Technical Note

MT9V024 High Dynamic Range

Introduction

This technical note addresses the Aptina® MT9V024 CMOS image sensor and the flexible high dynamic range (HDR) feature. Different scenes or applications require different distributions of the intrascene dynamic range of the MT9V024. This technical note assists system designers in achieving a desired dynamic range and pixel response. The technical note is broken up into two sections:

- "High Dynamic Range Theory"

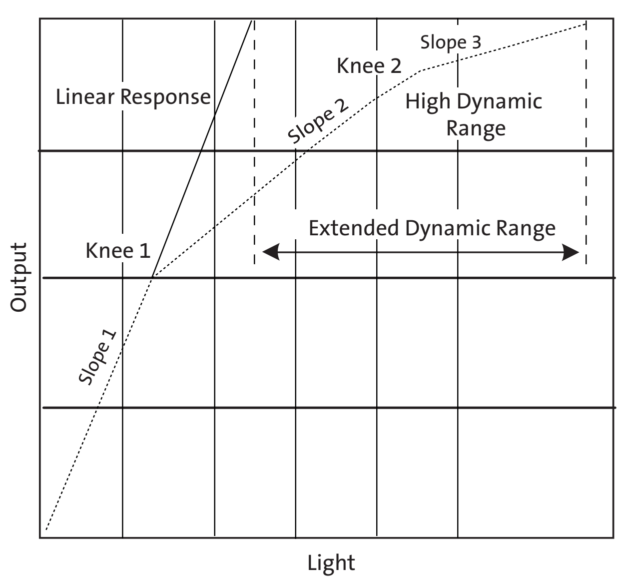
and

- "Using the MT9V024 under Real World Conditions" on page 11

High Dynamic Range Theory

The MT9V024 has a linear-pixel-response dynamic range of approximately 56dB. A higher dynamic range can be achieved by using a piecewise linear response, as illustrated in Figure 1. By lowering the slope of the response, or contrast, in the higher luminance ranges, the pixels in the MT9V024 can be used to quantize a much greater luminance range before saturation. Progressively lower response slopes enable the MT9V024 to simultaneously maintain good low-signal contrast (shadow detail) and significantly extend the range of quantifiable luminance levels.

Figure 1: High Dynamic Range with Three-Segment Response



Background

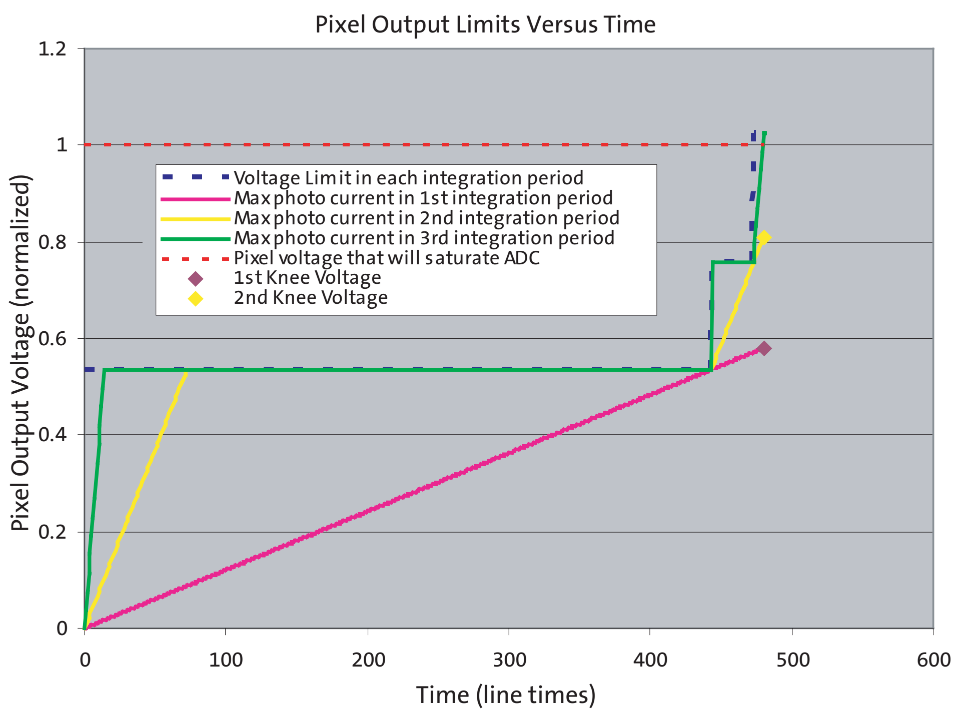
The high dynamic range response of the MT9V024 can be tailored to the designer's required response by adjusting slope of the three response segments and the position of "knee points" between them. Required response is built through register parameters, as explained in this technical note.

For more detailed information regarding a similar sensor's pixel operation in HDR mode, refer to the Aptina Imaging technical note TN-09-18, "High Dynamic Range Feature."

Pixel Response across Three Integration Periods

In HDR mode, the MT9V024 divides the total integration time, or total shutter width, into three periods: t_1, t_2, and t_3. During each integration period, there is a different potential barrier applied to the pixels that limits the maximum photo current that can be quantized during that period. The potentials applied are v_1, v_2, and v_3, respectively. This concept is illustrated in Figure 2.

Figure 2: Photo Current Limits in Each Integration Period



Integration Periods: t_1, t_2, and t_3 (Manual Control)

The three integration periods end at shutter width 1 (R0x08), shutter width 2 (R0x09), and total shutter width (R0x0B) lines of integration, respectively. The relationship between the shutter width register settings and the length of each integration period is as follows:

$$t_1 = SW_1(\text{R0x08}) \tag{EQ 1}$$

$$t_2 = SW_2(\text{R0x09}) - SW_1(\text{R0x08}) \tag{EQ 2}$$

$$t_3 = SW_{\text{TOTAL}}(R0x0B) - SW_2(\text{R0x09}) \tag{EQ 3}$$

In Figure 2 on page 2, the MT9V024 is programmed for 480 lines of total shutter width (R0x0B = 480); shutter width 1 is set to 443 lines (R0x08 = 443) and shutter width 2 is set at 473 lines (R0x09 = 473). With these settings, the integration periods are: t_1 = 443 lines, t_2 = 30 lines, and t_3 = 7 lines.

Integration Periods: t_1, t_2, and t_3 (Automatic Control for Context A Registers)

Alternatively, the integration periods can be specified using the exposure knee point auto adjust feature (R0x0A[8] = 1). When this feature is enabled, the image sensor automatically calculates the correct number of lines of exposure given the current exposure time. The relationship between the shutter width register settings and the length of each integration period is as follows:

$$t_3 = SW_{TOTAL}(\text{R0x0B}) \cdot \left(\frac{1}{2}\right)^{\text{t3\_ratio(R0x0A[7:4])}} \tag{EQ 4}$$

$$t_2 = SW_{TOTAL}(\text{R0x0B}) \cdot \left(\frac{1}{2}\right)^{\text{t2\_ratio(R0x0A[3:0])}} \tag{EQ 5}$$

$$t_1 = SW_{TOTAL}(\text{R0x0B}) - t_2 - t_3 \tag{EQ 6}$$

In this mode, each integration period is truncated to an integer number of lines of integration. For example, when $SW_{TOTAL} = 480$ *lines* and *t3_ratio = 8*, t_3 returns a value of 1 line of exposure. Importantly, when $SW_{TOTAL} = 480$ *lines* and *t3_ratio = 9*, t_3 returns a value of 0 lines (no t_3 exposure happens).

Potential Barrier Limits: V_1, V_2, and V_3

The potential barrier limiting pixel integration during each integration period is controlled by the V_1, V_2, and V_3 control voltage registers: R0x31, R0x32, and R0x33, respectively. Control voltage V_4 (R0x34) is used as a “parking” voltage for the pixel and can generally be left at the default value of “4” and will not affect the high dynamic range pixel response.

Maximum Photo Current during Each Integration Period

The integration voltage limit and the integration period of t_1, t_2, or t_3 determine the maximum photo current that will not saturate the pixel during that period. In a plot of pixel output versus time (Figure 2 on page 2), photo current response is represented as a line with a slope of volts per second. The maximum photo currents that will not saturate the pixel in t1, t2, and t3 are represented by magenta, yellow, and green lines, respectively.

