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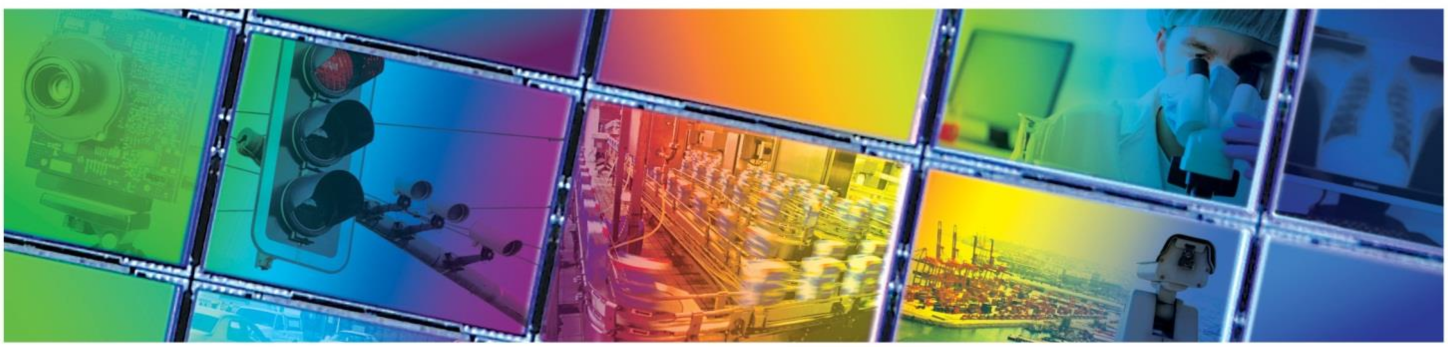
ON Semiconductor®

KAC-06040 IMAGE SENSOR

2832 (H) X 2128 (V) CMOS IMAGE SENSOR



JUNE 13, 2014

DEVICE PERFORMANCE SPECIFICATION

REVISION 1.1 PS-1593

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Summary Specification

KAC-06040 Image Sensor

Description

The KAC-06040 Image Sensor is a high-speed 6 megapixel CMOS image sensor in a 1” 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 160 frames per second.

Each LVDS output bank consists of up to 8 differential pairs operating at 200 MHz DDR for a 400 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.

The image sensor has a pre-configured QHD (4 x 720p, 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.

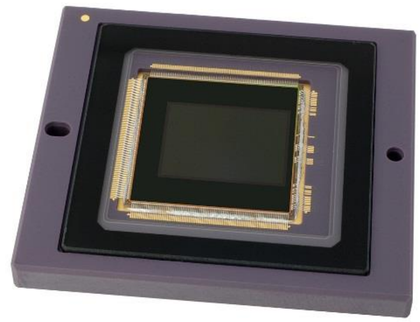
Additional features include interspersed video streams (dual-video), on-chip responsivity calibration, black clamping, overflow pixel for blooming reduction, black-sun correction (anti-eclipse), column and row noise correction, and integrated timing generation with SPI control, 4:1 and 9:1 averaging decimation modes.

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



Parameter	Typical Value
Architecture	5T Global Shutter CMOS
Resolution	6 megapixels
Aspect Ratio	4:3
Pixel Size	4.7 µm (H) x 4.7 µm (V)
Total Number of Pixels	3024 (H) x 2320 (V)
Number of Effective Pixels	2848 (H) x 2144 (V)
Number of Active Pixels	2832 (H) x 2128 (V)
Active Image Size	13.1 mm (H) x 10.0 mm (V) 16.65 mm (diag.), 1” optical format
Master Clock Input Speed	5 MHz to 50 MHz
Maximum Pixel Clock Speed	200 MHz DDR LVDS, 400 Mbps
Number of LVDS Outputs	64 differential pairs
Number of Output Banks	8, 4, or 2
Frame Rate, 6 MP	1 - 160 fps 10 bits
Charge Capacity	17,000 electrons
Quantum Efficiency KAC-06040-CBA KAC-06040-ABA	 40%, 47%, 45% (470, 540, 620 nm) 53%, 15%, 10% (500, 850, 900 nm)
Read Noise (at maximum LVDS clock)	3.4 e^- rms, Rolling Shutter 25 e^- rms, Global Shutter
Dynamic Range	74 dB, Rolling Shutter 57 dB, Global Shutter
Blooming Suppression	>10,000x
Image Lag	1.6 electron
Digital Core Supply	2.0 V
Analog Core Supply	1.8 V
Pixel Supply	2.8 V & 3.5 V
Power Consumption	2.3 W for 6 Mp @ 160 fps 10 bits
Package	267 pin ceramic micro-PGA
Cover Glass	AR Coated, 2-sides

All parameters are specified at T = 40 °C unless otherwise noted

Ordering Information

KAC-06040 Image Sensor

Catalog Number	Product Name	Description	Marking Code
4H2284	KAC-06040-ABA-JD-AA	Monochrome, micro-PGA Package, Sealed Clear Cover Glass with AR coating(both sides), Standard Grade	KAC-06040-ABA Serial Number
4H2286 (1)	KAC-06040-ABA-JD-AE	Monochrome, micro-PGA Package, Sealed Clear Cover Glass with AR coating(both sides), Engineering Grade	KAC-06040-ABA Serial Number
4H2287	KAC-06040-CBA-JD-AA	Bayer (RGB) Color Filter Pattern, micro-PGA Package, Sealed Clear Cover Glass with AR coating(both sides), Standard Grade	KAC-06040-CBA Serial Number
4H2289 (1)	KAC-06040-CBA-JD-AE	Bayer (RGB) Color Filter Pattern, micro-PGA Package, Sealed Clear Cover Glass with AR coating(both sides), Engineering Grade	KAC-06040-CBA Serial Number

Notes:

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.

Evaluation Support

Catalog Number	Product Name	Description
4H2306	KEK-TBD-KAC-06040-CB	Evaluation Hardware for KAC-06040 Image Sensor (Bayer). Includes Image Sensor.
4H2307	KEK-TBD-KAC-06040-AB	Evaluation Hardware for KAc-06040 Image Sensor (monochrome). Includes Image Sensor.
4H2211	Lens Mount Kit	Lens Mount Kit that supports C, CS, and F mount lenses. Includes IR cut-filter for color imaging.

