Technical Note

MT9V032
High Dynamic Range Feature

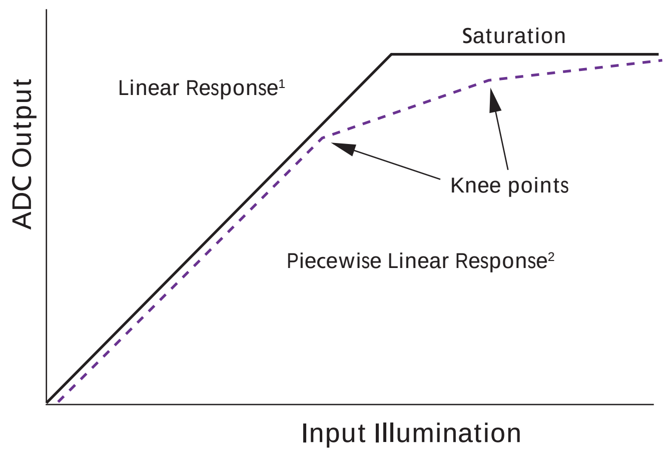
Introduction

The pixel of the Micron® MT9V032 sensor was designed to enhance the range of illumination levels that can be distinguished, giving it an intrascene optical dynamic range exceeding 110dB. This, coupled with low-temporal noise (~1.5 LSBs), makes it ideal for supporting the demands of interior and exterior security, and machine-vision imaging needs in real-world environments.

Operation Overview

To achieve a high, intrascene dynamic range (HiDy), the MT9V032's pixel, the analog signal chain, and the ADC have been designed to ensure that saturation occurs only at extremely high levels of illumination. The pixel operation allows either automatic exposure control or the user to adjust the pixel saturation level (or knee points) during the exposure period. This control mechanism creates a piecewise linear response to the illumination. By adjusting the exposure time and the maximum storage charge of the pixel knee points, the user can achieve a response curve that is a combination of piecewise linear segments of decreasing gradients, as shown in Figure 1.

Figure 1: Response Curves



Notes:
1. Linear response causes loss of high-intensity detail in the flat region.
2. Piecewise linear response causes compression of high-intensity detail. A greater scene dynamic is available.

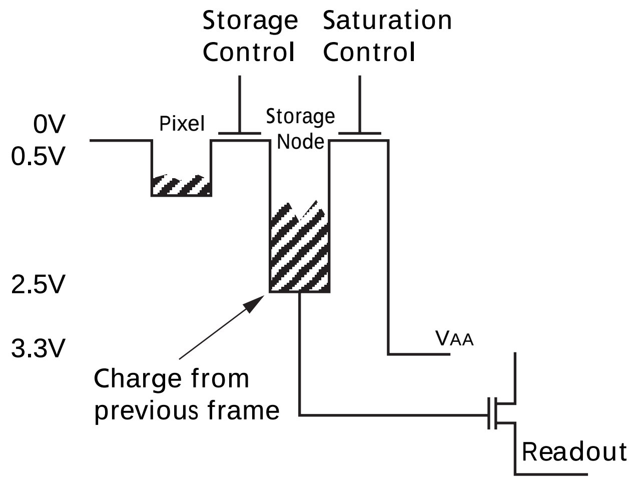
Pixel Operation Details

The following sequence of charge diagrams (Figure 2, Figure 3 on page 2, and Figure 4 on page 3) illustrate the principle of the pixel operation.

Start of Exposure

To start the exposure, the charge in the pixel is flushed through a reset mechanism. Exposure starts and charge accumulates in the pixel. At this time, the charge from the previous frame is on the storage node and is being read out; therefore, the storage control voltage is at 0V.

