A GLOBAL SHUTTER SENSOR USED IN ACTIVE GATED IMAGING FOR AUTOMOTIVE

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Abstract

A global shutter pixel and sensor was developed to support an Active Gated Imaging System (AGIS) for automotive applications. The optimized gated pixel can reach transfer noise of less than 1e. It is shown that the Fix Pattern Noise associated with charge transfer and gating operation can be minimized.

Keywords: Gated CMOS Imager Sensor (GCMOS), Active Gated Imaging System (AGIS).

Introduction

Active Gated Imaging System (AGIS) for automotive applications was first introduced using an Image Intensifier (II) which was coupled to CCD as its camera element [1]-[2]. The AGIS has two main components: an Illuminator, which is usually a pulsed light source, and a camera. Its operation principle is similar to a Time Of Flight (TOF) system and described schematically on Figure 1. The scene is illuminated by series of short pulses. Each pulse triggers a short integration event in the camera. The Integration is delayed with respect to the light pulse by a programmable T_{delay}, and integration time T_{int} is programmable as well. The time delay and the integration time are determined according to the distance and depth of field the camera is monitoring. In the early versions of the AGIS the II was used as an electronic shutter to control T_{int} and T_{delay}. The charge for multiple reflected pulses was collected in a CCD to create the gated frame image. Image systems based on gating operation are very attractive for automotive applications. They can detect road hazard further than the driver line on sight and are less affected by illumination conditions, harsh weather or other active systems in other cars [3]-[5]. However there is a real need to replace the II sensor with a modern CIS, which can reduce bulkiness of the system, while keeping the cost down and making the system affordable for mass-market. In this work we will discuss the design and performance of a global shutter image sensor which replaces both the CCD and II in the system.

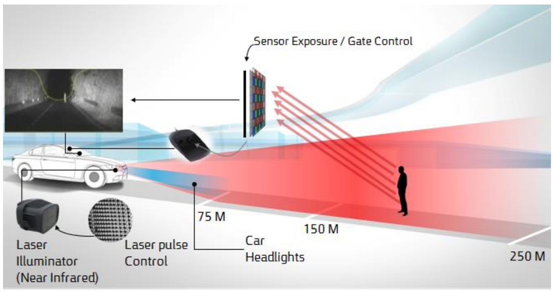

Figure 1. Typical AGIS block diagram comprising two main modules: a camera unit and an illuminator unit (i.e. light source).

Sensor and Operation Description

The Camera unit consists of a dedicated gated image sensor. The Gated CMOS Imager Sensor (GCMOS) is fabricated using 0.18μm TowerJazz CIS technology on the enhanced NIR global shutter platform. In the gated operation mode, the sensor is triggered by the illuminator. One single frame is typically composed from N repeating global exposures events which correspond to P_{Gate} light pulses from the illuminator unit. Each exposure is delayed with respect to its illumination event as described in Figure 2

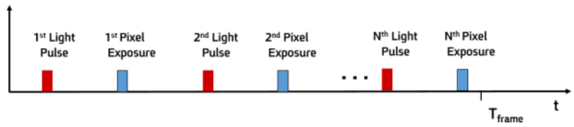

Figure 2. Illustration of a single frame which is composed of N global exposures events.

The sensor is using a global shutter pixel with five transistors. The pixel electrical schematic is shown on Figure 3.

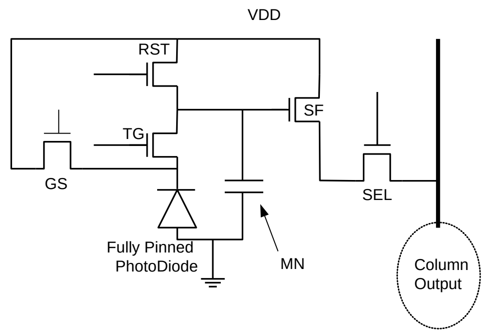

Figure 3. Schematics of the Pixel used for the gated imager.