See Application Note Product Naming Convention 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.truesenseimaging.com.

Please address all inquiries and purchase orders to:

Truesense Imaging, Inc.
1964 Lake Avenue
Rochester, New York 14615

Phone: (585) 784-5500
E-mail: info@truesenseimaging.com

Device Description

ARCHITECTURE

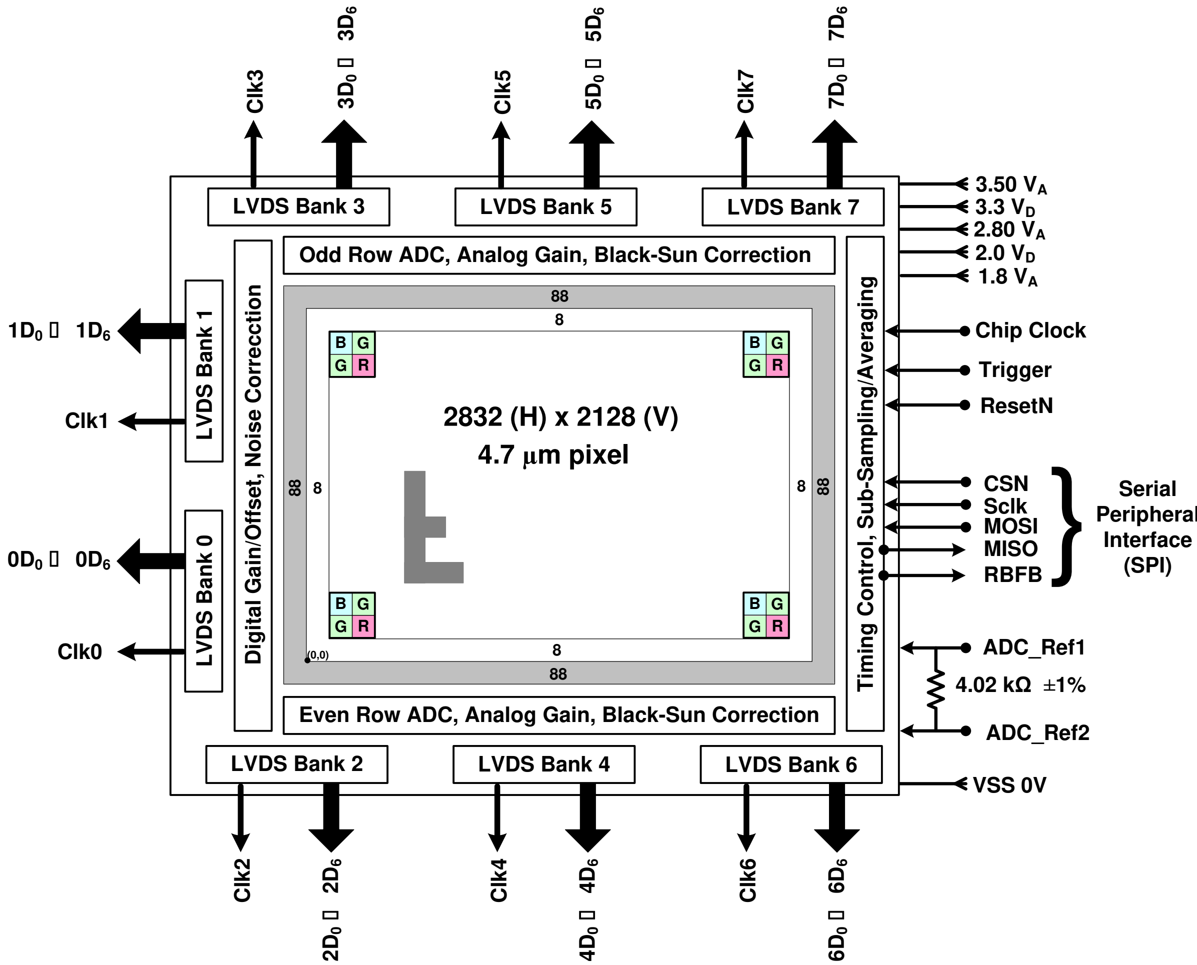


Figure 1: Block Diagram

Physical Orientation

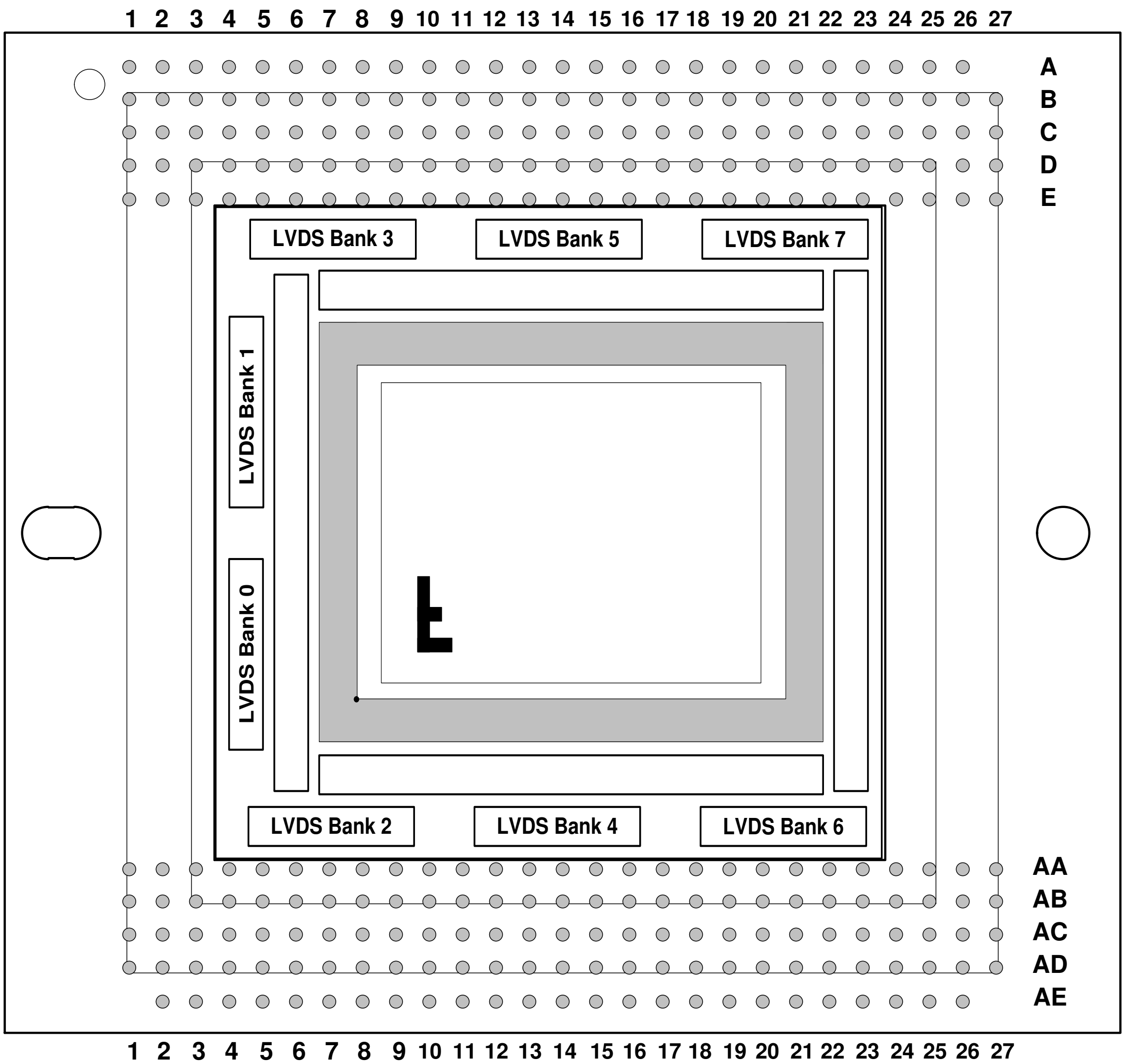


Figure 2: Package Pin Orientation – Top x-ray view

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

Primary Pin Description

Pin	Name	Type	Description
AB09	RESETN	DI	Sensor reset (0 V = Reset State)
E07	CLK_In1	DI	Sensor Input Clk_In1 (5 – 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
AA06	CSN	DI	SPI Chip Select (0 V = Selected)
AA07	MISO	DO	SPI Master Input, Slave Output
AA08	MOSI	DI	SPI Master Output Slave Input
AB05	FB	DO	SPI register read feedback
D07	SPI_MS	DI	SPI CPOL/CPHA mode select
AA14	ADC_Ref1	AO	4.02 kΩ ±1% resistor between Ref1 & Ref2
AA15	ADC_Ref2	AO	4.02 kΩ ±1% resistor between Ref1 & Ref2
AB06	FLO	DO	Flash output sync (optional)
AB07	MSO	DO	Mechanical Shutter output sync (optional)
E05	FEN	DO	Frame ENable reference output (optional)
E06	LEN	DO	Line ENable reference output (optional)

Notes:

1. DI = Digital Input, DO = Digital Output, AO = Analog Output
2. Tie unused DI pins to Ground, No Connect (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 kΩ internal pull-up resistor, so if left floating the chip will not be in reset mode.
5. The TRIGGER pin has an internal 100 kΩ pull down resistor. If left floating (and at default polarity) then the sensor state will not be affected by this pin (ie defaults to 'not triggered' mode if floated)
