1/2.5-Inch CMOS Digital Image Sensor

MT9P031 Developer Guide, Rev. A

For the latest data sheet, refer to Aptina's Web site: www.aptina.com

MTP031
Developer Guide

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Introduction

This Developer Guide provides detailed descriptions and usage guidelines for various features of the MT9P031 image sensor. Also provided are guidelines for optimal settings for various use cases. For detailed electrical and timing specifications or register descriptions, refer to the MT9P031 Data Sheet and the MT9P031 Register Reference documents, respectively.

MT9P031 Optimized Register Set

This section provides an optimized register set used in programming the MT9P031 sensor, which includes:

- Configuration of the sensor phase-locked loop (PLL) oscillator to provide a 96 MHz pixel clock.
- Register fix for a color swapping issue seen at 96 MHz.
- Register fix for a blue strip issue appearing in bright lighting.
- Optimized register settings to obtain 14 fps at full resolution.
- Optimized skip and binning mode register settings.

High Frame Rates

By default, the sensor is configured to a resolution of 2592 x 1944 with a pixel clock of 24 MHz. Higher frame rates can be achieved when the clock frequency is increased and the resolution of the image is reduced.

96 MHz Pixel Clock

To configure the MT9P031at 96 MHz, place the sensor in standby mode and set the following to power and configure the PLL:

Register Name	Register Address	Default Value	New Value
PLL Control	0x10	0x0050	0x0051
PLL Config 1	0x11	0x6404	0x1801
PLL Config 2	0x12	0x0000	0x0002

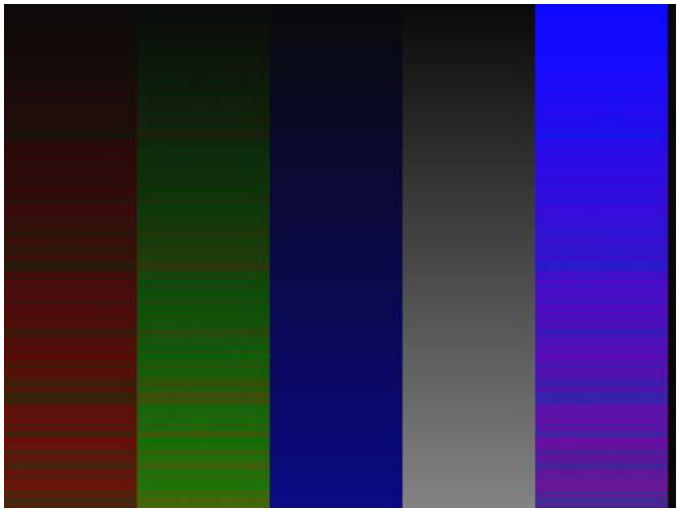
Wait 1ms for the PLL to adjust to the new setting, then enable the PLL by setting R0x010[1:0] to 3.

Register Name	Register Address	Default Value	New Value
PLL Control	0x10	N/A	0x0053

Color Swapping and Resolution

Color swapping can be caused by timing skew when running the sensor at frequencies above 68 MHz; the timing skew can cause a pixel readout to be skipped, leading to the Bayer pattern being flipped.

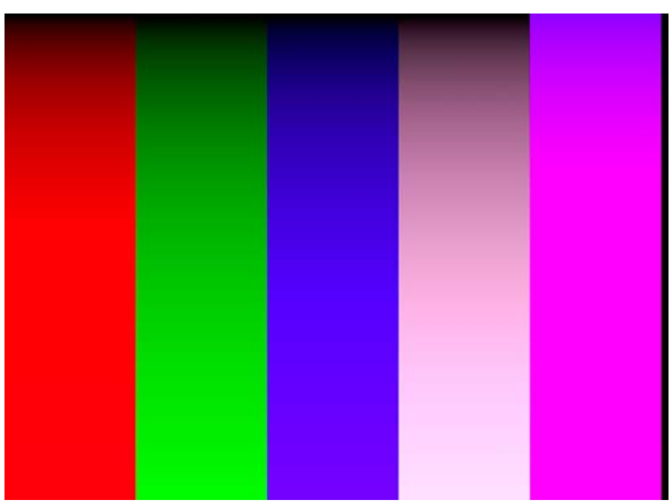
Figure 1: Color Swapping at 96 MHz



To turn on the color bar test pattern, change register 0xA0 to 0x41. To resolve the color swapping, a FIFO in the parallel interface is enabled and the horizontal blanking is set to a minimum of 450. The output data will be seen at 72 MHz as it extends into the horizontal blanking period. The internal sensor will still be running at 96 MHz and the sensor frame rate will not be decreased.

Register Name	Register Address	Default Value	New Value
Horizontal Blanking	0x05	0x0000	0x01C2
Output Control	0x07	0x1F82	0x1F8E

Figure 2: Normal Color Bar



Blue Strip and Resolution

A blue strip is often seen when a bright light is directed to the bottom or top of the sensor array, as shown in Figure 3. This effect can be mitigated effectively by setting R0x7F to 0x0000. This register change does not affect the imaging performance of the sensor.

Figure 3: Examples of R0x7F set to 0x0000

Before **After**

Vertical Blanking Update

There is a timing problem such that increasing Vertical Blank (R0x06) may result in image output halting. The workaround solution is to perform a restart command (R0xB[0]) at the end of Frame Valid whenever vertical blank is changed.

Frame Rate and Resolution Register Settings

In order to run the MT9P031 in the following resolutions and frame rates, select the matching presets in Devware or change the registers according to the following tables.

[1080P 30FPS INCREASED VERTICAL BLANKING]

//SETTINGS FOR 1080P WITH 30 FPS. ROLLING SHUTTER ARTIFACT REDUCED BY 12%.

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 431//ROW WINDOW START

REG=0, 0x02, 335// COL WINDOW START

REG=0, 0x03, 1079// ROW_WINDOW_SIZE_REG

REG=0, 0x04, 1919// COL_WINDOW_SIZE_REG

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0091// VERT_BLANK_REG=145

REG=0, 0x08, 0x0000// SHUTTER_WIDTH_HI

REG=0, 0x09, 0x01AC// INTEG_TIME_REG

REG=0, 0x0C, 0x0000// SHUTTER_DELAY_REG

REG=0, 0x22, 0x0000// ROW_MODE

REG=0, 0x23, 0x0000// COL_MODE

LOAD = Rolling Artifact Optimization

[**1080P 30FPS INCREASED FOV BY 12%**]

//SETTINGS FOR 1080P WITH SHORTER ROW TIME BUT INCREASED FIELD OF VIEW. ROLLING SHUTTER ARTIFACT REDUCED BY 6%

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 401//ROW WINDOW START

REG=0, 0x02, 281// COL WINDOW START

REG=0, 0x03, 1141// ROW_WINDOW_SIZE_REG

REG=0, 0x04, 2029// COL_WINDOW_SIZE_REG

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0000// VERT BLANK 0

REG=0, 0x08, 0x0000// SHUTTER_WIDTH_HI

REG=0, 0x09, 0x01AC// INTEG_TIME_REG

REG=0, 0x0C, 0x0000// SHUTTER_DELAY_REG

REG=0, 0x22, 0x0000// ROW_MODE

REG=0, 0x23, 0x0000// COL_MODE

LOAD = Rolling Artifact Optimization

[**1080P 34FPS**]

//SETTINGS FOR 1080P WITH SHORTER ROW TIME AND FASTER FRAME RATE

//ROLLING SHUTTER ARTIFACT REDUCED BY 12%.

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 431//ROW WINDOW START

REG=0, 0x02, 335// COL WINDOW START

REG=0, 0x03, 1079// ROW_WINDOW_SIZE_REG

REG=0, 0x04, 1919// COL_WINDOW_SIZE_REG

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0000// VERT BLANK 0

REG=0, 0x08, 0x0000// SHUTTER_WIDTH_HI

REG=0, 0x09, 0x01AC// INTEG_TIME_REG

REG=0, 0x0C, 0x0000// SHUTTER_DELAY_REG

REG=0, 0x22, 0x0000// ROW_MODE

REG=0, 0x23, 0x0000// COL_MODE

LOAD = Rolling Artifact Optimization

[1080P 30FPS]

//DEFAULT SETTINGS FOR 1080P

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 431//ROW WINDOW START

REG=0, 0x02, 335// COL WINDOW START

REG=0, 0x03, 1079// ROW_WINDOW_SIZE_REG

REG=0, 0x04, 1919// COL_WINDOW_SIZE_REG

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0000// VERT BLANK 0

REG=0, 0x08, 0x0000// SHUTTER_WIDTH_HI

REG=0, 0x09, 0x01AC// INTEG_TIME_REG

REG=0, 0x0C, 0x0000// SHUTTER_DELAY_REG

REG=0, 0x22, 0x0000// ROW_MODE

REG=0, 0x23, 0x0000// COL_MODE

REG=0, 0x06, 0x0037// VERT_BLANK_REG has been adjusted to give precisely 30fps

REG=0, 0x05, 0x0000// HORZ_BLANK_REG

[720P 30FPS LONG VERTICAL BLANKING]

