

KAC-12040

4000 (H) x 3000 (V) CMOS Image Sensor

Description

The KAC-12040 Image Sensor is a high-speed 12 megapixel CMOS image sensor in a 4/3" optical format based on a 4.7 μm 5T CMOS platform. The image sensor features very fast frame rate, excellent NIR sensitivity, and flexible readout modes with multiple regions of interest (ROI). The readout architecture enables use of 8, 4, or 2 LVDS output banks for full resolution readout of 70 frames per second.

Each LVDS output bank consists of up to 8 differential pairs operating at 160 MHz DDR for a 320 Mbps data rate per pair. The pixel architecture allows rolling shutter operation for motion capture with optimized dynamic range or global shutter for precise still image capture.

Table 1. GENERAL SPECIFICATIONS

| Parameter | Typical Value |
|--|---|
| Architecture | 5T Global Shutter CMOS |
| Resolution | 12 Megapixels |
| Aspect Ratio | 4:3 |
| Pixel Size | 4.7 μm (H) \times 4.7 μm (V) |
| Total Number of Pixels | 4224 (H) \times 3192 (V) |
| Number of Effective Pixels | 4016 (H) \times 3016 (V) |
| Number of Active Pixels | 4000 (H) \times 3000 (V) |
| Active Image Size | 18.8 mm (H) \times 14.1 mm (V) 23.5 mm (Diagonal), 4/3" Optical Format |
| Master Clock Input Speed | 5 MHz to 50 MHz |
| Maximum Pixel Clock Speed | 160 MHz DDR LVDS, 320 Mbps |
| Number of LVDS Outputs | 64 Differential Pairs |
| Number of Output Banks | 8, 4, or 2 |
| Frame Rate, 12 Mp | 1–70 fps 10 bits 1–75 fps 8 bits |
| Charge Capacity | 16,000 electrons |
| Quantum Efficiency KAC-12040-CBA KAC-12040-ABA | 40%, 47%, 45% (470, 540, 620 nm) 53%, 15%, 10% (500, 850, 900 nm) |
| Read Noise (at Maximum LVDS Clock) | 3.7 e^- rms, Rolling Shutter 25.5 e^- rms, Global Shutter |
| Dynamic Range | 73 dB, Rolling Shutter 56 dB, Global Shutter |
| Blooming Suppression | > 10,000x |
| Image Lag | 1.3 electron |
| Digital Core Supply | 2.0 V |
| Analog Core Supply | 1.8 V |
| Pixel Supply | 2.8 V & 3.5 V |
| Power Consumption | 1.5 W for 12 Mp @ 70 fps 10 bits |
| Package | 267 Pin Ceramic Micro-PGA |
| Cover Glass | AR Coated, 2-sides |

NOTE: All Parameters are specified at T = 40°C unless otherwise noted.



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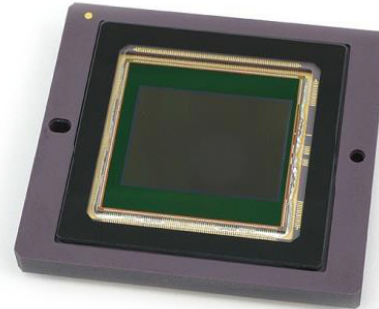


Figure 1. KAC-12040 CMOS Image Sensor

Features

- Global Shutter and Rolling Shutter
- Very Fast Frame Rate
- High NIR Sensitivity
- Multiple Regions of Interest
- Interspersed Video Streams

Applications

- Machine Vision
- Intelligent Transportation Systems
- Surveillance

ORDERING INFORMATION

See detailed ordering and shipping information on page 2 of this data sheet.

KAC-12040

The image sensor has a pre-configured QFHD ($4 \times 1080p$, 16:9) video mode, fully programmable, multiple ROI for windowing, programmable sub-sampling, and reverse readout (flip and mirror). The two ADCs can be configured for 8-bit, 10-bit, 12-bit or 14-bit conversion and output.

Additional features include interspersed video streams (dual-video), on-chip responsivity calibration, black

clamping, overflow pixel for blooming reduction, black-sun correction (anti-eclipse), column and row noise correction, and integrated timing generation with SPI control, 4:1 and 9:1 averaging decimation modes.

ORDERING INFORMATION

Table 2. ORDERING INFORMATION – KAC-12040 IMAGE SENSOR

| Part Number | Description | Marking Code |
|---------------------|--|--------------------------------|
| KAC-12040-ABA-JD-BA | Monochrome, Micro-PGA Package, Sealed Clear Cover Glass with AR Coating (Both Sides), Standard Grade. | KAC-12040-ABA Serial Number |
| KAC-12040-ABA-JD-AE | Monochrome, Micro-PGA Package, Sealed Clear Cover Glass with AR Coating (Both Sides), Engineering Grade. | |
| KAC-12040-CBA-JD-BA | Bayer (RGB) Color Filter Pattern, Micro-PGA Package, Sealed Clear Cover Glass with AR Coating (Both Sides), Standard Grade. | KAC-12040-CBA Serial Number |
| KAC-12040-CBA-JD-AE | Bayer (RGB) Color Filter Pattern, Micro-PGA Package, Sealed Clear Cover Glass with AR Coating (Both Sides), Engineering Grade. | |

1. Engineering Grade samples might not meet final production testing limits, especially for cosmetic defects such as clusters, but also possibly column and row artifacts. Overall performance is representative of final production parts.

Table 3. ORDERING INFORMATION – EVALUATION SUPPORT

| Part Number | Description |
|-----------------------|---|
| KAC-12040-CB-A-GEVK | Evaluation Hardware for KAC-12040 Image Sensor (Color). Includes Image Sensor. |
| KAC-12040-AB-A-GEVK | Evaluation Hardware for KAC-12040 Image Sensor (Monochrome). Includes Image Sensor. |
| LENS-MOUNT-KIT-C-GEVK | Lens Mount Kit that Supports C, CS, and F Mount Lenses. Includes IR Cut-filter for Color Imaging. |

See the ON Semiconductor *Device Nomenclature* document (TND310/D) for a full description of the naming convention used for image sensors. For reference documentation, including information on evaluation kits, please visit our web site at www.onsemi.com.

DEVICE DESCRIPTION

Architecture

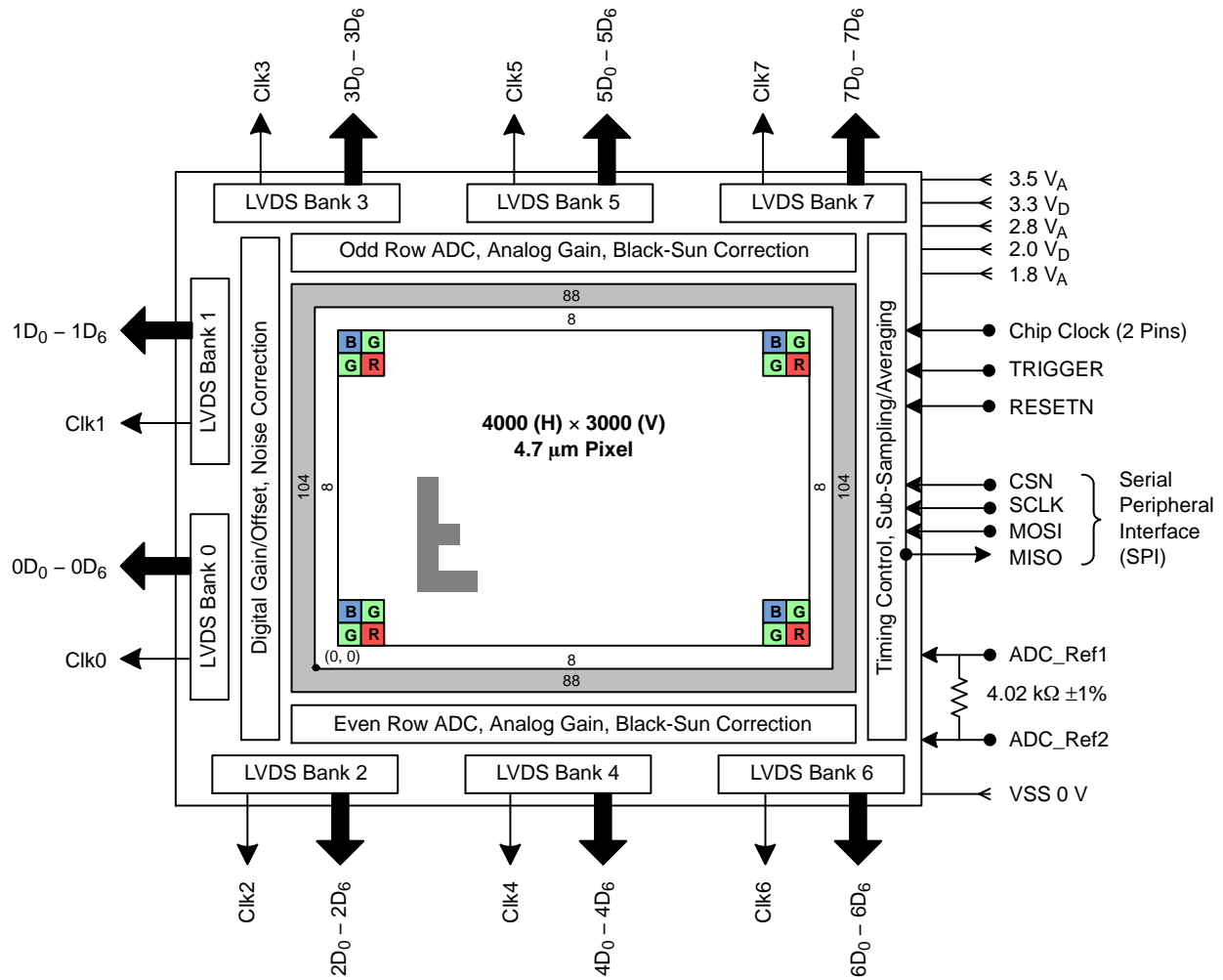
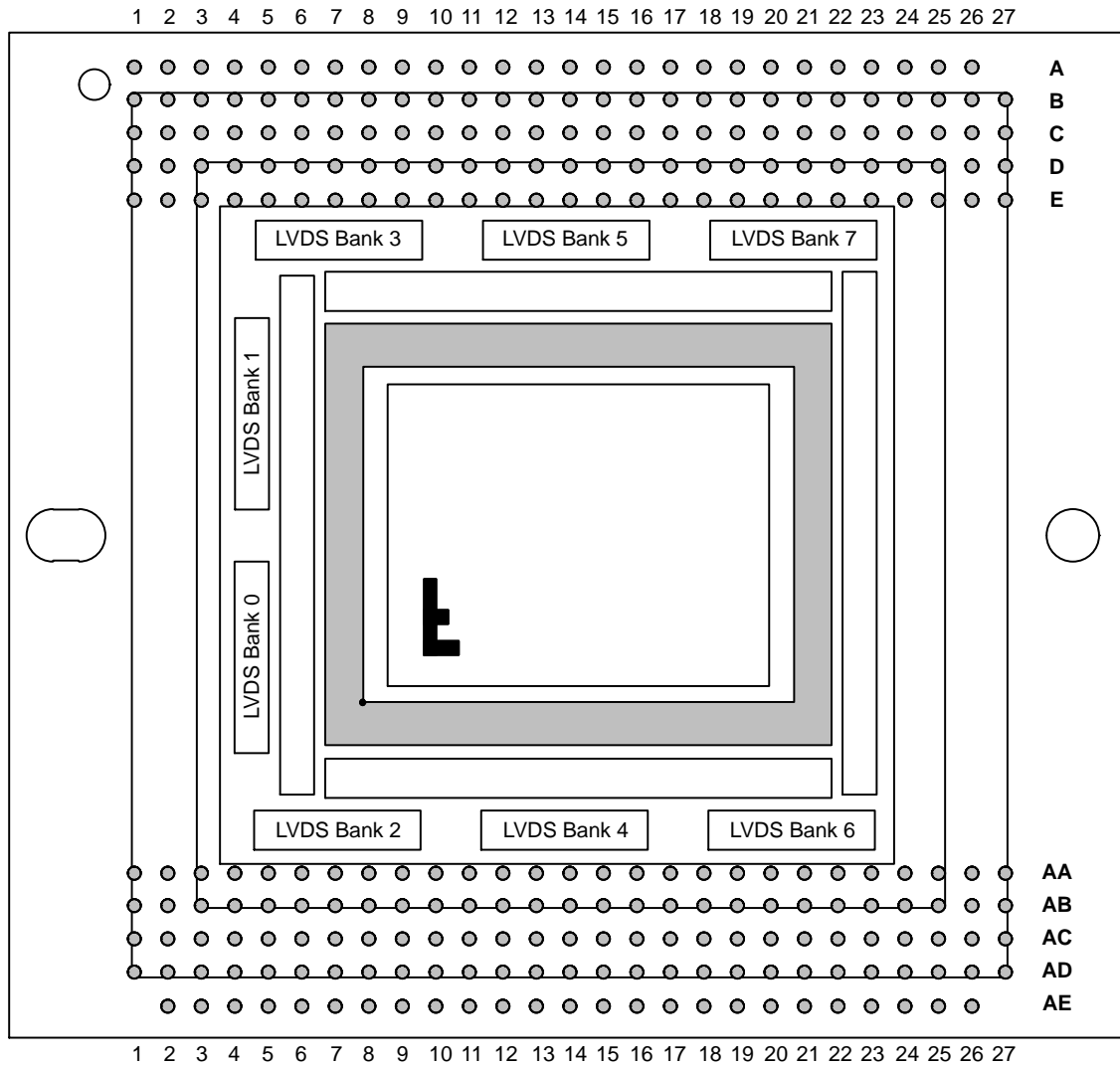


Figure 2. Block Diagram

Physical Orientation



Notes:

1. The center of the pixel array is aligned to the physical package center.
2. The region under the sensor die is clear of pins enabling the use of a heat sink.
3. Non-symmetric mounting holes provide orientation and mounting precision.
4. Non-symmetric pins prevent incorrect placement in PCB.
5. Letter "F" indicator shows default readout direction relative to package pin 1.

Figure 3. Package Pin Orientation – Top X-Ray View

Table 4. PRIMARY PIN DESCRIPTION

| Pin | Name | Type | Description |
|------|----------|------|---|
| AB09 | RESETN | DI | Sensor Reset (0 V = Reset State) |
| E07 | CLK_In1 | DI | Sensor Input Clk_In1 (45–50 MHz) |
| D08 | CLK_In2 | DI | Sensor Input Clk_In2 (Connect to Clk1) |
| AB08 | TRIGGER | DI | Trigger Input (Optional) |
| AA05 | SCLK | DI | SPI Master Clock |
| AA08 | MOSI | DI | SPI Master Output, Slave Input |
| AA07 | MISO | DO | SPI Master Input, Slave Output |
| AA06 | CSN | DI | SPI Chip Select (0 V = Selected) |
| AA14 | ADC_Ref1 | AO | 4.02 k Ω \pm 1% Resistor between Ref1 & Ref2 |
| AA15 | ADC_Ref2 | AO | 4.02 k Ω \pm 1% Resistor between Ref1 & Ref2 |
| AB07 | MSO | DO | Mechanical Shutter Output Sync (Optional) |
| AB06 | FLO | DO | Flash Output Sync (Optional) |
| E05 | FEN | DO | Frame Enable Reference Output (Optional) |
| E06 | LEN | DO | Line Enable Reference Output (Optional) |

1. DI = Digital Input, DO = Digital Output, AO = Analog Output.
2. Tie unused DI pins to Ground, NC unused DO pins.
3. By default Clk_In2 should equal Clk_In1 and should be the same source clock.
4. The RESETN pin has a 62 k Ω internal pull-up resistor, so if left floating the chip will not be in reset mode.
5. The TRIGGER pin has an internal 100 k Ω pull down resistor. If left floating (and at default polarity) then the sensor state will not be affected by this pin (i.e. defaults to 'not triggered' mode if floated).
6. All of the DI and DO pins nominally operate at 0 V \rightarrow 2.0 V and are associated with the VDD_DIG power supply.