6. All of the DI and DO pins nominally operate at 0 V → 2.0 V and are associated with the VDD_DIG power supply.
7. The SPI_MS pin has an internal 100 kΩ pull down resistor. If left floating the CPOL/CHPA will be compatible with CPOL=CPHA=0 or CPOL=CPHA=1

Power Pin Description

Name	Voltage	Pins	Description
VDD_LVDS	3.3V D	C04, C05, C23, C24, D04, D24, E04, E24, AA04, AA24, AB04, AB24, AC04, AC05, AC23, AC24	LVDS output supply
VDD_DIG	2.0V D	C18, C19, C20, C21, C22, D18, D19, D20, D21, D22, D23, E08, E18, E20, E21, E22, AA18, AA20, AA21, AA22, AB18, AB19, AB20, AB21, AB22, AB23, AC18, AC19, AC20, AC21, AC22, AB15	Digital core supply
VDD_HV	3.5V A	C11, D11, E11, AA11, AB11, AC11, C10, D10, E10, AA10, AB10, AC10	Pixel supply 1
Vref_P	2.8V A	C13, D13, E13, AA13, AB13, AC13	Pixel supply 2
AVDD_LV	1.8V 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	A02, A14, A26, B14, C03, C06, C12, C14, C25, D03, D12, D14, D25, E03, E12, E19, E23, E25, AA03, AA12, AA19, AA23, AA25, AB03, AB12, AB14, AB25, AC03, AC06, AC12, AC14, AC25, AD14, AE02, AE14, AE26, D15, E15, AA09	Sensor ground reference
No Connect	NA	A01, E14, E16, C09, D09, D05, D06, AA16, AC09	Unused and test-only pins. These pins must be floated.

LVDS PIN DESCRIPTION

Pin	Name	Descr
E01	1DCLK+	Bank 1 LVDS Clock
E02	1DCLK-	
D01	1DATA0+	Bank 1 LVDS Data
D02	1DATA0-	
C01	1DATA1+	
C02	1DATA1-	
B01	1DATA2+	
B02	1DATA2-	
A03	1DATA3+	
B03	1DATA3-	
A04	1DATA4+	
B04	1DATA4-	
A05	1DATA5+	
B05	1DATA5-	
A06	1DATA6+	
B06	1DATA6-	

Pin	Name	Descr
C07	3DCLK+	Bank 3 LVDS Clock
C08	3DCLK-	
A07	3DATA0+	Bank 3 LVDS Data
B07	3DATA0-	
A08	3DATA1+	
B08	3DATA1-	
A09	3DATA2+	
B09	3DATA2-	
A10	3DATA3+	
B10	3DATA3-	
A11	3DATA4+	
B11	3DATA4-	
A12	3DATA5+	
B12	3DATA5-	
A13	3DATA6+	
B13	3DATA6-	

