A 1.2MP 1/3” CMOS Image Sensor with Light Flicker Mitigation

Chris Silsby[1], Sergey Velichko[2], Scott Johnson[2], Yan Ping Lim[1], Ray Mentzer[1], Jeff Beck[1]
[1]ON Semiconductor, Corvallis, OR, USA,
[2]ON Semiconductor, Meridian, ID, USA

ON Semiconductor, 4238 SW Research Way, Suite 101, Corvallis, Oregon 97333, chris.silsby@onsemi.com, ph. 541-908-1721

Introduction

In prior imaging systems [1-3], image artifacts may be caused by flickering lighting and objects with changing illumination in an image frame. Such artifacts may include, for example, missing parts of an object, edge color artifacts, and object distortion. Examples of objects with changing illumination include light-emitting diode (LED) traffic signs (which can flicker several hundred times per second), and LED stop and head lights of modern cars.

While electronic rolling shutter (ERS) and global shutter (GS) modes produce images with different artifacts, the root cause for such artifacts is common for both modes of operation. Typically, image sensors acquire light asynchronously relative to the scenery being captured. This means that portions of an image frame may not be exposed for part of the frame duration. This is especially true for bright scenery when integration times are much shorter than the frame time used. Zones in an image frame that are not fully exposed to dynamic scenery may result in object distortion, saturation data loss, and color artifacts.

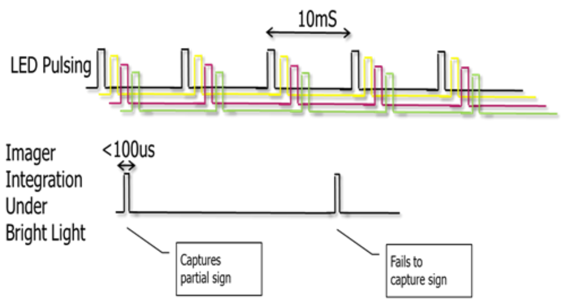

Figure 1. LED Pulsing vs. Pixel Integration Sample Window

This loss of information will become more of an issue over time, especially as automotive lighting and traffic sign use of LED’s increases.

- Traffic density will increase dramatically over the next decade
- Traffic control for safety, energy reduction, and commute time reduction, will be highly desired
- Sensitivity requirements are increasing each year from organizations such as Euro NCAP.
- These factors increase the importance of capturing variable emission traffic signs without loss of sensitivity

Proposed Solution

A new method is proposed using a shutter element to realize the world’s first electrically programmable linear pixel sensitivity to avoid flicker issues in automotive, surveillance, and industrial imaging applications without loss in low light sensitivity or other performance measures, especially in smaller pixel sizes. General pixel schematic for the light flicker mitigation (LFM) is shown in Figure 2a for a 4T pixel and Figure 2b for a 5T GS pixel.

