1 Introduction

The image sensors used in today's cameras mostly provide an electronic shutter control. This means, the shutter is in the sensor itself. After the integration of an image ends, the charge is shifted into a so-called storage node (floating diffusion) which is shielded from light and can be read out. Ideally, there would be no further integration taking place during this period, in reality, this is not the case. This effect is called **P**arasitic-**L**ight-**S**ensitivity *PLS,* sometimes also called *Shutter Efficiency*.

2 Explanation

2.1 What is PLS?

To understand what PLS actually is, we need to reconsider how a global shutter image sensor works.

In these sensors, we have the following phases (which may overlap, but for simplicity, we treat them as successive):

1. Reset of the photo-diode → Start of exposure time.
2. Image accumulation: The photons of the incident light generate electron-hole pairs in the photo-diode of the pixel and the electrons are accumulated.
3. End of exposure time → Transfer of the accumulated electrons into the (light shielded) storage node.
4. Readout of the image line-by-line.

In an ideal world, the image would be frozen as soon as it is transferred into the storage node. Unfortunately, the storage node isn't 100 % light shielded. Photons can still pass into the storage node and generate electron-hole pairs and these electrons would be accumulated in the storage node either. So, the readout time serves as the effective exposure time in the storage node.

Because the first line of the image is read out directly after the charge transfer (i.e., exposure end), it is not affected, but the following lines are affected more and more. This is the reason, why we may see a brightness gradient from top to bottom of an image. The longer the wavelength, the easier it is for the photons to pass into the storage node, meaning we also would see a color dependence of the gradient.

Figure 1: PLS caused brightness change in y-direction (in this example 20 % for better visibility)

2.2 When does the PLS effect occur?

High quality CMOS image sensors provide good shielding of the storage node, which is expressed in a suppression factor, typically in dB. This factor is in a range of -70 dB…-95 dB, meaning the storage node is 3200…60000 times less sensitive than the actual photo-diode.

For example, the IMX sensor families of Sony provide a PLS suppression of:

- Gen 1, 2 & 3: ~ -94 dB
- Gen 4: ~ -74 dB (the optimized pixel performance and back-side illumination comes with some sacrifice on the PLS)

But if we use very short exposure time and have a sensor which is read out slowly, we will see the effect. This is, if the exposure time and the readout time (in the range of the PLS suppression times) are in the same ballpark. We can express the amount of additional brightness as:

$$Factor_{PLS} = \frac{T_{readout} + T_{exposure}}{PLS \cdot T_{exposure}} \qquad (1)$$

The $Factor_{PLS}$ tells us how many times the last line of the image is brighter than the first one.

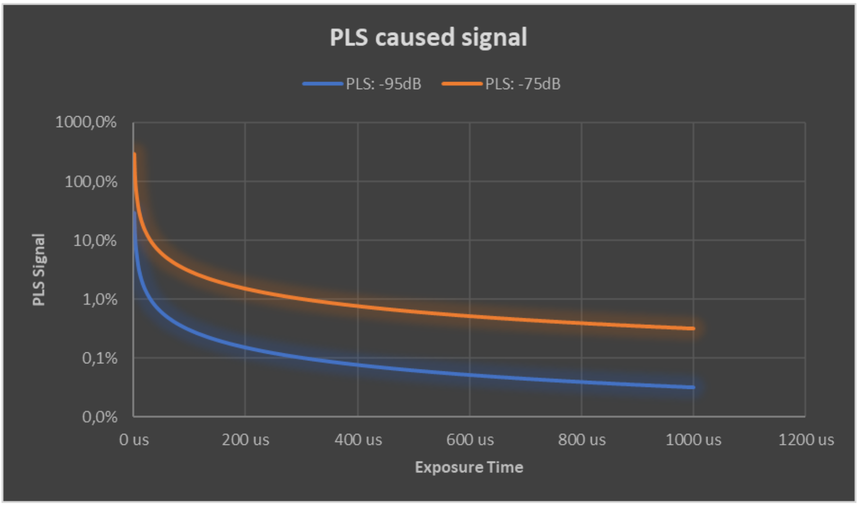

Figure 2: PLS caused signal for different PLS values at 60 fps (17 ms) readout speed

2.3 What can we do about it?

PLS is a sensor parameter, and we cannot do much about the shielding of the storage node. But we also learned that the second important factor for occurring PLS effect is the readout time. MATRIX VISION cameras use an image buffer to store the image during transmission. This means, we can decouple the image readout from the image transfer. This also helps us here, because the “PLS exposure time” is not equal to the image transfer time, but to the readout time into the frame buffer.

