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Application note for CMV

HDR modes

Change record

Issue	Date	Modification
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Table of Contents

1 INTRODUCTION

This document describes the possible optical HDR (High Dynamic Range) modes on the sensor. It describes the advantages, disadvantages, setup and calibrations.

This document applies to the following sensors:

- CMV300
- CMV2000
- CMV4000
- CMV8000
- CMV12000
- CMV20000

2 DIFFERENT HDR MODES

There are two main HDR modes: dual-exposure (DE) and piecewise linear response (PLR).

You could also take multiple images with different exposures and average them down. Of course this can lead to motion-blur issues (if the object is moving), but due to the very high speeds the sensors can have, this can be minimal. For example, the CMV12000 can run at 300fps, so you can take 10 images, average them and have 30fps.

2.1 DUAL-EXPOSURE MODE

2.1.1 OPERATION

In DE mode, you can have 2 different exposure times for every other row (or column). You can choose a short one, to keep the highlights preserved and a longer one to have detail in darker areas. Both exposure end at the same time (so one starts later) and are the usual linear response. So you will basically end up with a dark and bright half-resolution image and with some smart algorithms, you can create a HDR full resolution image again. Of course some resolution/sharpness/detail will be lost.

Below you can see an example of the response of an odd and even row vs. light input.

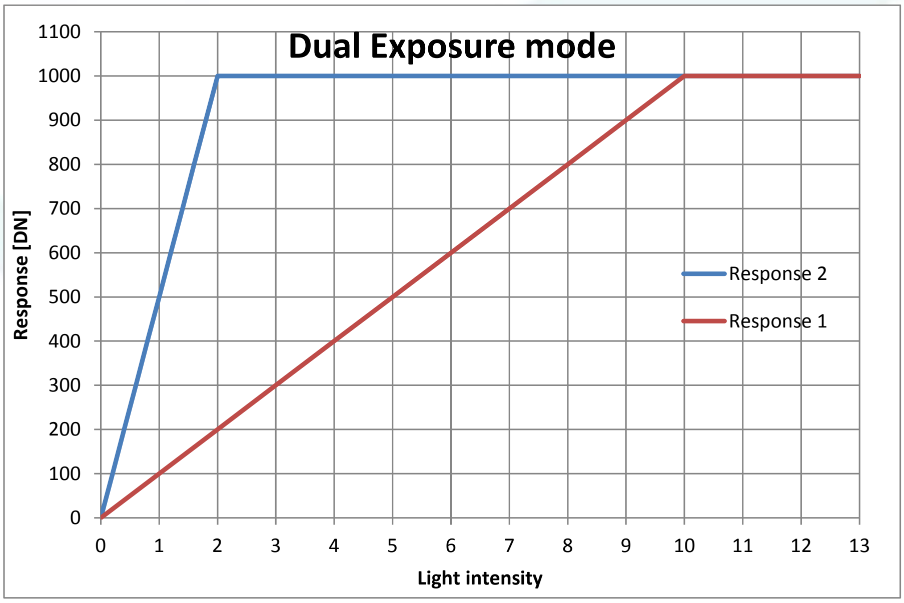

FIGURE 1: DUAL EXPOSURE MODE PLOT

The blue plot is the one with the longer exposure time, meaning that it will saturate sooner than the one with the short exposure. So for example, if we have a dark area in the image, with a light intensity of 1 falling on it, the short exposure will give 100DN response, while the long exposure will give a response of 500DN. The latter will show better image quality (as we otherwise had to digitally gain the darker 100DN, also increasing the noise). If there is a bright area (light intensity of 6), the long exposure will already have saturated the pixels and no detail can be seen anymore. The short exposure on the other hand will have a response of 600DN and therefor detail can still be seen.

2.1.2 Setup

Best is to find an optimal ratio between the 2 exposure times. Say for example 1/10. So based on your longest exposure needed, you can calculate the short exposure to use. You can easily find both the wanted exposure times by looking at a typical scene (with dark and bright objects) and using normal mode. Now you set the exposure time until you see enough details in dark that you want. Then you decrease the exposure time until you have the details in bright areas that you want.

You can also use a gradient test chart or adjustable light source to find the exposures ratio.

