Society of Motion Picture and Television Engineers Standard 274

and the

KAI-2093 CCD Image Sensor

Revision No. 0
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Introduction:

The KAI-2093 image sensor is designed to provide HDTV resolution video at 30fps in a progressive scan mode. In this mode, the sensor can be read out in a manner that is compatible with the Society of Motion Pictures and Television Engineers (SMPTE) 274 video standard.

The sensor can also be read out in an interlaced fashion. However, in order to provide interlaced video in accordance with the SMPTE 274 standard, the KAI-2093 image sensor must be clocked at a pixel rate exceeding that in the sensor specification.

For extremely high light level situations, it is sometimes desirable to electronically shutter at the beginning of *each line* rather than *each frame*. Due to the extra time that this operation requires, and the timing requirements imposed by SMPTE 274, this mode of operation, whether progressive scan or interlaced, also requires pixel rates that exceed those recommended in the sensor specification.

In the pages that follow is a description of the timing required for each of these modes of operation.

Description of SMPTE 274 HDTV Standard:

SMPTE 274 is standard for HDTV video. CCD timing parameters specified by the standard are summarized in Table 1.

Samples per active line (S/AL)	1920
Active lines per frame	1080
Frame rate (Hz)	30
Scanning format	progressive or interlaced
Interface Sampling Frequency (MHz)	74.25
Samples per total line (S/TL)	2200
Total lines per frame	1125

Table 1 - SMPTE 274 Timing Requirements

Description of the KAI-2093:

The KAI-2093 is a high-performance interline charge-coupled device (CCD) designed for applications requiring HDTV resolution and frame rates. The device is built using an advanced two-phase, double-polysilicon, NMOS CCD technology. The p+npn- photodiodes eliminate image lag while providing antiblooming protection and electronic shutter capability. The 7.4 square pixels provide high sensitivity and large dynamic range. The device has two outputs, each capable of operating at 40MHz for >30fps operation. The sensor architecture is shown in Figure 1.

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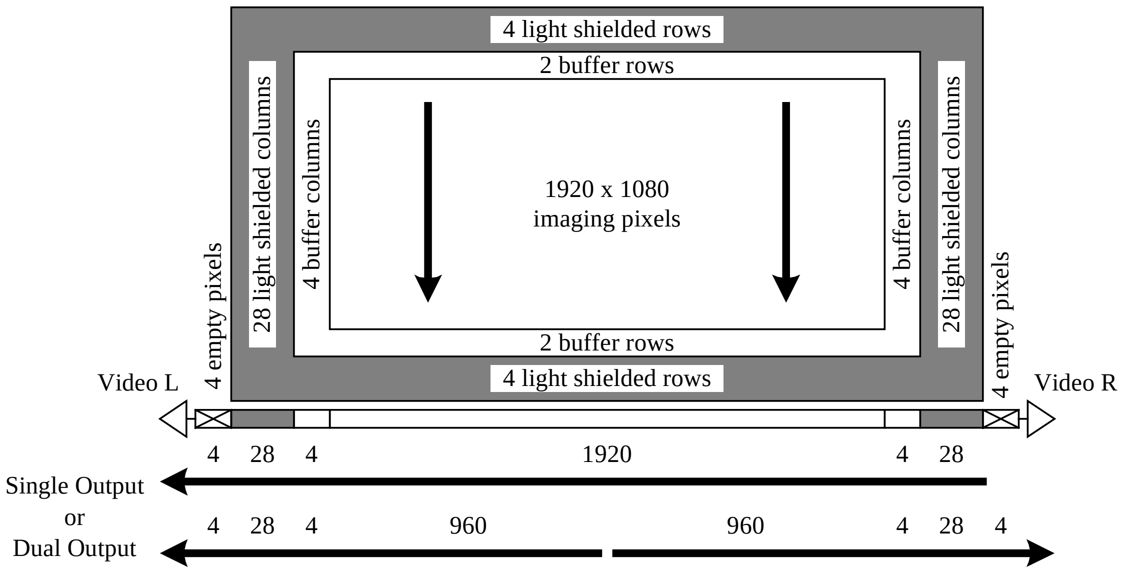

Figure 1 - Sensor Architecture

Each line, which for two-ouput operation is half of the HCCD, includes 4 empty pixels, 28 dark pixels, 4 buffer pixels, and 960 active pixels, in that order, for a total of 996 pixels.