Pin	Name	Descr
C15	5DCLK+	Bank 5 LVDS Clock
C16	5DCLK-	
A15	5DATA0+	Bank 5 LVDS Data
B15	5DATA0-	
A16	5DATA1+	
B16	5DATA1-	
A17	5DATA2+	
B17	5DATA2-	
A18	5DATA3+	
B18	5DATA3-	
A19	5DATA4+	
B19	5DATA4-	
A20	5DATA5+	
B20	5DATA5-	
A21	5DATA6+	
B21	5DATA6-	

Pin	Name	Descr
A22	7DCLK+	Bank 7 LVDS Clock
B22	7DCLK-	
A23	7DATA0+	Bank 7 LVDS Data
B23	7DATA0-	
A24	7DATA1+	
B24	7DATA1-	
A25	7DATA2+	
B25	7DATA2-	
B27	7DATA3+	
B26	7DATA3-	
C27	7DATA4+	
C26	7DATA4-	
D27	7DATA5+	
D26	7DATA5-	
E27	7DATA6+	
E26	7DATA6-	

Pin	Name	Descr
AA01	0DCLK+	Bank 0 LVDS Clock
AA02	0DCLK-	
AB01	0DATA0+	Bank 0 LVDS Data
AB02	0DATA0-	
AC01	0DATA1+	
AC02	0DATA1-	
AD01	0DATA2+	
AD02	0DATA2-	
AE03	0DATA3+	
AD03	0DATA3-	
AE04	0DATA4+	
AD04	0DATA4-	
AE05	0DATA5+	
AD05	0DATA5-	
AE06	0DATA6+	
AD06	0DATA6-	

Pin	Name	Descr
AC07	2DCLK+	Bank 2 LVDS Clock
AC08	2DCLK-	
AE07	2DATA0+	Bank 2 LVDS Data
AD07	2DATA0-	
AE08	2DATA1+	
AD08	2DATA1-	
AE09	2DATA2+	
AD09	2DATA2-	
AE10	2DATA3+	
AD10	2DATA3-	
AE11	2DATA4+	
AD11	2DATA4-	
AE12	2DATA5+	
AD12	2DATA5-	
AE13	2DATA6+	
AD13	2DATA6-	

Pin	Name	Descr
AC15	4DCLK+	Bank 4 LVDS Clock
AC16	4DCLK-	
AE15	4DATA0+	Bank 4 LVDS Data
AD15	4DATA0-	
AE16	4DATA1+	
AD16	4DATA1-	
AE17	4DATA2+	
AD17	4DATA2-	
AE18	4DATA3+	
AD18	4DATA3-	
AE19	4DATA4+	
AD19	4DATA4-	
AE20	4DATA5+	
AD20	4DATA5-	
AE21	4DATA6+	
AD21	4DATA6-	

Pin	Name	Descr
AE22	6DCLK+	Bank 6 LVDS Clock
AD22	6DCLK-	
AE23	6DATA0+	Bank 6 LVDS Data
AD23	6DATA0-	
AE24	6DATA1+	
AD24	6DATA1-	
AE25	6DATA2+	
AD25	6DATA2-	
AD26	6DATA3+	
AD27	6DATA3-	
AC26	6DATA4+	
AC27	6DATA4-	
AB26	6DATA5+	
AB27	6DATA5-	
AA26	6DATA6+	
AA27	6DATA6-	

Notes:

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

Typical Operation 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 msec (1400d LL, register 0201h)	
Readout Mode	Dual-Scan, Global Shutter, 320 MHz PLL2	
Clamps	Column/Row Noise Correction active, Frame Black Level Clamp active	
ADC Bit Depth	10 bit	
Analog Gain	Unity gain or referred back to unity gain.	

Notes:

1. For monochrome sensor, only green LED used.

Performance Specifications All Configurations

Description	Symbol	Min.	Nom.	Max.	Units	Sampling Plan	Temperature Tested At (°C)	Test	Notes
Photodiode Charge Capacity	PNe	-	17	-	ke^-	Die	27 & 40	16	
Read Noise	ne-T	-	3.4 RS/GR DS 3.7 RS/GR TS 25 GS DS/TS	-	e^-rms	Die	27	8	
Total Pixelized Noise	TPN	-	3.6 RS/GR DS 3.9 RS/GR TS 25 GS DS/TS	-	e^-rms	Die	27	19	
Dynamic Range	DR	-	74 RS/GR DS 73 RS/GR TS 57 GS DS/TS	-	dB	Die	27		3
Column Noise	Cn	-	0.4 RS/GR DS/TS 2.4 GS DS/TS	-	e^-rms	Die	27	9	5
Row Noise	Rn	-	0.4 RS/GR DS 0.7 RS/GR TS 2.7 GS DS/TS	-	e^-rms	Die	27	10	6
Dark Field Local Non-Uniformity Floor	DSNU_flr	-	1.3 RS/GR DS 1.7 RS/GR TS 10 GS DS/TS	-	e^-rms	Die	27 & 40	1	4
Bright Field Local Photoresponse Non-Uniformity	PRNU_1	-	1.1 Mono 1.5 Bayer	-	%rms	Die	27 & 40	2	1
Bright Field Global Photoresponse Non-Uniformity	PRNU_2	-	3.7 Mono 5.4 Bayer	-	%pp	Die	27 & 40	3	1
Maximum Photoresponse Nonlinearity	NL	-	5.4	-	%	Die	27 & 40	11	2
Maximum Gain Difference Between Outputs	ΔG	-	0.3	-	%	Die	27 & 40	12	7
Photodiode Dark Current	Ipd	-	6.6	-	e/p/s	Die	40	13	8
Storage Node Dark Current	Ivd	-	1490	-	e/p/s	Die	40	14	4
Image Lag	Lag	-	1.6	-	e^-	Design	27, 40	15	
Black-Sun Anti-Blooming	Xab	-	15 >10,000	-	W/cm^2 xIllumSat	Design	27	7	13
Parasitic Light Sensitivity	PLS	-	728	-	-	Design	27	6	9
Dual-Video WDR		-	140 RS 120 GS	-	dB	Design	27		10, 11
Pulsed Pixel WDR (GS only)		-	100	-	dB	Design	27		12, 11