Table 5. POWER PIN DESCRIPTION

| Name | Voltage | Pins | Description |
|------------|---------|--|--|
| VDD_LVDS | 3.3 V D | C04, C05, C23, C24, D04, D24, E04, E24, AA04, AA24, AB04, AB24, AC04, AC05 AC23, AC24 | LVDS Output Supply |
| VDD_DIG | 2.0 V D | C18, C19, D18, D19, E18, AA18, AB18, AB19, AC18, AC19, C20, C21, C22, D20, D21, D22, D23, E20, E21, E22, AA20, AA21, AA22, AB20, AB21, AB22, AB23, AC20, AC21, AC22, AB15, E08 | Digital Core Supply |
| AVDD_HV | 3.5 V A | C11, D11, E11, AA11, AB11, AC11, C10, D10, E10, AA10, AB10, AC10 | Pixel Supply 1 |
| Vref_P | 2.8 V A | C13, D13, E13, AA13, AB13, AC13 | Pixel Supply 2 |
| AVDD_LV | 1.8 V A | C17, D16, D17, E17, AA17, AB16, AB17, AC17 | Analog Low Voltage Supply |
| Vpixel_low | 0 V | E09 | Pixel Supply 3. Combine with VSS for normal operation. Can be pulsed for Extended Dynamic Range Operation. |
| VSS | 0 V | C12, C14, D12, D14, E12, AA12, AB12, AB14, AC12, AC14, E15, D15, AA09, A02, A14, A26, B14, C03, C06, C25, D03, D25, E03, E19, E23, E25, AA03, AA19, AA23, AA25, AB25, AC03, AC06, AC25, AD14, AE02, AE14, AE26 | Sensor Ground Reference |
| No Connect | NA | A01, AC09, E14, E16, C09, D09, D05, D06, D07, AA16, AB05 | Unused and test-only pins. These pins must be floated. |

Table 6. LVDS PIN DESCRIPTION

| Pin | Name | Description | Pin | Name | Description | Pin | Name | Description | Pin | Name | Description |
|-----|---------|----------------------|-----|---------|----------------------|-----|---------|----------------------|-----|---------|----------------------|
| E01 | 1DCLK+ | Bank 1 LVDS Clock | C07 | 3DCLK+ | Bank 3 LVDS Clock | C15 | 5DCLK+ | Bank 5 LVDS Clock | A22 | 7DCLK+ | Bank 7 LVDS Clock |
| E02 | 1DCLK- | | C08 | 3DCLK- | | C16 | 5DCLK- | | B22 | 7DCLK- | |
| D01 | 1DATA0+ | Bank 1 LVDS Data | A07 | 3DATA0+ | Bank 3 LVDS Data | A15 | 5DATA0+ | Bank 5 LVDS Data | A23 | 7DATA0+ | Bank 7 LVDS Data |
| D02 | 1DATA0- | | B07 | 3DATA0- | | B15 | 5DATA0- | | B23 | 7DATA0- | |
| C01 | 1DATA1+ | | A08 | 3DATA1+ | | A16 | 5DATA1+ | | A24 | 7DATA1+ | |
| C02 | 1DATA1- | | B08 | 3DATA1- | | B16 | 5DATA1- | | B24 | 7DATA1- | |
| B01 | 1DATA2+ | | A09 | 3DATA2+ | | A17 | 5DATA2+ | | A25 | 7DATA2+ | |
| B02 | 1DATA2- | | B09 | 3DATA2- | | B17 | 5DATA2- | | B25 | 7DATA2- | |
| A03 | 1DATA3+ | | A10 | 3DATA3+ | | A18 | 5DATA3+ | | B27 | 7DATA3+ | |
| B03 | 1DATA3- | | B10 | 3DATA3- | | B18 | 5DATA3- | | B26 | 7DATA3- | |
| A04 | 1DATA4+ | | A11 | 3DATA4+ | | A19 | 5DATA4+ | | C27 | 7DATA4+ | |
| B04 | 1DATA4- | | B11 | 3DATA4- | | B19 | 5DATA4- | | C26 | 7DATA4- | |
| A05 | 1DATA5+ | | A12 | 3DATA5+ | | A20 | 5DATA5+ | | D27 | 7DATA5+ | |
| B05 | 1DATA5- | | B12 | 3DATA5- | | B20 | 5DATA5- | | D26 | 7DATA5- | |
| A06 | 1DATA6+ | | A13 | 3DATA6+ | | A21 | 5DATA6+ | | E27 | 7DATA6+ | |
| B06 | 1DATA6- | | B13 | 3DATA6- | | B21 | 5DATA6- | | E26 | 7DATA6- | |

| Pin | Name | Description | Pin | Name | Description | Pin | Name | Description | Pin | Name | Description |
|------|---------|----------------------|------|---------|----------------------|------|---------|----------------------|------|---------|----------------------|
| AA01 | 0DCLK+ | Bank 0 LVDS Clock | AC07 | 2DCLK+ | Bank 2 LVDS Clock | AC15 | 4DCLK+ | Bank 4 LVDS Clock | AE22 | 6DCLK+ | Bank 6 LVDS Clock |
| AA02 | 0DCLK- | | AC08 | 2DCLK- | | AC16 | 4DCLK- | | AD22 | 6DCLK- | |
| AB01 | 0DATA0+ | Bank 0 LVDS Data | AE07 | 2DATA0+ | Bank 2 LVDS Data | AE15 | 4DATA0+ | Bank 4 LVDS Data | AE23 | 6DATA0+ | Bank 6 LVDS Data |
| AB02 | 0DATA0- | | AD07 | 2DATA0- | | AD15 | 4DATA0- | | AD23 | 6DATA0- | |
| AC01 | 0DATA1+ | | AE08 | 2DATA1+ | | AE16 | 4DATA1+ | | AE24 | 6DATA1+ | |
| AC02 | 0DATA1- | | AD08 | 2DATA1- | | AD16 | 4DATA1- | | AD24 | 6DATA1- | |
| AD01 | 0DATA2+ | | AE09 | 2DATA2+ | | AE17 | 4DATA2+ | | AE25 | 6DATA2+ | |
| AD02 | 0DATA2- | | AD09 | 2DATA2- | | AD17 | 4DATA2- | | AD25 | 6DATA2- | |
| AE03 | 0DATA3+ | | AE10 | 2DATA3+ | | AE18 | 4DATA3+ | | AD26 | 6DATA3+ | |
| AD03 | 0DATA3- | | AD10 | 2DATA3- | | AD18 | 4DATA3- | | AD27 | 6DATA3- | |
| AE04 | 0DATA4+ | | AE11 | 2DATA4+ | | AE19 | 4DATA4+ | | AC26 | 6DATA4+ | |
| AD04 | 0DATA4- | | AD11 | 2DATA4- | | AD19 | 4DATA4- | | AC27 | 6DATA4- | |
| AE05 | 0DATA5+ | | AE12 | 2DATA5+ | | AE20 | 4DATA5+ | | AB26 | 6DATA5+ | |
| AD05 | 0DATA5- | | AD12 | 2DATA5- | | AD20 | 4DATA5- | | AB27 | 6DATA5- | |
| AE06 | 0DATA6+ | | AE13 | 2DATA6+ | | AE21 | 4DATA6+ | | AA26 | 6DATA6+ | |
| AD06 | 0DATA6- | | AD13 | 2DATA6- | | AD21 | 4DATA6- | | AA27 | 6DATA6- | |

1. All LVDS Data and Clock lines must be routed with 100 Ω differential transmission line traces.
2. All the traces for a single LVDS Bank should be the same physical length to minimize skew between the clock and data lines.
3. In 2 Bank mode, only LVDS banks 0 and 1 are active.
4. In 4 Bank mode, only LVDS bank 0, 1, 2, and 3 are active.
5. Float the pins of unused LVDS Banks to conserve power.
6. Unused pins in active banks (due to ADC bit depth < 14) are automatically tri-stated to save power, but these can also be floated.

IMAGING PERFORMANCE

Table 7. TYPICAL OPERATIONAL CONDITIONS

(Unless otherwise noted, the Imaging Performance Specifications are measured using the following conditions.)

| Description | Condition | Notes |
|------------------|---|-------|
| Light Source | Continuous Red, Green and Blue LED Illumination | 1 |
| Temperature | Measured Die Temperature: 40°C and 27°C | |
| Integration Time | 16.6 ms (1400d LL, Register 0201h) | |
| Readout Mode | Dual-Scan, Global Shutter, 320 MHz, PLL2 | |
| Clamps | Column/Row Noise Corrections Active, Frame Black Level Clamp Active | |
| ADC Bit Depth | 10 bit | |
| Analog Gain | Unity Gain or Referred Back to Unit Gain | |

1. For monochrome sensor, only green LED used.

Table 8. KAC-12040-ABA CONFIGURATION (MONOCHROME)

| Description | Symbol | Wavelength (nm) | Min. | Nom. | Max. | Unit | Sampling Plan | Temperature Tested at (°C) | Test |
|-------------------------|-------------------|-----------------|------|------|------|----------------------------|---------------|----------------------------|------|
| Peak Quantum Efficiency | QE _{MAX} | 550 | – | 53 | – | % | Design | 27 | |
| Green | | 850 | – | 15 | – | | | | |
| NIR1 | | 900 | – | 10 | – | | | | |
| NIR2 | | | | | | | | | |
| Responsivity | | | – | 84 | – | $\frac{ke^-}{Lux \cdot s}$ | Design | 27 | 20 |
| Responsivity | | | – | 7.0 | – | $\frac{V}{Lux \cdot s}$ | Design | 27 | 21 |

Table 9. KAC-12040-CBA CONFIGURATION (BAYER RGB)

| Description | Symbol | Wavelength (nm) | Min. | Nom. | Max. | Unit | Sampling Plan | Temperature Tested at (°C) | Test |
|-------------------------|-------------------|-----------------|------|------|------|----------------------------|---------------|----------------------------|------|
| Peak Quantum Efficiency | QE _{MAX} | 470 | – | 40 | – | % | Design | 27 | |
| Green | | 540 | – | 47 | – | | | | |
| NIR1 | | 620 | – | 45 | – | | | | |
| NIR2 | | 850 | – | 15 | – | | | | |
| | | 900 | – | 10 | – | | | | |
| Responsivity | | Blue | – | 17 | – | $\frac{ke^-}{Lux \cdot s}$ | Design | 27 | 20 |
| | | Green | – | 35 | – | | | | |
| | | Red | – | 38 | – | | | | |
| Responsivity | | Blue | – | 1.4 | – | $\frac{V}{Lux \cdot s}$ | Design | 27 | 21 |
| | | Green | – | 2.9 | – | | | | |
| | | Red | – | 3.2 | – | | | | |

Table 10. PERFORMANCE SPECIFICATIONS ALL CONFIGURATIONS

| Description | Symbol | Min. | Nom. | Max. | Unit | Sampling Plan | Temperature Tested at (°C) | Test | Notes |
|---|-------------------|--------|-------------------|--------|-------------------------------|---------------|----------------------------|------|-----------|
| Photodiode Charge Capacity | PNe | – | 16 | – | ke ⁻ | Die | 27, 40 | 16 | |
| Read Noise | ne ⁻ T | – – | 3.7 RS 25.5 GS | – – | e ⁻ rms | Die | 27 | 8 | 1 |
| Total Pixelized Noise | | – – | 4.5 RS 28.3 GS | – – | e ⁻ rms | Die | 27 | 19 | 1 |
| Dynamic Range | DR | – – | 73 RS 56 GS | – – | dB | Die | 27 | | 1, 4 |
| Column Noise | C _N | – – | 0.6 RS 3.0 GS | – – | e ⁻ rms | Die | 27 | 9 | 1, 6 |
| Row Noise | R _N | – – | 1.0 RS 5.0 GS | – – | e ⁻ rms | Die | 27 | 10 | 1, 7 |
| Dark Field Local Non-Uniformity Floor | DSNU_flr | – – | 3.0 RS 21 GS | – – | e ⁻ rms | Die | 27, 40 | 1 | 1, 5 |
| Bright Field Global Photoresponse Non-Uniformity | PRNU_1 | – | 1.5 | – | % rms | Die | 27, 40 | 2 | 2 |
| Bright Field Global Peak to Peak Photoresponse Non-Uniformity | PRNU_2 | – | 6.5 | – | % pp | Die | 27, 40 | 3 | 2 |
| Maximum Photoresponse Non-Linearity | NL | – | 6.3 | – | % | Die | 27, 40 | 11 | 3 |
| Maximum Gain Difference between Outputs | ΔG | – | 0.3 | – | % | Die | 27, 40 | 12 | 8 |
| Photodiode Dark Current | I _{PD} | – | 4.6 | 70 | e/p/s | Die | 40 | 13 | 9 |
| Storage Node Dark Current | I _{VD} | – | 1,200 | 5,000 | e/p/s | Die | 40 | 14 | 5 |
| Image Lag | Lag | – | 1.3 | 10 | – | Design | 27, 40 | 15 | |
| Black-Sun Anti-Blooming | X _{AB} | – – | 12 > 10,000 | – – | W/cm ² xllumSat | Design | 27 | 7 | 14 |
| Parasitic Light Sensitivity | PLS | – | 730 | – | – | Design | 27 | 6 | 10 |
| Dual-Video WDR | | – – | 140 RS 120 GS | – – | dB | Design | 27 | | 1, 11, 12 |
| Pulsed Pixel WDR (GS Only) | | – | 100 | – | dB | Design | 27 | | 12, 13 |

1. RS = Rolling Shutter Operation Mode, GS = Global Shutter Operation Mode.
2. Measured per color, worst of all colors reported.
3. Value is over the range of 10% to 90% of photodiode saturation, Green response used.
4. Uses 20LOG (PNe / ne⁻T).
5. Photodiode dark current made negligible.
6. Column Noise Correction active.
7. Row Noise Correction active.
8. Measured at ~70% illumination.
9. Storage node dark current made negligible.
10. GSE (Global Shutter Efficiency) = 1 – 1 / PLS.
11. Min vs Max integration time at 30 fps.
12. WDR measures expanded exposure latitude from linear mode DR.
13. Min/Max responsivity in a 30 fps image.
14. Saturation Illumination referenced to a 3 line time integration.

TYPICAL PERFORMANCE CURVES

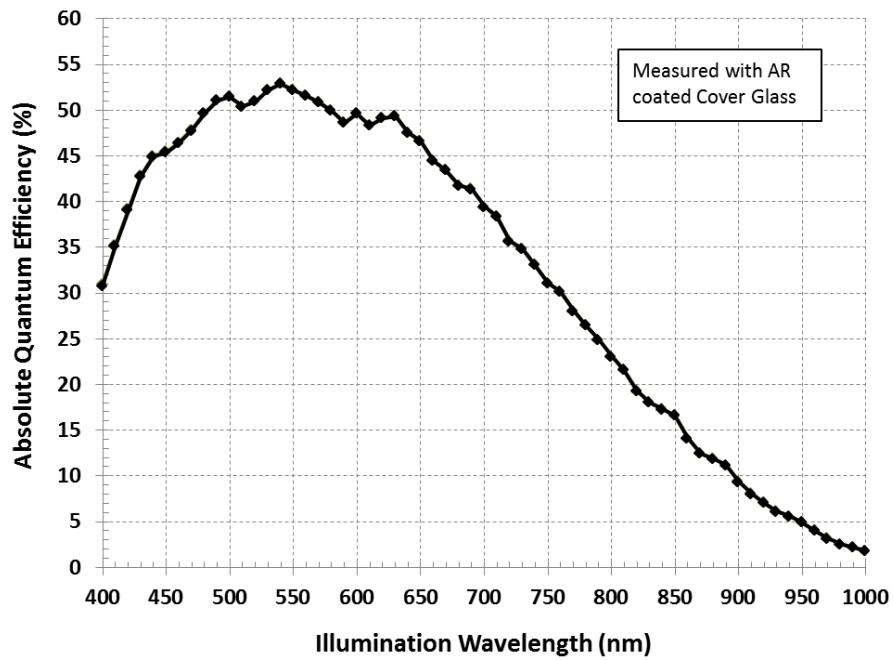


Figure 4. Monochrome QE (with Microlens)

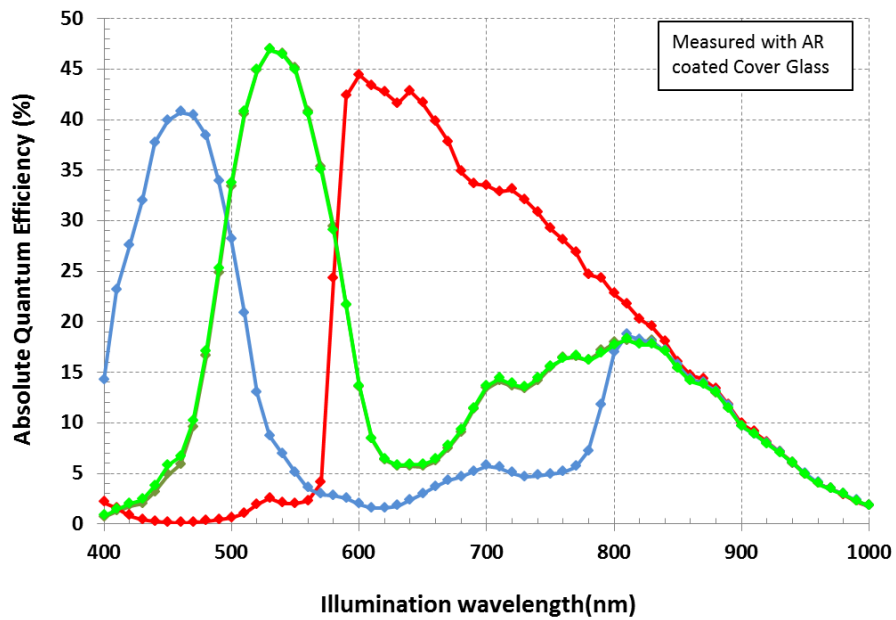


Figure 5. Bayer QE (with Microlens)

Angular Quantum Efficiency

For the curves marked “Horizontal”, the incident light angle is varied along the wider array dimension.
For the curves marked “Vertical”, the incident light angle is varied along the shorter array dimension.