Two-Knee-Point Voltages

Photo currents resulting from illumination levels that are lower than the maximum photo current during t1 (the magenta line in Figure 2 on page 2) integrate without saturating the pixel throughout the total shutter width [R0x0B]. The voltage that is reached at the end of the integration period (480 lines in Figure 2) due to this maximum photo current corresponds directly to the first knee of the output response curve (Figure 1 on page 1). All of the photo currents below this limit will result in an output code versus illumination slope that is equivalent to that of the MT9V024 linear mode response slope (for example, Slope 1 in Figure 1 on page 1).

Response Slopes

The three segments of the pixel response curve (Figure 1 on page 1) each have a different slope. The slope of the first segment is dependent only on the total shutter width and is the same as the slope in linear operation mode with the same total shutter width setting. Slope 2 has a lower slope than Slope 1, and Slope 2 has a lower slope than Slope 3.

Figure 2 on page 2 shows that the maximum photo current that will not saturate the pixel during t2 (the yellow line) is significantly larger than the maximum photo current that will not saturate the pixel during t1 (the magenta line). The range of photo currents between these two limits represent the illumination levels that will integrate to voltages between the first two knee-point voltages, VKnee1 and VKnee2.

The ratio of the Slope 1 to Slope 2 in the response curve is determined by the ratios of their exposure times. The Slope 1 response is due to photo current integration for the total integration time, or SW1, and the Slope 2 response is due to photo current integration during t2 and t3. Therefore, the ratio between Slope 1 and Slope 2 in the response curve can be determined from:

$$Slope\ 1/Slope\ 2 = SW_{TOTAL}/(t_2 + t_3) = SW_{TOTAL}/(SW_{TOTAL} - SW_1) \quad \text{(EQ 7)}$$

where t_2, t_3 = the second and third integration periods

Note: $(t_2 + t_3)$ is equal to $SW_{TOTAL} - SW_1$, which means that the slope of the second segment of the response curve is dependent only on SW_1 *(R0x08)*, assuming a fixed total integration period.

In the third segment of the response curve, photo currents between the maximum photo currents of integration periods t_2 and t_3 (the yellow and green lines of Figure 2) integrate to voltages between the second knee voltage and the maximum voltage reached at the end of the total shutter width.

The ratio of *Slope 2* to *Slope 3* in the response curve is determined by the ratios of their exposure times. The *Slope 2* response is due to photo current integration for periods t_2 and t_3; the *Slope 3* response is due to photo current integration during t_3. Therefore, the ratio between *Slope 2* and *Slope 3* in the response curve can be determined from:

$$Slope\ 2 / Slope\ 3 = (t_2 + t_3)/t_3 = (SW_{TOTAL} - SW_1)/(SW_{TOTAL} - SW_2) \quad \text{(EQ 8)}$$

where t_2, t_3 = the second and third integration periods

Note: t_3 is equal to $SW_{TOTAL} - SW_2$, which means that the slope of the third segment of the response curve is dependent only on SW_2 *(R0x09)*.

Setting the Second Segment Slope Using SW_1

The second segment slope is dependent on the SW_1/SW_{TOTAL} ratio. Assuming that the total shutter width, SW_{TOTAL}, has been selected for the desired first segment response, the desired second segment slope should be selected using SW_1 (R0x08) according to the following:

$$Slope\ 1/Slope\ 2 = SW_{TOTAL}/(SW_{TOTAL} - SW_1) \quad \text{(EQ 9)}$$

or

$$SW_1 = SW_{TOTAL} \times (1 - Slope\ 2/Slope\ 1) \quad \text{(EQ 10)}$$

For example, if $SW_{TOTAL} = 480$ and a second segment slope that is 1/8 the slope of the first segment slope is desired, then:

$$SW_1 = 480(1 - 1/8) = 420 \quad \text{(EQ 11)}$$

The results of setting the linear exposure settings using a bright target can be seen in Figure 14 on page 17.

Setting the Third Segment Slope Using SW_2

Using the SW_{TOTAL}, and SW_1 values from the previous steps, the slope of the third segment can be set using SW_2 (R0x09):

$$Slope\ 2/Slope\ 3 = (SW_{TOTAL} - SW_1)/(SW_{TOTAL} - SW_2) \quad \text{(EQ 12)}$$

or

$$SW_2 = SW_{TOTAL} - (SW_{TOTAL} - SW_1) \times Slope\ 3/Slope\ 2 \quad \text{(EQ 13)}$$

For example, if $SW_{TOTAL} = 480$ and $SW_1 = 424$, and a Slope 2/Slope 3 ratio of 12:1 is desired then:

$$SW_2 = 480 - (480 - 424) * 1/12 = 475.3 \quad (EQ\ 14)$$

which, when rounded to 475 would result in the closest possible Slope 2/Slope 3 ratio of 11.2. The results of adjusting contrast ratio can be seen in Figure 14 on page 17.

Pixel Response Equation Summary and Required Conditions

Table 1 on page 6 summarizes the high dynamic range pixel response equations defined in the previous sections (reference Figure 2 on page 2). For these equations to accurately predict the behavior of the MT9V024, several conditions must be met:

- SW_{TOTAL} (R0x0B) > SW_2 (R0x09) > SW_1 (R0x08)
- For simultaneous exposure mode, vertical blanking (R0x06) > $SW_{TOTAL} - SW_1$. The MT9V024 switches the pixel threshold voltage from V_1 to V_2 and from V_2 to V_3 during the vertical blanking period, so the interval must be longer than $t_2 + t_3$ for HDR mode to function properly.
- V_1 (R0x31) > V_2 (R0x32) > V_3 (R0x33) —> $v_1 < v_2 < v_3$

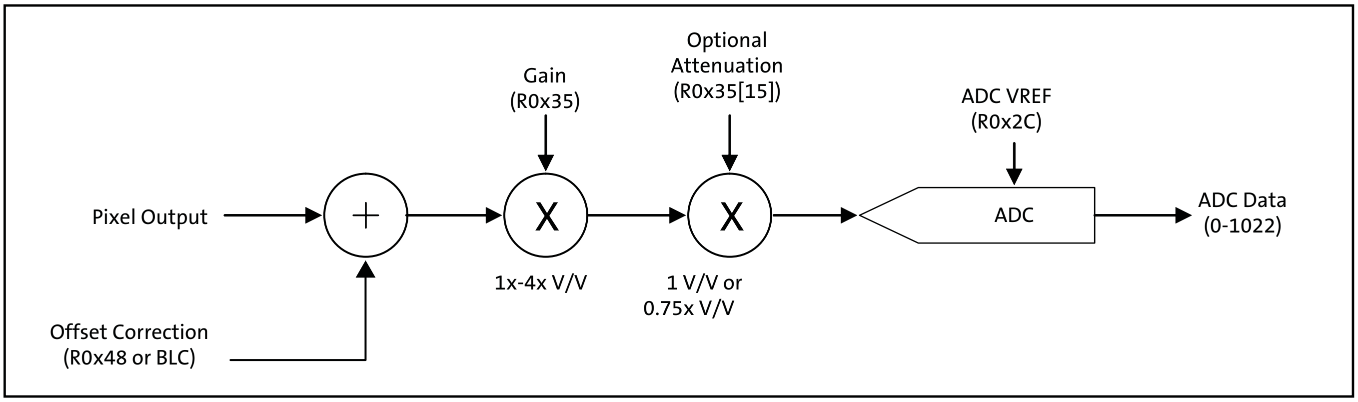
Table 1: Summary of Pixel Response Equations

$t_1 = SW_1$ (R0x08)	v_1: determined by R0x31 value
$t_2 = SW_2$ (R0x09) - SW_1 (R0x08)	v_2: determined by R0x32 value
$t_3 = SW_{TOTAL}$ (R0x0B) - SW_2	v_3: determined by R0x33 value
Slope 1 = same slope as linear response with same SWTOTAL setting	
Slope 1/Slope 2 = $SW_{TOTAL} / (t_2 + t_3) = SW_{TOTAL} / (SW_{TOTAL} - SW_1)$	
Slope 2/Slope 3 = $(t_2 + t_3) / t_3 = (SW_{TOTAL} - SW_1) / (SW_{TOTAL} - SW_2)$	

Mapping the Pixel Response to Output Codes

The MT9V024 ADC converts the analog output from the pixel, after offset correction and analog gain, into a digital output code ranging from 0 through 1022. To achieve the maximum dynamic range from the MT9V024, the output range of the pixel must be matched as closely as possible to the input range of the ADC.

