UNLOCKING ULTRA-FAST TCSPC: AN INTEGRATED READOUT CIRCUIT FOR A 3D DIGITAL SILICON PHOTOMULTIPLIER

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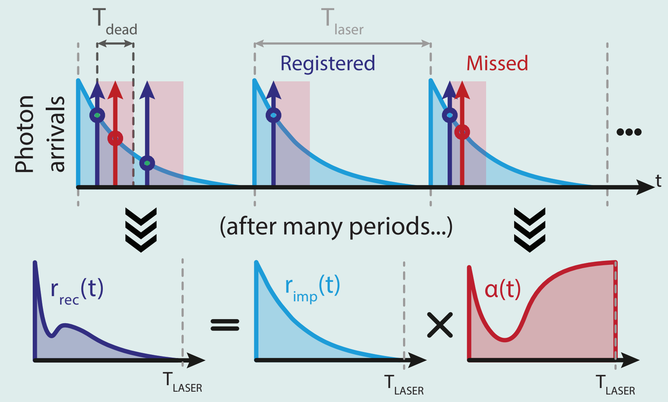
THE PILE-UP LIMITATION IN TCSPC

Time-Correlated Single-Photon Counting measurements are subject to pile-up distortion at high count rates.



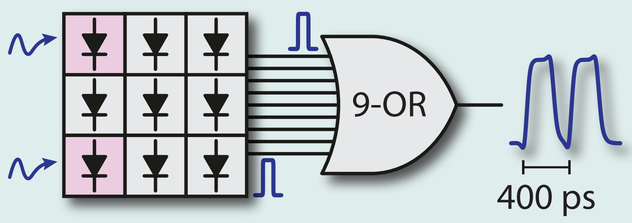
Conventional TCSPC count rate is limited to ~5% of the excitation rate to avoid pile-up distortions, leading to long acquisition times.

If α(t) is known, we can reconstruct $r_{imp}(t)$ from $r_{rec}(t)$, without imposing any limitation on the count rate.

ULTRA-FAST TIMING AS A SOLUTION

While analog SiPM readouts suffer from massive capacitive load and slow readout recovery, single SPAD readouts are bottlenecked by rigid quench-reset dead time cycles.

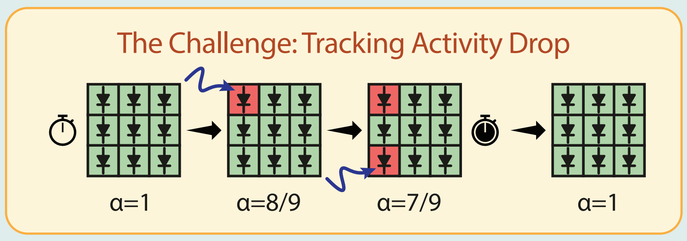
We couple 9 SPAD cells to dedicated Passive Quenching and Active Reset (PQAR) circuits. A high-speed 9-input OR gate merges the timing outputs.



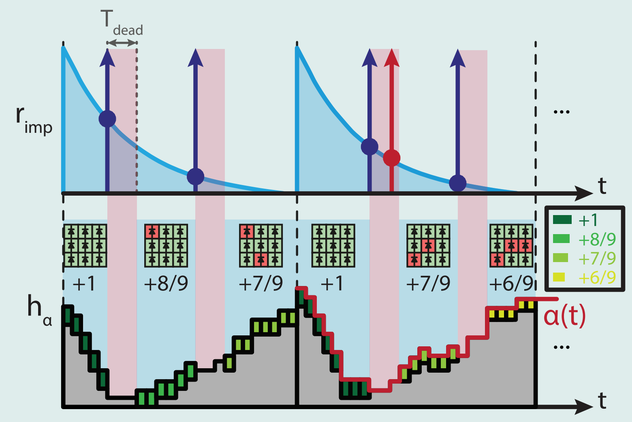
While too few cells would saturate under high flux, too many would create slow logic. This 9-cell "sweet spot" allows for an ultra-fast readout that enables 400 ps dead time and high measurement efficiency.

APPLYING CONSTRAINT-FREE TCSPC

Unlike a single SPAD (binary on/off) or a large SiPM (where thousands of cells make activity losses negligible), each hit in our 9-cell array reduces availability by a significant 1/9.

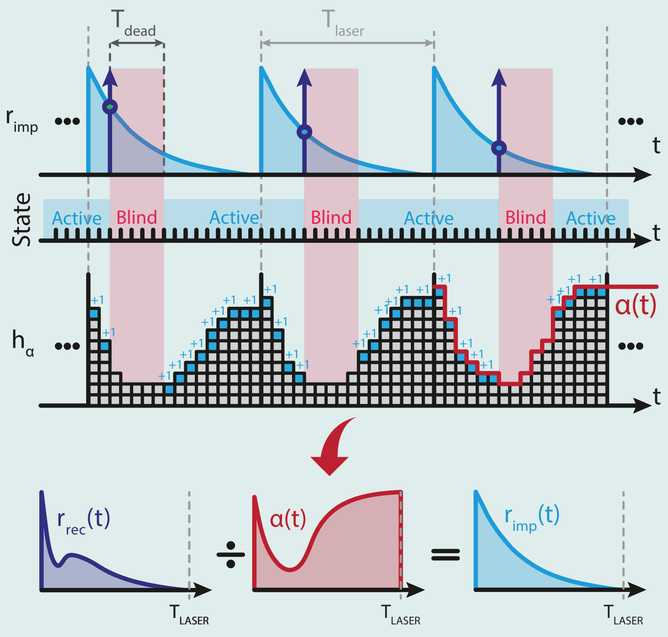


Fired cells are held blind via PQAR until a period-end reset. A counting branch counts the number of fired cells.



