Technical Note

MT9V022

Master Exposure Mode Operation

Introduction

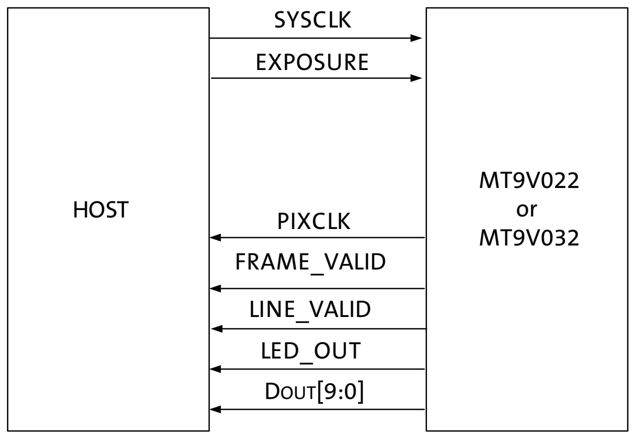
Aptinas's MT9V022 CMOS image sensor is designed to operate in a free-running mode. In this mode, called master exposure mode, the sensor continually outputs frames of video data at a predetermined frame rate and exposure time. This feature, coupled with its global shutter mode of operation, makes the MT9V022 ideal for supporting the demands of machine vision systems and of interior and exterior automotive environments.

Operation Details

Many imaging applications have the image capture performed by one or more asynchronously free-running sensor systems. These systems commonly output to an image processing engine controlled by the sensor's synchronization output signals or to a video monitor where a human can view the video data. To accommodate these imaging applications, the MT9V022 supports a master exposure operating mode that offers the ability to program both the frame rate and exposure time of the image sensor. Additionally, the image sensor offers the ability to select many image processing algorithms (for example, automatic gain control) to simplify the system design and make the output video image more pleasing to the viewer. Once programmed, the image sensor continually captures and outputs frames of video data.

The image sensor can be operated in either simultaneous or sequential readout mode. The simultaneous readout mode allows higher frame rates compared to the sequential readout mode. However, when connecting to some machine vision imaging platforms, the sequential readout mode may be more practical. This technical note addresses only the single image sensor (non-stereoscopic) master mode of operation.