//RUNS AT HALF THE NORMAL SPEED BUT ROLLING ARTIFACT IS SAME AS DEFAULT 60FPS

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 0x0040// ROW_WINDOW_START_REG

REG=0, 0x02, 0x0018// COL_WINDOW_START_REG

REG=0, 0x03, 0x059F // ROW_WINDOW_SIZE_REG=1439

REG=0, 0x04, 0x09FF // COL_WINDOW_SIZE_REG=2559

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x02D0 // VERT_BLANK_REG=720

REG=0, 0x09, 0x0400 // INTEG_TIME_REG=1024

REG=0, 0x22, 0x0011 // ROW_MODE, ROW_SKIP=1. ROW_BIN=1

REG=0, 0x23, 0x0011 // COL_MODE, COL_SKIP=1, COL_BIN=1

REG=0, 0x20, 0x0060 // READ_MODE_2, COL_SUM

REG=0, 0x08, 0x0000//(1) SHUTTER_WIDTH_HI

REG=0, 0x09, 0x0296//(1) INTEG_TIME_REG

REG=0, 0x0C, 0x0000//(1) SHUTTER_DELAY_REG

LOAD = Subsample Optimization

[720P 30FPS]

//RUNS 30FPS 720P WITH LONGER INTEGRATION TIME AND SETTINGS WHICH ARE ALREADY BEST-CASE SCENARIO FOR ROLLING SHUTTER ARTIFACT

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 0x0040// ROW_WINDOW_START_REG

REG=0, 0x02, 0x0018// COL_WINDOW_START_REG

REG=0, 0x03, 0x059F // ROW_WINDOW_SIZE_REG=1439

REG=0, 0x04, 0x09FF // COL_WINDOW_SIZE_REG=2559

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0000// VERT BLANK 0

REG=0, 0x09, 0x0400 // INTEG_TIME_REG=1024

REG=0, 0x22, 0x0011 // ROW_MODE, ROW_SKIP=1. ROW_BIN=1

REG=0, 0x23, 0x0011 // COL_MODE, COL_SKIP=1, COL_BIN=1

REG=0, 0x20, 0x0060 // READ_MODE_2, COL_SUM

REG=0, 0x08, 0x0000//(1) SHUTTER_WIDTH_HI

REG=0, 0x09, 0x05AF//(1) INTEG_TIME_REG

REG=0, 0x0C, 0x0000//(1) SHUTTER_DELAY_REG

LOAD = Subsample Optimization

[720P 60FPS]

//RUNS THE DEFAULT 60FPS 720P SETTINGS WHICH ARE ALREADY BEST-CASE SCENARIO FOR ROLLING SHUTTER ARTIFACT

LOAD = Reset

LOAD = 96MHz + Devware Bayer Offset

REG=0, 0x01, 0x0040// ROW_WINDOW_START_REG

REG=0, 0x02, 0x0018// COL_WINDOW_START_REG

REG=0, 0x03, 0x059F // ROW_WINDOW_SIZE_REG=1439

REG=0, 0x04, 0x09FF // COL_WINDOW_SIZE_REG=2559

REG=0, 0x05, 0x0000// HORZ BLANK 0

REG=0, 0x06, 0x0000// VERT BLANK 0

REG=0, 0x09, 0x0400 // INTEG_TIME_REG=1024

REG=0, 0x22, 0x0011 // ROW_MODE, ROW_SKIP=1. ROW_BIN=1

REG=0, 0x23, 0x0011 // COL_MODE, COL_SKIP=1, COL_BIN=1

REG=0, 0x20, 0x0060 // READ_MODE_2, COL_SUM

REG=0, 0x08, 0x0000//(1) SHUTTER_WIDTH_HI

REG=0, 0x09, 0x0296//(1) INTEG_TIME_REG

REG=0, 0x0C, 0x0000//(1) SHUTTER_DELAY_REG

LOAD = Subsample Optimization

[**640x480 resolution,bin4x**]

REG=0, 0x03, 0x0778//(10) ROW_WINDOW_SIZE_REG

REG=0, 0x04, 0x09F8//(7) COL_WINDOW_SIZE_REG

REG=0, 0x08, 0x0000//(6) SHUTTER_WIDTH_HI

REG=0, 0x09, 0x01AC//(6) INTEG_TIME_REG

REG=0, 0x0C, 0x0000//(6) SHUTTER_DELAY_REG

REG=0, 0x22, 0x0033//(2) ROW_MODE - SKip Bin registers (00->1xbin, 11->2xbin, 33->4xbin)

REG=0, 0x23, 0x0033//(3) COL_MODE - SKip Bin registers (00->1xbin, 11->2xbin, 33->4xbin)

REG=0, 0x08, 0x0000//(1) SHUTTER_WIDTH_HI

REG=0, 0x09, 0x0296//(1) INTEG_TIME_REG

REG=0, 0x0C, 0x0000//(1) SHUTTER_DELAY_REG

LOAD = Subsample Optimization

Global Reset Release Snapshot

This section provides instructions for switching between modes with Aptina's MT9P031 sensor. It briefly describes the global reset release snapshot (GRRS) mode and provides instructions for:

- Entering preview mode
- Switching to global reset release snapshot (GRRS) mode
- Returning to preview mode

Global Reset Release Snapshot Mode

The GRRS mode eliminates the shearing effect that often accompanies an electronic rolling shutter (ERS) by starting all of the rows' exposures at the same time. Instead of the first scan used in ERS mode, the reset to each row is released simultaneously. The second scan occurs as normal, so the exposure time for each row is different. Typically, an external mechanical shutter would be used to stop the exposure of all rows simultaneously. In default mode, the sensor continuously samples and outputs full resolution frames. However, in snapshot or triggered mode, the sensor samples and outputs a frame only when triggered. To leave snapshot mode, it is necessary to first clear the snapshot register field, then issue a RESTART.

Enter Preview Mode (VGA Resolution)

To place the MT9P031 sensor into preview mode:

1. Ensure that TRIGGER is set to "1" (HIGH).
2. Set R0x22 to 0x0033 to enable row bin/skip 4x.
3. Set R0x23 to 0x0033 to enable column bin/skip 4x.
4. Set R0x0B to 0x0001 to restart the sensor.

Switch to GRRS Mode

Before entering GRRS mode, it is necessary to set reserved register R0x30 to 1. Upon exiting GRRS mode, return R0x30 to default value 0. To take a GRR snapshot in full resolution:

1. Set R0x1E to 0x4186. This will enable the global reset and the snapshot mode. To also enable the Strobe signal (for example, when using mechanical shutter) set R0x1E to 0x4196 instead.
2. Put the sensor in full resolution:
   2a. Set R0x22 to 0x0000 to enable row bin/skip 1x.
   2b. Set R0x23 to 0x0000 to enable column bin/skip 1x.
3. Wait 1ms.
4. Trigger the next frame:
   4a. Set TRIGGER to "0" (LOW).
   4b. Wait for 200ns.
   4c. Set TRIGGER to "1" (HIGH).

Return to Preview Mode

To return the sensor to preview mode:

1. Set R0x1E to 0x4006 to enable continuous mode.
2. Set R0x22 to 0x0033 to enable column bin/skip 4x.
3. Set R0x23 to 0x0033 to enable column bin/skip 4x.

4. Set R0x0B to 0x0001 to restart the sensor.

Figure 4: GRR Snapshot

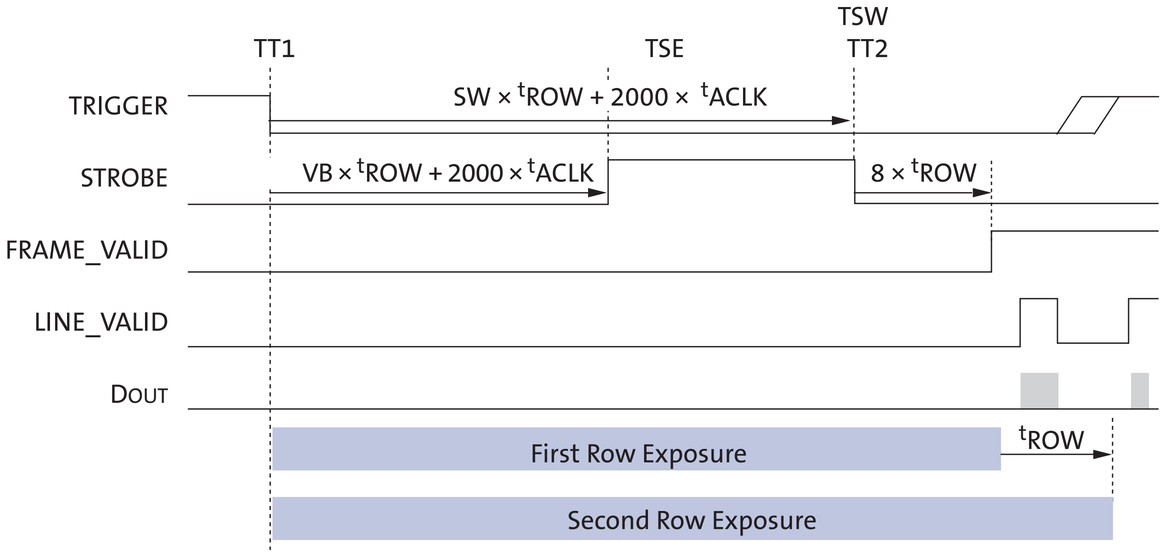


Image Acquisition Modes

The MT9P031 supports two image acquisition modes (Shutter Types) (see "Operating Modes" on page 15), electronic rolling shutter and global reset release.

