Thesis summary

Title: CMOS Circuits and devices for 3D Time-of-Flight Cameras

Student: Daniël Van Nieuwenhove

Promoter: Prof. dr. ir. Maarten Kuijk

This dissertation presents a study of novel circuits and devices for time-of- flight range finding applications, and describes their conception, implementation in CMOS technology and practical testing.

A novel current assisted photonic demodulator device, mixing the photo-generated charges before actual detection, is presented. The device largely improves the signal-to noise ratio in time-of-flight applications. Demodulation contrast of over 99%, a bandwidth of over 50 MHz and high sensitivity are acknowledged through measurements. An adapted configuration implements a drain tap to effectively modulate the gain at run-time from nearly 100% to below 1%.

Three different types of read-out circuits connecting to the novel demodulator are investigated for application in a time-of-flight pixel.

Firstly, a straight forward 3 transistor circuit, based on the active pixel circuit known in CMOS imagers, is studied in view of its use with the novel demodulator device. High signal-to-noise ratio, reasonable dynamic range and low background light tolerance are obtained. Methods to further improve the behavior, such as burst mode and multiple sampling, are discussed and demonstrated.

Secondly, several novel non-linear read-out circuits are studied. Extremely high dynamic range is obtained, however signal-to-noise becomes poor due to added transistor noise. Fortunately with a novel circuit, given the name of "averaging peak detector", a low pass filter with a configurable cut-off frequency between 1 Hz and 1 kHz can be realized on a small silicon area of 25 m^2. Including such a filter in connection to a non-linear read-out pixel, the noise bandwidth can be reduced, which improves the signal-to-noise ratio considerably. An example pixel was implemented and proof of principle measurements were conducted.

Thirdly, a novel self-reset read-out circuit is conceived releveling the detector voltage during integration. An optimized technique is presented that requires little or no in-pixel memory and at the same time introduces nearly unlimited background light tolerance. Different implementations are discussed.

A noise analysis shows that the cascode-improved self-reset circuit adds only little noise. Two fabricated devices are presented, validating the principle in practice.

A first 0.35 μm standard CMOS 32x32 3D time-of-flight imager chip is discussed.

The pixel combines a three transistor integrating circuit with a differential square current assisted photonic demodulator. It measures 30 μm x 30 μm and has a 66% fill factor. A measured noise floor of 46 e^- and a dynamic range of 61 dB are obtained.

First distance measurements on an integrated 3D time-of-flight camera system are included. The custom made platform generates the modulation signals for the chip and LED illumination board using a field programmable gate array. Communication to a personal computer is provided through USB 2.0. The different system components are discussed in short. When combined with the completed time-of-flight imager, sub-cm to several cm distance accuracy was confirmed at 25 fps for distances from 1m to 6m.