The pixel exposure control is shown in Figure 4. Before each illuminator pulse the collecting diode in the pixel is fully evacuated from electrons by activating the Global Shutter (GS) transistor. The GS transistor is kept active during a short programmable T_{delay} after the light pulse. All the collected electrons at this time are drained though GS to Vdd. At the end of T_{delay} the GS is deactivated and the collecting diode starts to integrate for programmable time T_{int}. Integration stops by full transfer of all collected charge to the Memory Node (MN). At the end of T_{frame} the information stored in the MN is read out in a regular double sampling (3T like). The sensor also supports digital correlated double sampling as well.

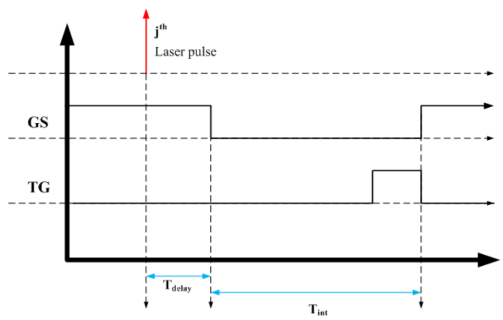

Figure 4. Pixel exposure control.

Pixel Optimization

The GCMOS working in the proto type AGIS needs to perform well in two different extreme conditions.

The first is a photon starved scenario – this is the regular scenario where the system is looking on reflection from diffusive objects. The signal collected in each partial exposure can be low as 1-3e. In gating mode, the transfer noise, which is usually neglected with respect to the SF noise and the readout noise, can become the dominant noise source. As in this mode we use multiple transfers of small electron packets to create a large frame signal, and perform only a single readout at the end of image frame. Equation 1 describes the noise expected from the gated pixel where S is the signal level, P_{Gate} is the number of exposures/pulses per image frame, N_{Gate} is the transfer noise per gate, $N_{Readout}$ is the read-out noise, N_{Analog} is the analog chain noise and DC is the dark current noise.

$$Noise = \sqrt{S + (P_{Gate} * N_{Gate}) + N_{Readout}^2 + N_{Analog}^2 + DC}$$

Equation 1. Gated pixel expected noise.

The second scenario is reflections from road signs [6], other reflectors or during high ambient light conditions (e.g. day-time). In this case the signal for each partial exposure can be larger than 10ke (see Figure 5).

Figure 5. Vehicle with high headlights and a road sign are located 20m from the AGIS.

In addition, the Parasitic Light Sensitivity (PLS) in our system needs to be kept low, since vehicle headlights can cause photoelectrons generation in the sensor, uncorrelated to gating activity (see Figure 6). Other reason is that partial exposure time is very short in compare to the total frame time. Other parameters of a global shutter pixel, such as dark current generation of MN and the MN conversion gain need some attention as well [7].

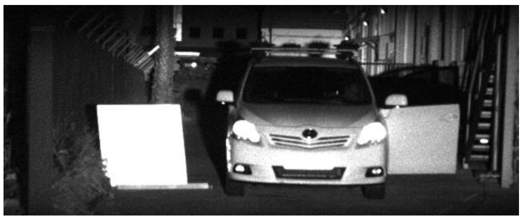

Figure 6. Vehicle with low headlights and a road sign are located 20m from the AGIS.

To optimize for the NIR photon starved scenario, a relatively large pixel of 10um pitch was chosen, an optimized anti-reflecting coating and an optimized micro-lenses were used as well [8]. The sensor is fabricated on a thick high resistivity wafer, which was designed to enhance the sensor Quantum Efficiency (QE) multiplied by the pixel Fill Factor (FF) in the NIR (see Figure 7), while achieving very low cross talk between pixels [9].

As expected the gating sensor enhanced charge transfer problems. We found that our standard TowerJazz pixel integration scheme, which was developed to support single transfer pixels with perfect lag and excellent linearity at low illumination, could not be used for gated sensor. This was mainly due to very large pixel to pixel variation with respect to charge transfer efficiency. We found that the main key for reducing this source of fix pattern noise was creating much higher lateral field at the Transfer Gate (TG) channel than in TowerJazz standard technology. The GS implants were optimized to create leakage path of electrons to VDD. This prevented leakage to other pixels in the sensors in the reflection scenario. In similar way, in order to enhance pixel rejection ratio to vehicle headlights, the RST transistor was designed to enhance leakage of electrons to VDD, if the MN voltage is reduced below a threshold level.

