

Technical Note

MT9V024

Snapshot Exposure Mode Operation

Introduction

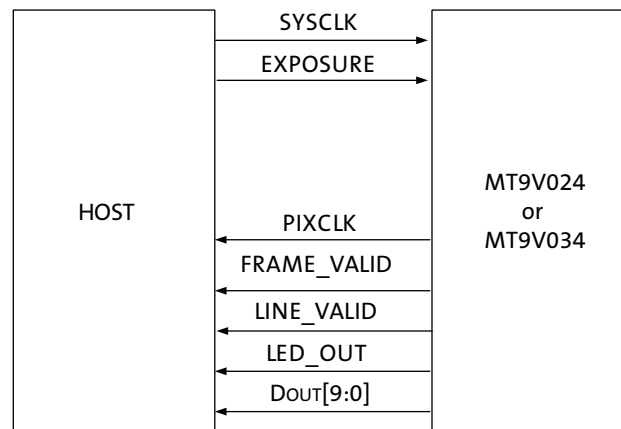
The Aptina[®] MT9V024 CMOS image sensors are designed to be able to have the exposure starting time synchronized to an external control source. This feature, called snapshot exposure, coupled with the global shutter mode of operation, is ideal for supporting the demands of machine vision systems, security 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 MT9V024 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 technical note only addresses the single image sensor (non-stereoscopic) snapshot mode of operation.

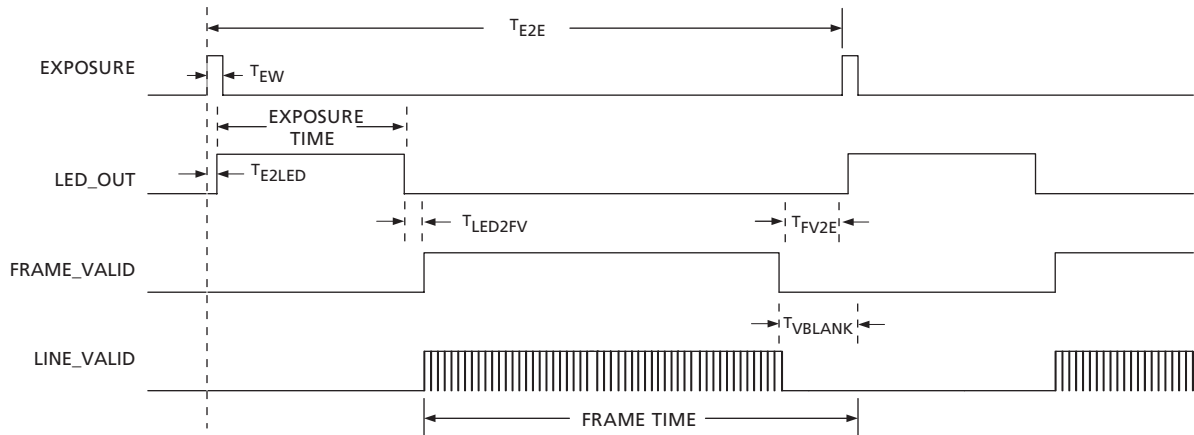
Figure 1: Block Diagram



Exposure Mode Overview

When the image sensor is set to snapshot mode (R0x07, bit 4 = 1), the beginning and duration of the exposure time are controlled. The global shutter feature of the image sensor allows all pixels to be exposed in parallel—all pixels start exposing (integrating charge) simultaneously and stop exposing simultaneously. When exposure stops, the per-pixel integrated charges are digitized and read out of the chip. A new exposure begins only after the readout of all of the pixels is completed.

Figure 2: Exposure Time



- Notes:
1. Not drawn to scale.
 2. Frame readout shortened for clarity.
 3. Progressive scan readout mode shown.
 4. $T_{LED2FV} + T_{FV2E} + T_{E2LED} = T_{VBLANK} + T_{LEDOFF}$.