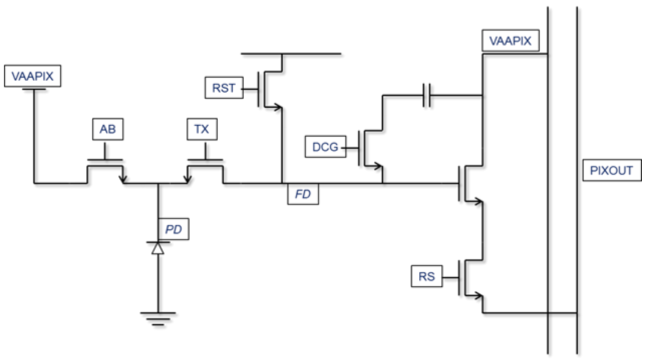

Figure 2a. LFM and AB gate added to typical automotive 4T pixel

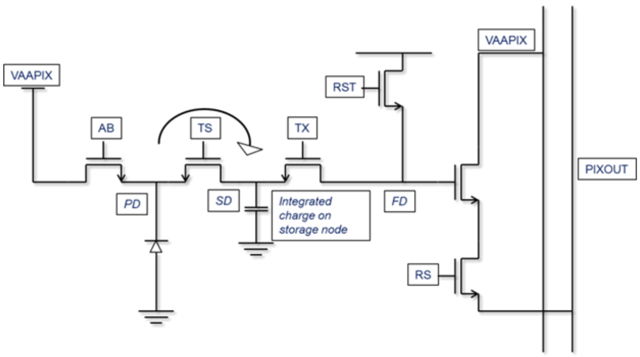

Figure 2b. LFM and AB gate added to typical automotive 5T pixel

Both methods were built and tested in separate test vehicles, both with similar floor plans as shown in Figure 7. In this case a 3.0µm pixel was used with minimal size and performance impact from the conversion to LFM capability, maintaining excellent low light sensitivity. This allows the technology to scale very effectively to very small sizes and GS pixels. The technology was designed to integrate well with existing pixel technologies while adding the capability to capture flicker light illuminants of 80Hz or higher with 10% duty cycle or higher.

The proposed method of operation diagram is shown in Figure 3. Using 3µm LFM pixel technology and new pixel shutter sampling methods a 1.2MP 1/3" CMOS imager was designed and tested. Dynamic shutter gate (AB) and transfer gate (TX) operations allow exposure extending over the frame size thus mitigating any flicker artifacts in an image.

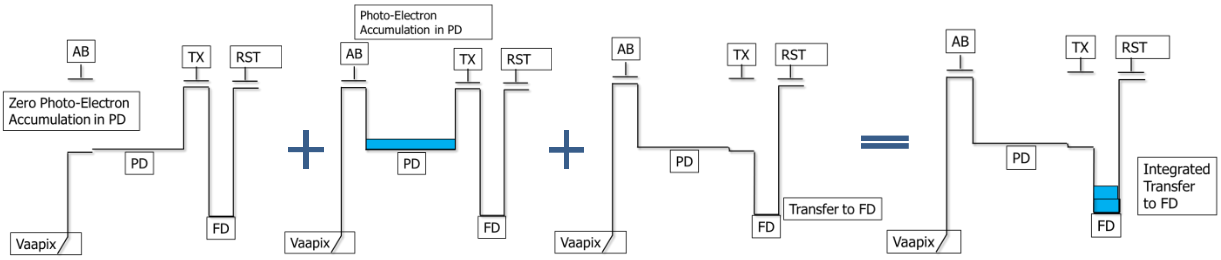

Figure 3. LFM Sample and Integration Cycle (result integrates a variable count of cycle iterations)

In Figure 4 the timing is shown for the shutter and the integration cycle, which can be repeated for 'n' times. Also, the duty cycle of the AB signal during each integration cycle can be varied.

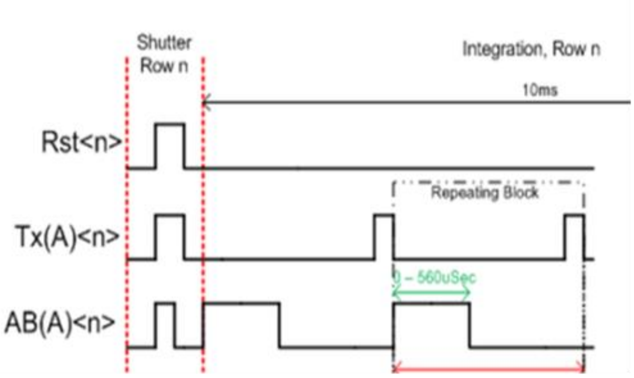

Figure 4. LFM Shutter and LFM Cycles of Integration

In the test chip, minimum sensitivity was limited by minimum AB to TX sample times, as well as row blank period timing. For example, the AB signal can either be left low at the end of each cycle or kept high. Leaving it low allows the photo diode to continue to collect charge and allows the possibility of the very sensitive element to forward bias in very bright light during a horizontal blank period. Keeping the AB signal high at the end of the row period keeps the photo diode in a charge collection state. These limitations are being addressed in future product development.

Using both number of cycles and duty cycle as variables in row timing signals the effective linear pixel sensitivity can be widely varied as show in Figure 5. This is particularly unique because no knee points are needed to change the sensitivity, simplifying the processing of the image and its interpretation for uses like traffic sign reading or optical character recognition (OCR). Minimum number of samples and duty cycles are being investigated as part of the development.