Figure 3: Gain



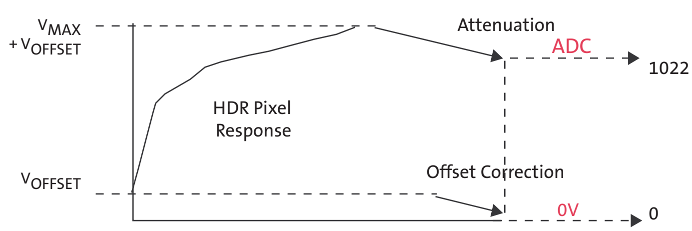
If the ADC is operating in 10-bit linear mode, the output code can be predicted by the following equation:

$$\text{ADC output code} = V_{Pixel} * \text{Gain} * \text{Attenuation} * 1022/\text{ADC\_V}_{\text{REF}} \quad \text{(EQ 15)}$$

where V_{Pixel} is the sampled pixel output voltage.

ADC Input Range

Figure 4: ADC Input Range



By default, the pixel output range is considerably larger than the default ADC input range. This is typical of default image sensor configurations because it is often desirable to match the most linear region of the response of the pixel to the input range of the ADC. In high dynamic range applications, the output response of the pixel is intentionally nonlinear and the goal is to monotonically quantize as much of the output range of the pixel as possible.

To ensure the maximum amount of dynamic range, care must be taken to adjust the output range of the pixel to match the input range of the sensor. The output range of the pixel can be matched to the input range of the ADC by one of the following methods:

- Using attenuation (set R0x35[15] = 1) for context A
- Adjusting the ADC reference voltage (VREF_ADC Control, R0x2C)
- Adjusting the maximum output voltage (V_3, R0x33)

Of these three options, the best way to match the pixel response range to the ADC range is to employ the optional signal attenuation by setting R0x35[15] = 1 for context A. Attenuation provides an optional 0.75x V/V analog gain applied after the programmable gain amplifier controlled by R0x35.

The ADC input reference range can also be adjusted by changing the value of the VREF_ADC Control, R0x2C. Changing the VREF_ADC Control changes the ADC input range according to the values in Table 2. Of the eight possible values for VREF_ADC, 4, 5, and 6 are the only reasonable options to use to help match the pixel output range (usually > 1.0V) to the ADC input range. Seven is not a reasonable setting for the ADC reference voltage because 1.5V is beyond the typical pixel output range and attenuation can more effectively be used to reduce the ADC signal input signal range to close to 1.0V.

Table 2: ADC Reference Settings

VREF_ADC (R0x2C)	ADC Input Range
0	0.71V
1	0.79V
2	0.86V
3	0.93V
4	1.0V
5	1.07V
6	1.14V
7	1.5V

To avoid capturing pixel-to-pixel saturation mismatches, it is best if the output range of the pixel (v_3) is slightly larger (by at least 25mV) than the input range of the ADC.

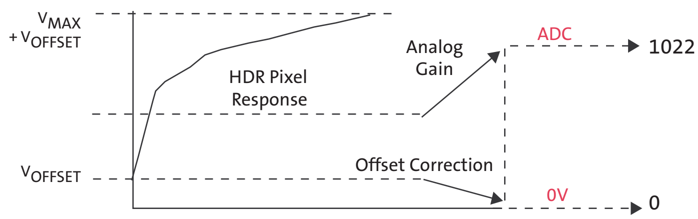
Offset Correction

Offset correction is the first analog process applied to the sampled pixel response output. Achieving a wide dynamic range is impossible if the offset calibration is not properly calibrated. The offset correction parameters should be programmed such that the minimum detectable signal from the pixel produces an output code slightly above zero codes—perhaps with a mean of 6–8 10-bit ADC codes. Failure to properly set the offset correction will result in either loss of low-light signal details (a crushed black level) or a loss of high signal dynamic range. All the pixel response equations used in this technical note assume that an accurate black level correction was applied to the pixel output of the MT9V024.

The offset correction in the MT9V024 has an offset correction DAC that can either be programmed to a manual offset level, or be automatically adjusted by an adjustable black level calibration algorithm. Refer to the MT9V024 image sensor data sheet for further details regarding the black level calibration settings.

Using Analog Gain with High Dynamic Range Mode Enabled

Figure 5: High Dynamic Range Pixel Response



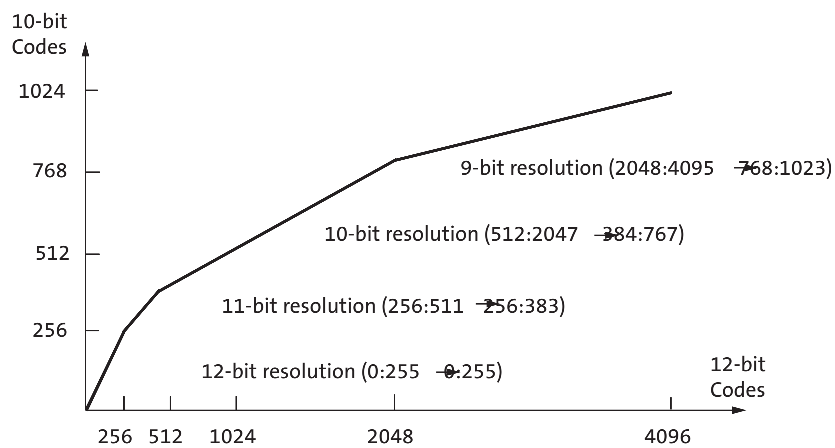
Analog gain is applied to the pixel response after it has been sampled, and therefore does not change the equations that predict the ratios of Slope 1/Slope 2 or Slope 2/Slope 3. But it does directly affect what range of the signal will be quantized by the ADC. When the analog gain is set to anything greater than 1 V/V, and a multi-segment high dynamic range response is still desired, care should be taken to check that knee-points 1 and 2 are still within the quantifiable range of the ADC.

Any analog gain setting of greater than 1 V/V causes a smaller portion of the well capacity of the pixel to be quantized by the ADC, so the loss in dynamic range must be weighed against the gain in sensitivity.

Companding

By default, the MT9V024 ADC has a linear response with 10-bit resolution. The ADC can also be configured to have a 12- to 10-bit companding response as illustrated in Figure 6. This mode allows higher ADC resolution (12-bit) for low level signals (shadow details) and lower ADC resolution (9-bit) for high level signals (highlight details). Companding can be enabled by setting R0x1C bits 1 and 0 for context A (R0x1C = 0x0003) and by setting bits 9 and 8 for context B (R0x1C = 0x0300).

Figure 6: 12 to 10-Bit ADC Companding Response



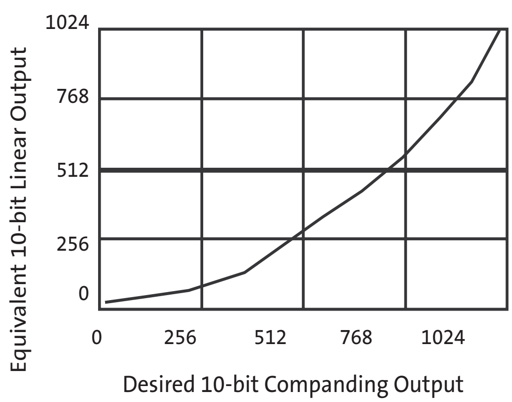
Companding can be effectively used with the high dynamic range mode to enhance shadow detail, but it must be considered when customizing the high dynamic range response curve. Given a desired response curve with ADC companding enabled, the best way to determine the appropriate HDR parameters is to first apply the inverse of the companding response to the desired response. This results in a curve representing the desired response if a linear 10-bit ADC was used. The appropriate high dynamic range parameters can then be selected using the procedure outlined in the section "Using the MT9V024 under Real World Conditions" on page 11.

The inverse of the companding response can be determined as shown in Table 3.