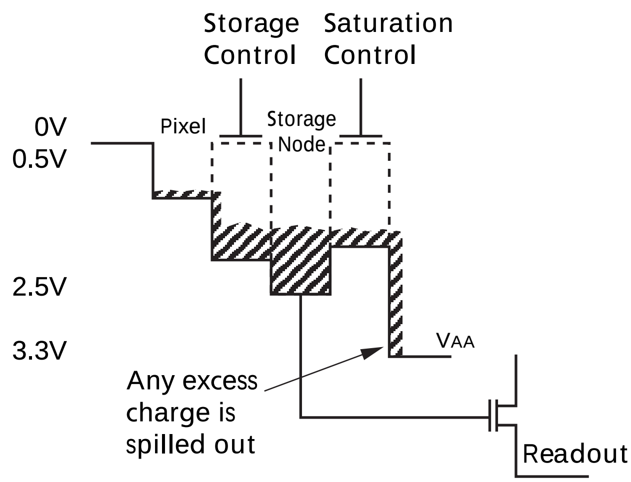
Figure 2: Exposure Start



Storage Gate Opens

Once the previous frame's charge is read out of the storage node, the storage control gate is opened and the saturation control gate is adjusted to level V1 (R0x31). Any charge already accumulated above this level is spilled out to VAA.

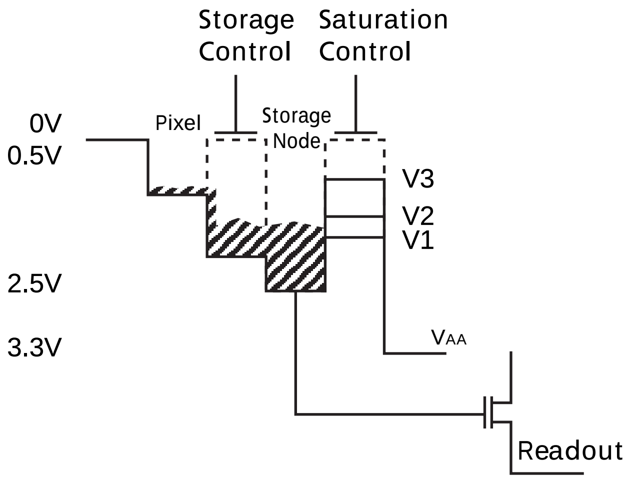
Figure 3: Storage Control Gate Open



Further Accumulation of Charge

After time Shutter Width 1, the saturation control gate voltage is adjusted to level V2 (R0x32), allowing further charge to accumulate or spill out if it exceeds the level set by V2 (R0x32). After Shutter Width 2, the gate is further adjusted to voltage level V3 (R0x33). Finally, after time Total Shutter Width, the storage control is closed. All the charge on the storage node is isolated. This will be read out during the following frame integration time.