Vertical-to-Horizontal Transfer:

According to the 274 standard, and assuming two-output operation, each output will read out 2200/2 = 1100 pixels per line. Since there are only 996 pixels per line corresponding to each output, there is a window of 1100 – 996 = 104 pixel periods during which the vertical-to-horizontal transfer can take place. At the standard's rate of 37.125MHz, 1 pixel period = 27ns, so 104 pixel periods = 2.8 µs. In all cases discussed below, when reconstructing the image, data from Video R will have to be reversed in a line buffer and appended to the Video L data.

Progressive Scan Operation*:*

For progressive scan operation, one vertical-to-horizontal transfer is required per line. From Figure 2 of the Appendix, the minimum time for VCCD transfer is 1.3 µs. Following the transfer, a waiting period of at least 1.3 µs is required (HCCD delay). The total time required is therefore 2.6 µs, which is less than the 2.8 µs allowed. This means that enough time is provided so that video can come directly off the chip as specified by SMPTE 274.

Progressive Scan Operation with Electronic Shuttering each Line:

For high-luminance applications, it is sometimes desirable to drain the photodiode before each line transfer. This is only required if the antiblooming protection provided by the sensor's vertical overflow drain is not sufficient to drain away charge accumulated in the photodiode during frame read-out. Electronic shuttering cannot be performed in parallel with VCCD transfers without losing some charge from the vertical shift registers. Therefore the two operations must be performed serially as listed below:

Shutter pulse (3.0μs)
Shutter delay (1.0μs)
VCCD Transfer (1.3μs)
HCCD delay (1.3 μs)

A total time of 6.6μs is needed to perform these operations, which is more than the 2.8μs allowed. Therefore, if the device must be shuttered during each line transfer, video cannot be streamed directly from the CCD in conformance with SMPTE 274. Rather, the CCD must be clocked faster than 37.125MHz to create a larger window for shuttering and transferring each line. The video must be buffered and then transmitted according to the standard.

The required pixel rate is calculated using

$$[(1100 \text{ samples/line})/(37.125E6 \text{ samples/s})] - [(996 \text{ pixels})/(R \text{ pixels/s})] = T \qquad (1)$$

where T is the time needed between horizontal line read-outs, and R is the required pixel rate.

For T = 6.6μs, Equation 1 gives a required pixel rate of 43.30MHz.

Interlaced Operation:

Interlaced operation requires two vertical transfers per line, as shown in Figure 4 of the Appendix. After each transfer, a HCCD delay is required. The total time needed for these two transfers per line is 4*1.3 = 5.2μs. Since this is more than 2.8μs, the sensor must be run at a higher pixel rate and the video must be buffered. According to Equation 1, the pixel rate required for interlaced operation is 40.82MHz.

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Interlaced Operation with Electronic Shuttering each Line:

If interlaced operation and electronic shuttering of each line are both required, the following tasks must be performed during each shift period:

Shutter pulse (3.0 µs)
Shutter delay (1.0 µs)
VCCD Transfer (1.3 µs)
HCCD delay (1.3 µs)
VCCD transfer (1.3 µs)
HCCD delay (1.3 µs)

A total time of 9.2 seconds is needed to perform these operations. According to Equation 1, this requires a pixel rate of 48.83MHz and buffering of the video.

Summary:

Scan Mode	Required Pixel Rate (MHz)
Progressive scan with shuttering once per frame	37.125
Progressive scan with shuttering once per line	43.30
Interlaced with shuttering once per frame	40.82
Interlaced with shuttering once per line	48.83

In the KAI-2093 sensor specification, all sensor performance parameters are measured at 40MHz. Eastman Kodak cannot guarantee that the sensor will meet these specifications when operated at speeds greater than 40MHz. Increased sensor noise should be expected when operating the sensor at speeds greater than 40MHz.

