40 × 10 SPAD Array for Laser Rangefinders with Region-Of-Interest Selection and Smart TDC Routing

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In this work we present a new 40 × 10 SPAD array designed for direct Time-Of-Flight single-point distance measurement to be exploited in automated industrial lines. The aim of this project is the design of a reliable detector with good performances when the SPADs are operating in low photon rate regime, and able to reach one centimeter resolution with a minimum range of 1 m even with 3 klux background illumination (corresponding to a halogen lamp impinging directly on the sensing area) and a 3 ns FWHM laser pulse-width and 100 mW peak power. In order to improve the precision, Time-Correlated Single-Photon Counting (TCSPC) histograms must be built and the centroid of the resulting distribution is computed by an external processor [1].
The strong mechanical vibrations typical in industrial environments force the choice of a non-confocal optical setup, which does not require precise alignments, but results in a 1D displacement of the backscattered light on the detector, which depends on the target distance. For this reason, the sensing area has a rectangular shape (40 × 10 SPADs with 24 µm pitch, i.e. 0.96 × 0.24 mm^2), with the short side that fits the 150 µm spot diameter and the long one determined by the optical setup specifications and the maximum target distance. As can be seen in Figure 1(a), only about 37 SPADs out of 400 are illuminated by the laser signal, whereas all pixels are exposed to background illumination. Thus a new architecture that implements a Region-Of-Interest (ROI) selection and a smart sharing of the timing electronics (Time-to-Digital Converters, TDCs) has been proposed to connect to the TDCs only those SPADs that have been actually illuminated by the laser spot. As exemplified in Figure 1(b) this implementation is expected to improve the Signal-to-Noise Ratio (SNR) of the TCSPC histogram, by removing the spurious contributions due to the non-illuminated pixels.
The ROI selection is performed by repeatedly subtracting, in each pixel, the number of events detected in a first time slot that includes the laser expected return time, to the number of background events detected in a second time interval without laser. The result of this operation is expected to be different for pixels within the laser spot and the ones exposed to background only, as can be seen in Figure 1(c), allowing to discriminate the pixels which contain useful signal from the others. Only 80 TDCs are shared among the 400 SPADs, with a self-reconfigurable routing which dynamically connects the SPADs within the ROI to the available TDCs. The implemented TDCs are based on a multiphase clock architecture, with 75 ps Least Significant Bit (LSB) and 19.2 ns Full-Scale Range (FSR), ensuring up to 2 m measurements.
The array has been fabricated in 160 nm BCD technology, that allows to achieve State-of-Art SPAD performance [2], and also to integrate SPAD front-end and fast timing electronics [3]. The chip layout is shown in Figure 1(d).

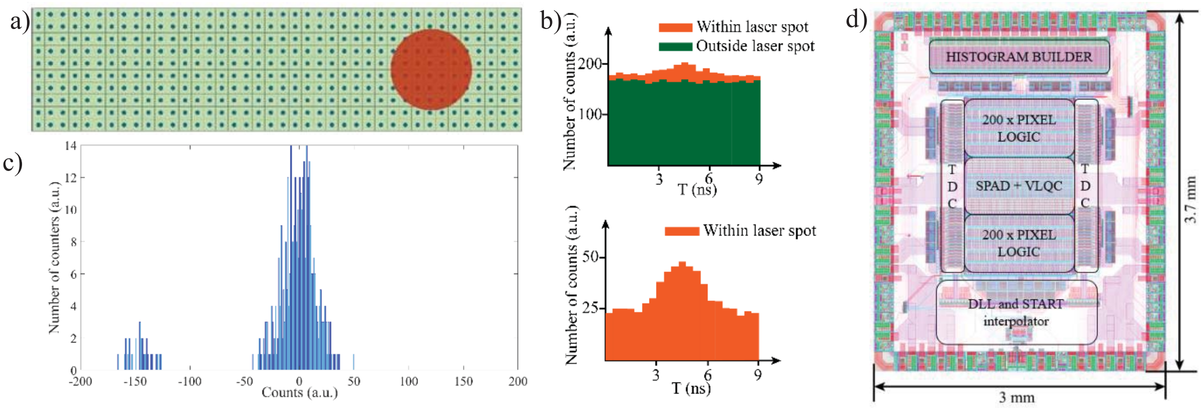

Figure 1. a) Representation of the array where the SPADs exposed to the laser pulse are colored in orange, while those exposed to background only are green. b) Schematic representation of the histograms that can be obtained with the conversions from all SPADs (on the top) or considering only the SPADs exposed (on the bottom). c) Matlab simulation of the possible distribution of counts of the pixel counters in the ROI selection after 500 samples. d) Chip layout.

References

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