Electronic Rolling Shutter Exposure

The ERS modes take pictures by scanning the rows of the sensor twice. On the first scan, each row is released from reset, starting the exposure. On the second scan, the row is sampled, processed, and returned to the reset state. The exposure for any row is therefore the time between the first and second scans. Each row is exposed for the same duration, but at slightly different point in time, which can cause a shear in moving subjects.

Whenever the mode is changed to an ERS mode (even from another ERS mode), and before the first frame following reset, there is an anti-blooming sequence where all rows are placed in reset. This sequence must complete before continuous readout begins. This delay is:

$^{t}ALLRESET = 16 \times 2004 \times {}^{t}ACLK$

The nominal exposure time, ^{t}EXP, is the effective shutter time in ERS modes, and is defined by the shutter width, SW, and the shutter overhead, SO, which includes the effect of Shutter_Delay. Exposure time for other modes is defined relative to this time. Increasing Shutter_Delay (SD) decreases the exposure time. Exposure times are typically specified in units of row time, although it is possible to fine-tune exposures in units of $^{t}ACLKs$ (where $^{t}ACLK$ is 2 * $^{t}PIXCLK$).

$^{t}EXP = SW \times {}^{t}ROW - SO \times 2 \times {}^{t}PIXCLK$

where:

$SW = \max(1, (2 * 16 \times Shutter\_Width\_Upper) + Shutter\_Width\_Lower)$

$SO = 208 \times (Row\_Bin + 1) + 98 + \min(SD, SDmax) - 94$

$SD = Shutter\_Delay + 1$

$SDmax = 1232;\quad \text{if } SW < 3$

$\qquad\qquad 1504, \text{ otherwise}$

The exposure time is calculated by determining the reset time of each pixel row (with time 0 being the start of the first row time), and subtracting it from the sample time. Under normal conditions in ERS modes, every pixel should end up with the same exposure time. In global shutter release modes, or in row binning modes, the exposure times of individual pixels can vary.

Global Shutter Exposure

In global shutter release modes, exposure time starts simultaneously for all rows, but still ends as defined above. In a real system, the exposure would be stopped by a mechanical shutter, which would effectively stop the exposure to all rows simultaneously. Each output row's exposure time will differ by ^{t}ROW from the previous row because this specification does not consider the effect of an external shutter .

Global shutter modes also introduce a constant added to the shutter time for each row, because the exposure starts during the global shutter sequence, and not during any row's shutter sequence. For each additional row in a row bin, this offset will increase by the length of the shutter sequence.

In Bulb_Exposure modes (see details in Table 1), the exposure time is determined by the width of the TRIGGER pulse rather than the shutter width registers. In ERS bulb mode, it is still a multiple of row times, and the shutter overhead equation still applies. In GRR bulb mode, the exposure time is granular to ACLKs, and shutter overhead (and thus Shutter_Delay) has no effect.

The GRR modes attempt to address the shearing effect by starting all rows' exposures at the same time. Instead of the first scan used in ERS mode, the reset to each row is released simultaneously. The second scan occurs as normal, so the exposure time for each row would different. Typically, an external mechanical shutter would be used to stop the exposure of all rows simultaneously.

In GRR modes, there is a startup overhead before each frame as all rows are initially placed in the reset state (^{t}ALLRESET). Unlike ERS mode, this delay always occurs before each frame. However, it occurs as soon as possible after the preceding frame, so typically the time from trigger to the start of exposure does not include this delay. To ensure that this is the case, the first trigger must occur no sooner than ^{t}ALLRESET after the previous frame is read out.

Operating Modes

In default operating mode, the MT9P031continuously samples and outputs frames. It can be put in "snapshot" or triggered mode by setting snapshot, which means that it samples and outputs a frame only when triggered. To leave snapshot mode, it is necessary to first clear Snapshot then issue a restart.

When in snapshot mode, the sensor can use the ERS or the GRR. The exposure can be controlled as normal, with the Shutter_Width_Lower and Shutter_Width_Upper registers, or it can be controlled using the external TRIGGER signal. The various operating modes are summarized in Table 1.

Table 1: Operating Modes

Mode	Settings	Description
ERS Continuous	Default	Frames are output continuously at the frame rate defined by ^{t}FRAME. ERS is used, and the exposure time is electronically controlled to be ^{t}EXP.
ERS Snapshot	Snapshot = 1	Frames are output one at a time, with each frame initiated by a trigger. ERS is used, and the exposure time is electronically controlled to be ^{t}EXP.
ERS Bulb	Snapshot = 1; Bulb_Exposure = 1	Frames are output one at a time, with each frame's exposure initiated by a trigger. ERS is used. End of exposure and readout are initiated by a second trigger.
GRR Snapshot	Snapshot = 1; Global_Reset = 1	Frames are output one at a time, with each frame initiated by a trigger. GRR is used. Readout is electronically triggered based on SW.
GRR Bulb	Snapshot = 1; Bulb_Exposure = 1; Global_Reset = 1	Frames are output one at a time, with each frame initiated by a trigger. GRR is used. Readout is initiated by a second trigger.

Note: In ERS bulb mode, SW must be greater than 4 (use trigger wider than ^{t}ROW * 4).

All operating modes share a common set of operations:

1. Wait for the first trigger, then start the exposure.
2. Wait for the second trigger, then start the readout.

The first trigger is by default automatic, producing continuous images. If snapshot is set, the first trigger can either be a low level on the TRIGGER pin or writing a "1" to the trigger register field. If Invert_Trigger is set, the first trigger is a high level on TRIGGER pin or a "1" written to trigger register field. Because TRIGGER is level-sensitive, multiple frames can be output (with a frame rate of ^{t}FRAME) by holding TRIGGER pin at the triggering level.

The second trigger is also normally automatic, and generally occurs SW row times after the exposure is started. If Bulb_Exposure is set, the second trigger can either be a high level on TRIGGER or a write to Restart. If Invert_Trigger is set, the second trigger is a low level on TRIGGER (or a Restart). In bulb modes, the minimum possible exposure time depends on the mechanical shutter used.

After one frame has been output, the chip will reset step 1, above, eventually waiting for the first trigger again. The next trigger may be issued after ((VB - 8) x ^{t}ROW) in ERS modes or ^{t}ALLREST in GRR modes.

The choice of shutter type is made by Global_Reset. If it is set, the GRR shutter is used; otherwise, ERS is used.

The default ERS continuous mode is shown in Figure 5. Figure 5 shows default signal timing for ERS snapshot modes, while Figure 6 on page 17 shows default signal timing for GRR snapshot modes.