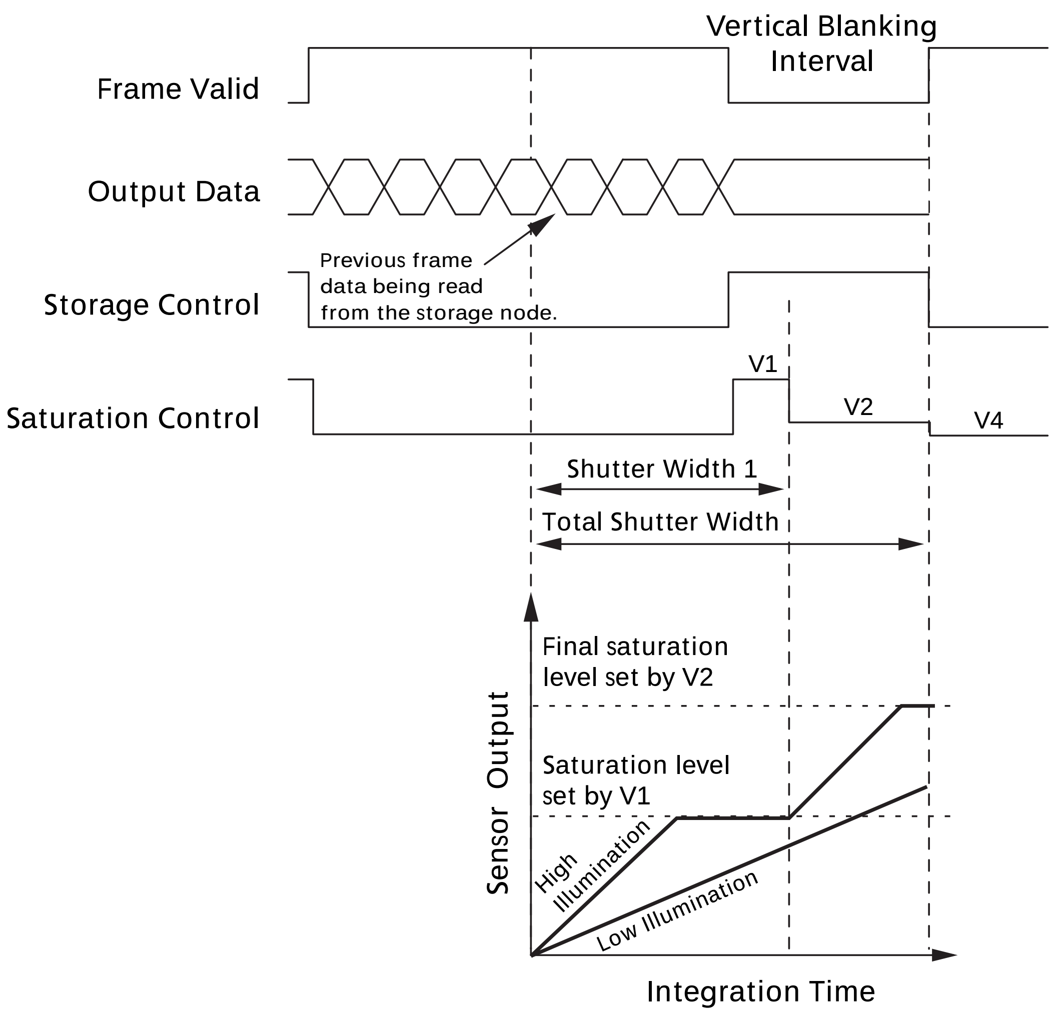
Figure 4: Final Steps



Single Knee Point Behavior

When the sensor is in single-knee operation, only one knee point can be controlled. Figure shows the relationship between integration segments and saturation voltage for a single knee saturation control in manual mode (R0x0A[8] = 0; R0x0A[9] = 1) or in auto knee-adjust mode (R0x0A[8] = 1; R0x0A[9] = 1).

Figure 5: Integration Segments and Saturation Voltage: Single Knee Saturation



The start time for integration is determined from the trailing edge of the vertical blanking interval and the total shutter width. Micron recommends keeping the total shutter width to the maximum 480 rows whenever possible to achieve the highest dynamic range.

The user must ensure that the Shutter Width 1 does not allow the HiDy operation to start before the completion of the readout of the previous frame. This relationship can be expressed as:

$$VerticalBlank > (TotalShutterWidth - ShutterWidth1) \quad \text{(EQ 1)}$$

Note: If operating the MT9V032 in single knee automatic exposure mode (R0x0A[8] = 1, R0x0A[9] = 1), then the Shutter Width 1 is determined by the T2 Ratio (R0x0A[3:0]). Total Shutter Width can be set either by R0x0B[14:0] or by the AEC algorithm.