2.1.3 Image correction

Once you have taken your image, you need to combine the dark and bright pixels to get a HDR image. A simple way is to merge the two images 5120x1920 and then scale that back to 5120x3840. Of course you will lose sharpness this way. More complex algorithms (based on neighbor pixels, thresholds …) will get better results.

Below you can see 2 normal images taken at an exposure time ratio of 10. In the 1st you can see detail outside, but inside the image is too dark. In the 2ns image, the outside is saturated, but the inside is clear. The bottom image is an averaged dual-exposure image using those two exposure times. You now can see details inside as well as outside.

 Exp_time = 5ms	 Exp_time = 50ms

Averaged dual exposure image

FIGURE 2: DUAL EXPOSURE EXAMPLE

2.1.4 Pros and Cons

Pros:

- Easily find the wanted exposure times
- Each response is a normal linear response and behaves like the sensor would in normal dynamic mode. So FPN, PRNU and color corrections are easier.

Cons:

- Less resolution/sharpness because of the merging of 2 lower resolution images. Good correction algorithms can improve this.
- Only 2 exposure times
- Exposure start and motion-blur difference between the short and long exposure.

2.2 Piecewise Linear Mode

2.2.1 Operation

In PLR mode, you can create a non-linear response to light consisting of up to 3 separate linear slopes. This feature will clip and hold illuminated pixels at a programmable voltage for a certain exposure time (kneepoint), while leaving the darker pixels untouched. The clipping level can be adjusted 2 times within one exposure time to achieve a maximum of 3 slopes in the response curve. More details can be found in the figure below.

The pixel can create these kneepoints by not opening the transfer gate voltage (TX) fully. During normal exposure time, the transfer gate is fully open (cf. switch: open = no flow) so charge that is collecting in the diode will not flow to the floating diffusion (FD) and reset to VDDPIX. When using piecewise linear exposure, the transfer gate will not be fully closed during exposure so charge will start to leak to the FD if it reaches a certain amount (so the collected charge is kept at a certain level for a certain time). These amounts are set with the kneepoint levels.

In Figure 3 you can see the layout of the pixel transfer gate and the TX and RST voltages during operation. In Figure 4 you can see the charge building up in a dark and a brighter pixel. You can see that in normal mode the bright pixel would have been saturated (clipped) so no useful information would visible anymore. By using this HDR mode, the bright pixel will now show in the image as a bright, but not clipped, pixel.