APPENDIX - KAI-2093 Timing:

Symbol	Description	Min.	Nom.	Max.	Units	Notes
T_{HD}	HCCD Delay	1.3	1.5	10.0	µs	
T_{VCCD}	VCCD Transfer Time	1.3	1.5		µs	
T_{V3rd}	Photodiode Transfer Time	8.0	12.0	15.0	µs	
T_{3P}	VCCD Pedestal Time	20.0	25.0	50.0	µs	
T_{3D}	VCCD Delay	15.0	20.0	100.0	µs	
T_R	Reset Pulse Time	5.0	10.0		ns	
T_S	Shutter Pulse Time	3.0	5.0	10.0	µs	
T_{SD}	Shutter Pulse Delay	1.0	1.6	10.0	µs	
T_H	HCCD Clock Period	25.0	50.0	200.0	ns	
T_{VR}	VCCD Rise/Fall Time	0.0	0.1	1.0	µs	

Table 2 - KAI-2093 Timing Requirements

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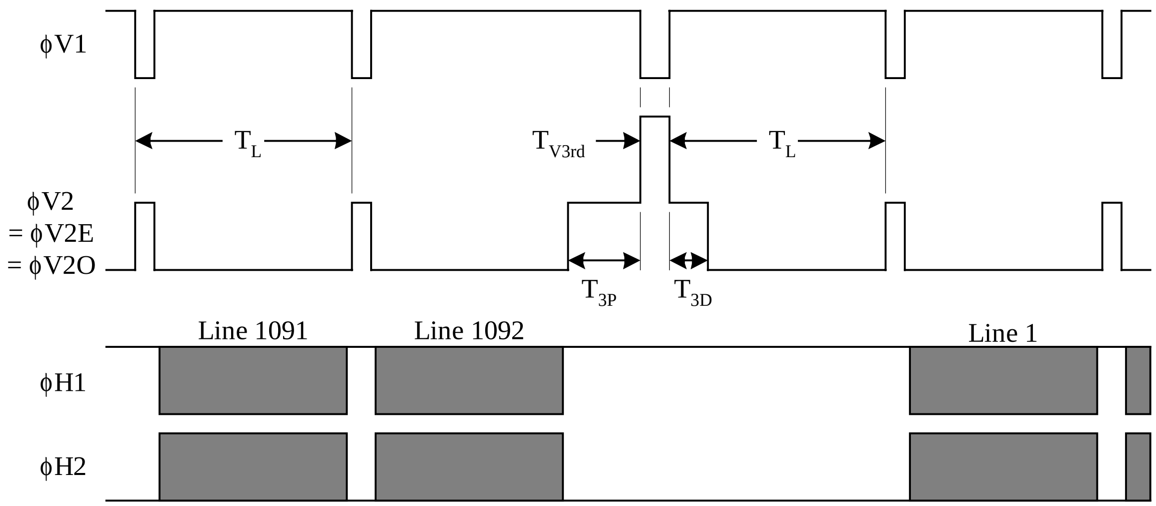
Progressive Frame Timing