Table 1: Exposure Timing

Symbol	Description	Value
T_{E2E}	EXPOSURE signal period	EXPOSURE TIME + FRAME TIME + T_{LEDOFF} (MIN)
T_{EW}	EXPOSURE signal pulse width	1 SYSCLK-cycles (MIN)
T_{E2LED}	EXPOSURE to LED_OUT	259 SYSCLK-cycles
T_{LED2FV}	LED_OUT to FRAME_VALID	6 row times - 283 SYSCLK cycles (normal mode) 6 row times - 292 SYSCLK cycles (bin 2 or bin 4 mode)
T_{FV2E}	FRAME_VALID to EXPOSURE	[R0x06 -4] row-times - 156 SYSCLK cycles (normal mode) [R0x06-4] row-times - 167 SYSCLK cycles (bin 2 and bin 4 mode))
T_{BLANK}	Vertical blanking time	R0x06 row-times
T_{LEDOFF}	Required time between successive exposures (not shown in Figure 2)	2 row-times + 4 SYSCLK-cycles (MIN)

- Notes:
1. See “Row-Time Definition” on page 4 for the row-time unit definition.
 2. SYSCLK-cycle unit is defined as the reciprocal of the SYSCLK input frequency.
 3. To change exposure time, change the total shutter width register (R0x0B).
 4. To change frame rate, change the T_{E2E} value.

Register Settings

The snapshot mode of operation requires that certain automatic functions of the image sensor be disabled or set to fixed values, as shown in Table 2.

Table 2: Snapshot Mode Register Settings

Register	Register Name	Bit	Bit Name	Bit Description	Value in Dec (Hex)
0x07	Chip Control	3	Sensor Master/Slave Mode	0 = Slave mode 1 = Master mode	1
0x07	Chip Control	4	Sensor Snapshot Mode	0 = Snapshot disabled 1 = Snapshot mode enabled	1
0x07	Chip Control	5	Stereoscopy Mode	0 = Stereoscopy disabled 1 = Stereoscopy enabled	0
0x07	Chip Control	6	Stereoscopic Master/Slave Mode	0 = Stereoscopic master 1 = Stereoscopic slave	0
0x07	Chip Control	8	Simultaneous/Sequential Mode	0 = Sequential mode 1 = Simultaneous mode	1
0x20	Reserved	1	Reserved	0 = Normal operation 1 = Reset Boosted	1 Note: If exposure time less than 456 SYS_CLK set to 0
0x20	Reserved	2	CR Enable	0 = Normal operation 1 = CR enabled	1
0x20	Reserved	9	RST Enable	0 = Normal operation 1 = RST enabled	1
0xAF	AGC/AEC Enable	0	AEC Enable	0 = Disable automatic exposure control 1 = Enable automatic exposure control	0

Automatic black level correction and automatic gain correction functions are optimized to work in an imaging system where the frame rate, exposure time, and scene dynamic range can be considered to remain constant. Therefore, for best performance in snapshot mode, it is recommended to disable these functions. The automatic black level correction is disabled by setting R0x47 bit 0 to “1”; the automatic gain correction is disabled by setting R0xAF bit 1 to “0.”

Start of Exposure

The start of exposure is controlled by the EXPOSURE input on the image sensor. Normally, EXPOSURE is held in a LOW state. To start exposing, this signal is changed to a HIGH state. This HIGH state is then sampled on the rising edge of the master clock (SYSCLK) of the image sensor. Thus, EXPOSURE must be held HIGH for greater than one master clock cycle.

Duration of Exposure

The duration of the exposure is set by the value stored in R0x0B which represents an equivalent number of row-times and the value stored in R0xD5 which represents the number of equivalent pixel time (for context B R0xD2 and R0xD8) (see “Row-Time Definition” on page 4) to the actual exposure time. If the exposure time is to be set to approximately 3.172ms and default settings are being used (where one row-time equals 31.72µs), a value of “100” is entered in R0x0B (3.172ms / 31.72µs = 100). It is also possible to program exposure time in terms of sub-row times. This is done by via R0xD5 for context A and R0xD8 for context B. The value in these registers refers to the number of master clock cycles the exposure time is. When row time is set to 0 the minimum value in the fine exposure time register is 255. Note: when programming a value less than 456 one must set R0x20[9] = 0.

The minimum exposure time supported by the MT9V024 image sensors in snapshot mode is 255 pixel clocks (Note: When exposure time is less than 456 pixel clocks R0x20[9] = 0).