Figure 5: ERS Snapshot Timing

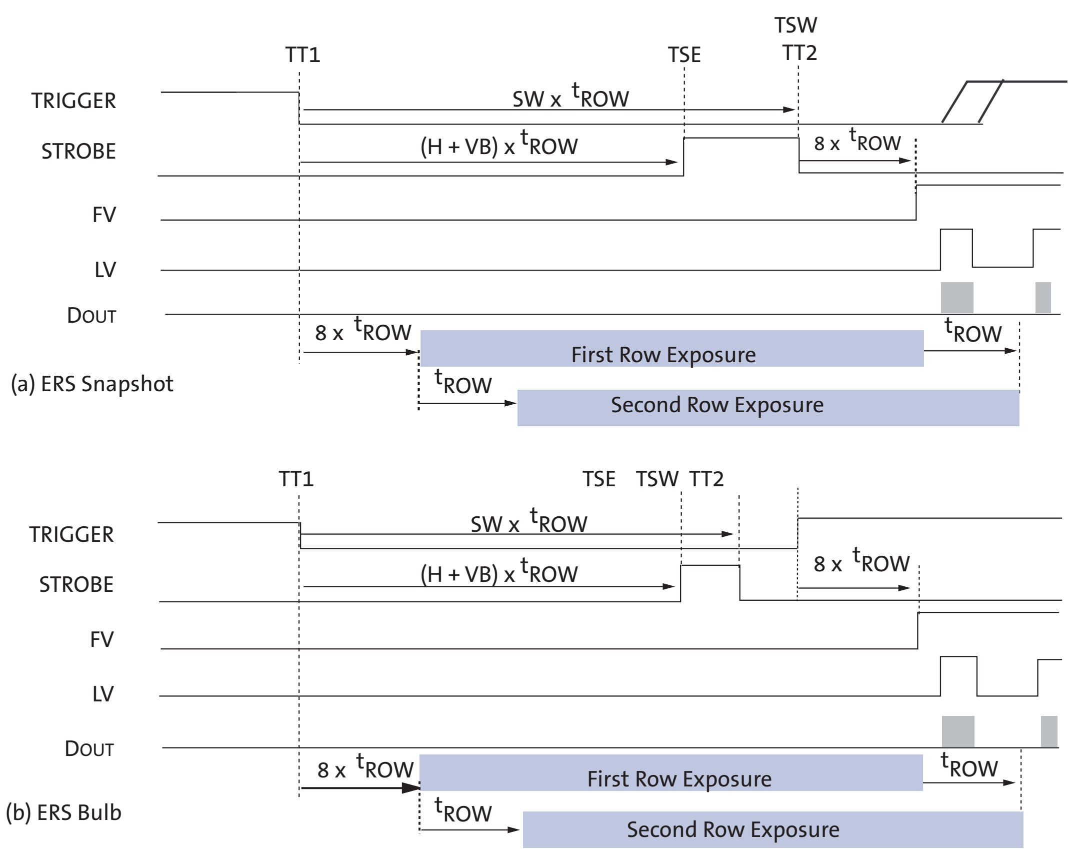
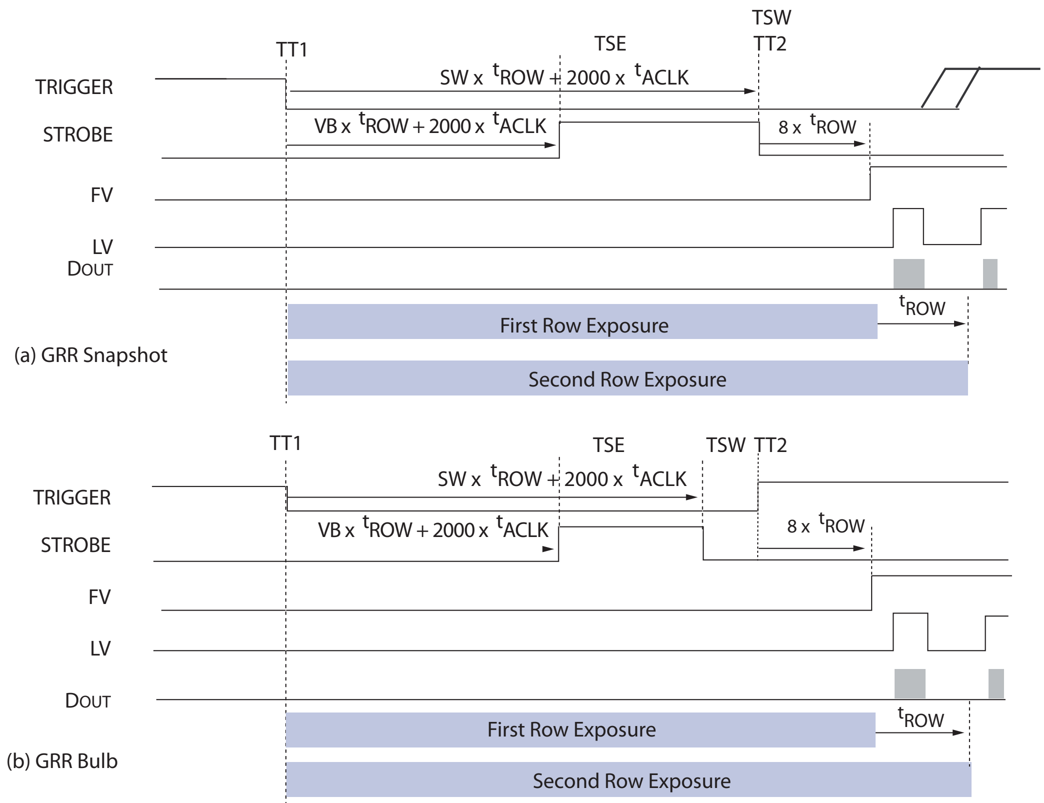


Figure 6: GRR Snapshot Timing



Strobe Control

To support synchronization of the exposure with external events such as a flash or mechanical shutter, the MT9P031 produces a STROBE output. By default, this signal is asserted for approximately the time that all rows are simultaneously exposing, minus the vertical blanking time, as shown in Figure 5 on page 16 and Figure 6. Also indicated in these figures are the leading and trailing edges of STROBE, which an be configured to occur at one of several timepoints. The leading edge of STROBE occurs at STROBE_Start, and the trailing edge at STROBE_End, which are set to codes described in Table 2.

Table 2: STROBE Timepoints

Symbol	Timepoint	Code
TT1	Trigger 1 (start of shutter scan)	–
TSE	Start of exposure (all rows simultaneously exposing) offset by VB	1
TSW	End of shutter width (expiration of the internal shutter width counter)	2
TT2	Trigger 2 (start of readout scan)	3

If STROBE_Start and STROBE_End are set to the same timepoint, the strobe is a ^{t}ROW wide pulse starting at the STROBE_Start timepoint. If the settings are such that the strobe would occur after the trailing edge of FV, the strobe may be only ^{t}ACKL wide; however, because there is no concept of a row at that time. The sense of the STROBE signal can be inverted by setting Invert_Strobe (R0x1E[5] = 1). To use strobe as a flash in snapshot modes or with mechanical shutter, set the Strobe_Enable register bit field R0x1E[4] = 1.

Maintaining a Constant Frame Rate

Often it is desirable to maintain a constant frame rate while still having the ability to adjust certain parameters. This is not always possible, however, since register updates are synchronized to the read pointer and the shutter pointer for a frame is usually active during the readout of the previous frame. Therefore, any register changes that could affect the row time or the set of rows sampled will cause the shutter pointer to start over at the beginning of the next frame. The following register fields will cause a "bubble" in the output rate (that is, the vertical blank will increase for one frame) if they are written in continuous mode, even if the new values would not change the resulting frame rate:

- Row_start
- Row_size
- Column_Size
- Horizontal_blank
- Vertical_blank
- Shutter_delay
- Mirror_row
- Row_bin
- Row_skip
- Column_skip

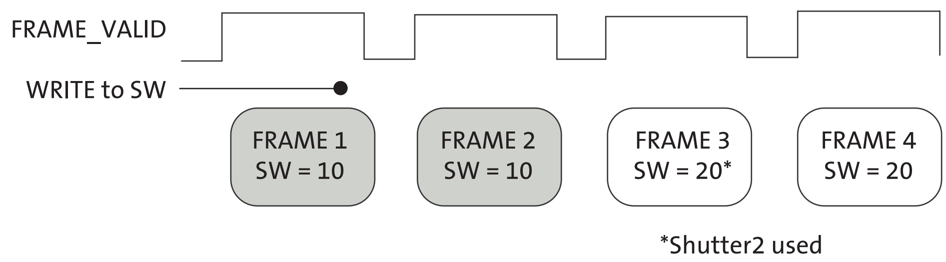
The size of this bubble is (Shutter_Width × tROW), calculating the row time according to the new settings.

The Shutter_Width_Lower and Shutter_Width_Upper fields may be written without causing a bubble in the output rate under certain circumstances. Since the shutter sequence for the next frame often is active during the output of the current frame, this would not be possible without special provisions in the hardware. Writes to these registers take effect two frames after the frame they are written, which allows the shutter width to increase without interrupting the output or producing a corrupt frame (so long as the change in shutter width does not affect the frame time).

Figure 2 shows the timing of WRITEs to the shutter width registers in ERS continuous mode (in snapshot modes, shutter width changes generally take effect immediately). In the example, the shutter width is changed from 10 to 20 during Frame 1. The effective shutter width of Frame 3 is smaller than that of Frame 4, since Frame 3 was exposed using Shutter2 and Frame 4 was exposed using Shutter1. This difference is tsh2, as defined in Equation 1:

$$ {}^{t}sh2 = \begin{cases} (\text{Shutter\_Sequence\_Length} + 1) \times 2) \times {}^{t}aclk & \text{if R0x1E[14] = 0} \\ 3 \times {}^{t}aclk & \text{otherwise} \end{cases} \qquad \text{(EQ 1)} $$

Figure 7: Writing Shutter Width Registers



Readout Modes

Subsampling

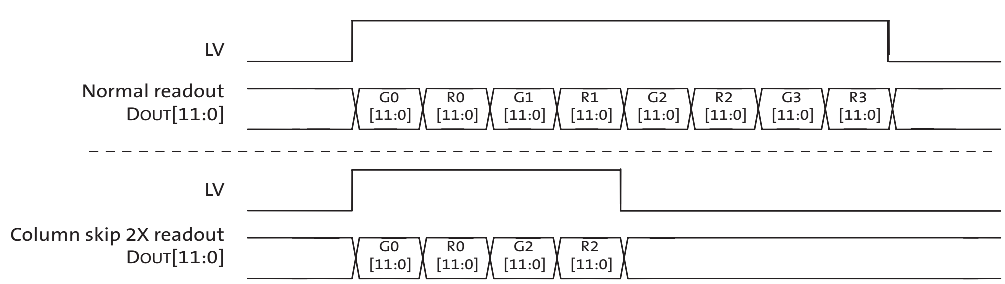
By default, the resolution of the output image is the full width and height of the FOV. The output resolution can be reduced by three methods: Binning, Skipping and Cropping.