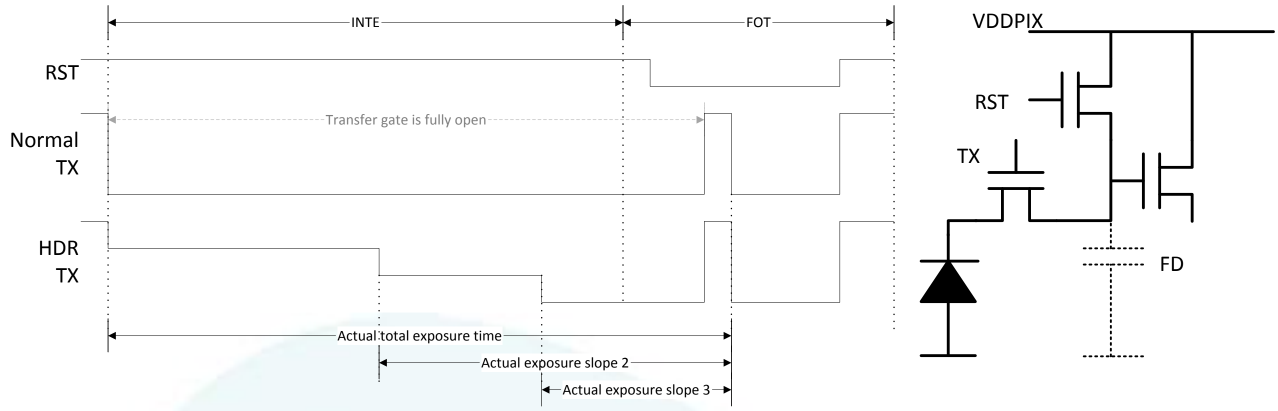

FIGURE 3: TRANSFER GATE TIMING

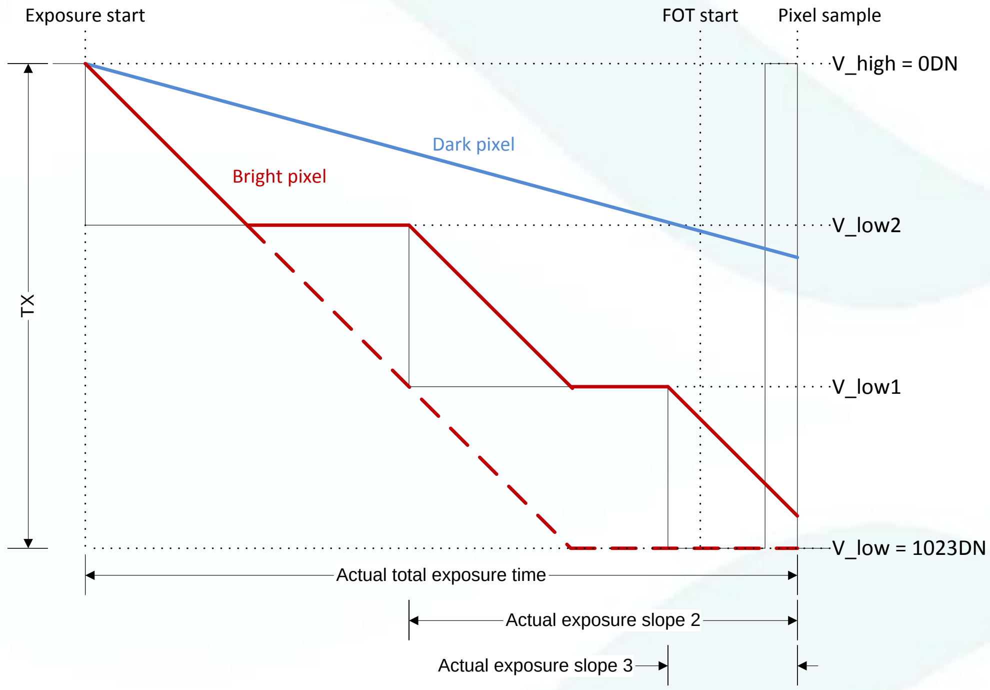

FIGURE 4: TRANSFER GATE VOLTAGE

Using this feature, an output response as detailed in Figure 5 can be achieved. The placement of the kneepoints in X (incoming light or electrons) is controlled by the V_low2/3 programming, while the slope of the segments is controlled by the programmed exposure times.

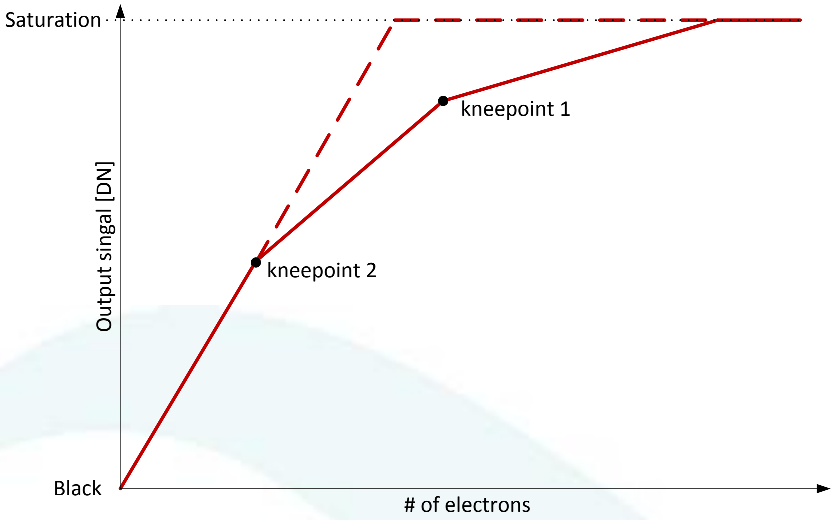

FIGURE 5: PIECEWISE LINEAR RESPONSE

2.2.2 SETUP

First you will have to decide where the kneepoints should be, both level- and slope-wise. This will depend on your preference, but a good starting point would be to have the kneepoint at 75% of saturation when using 2 slopes.