Table 3: Companding Equation

10-Bit Code with Companding Enabled	10-Bit Code with Companding Disabled
0 through 255	Divide by 4
256 through 383	Subtract 128 then divide by 2
384 through 767	Subtract 256
768 through 1023	Subtract 512 then multiply by 2

Figure 7: Companding to Linear Response



Using the MT9V024 under Real World Conditions

Overview

- Examples of real world illumination levels and reflectances:
  This section highlights real world scenes. Figure 8 and Figure 9 show examples of real world scenes which require high dynamic range sensor operation. Figure 10 on page 12 shows a typical sensor response curve that attempts to map real world scenes to the dynamic range of the sensor.
- Discussion of a high dynamic range test setup and illumination level measurements:
  This section covers the requirements for a high dynamic range test setup (see Figure 11 on page 13).
- Outline of adjustment procedures in a logical progression:
  This process is covered in "Customizing HDR Response: MT9V024 Adjustment Procedure" on page 14.

Figure 8: Example of Real World Conditions (Parking Garage at Noon)

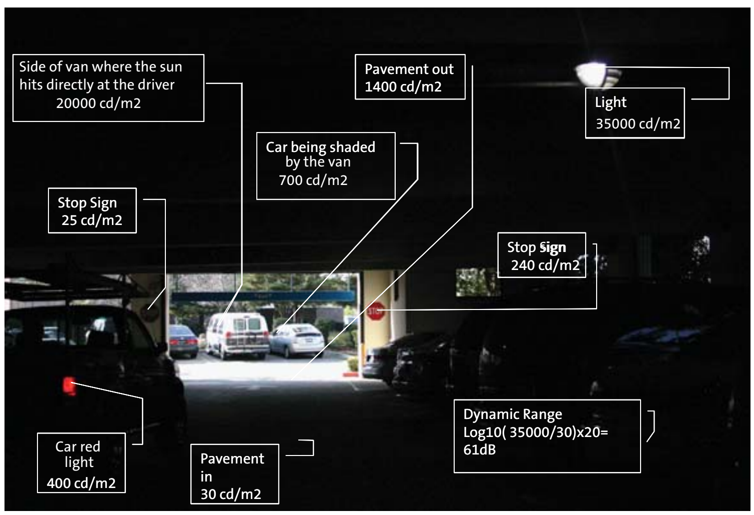


Figure 9: Example of Real World Conditions (Light Rail Station at Night)

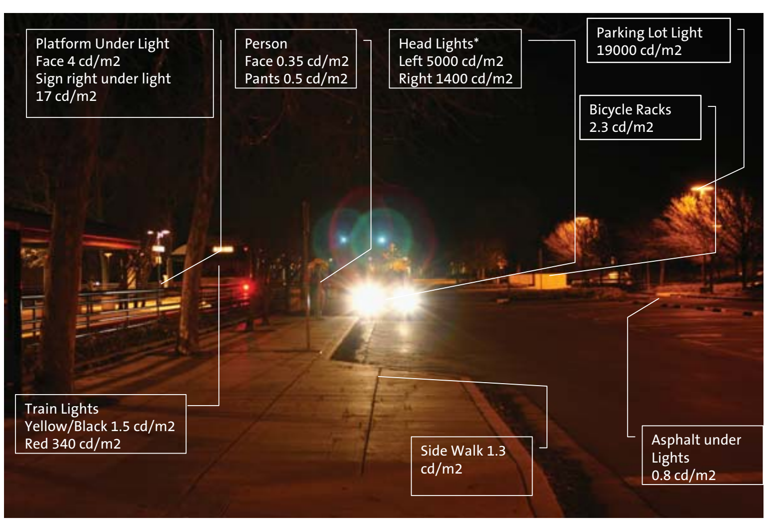
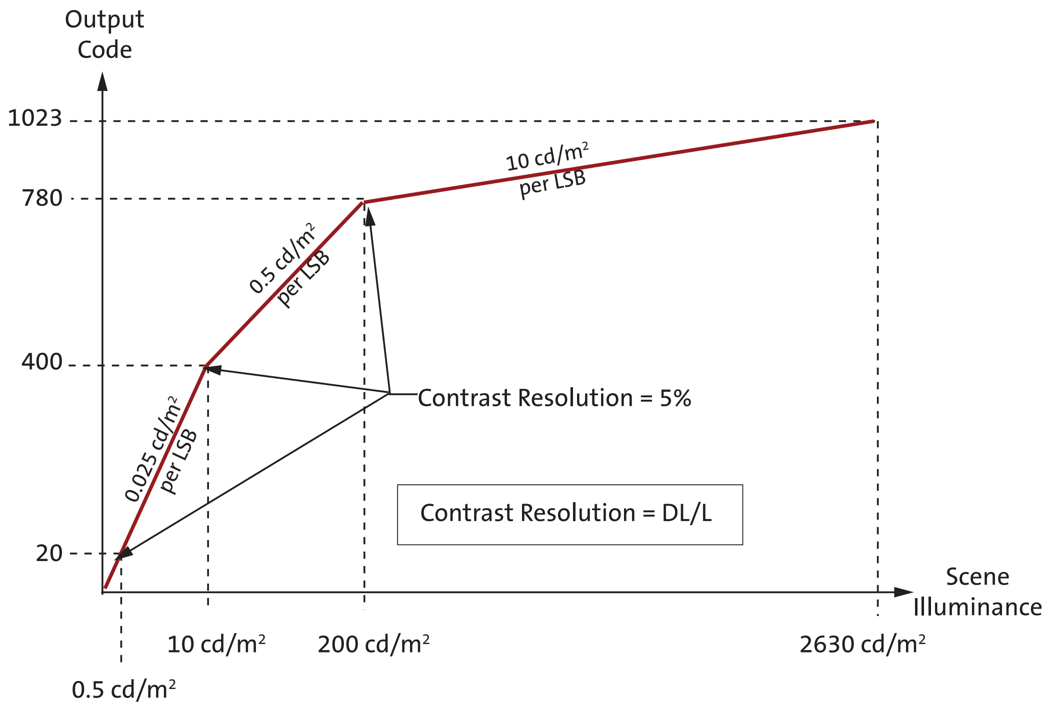


Figure 10: Typical Sensor Response Curve that Maps to Real World Scenes



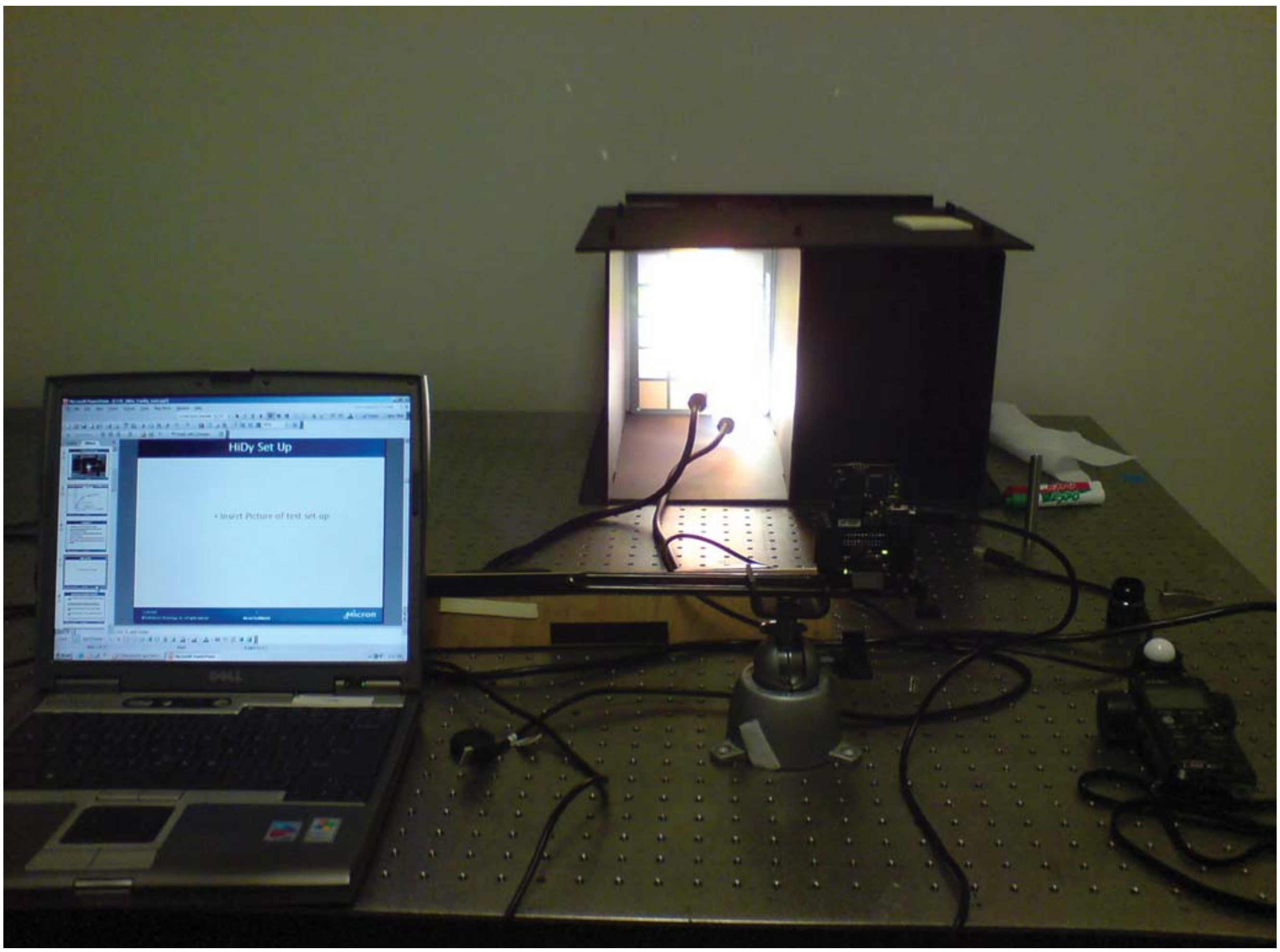
Test Environment to Simulate Real World Conditions