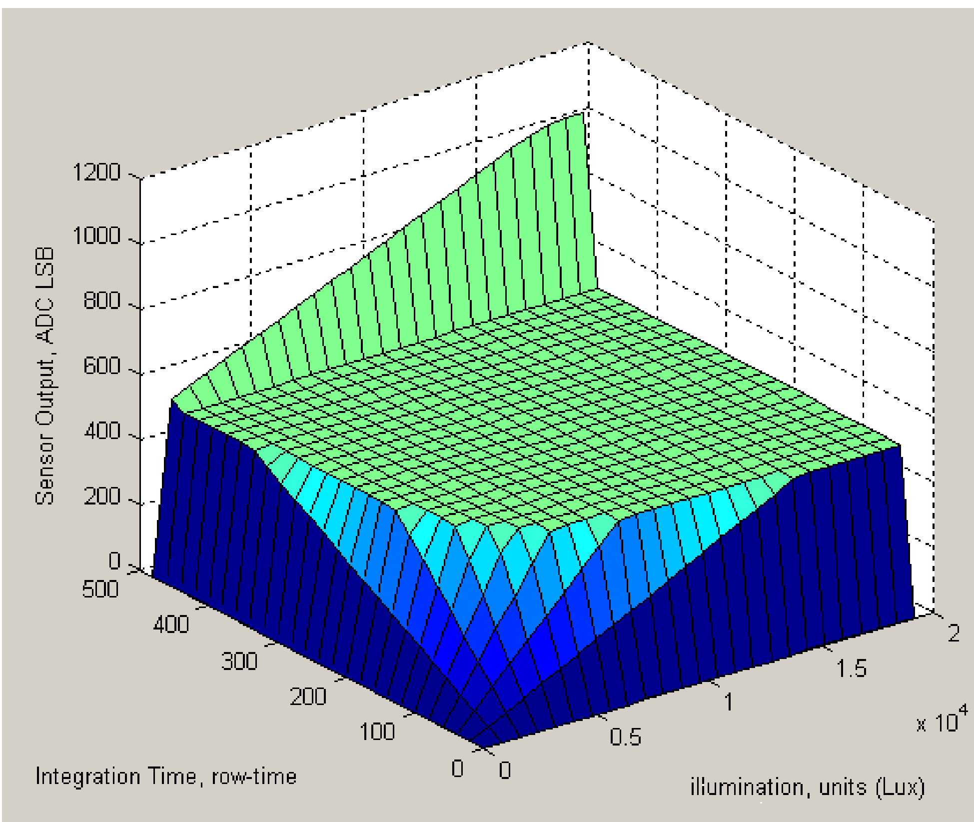
$$ShutterWidth1 = TotalShutterWidth \times (1 - (1/2)^{T2Ratio} - (1/2)^{T3Ratio}) \quad \text{(EQ 2)}$$

For example, if the Auto Shutter Width determined by the auto exposure is 400 rows, T2 Ratio = 4, and T3 Ratio = 6, then the knee point occurs after *400 – 25 – 6 = 369* rows.

Single Knee Pixel Output Response

Figure 6 shows how the pixel output changes because of changes in either integration time or illumination intensity for a single knee algorithm.

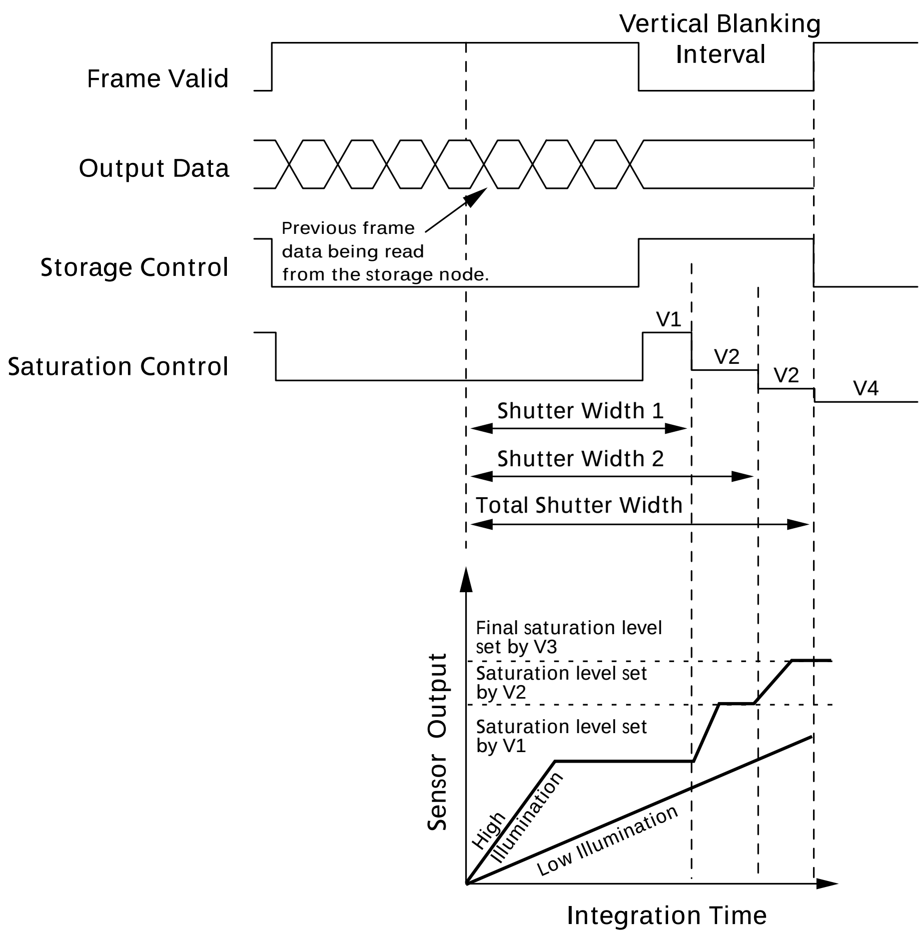
Figure 6: Pixel Output Response to Illumination and Integration Time for a Single Knee



