

## SwissSPAD3 – a dual-gate photon-counting SPAD sensor for widefield FLIM imaging

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Standard CMOS-based single-photon avalanche diodes (SPADs) have made great progress during the past 17 years, thanks to their photon-counting properties, exquisite temporal resolution, absence of readout noise, natively digital nature, and high speed [1]. The design of SPAD imagers has immediately followed, with increasing resolution up to the Megapixel frontier achieved in 2019, and application in (Quantum-)Image Scanning Microscopy, FCS, and FLIM. Building on the SwissSPAD2 sensor [2], we developed SwissSPAD3, a large gated binary SPAD sensor of  $500 \times 500$  pixels with state-of-the-art sensitivity and noise. In intensity mode, the sensor delivers  $\frac{1}{4}$ Mpixel binary frames at 49.8 kfps (which can be accumulated as in Fig. 1 *left*), whereas photon detection is virtually shot noise and pile-up limited. SwissSPAD3 features rolling shutter readout and a dual-gate shutter mechanism which enables 100% duty cycle (Fig. 1 *top centre*). Gate lengths as short as 1 ns have been achieved, with substantially improved skew over the whole pixel array (Fig. 1 *top right*). First FLIM images are shown in Fig. 1 *bottom*; effective PDE is enhanced by microlenses deposited directly on pixels. Ongoing work includes phasor-based real-time on-FPGA data processing.

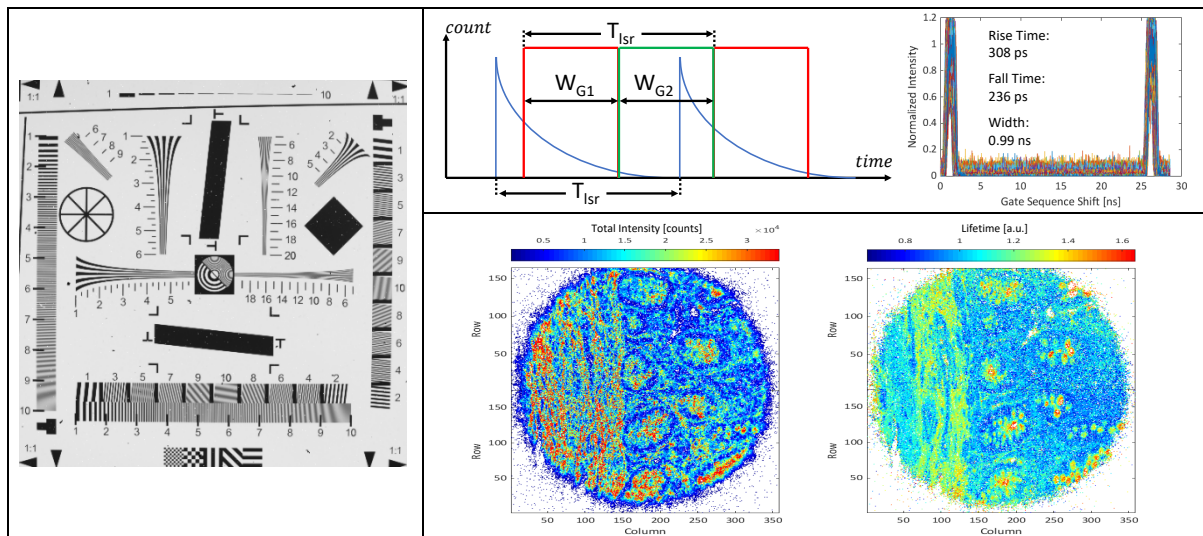


Figure 1: *Left*: 16-bit intensity image of USAF pattern (gate fully open); *Top*: gating diagram (*centre*) and characterisation with the shortest gates (*right*); *Bottom*: intensity (*centre*) and FLIM (*right*) image of mammal colon cells, H&E stained (relative lifetime before calibration).

[1] C. Bruschini, H. Homulle, I. M. Antolovic, S. Burri, and E. Charbon, “Single-photon avalanche diode imagers in biophotonics: review and outlook,” *Light: Science & Applications*, vol. 8, p. 87 (2019).

[2] A. Ulku, A. Ardelean, M. Antolovic, S. Weiss, E. Charbon, C. Bruschini, and X. Michalet, “Wide-field time-gated SPAD imager for phasor-based FLIM applications,” *Methods and Applications in Fluorescence*, vol. 8, no. 2, p. 024002 (2020).