RS = Rolling Shutter operation mode, GS = Global Shutter operation mode, GR = Global Reset
DS = Dual-Scan, TS = Tri-Scan

KAC-06040-ABA Configuration (Monochrome)

Description	Symbol	Wavelength (nm)	Nom.	Units	Sampling Plan	Temperature Tested At (°C)	Notes	Test
Peak Quantum Efficiency Green NIR1 NIR2	QE_{max}	550 850 900	52 15 9.0	%	Design	27		
Responsivity			83	$\frac{ke^-}{Lux * s}$	Design	27		20
Responsivity			7.3	$\frac{V}{Lux * s}$	Design	27		21

KAC-06040-CBA Configuration (Bayer RGB)

Description	Symbol	Wavelengt h (nm)	Nom.	Units		Sampling Plan	Temperature Tested At (°C)	Notes	Test
Peak Quantum Efficiency Gree n NIR1 NIR2	QE_{max}	470 540 620 850 900	42 47 44 16 9.8	%		Design	27		
Responsivity		Blue Green Red	18 36 39	$\frac{ke^-}{Lux * s}$		Design	27		20
Responsivity		Blue Green Red	1.6 3.1 3.4	$\frac{V}{Lux * s}$		Design	27		21

Notes

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

Typical Performance Curves

Quantum Efficiency

Monochrome with Microlens

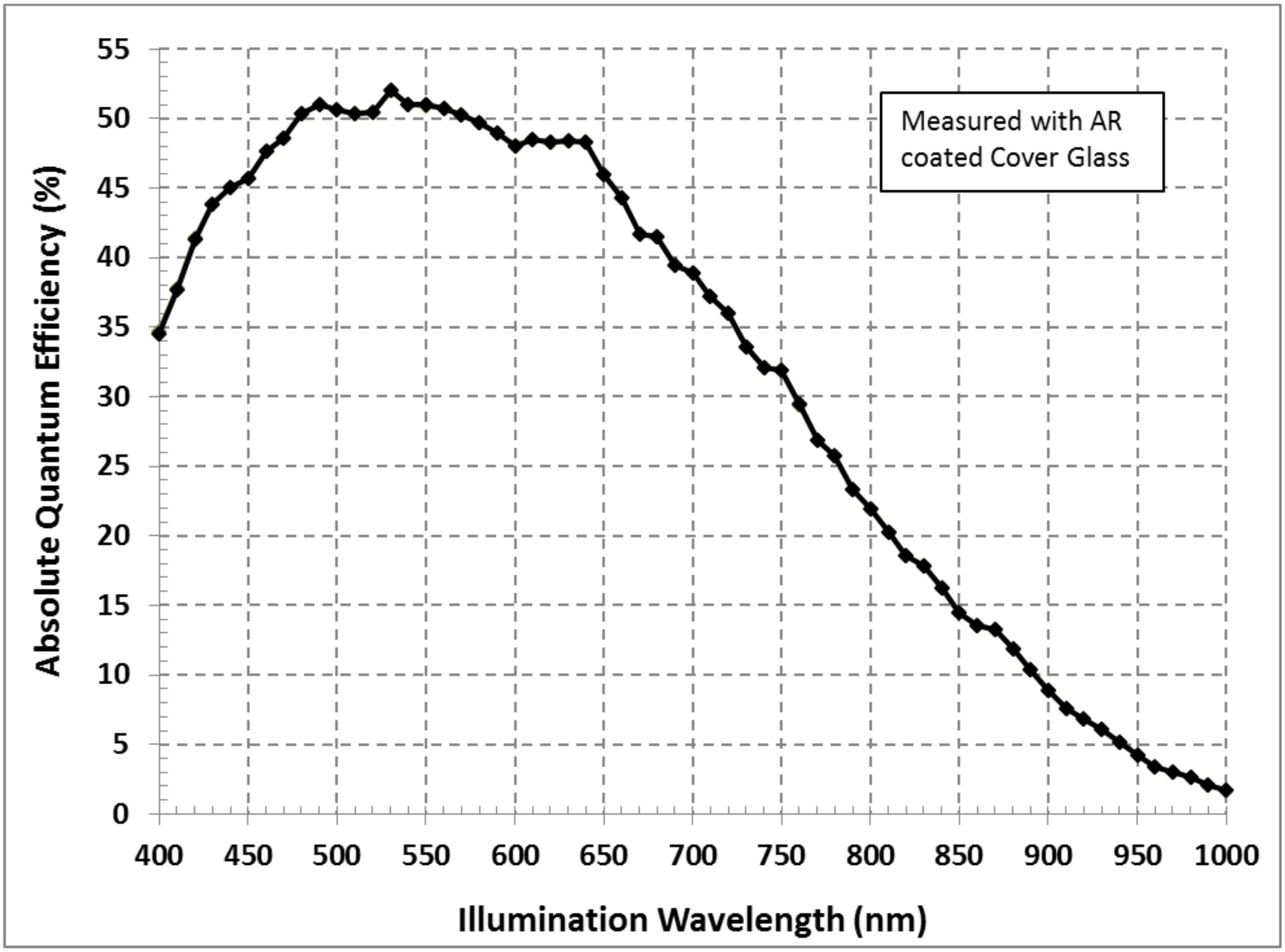


Figure 3: Monochrome QE (with Microlens)