Two Knee Point Behavior

Figure 7 shows the relationship between integration segments and saturation voltage for a two knee control in manual mode (R0x0A[8] = 0; R0x0A[9] = 0) or in auto knee-adjust mode (R0x0A[8] =1; R0x0A[9] = 0).

Figure 7: Integration Segments and Saturation Voltage for a Two Knee Control



The start time for integration is determined from the trailing edge of the vertical blanking interval and the total shutter width. Micron recommends keeping the total shutter width to the maximum 480 rows whenever possible to achieve the highest dynamic range.

The user must take care to ensure that the Shutter Width 1 does not allow the HiDy operation to start prior to the completion of the readout of the previous frame.

$$VerticalBlank > (TotalShutterWidth - ShutterWidth1) \quad \text{(EQ 3)}$$

Note: If operating the MT9V032 in automatic adjust mode R0x0A[8]=1, R0x0A[9]=0, then the placement of the knee points is determined by T2 Ratio (R0x0A[3:0]) and T3 Ratio (R0x0A[7:4]). Total Shutter Width can be set either by R0x0B[14:0] or by the AEC algorithm.

$$ShutterWidth1 = TotalShutterWidth \times (1 - (1/2)^{T2Ratio} - (1/2)^{T3Ratio}) \quad \text{(EQ 4)}$$

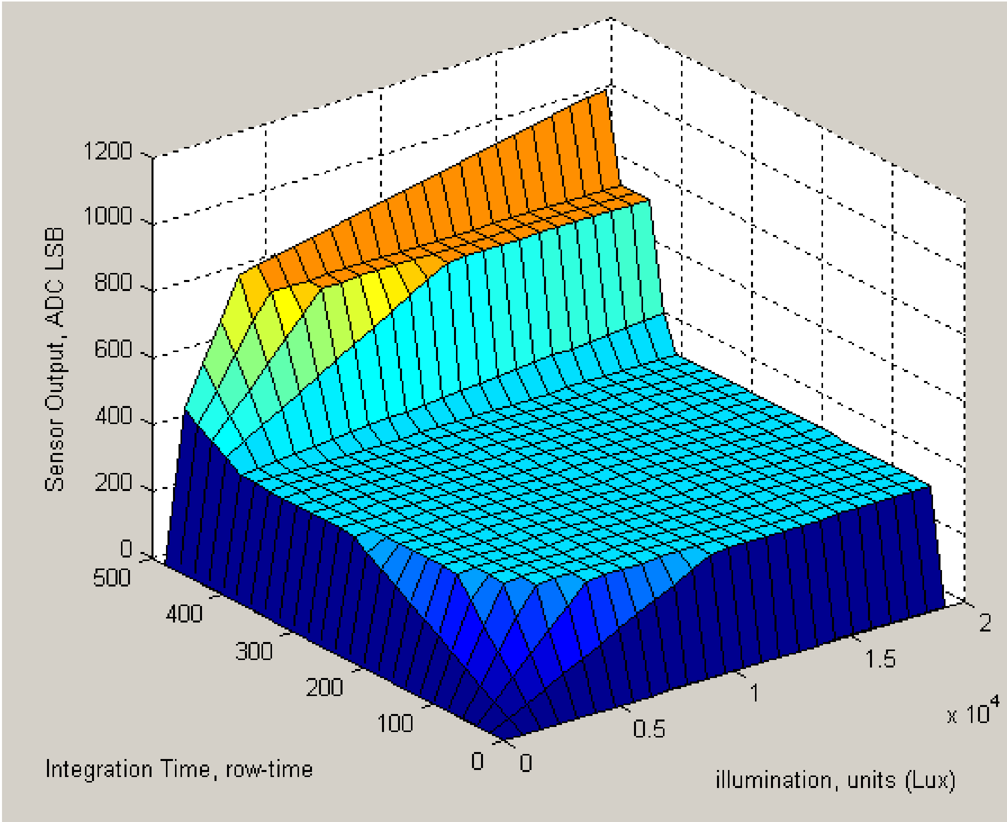
$$ShutterWidth2 = TotalShutterWidth \times (1 - (1/2)^{T3Ratio}) \quad \text{(EQ 5)}$$