To simulate real world conditions the following equipment is recommended:

- Two Macbeth charts used as reference targets
- High dynamic range light box with divider and two DC halogen, high-intensity lamps
- Combination light and spot meter to measure illumination level and reflectance
- MT9V024, demo kit, and THE LATEST VERSION OF DevWare
- Variable focus and aperture lens with f1.4 aperture setting and IR cut-off filter

A lab environment using this equipment is shown in Figure 11.

Figure 11: Lab Environment to Simulate the Real World



Customizing HDR Response: MT9V024 Adjustment Procedure

Overview of MT9V024 Adjustment Procedure

This section defines the steps that can be used to customize the MT9V024's high dynamic range pixel response. The process involves two sequences. First, coarse adjustments are made to establish overall dynamic range and contrast. Following the coarse adjustments, optional fine adjustments will be used to further increase dynamic range and allow the user to vary the contrasts per slope 2 and 3 as shown in Figure 10 on page 12. Context A will be used in the following sections but the same procedure applies to context B.

Coarse Adjustments (Setting Shutter Width)

1. Adjust illumination range to achieve maximum scene dynamic range and provide illumination in mid-level intensities.
2. Determine two separate linear exposures that provide maximum contrast for both dark and bright target region. A third linear exposure can also be to used to determine the third slope.
3. Apply and activate these linear exposures to the high dynamic range mode.

Fine Adjustments (Setting Contrast Ratio - Optional)

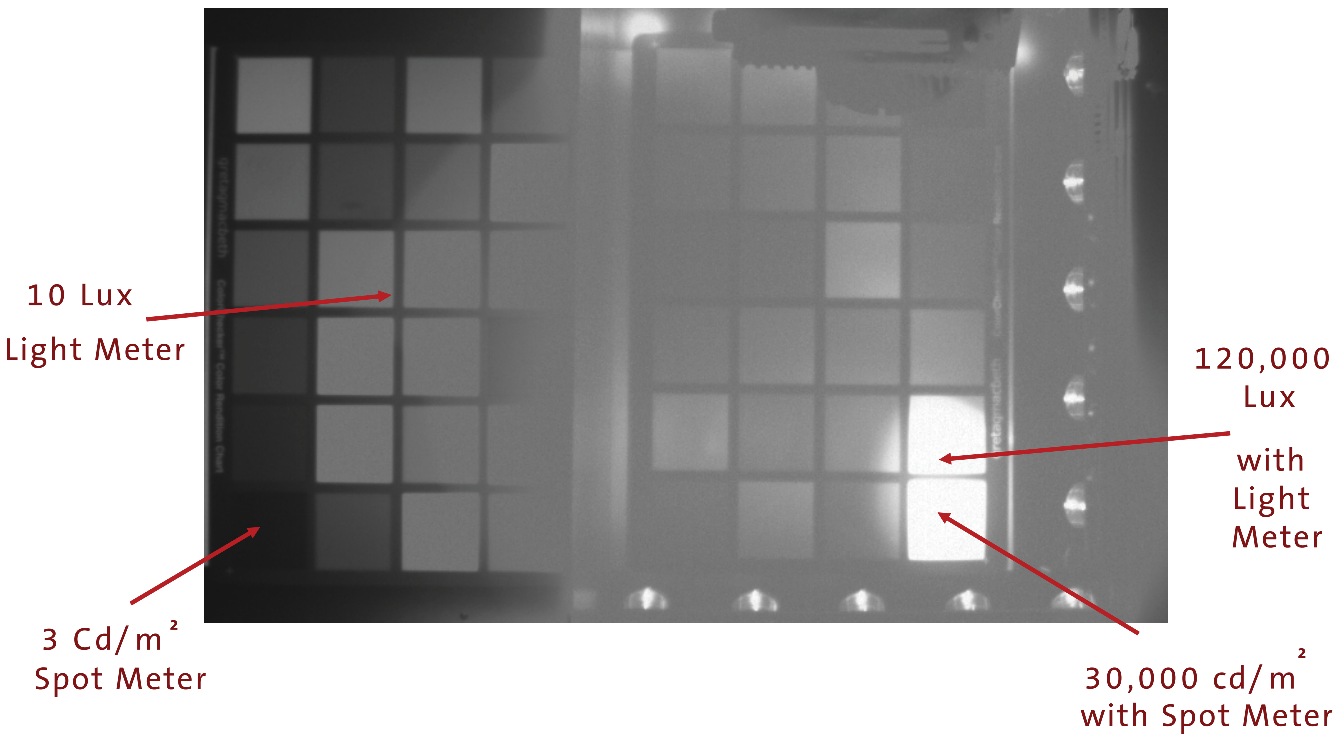
1. Determining equivalent auto knee settings from the coarse shutter widths settings.
2. Adjusting the first knee point vertical position by using V1.
3. Adjusting the second knee point vertical position by using V2.
4. Adjust and verify the black level.
5. Fine shutter width control using registers R0xD3, R0xD4, and R0xD5.

Coarse Adjustment Procedure

Step1: Set Illumination Range

1. Using the light meter, locate the darkest patch on the dark side of the target and adjust the illumination level while reading illumination levels from the meter until you reach the desired level for the darkest patch.
2. Repeat the same procedure for the bright target side but use the brightest patch on the bright target side.
3. These two patches will set the optical dynamic range extremes.
4. Select a mid-level patch on the bright side target and further adjust illumination until a good mid-level intensity is achieved. The following figure is an example a a high dynamic range test setup and illumination and reflectance levels.