Color (Bayer RGB) with Microlens

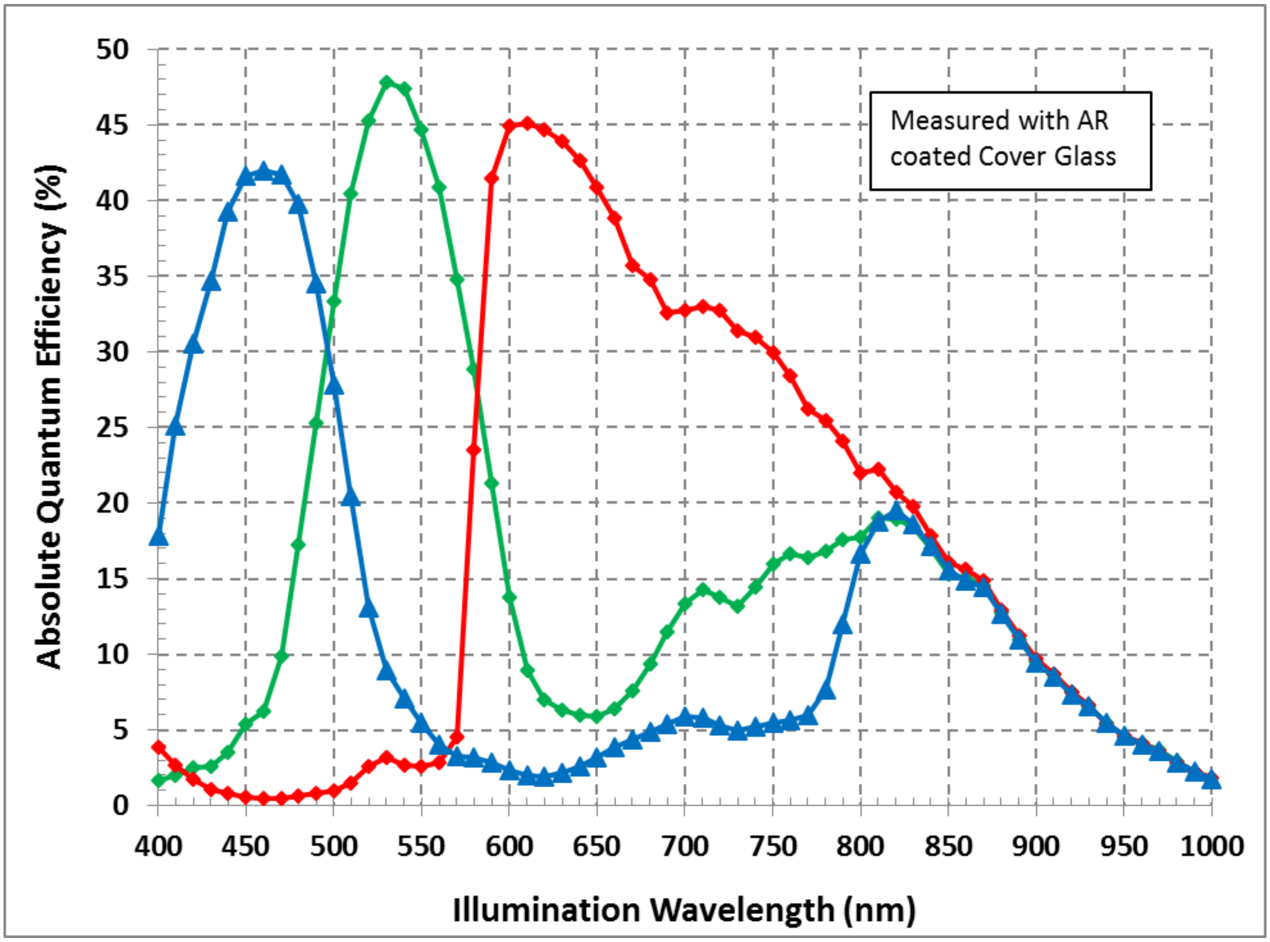


Figure 4: Bayer QE (with Microlens)

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.

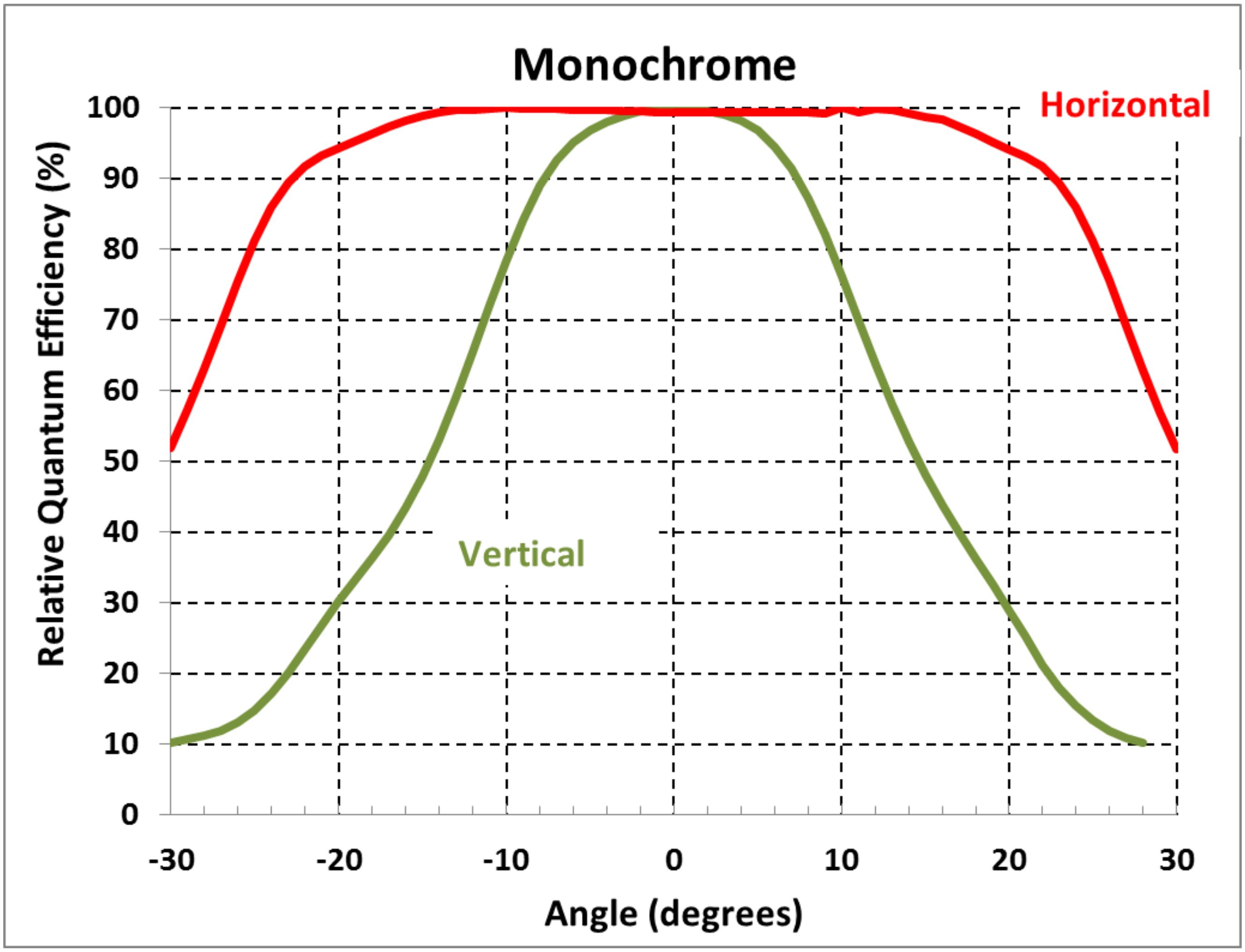


Figure 5: Monochrome Relative Angular QE (with Microlens)

