Differential Count Rate

Ideally, a decay curve and the corresponding IRF are recorded at the same *differential count rate*. That means NOT at the same average count rate. *Differential count rate* is the real, momentary photon density (probability of encountering a photon) during a time interval when a detected signal is really present.

In TCSPC, decay curves are measured at count rates that are 1..2 % of the SYNC rate (laser repetition rate). This is an established "rule of thumb". According to textbooks, it is required by basic principles of TCSPC in order to avoid various counting losses.(E.g. to avoid the pile-up effect). However, for an IRF measurement the same "low" average count rate can be far too high.

Consider a 150 ps FWHM IRF measured at an average count rate of 100 kcps (kilocounts per second) at 10 MHz SYNC rate. This is "just" 1 % of SYNC. According to the "rule of thumb" it should be fine. But it means already more than 66 Mcps *differential count rate* at the detector!

Differential count rate = 100 000 counts ⁄ (10 000 000 pulses · $150 \cdot 10^{-12}$ second) ≅ 66 666 667 cps

This is still just an optimistic approximation based on an average value over the whole pulse duration. At the moment of **peak** intensity, the momentary *differential count rate* is even higher. Depending on pulse shape, it can be higher by several orders of magnitude. This causes not only counting losses (⇒ invalid IRF shape) but also an increased probability to detect afterpulsing.

A frequently asked question is: "*Why we have to consider some differential count rate if we are detecting rarely one photon (count) per excitation cycle, anyway? Detection probability of two or more photons in one cycle is completely negligible!*"

Not really. In case of pulsed signals the average count rate is a misleading quantity. An average count rate value does not take into account **when** and **how** those photons are emitted and detected. Interpreting a 100 kcps intensity as a constant emission rate (Poisson mean rate, in math terms) is a misconception. The physics of the measurement is completely different. These photons are obviously not emitted evenly, one by one over the whole one second period. They arrive to the detector bunched, as flashes. These are short time intervals with huge photon density (rate), separated by long "dark", quiet periods.

In yet another words, achieving a final count rate at "1% of SYNC rate" is a result of **sparse sampling with dead time**. The sampled signal features much higher photon density, but lasts only for a short time.

In mathematical terms, "average count rate of 1..2% of SYNC rate" means the overall detection probability, integrated over the whole duration of a measurement. The concept of *differential count rate* is related to the *probability density function*. The detected signal in TCSPC has a very inhomogeneous time distribution.

Note: for detectors that exhibit count rate dependent shifting of the IRF, extra care has to be taken when measuring the IRF and directly using it for decay analysis. [1)]

1)

Takuhiro Otosu, Kunihiko Ishii and Tahei Tahara, Note: Simple calibration of the counting-rate dependence of the timing shift of single photon avalanche diodes by photon interval analysis, Rev. Sci. Instrum. **84**, 036105 (2013); http://dx.doi.org/10.1063/1.4794769

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