Figure 12: Example of High Dynamic Range Image after Step1



Step 2. Determine the Required Total Shutter Width, SW_{TOTAL}

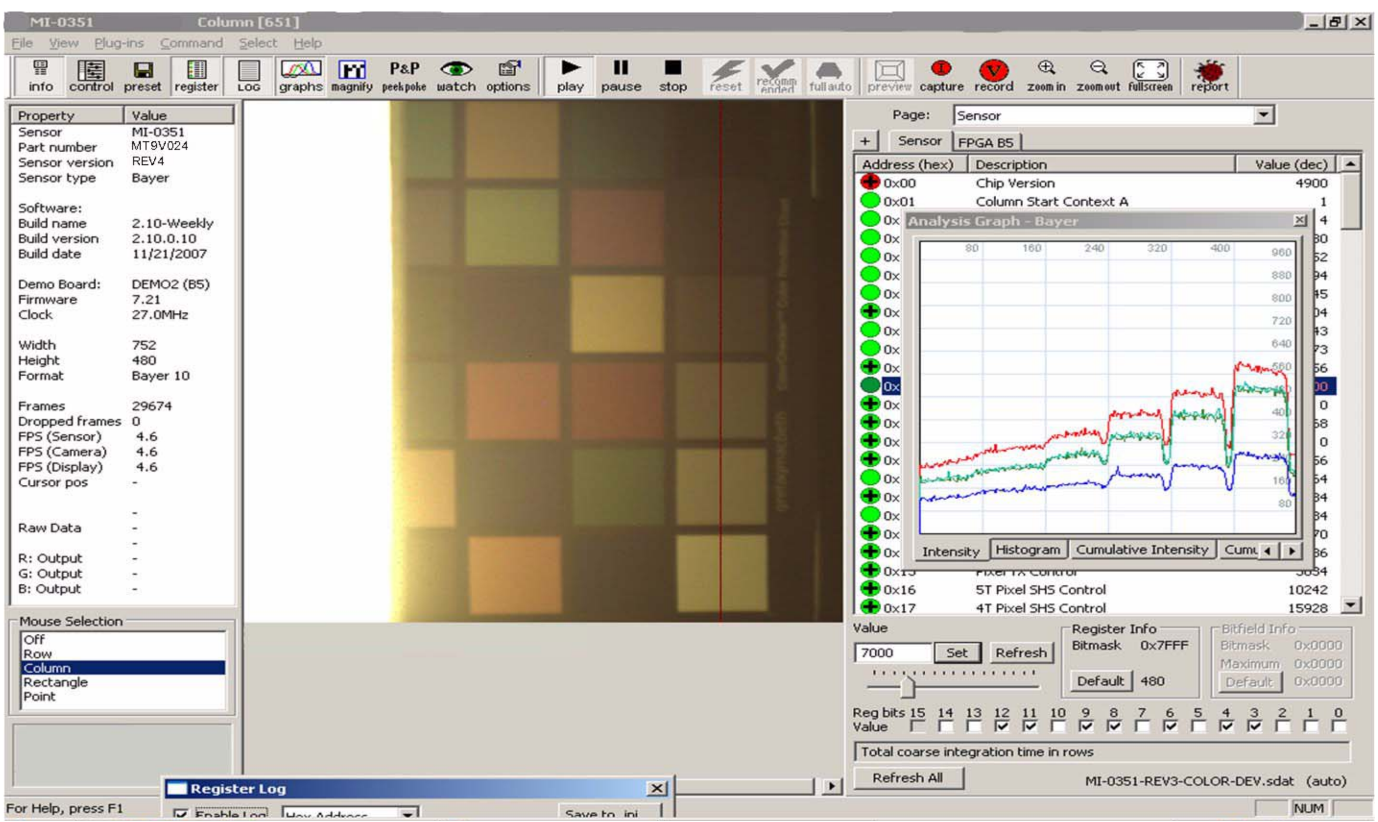
The slope of the first segment of the response curve is dependent on the total integration time and is not affected by any of the other high dynamic range parameters. SW_{TOTAL} should be selected so that the darkest scene details are detectable with the minimum required signal-to-noise ratio. Use DevWare to find this value.

Using DevWare to Set Total Shutter Width

Sequence for setting up linear mode:

1. Open DevWare and load preset linear mode settings with the following exceptions:
   - 1a. Auto exposure/gain register 0xAF: Set to 0x00 – disables auto functions.
   - 1b. Row noise register 0x70: Set to 0x14 – disables row noise correction.
   - 1c. Disable "Subtract True Black Level" – DevWare sensor control window, "Data Interpretation" tab. This turns off DevWare black level processing.
   - 1d. Context A only is used in example but the same process applies for Context B.
2. Select column graph and place column on gray scale target while viewing live video (DevWare: Select Menu -> Row)
3. Select a total shutter width that gives the contrast desired on the dark scene illumination target but still maintains the minimum frame rate requirement.
   - 3a. An approximate 50% contrast range from the whitest to the darkest patch is a good starting point. This shutter width will become the total shutter width value for high dynamic range mode. The resulting linear exposure settings can be seen in Figure 13.

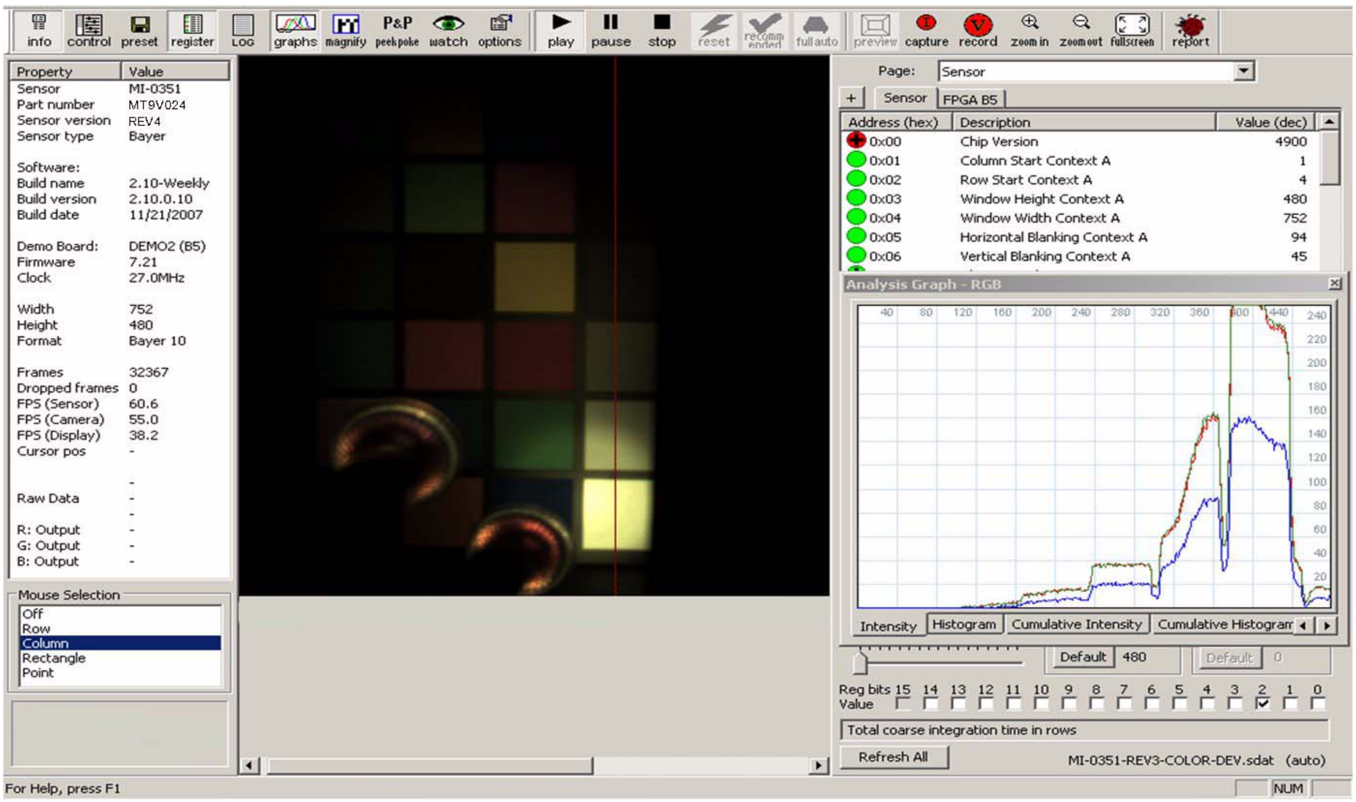
Figure 13: Linear Exposure Settings Using a Dark Target



4. Repeat step 3 for a bright target.

4a. This value subtracted from the total shutter width becomes SW1. Select a register value between SW1 and total shutter width from the dark target for SW2 or select a third linear exposure for the extreme bright region. This exposure subtracted from the total shutter width then becomes SW2. The resulting linear exposure settings can be seen in Figure 14.