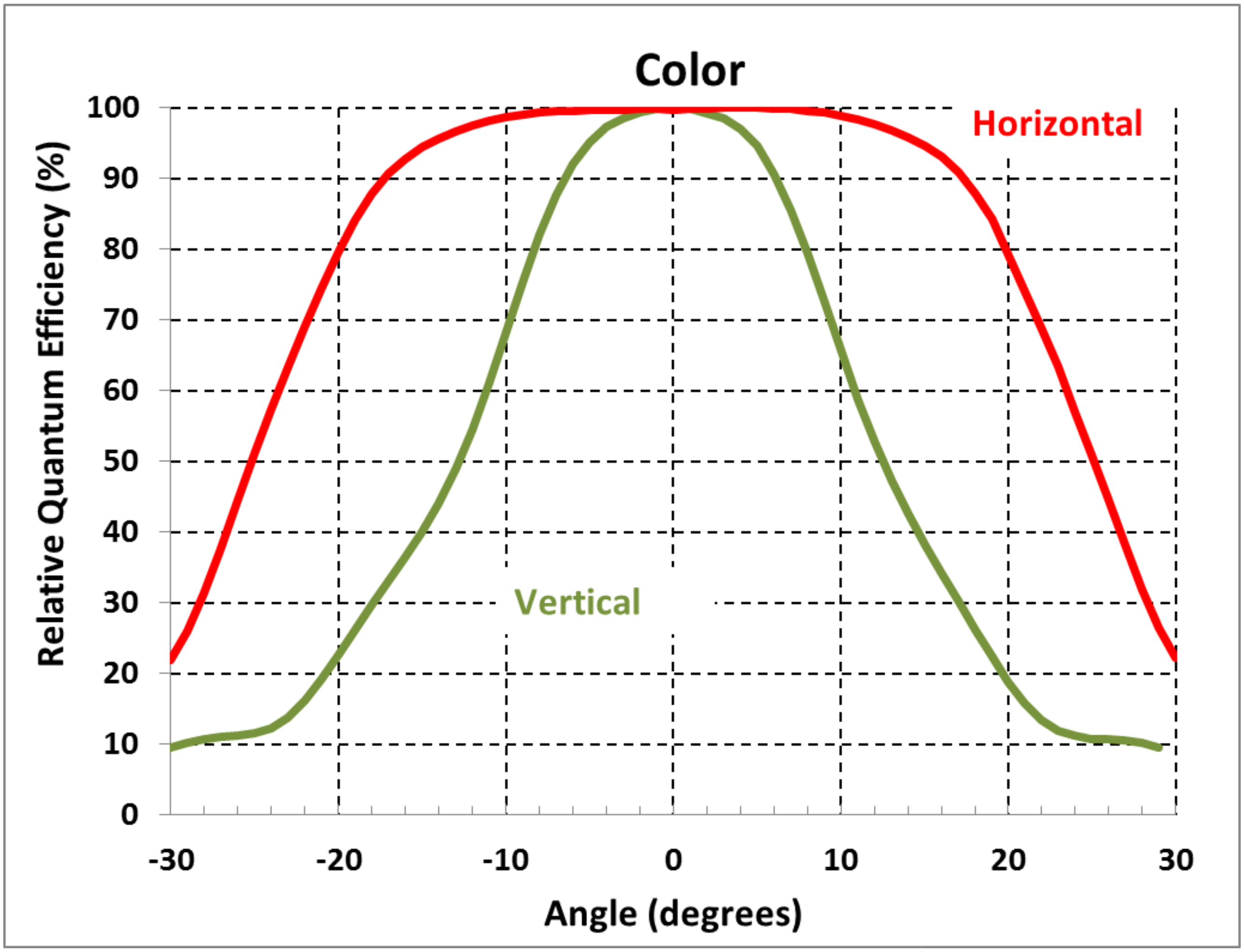


Figure 6: Monochrome Relative Angular QE (with Microlens)