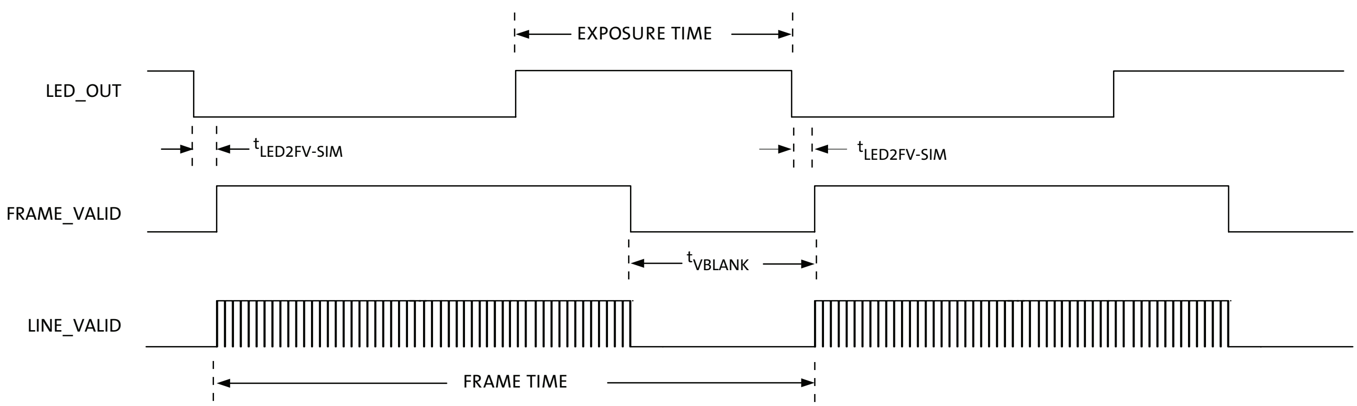
Figure 1: Block Diagram



Exposure Mode Overview

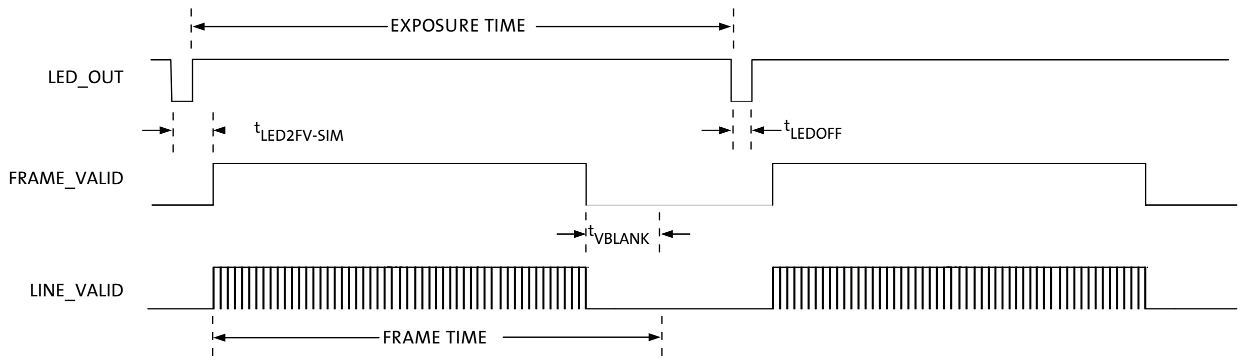
When the image sensor is set to master exposure mode (R0x07, bit 3 = 1), the frame rate and exposure time are controlled by programming the appropriate register set. The global shutter feature of the image sensor allows all pixels to be exposed in parallel—all pixels start exposing (integrating charge) simultaneously and stop exposing simultaneously. When exposure stops, the per-pixel integrated charges are digitized and read out of the chip. In simultaneous readout mode, the readout of the current frame and the integration of the next frame can happen simultaneously. In sequential readout mode, the integration of the next frame begins only after the readout of the current frame has finished.

Figure 2: Simultaneous Readout Exposure Timing (Frame Time Greater Than Exposure Time)



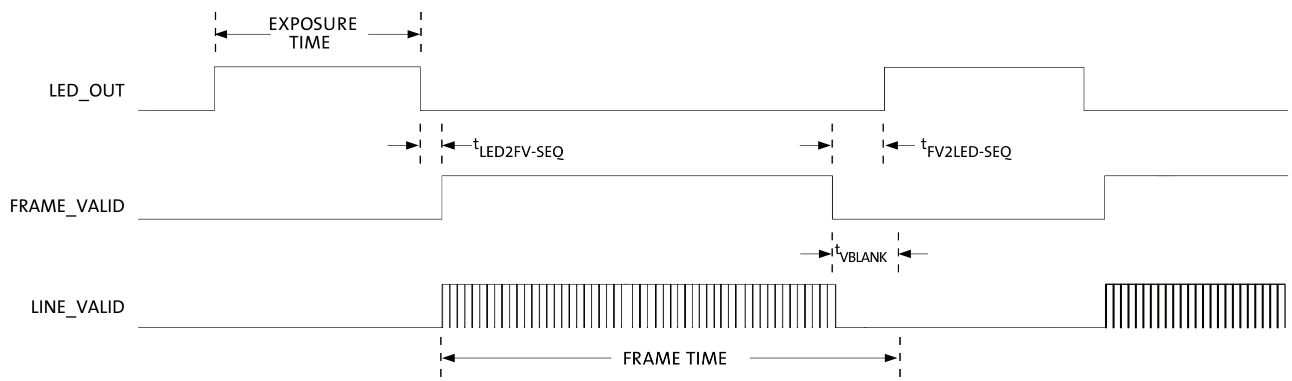
Notes:
1. Drawing not to scale.
2. Frame readout shortened for clarity.
3. Progressive scan readout mode shown.

Figure 3: Simultaneous Readout Exposure Timing (Exposure Time Greater Than Frame Time)



Notes:
1. Drawing not to scale.
2. Frame readout shortened for clarity.
3. Progressive scan readout mode shown.

Figure 4: Sequential Readout Exposure Timing



Notes:
1. Drawing not to scale.
2. Frame readout shortened for clarity.
3. Progressive scan readout mode shown.
4. $t_{LED2FV-SEQ} + t_{FV2LED-SEQ} = t_{VBLANK} + t_{LEDOFF}$.