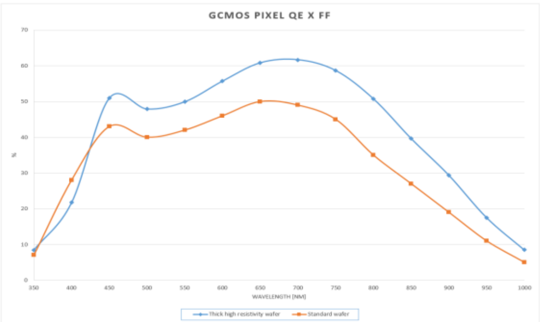

Figure 7. Pixel QE X FF response.

Results and Discussion

A typical active image at night-time is shown in Figure 8. The image was taken with the GCMOS (with a resolution of 1.2Mp), using T_{delay}=0. This shows full range of the camera and illuminator. High reflective road signs are clearly seen as well as the road illumination together with a pedestrian at 115m. This shows the excellent dynamic range and blooming performance achieved by the pixel and GCMOS.

Figure 8. AGIS imagery at night. A pedestrian is clearly seen at a range of 115 meters.

A passive gated image at day time is presented in Figure 10. The image was taken with the GCMOS sensor with a spectral filter about 800nm.

Two examples of active gated images are shown in Figure 9. These consecutive images were taken in an urban scenario. The upper image (A) is a taken with T_{delay}=0 which give a “full” range of the AGIS, with depth of field image up to 250m where the lower image (B) is a “partial” depth of field image up to 90m. It can be easily noticeable that the pedestrian was separated from the background using this operation mode. This indicates a good shutter operation for a single gating exposure.

Figure 9. Two different selected depths of field in two different locations at night-time.

In Figure 11 we present a graph of Fix Pattern Noise (FPN) curve versus the collected signal in gated mode. In this graph we used P_{Gate}=700 gating pulses. Light intensity is changed from an average of 6e in a single exposure to level of less than 1e in average. It can be seen that in high illumination FPN is linearly reduced with signal. At low illumination we see two different behaviours: For the optimized pixel the FPN continues its linear trend of reduction with signal. For the non-optimized pixels the FPN flattens at low signal which indicated on additional noise source.

Figure 10. AGIS raw imagery at day-time. Images are taken with a narrow band filter at 800nm and there is no active illumination.

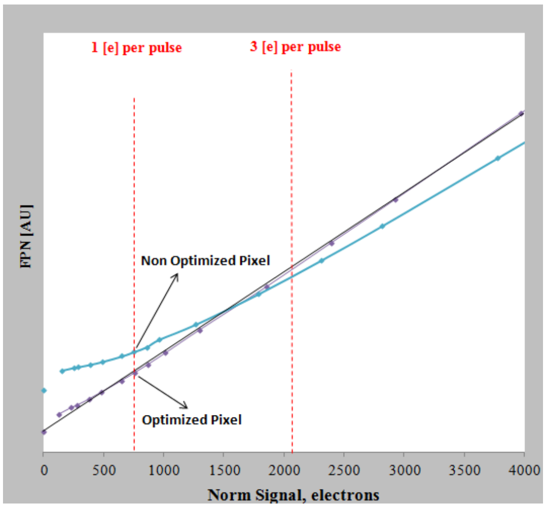

Figure 11. Pixel FPN versus signal in Gated mode. For two different pixel designs.

Summary

A global shutter pixel and sensor was developed to support an Active Gated Imaging System (AGIS) for automotive applications. The optimized gated pixel can reach transfer noise of less than 1e. The pixel fix pattern noise in gated noise was shown to be dominated by photon response non uniformity rather than transfer efficiency distribution.

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