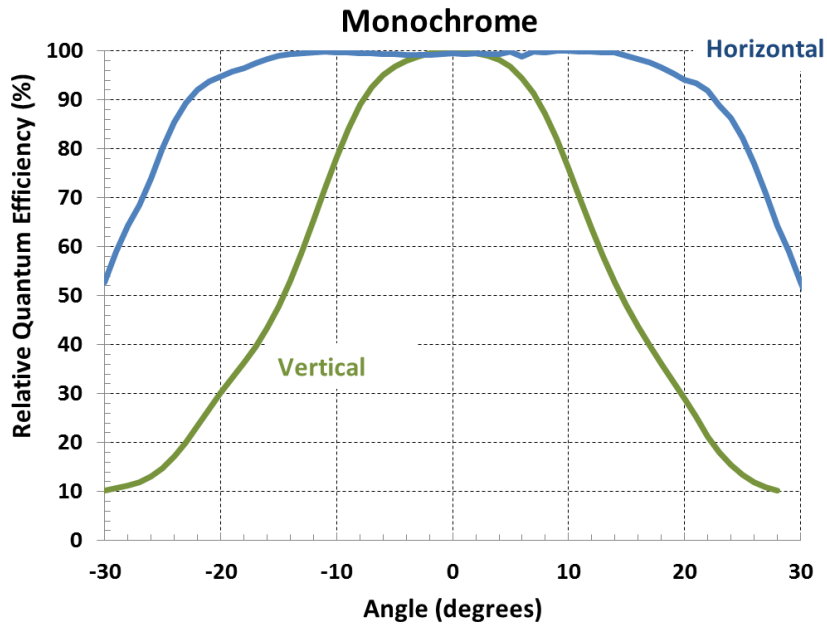


Figure 6. Monochrome Relative Angular QE (with Microlens)

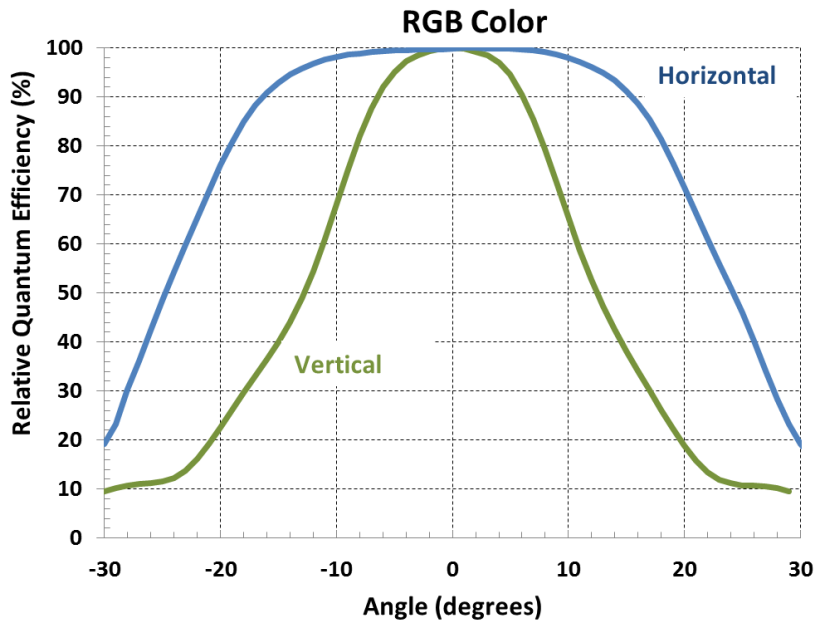
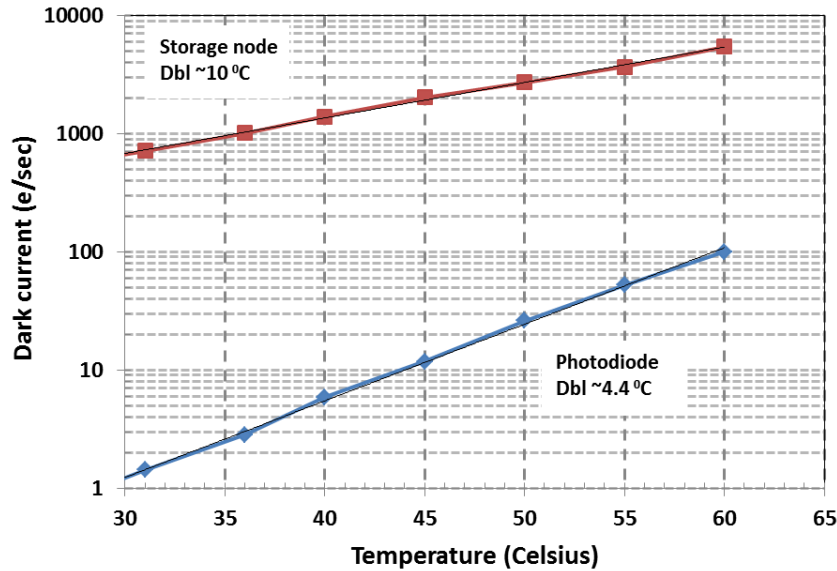


Figure 7. Bayer Relative Angular QE (with Microlens)

Dark Current vs. Temperature



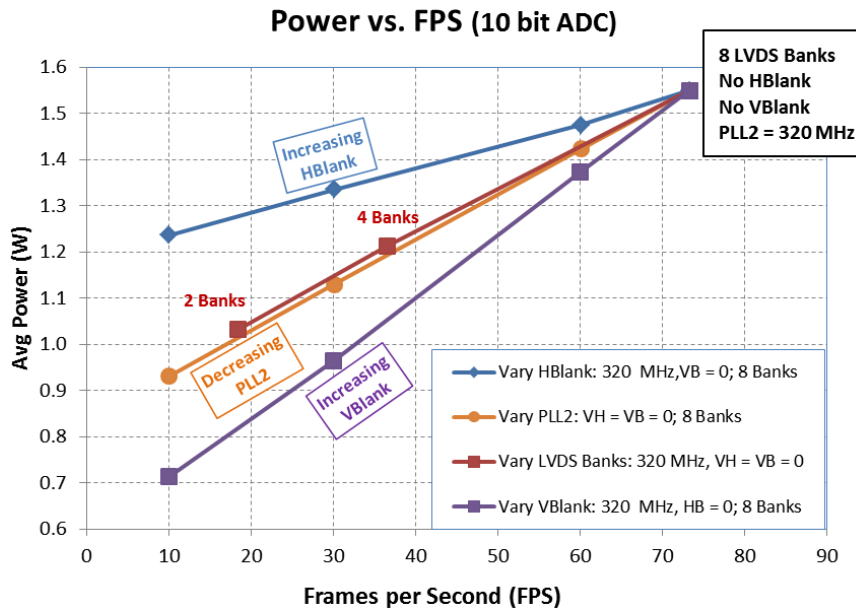
NOTE: "Dbl" denotes an approximate doubling temperature for the dark current for the displayed temperature range.

Figure 8. Dark Current vs. Temperature

Power vs. Frame Rate

The most effective method to use the maximum PLL2 speed (313 → 320 MHz) and control frame rate with minimum Power and maximum image quality is to adjust Vertical Blanking. (register 01F1h). Unnecessary chip

operations are suspended during Vertical Blanking conserving significant power consumption and also minimizing the image storage time on the storage node when in Global Shutter Operation.



NOTE: The LVDS clock is 1/2 the PLL2 clock speed.

Figure 9. Power vs. Frame Rate, 10 bit Mode

Power and Frame Rate vs. ADC Bit Depth

Increasing the ADC bit depth impacts the frame rate by changing the ADC conversion time. The following figure

shows the power and Frame rate range for several typical cases.

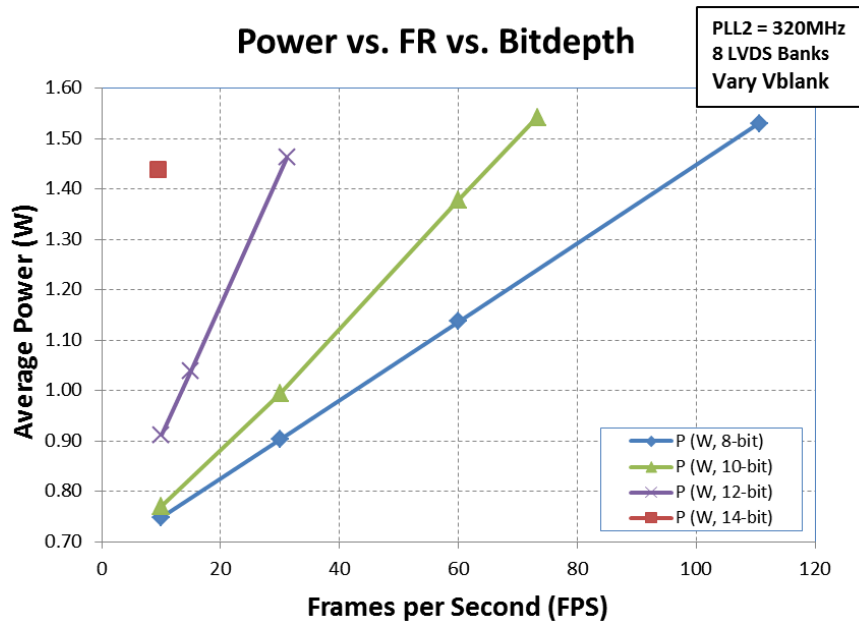


Figure 10. ADC Bit Depth Impact on Frame Rate and Power

DEFECT DEFINITIONS

Table 11. OPERATION CONDITIONS FOR DEFECT TESTING

| Description | Condition | Notes |
|-----------------------------|---|-------|
| Operational Mode | 10 bit ADC, 8 LVDS Outputs, Global Shutter and Rolling Shutter Modes, Dual-Scan, Black Level Clamp ON, Column/Row Noise Corrections ON, 1× Analog Gain, 1× Digital Gain | |
| Pixels per Line | 4,000 | |
| Lines per Frame | 3,000 | |
| Line Time | 8.7 μ s | |
| Frame Time | 13.9 ms | |
| Photodiode Integration Time | 33 ms | |
| Storage Readout Time | 13.9 ms | |
| Temperature | 40°C and 29°C | |
| Light Source | Continuous Red, Green and Blue LED Illumination | 1 |
| Operation | Nominal Operating Voltages and Timing, PLL1 = 320 MHz, Wafer Test | |

1. For monochrome sensor, only the green LED is used.

Table 12. DEFECT DEFINITIONS FOR TESTING

| Description | Definition | | Limit | Test | Notes |
|--------------------------------------|---|---|-------|------|---------|
| Dark Field Defective Pixel | 30°C RS: Defect \geq 20 dn GS: Defect \geq 180 dn | 40°C RS: Defect \geq 30 dn GS: Defect \geq 240 dn | 120 | 4 | 1, 4, 5 |
| Bright Field Defective Pixel | Defect $\geq \pm 12\%$ from Local Mean | | 120 | 5 | 2, 5 |
| Cluster Defect | A group of 2 to 10 contiguous defective pixels, but no more than 3 adjacent defects horizontally. | | 22 | | 3 |
| Column/Row Major Defect | A group of more than 10 contiguous defective pixels along a single column or row. | | 0 | | |
| Dark Field Faint Column/Row Defect | RS: 3 dn Threshold GS: 10 dn Threshold | | 0 | 17 | 1 |
| Bright Field Faint Column/Row Defect | RS: 12 dn Threshold GS: 18 dn Threshold | | 0 | 18 | 1 |

1. RS = Rolling Shutter, GS = Global Shutter.
2. For the color devices, all bright defects are defined within a single color plane, each color plane is tested.
3. Cluster defects are separated by no less than two good pixels in any direction.
4. Rolling Shutter Dark Field points are dominated by photodiode integration time, Global Shutter Dark Field defects are dominated by the readout time.
5. The net sum of all bright and dark field pixel defects in rolling and global shutter are combined and then compared to the test limit.

Defect Map

The defect map supplied with each sensor is based upon testing at an ambient (29°C) temperature. All defective

pixels are reference to pixel (0, 0) in the defect maps. See Figure 11 for the location of pixel (0, 0).

TEST DEFINITIONS

Test Regions of Interest

Image Area ROI: Pixel (0, 0) to Pixel (4015, 3015)
 Active Area ROI: Pixel (8, 8) to Pixel (3999, 2999)
 Center ROI: Pixel (1958, 1458) to Pixel (2057, 1557)

Only the Active Area ROI pixels are used for performance and defect tests.

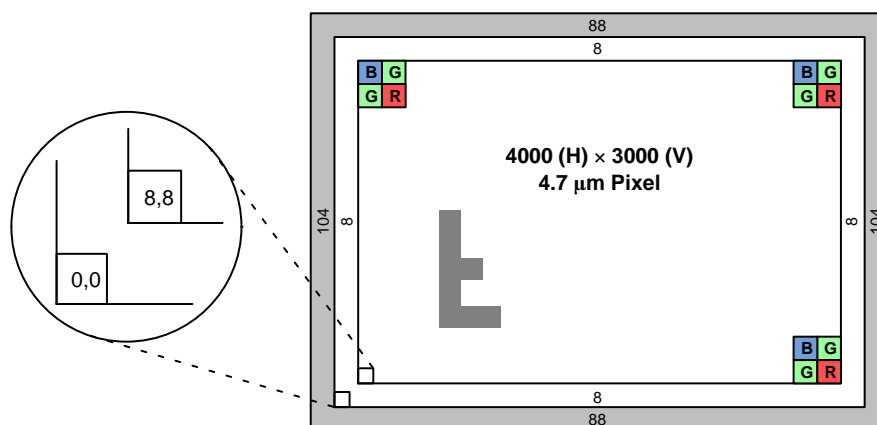


Figure 11. Regions of Interest

Test Descriptions

1) Dark Field Local Non-Uniformity Floor (DSNU_{flr})

This test is performed under dark field conditions. A 4 frame average image is collected. This image is partitioned into 300 sub-regions of interest, each of which is 200 by 200 pixels in size. For each sub-region the standard deviation of all its pixels is calculated. The dark field local non-uniformity is the largest standard deviation found from all the sub regions of interest. Units: e⁻ rms (electrons rms).

2) Bright Field Global Photoresponse Non-Uniformity (PRNU₁)

The sensor illuminated to 70% of saturation (~700 dn). In this condition a 4 frame average image is collected. From this 4 frame average image a 4 frame average dark image is subtracted. The Active Area Standard Deviation is the standard deviation of the resultant image and the Active Area Signal is the average of the resultant image.

$$PRNU_1 = 100 \cdot \left(\frac{\text{Active Area Standard Deviation}}{\text{Active Area Signal}} \right)$$

Units : % rms

3) Bright Field Global Peak to Peak Non-Uniformity (PRNU₂)

This test is performed with the sensor uniformly illuminated to 70% of saturation (~700 dn), a 4 frame average image is collected and a 4 frame averaged dark image is subtracted. The resultant image is partitioned into 300 sub regions of interest, each of which is 200 by 200 pixels in size. The average signal level of each sub regions of interest (sub-ROI) is calculated.

The highest sub-ROI average (Maximum Signal) and the lowest sub-ROI average (Minimum Signal) are then used in the following formula to calculate PRNU₂.

$$PRNU_2 = 100 \cdot \left(\frac{\text{Max. Signal} - \text{Min. Signal}}{\text{Active Area Signal}} \right)$$

Units : % pp

4) Dark Field Defect Test

This test is performed under dark field conditions. The sensor is partitioned into 300 sub regions of interest, each of which is 128 by 128 pixels in size. In each region of interest, the median value of all pixels is found. For each region of interest, a pixel is marked defective if it is greater than or equal to the median value of that region of interest plus the defect threshold specified in the Defect Definition Table section.

5) Bright Field Defect Test

This test is performed with the imager illuminated to a level such that the output is at approximately 700 dn. The average signal level of all active pixels is found. The bright and dark thresholds are set as:

Dark Defect Threshold = Active Area Signal · Threshold

Bright Defect Threshold = Active Area Signal · Threshold

The sensor is then partitioned into 300 sub regions of interest, each of which is 128 by 128 pixels in size. In each region of interest, the average value of all pixels is found. For each region of interest, a pixel is marked defective if it is greater than or equal to the median value of that region of interest plus the bright threshold specified or if it is less than

or equal to the median value of that region of interest minus the dark threshold specified.

Example for bright field defective pixels:

- Average value of all active pixels is found to be 700 dn
- Lower defect threshold: $700 \text{ dn} \cdot 12\% = 84 \text{ dn}$
- A specific 128×128 ROI is selected:
 - ♦ Median of this region of interest is found to be 690 dn.
 - ♦ Any pixel in this region of interest that is $\leq (690 - 84 \text{ dn})$ in intensity will be marked defective.
 - ♦ Any pixel in this region of interest that is $\geq (690 - 84 \text{ dn})$ in intensity will be marked defective.
- All remaining 299 sub regions of interest are analyzed for defective pixels in the same manner.