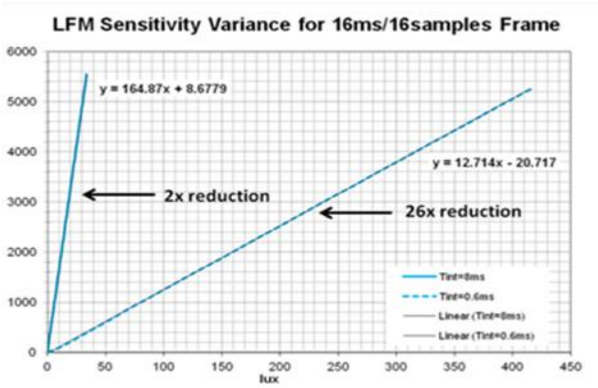

Figure 5. Electrical Tuning of Linear Sensitivity

Because the LFM mode is able to use sampled ERS timing, it is possible to overlap LFM mode images with normal ERS video frames. This allows using the LFM frame in cases where very sensitive photo diodes would saturate with exposures required to capture all traffic sign information. Read noise is higher in the LFM imaging mode, but in these brighter light use cases, the read noise floor SNR1 lux level is not a limiter. Figure 6 shows the test result difference between the 3um normal imaging results and the LFM sample results on the same die.

Testchip 3µm Green Pixel – Normal LCG Mode

Light Source	Temperature Tj	Pixel Responsivity	Readout Noise	Integration Time	Lens F#	Lens Transmission	IRCF Transmission	ReadNoise Floor SNR1	TempNoise Floor SNR1
		e-/lux-sec	e-	e-	e-/sec	Sec		lux	lux
3200K	60C	25200	7	0.03333	2.8	0.9	0.97	0.299	0.309

Testchip 3µm Green Pixel – LFM LCG Mode

Light Source	Temperature Tj	Pixel Responsivity	Readout Noise	Integration Time	Lens F#	Lens Transmission	IRCF Transmission	ReadNoise Floor SNR1	TempNoise Floor SNR1
		e-/lux-sec	e-	e-	e-/sec	Sec		lux	lux
3200K	60C	25200	19	0.03333	2.8	0.9	0.97	0.815	0.891

Figure 6. Test Results Switching Between Normal Mode (top) and LFM Mode (bottom)

With pulsed illumination, minimum frequency and duty cycle are considered to obtain the optimum consistency in signal from frame to frame to make sure all information is captured.

For imaging tests, an LFM Exposure period of 10mS, and an expected worst case LED width of 1ms, led to a sample ratio of (exposure time)/(LED width) of >10 and resulted in about 44 row times or ERS of 200us total exposure period.

Using these settings, image results are illustrated both in lab environment as shown in Figure 10 and Figure 11, and outdoors as shown in Figure 12. Both LED flicker and fluorescent light flicker mitigation were successfully demonstrated in these scenes. In Figure 10, the problem is illustrated on the left image. Some variable emission traffic signs are not readable by all-camera based traffic sign recognition systems. In the right image it is demonstrated that Light Flicker Mitigation can capture the entire sign information.

The LFM test chip capability was added to an existing automotive imaging product without impacting the floor plan, see Figure 7. 3µm LFM pixel quantum efficiency and other parameters are shown in Figures 8 and 9.

The technology allows future products to deliver the industry's leading reliable and safe capture of a wide range of pulsed illumination frequencies.

Conclusion

We have successfully demonstrated a 1st generation LFM pixel architecture, enabled by prior development of ON Semiconductor's patented pixel pumping charge transfer method [3], to modify the "effective" sensitivity of the pixel without introducing knee points. This architecture extends the useful applications of a high performance automotive pixel, without compromising extreme low light sensitivity or HDR performance, by increasing the "effective maximum exposure time" without saturation.

The unique capability of LFM video capture mode has been shown to enable 120dB high DR pixel performance + traffic signal capture.

