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Shutter Operations for CCD and CMOS Image Sensors

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APPLICATION NOTE

Introduction

In digital cameras, an image is captured by converting the light from an object into an electronic signal at the photosensitive area (photodiode) of a solid-state CCD or CMOS image sensor. The amount of signal generated by the image sensor depends on the amount of light that falls on the imager, in terms of both intensity and duration. Therefore, like conventional film cameras, digital cameras require some form of shutter to control exposure. This is generally achieved either by incorporating an external mechanical shutter in front of the image sensor or an on-chip electronic shutter.

For digital cameras equipped with a mechanical shutter, the photodiode integration time depends on the duration of the opening of the mechanical shutter. Some image sensors provide electronic means for controlling integration time. These types of image sensors may allow the elimination of the mechanical shutter. Most commonly in photographic cameras, a combination of electronic and mechanical shuttering is used to control exposure.

In this application note three electronic shutter mechanisms are described:

- CCD Image Sensor with Electronic Shutter
- CMOS Image Sensor with a Conventional Rolling Shutter
- CMOS Image Sensor with a Global Shutter

CCD Imager with Electronic Shutter

Interline CCDs (designated by KAI in the ON Semiconductor catalog) have electronic shuttering capability. There are two types of interline CCDs: progressive scan and interlaced scan. All ON Semiconductor Interline CCDs support progressive scan read out. Whether an Interline CCD operates in progressive scan or interlaced scan mode affects how and whether a mechanical shutter is required.

In a progressive scan CCD with a built-in electronic shutter, the entire imager is reset before integration to remove any residual signal in the photodiodes. The photodiodes then accumulate charge during the exposure. At the end of the integration period, all charges are simultaneously transferred to light shielded areas of the sensor. The charges are then shifted out of the light shielded areas of the sensor and read out. In this mode a mechanical shutter is not required for exposure control.

Some Interline CCDs are not capable of the progressive scan read out described above. They can be read out only in an interline mode. In this mode, the electronic shuttering resets all of the photodiodes at the beginning of the exposure, just as in the progressive scan mode. But at the end of the exposure, not all charges can be transferred out of the photodiodes simultaneously. Charges from the even and odd lines of the imager must be transferred over at different times. So the imager can't properly end the exposure − the even and odd rows will have different integration times. In this case a mechanical shutter is required to end the exposure properly. Once the mechanical shutter is closed, the even and odd fields on the imager can be read out one at a time without any additional exposure. This is the way most consumer digital still cameras operate.

CMOS Imager with Rolling Shutter

The rolling shutter in a CMOS image sensor works similar to a focal plane shutter in a film camera (the rolling shutter is sometimes referred to as an electronic focal plane shutter). Typically, the rows of pixels in the image sensor are reset in sequence, starting at the top of the image and proceeding row by row to the bottom. When this reset process has moved some distance down the image, the readout process begins: rows of pixels are read out in sequence, starting at the top of the image and proceeding row by row to the bottom in exactly the same fashion and at the same speed as the reset process.

The time delay between a row being reset and a row being read is the integration time. By varying the amount of time between when the reset sweeps past a row and when the readout of the row takes place, the integration time (hence, the exposure) can be controlled. In the rolling shutter, the integration time can be varied from a single line (reset followed by read in the next line) up to a full frame time (reset reaches the bottom of the image before reading starts at the top) or more.

Since the integration process moves through the image over some length of time, some motion artifacts may become apparent. For example, if a vehicle is moving through the image during capture, then light from the top of vehicle will be integrated at some earlier time than light from the bottom of the vehicle, causing the bottom of the vehicle to appear slanted forward in the direction of motion. While this may cause the vehicle to look somewhat sporty, it is not a fully accurate representation of the vehicle. Depending on the relationship between moving objects in the image and the rolling shutter, various distortions may occur. A similar effect may be noted in conventional film cameras that employ a focal plane shutter.