6) Parasitic Light Sensitivity (PLS)

Parasitic Light Sensitivity is the ratio of the light sensitivity of the photodiode to the light sensitivity of the storage node in Global Shutter. There is no equivalent distortion in Rolling Shutter. A low PLS value can provide distortion of the image on the storage node by the scene during readout.

$$\text{PLS} = \frac{\text{Photodiode Responsivity}}{\text{Storage Node Responsivity}} \quad (\text{UnitlessRatio})$$

GSE (Global Shutter Efficiency) is a related unit.

$$\text{GSE} = \left(1 - \frac{1}{\text{PLS}}\right) \%$$

Detailed Method: Photodiode Responsivity:

The sensor is set in global shutter serial mode (integration time not overlapping readout) and the FLO signal is used to control a 550 nm normal incident (or large f# focused) illumination source so that the sensor is illuminated only during photodiode integration time (not illuminated during readout time). The integration time is not critical but should be large enough to create a measurable mean during this time. A 16 frame-average illuminated photodiode image is recorded. A 16 frame-average dark frame using the same sensor settings is captured and is subtracted from the illuminated image.

Detailed Method: Storage Node Responsivity:

The sensor is set to a special characterization mode where the PD signal is discarded and does not impact the storage node. A long total frame time (storage node exposure time) is used to increase the storage node signal. A 16 frame-average dark frame is captured. The sensor is illuminated by the same 550 nm incident light source used for the photodiode responsivity. A 16 frame-average illuminated photodiode image is recorded; the dark frame image is subtracted from this. The integration time is not critical but should be set such that a significant response is detected, typically several orders of magnitude greater than the photodiode integration time.

7) Black-Sun Anti-Blooming

A typical CMOS image sensor has a light response profile that goes from 0 dn to saturation (1023 dn for KAC-12040 in 10 bit ADC mode) and, with enough light, back to 0 dn. The sensor reaching 0 dn at very bright illumination is often called the “Black-sun” artifact and is undesirable. Black-sun artifact is typically the dominant form of anti-blooming image distortion. For the KAC-12040 the Black-sun artifact threshold is measured at the onset of saturation distortion, not at the point where the output goes to 0 dn. To first order the onset of black-sun artifact for the KAC-12040 is not proportional to the integration time or readout time.

The sensor is placed in the dark at unity gain and illuminated with a 532 nm laser with the intensity of about 26 W/cm^2 at the center of the sensor. The laser is strong enough to make the center of the laser spot below 1020 dn without any ND filters. ND filters are added to adjust the laser intensity until the signal in the region at the center of the spot increases to $> 1020 \text{ dn}$.

This illumination intensity at this ND filter is recorded (W/cm^2) as the Black-Sun Anti-blooming.

The ‘xIllumSat’ unit is calculated using and integration time of 100 μsec .

Exposing the sensor to very strong illumination for extended periods of time will permanently alter the sensor performance in that localized region.

8) Read Noise

This test is performed with no illumination and one line of integration time. The read noise is defined as one standard deviation of the frequency histogram containing the values of all pixels after the excessively deviant pixels (\pm three standard deviations) are removed.

9) Column Noise

After all rows are averaged together. Shading (low frequency change wrt column address) is removed. A frequency histogram is constructed of the resulting column values. The column noise is the standard deviation of the frequency histogram of the column values.

10) Row Noise

All columns are averaged together. Shading (low frequency change wrt row address) is removed. A frequency histogram is constructed of the resulting row values. The row noise is the standard deviation of the frequency histogram of the row values.

11) Maximum Photoresponse Non-Linearity

The photoresponse non-linearity is defined as the deviation from the best fit of the sensor response using 70% of saturation and zero signal as the reference points. The different signal levels are determined by varying the integration time. The sensor saturation level is (1023-dark offset). The dark offset is subtracted from the image for the following M_{AVG} and L_{AVG} .

- The integration time is varied until the integration time required to reach the 70% saturation is determined.
 M_{AVG} = the active array mean at the 70% saturation integration time.
- The integration is set to 1/14 (5% exposure point).
 L_{AVG} = meant at the 5% exposure point.
- PRNL (@ 5% saturation) = $((L_{AVG}/M_{AVG}) \cdot (14/1) - 1) \cdot 100$

12) Maximum Gain Difference between Outputs

The sensor contains two ADC and four channels of analog data in its highest frame rate configuration. The sensor is factory calibrated to reduce the gain differences between the channels. The gain variations are manifest as a row oriented pattern where every other row uses a different ADC. Using triple scan read out mode, an additional two analog channels are introduced resulting in a four row pattern. With one channel ('Top Ping') used as the reference, the residual gain difference is defined as:

$$\left(\frac{\text{Bottom Ping Row Average}}{\text{Top Ping Row Average}} - 1 \right) \cdot 100$$

$$\left(\frac{\text{Top Pong Row Average}}{\text{Top Ping Row Average}} - 1 \right) \cdot 100$$

$$\left(\frac{\text{Bottom Pong Row Average}}{\text{Top Ping Row Average}} - 1 \right) \cdot 100$$

13) Photodiode Dark Current

The photodiode dark current is measured in rolling shutter read out mode using 105 ms integration time and an analog gain = 8. The value is converted to electrons/pix/sec using the formula:

$$\text{Photodiode Dark Current} = \text{Aver. Signal (DN)} \cdot \frac{\text{el-per-DN (gain=8)}}{0.105 \text{ seconds}}$$

where 'average signal (DN)' is the average of all pixels in the sensor array, and 'el-per-DN (gain=8)' is measured on each sensor using the photon transfer method.

14) Storage Node Dark Current

The storage node dark current is measured in global shutter read out mode using a special timing mode to prevent the photodiode dark current from being transferred to the storage node. In global shutter mode, the integration time of the storage node is the time it takes to read out a frame. The sensor analog gain is set to 2:

$$\text{Storage Node Dark Current} = \text{Aver. Signal (DN)} \cdot \frac{\text{el-per-DN (gain=2)}}{0.138 \text{ seconds}}$$

where 'average signal (DN)' is the average of all pixels in the sensor array and 'el-per-DN (gain=2)' is measured on each sensor using the photon transfer method.

15) Lag

Lag is measured as the number of electrons left in the photodiode after readout when the sensor is illuminated at 70% of Photodiode Charge Capacity.

Analog gain is set to 8. With no illumination a 64 average dark image is recorded (Dark_ref). The 'el-per-DN' is measured using the photon transfer method.

Illumination is adjusted blink every other frame such that the mean image output is 70% of the Photodiode Charge Capacity for even frames, and with no illumination for odd frames. A 64 frame average of Odd Dark Frames is recorded as Dark_Lag.

$$\text{Lag} = (\text{Dark_Lag} - \text{Dark_Ref}) \cdot \text{el-per-DN}$$

Units : Electrons rms

16) Photodiode Charge Capacity

The sensor analog gain is reduced to < 1 to prevent ADC clipping at 1023 dn. The 'el-per-DN' is measured using the photon transfer method. The sensor is illuminated at a light level ~1.5x the illumination at which the pixel output no longer linearly changes with illumination level. The Photodiode Charge Capacity is equal to the average signal (DN) · el-per-DN. Units: electrons rms.

17) Dark Field Faint Column/Row Defect

A 4 frame average, no illumination image is acquired at one line time of integration. Major defective pixels are removed (> 5 Sigma). All columns or rows are averaged together. The average of the local ROI of 128 columns or rows about the column/row being tested is determined. Any columns/rows greater than the local average by more than the threshold are identified.

18) Bright Field Faint Column/Row Defect

A 4 frame average, 70% illumination image is acquired at one line time of integration. Major defective pixels are removed (> 5 Sigma). All columns or rows are averaged together. The average of the local ROI of 128 columns or rows about the column/row being tested is determined. Any columns/rows greater than the local average by more than the threshold are identified.

19) Total Pixelized Noise

This test is performed with no illumination and one line of integration time. A single image is captured including both Temporal and Fixed Pattern Noise (FPN). A spatial low pass filter is applied to remove shading and deviant pixels (\pm three standard deviations) are removed. The Total Pixelized Noise is defined as one standard deviation of the frequency histogram.

20) Responsivity $ke^{-}/lux\text{-sec}$

This number is calculated by integrating the multiplication of the sensor QE by the human photopic response assuming a 3200K light source with a QT100 IR filter. This is a sharp 650 nm cutoff filter. If the IR filter is removed a higher response value will result.

21) Responsivity $V/lux\text{-sec}$

Voltage levels are not output from the sensor. This metric uses the pixel output in volts at the ADC input for 1x Analog Gain.

OPERATION

This section is a brief discussion of the most common features and functions assuming default conditions. See the *KAC-12040 User Guide* for a full explanation of the sensor operation modes, options, and registers.

Register Address

The last bit of any register address is a Read/Write bit. Most references in this document refer to the Write address.

All SPI reads are to an even address, all SPI writes are to an odd address.

Sensor States

Figure 12 shows the sensor states, see the *KAC-12040 User Guide* for detailed explanation of the States.

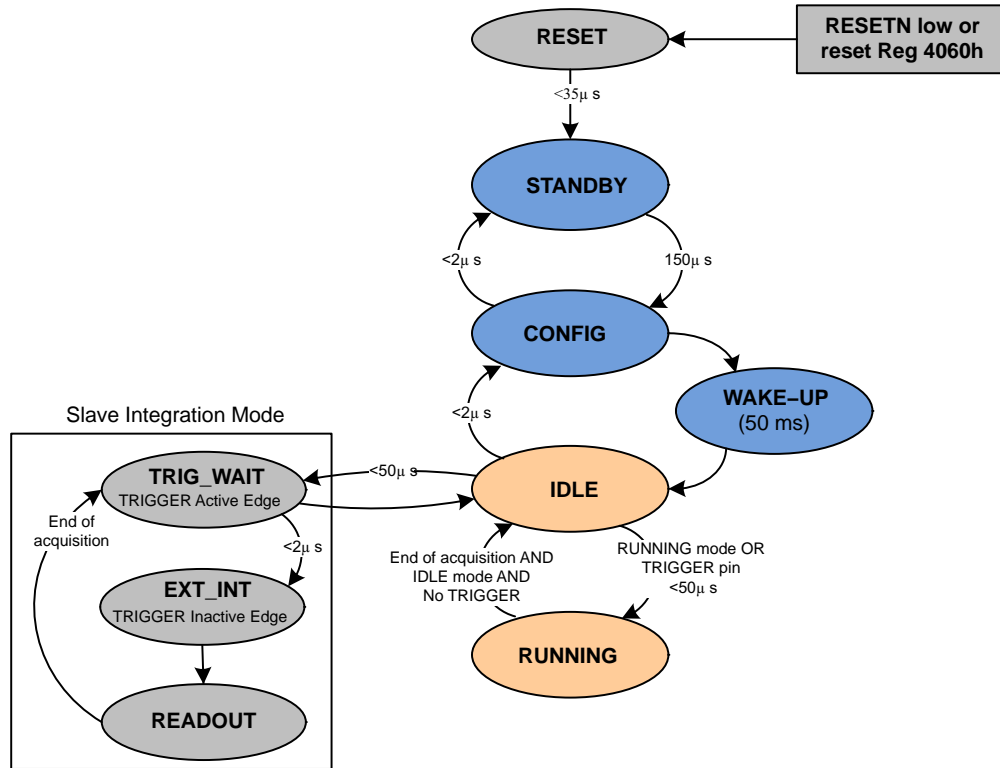


Figure 12. Sensor State Diagram

Encoded Syncs

To facilitate system acquisition synchronization the KAC-12040 places synchronization words (SW) at the beginning and at the end of each output row as indicated in

the following Figure 13. This is performed for each of the 8 LVDS output banks providing frame, line, and output synchronization. See the *KAC-12040 User Guide* for additional detail on LVDS and Encoded Sync output.

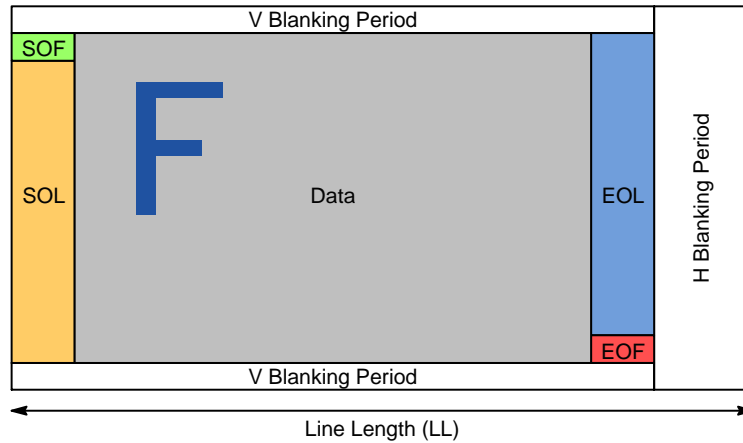


Figure 13. Encoded Frame Syncs

Line Time

This Datasheet presumes the recommended startup script that is defined in the *KAC-12040 User Guide* has been applied. The KAC-12040 defaults to Dual-Scan mode. In this mode the LVDS data readout overlaps the pixel readout and ADC conversion time. The Pixel and ADC conversion time are fixed (for 10 bit operation) and total $\sim 8.66 \mu\text{s}$. The LVDS time will be dependent on the PLL2 frequency selected. If the $\text{PLL2} < 313 \text{ MHz}$, then the LVDS data readout will dominate the row time. For $\text{PLL2} > 313 \text{ MHz}$, the Pixel + ADC will set the minimum Line Time. The Line Time is not impacted by the selection of Rolling Shutter or Global Shutter mode.

The KAC-12040 architecture always outputs two rows at once, one row from the top ADC, and one from the bottom ADC. Each ADC then divides up the pixel into $1 \rightarrow 4$ parallel pixel output LVDS Banks. The default is 4 output banks per ADC for a total of 8 parallel pixel outputs to minimize the LVDS data output time. Since the sensor always outputs 2 rows at a time the timing and registers are based on a Line Time (LT) or Line Length (LL) where one $\text{LT} =$ the time to readout 2 rows in parallel (one even row and one odd row).

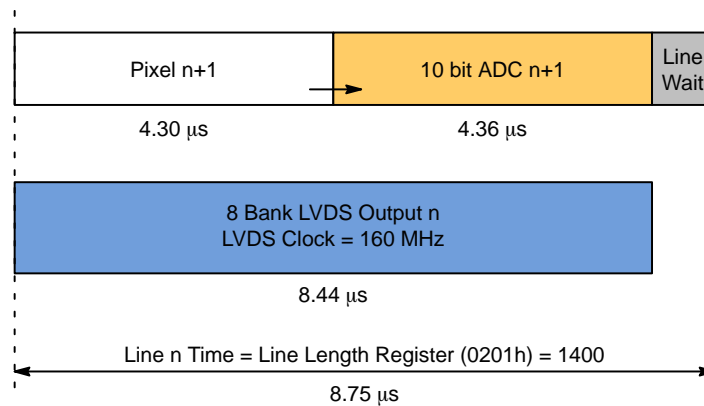


Figure 14. Default Line Time (Dual-Scan) with PLL2 = 320 MHz

Frame Time

The frame time is defined in units of Line Time. 1 Line Time unit = 2 output rows. To first-order the frame rate is not directly impacted by selection of Global Shutter, Rolling Shutter, Dual-Scan, or Tri-Scan.

The Frame Time is made up of three phases:

1. Integration Phase
2. Readout Phase
3. Frame Wait Phase (Vertical Blanking, V_{BLANK})

By default the Integration Phase overlaps the Readout and Frame Wait Phases. If the Integration Phase is larger than the Readout + Frame Wait time, then the Integration Phase will determine the video frame rate. Otherwise the frame rate will be set by the Readout + Frame Wait time. In other words, if the programmed integration time is larger than the minimum readout time (and vertical blanking) then extra vertical blanking will be added and the frame rate will slow to accommodate the requested integration time.

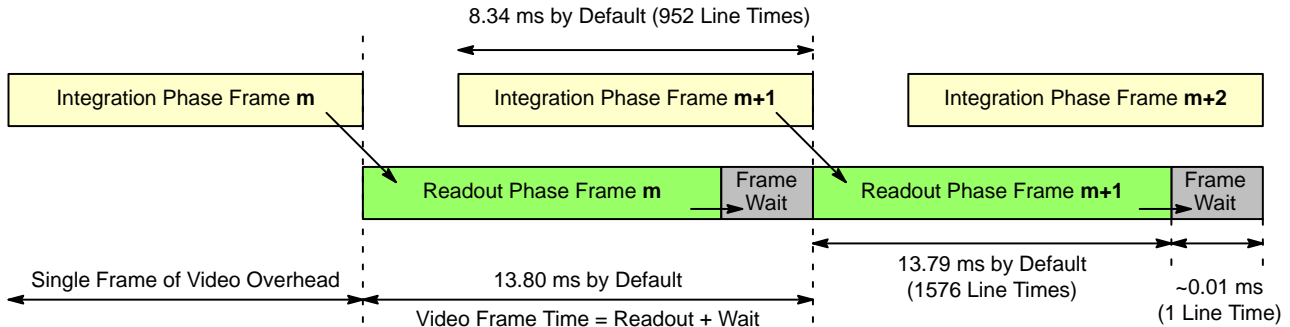


Figure 15. Default Frame Time Configuration (Frame A)

If the Integration Phase is less than the Readout Phase then the start of integration is automatically delayed to minimize the storage time and dark current.