The exposure time for the MT9V024 is the same as the values programmed in the Coarse Shutter Width and Fine Shutter Width total registers. The equation for exposure time is shown in EQ1.

$$exposure_time = [coarse_shutter_width \times (row_time)] + [fine_shutter_width / SYSCLK_frequency] \quad (EQ\ 1)$$

An exposure time calculation example is shown for the image sensor operating under default register settings. Shutter_width is the value stored in R0x0B. Row_time is defined in “Row-Time Definition.”

$$exposure_time_{default_settings} = \left[(480\ rows) \times \left(\frac{31.72\ \mu s}{row} \right) \right] + [0 / 26.67\ MHz] \quad (EQ\ 2)$$

$$exposure_time_{default_settings} = [15.23\ ms] + [22.16\ \mu s] = 15.25\ ms \quad (EQ\ 3)$$

Row-Time Definition

One row-time is equal to the sum of the number of active pixels (columns) (R0x04 for context A and R0xCC for context B) and the number of horizontal blanking pixels (R0x05 for context A and R0xCD for context B) divided by the pixel readout rate:

$$row_time = \frac{active_pixels + horizontal_blank_pixels}{SYSCLK_frequency} \quad (EQ\ 4)$$

$$row_time_{default_settings} = \frac{752 + 94}{26.67\ MHz} = 31.72\ \mu s \quad (EQ\ 5)$$

Column binning does not affect the row-time (column binning factor applies equally to both the numerator and denominator of the row-time equation, thereby canceling itself out).

Note: Proper operation of the image sensor requires that the sum of the number of active pixels and the number of horizontal blanking pixels (R0x04 + R0x05) must be a value greater than or equal to 660.

Exposure and Data Synchronization Outputs

The MT9V024 image sensors offer an output synchronization signal (LED_OUT) that can be used to control the flash of a light source. The timing of this signal in snapshot mode is similar to the other exposure modes. The signal is normally held in a LOW state. LED_OUT changes to a HIGH state when the image sensor is exposing (integrating charge). LED_OUT returns to the normal LOW state once the exposure (set by R0x0B and R0xD5 for context A and R0xD2 and R0xD8 for context B) has timed out.

To indicate a valid frame of video data is being output from the image sensor, FRAME_VALID switches to a HIGH state. The change of state occurs slightly over 5 row-times after the exposure time ends. FRAME_VALID returns to a LOW state after the active rows have been read out. The number of active rows is stored in the window height register (R0x03) (default value is 480).

During the valid video frame state, LINE_VALID switches to a HIGH state to indicate a valid row of video data is being presented. LINE_VALID returns to a LOW state after a set number of master clock cycles. This set number of master clock cycles equals the number of pixels stored in the window width register (R0x04 for context A and R0xCC for context B) (default value is 752).

For complete information on these and other synchronization signals, refer to the MT9V024 data sheets.

Exposure Input Restrictions

In snapshot mode, the MT9V024 operate as a sequential readout image sensor, that is, the image sensor first exposes all the pixels in a frame and then, after completing the exposure, reads them out. A new exposure can start only after this readout has been completed.

The minimum time between two successive EXPOSURE input pulses (shown as T_{E2E} in Figure 2 on page 2) is calculated from the exposure time and the frame time. The exposure time is described in “Exposure and Data Synchronization Outputs” on page 5. The frame time is calculable from two variables: the row-time, and the number of rows-per-frame. The number of rows-per-frame is equal to the sum of the number of active rows (R0x03 for context A and R0xCB for context B) and the number of vertical blanking rows (R0x06 for context A and R0xCE for context B) divided by a row-binning factor (see MT9V024 data sheet definition for R0x0D, bit [1:0]) (row-binning factor equals 1 for no binning, 2 for 2X binning, or 4 for 4X binning):

$$\text{rows_per_frame} = \frac{\text{active_rows} + \text{vertical_blank_rows}}{\text{row_binning_factor}} \quad (\text{EQ } 6)$$

$$\text{row_per_frame}_{\text{default_settings}} = \frac{480 + 45}{1} = 525 \text{ rows} \quad (\text{EQ } 7)$$