For example, if the Auto Shutter Width determined by the auto exposure is 400 rows, T2 Ratio = 4, and T3 Ratio = 6, then the first knee point will occur after 369 rows and the second after 394 rows.

Two Knee Pixel Output Response

Figure 8 shows how the pixel output changes due to changes in either integration time or illumination intensity for two knee operation.

Figure 8: Pixel Output Response to Illumination and Integration Time for a Two Knee Operation



Measuring the Intrascene Dynamic Range

The standard method for calculating dynamic range for a linear response sensor is to divide the effective full well capacity by the read noise. The effective full well is either where the conversion factor changes (reduces) sharply at full well, or where the ADC approaches saturation (pinching off the temporal noise). The effective full well then becomes the point where temporal noise is maximum.

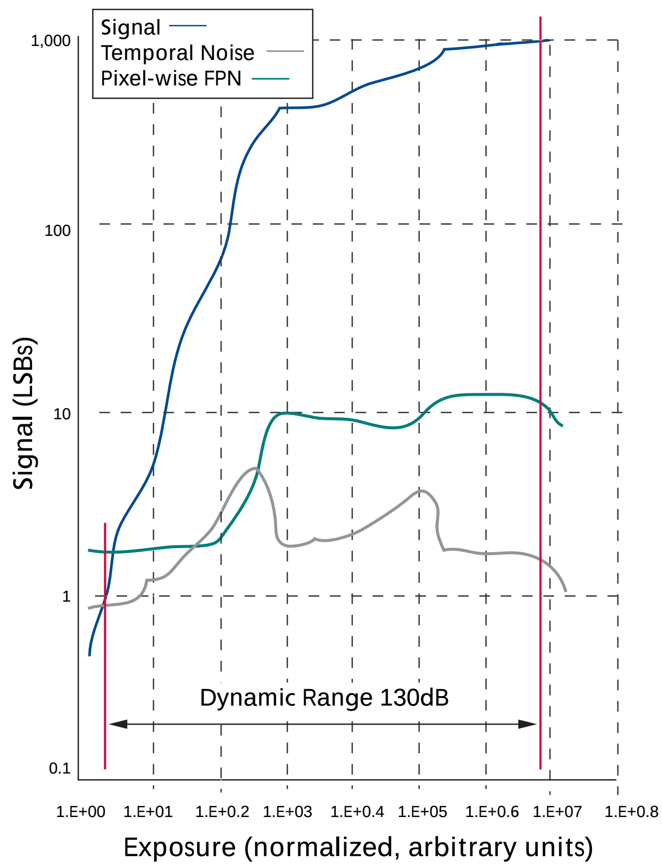
For the linear sensor, the signal dynamic range, as described above, corresponds to optical dynamic range that is calculated as maximum exposure corresponding to effective well capacity, divided by minimum exposure corresponding to readout noise.

For the high dynamic range sensor, the same approach can be used to determine optical dynamic range, with the exception that for maximum exposure, the region past the last knee-point and before the approach to ADC saturation (when temporal noise begins to decline) must be examined.

Intrascene Dynamic Range Test

An Intrascene Dynamic Range Test (Figure 9) was generated using a calibrated white LED. The measurements were taken with default register values. The saturation control settings used were V1: (R0x31 = 0x1F), V2: (R0x32 = 0x1F), V3: (R0x33 = 0x0), and V4: (R0x34 = 0x13). These settings provide a single knee signal response curve.