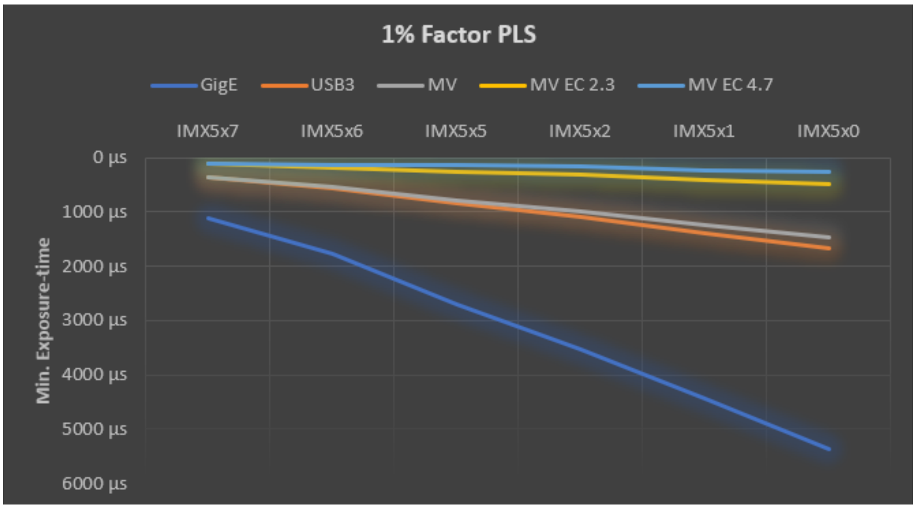

Figure 3: Min. exposure time at 1% brightness gradient (Factor PLS) with Sony Gen4 sensor at different hardware interfaces GigE/USB3: max. sensor readout due to the interface limit

Figure 3 shows the minimum exposure time allowed to get a PLS effect of 1%. If a longer exposure time is used, the PLS effect would be getting smaller. The respective curves are:

- GigE and USB3: Represents the curves, where sensor readout time = transfer time (without frame buffer).
- MV: Represent the actual curve of the mvBlueFOX3/mvBlueCOUGAR-XD cameras where a frame buffer is used which allows slightly faster readout. If the mvBlueCOUGAR-XD is used with just one network connection, the readout time of the sensor remains constant, thanks to the frame buffer.
- MV EC 2.3: Represents the curve of the mvBlueCOUGAR-XT and mvBlueNAOS4. The mvBlueCOUGAR-XT also uses a frame buffer and has a 10GigE interface. If the mvBlueCOUGAR-XT is used in a 1GigE network, the readout time of the sensor remains constant, thanks to the frame buffer.
  The mvBlueNAOS4 has no frame buffer, but the DMA transfer of the image allows sensor readout at the maximum sensor readout speed, so the interface would not be a bottleneck.
- MV EC 4.7: Represents the curve of an optimized sensor readout which could be provided on the mvBlueCOUGAR-XT series if required.

2.3.1 Side effects

We may already suffer from the brightness change from top to bottom, but this could be compensated. A more serious effect is the changing motion blur from top to bottom. If you optimized the exposure time to allow only a certain motion-blur, this might be corrupted by the PLS. While the motion blur in the upper region of the image is still ok, it will get worse towards the bottom of the image and can hardly being compensated.

2.3.2 Compensation

We could compensate the brightness change caused by PLS using a linear correction function. The best way is to actually measure the PLS caused slope in the brightness change and use the resulting curve to perform a compensation. We could also calculate the curve using the PLS value may be provided by the sensor manufacturer, but this value is a typical value and will vary from sensor to sensor making a compensation quite unprecise.

2.3.3 Color Sensors

As mentioned before, the PLS also depends on the wavelength (like the QE). So, for color sensors we would see a different slope of the brightness change for each color channel, causing a color shading from top to bottom. If compensation is used, you have to calculate the correction function for each color channel separately.

3 Conclusion

Every image sensor suffers from PLS. Whether this is an issue really depends on the application. The PLS value alone doesn't tell us whether an image sensor suits our application, we also need to consider the readout time of the sensor (which is typically the inverse of the max. burst frame rate of a camera, ask the manufacturer if you are not sure), which is effectively the exposure time in the storage node).

For some applications, it might make sense to use 10GigE.

For the majority of applications, PLS is not an issue for the high quality sensors available on the market today.

4 Appendix

4.1 Abbreviations

PLS	Parasitic Light Sensitivity
fps	Frames Per Second
QE	Quantum Efficiency

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