Frame Timing for Vertical Binning by 2

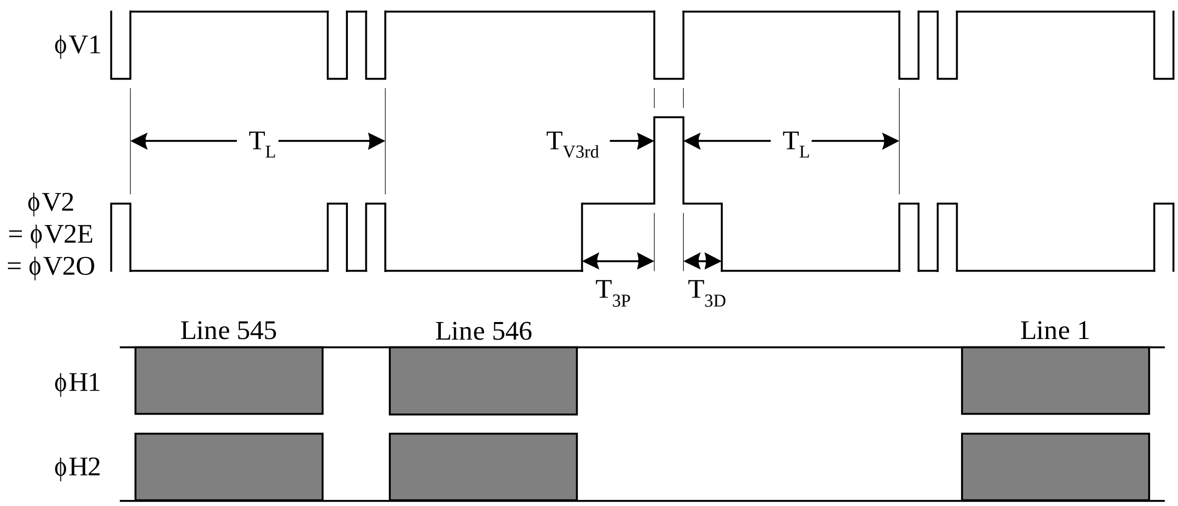
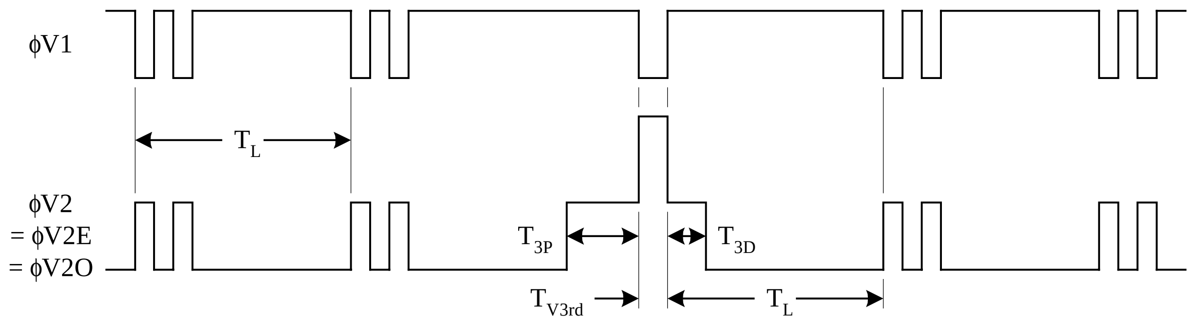


Figure 2 - Progressive Frame Timing

Interlaced Frame Timing - Field