The frame time is equal to the product of the number of rows-per-frame and the row-time.

$$\text{frame_time} = (\text{rows_per_frame}) \times (\text{row_time}) \quad (\text{EQ } 8)$$

$$\text{frame_time}_{\text{default_settings}} = (525 \text{ rows}) \times \left(\frac{31.72 \mu\text{s}}{\text{row}} \right) = 16.65 \text{ms} \quad (\text{EQ } 9)$$

The minimum time between two successive EXPOSURE pulses equals the sum of the frame time, the exposure time, and T_{LEDOFF}

$$EXPOSURE_input_period_{minimum} = (frame_time) + (exposure_time) + (T_{LEDOFF}) \quad (EQ 10)$$

Further, the maximum allowable frame rate may be calculated from these same three variables. The maximum frame rate is the reciprocal of the sum of the frame time, the exposure time, and T_{LEDOFF}

$$frame_rate = \frac{1}{[frame_time] + [exposure_time + T_{LEDOFF}]} \quad (EQ 11)$$

The EXPOSURE pulse to start the next exposure may be asserted as early as [(R0x06)-4] row-times after the FRAME_VALID output has switched to its invalid state (under default settings, a LOW state). If the EXPOSURE pulse occurs earlier, it is ignored, and the request to start the next exposure is missed.

Example Frame Rate Calculations

Two examples follow on performing frame rate calculations for the MT9V024 image sensors, shown in Table 3 below and Table 4 on page 7.

Table 3: Example 1: Shows Maximum Allowable Frame Rate
 (with a smaller image window and short exposure time)

Image Sensor Condition	Setting Description	Register [Bits] = Value
Exposure mode	Snapshot	0x07[4] = 1
Clock frequency	26.67 MHz	N/A
Window height	450	0x03[8:0] = 450
Window width	730	0x04[9:0] = 730
Horizontal blanking	87	0x05[9:0] = 87
Vertical blanking	20	0x06[14:0] = 20
Shutter width	200	0x0B[14:0] = 200
Row bin	No binning	0x0D[1:0] = 0

Step 1: Calculate the row-time.

$$row_time = \frac{active_pixels + horizontal_blank_pixels}{SYSCLK_frequency} \quad (EQ 12)$$

$$row_time = \frac{730 + 87}{26.67\ MHz} = 30.63\ \mu s \quad (EQ 13)$$

Step 2: Calculate the rows-per-frame read out.

$$rows_per_frame = \frac{active_rows + vertical_blank_rows}{row_binning_factor} \quad (EQ 14)$$

$$row_per_frame = \frac{450 + 20}{1} = 470\ rows \quad (EQ 15)$$

Step 3: Calculate the frame time.

$$frame_time = (rows_per_frame) \times (row_time) \quad (EQ\ 16)$$

$$frame_time = (470\ rows) \times \left(\frac{30.63\ \mu s}{row} \right) = 14.40ms \quad (EQ\ 17)$$

Step 4: Calculate the actual exposure time.

$$exposure_time = [(Shutter_width) \times (row_time)] + \left[row_time - \frac{255}{SYSCLK_frequency} \right] \quad (EQ\ 18)$$

$$exposure_time = \left[(200\ rows) \times \left(\frac{30.63\ \mu s}{row} \right) \right] + \left[\left(\frac{30.63\ \mu s}{row} \right) - \frac{255}{26.67\ MHz} \right] \quad (EQ\ 19)$$

$$exposure_time = [6.13ms] + [21.07\ \mu s] = 6.15ms \quad (EQ\ 20)$$

Step 5: Calculate T_{LEDOFF} .

$$T_{LEDOFF} = [2 \times (row_time)] + \left[\frac{4}{SYSCLK_frequency} \right] \quad (EQ\ 21)$$

$$T_{LEDOFF} = [2 \times (30.63\ \mu s)] + \left[\frac{4}{26.67\ MHz} \right] \quad (EQ\ 22)$$

$$T_{LEDOFF} = [61.26\ \mu s] + [0.15\ \mu s] = 61.41\ \mu s \quad (EQ\ 23)$$

Step 6: Calculate the maximum allowable frame rate.