Table 1: Master Exposure Mode Timing Values

Symbol	Description	Value
$t_{LED2FV-SIM}$	End of exposure to start of readout (simultaneous readout)	5 row-times + 25 SYSCLK-cycles
$t_{LED2FV-SEQ}$	End of exposure to start of readout (sequential readout)	5 row-times + 25 SYSCLK-cycles
t_{VBLANK}	Vertical blanking time (all readouts)	R0x06 row-times + 4 SYSCLK-cycles
t_{LEDOFF}	End of current exposure to start of next exposure (all readouts)	2 row-times + 4 SYSCLK-cycles
$t_{FV2LED-SEQ}$	End of readout to start of next exposure (sequential readout)	[R0x06 - 3] row-times - 21 SYSCLK-cycles

Note: See "Row-Time Definition" on page 5 for the row-time unit definition. SYSCLK-cycle unit is defined as the reciprocal of the SYSCLK input frequency.

Register Settings

The master exposure mode of operation requires that certain registers of the image sensor be set to fixed values, as shown in Table 2.

Table 2: Master Exposure 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	0
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

Improved performance for simultaneous mode (R0x07[8] = 1) is obtained by setting R0x20 = 0x3D5. Improved performance for sequential mode (R0x07[8] = 0) is obtained by setting R0x20 = 0x3F5. In simultaneous mode, where exposure time exceeds readout time, the vertical blanking is internally extended, but the vertical blank register (R0x06) is not updated.

Exposure Time Control

The exposure time is set by the value stored in the total shutter width register (R0x0B), which represents an equivalent number of row-times to the actual exposure time. If the exposure time is to be set to approximately 3.172ms and default settings are used (where one row-time equals 31.72µs), a value of "100" is entered in R0x0B (3.172ms/31.72µs = 100). In this mode, only whole number row-time increments are allowed—no fractional time increments can be achieved. It may be possible to adjust the number of horizontal active or blanking pixels to bring the desired exposure time to a whole number row-time increment.

Using automatic exposure control (AEC)(R0xAF[0] = 1) or high dynamic range (R0x0F[6] = 1) will change how the image sensor uses the value stored in the total shutter width register. Refer to the MT9V022 data sheet and other applicable technical notes for further details on exposure time in these modes.

The minimum exposure time supported by the MT9V022 image sensor is one row-time (R0x0B = 1); older revisions (Rev 2 and earlier) can only support a minimum of two row-time exposures.

The exposure time for the MT9V022 is slightly longer than the value stored in the total shutter width register (R0x0B) (or, if applicable, the AEC exposure output register [R0xBB]). There is a short overhead of additional exposure time that is small but consequential under very short exposure settings. This overhead time is equal to one row-time minus 255 SYSCLK-cycles. Under default register settings, this overhead is equal to 22.16µs—an additional 0.7 row-times of exposure. The actual exposure time can be calculated as follows:

$$exposure\_time = [(shutter\_width)x(row\_time)] + \left[row\_time - \frac{255}{SYSCLK\_frequency}\right] \quad \text{(EQ 1)}$$

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

$$exposure\_time_{default\_settings} = \left[(480\ rows)x\left(\frac{31.72\mu s}{row}\right)\right] + \left[\left(\frac{31.72\mu s}{row}\right) - \frac{255}{26.67\ MHz}\right] \quad \text{(EQ 2)}$$

$$exposure\_time_{default\_settings} = [15.23ms] + [22.16\mu s] = 15.25ms \quad \text{(EQ 3)}$$

Row-Time Definition

One row-time is equal to the sum of the number of active pixels (columns) (R0x04) and the number of horizontal blanking pixels (R0x05) divided by the SYSCLK_frequency:

$$row\_time = \frac{active\_pixels + horizontal\_blank\_pixels}{SYSCLK\_frequency} \quad \text{(EQ 4)}$$

$$row\_time_{default\_settings} = \frac{752 + 94}{26.67\ MHz} = 31.72\mu s \quad \text{(EQ 5)}$$

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.

Frame Time Control

The frame time is controlled by user-programmed image sensor register values. 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) and the number of vertical blanking rows (R0x06) divided by a row-binning factor (see the MT9V022 data sheet definition for R0x0D, bits [1:0]) (row-binning factor equals "1" for no binning, "2" for 2X binning, or "4" for 4X binning):

$$rows\_per\_frame = \frac{active\_rows + vertical\_blank\_rows}{row\_binning\_factor} \quad \text{(EQ 6)}$$

$$row\_per\_frame_{default\_settings} = \frac{480 + 45}{1} = 525\ rows \quad \text{(EQ 7)}$$

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

$$frame\_time = (rows\_per\_frame)\ x\ (row\_time) \quad \text{(EQ 8)}$$

$$frame\_time_{default\_settings} = (525\ rows)x\left(\frac{31.72\mu s}{row}\right) = 16.65ms \quad \text{(EQ 9)}$$

For accuracy, a small overhead time of four SYSCLK-cycles should be added to the frame time; it has been omitted from Equation 8 for clarity.