Figure 1. This Image of a Bus was taken using a CMOS Imager in Rolling Shutter Mode

CMOS Imager with Global Shutter

A CMOS image sensor employing a global shutter controls exposure in a similar fashion to an interline CCD described above. In the global shutter operation, the entire imager is reset before integration. The pixels are allowed to accumulate charge during the integration time. At the end of the integration time, the accumulated charge in each pixel is simultaneously transferred to a light-shielded storage area. Then the signals are read out from the light-shielded area. Since all the pixels are reset at the same time, integrate over the same interval, and are transferred to a light shielded storage area at the same time, there is no potential for motion artifacts.

Application of Photoflash in CMOS Sensors

Photoflash is commonly used in digital photography cameras to expose the image properly in a low-light environment. The duration of an electronic flash is generally very short (on the order of hundreds of microseconds to milliseconds), but the readout time for a CMOS image sensor may be much longer. Using a photoflash with a CMOS image sensor therefore requires special consideration.

The following cases are described below:

- CMOS Image Sensor (Rolling or Global Electronic Shutter) with a Mechanical Shutter
- CMOS Imager with a Global Shutter
- CMOS Imager with a Rolling Shutter

Photoflash Used with a Rolling Shutter CMOS Sensor and Mechanical Shutter

If a mechanical shutter is used in conjunction with a CMOS image sensor, the photoflash operation is as follows:

1. The integration time of the CMOS imager's electronic shutter is adjusted so that all the pixels are integrating light at the same time (this may require a very long integration time setting compared to the desired exposure)
2. The mechanical shutter is opened
3. The photoflash is fired
4. The mechanical shutter is closed
5. The imager is read out

Since the duration of the photoflash is very short compared to the overall readout time of the imager, the photoflash can only be used when all the pixels of the imager are integrating at the same time. Consider the case in which the time between reset and readout is less than a full frame time; say one-quarter the number of lines of the imager. In this case, as the integration process moves through the imager area, only those areas of the imager that are integrating during the photoflash will be affected by the photoflash. Depending on the timing of the photoflash, this will lead to a properly exposed band in the middle of the image (exposed by the photoflash) with underexposed areas above and below (integrating before and after the photoflash and hence integrating only available light). This is the reason that the sensor's programmed integration time may need to be longer than otherwise necessary in this case.

Photoflash Used with a Rolling Shutter CMOS Sensor without a Mechanical Shutter

The operation of a photoflash with a CMOS imager operating in rolling shutter mode is as follows:

1. The integration time of the imager is adjusted so that all the pixels are integrating simultaneously for the duration of the photoflash (again, this may require a very long integration time setting for the imager)
2. The reset process progresses through the image row by row until the entire imager is reset

3. The photoflash is fired
4. The imager is read out row by row until the entire imager is read out

Since all the pixels of the image sensor must be integrating simultaneously, the amount of time for the reset process to sweep completely through the image plus some amount of time for the photoflash, sets the minimum exposure time to use for photoflash operation.

The net exposure in this mode will result from integrating both ambient light and the light from the photoflash. As previously mentioned, to obtain the best image quality, the ambient light level should probably be significantly below the minimum light level at which the photoflash can be used, so that the photoflash contributes a significant portion of the exposure illumination. Depending on the speed at which the reset and readout processes can take place, the minimum exposure time to use with photoflash may be sufficiently long to allow image blur due to camera or subject motion during the exposure. To the extent that the exposure light is provided by the short duration photoflash, this blur will be minimized.

Photoflash Used with CMOS Sensor with Global Shutter

A CMOS sensor with global shutter can accommodate the photoflash quite easily. In this case, the photoflash operation is as follows:

1. Mechanical Shutter is opened (if used)
2. All the pixels of the imager are reset simultaneously
3. The photoflash is fired
4. The accumulated charges at each pixel are transferred simultaneously to light shielded storage areas
5. Mechanical Shutter is closed (if used)
6. The light shielded areas of the imager are read out

The time between step 2 and step 4 needs to be only as long as the duration of the photoflash. As mentioned above, this can be a very short time. The resulting exposure will be primarily due to the illumination provided by the photoflash, and will depend a little on the ambient light illumination.

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