Figure 9: Intrascene Dynamic Range Test



When examining this plot, first notice that both axes are logarithmic. Second, notice that temporal noise increases with exposure due to photon shot noise, but is reduced as the signal crosses the knee-points. The maximum effective exposure occurs when the signal approaches ADC code 990; temporal noise is then reduced as the ADC becomes saturated. The minimum exposure corresponds to the condition where the signal is equal to the temporal noise.

Figure 9 shows that the dynamic range is equal to 130dB.

Effects of a HiDy Sensor

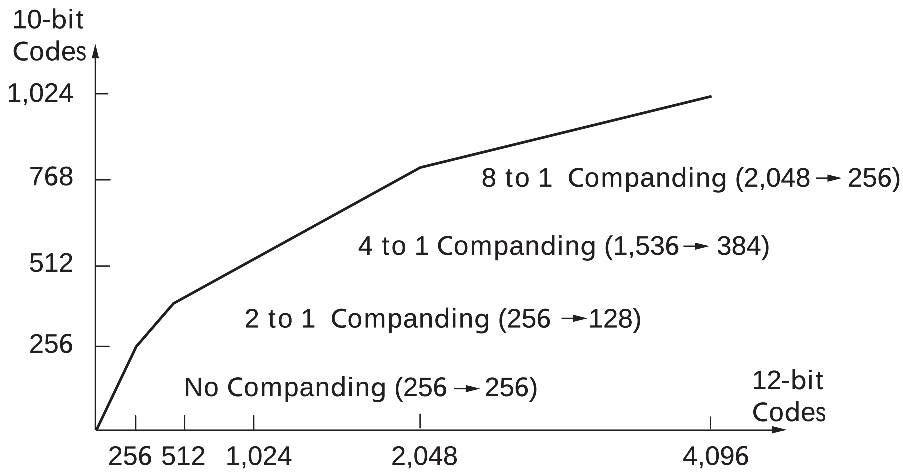
Ordinarily, the slope of FPN is expected to follow that of the slope of the signal, and it does from exposures of 10 to 100. However, absolute FPN (in LSBs) can be reduced with increased exposure, which is due to a changing (lowering) conversion factor. A typical HiDy sensor will show a large decrease in FPN after crossing knee-points, which is an advantage of this sensor in terms of image quality.

The maximum temporal noise is about four ADC codes; however, most of the signal range measures about 1.5 LSBs of temporal noise. This is another advantage of the HiDy sensor. A normal linear sensor will measure about four LSBs of temporal noise (mainly due to photon shot noise) across most of the signal range. When running the demo camera capturing still images, temporal noise is so low that it is hard to tell that the camera is actually capturing pictures.

Enhancing Contrast in the Low Tones

By enabling 12-bit to 10-bit companding (R0x1C[1:0] = 0b11), the contrast in low tones can be enhanced (at the expense of mid and high tones). The response curve in Figure 10 shows the mapping when 12V 10-bit compression is enabled.

Figure 10: Mapping When 12V 10-Bit Compression is Enabled



An Outdoor Shot of a Traffic Intersection on a Sunny Day

Figure 11 shows two images of the same scene. The top image is taken with HiDy disabled, the lower image is taken with HiDy enabled. HiDy mode allows details in both the bright and dark areas to be resolved in a single image. For example, in the lower image the details of the upper right corner of the scene can be distinguished. The same area of the upper image (with HiDy disabled) is washed out and details are lost.

Figure 11: Outdoor Shot With HiDy OFF Versus HiDy ON

Note: A high-dynamic range image may be limited by the dynamic range of the rendering system. A typical dynamic range of a CRT monitor is approximately 50dB (that of a printer is approximately 70dB).

Conclusion

The optimal choice of settings (with optimal contrast) will ultimately depend on the scene conditions. Capturing a scene with a very large luminance spread into 1,024 values of LSB is a trade-off between the dynamic range of the scene and the desired contrast at different illumination levels. Micron's MT9V032 sensor has been specifically designed to generate high quality images under high dynamic range conditions.

For further information and assistance on this feature, contact Micron Imaging applications at www.micron.com/imaging.

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Revision History

Rev. A 8/16/2006

- Initial release