Row and column skip modes use subsampling to reduce the output resolution without reducing FOV. The MT9P031 also has row and column binning modes, which can reduce the impact of aliasing introduced by the use of skip modes. This is achieved by the averaging of 2 or 3 adjacent rows and columns (adjacent same-color pixels). Both 2X and 4X binning modes are supported. Rows and columns can be binned independently.

Skipping

Skipping reduces resolution by using only selected pixels from the FOV in the output image. In skip mode, entire rows and columns of pixels are not sampled, resulting in a lower resolution output image. A skip 2X mode skips one Bayer pair of pixels for every pair output. Skip 3X skips two pairs for each one pair output. Rows and columns are always read out in pairs. If skip 2X mode is enabled with otherwise default sensor settings, the columns in the output image correspond to the pixel array columns 16, 17, 20, 21, 24, 25... .

Figure 8: Eight Pixels in Normal and Column Skip 2X Readout Modes



Skipping can be enabled separately for rows and columns. To enable skip mode, set either or both of Row_Skip and Column_Skip to the number of pixel pairs that should be skipped for each pair used in the output image. For example, to set column skip 2X mode, set Column_Skip to “1.”

The size of the output image is reduced by the skip mode as shown in the following two equations:

$$W = 2 \times \text{ceil}((\text{Column\_Size} + 1)\ /\ (2 \times (\text{Column\_Skip} + 1)))$$

$$H = 2 \times \text{ceil}((\text{Row\_Size} + 1)\ /\ (2 \times (\text{Row\_Skip} + 1)))$$

Figure 9: Pixel Readout (no skipping)

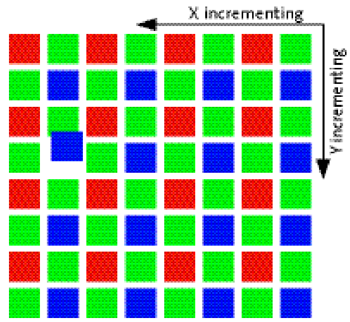


Figure 10: Pixel Readout (Column Skip 2X)

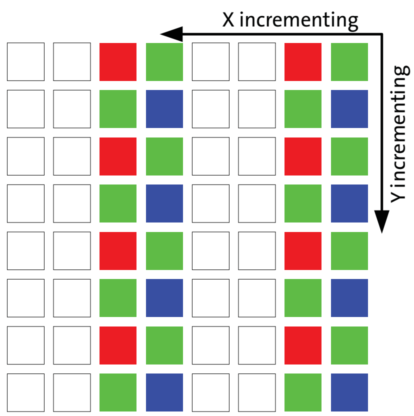


Figure 11: Pixel Readout (Row Skip 2X)

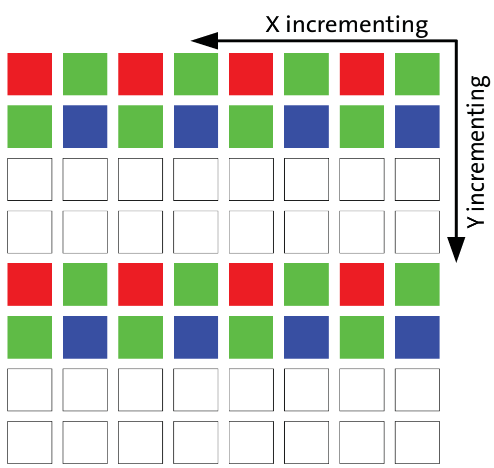
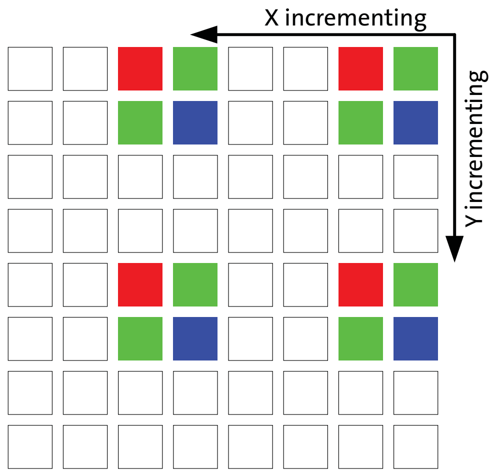


Figure 12: Pixel Readout (Column Skip 2X, Row Skip 2X)



Binning

Binning reduces resolution by combining adjacent same-color imager pixels to produce one output pixel. All of the pixels in the FOV contribute to the output image in bin mode. This can result in a more pleasing output image with reduced subsampling artifacts. It also improves low-light performance. For columns, the combination step can be either an averaging or summing operation. Depending on lighting conditions, one or the other may be desirable. In low-light conditions, summing produces a gain roughly equivalent to the column bin factor. Column summing may be enabled by setting Column_Sum.

Binning works in conjunction with skipping. Pixels that would be skipped because of the Column_Skip and Row_Skip settings can be averaged instead by setting Column_Bin and Row_Bin to the number of neighbor pixels to be averaged with each output pixel. For example, to set bin 2x mode, set Column_Skip and Column_Bin to 1. Additionally, Column_Start must be a multiple of (2 * (Column_Bin + 1)) and Row_Start must be a multiple of (2 * (Row_Bin + 1)).

Only certain combinations of binning and skipping are allowed.

These are shown in Table 3. If an illegal skip value is selected for a bin mode, a legal value is selected instead.

Table 3: Legal Values for Column_Skip Based on Column_Bin

Column_Bin	Legal Values for Column_Skip
0 (no binning)	0, 1, 2, 3, 4, 5, 6
1 (Bin 2x)	1, 3, 5
3 (Bin 4x)	3

Note: Ensure that Column_Start (R0x02) is set in the form shown below, where n is an integer:

	Mirror Column = 0	Mirror Column = 1
no bin	4n	4n + 2
Bin 2x	8n	8n + 4
Bin 4x	16n	16n + 8

Bin mode is illustrated in Figure 13 and Figure 14.

Figure 13: Pixel Readout (Column Bin 2X)

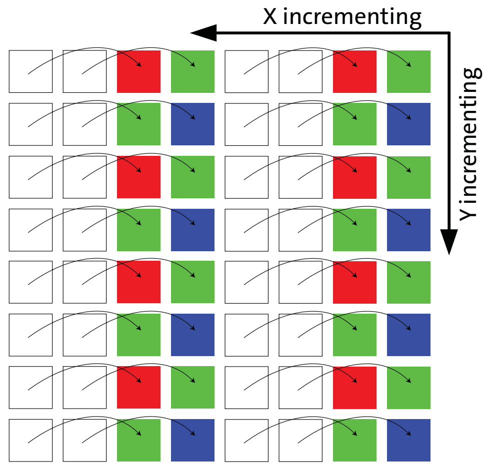
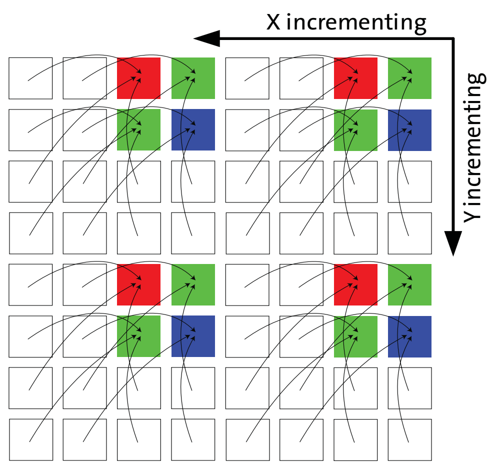


Figure 14: Pixel Readout (Column Bin 2X, Row Bin 2X)



Cropping

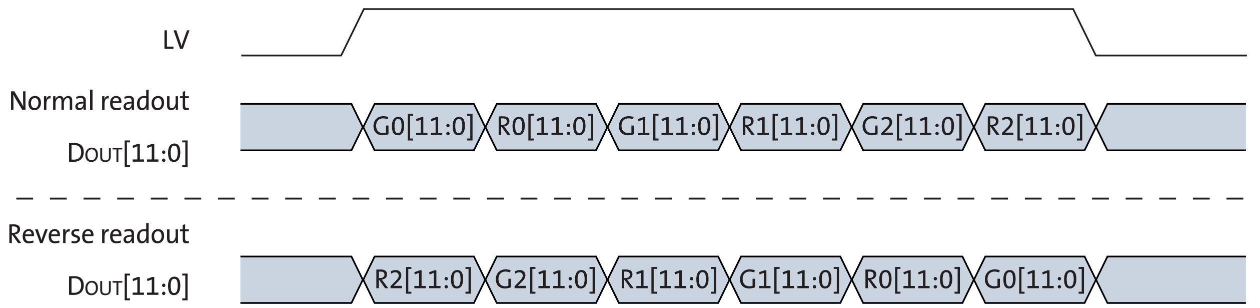
The field of view and output image size can be reduced by reducing the values of two registers. The height of the output can be reduced by changing register 0x03, ROW_WINDOW_SIZE_REG. The width of of the output can be reduced by changing register 0x04, COL_WINDOW_SIZE_REG. Unlike binning and skipping, cropping will not maintain the same field of view as the full resolution output.