Acknowledgement

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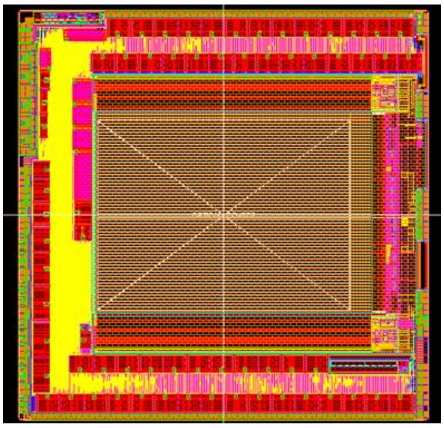

Figure 7. Image Sensor Floor Plan

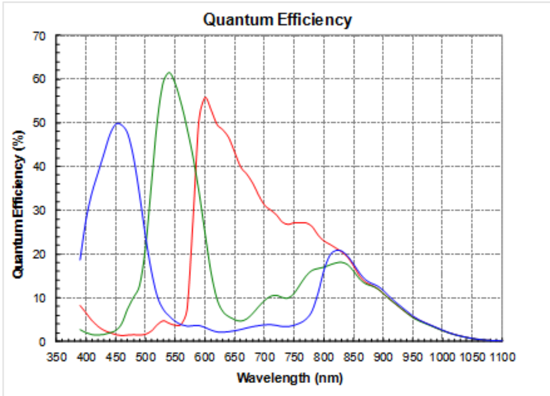

Figure 8. 3µm LFM Pixel Quantum Efficiency

Parameter	Units	Value	Notes
Pixel pitch	um	3.0	
Readout noise	e-	1.7	
Photoresponse non-uniformity	%	0.54	
Dark signal non-uniformity	e-	2.0	
Responsivity	Ke-/lux*s	20.6	D65, F#2.8, IRCF, 15 FPS
Max Quantum Efficiency	%	61.5	green
Linear Full-well Capacity	Ke-/lux*s	12	
Dark Current Average	e-/sec	100	Tj=60C

Figure 9. 3µm LFM Pixel Basic Performance Parameters

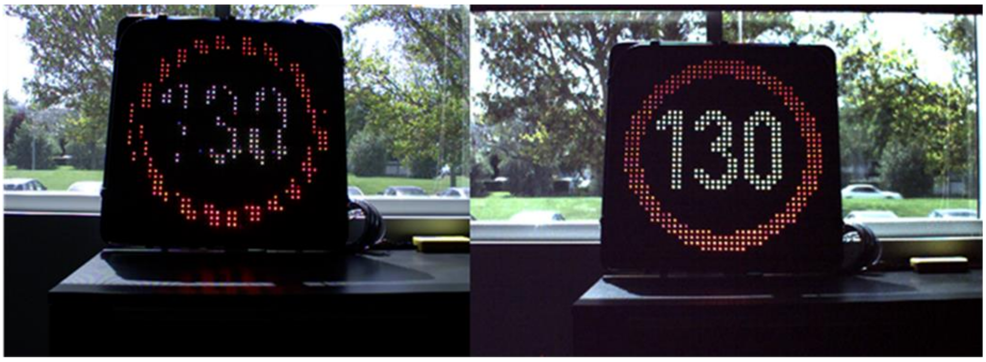

Figure 10. Left: Flicker problem missing information, Right: Light Flicker Mitigation captures all sign information

Figure 11. Lab set-up LEF and Flourescent flicker in ERS mode (left), no flicker LFM mode (middle), saturation ERS mode (right)

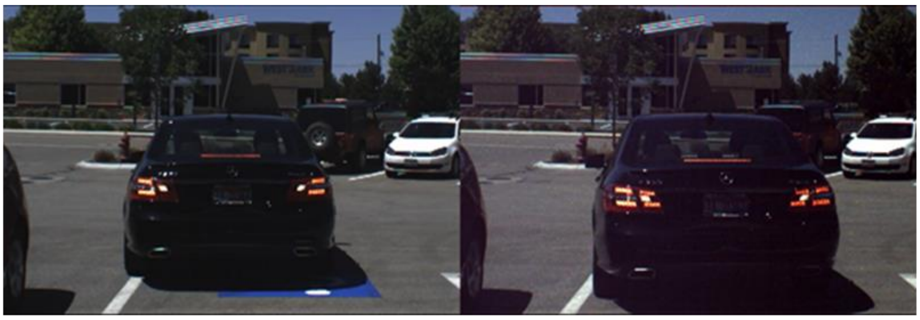

Figure 12. Outdoor car missed brake lights in ERS mode (left) captured in LFM mode (right)