Figure 14: Linear Exposure with a Bright Target



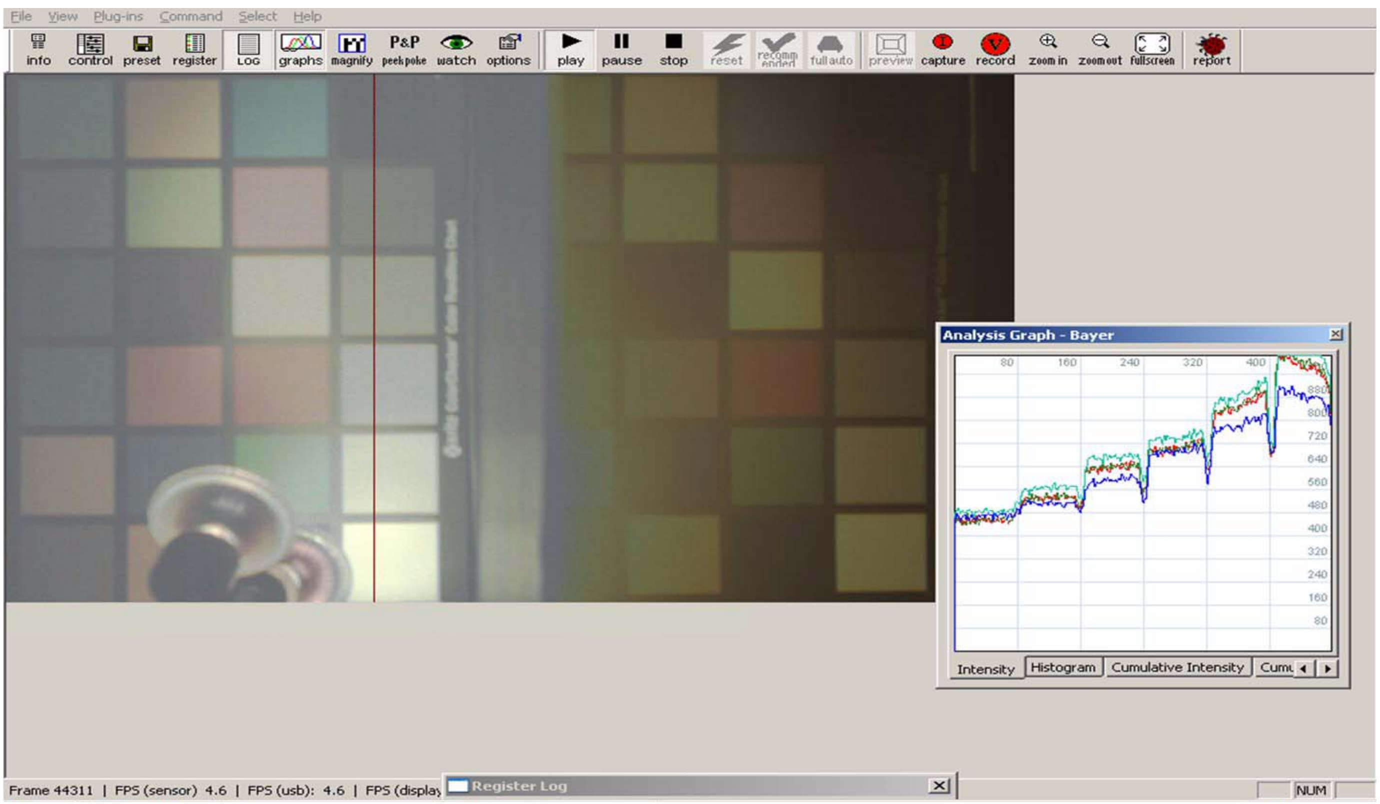
Step 3: Enable High Dynamic Range with Default Values for SW1–SW4 (see Figure 15).

Set the following registers to achieve manual exposure defaults for SW1–SW4:

REG = 0x08, 0x1B40 // COARSE_SHUTTER_WIDTH_1_CONTEXTA
REG = 0x09, 0x1B57 // COARSE_SHUTTER_WIDTH_2_CONTEXTA
REG = 0x0A, 0x0064 // SHUTTER_WIDTH_CONTROL_CONTEXTA
REG = 0x0B, 0x1B58 // COARSE_SHUTTER_WIDTH_TOTAL_CONTEXTA
REG = 0x0F, 0x0101 // PIXEL_OPERATION_MODE
REG = 0x31, 0x0027 // V1_CONTROL_CONTEXTA
REG = 0x32, 0x001A // V2_CONTROL_CONTEXTA
REG = 0x33, 0x0005 // V3_CONTROL_CONTEXTA
REG = 0x34, 0x0003 // V4_CONTROL_CONTEXTA
REG = 0x35, 0x8010 // GLOBAL_GAIN_CONTEXTA_REG

The registers highlighted in red enable high dynamic range mode. The results of these register settings can be seen in Figure 15.

Figure 15: High Dynamic Range with Default Values



Fine Adjustment Procedure (Optional)

Equally as important as dynamic range is the contrast ratio of each slope.

Adjustment of V1–V4 allows the ability of increasing or decreasing the knee point vertical position. An example of varying the knee point voltage and the contrast improvements as compared to default knee point voltage settings is described for the MT9V024 and shown in Figure 16 and Figure 17 on page 21.

Step 1. Auto Knee Adjustment

Using values determined by test setup SW_Total, SW1, and SW2, the resulting values can be applied to Equation 1–Equation 3 on page 3 to determine t1, t2, and t3.

By applying t1, t2, and t3 to Equation 4–Equation 6 on page 3, the appropriate Auto Knee register (0x0B) values can be determined and the image should be comparable to the one achieved with manual settings.

Step 2. Set the First Knee Point Using V_1

The first knee point can be adjusted by setting V_1 (R0x31).

The actual response transition of the MT9V024 from one linear segment to the next is not a sharp knee but a rounded transition. Therefore, one should choose to more accurately control the slope of the segments using SW_1 and SW_2, rather than trying to exactly pinpoint the knee codes.

In the typical case where *ADC_VREF = 1.0V* and attenuation is enabled, the minimum possible code for the first knee is when $V_1 = 31$ and it is dependent on the SW_{TOTAL}: SW_1 ratio.

Step 3. Set the Second Knee Point Using V_2

The second knee point can be adjusted by setting V_2 (R0x32).

If the knee point of transition between the second and the third segment of the response curve must be more accurate than the slope of the third segment, then SW_2 may be adjusted to get a more accurate knee point code at the expense of the accuracy of the third segment slope.

Comparison of Knee Point Defaults versus Modified V1-V4 Registers

```
REG = 0x08, 0x1B40  // COARSE_SHUTTER_WIDTH_1_CONTEXTA
REG = 0x09, 0x1B57  // COARSE_SHUTTER_WIDTH_2_CONTEXTA
REG = 0x0A, 0x0064  // SHUTTER_WIDTH_CONTROL_CONTEXTA
REG = 0x0B, 0x1B58  // COARSE_SHUTTER_WIDTH_TOTAL_CONTEXTA
REG = 0x0F, 0x0101  // PIXEL_OPERATION_MODE
REG = 0x31, 0x0027  // V1_CONTROL_CONTEXTA
REG = 0x32, 0x0012  // V2_CONTROL_CONTEXTA
REG = 0x33, 0x000F  // V3_CONTROL_CONTEXTA
REG = 0x34, 0x0003  // V4_CONTROL_CONTEXTA
REG = 0x35, 0x8010  // GLOBAL_GAIN_CONTEXTA_REG
```

The registers highlighted in red signify changes from the default values for V1–V3. The difference in default versus modified registers can be seen in Figure 16 and Figure 17 on page 21.