Mirror

Column Mirror Image

By setting R0x20[14] = 1, the readout order of the columns is reversed, as shown in Figure 15. The starting color, thus Bayer pattern, is preserved when mirroring the columns.

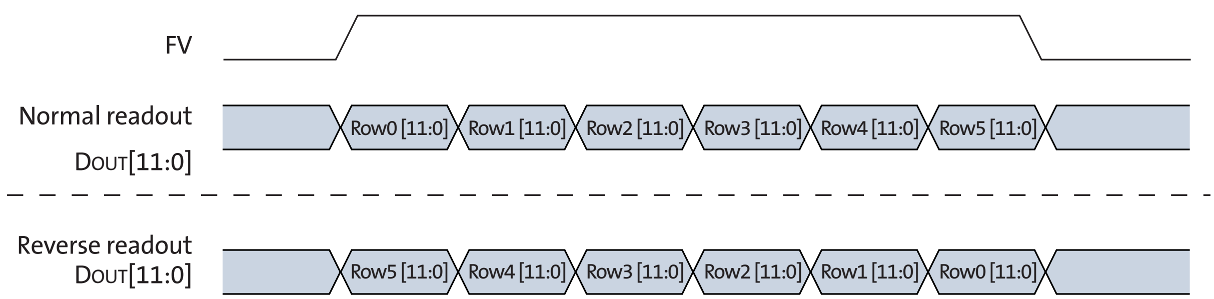
Figure 15: Six Pixels in Normal and Column Mirror Readout Modes



Row Mirror Image

By setting R0x20[15] = 1, the readout order of the rows is reversed as shown in Figure 16. The starting color, thus Bayer pattern, is preserved when mirroring the rows.

Figure 16: Six Rows in Normal and Row Mirror Readout Modes



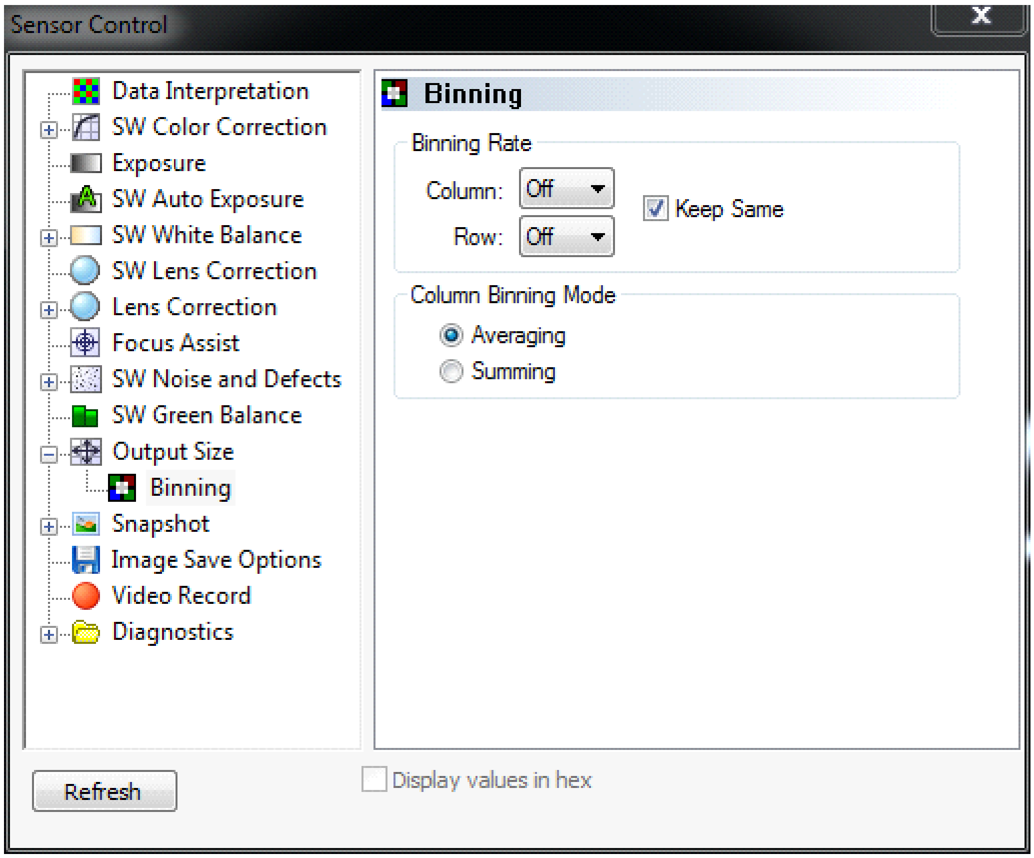
By default, active pixels in the resulting image are output in row-major order (an entire row is output before the next row is begun), from lowest row/column number to highest. If desired, the output (and sampling) order of the rows and columns can be reversed. This affects only pixels in the active region defined above, not any pixels read out as dark rows or dark columns. When the readout direction is reversed, the color order is reversed as well (red, green, red, and so on, instead of green, red, green, and so on, for example).

If row binning is combined with row mirroring, the binning is still done in the positive direction. Therefore, if the first output row in bin 2x + row mirror was 1997, pixels on rows 1997 and 1999 would be averaged together. The next pixel output would be from rows 1996 and 1998, followed by the average of 1993 and 1995.

For column mirroring plus binning, the span of pixels used should be the same as with non-mirror mode.

To use the binning function in DevWare, expand "Output Size" from Sensor Control and select Binning.

Figure 17: Binning Options



As seen in Figure 17, DevWare allows either 2:1 or 4:1 binning rate on both row and column. The binning can be either an averaging or a summing operation. By checking the "Keep Same" checkbox, the aspect ratio of the output image will be maintained.

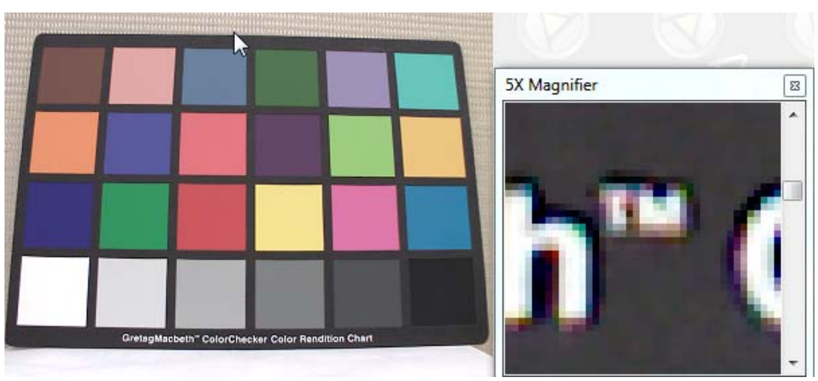
Figure 18: Original Image

Figure 19: Row Binning, 2:1

Figure 20: Column Binning, 4:1

Figure 19 and Figure 20 illustrate row binning and column binning respectively, without keeping the same aspect ratio.

Figure 21: Row and Column Binning at 2:1

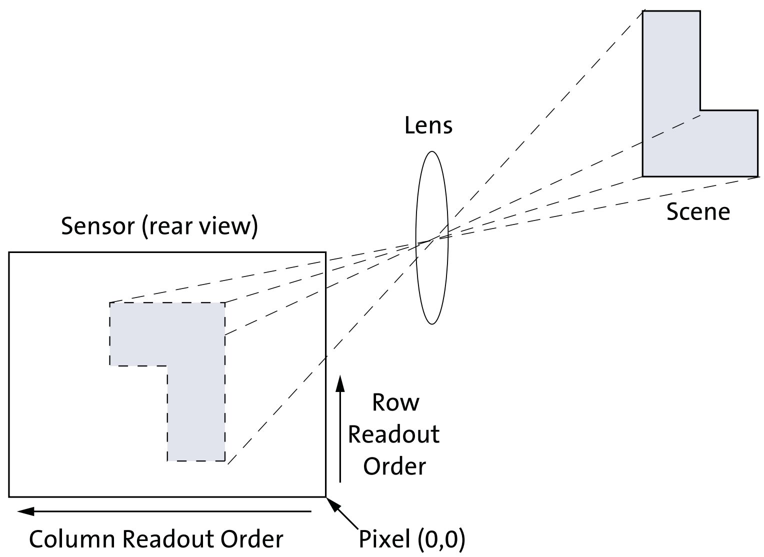


Note that when using binning by averaging, even though the resolution decreases, there is an improvement in noise performance.