Finding the V_low level can be done in the following way. Use the normal linear mode, set the maximum exposure time and increase the light so the sensor is just saturating. No enable a kneepoint, set the exposure of 2nd slope to its minimum ans increase V_low2. You will start to see the saturation level decrease. This is close to the kneepoint level (there is a small error because of the minimum exposure time for slope 2 isn't 0). When you have set the V_low2 level, now increase the slope 2 exposure time untill you again have saturation clipping in white.

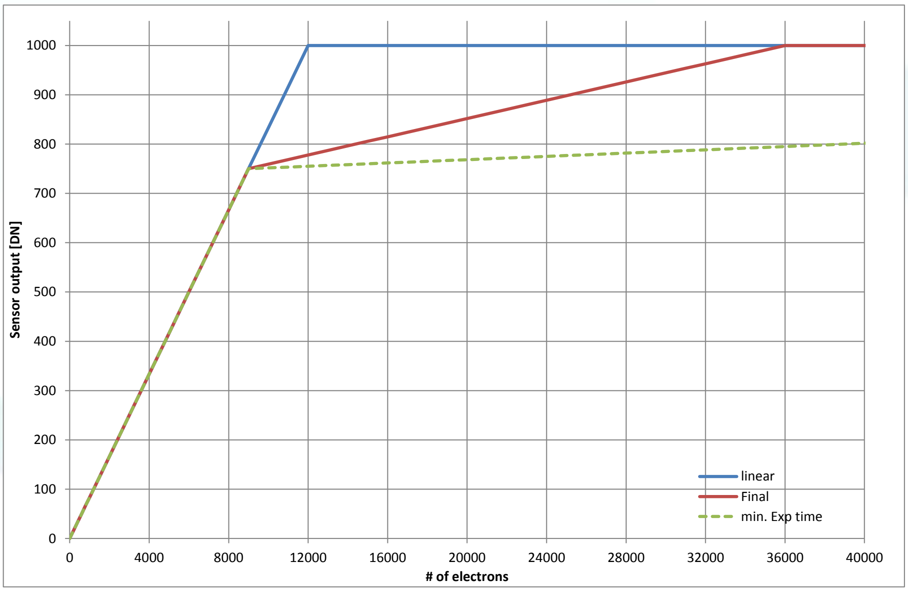

FIGURE 6: PLR SETUP

2.2.3 IMAGE CORRECTIONS

Image correction is more complex than in dual exposure mode because of several reasons.

First, the on-chip correlated double sampling is not happening in the 2^{nd} and 3^{rd} slope. This means that those pixels will have a much higher FPN and noise then the 1^{st} or linear slope.

Second, one can notice that the noise in the image increases in the second and third slope responses. This is due to the fact that the Signal to Noise ratio is limited by the shot noise. This shot noise is the square root of the integrated charge at the photodiode which is proportional to the actual response in single slope. This means that the SNR also increases with the square root of the actual response as well in the single slope operation. However in the multiple slope operation the collected charge on the photo diode is increased in the second and third slope and artificial mapped to a lower response. Therefore the shot noise still increases proportional to the collected charge but the SNR decreases in the second slope because the signal itself is mapped to a lower value.

Third, the kneepoints are not sharp, but have a soft transition. So if you want to correct pixels (flat fielding) using the kneepoint level as a threshold, you cannot correct for it perfectly.

Fourth, the kneepoint level itself isn't uniform over the entire sensor array. It can vary per pixel and per device. Therefor two pixels next to each other can have a large difference in their kneepoint level. The slopes will not vary as much. To correct for this per-pixel flat-fielding is needed at the kneepoints. Below is a plot of 2 pixels on the same sensor showing the difference in the kneepoint level that can occur. You can also see the soft transition of the slopes.