Integration Mode - Even Field Readout



Interlaced Frame Timing - Field Integration Mode - Odd Field Readout

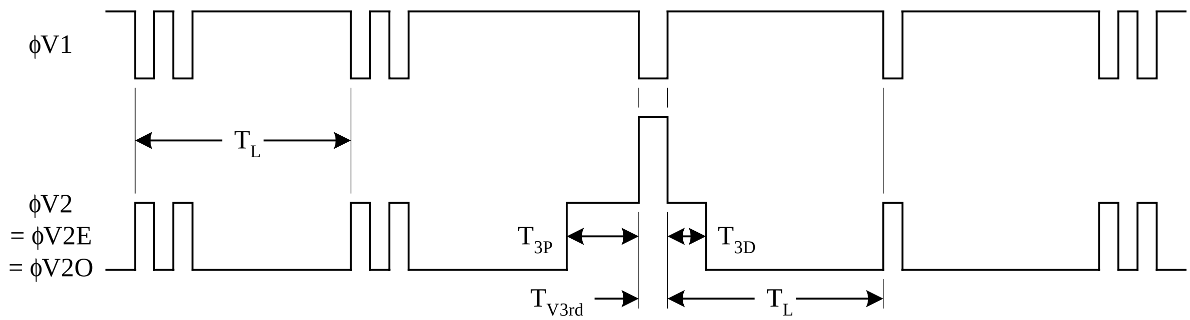
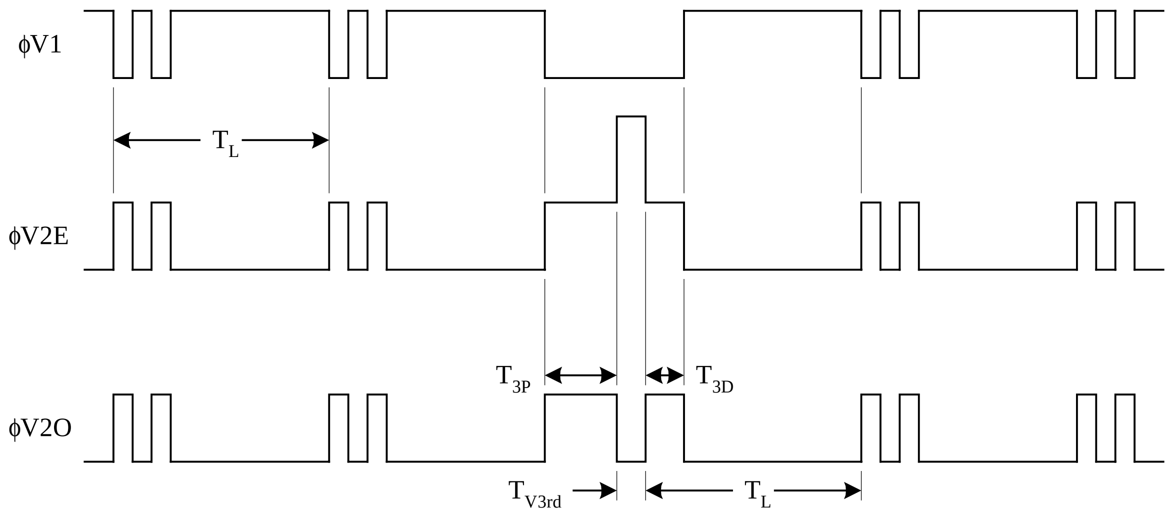