Simultaneous Mode Frame Rate

In simultaneous readout mode, this frame time sets the maximum frame rate achievable by the image sensor. The maximum frame rate for simultaneous mode is the reciprocal of the frame time. The actual frame rate is determined by either the frame time or the sum of the exposure time and ^{t}LEDOFF, whichever is larger.

$$frame\_rate_{simultaneous} = \frac{1}{larger\ of[frame\_time]\ or\ [exposure\_time + {}^{t}LEDOFF]} \quad \text{(EQ 10)}$$

If the exposure time is 33.27ms and default register settings are used, the maximum frame rate that is achievable is 30Hz (*1/[33.27+0.06]ms*) because 33.33ms is greater than the default register setting frame time of 16.65ms. Further, if the exposure time is 8.33ms and default register settings are used, the maximum frame rate that is achievable is 60Hz (*1/16.65ms*) because 8.33ms is less than the default register setting frame time of 16.65ms.

Note: ^{t}LEDOFF, the minimum time between the end of current exposure [n] and start of next exposure [n+1], is *2 row-times + 4 SYSCLK-cycles*, which equals 63.56µs under default settings.

Sequential Mode Frame Rate

In sequential readout mode, the actual frame rate is the reciprocal of the sum of the frame time, the exposure time, and ^{t}LEDOFF.

$$frame\_rate_{sequential} = \frac{1}{[frame\_time] + [exposure\_time + {}^{t}LEDOFF]} \quad \text{(EQ 11)}$$

A faster frame rate can only be achieved by reducing the number of active or blanking pixels (columns), by reducing the number of active or blanking rows, or by shortening the exposure time.

Note: ^{t}LEDOFF, the minimum time between the end of current exposure [n] and start of next exposure [n+1], is *2 row-times + 4 SYSCLK-cycles*, which equals 63.56µs under default settings.

Exposure and Data Synchronization Outputs

The MT9V022 image sensor offers an output synchronization signal (LED_OUT) that can be used to control the flash of a light source. The timing of this signal in master 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 has timed out.

To indicate that a valid frame of video data is being output from the image sensor, FRAME_VALID switches to a HIGH state. This change of state occurs slightly over five 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 that 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) (default value is 752).

For complete information on these and other synchronization signals, refer to the MT9V022 data sheet.

Frame Rate Calculations

Two examples follow on performing frame rate calculations for the MT9V022 image sensors:

- “Example 1: Simultaneous Readout Frame Rate”
- “Example 2: Sequential Readout Frame Rate” on page 9

Table 3 below and Table 4 on page 9 show the settings used in the calculations.

Example 1: Simultaneous Readout Frame Rate

Table 3: Settings for Example 1
(with a smaller image window and short exposure time)

Image Sensor Condition	Setting Description	Register [Bits] = Value
Exposure mode	Master	0x07[3] = 1
Readout mode	Simultaneous	0x07[8] = 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.

$$row\_time = \frac{active\_pixels + horizontal\_blank\_pixels}{SYSCLK\_frequency} \quad \text{(EQ 12)}$$

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

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

$$rows\_per\_frame = \frac{active\_rows + vertical\_blank\_rows}{row\_binning\_factor} \quad \text{(EQ 14)}$$

$$row\_per\_frame = \frac{450 + 20}{1} = 470\ rows \quad \text{(EQ 15)}$$

Step 3: Calculate the frame time.

$$frame\_time = (rows\_per\_frame)x(row\_time) \quad \text{(EQ 16)}$$

$$frame\_time = (470\ rows)x\left(\frac{30.63\mu s}{row}\right) = 14.40ms \quad \text{(EQ 17)}$$

Step 4: Calculate the actual exposure time.

$$exposure\_time = [(shutter\_width)x(row\_time)] + \left[row\_time - \frac{255}{SYSCLK\_frequency}\right] \quad \text{(EQ 18)}$$