CONSTRAINT-FREE METHODOLOGY

By tracking the detector activity over each period to get α(t), undistorted photon histograms can be reconstructed without traditional acquisition limits (Rech et al, 2023).



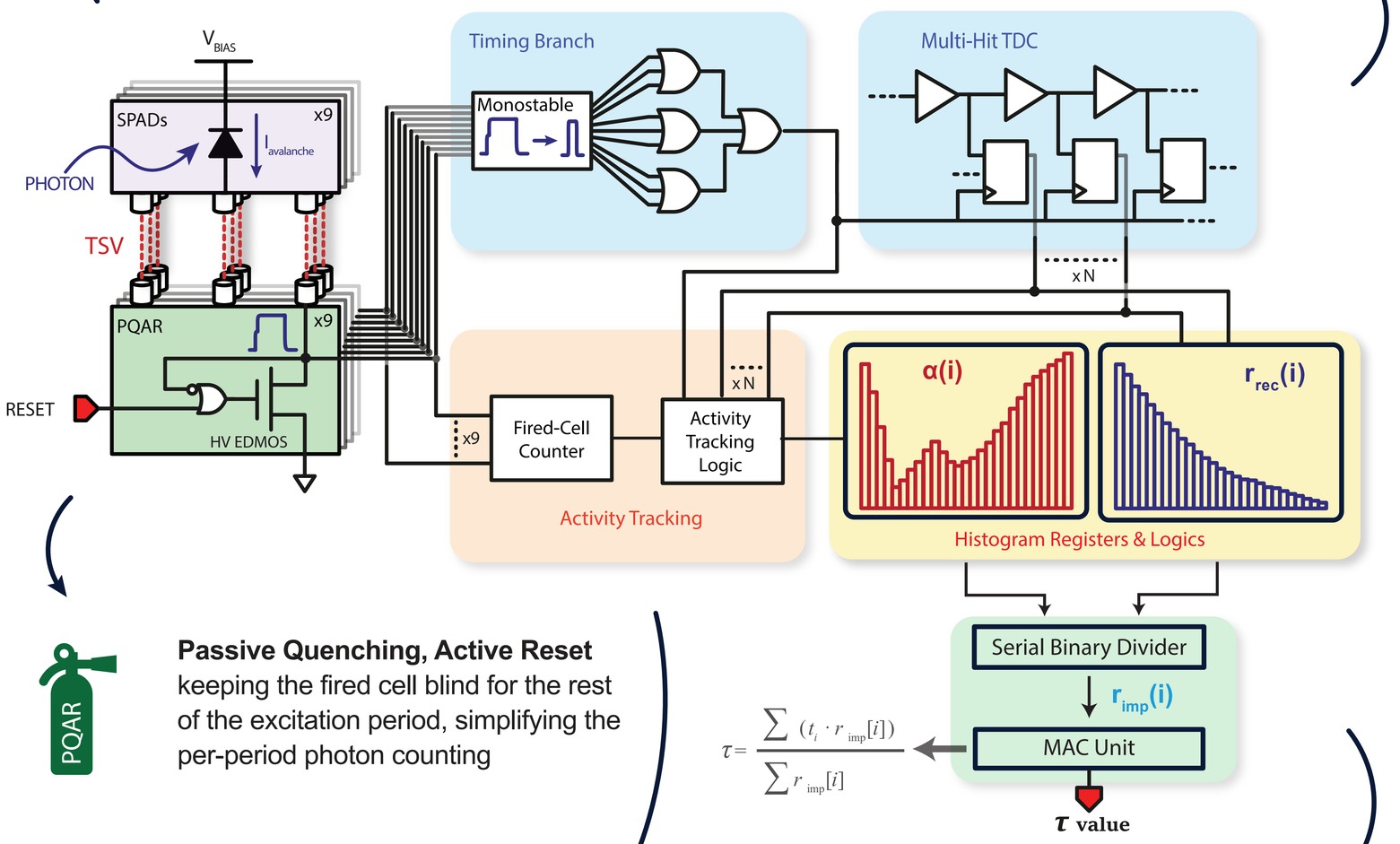
With short dead time, this method can acquire multiple photons per period with negligible distortion.

THE DUAL-BRANCH READOUT FOR ULTRA-FAST CONSTRAINT-FREE TCSPC

9 SPAD cells
with dedicated quenching logic while maintaining shared-output simplicity

Timing Branch
a per-cell monostable feeding a single 9-input OR gate to feed the multi-hit TDC.

Multi-hit TDC
a PLL and DLL drive a looped tapped delay line, using an inverter chain and DFFs to quantize hits.



Passive Quenching, Active Reset
keeping the fired cell blind for the rest of the excitation period, simplifying the per-period photon counting

Activity Tracking
a memory tracking the cells fired within the period, enabling an accurate reconstruction of α(t).

Histogram Registers & Correction Algorithm
registers build hit and activity histograms, feeding a shared serial divider and MAC unit to extract corrected lifetime tau.

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