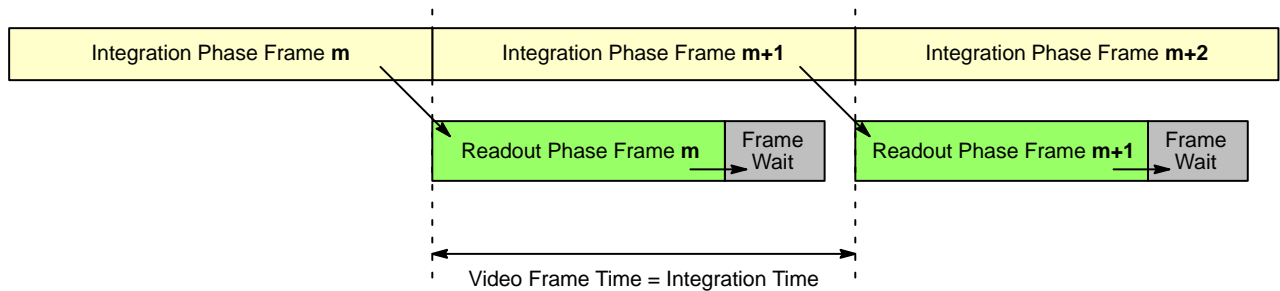


Figure 16. Frame Time with Extended Integration Time

If the Readout Phase (+ $V_{BLANKING}$) is less than the Integration Phase, then the readout occurs as soon the integration is complete to minimize the storage time and dark current.

See the *KAC-12040 User Guide* for detailed calculation of the Integration Phase, Readout Phase, and Frame Wait.

To first-order the Readout Phase is equal to the number of rows \cdot row_time.

Global Shutter Readout

Global Shutter readout provides the maximum precision for freezing scene motion. Any motion artifacts will be 100% defined by an ideal integration time edge. Every pixel in the array starts and stops integration at the same time.

Figure 17 illustrates a Global Shutter Frame readout assuming the recommended Start-up Script defined in the *KAC-12040 User Guide* (8 LVDS banks, Dual-Scan, 8.75 μ s line time). The Frame Wait Phase is not shown due to its small default size (1 LL) and for clarity.

Global Shutter readout mode is selected using Bits [1:0] of Register 01D1h.

Images can be initiated by setting and holding the TRIGGER input pin or by placing the sensor into RUNNING mode by writing 03d to register 4019h. If the TRIGGER input pin is true when at the start of the integration time for the next frame then the sensor will complete an additional frame integration and readout. In the case shown in Figure 17 two frames will be output.

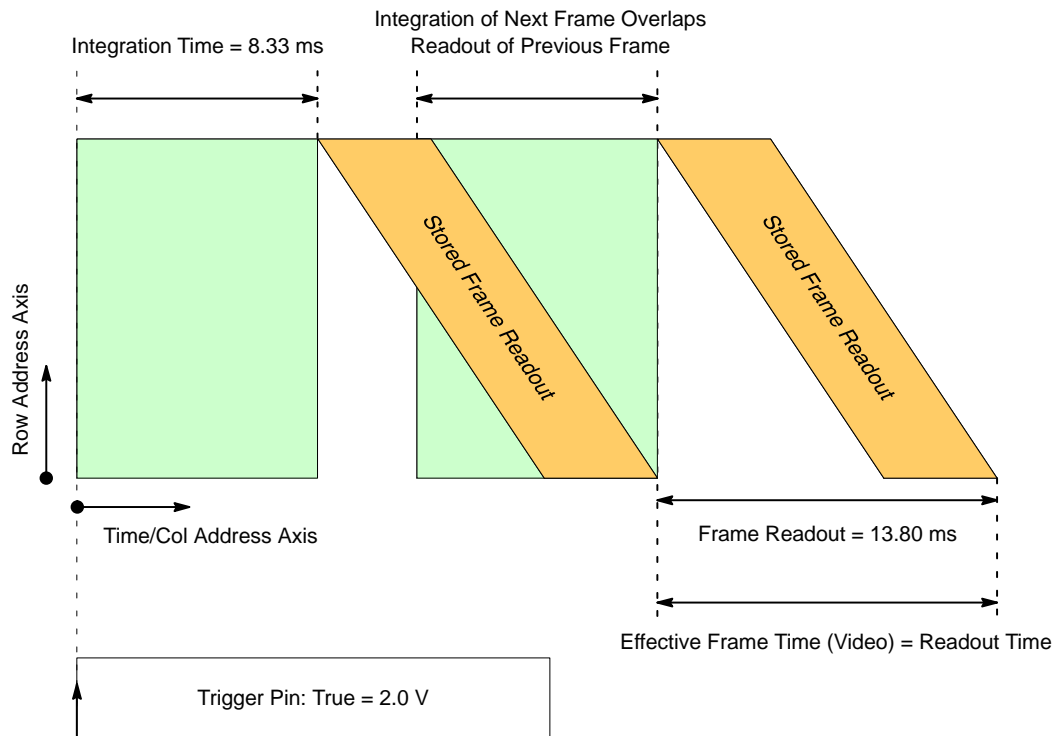


Figure 17. Illustration of Frame Time for Global Shutter Readout

Rolling Shutter Readout

The KAC-12040 high speed Rolling Shutter readout provides the maximum dynamic range while still providing excellent motion capture. In Rolling Shutter the readout more closely matches a film camera shutter. Each row of the image receives the same integration time, but each row starts and ends at a different time as the shutter travels from the top

of the array to the bottom. In the Figure 18 frame time illustration this 'moving shutter' displays as a sloped edge for the blue pixel array region, just as the readout edge is sloped.

The Figure 18 illustration shows a 2 frame output sequence using the external TRIGGER pin.

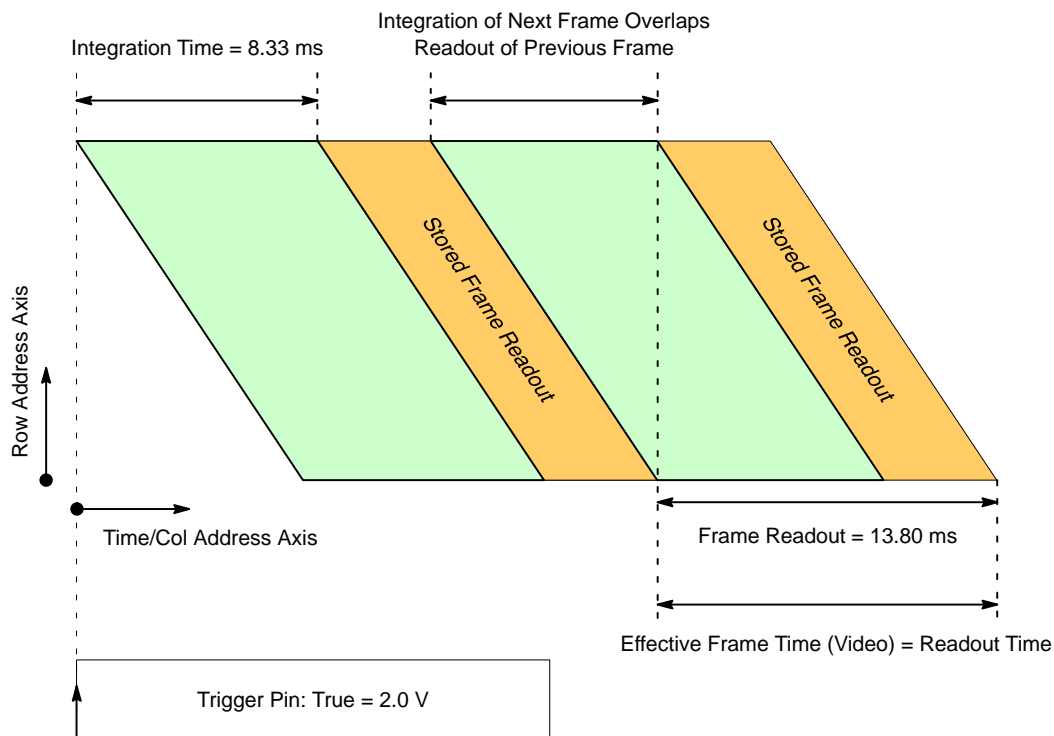


Figure 18. Illustration of Frame Time for Rolling Shutter Readout

Rolling Readout mode can be selected using Bits [1:0] of Register 01D1h.

Images can be initiated by setting and holding the TRIGGER input pin or by placing the sensor into

RUNNING mode by writing 03d to register 4019h. If the TRIGGER input pin is True when at the start of the integration time for the next frame then the sensor will complete an additional frame integration and readout.

8 BANK LVDS DATA READOUT

LVDS Banks

The KAC-12040 provides 8 parallel pixel banks, each consisting of 8 LVDS differential pairs (7 data pairs + 1 clock pair). This allows the output of 8 pixels per LVDS clock

period. All 7 data pairs, of each bank, are used only in 14 bit operation mode. By default only 5 data pairs are used for 10 bit mode (D4 → D0). The unused pairs are held in low-power high impedance mode.

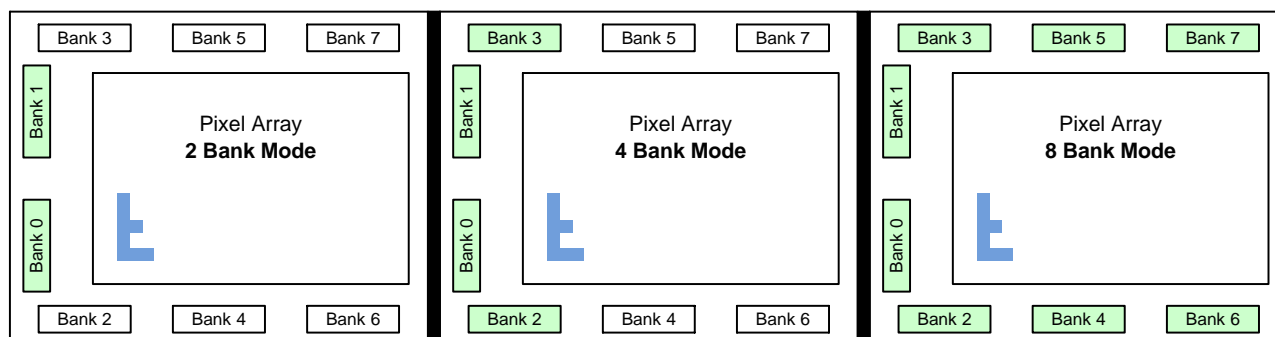


Figure 19. LVDS Bank Labeling

The number of output banks used is independent of the ADC bit depth chosen. By default the KAC-12040 uses all 8 output banks for maximum frame rate. If technical restrictions prevent the use of 8 LVDS banks, the sensor can be programmed to use 4 or 2 banks, however this can result in reduced frame rate and reduction of image quality. It is recommended that 8 banks be used when possible. Only the 8 bank option is discussed in detail in this specification, see the *KAC-12040 User Guide* for additional detail on 4 and 2 bank mode.

In order to minimize the LVDS clock rate (and power) for a given data rate the pixels are output in DDR (Double Data Rate) where the MSB is always sent first (on rising edge) and the LSB second (falling edge) This is not programmable.

Ports per LVDS Bank

The MSB comes out first on the falling edge, followed by the LSB on the net rising edge.

Table 13. NUMBER OF LVDS PAIRS (PORTS) USED VS. BIT DEPTH

| Bit Depth | Edge of DATA CLK | Data0 | Data1 | Data2 | Data3 | Data4 | Data5 | Data6 |
|-----------|----------------------|-------|-------|-------|-------|-------|-------|-------|
| 14 bits | Falling (MSB Nibble) | D7 | D8 | D9 | D10 | D11 | D12 | D13 |
| | Rising (LSB Nibble) | D0 | D1 | D2 | D3 | D4 | D5 | D6 |
| 12 bits | Falling (MSB Nibble) | D6 | D7 | D8 | D9 | D10 | D11 | HiZ |
| | Rising (LSB Nibble) | D0 | D1 | D2 | D3 | D4 | D5 | HiZ |
| 10 bits | Falling (MSB Nibble) | D5 | D6 | D7 | D8 | D9 | HiZ | HiZ |
| | Rising (LSB Nibble) | D0 | D1 | D2 | D3 | D4 | HiZ | HiZ |
| 8 bits | Falling (MSB Nibble) | D4 | D5 | D6 | D7 | HiZ | HiZ | HiZ |
| | Rising (LSB Nibble) | D0 | D1 | D2 | D3 | HiZ | HiZ | HiZ |

8 Bank Pixel Order

The KAC-12040 always processes two rows at a time. Even row decodes are sent to the bottom ADC and LVDS output banks (0, 2, 4, 6). Odd rows are sent to the top ADC and LVDS banks (1, 3, 5, 7). The ROI must be (and is internally forced to) an even size and always starting on an even row decode.

The rows are read out progressively left to right (small column address to large). Eight pixels are sent out of the chip at once, one pixel per LVDS bank per LVDS clock cycle.

Pixel Readout order:

1. Two rows are selected, the even row is sent to the bottom ADC and the odd row to the top ADC.
2. Each ADC converts its row of pixel data at once and stores the result in a line buffer.
3. At default settings there are 4 output LVDS banks for each ADC.

4. Each LVDS Bank outputs one pixel per clock cycle, so 4 pixels of each row are output each full LVDS clock cycle, two rows in parallel for 8 pixels per clock cycle total.
5. The pixels are sent out from left to right (low column number to high column number). So the first 4 pixels are sent out on clock cycle 1, and the next 4 pixels to the right are sent out on clock cycle 2.
6. To conserve the number of wires per port, the 10 bits per pixel are sent out DDR (Dual Data Rate) over 5 ports. On the falling edge the upper 5 MSB bits are sent out, and on the rising edge the lower 5 bits LSB are sent out. Completing one full LVDS clock cycle and one set of eight pixels.

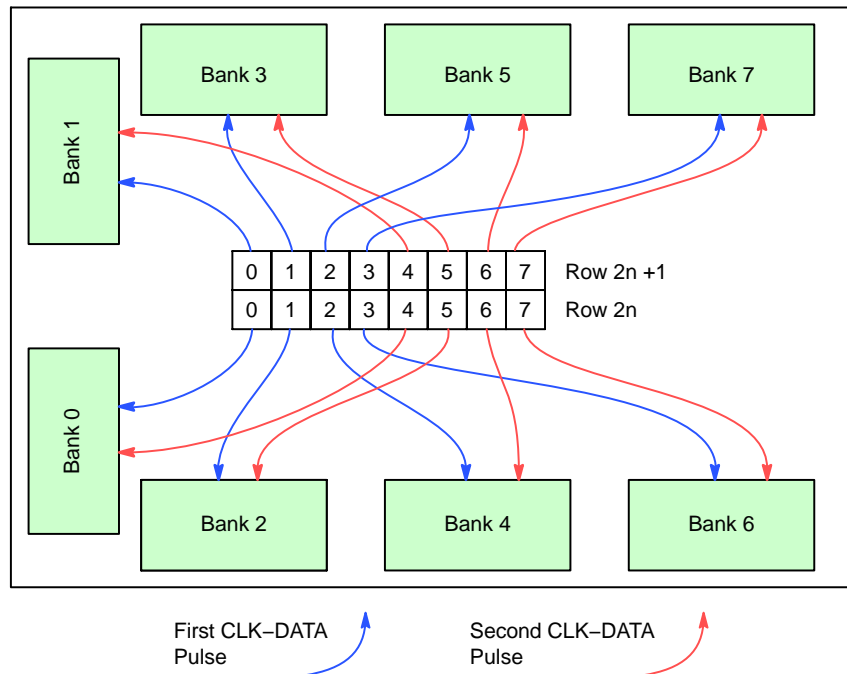


Figure 20. Pixel Readout Order Diagram

Table 14. PIXEL READOUT ORDER TABLE

| LVDS Bank | Row | Pixel Number | | | | |
|------------------|------------|--------------|---|----|----|----|
| Bank 0 | 2n (Even) | 0 | 4 | 8 | 12 | 16 |
| Bank 2 | 2n (Even) | 1 | 5 | 9 | 13 | 17 |
| Bank 4 | 2n (Even) | 2 | 6 | 10 | 14 | 18 |
| Bank 6 | 2n (Even) | 3 | 7 | 11 | 15 | 19 |
| Bank 1 | 2n+1 (Odd) | 0 | 4 | 8 | 12 | 16 |
| Bank 3 | 2n+1 (Odd) | 1 | 5 | 9 | 13 | 17 |
| Bank 5 | 2n+1 (Odd) | 2 | 6 | 10 | 14 | 18 |
| Bank 7 | 2n+1 (Odd) | 3 | 7 | 11 | 15 | 19 |
| LVDS Clock Cycle | | 1 | 2 | 3 | 4 | 5 |

And each of the active LVDS banks each output all 4 sync codes for the EOL/EOF.