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

$$exposure\_time = [6.13ms] + [21.07\mu s] = 6.15ms \quad \text{(EQ 20)}$$

Step 5: Calculate $^{t}LEDOFF$.

$$^{t}LEDOFF = [2x(row\_time)] + \left[\frac{4}{SYSCLK\_frequency}\right] \quad \text{(EQ 21)}$$

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

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

Step 6: Compare frame time with sum of actual exposure time and $^{t}LEDOFF$.

$$frame\_time \Leftrightarrow [exposure\_time + {}^{t}LEDOFF] \quad \text{(EQ 24)}$$

$$14.40ms \Leftrightarrow [6.15ms + 61.41us] \quad \text{(EQ 25)}$$

$$14.40ms > 6.15ms \quad \text{(EQ 26)}$$

Step 7: Use larger value from Step 6 to calculate frame rate.

$$frame\_rate_{simultaneous} = \frac{1}{larger\ of[frame\_time]or[exposure\_time + {}^{t}LEDOFF]} \quad \text{(EQ 27)}$$

$$frame\_rate = \frac{1}{14.40ms} \quad \text{(EQ 28)}$$

$$frame\_rate = 69.44Hz \quad \text{(EQ 29)}$$

Example 2: Sequential Readout Frame Rate

Table 4: Settings for Example 2
(with a smaller image window)

Image Sensor Condition	Setting Description	Register [Bits] = Value
Exposure mode	Master	0x07[3] = 1
Readout mode	Sequential	0x07[8] = 0
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.

$$row\_time = \frac{active\_pixels + horizontal\_blank\_pixels}{SYSCLK\_frequency} \quad \text{(EQ 30)}$$

$$row\_time = \frac{730+87}{26.67\ MHz} = 30.63\mu s \quad \text{(EQ 31)}$$

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

$$rows\_per\_frame = \frac{active\_rows + vertical\_blank\_rows}{row\_binning\_factor} \quad \text{(EQ 32)}$$

$$row\_per\_frame = \frac{450+20}{1} = 470\ rows \quad \text{(EQ 33)}$$

Step 3: Calculate the frame time.

$$frame\_time = (rows\_per\_frame)x(row\_time) \quad \text{(EQ 34)}$$

$$frame\_time = (470\ rows)x\left(\frac{30.63\mu s}{row}\right) = 14.40ms \quad \text{(EQ 35)}$$

Step 4: Calculate the actual exposure time.

$$exposure\_time = [(shutter\_width)x(row\_time)] + \left[row\_time - \frac{255}{SYSCLK\_frequency}\right] \quad \text{(EQ 36)}$$

$$exposure\_time = \left[(200\ rows)x\left(\frac{30.63\,\mu s}{row}\right)\right] + \left[\left(\frac{30.63\,\mu s}{row}\right) - \frac{255}{26.67\ MHz}\right] \quad \text{(EQ 37)}$$

$$exposure\_time = [6.13ms] + [21.07\,\mu s] = 6.15ms \quad \text{(EQ 38)}$$

Step 5: Calculate ${}^tLEDOFF$.

$${}^tLEDOFF = [2x(row\_time)] + \left[\frac{4}{SYSCLK\_frequency}\right] \quad \text{(EQ 39)}$$

$${}^tLEDOFF = [2x(30.63\,\mu s)] + \left[\frac{4}{26.67\ MHz}\right] \quad \text{(EQ 40)}$$

$${}^tLEDOFF = [61.26\,\mu s] + [0.15\,\mu s] = 61.41\,\mu s \quad \text{(EQ 41)}$$

Step 6: Calculate frame rate.

$$frame\_rate_{sequential} = \frac{1}{[frame\_time] + [exposure\_time + {}^tLEDOFF]} \quad \text{(EQ 42)}$$

$$frame\_rate = \frac{1}{[14.40ms] + [6.15ms + 61.41\,\mu s]} \quad \text{(EQ 43)}$$

$$frame\_rate = \frac{1}{20.61ms} \quad \text{(EQ 44)}$$

$$frame\_rate = 48.52Hz \quad \text{(EQ 45)}$$

Conclusion

The master exposure mode of the MT9V022 image sensor supports imaging applications where it is desired to have the image sensor in a free-running operation.

For more information on this and other features, refer to the MT9V022 data sheet located at Aptina's Web site at www.aptina.com.

Revision History

Rev. C 9/10

- Updated to Aptina template

Rev. B 8/06

- Minor edits

Rev. A 1/06

- Initial release

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