Figure 3 - Interlaced Frame Timing - Field Integration Mode

Interlaced Frame Timing - Frame Integration Mode - Even Field Readout



Interlaced Frame Timing - Frame Integration Mode - Odd Field Readout

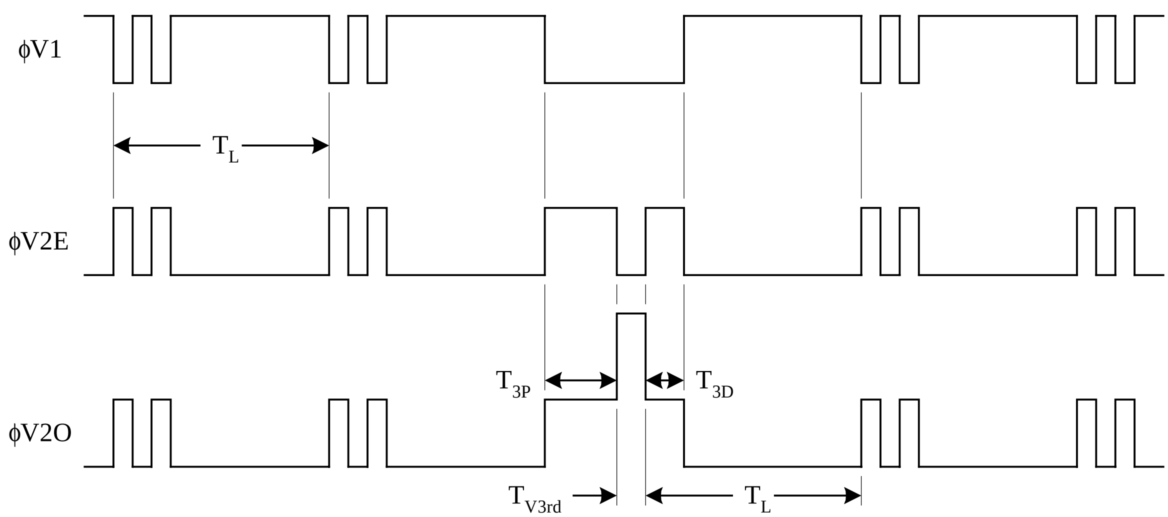


Figure 4 - Interlaced Frame Timing - Frame Integration Mode

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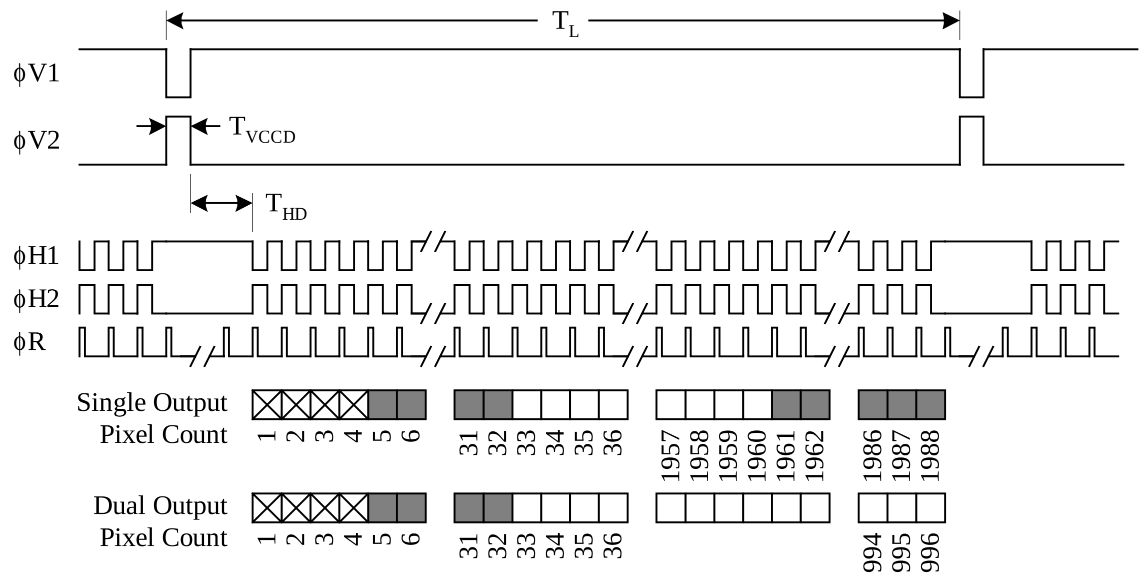
Progressive Line Timing