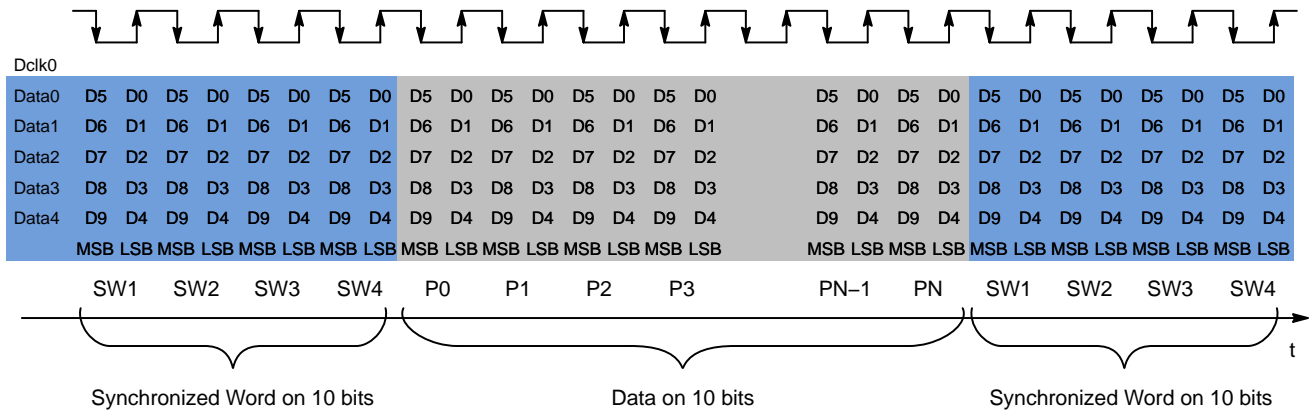


Figure 21. Data Stream of One LVDS Bank for 10 bits ADC Resolution

REGISTER DEFINITION

Table 15. REGISTER DEFINITION

| 16 bit Write Address (Hex) | Default Value Hex/Dec | SPI State | Group | Register Name |
|-------------------------------|--------------------------|-----------|--------------------|----------------------------|
| 0001 | 420d | Any | Frame A Definition | Frame A ROI y1 |
| 0009 | 2176d | Any | Frame A Definition | Frame A ROI h1 |
| 0011 | 80d | Any | Frame A Definition | Frame A ROI x1 |
| 0019 | 3856d | Any | Frame A Definition | Frame A ROI w1 |
| 0021 | 0d | Any | Frame A Definition | Frame A sub-ROI y2 |
| 0029 | 0d | Any | Frame A Definition | Frame A sub-ROI h2 |
| 0031 | 0d | Any | Frame A Definition | Frame A sub-ROI x2 |
| 0039 | 0d | Any | Frame A Definition | Frame A sub-ROI w2 |
| 0041 | 0d | Any | Frame A Definition | Frame A sub-ROI y3 |
| 0049 | 0d | Any | Frame A Definition | Frame A sub-ROI h3 |
| 0051 | 0d | Any | Frame A Definition | Frame A sub-ROI x3 |
| 0059 | 0d | Any | Frame A Definition | Frame A sub-ROI w3 |
| 0061 | 0d | Any | Frame A Definition | Frame A sub-ROI y4 |
| 0069 | 0d | Any | Frame A Definition | Frame A sub-ROI h4 |
| 0071 | 0d | Any | Frame A Definition | Frame A sub-ROI x4 |
| 0079 | 0d | Any | Frame A Definition | Frame A sub-ROI w4 |
| 0081 | 0033d | Any | Frame A Definition | Frame A Decimation |
| 0089 | 0d | Any | Frame A Definition | Frame A Video Blanking |
| 0091 | 800d | Any | Frame A Definition | Frame A Integration Lines |
| 0099 | 0d | Any | Frame A Definition | Frame A Integration Clocks |
| 00A1 | 10d | Any | Frame A Definition | Frame A Black Level |
| 00A9 | 001Fh | Any | Frame A Definition | Frame A Gain |
| 00E9 | 0d | Any | Frame B Definition | Frame B ROI y1 |
| 00F1 | 3016d | Any | Frame B Definition | Frame B ROI h1 |
| 00F9 | 0d | Any | Frame B Definition | Frame B ROI x1 |
| 0101 | 4016d | Any | Frame B Definition | Frame B ROI w1 |
| 0109 | 0d | Any | Frame B Definition | Frame B sub-ROI y2 |
| 0111 | 0d | Any | Frame B Definition | Frame B sub-ROI h2 |
| 0119 | 0d | Any | Frame B Definition | Frame B sub-ROI x2 |
| 0121 | 0d | Any | Frame B Definition | Frame B sub-ROI w2 |
| 0129 | 0d | Any | Frame B Definition | Frame B sub-ROI y3 |
| 0131 | 0d | Any | Frame B Definition | Frame B sub-ROI h3 |
| 0139 | 0d | Any | Frame B Definition | Frame B sub-ROI x3 |
| 0141 | 0d | Any | Frame B Definition | Frame B sub-ROI w3 |
| 0149 | 0d | Any | Frame B Definition | Frame B sub-ROI y4 |
| 0151 | 0d | Any | Frame B Definition | Frame B sub-ROI h4 |
| 0159 | 0d | Any | Frame B Definition | Frame B sub-ROI x4 |
| 0161 | 0d | Any | Frame B Definition | Frame B sub-ROI w4 |
| 0169 | 033h | Any | Frame B Definition | Frame B Decimation |
| 0171 | 0d | Any | Frame B Definition | Frame B Video Blanking |
| 0179 | 800d | Any | Frame B Definition | Frame B Integration Lines |
| 0181 | 0d | Any | Frame B Definition | Frame B Integration Clocks |
| 0189 | 10d | Any | Frame B Definition | Frame B Black Level |
| 0191 | 001Fh | Any | Frame B Definition | Frame B Gain |

Table 15. REGISTER DEFINITION (continued)

| 16 bit Write Address (Hex) | Default Value Hex/Dec | SPI State | Description |
|-------------------------------|--------------------------|----------------|----------------------------|
| 01D1 | CC11h | CONFIG Only | Config1 |
| 01D9 | 0000h | CONFIG or IDLE | Config2 |
| 01E1 | 000Ah | CONFIG or IDLE | Analog/Digital Power Mode |
| 01E9 | 0000h | CONFIG or IDLE | Dual-Video Repetition |
| 01F1 | 0d | CONFIG or IDLE | Vertical Blanking |
| 01F9 | 1938d | CONFIG or IDLE | Fixed Frame Period |
| 0201 | 1376d | CONFIG or IDLE | Line Length (LL) |
| 0209 | 0028h | CONFIG or IDLE | ADC Bit Depth |
| 0211 | 0000h | CONFIG or IDLE | FLO Edge |
| 0219 | 0000h | CONFIG or IDLE | MSO Edge |
| 0709 | 0000h | Any | CFA Feedback |
| 0711 | 0000h | Any | Temperature Sensor FB |
| 0719 | 0000h | Any | General Feedback |
| 2059 | 0300h | CONFIG Only | Output Bank Select 1 |
| 2099 | 2877h | CONFIG Only | PLL1 Setting |
| 20A1 | 0861h | CONFIG Only | PLL2 Setting |
| 2449 | 0432h | CONFIG Only | Sub-LVDS Enable |
| 2479 | 10ABh | Any | Column Clamp Threshold A |
| 2481 | 20C7h | Any | Column Clamp Threshold B |
| 2499 | 0011h | CONFIG or IDLE | Test Pattern Control 1 |
| 24A1 | 0220h | CONFIG or IDLE | Test Pattern Control 2 |
| 24B9 | 202d | CONFIG Only | Slope 1 Length |
| 24C1 | 101d | CONFIG Only | Slope 2 Length |
| 24C9 | 101d | CONFIG Only | Slope 3 Length |
| 24D1 | 101d | CONFIG Only | Slope 4 Length |
| 24D9 | 101d | CONFIG Only | Slope 5 Length |
| 24E1 | 420d | CONFIG Only | Slope 6 Length |
| 24E9 | 0083g | CONFIG Only | Slope 1/2 Gain |
| 24F1 | 038Fh | CONFIG Only | Slope 3/4 Gain |
| 24F9 | 0FBFh | CONFIG Only | Slope 5/6 Gain |
| 2501 | 1F9Fh | CONFIG Only | Slope 7 Gain |
| 2559 | 4804h | Any | Defect Avoidance Threshold |
| 2561 | 0006h | Any | Defect Avoidance Enable |
| 25C1 | 0003h | CONFIG or IDLE | Encoded Sync Config |
| 25C9 | 000Ah | CONFIG Only | LVDS Power-Down |
| 2619 | 000Bh | CONFIG Only | Output Bank Select 2 |
| 2D89 | 0000h | CONFIG Only | FLO/MSO Polarity |
| 4001 | 4100h | Any | Chip Revision Code |
| 4009 | 0011h | Any | Chip ID Code MSB |
| 4011 | 0080h | Any | Chip ID Code LSB |
| 4019 | 0000h | Any | Set Sensor State |
| 4021 | 0000h | CONFIG or IDLE | OTP Address |

Table 15. REGISTER DEFINITION (continued)

| 16 bit Write Address (Hex) | Default Value Hex/Dec | SPI State | Description |
|-------------------------------|--------------------------|----------------|-----------------|
| 4029 | 0000h | CONFIG or IDLE | OTP Write Data |
| 4031 | 0000h | CONFIG or IDLE | Command_Done_FB |
| 4041 | 0000h | CONFIG or IDLE | OTP Read Data |
| 4061 | 0000h | CONFIG or IDLE | Soft Reset |

NOTES: SPI State (the Sensor State from which the register can be set):

1. "Any": Can be written from any state (including RUNNING).
2. "CONFIG or IDLE": These registers can be changed in IDLE or CONFIG states.
3. "CONFIG Only": Sensor must be in CONFIG state to set these registers.
4. Only Register 4018h and 4060h may be set when the sensor is in STANDBY state.

NOTES: Decimal, hexadecimal, binary values:

1. "b" denotes a binary number, a series of bits: MSB is on the left, LSB is on the right.
2. "h" or "hex" denotes a hexadecimal number (Base 16, 1–9, A–F). The letters in a hex number are always capitalized.
3. "d" denotes a decimal number.
4. Note that "0" and "1" are the same value in all number base systems and sometimes the base notation is omitted.

The KAC-12040 features an embedded microprocessor by Cortus.

ABSOLUTE MAXIMUM RATINGS

For Supplies and Inputs the maximum rating is defined as a level or condition that should not be exceeded at any time. If the level or the condition is exceeded, the device will be

degraded and may be damaged. Operation at these values will reduce Mean Time to Failure (MTTF).

Table 16. SUPPLIES

| Description | Value |
|-----------------------------------|---------------------------|
| AVDD_LV, VDD_DIG | -0.25 V; 2.3 V |
| AVDD_HV, Vref_P, VDD_LVDS | -0.25 V; 4 V |
| DC Input Voltage at Any Input Pin | -0.25 V; VDD_DIG + 0.25 V |

Table 17. CMOS INPUTS

| Parameter | Symbol | Minimum | Typical | Maximum | Unit |
|--------------------------|----------|--------------|---------|---------------|------|
| Input Voltage Low Level | V_{IL} | -0.3 | – | 0.35 VDD_DIG | V |
| Input Voltage High Level | V_{IH} | 0.65 VDD_DIG | – | VDD_DIG + 0.3 | V |

OPERATING RATINGS

Table 18. INPUT CLOCK CONDITIONS

| Parameter | Minimum | Typical | Maximum | Unit |
|------------------------------------|---------|---------|---------|------|
| Frequency for Clk_In1 and Clk_In2 | 45 | 48 | 50 | MHz |
| Duty Cycle for Clk_In1 and Clk_In2 | 40 | 50 | 60 | % |
| RESETN | 10 | – | – | ns |
| TRIGGER Pin Minimum Pulse Width | 20 | – | – | ns |

TRIGGER must be active at least 4 periods of PLL1 (~12.5 ns at 320 MHz) to start a capture cycle. The polarity of the active level is configurable by SPI (Register 01D8h Bit 0), the default is active high (i.e. pin = VDD_DIG = trigger request).

Table 19. OPERATING TEMPERATURE

| Description | Symbol | Minimum | Maximum | Unit |
|--------------------------------|-----------------|---------|---------|------|
| Operating Temperature (Note 1) | T _{OP} | –40 | 80 | °C |

1. Under conditions of no condensation on the sensor.

Table 20. CMOS IN/OUT CHARACTERISTICS

| Parameter | Symbol | Minimum | Typical | Maximum | Unit |
|--|----------------------|----------------|---------|---------|------|
| Output Voltage Low Level | V _{OL} | – | – | 0.45 | V |
| Output Voltage High Level | V _{OH} | VDD_DIG – 0.45 | – | – | V |
| Input Hysteresis Voltage | V _{TH} | – | 0.25 | – | |
| Pull-up Resistor Value for RESETN Pin | R _{PU} | 62 | – | – | kΩ |
| Pull-down Resistor Value for TRIGGER Pin | R _{PD} | 100 | – | – | kΩ |
| Current on ADC_REF Pin | I _{ADC_REF} | – | 100 | – | μA |

Table 21. SUPPLIES

| Parameter | Symbol | Minimum | Typical | Maximum | Unit |
|--------------------------------|----------|---------|---------|---------|------|
| LVDS IO Supply | VDD_LVDS | 3.15 | 3.30 | 3.63 | V |
| Pixel High Voltage Supply | AVDD_HV | 3.40 | 3.50 | 3.60 | V |
| Pixel Low Voltage Supply | Vref_P | 2.71 | 2.80 | 2.88 | V |
| Analog Power Supply | AVDD_LV | 1.71 | 1.80 | 1.89 | V |
| Digital Power Supply | VDD_DIG | 1.90 | 2.00 | 2.10 | V |
| AVDD_HV – Vref_P | | – | 0.5 | – | V |
| Power in STANDBY State | | – | 10 | – | mW |
| Current in STANDBY State | | | | | mA |
| VDD_LVDS | | – | < 0.5 | – | |
| AVDD_HV | | – | < 0.5 | – | |
| AVDD_LV | | – | < 0.5 | – | |
| Vref_P | | – | < 0.5 | – | |
| VDD_DIG | | – | 4 | – | |
| Power in CONFIG State | | – | 330 | – | mW |
| Current in CONFIG State | | | | | mA |
| VDD_LVDS | | – | < 0.5 | – | |
| AVDD_HV | | – | < 0.5 | – | |
| AVDD_LV | | – | < 0.5 | – | |
| Vref_P | | – | < 0.5 | – | |
| VDD_DIG | | – | 145 | – | |
| Power in IDLE State | | – | 410 | – | mW |
| Current in IDLE State | | | | | mA |
| VDD_LVDS | | – | < 0.5 | – | |
| AVDD_HV | | – | 20 | – | |
| AVDD_LV | | – | < 0.5 | – | |
| Vref_P | | – | < 0.5 | – | |
| VDD_DIG | | – | 145 | – | |
| Power in RUNNING State | | – | 1.5 | – | W |
| Current in RUNNING State | | | | | mA |
| VDD_LVDS in Standard LVDS Mode | | – | 164 | – | |
| VDD_LVDS in Sub-LVDS Mode | | – | 104 | – | |
| AVDD_HV | | – | 74 | – | |
| AVDD_LV | | – | 12 | – | |
| Vref_P | | – | 26 | – | |
| VDD_DIG | | – | 396 | – | |

1. Voltages relative to VSS. Current measurements made in darkness.
2. PLL2 = 320 MHz, Max frame rate (i.e., no row or frame wait time). These average power values will decrease at lower frame rate either from reduced PLL2 or low power state during Line and Frame blanking.
3. Sub-LVDS active.

SPI (SERIAL PERIPHERAL INTERFACE)

The SPI communication interface lets the application system to control and configure the sensor. The sensor has

an embedded slave SPI interface. The application system is the master of the SPI bus.

Table 22.

| Name | Sensor I/O Direction | Description |
|------|----------------------|---|
| CSN | I | SPI Chip Select – Active low, this input activates the slave interface in the sensor. |
| SCK | I | SPI Clock – Toggled by the master. |
| MISO | O | SPI Master Serial Data Input – Slave (sensor) serial data output. |
| MOSI | I | SPI Master Serial Data Output – Slave (sensor) serial data input. |

Table 23.

| Parameter | Minimum | Typical | Maximum | Unit |
|-----------------------|---------|---------|---------|------|
| SPI SCK | 5 | 25 | 50 | MHz |
| Duty Cycle on SPI SCK | 40 | 50 | 60 | % |

Clock Polarity and Phase

CPOL (Clock POLarity) and CPHA (Clock PHase) are commonly defined in SPI protocol such as to define SCK clock phase and polarity. The KAC-12040 defaults to

expecting the master to be configured with CPOL = 1 (the base value of the clock is VDD_DIG) and CPHA = 1 (data is valid on the clock rising edge).

