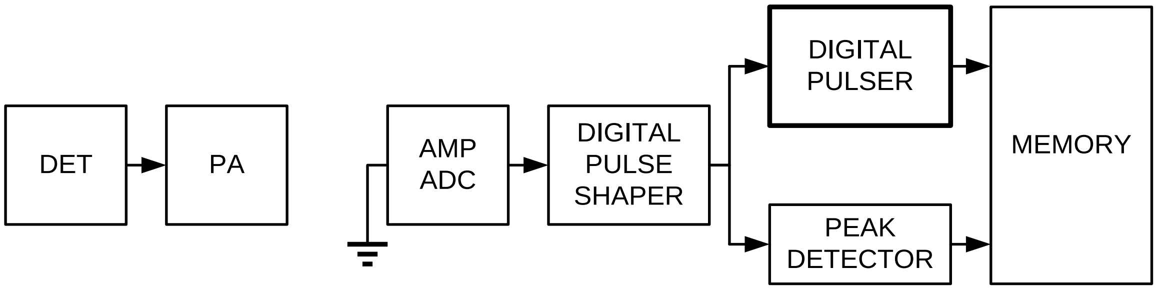


Fig. 6 Test configuration excluding detector and preamplifier from the signal processing chain.

The digital pulser allows to diagnose some hard to find problems in this “grounded configuration”. Fig. 7 shows an example digital pulser peak indicating amplifier oscillation or pick-up of external sinusoidal signals. The split peak results from the convolution of the sinusoidal signal and the electronic random noise of the system. If the preamplifier is connected, its noise dominates all other noise sources and the split peak disappears. The sinusoidaloscillation case of Fig. 7 was simulated by introducing 200kHz signal at one of the components of the main amplifier.

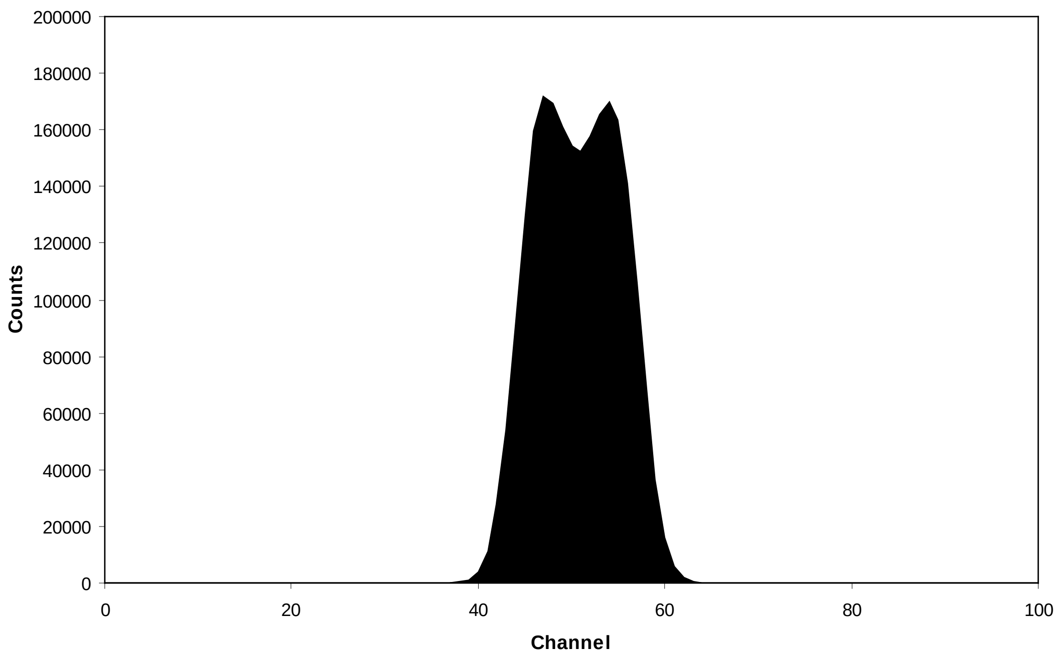


Fig. 7 Digital pulser peak from “grounded configuration” indicating presence of sinusoidal signal.

CONCLUSION

The digital pulser is a simple, but powerful concept that can easily be incorporated in most digital spectroscopy systems. The digital pulser does not add noise to the spectroscopy system, and does not interfere with the pulse processing and the spectrum acquisition. Its accurate estimation of the intrinsic electronic noise makes it an indispensable tool in the optimization of the digital pulse processing, characterization and optimization of the detector front-end electronics, accurate measurement of detector parameters such as Fano factor, quality control etc. Other traditional tasks, such as pole-zero adjustment, counting losses estimation, may also benefit from the use of the digital shaper.

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