Figure 16: High Dynamic Range Enabled, Bright Contrast, Default Values for SW1-SW4

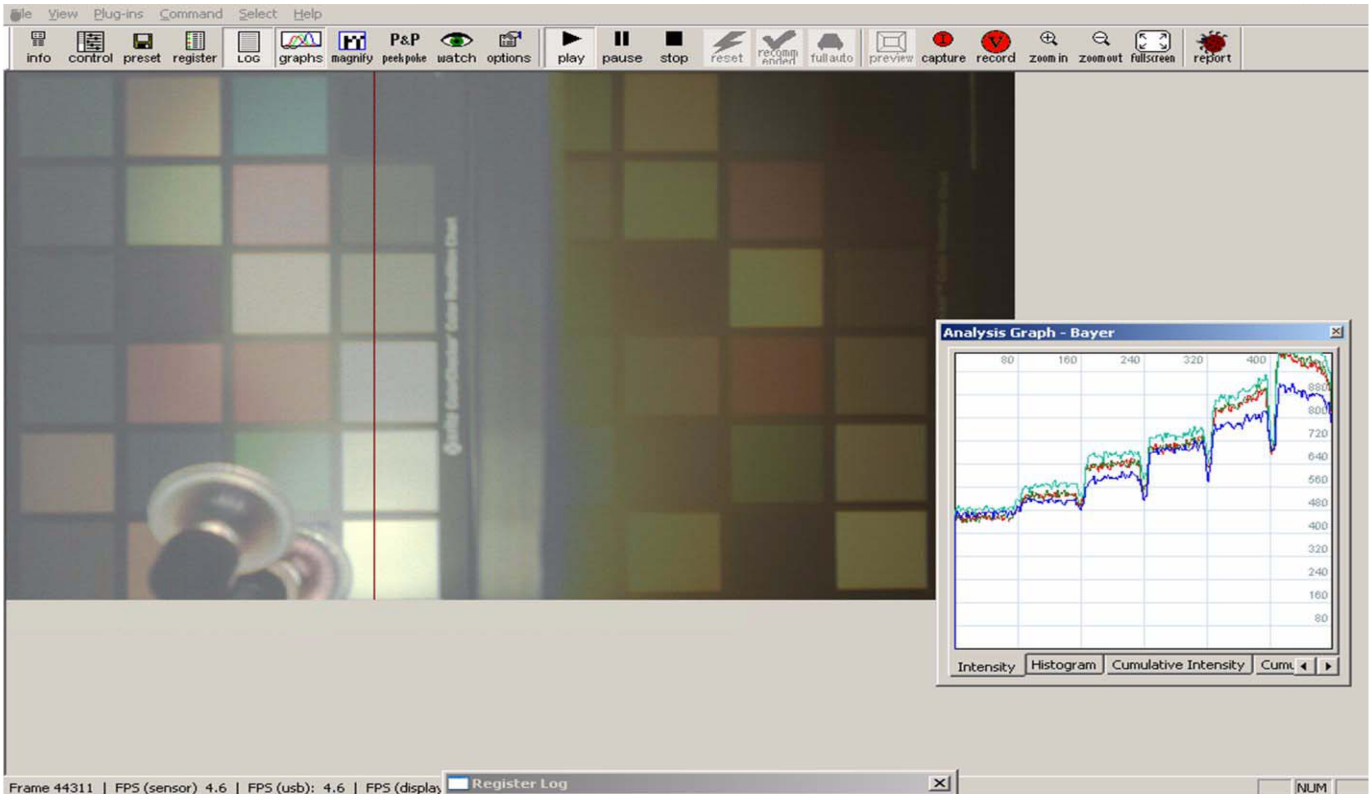
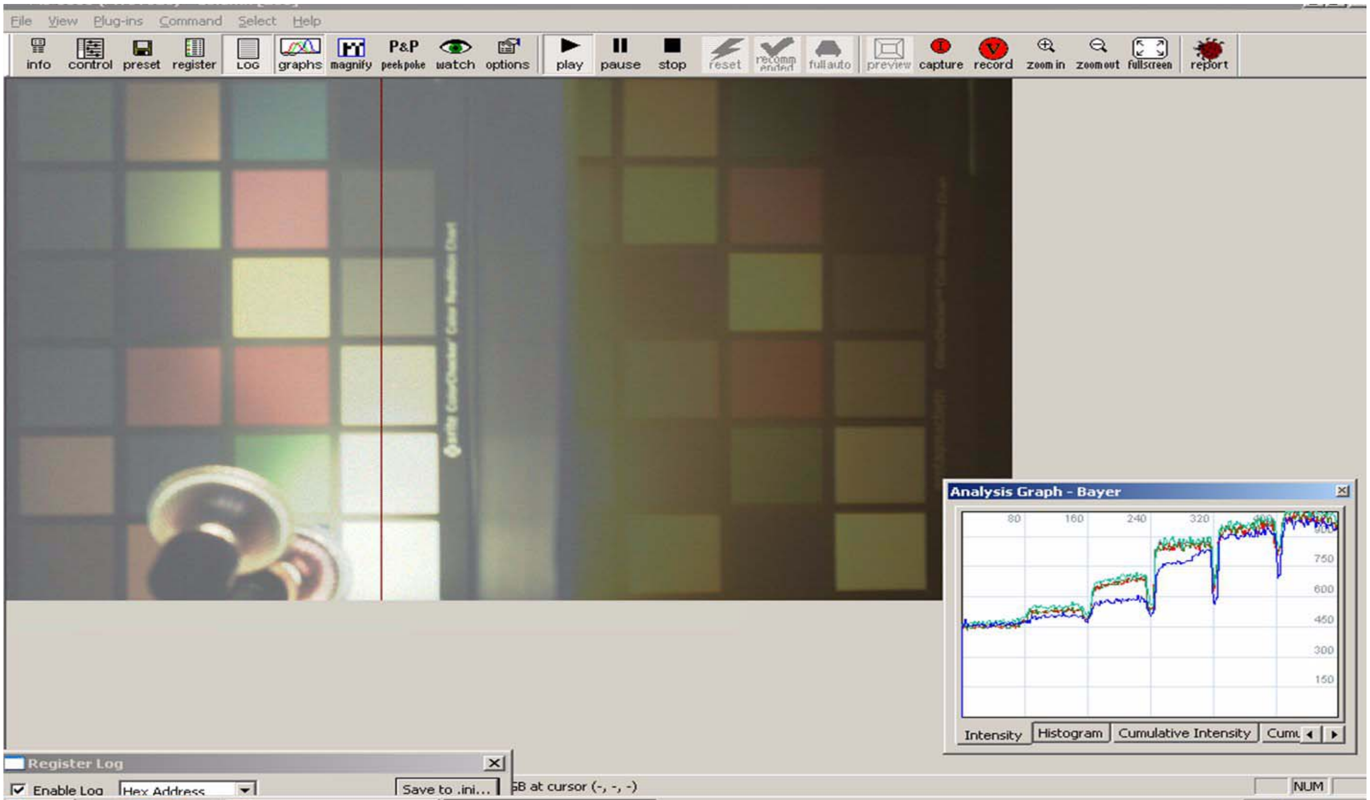


Figure 17: High Dynamic Range Enabled, Bright Contrast, V1-V4 Adjusted



Step 4. Adjust and Verify the Black Level

As mentioned in “Offset Correction” on page 8, accurately adjusting the black level such that the minimum detectable signal from the pixel produces an output code as close to zero as possible without clipping is critical to achieving expected high dynamic range results. The offset correction settings (either manual or automatic) should be optimized with row noise correction disabled (set R0x70[5] = 0) since row noise correction adds an additional post-ADC offset to output data. Figure 5 on page 9 shows a representative high dynamic range curve when the black level has been adjusted.

If the customer is using Aptina's DevWare application, ensure that “Subtract True Black” is disabled from the data interpretation page of the sensor control dialog box.

Step 5: Fine Shutter Width

Fine shutter width control (Fine_SW1, register 0xD3, and Fine_SW2, register 0xD4), can be used in addition to the coarse registers to fine tune the dynamic range curve.

Customizing the HDR Response—Procedure Summary

Table 4: Procedure Summary

Step	Procedure (Coarse Adjustments)
1	Adjust illumination range.
2	Determine the required total shutter width, SW_{TOTAL} (R0x0B).
3	Apply linear exposures to the high dynamic range mode.
Step	**Procedure (Fine Adjustments)**
1	Determine the auto knee settings.
2	Set the First Knee Point Using V_1
3	Set the Second Knee Point Using V_2
4	Adjust and Verify the Black Level
5	Determine fine shutter width

Conclusion

This technical note covers the theory behind the tuning of a sensor for high dynamic range applications and describes procedures to achieve them. It describes how mapping real world illumination values helps determine the best response curve(s) for high dynamic range and contrast for the application's needs. A test setup is described that can simulate real world extremes and is a good starting point for high dynamic range tuning. A process for making coarse adjustments for high dynamic range is provided, which tunes the total shutter width. A fine adjustment process is also provided. This process increases the vertical knee point adjustment range for V1–V4 on the MT9V024, which allows for increasing contrast ratios on the second and third slopes of the response curve. It also discusses the use of manual shutter width controls that can help in determining auto knee variables.

For more information on this and other features, refer to the MT9V024 data sheet on Aptina's Web site at www.aptina.com.

Revision History

Rev. A 6/1/12

- Initial release

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