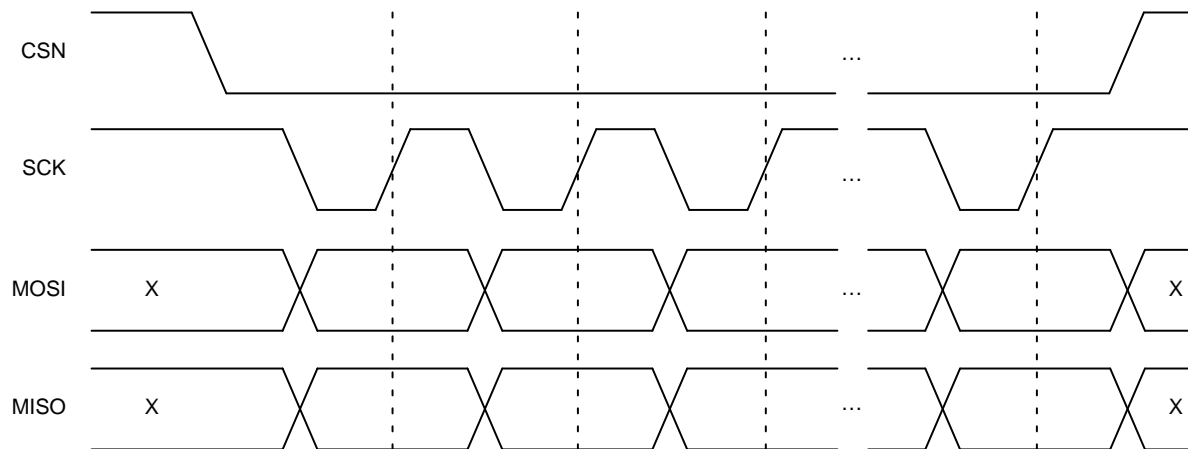


Figure 22. CPOL = 1 and CPHA = 1 Configuration

SPI Protocol

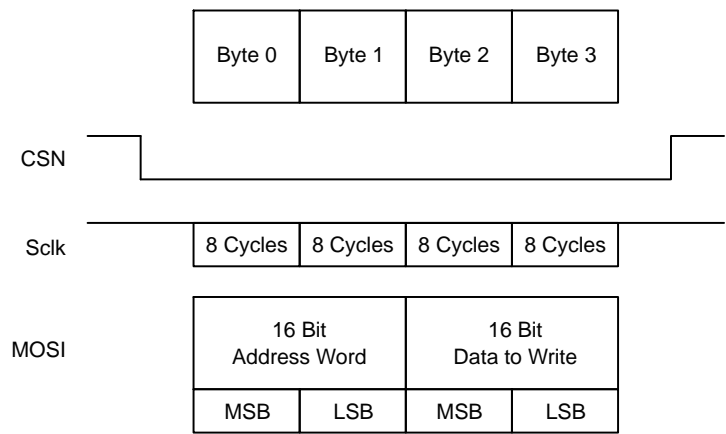


Figure 23. SPI Write Byte Order

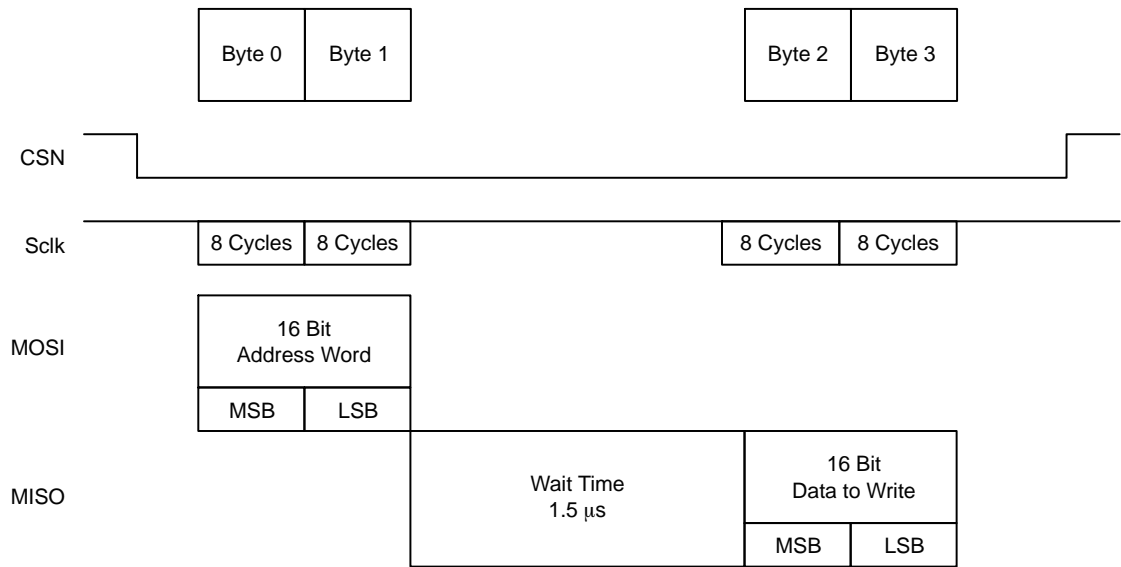


Figure 24. SPI Read Byte Order

There is a delay during readback between presenting the address to be read on the MOSI and being able to read the register contents on the MISO. This delay is not the same for all registers. Some are available immediately, some require a longer fetch time. The 1.5 μ s shown in Figure 15 is the maximum time to fetch a register's value when in CONFIG state (the recommended state for changing registers). Some registers can be adjusted during RUNNING state (see the Register Summary on page 25). If performing a readback during RUNNING state, the delay could be as long as 4.5 μ s depending on when in the row the request was sent and the sensor's microcontroller activity at that moment.

Note that readback does not provide the actual register value being used, but reflects the next value to be used. All

new register writes are placed in a shadow memory until they can be updated into the active memory. This active memory update occurs at the start of the next frame or upon entering the state listed in the Register Summary table on page 25. Register reads access this shadow memory not the active memory. For instance if the sensor is in RUNNING mode and you adjust the LL in register 200h. You can read back and confirm that your register change was received by the sensor; however, the LL will not change since register 200h can only be changed in CONFIG state. If you change the sensor state to CONFIG and then back to RUNNING, then the new LL will take effect.

SPI Interface

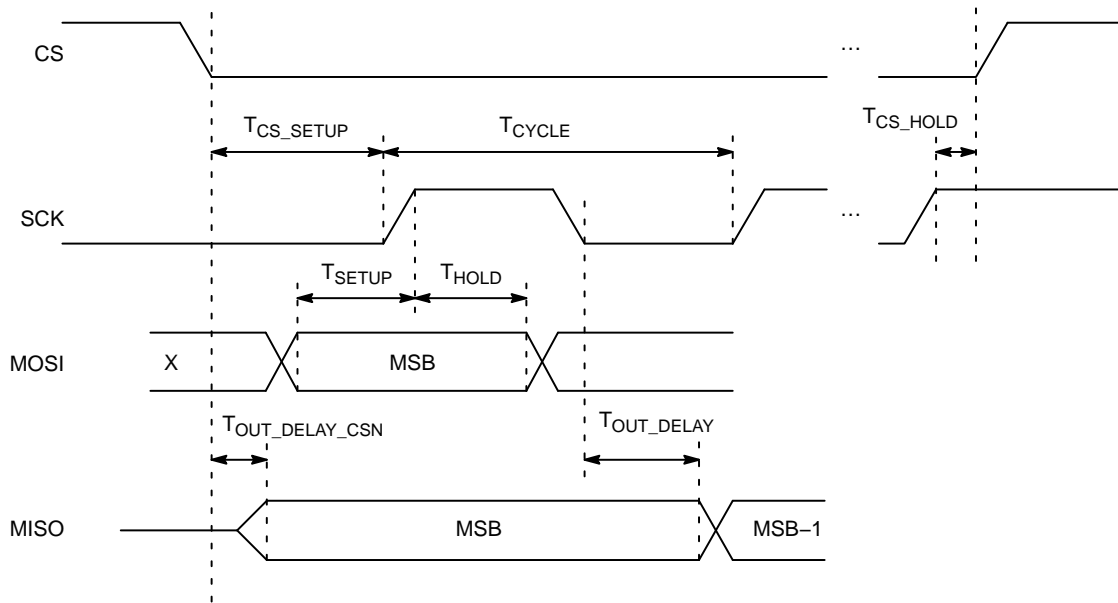


Figure 25. SPI Timing Chronogram

Table 24. SPI TIMING SPECIFICATION

| Symbol | Minimum Value | Maximum Value | Unit |
|------------------------------|---------------|---------------|------|
| T_{CYCLE} | 20 | 200 | ns |
| T_{SETUP} | – | 2.9 | ns |
| T_{HOLD} | 0.8 | – | ns |
| $T_{\text{CS_SETUP}}$ | – | 2.5 | ns |
| $T_{\text{CS_HOLD}}$ | 0.1 | – | ns |
| $T_{\text{OUT_DELAY_CSN}}$ | 3.1 | 4.7 | ns |
| $T_{\text{OUT_DELAY}}$ | 4.9 | 8.7 | ns |

LVDS INTERFACE

The data output can be configured to follow standard TIA/EIA-644-A LVDS specification or a low power mode compatible with common Sub-LVDS definition used in FPGA industry. (Please refer to the *KAC-12040 User Guide* for more information).

Unless otherwise noted, min/max characteristics are for $T = -40^{\circ}\text{C}$ to $+85^{\circ}\text{C}$, output termination resistance

$R_L = 100\ \Omega \pm 1\%$, Typical values are at $V_{DD_LVDS} = 3.3\ \text{V}$.

Use register 2449h to select standard or Sub-LVDS. This document assumes that Sub-LVDS is active for all power measurements. Standard LVDS can increase the average power consumption as much as 200 mW in the case of minimum horizontal and vertical blanking.

Table 25. STANDARD LVDS CHARACTERISTICS

| Parameter | Symbol | Minimum | Typical | Maximum | Unit |
|--|---------------------|--------------|---------|--------------|---------------|
| Differential Output Voltage | VOD | 250 | 355 | 450 | mV |
| VOD Variation between Complementary Output States | ΔVOD | -20 | - | 20 | mV |
| Common Mode Output Voltage | VOCM | 1.235 | 1.259 | 1.275 | V |
| VOCM Variation between Complementary Output States | ΔVOCM | -25 | - | 25 | mV |
| High Impedance Leakage Current | IOZD | -1 | - | 1 | μA |
| Output Short Circuit Current: When D+ or D- Connected to Ground When D+ or D- Connected to 3.3 V | IOSD | 2.9 12.25 | - - | 4.3 30.47 | mA |
| Output Capacitance | CDO | - | 1.3 | - | pF |
| Maximum Transmission Capacitance Load Expected (for 260 MHz LVDS Clock) | | - | - | 10 | pF |

Table 26. SUB-LVDS CHARACTERISTICS

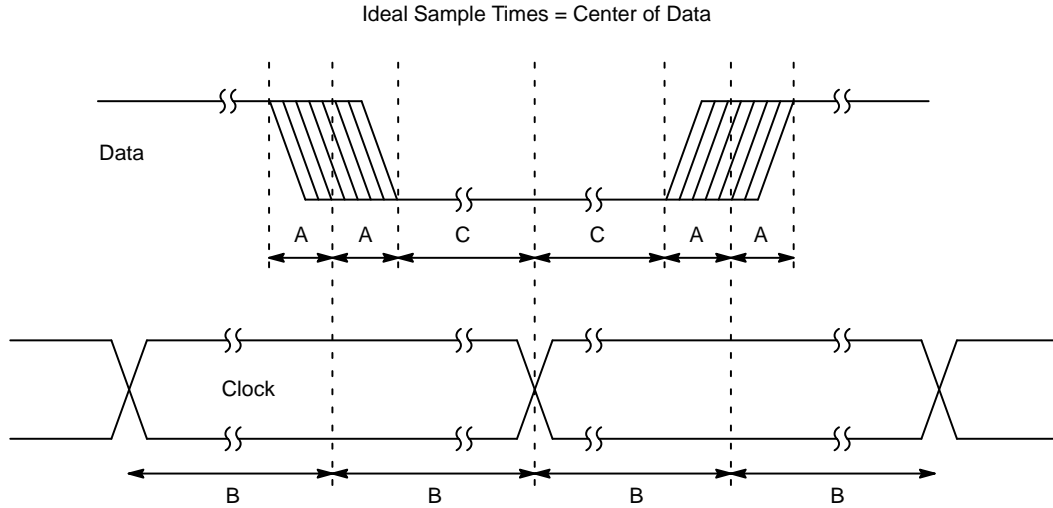
| Parameter | Symbol | Minimum | Typical | Maximum | Unit |
|--|-------------------------------|--------------|---------|--------------|---------------|
| Differential Output Voltage | V _{OD} | 140 | 180 | 220 | mV |
| VOD Variation between Complementary Output States | $\Delta\text{V}_{\text{OD}}$ | -5 | - | 5 | mV |
| Common Mode Output Voltage | V _{OCM} | 0.88 | 0.90 | 0.92 | V |
| VOCM Variation between Complementary Output States | $\Delta\text{V}_{\text{OCM}}$ | -10 | - | 10 | mV |
| High Impedance Leakage Current | I _{OZD} | -1 | - | 1 | μA |
| Output Short Circuit Current: When D+ or D- Connected to Ground When D+ or D- Connected to 3.3 V | I _{OSD} | 1.4 10.21 | - - | 2.2 30.47 | mA |
| Output Capacitance | C _{DO} | - | 1.3 | - | pF |
| Maximum Transmission Capacitance Load Expected (for 260 MHz LVDS Clock) | | - | - | 10 | pF |

Table 27.

| Parameter | Minimum | Typical | Maximum | Unit |
|------------------------|---------|---------|---------|------|
| LVDS_CLK | 50 | 160 | 160 | MHz |
| Duty Cycle on LVDS_CLK | - | 50 | - | % |

In-Block LVDS Timing Specification

The tables below give LVDS timing specifications for no data de-skew applied and with data de-skewing applied.

**Figure 26. LVDS Timing Chronogram****Table 28. IN-BLOCK LVDS TIMING SPECIFICATION** (Data Transition Uncertainty – No De-Skew Applied)

| Parameter | Value | Description |
|-----------|---------------------|---|
| A | 360 ps | Max Data Transition Uncertainty (Skew + Jitter) |
| B | LVDS Clock Period/4 | 1/4 LVDS Clock Period = 1/2 PLL2 Period |
| C | $C = B - A$ | Minimum Receiver Setup/Hold Time Sample Window |

KAC-12040 Example at Maximum PLL2 Speed (320 MHz):

LVDS Clock Frequency = $PLL2/2 = 160$ MHz
 LVDS Clock Period = 6250 ps
 $B = LVDS\ Clock\ Period/4 = 1563$ ps
 $C = B - A = 1563 - 360 = 1203$ ps

If the sampling window is too small the PLL2 can be reduced to increase the window (parameter C). Alternatively, the majority of the transition uncertainty is potential skew between the 7 data lines. Using de-skewing can remove 350 ps from the uncertainty window.

Table 29. IN-BLOCK LVDS TIMING SPECIFICATION (Data Transition Uncertainty – Data De-Skewing Applied)

| Parameter | Value | Description |
|-----------|---------------------|--|
| A | 10 ps | Max Data Transition Uncertainty (Jitter) |
| B | LVDS Clock Period/4 | 1/4 LVDS Clock Period = 1/2 PLL2 Period |
| C | $C = B - A$ | Minimum Receiver Setup/Hold Time Sample Window |

KAC-12040 Example at Maximum PLL2 Speed (320 MHz):

LVDS Clock Frequency = $PLL2/2 = 160$ MHz
 LVDS Clock Period = 6250 ps
 $B = LVDS\ Clock\ Period/4 = 1563$ ps
 $C = B - A = 1563 - 10 = 1553$ ps

Table 30. INTER-BLOCK LVDS TIMING SPECIFICATION

| Parameter | Minimum | Typical | Maximum | Unit |
|------------------|---------|---------|---------|-------------------|
| Inter-Block Skew | – | 6 | 12 | LVDS Clock Period |

STORAGE AND HANDLING

Table 31. STORAGE CONDITIONS

| Description | Symbol | Minimum | Maximum | Unit | Notes |
|---------------------|-----------------|---------|---------|------|-------|
| Storage Temperature | T _{ST} | -40 | 80 | °C | 1 |
| Humidity | RH | 5 | 90 | % | 2 |

1. Long-term storage toward the maximum temperature will accelerate color filter degradation.
2. T = 25°C. Excessive humidity will degrade MTTF.

For information on ESD and cover glass care and cleanliness, please download the *Image Sensor Handling and Best Practices* Application Note (AN52561/D) from www.onsemi.com.

For information on soldering recommendations, please download the Soldering and Mounting Techniques Reference Manual (SOLDERRM/D) from www.onsemi.com.