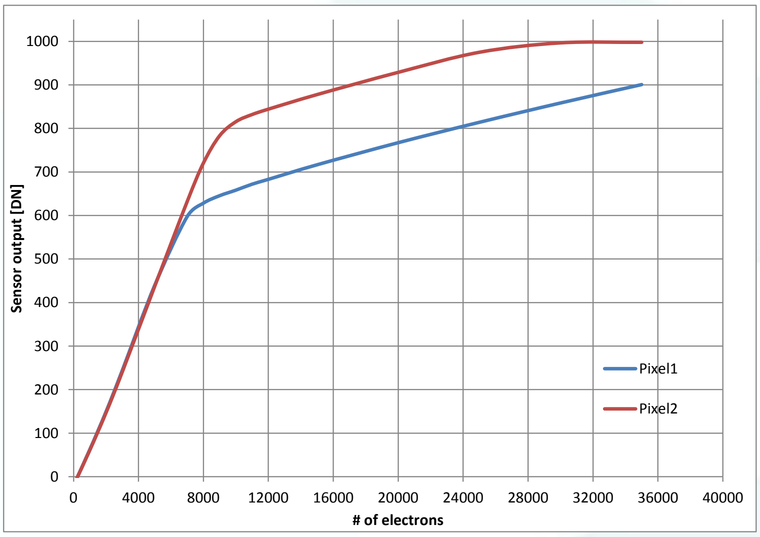

FIGURE 7: PLR OF 2 PIXELS

This means that even when taking a uniform image, the difference in levels will show up as non-uniformities in the image.

Last, the kneepoint levels are also light dependent, meaning that if bright light is falling on the pixel, the kneepoint level will shift upwards. Below is an example of a pixel where the exposure times are decreased (but the ratio of slope 1 and 2 is kept the same). For short exposure times (so more light is needed for saturation), the kneepoint level goes up. This behavior isn't linear and is due to leakage in the pixels.

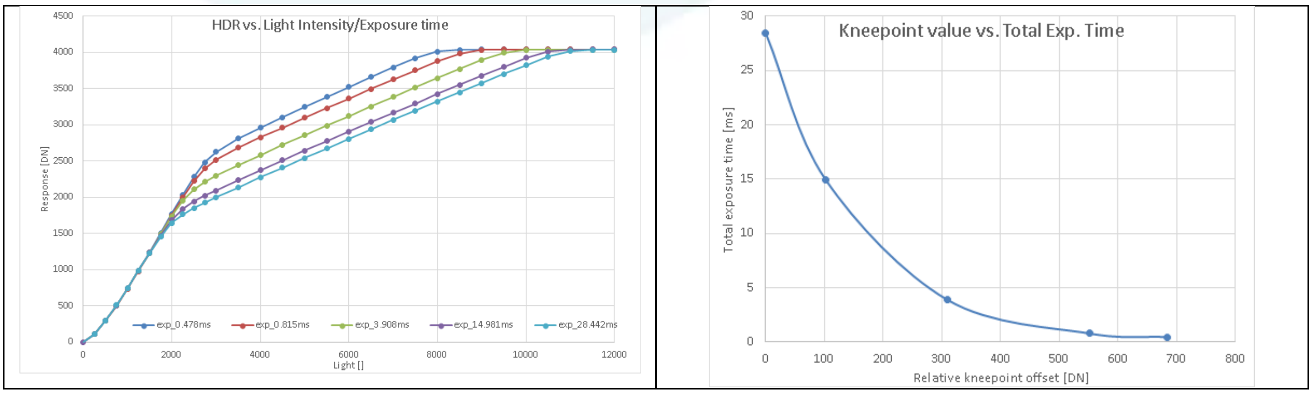

FIGURE 8: EXPOSURE TIME VS KNEEPOINT LEVEL

2.2.4 Pros and Cons

Pros:

- No loss in detail like in dual exposure mode
- No exposure differences

Cons:

- Higher FPN and noise
- Variations in kneepoint levels per pixel and device, so pixel flat-fielding needed.
- Variations in kneepoint levels per light/exposure time

3 Conclusion

In general we recommend using the dual exposure HDR mode as there are little variations and the slopes are linear and behave like normal non-HDR mode. The PLR mode has many variations, which yield heavy corrections and calibrations needed for decent image quality, but has the advantage of having an HDR image at the output without the resolution loss and algorithms of dual exposure mode.