Lens, Microlens, and CRA

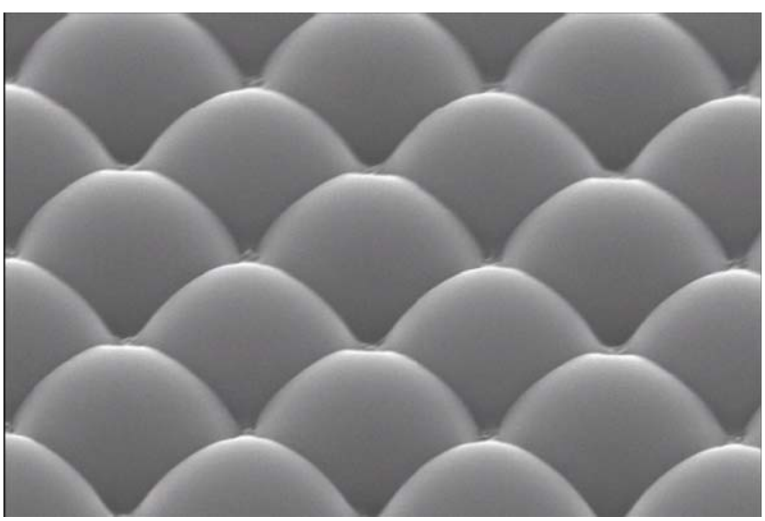
Typical CMOS sensors will have a small lens that will focus light on the sensor. This lens is called a mini-lens. The mini-lens should be symmetric, centered with the optical center of the sensor array, and parallel to the sensor. Because of the fine geometry of the sensor array, a slight mismatch due to module assembly tolerance will severely affect image quality.

Figure 22: Camera Module Optics



The sensor has micro lens above the color filter array. Figure 23 shows a microscopic photo of a typical micro lens.

Figure 23: Typical Micro Lens Surface Microscopic Image



The micro lens of the sensor is shifted (based on the position within the image array) to accommodate different incident angles of incoming light. The lens shading correction compensates for non-uniform light intensities over the sensor array due to lens characteristics and module assembly tolerance; however, overly compensating at the edges will amplify the noise as well as the desired image. For accurate color fidelity as well as minimum noise or mosaic artifact, the chief ray angle (CRA) characteristics of the camera module mini-lens must be within ± 2 degrees of the sensor's micro lens shift throughout the whole image array. This tolerance includes the spec mismatch between the CRA of the mini-lens and the micro lens shift plus any mechanical inaccuracies such as misalignment of center axis and mini-lens tilt. Refer to the MT9P031 data sheet for CRA plot.

Figure 24 illustrates the incoming light entering the micro lens at an angle then converging to the photodiode.

Figure 24: Micro Lens Shift

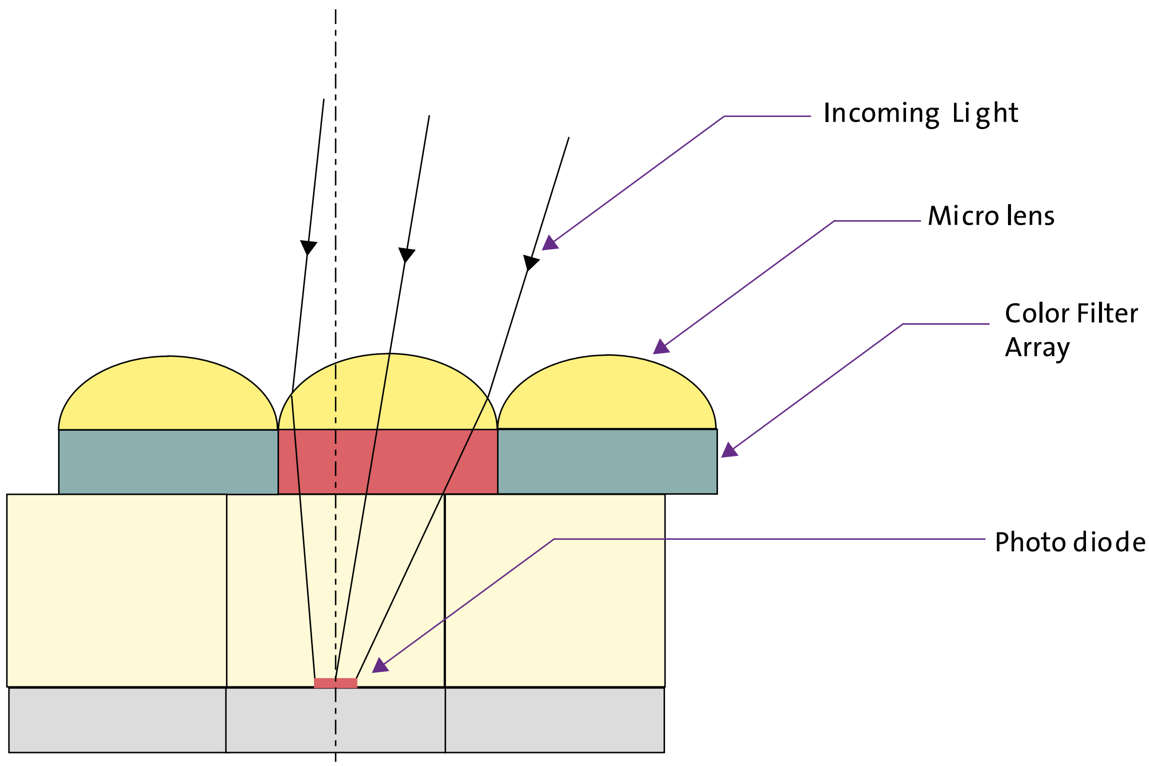
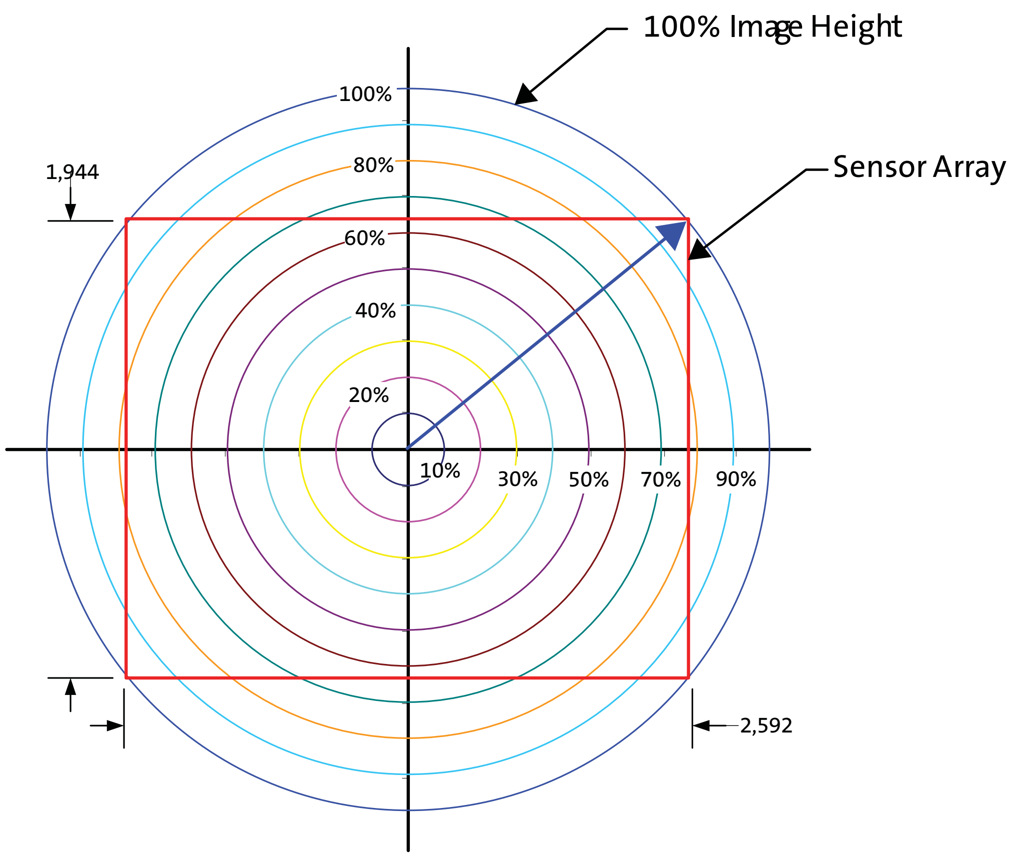


Image Height

The maximum image height is defined to be the distance from the center of the sensor array to one of the corners, as illustrated in Figure 25.