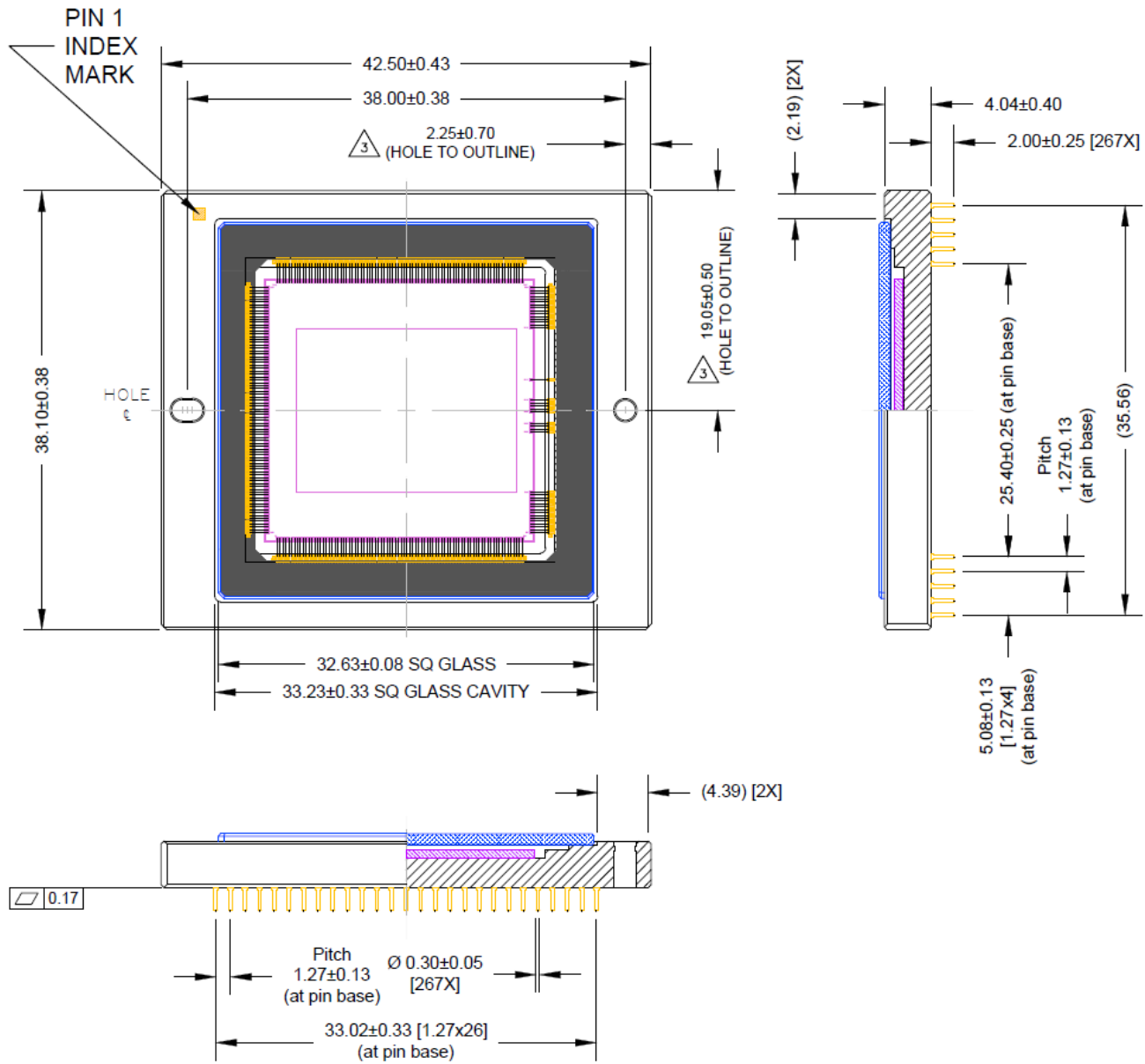
For quality and reliability information, please download the *Quality & Reliability Handbook* (HBD851/D) from www.onsemi.com.

For information on device numbering and ordering codes, please download the *Device Nomenclature* technical note (TND310/D) from www.onsemi.com.

For information on Standard terms and Conditions of Sale, please download [Terms and Conditions](http://www.onsemi.com) from www.onsemi.com.

MECHANICAL INFORMATION

Completed Assembly



Notes:

1. See Ordering Information for marking code.
2. No materials to interfere with clearance through package holes.
3. Imaging Array is centered at the package center.
4. Length dimensions in mm units.

Figure 27. Completed Assembly (1 of 5)

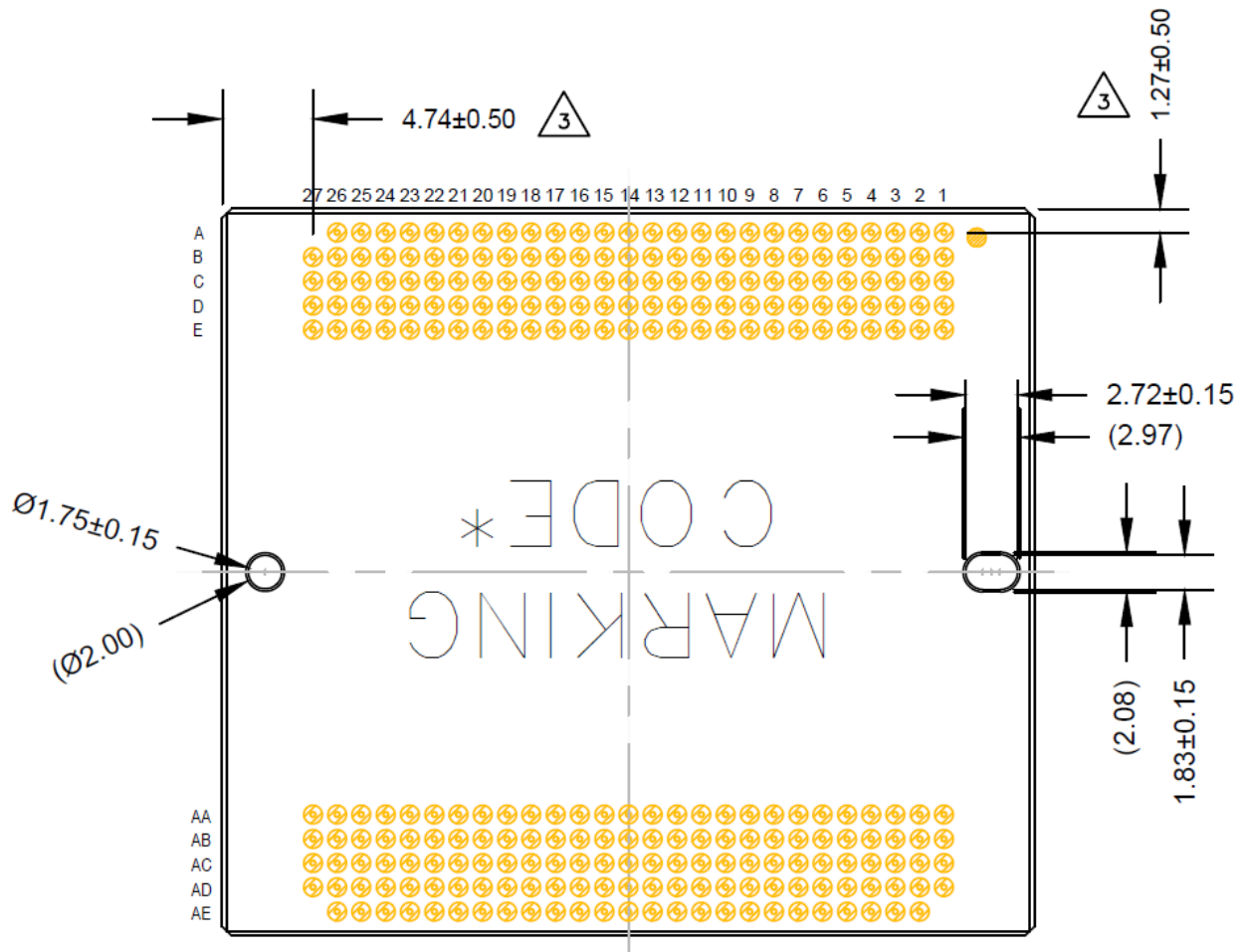


Figure 28. Completed Assembly (2 of 5)

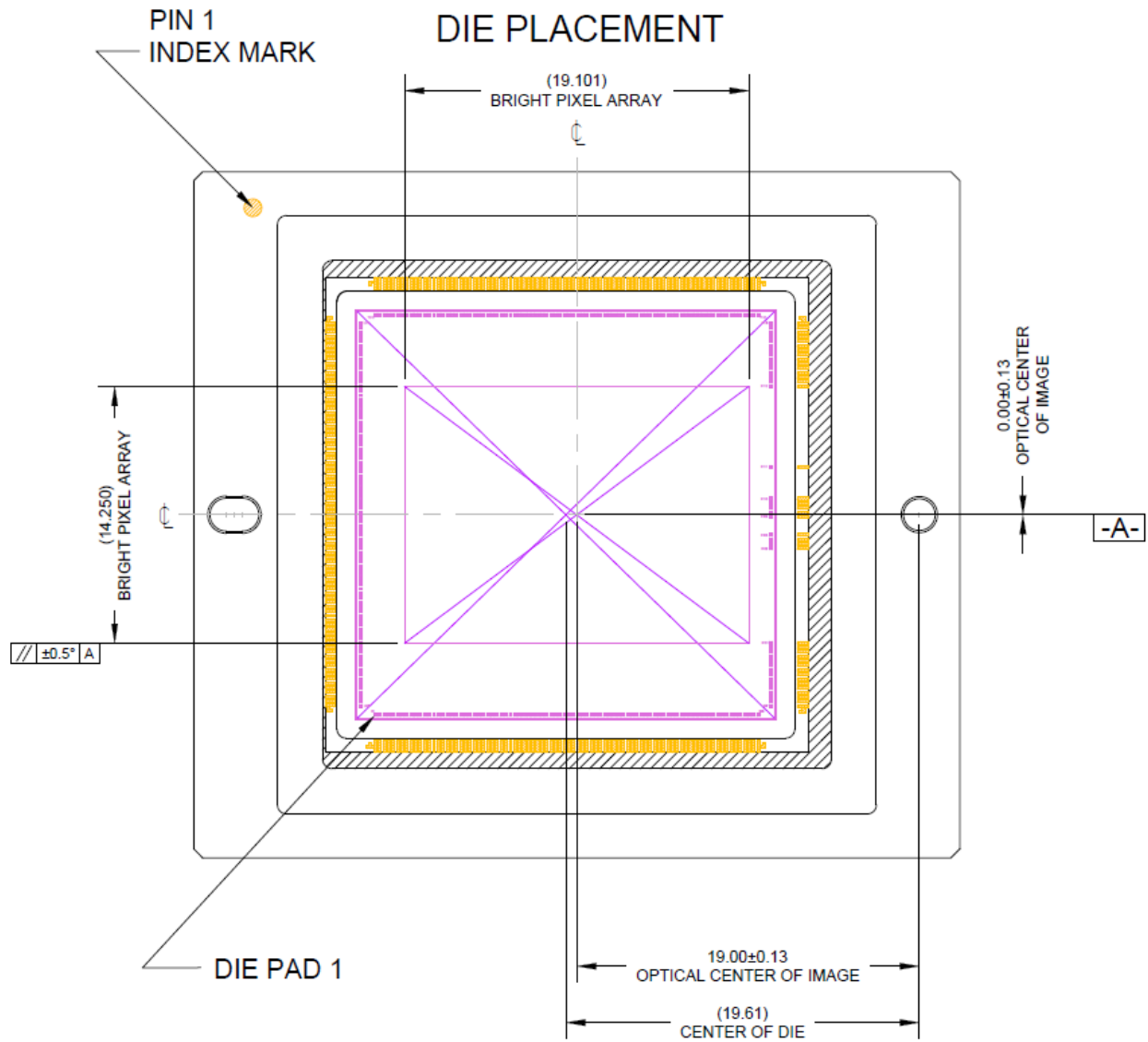


Figure 29. Completed Assembly (3 of 5)

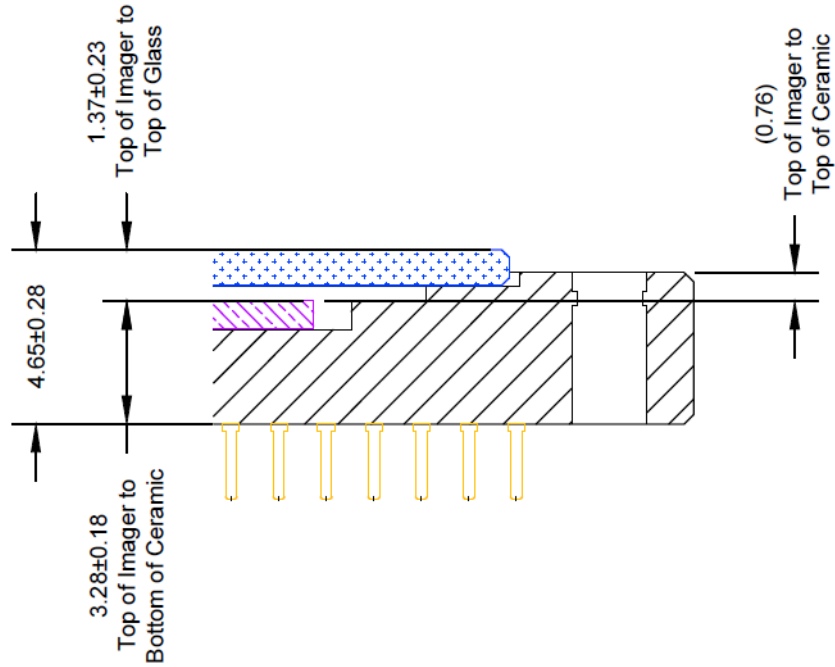


Figure 30. Completed Assembly (4 of 5)

IMAGE ORIENTATION

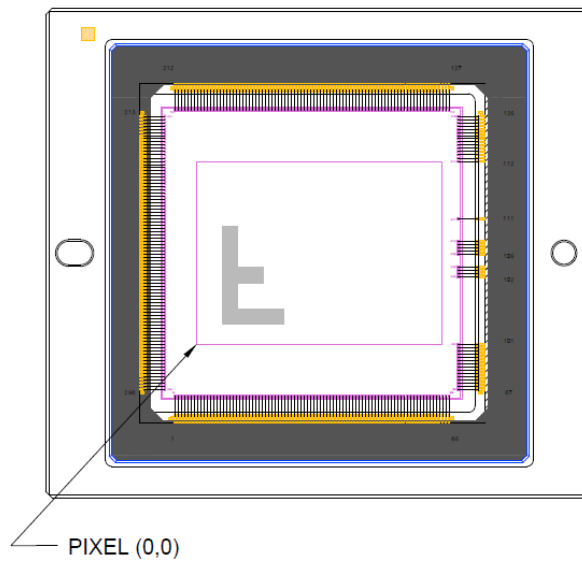
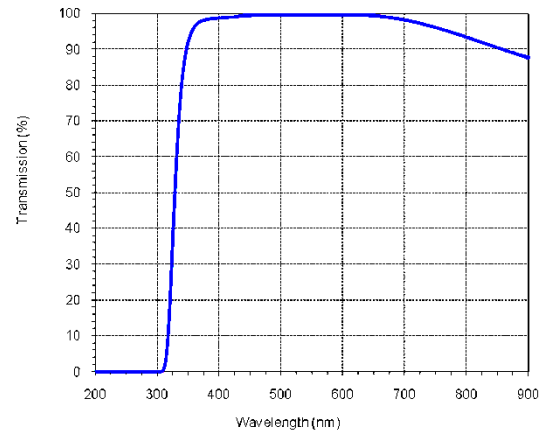
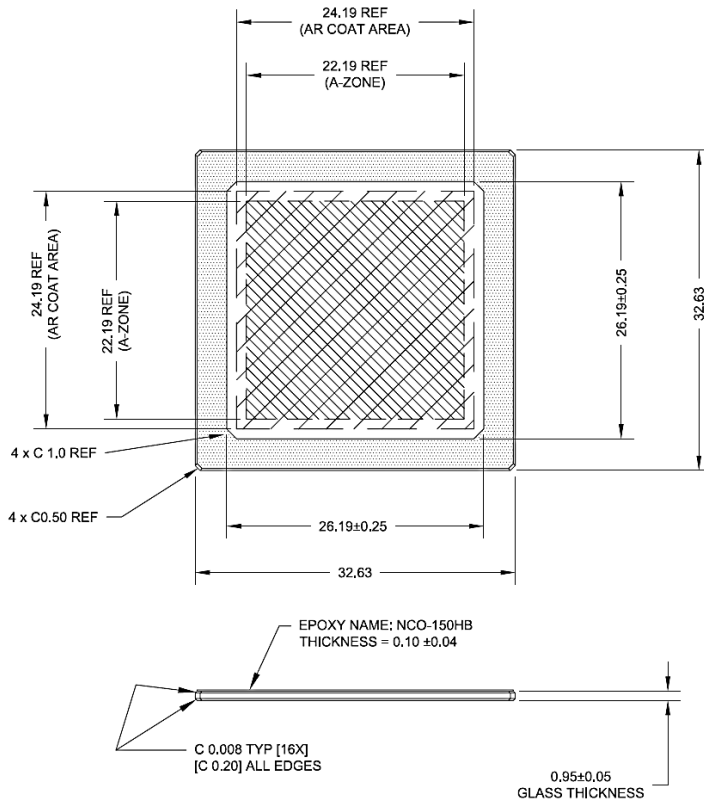


Figure 31. Completed Assembly (5 of 5)

MAR (Multi-Layer Anti-Reflective Coating) Cover Glass




405-450 nm T > 98%
 450-650 nm T > 99%
 650-690 nm T > 98%
 690-770 nm T > 94%
 770-870 nm T > 88%

Notes:

1. Units: IN [MM]
2. A-Zone Dust/Scratch Spec: 10 µm Maximum
3. Index of Refraction: 1.5231

Figure 32. MAR Cover Glass Specification

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