A simple pulse detection algorithm and its precision in energy measurement

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Many areas of science rely on experiments that use spectral measurements for diagnostics and theoretical validation. Spectral measurements separate the photons captured by the detectors according to their energy. Each photon produces an electrical pulse whose amplitude is proportional to the photon's energy. Nowadays, state-of-the-art spectrometers include analog-to-digital converters (ADC) that deliver more than a 100 mega-samples per second (MSPS), and enough processing power to run an operational system. On the other hand, small lab projects can make use of cheap microcontroller units (MCU) for spectral measurements. The spectrum resolution and size will be limited by the ADC sampling rate and bit precision, as well as electronic noise and the detector's intrinsic resolution [1].
For this purpose, a simple pulse detection algorithm can be implemented by separating the sampling range into 3 bands: low, middle, and high. A pulse counting occurs if the voltage signal goes from low to middle band, and then back again to low band. No other path combination should result in a pulse count. Before returning to the low band, the largest sampled value is kept in a register to later indicate which spectrum channel should be increased. In this study, the pulses were modeled using the bi-exponential function,

$$y(t) = h\left(1 - e^{-t/\tau_r}\right) e^{-t/\tau_d} \quad \text{for } t \geq 0$$

where τ_r/τ_d are rise/decay time constants, and h is the height parameter. The pulse height is given by

$$H = y(t_{pk}), \text{ where } y'(t_{pk}) = 0$$

With limited sampling rate, it is possible that the highest measured value is Δy away from the pulse height H (amplitude). With pulses arriving at random times, the average measured height will be H - $<\Delta y>$ and its uncertainty is related to the standard deviation $\sigma = \sqrt{<\Delta y^2>}$. While the lack of accuracy can be solved with calibration from known radioactive sources, the uncertainty is dictated by the sampling rate and bit resolution of the ADC. If the pulse width is shorter than the sampling period T_{ADC}, the detector algorithm may completely miss it! An example is pictured in Figure 1.

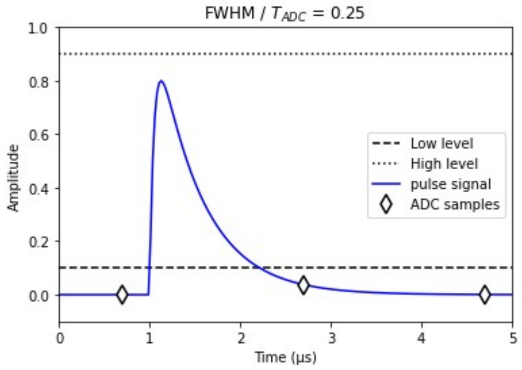

Figure 1. Example of very fast pulse

Cheap MCUs are usually bundled with slow ADC peripherals, with sampling rates less than 1 MSPS. However, the pulse width can be tweaked inside the analog signal chain, before the conversion to the digital domain. The project engineer can add a few analog filtering stages, each stage requiring only an operational amplifier, and a couple of capacitors and resistors. An important question arises, how many filtering stages are necessary to optimize the measurement's precision? Put another way, what should be the full width at half maximum (FWHM) to have a measurement uncertainty as small as 1 bit?
An error function can be defined as:

$$\varepsilon(x) = 2\sigma, \text{where } x = \text{FWHM}/T_{ADC}$$

which can be calculated numerically, using the bi-exponential function. Thus, the target width FWHM* is found by solving the equation $\varepsilon(x^*) = 1$ bit, where $x^* = \text{FWHM}^*/T_{ADC}$. This value will depend on the characteristics of the pulse and ADC. For a simple demonstration, we consider $\tau_d = 3.3\tau_r$, no electronic noise, and no hold time for the sampling. Table 1 shows some examples for common ADCs found in low-end MCUs. It is easy to include electronic noise in the calculations for more realistic estimates.

Table 1 – Target widths for different ADCs.

Sampling Rate	8-bit ADC [μs]	10-bit ADC [μs]	12-bit ADC [μs]
250 kSps	33	65	129
1.2 MSps	6.8	14	27
2.4 MSps	3.4	6.8	14
4.8 MSps	1.7	3.4	6.7

References

[1] KNOLL, G. H. Radiation Detection and Measurement. 4th ed. John Wiley & Sons, Inc.