For MT9P031, half of the diagonal distance of 2592 x 1944 active sensor array is approximately 3.5065mm, which is defined to be the 100 percent image height.

Figure 25: Sensor Array and Image Height



CRA Mismatch

Image quality is affected by mismatch between mini-lens CRA and micro lens shift.

There are several sources of mismatch:
- CRA curve spec difference
- Mini-lens center offset
- Mini-lens tilt

Black Level Calibration

Analog Black Level Calibration

The MT9P031 black level calibration circuitry provides a feedback control system since adjustments to the analog offset are imprecise by nature. The goal is that within the dark row region of any supported output image size, the offset should have been adjusted such that the average black level falls within the specified target thresholds.

The analog offsets normally need a major adjustment only when leaving the Reset state or when there has been a change to a color's analog gain. Factors like shutter width and temperature have lower-order impact, and generally only require a minor adjustment to the analog offsets. The MT9P031 has various calibration modes to keep the system stable while still supporting the need for rapid offset adjustments when necessary.

The two basic steps of black level calibration are:

1. Take a sample.
2. If necessary, adjust the analog offset.

Black level calibration is normally done separately for each color channel, and different channels can use different sample or adjustment methods at the same time. However, because both Green1 and Green2 pixels go through the same signal chain, and Red and Blue pixels likewise go through the same signal chain, it is expected that the chosen offset for these pairs should be the same as long as the gains are the same. If Lock_Green_Calibration is set, and (Green1_Analog_Gain = Green2_Analog_Gain) and (Green1_Analog_Multiplier = Green2_Analog_Multiplier), the calculated or user-specified Green1_Offset is used for both green channels. Similarly, if Lock_Red/Blue_Calibration is set, and (Red_Analog_Gain = Blue_Analog_Gain) and (Red_Analog_Multiplier = Blue_Analog_Multiplier), the calculated or user-specified Red_Offset is used for both the red and blue channels.

The current values of the offsets can be read from the Green1_Offset, Red_Offset, Blue_Offset, and Green2_Offset registers. Writes to these registers when Manual_BLC is set change the offsets being used. In automatic BLC mode, writes to these registers are effective when manual mode is re-entered. In Manual_BLC mode, no sampling or adjusting takes place for any color.

Digital Black Level Calibration

Digital black level calibration is the final calculation applied to pixel data before it is output. It provides a precise black level to complement the coarser-grained analog black level calibration, and also corrects for black level shift introduced by digital gain. This correction applies to the active columns for all rows, including dark rows.

Image Acquisition Modes

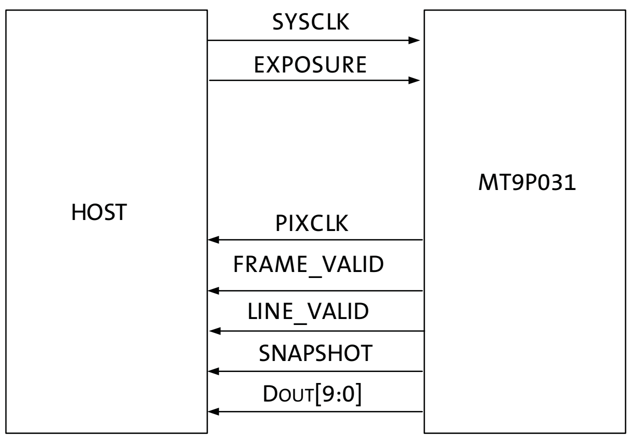
The Aptina® MT9P031 CMOS image sensors are designed to be able to have the exposure starting time synchronized to an external control source. This feature, called snapshot exposure, coupled with the global shutter mode of operation, is ideal for supporting the demands of machine vision systems, security and interior and exterior automotive environments. When compared to the slave mode of operation, this mode offers a simpler interface.

Operation Details

Many imaging applications commonly require the image sensor to capture an image only after a triggering action has taken place. This triggering action can be the passing of an object on a conveyor belt, the flash of a strobe light, or the press of a button.

The MT9P031 offers the ability to synchronize the start of the image sensor's exposure with this triggering action. This synchronization is controlled on the image sensor through the use of one trigger signal, the EXPOSURE input signal. Additionally, the image sensor offers the flexibility to program the exposure time remotely. This section only addresses the single image sensor (non-stereoscopic) snapshot mode of operation.

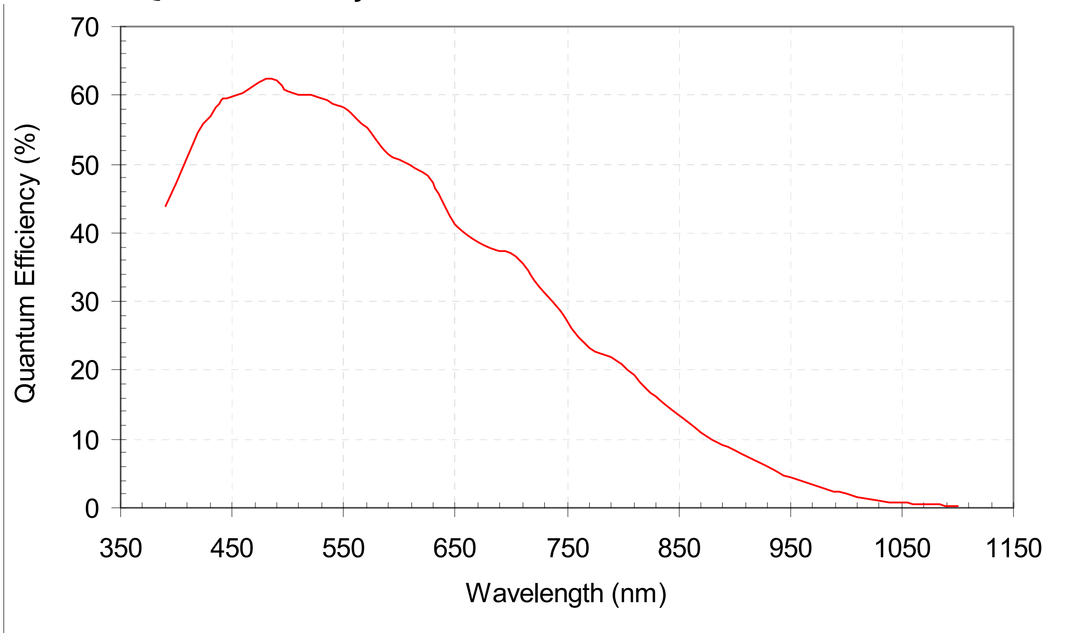
Figure 26: Block Diagram



Monochrome Spectral Characteristics

Figure 27 shows an example of the the quantum efficiency. The curve is based on response in a packaged part.

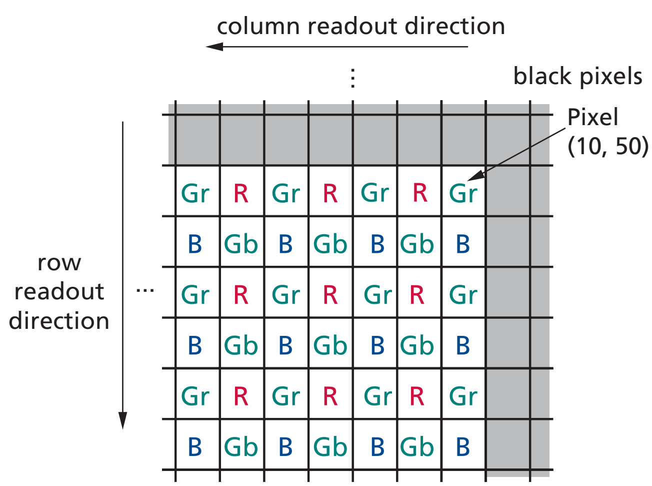
Figure 27: Monochrome Quantum Efficiency



Monochrome Gain Register Settings

For the monochrome version of the MTP031 all pixels are equivalent. However, the sensor maintains the separate gain adjustment registers from the color part. Thus care needs to be taken when setting analog and digital gain to either use Global Gain register, R0x35, or to set all of the separate color gain registers R0x2B through R0x2E. Figure 28 shows the color channel mapping for the gain registers.

Figure 28: Color Channel Mapping for Gain Registers



Revision History

Rev. A 7/3/13

- Initial release

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This data sheet contains minimum and maximum limits specified over the power supply and temperature range set forth herein. Although considered final, these specifications are subject to change, as further product development and data characterization sometimes occur.