$$frame_rate = \frac{1}{[frame_time] + [exposure_time] + T_{LEDOFF}} \quad (EQ\ 24)$$

$$frame_rate = \frac{1}{[14.40ms] + [6.15ms + 61.41\ \mu s]} \quad (EQ\ 25)$$

$$frame_rate = \frac{1}{20.61ms} \quad (EQ\ 26)$$

$$frame_rate = 69.44Hz \quad (EQ\ 27)$$

Table 4: Example 2: Shows Maximum Allowable Frame Rate
 (with a smaller image window, 2X row binning and long exposure)

Image Sensor Condition	Setting Description	Register[Bits] = Value
Exposure mode	Snapshot	0x07[4] = 1
Clock frequency	26.67 MHz	N/A
Window height	400	0x03[8:0] = 400
Window width	640	0x04[9:0] = 640
Horizontal blanking	44	0x05[9:0] = 44
Vertical blanking	8	0x06[14:0] = 8
Shutter width	3000	0x0B[14:0] = 3000

Table 4: Example 2: Shows Maximum Allowable Frame Rate
 (with a smaller image window, 2X row binning and long exposure)

Image Sensor Condition	Setting Description	Register[Bits] = Value
Row bin	2X binning	0x0D[1:0] = 1

Step 1: Calculate the row-time.

$$row_time = \frac{active_pixels + horizontal_blank_pixels}{SYSCLK_frequency} \quad (EQ\ 28)$$

$$row_time = \frac{640 + 44}{26.67\ MHz} = 25.65\ \mu s \quad (EQ\ 29)$$

Step 2: Calculate the rows-per-frame read out.

$$rows_per_frame = \frac{active_rows + vertical_blank_rows}{row_binning_factor} \quad (EQ\ 30)$$

$$row_per_frame = \frac{400 + 8}{2} = 204\ rows \quad (EQ\ 31)$$

Step 3: Calculate the frame time.

$$frame_time = (rows_per_frame) \times (row_time) \quad (EQ\ 32)$$

$$frame_time = (204\ rows) \times \left(\frac{25.65\ \mu s}{row} \right) = 5.23\ ms \quad (EQ\ 33)$$

Step 4: Calculate the actual exposure time.

$$exposure_time = [(shutter_width) \times (row_time)] + \left[row_time - \frac{255}{SYSCLK_frequency} \right] \quad (EQ\ 34)$$

$$exposure_time = \left[(3000\ rows) \times \left(\frac{25.65\ \mu s}{row} \right) \right] + \left[\left(\frac{25.65\ \mu s}{row} \right) - \frac{255}{26.67\ MHz} \right] \quad (EQ\ 35)$$

$$exposure_time = [76.94\ ms] + [16.09\ \mu s] = 76.95\ ms \quad (EQ\ 36)$$

Step 5: Calculate T_{LEDOFF} .

$$T_{LEDOFF} = [2 \times (row_time)] + \left[\frac{4}{SYSCLK_frequency} \right] \quad (EQ\ 37)$$

$$T_{LEDOFF} = [2 \times (25.65\ \mu s)] + \left[\frac{4}{26.67\ MHz} \right] \quad (EQ\ 38)$$

$$T_{LEDOFF} = [51.30\ \mu s] + [0.15\ \mu s] = 51.45\ \mu s \quad (EQ\ 39)$$

Step 6: Calculate the maximum allowable frame rate.

$$frame_rate = \frac{1}{[frame_rate] + (exposure_time + T_{LEDOFF})} \quad (EQ\ 40)$$

$$frame_rate = \frac{1}{[5.23ms] + [76.95ms + 51.45\mu s]} \quad (EQ\ 41)$$

$$frame_rate = \frac{1}{82.23ms} \quad (EQ\ 42)$$

$$frame_rate = 12.16Hz \quad (EQ\ 43)$$

Conclusion

The snapshot mode of the MT9V024 image sensor support imaging applications where it necessary to synchronize the exposure time of the image sensor with an external event.

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

Revision History

Rev. A6/14/10

- Initial release

10 Eunos Road 8 13-40, Singapore Post Center, Singapore 408600 prodmktg@aptina.com www.apina.com
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