Interlaced Line Timing
and Line Timing for Vertical Binning by Two

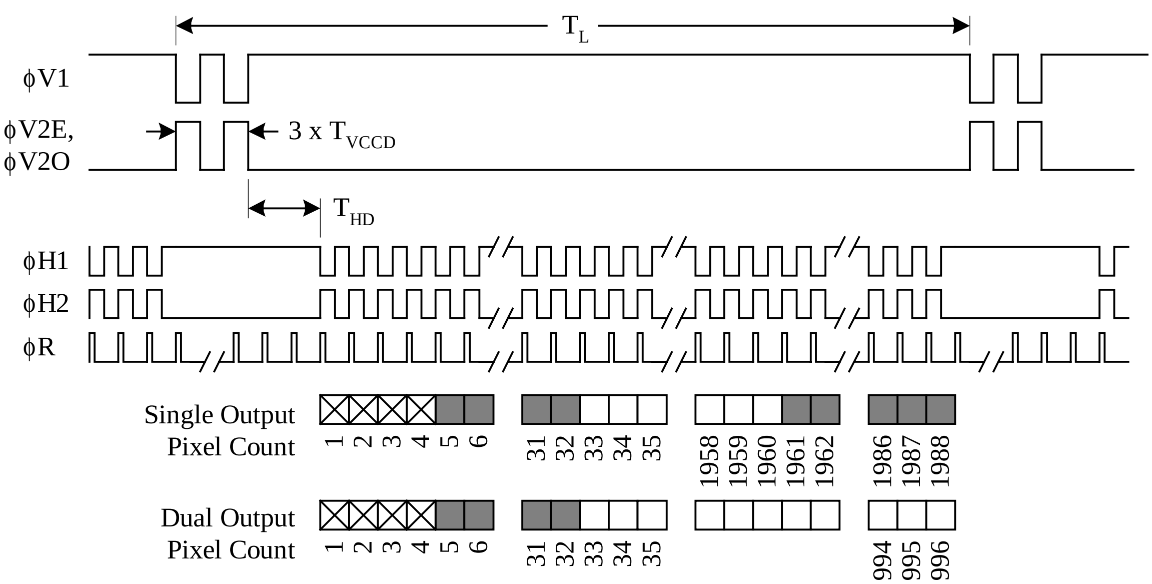


Figure 5 - Line Timing

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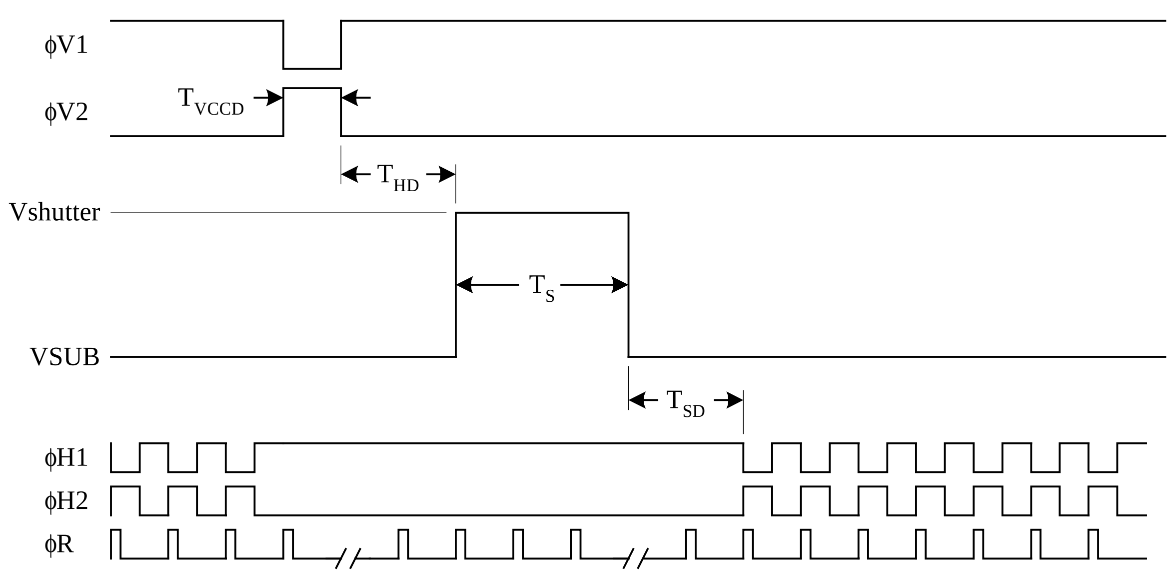
Electronic Shutter Line Timing



Integration Time Definition

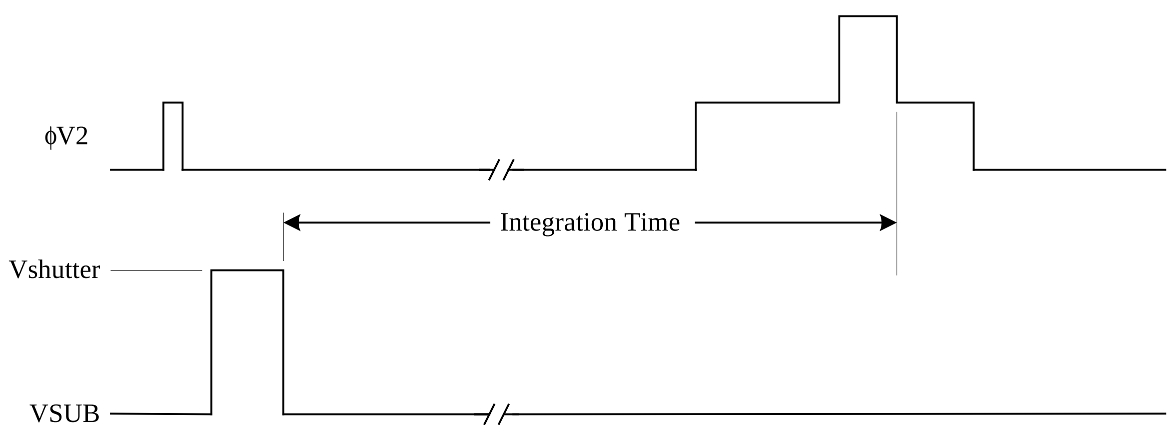


Figure 6 - Electronic Shutter Timing Diagram

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