DARK CURRENT VERSUS TEMPERATURE

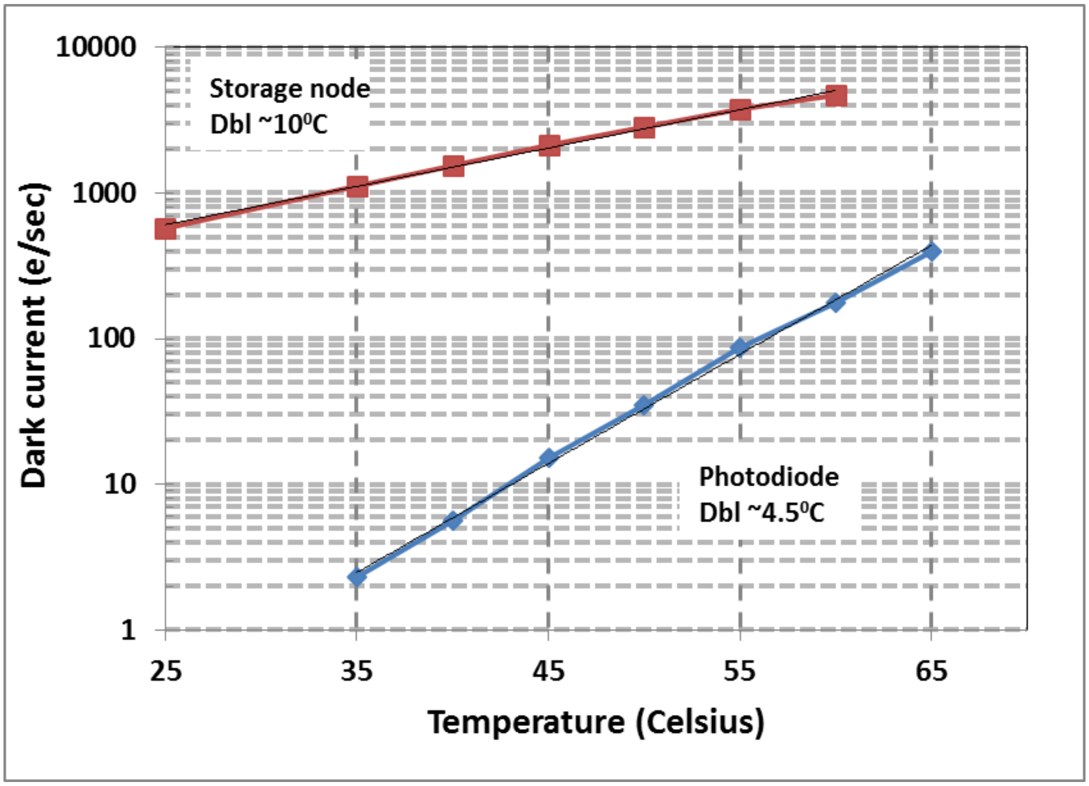


Figure 7: Dark Current vs Temperature

Note: “Dbl” denotes an approximate doubling temperature for the dark current for the displayed temperature range.

Power vs Frame Rate

The most effective method to set the frame rate is to use 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. Tri-scan can reach higher frame rates, but consumes more power at all frame rates. It is recommended use Dual-Scan unless the frame rate required can only be reached with Tri-Scan. The LVDS clock is ½ the PLL2 clock frequency.

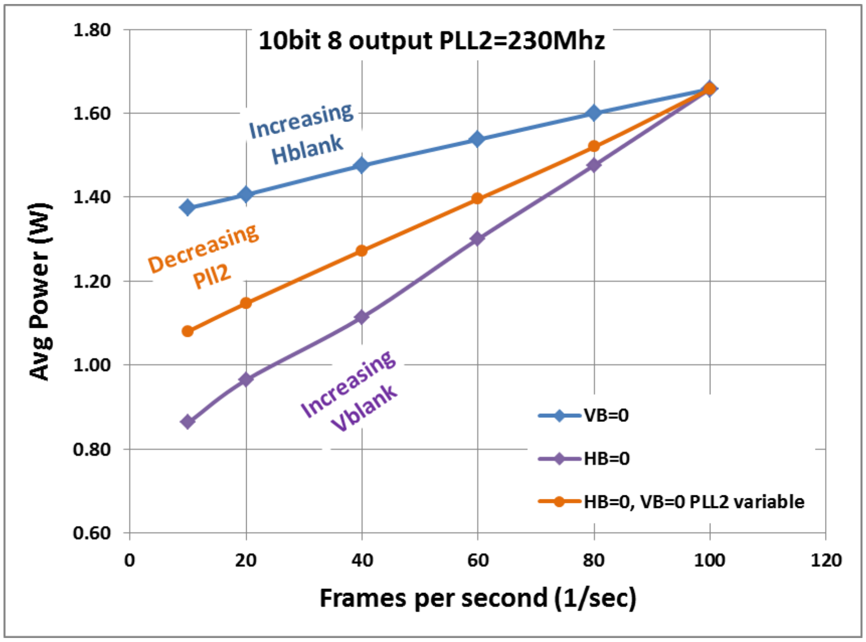


Figure 8: Dual-Scan Power vs Frame Rate, 10 bit mode

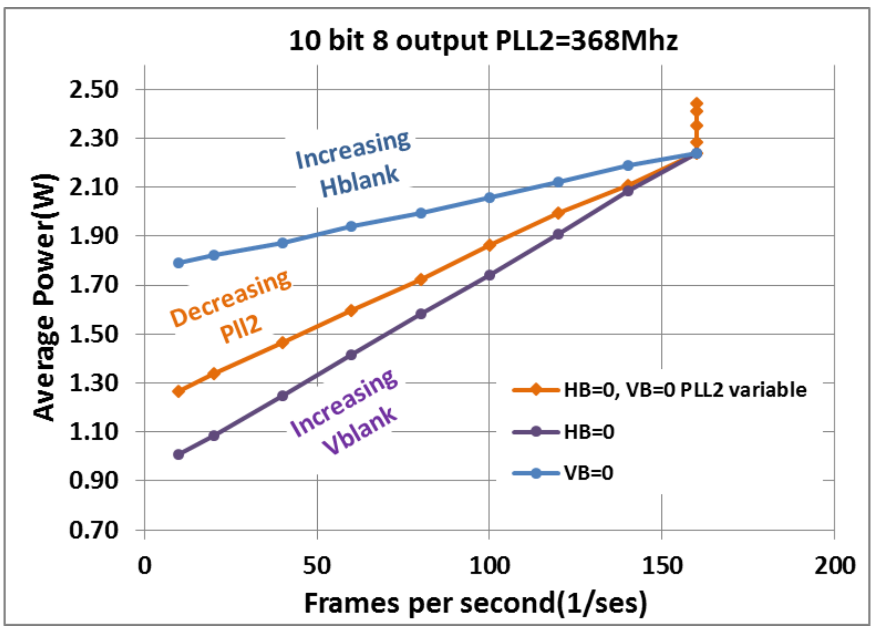


Figure 9: Tri-Scan Power vs Frame Rate, 10 bit mode

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. For optimum image quality and power consumption the PLL2 and vertical blanking have been optimized for each bit depth and target frame rate. Because of the different parameters impacting the line time, Tri-Scan only has significant benefit at 10 bit operation. At 8 bit operation the LVDS readout time dominates the line time; and at 12 and 14 bit the ADC time dominates the line time and the pixel time is not significant. But at 10 bit operation Tri-Scan can almost halve the line time at the cost of additional power consumption.

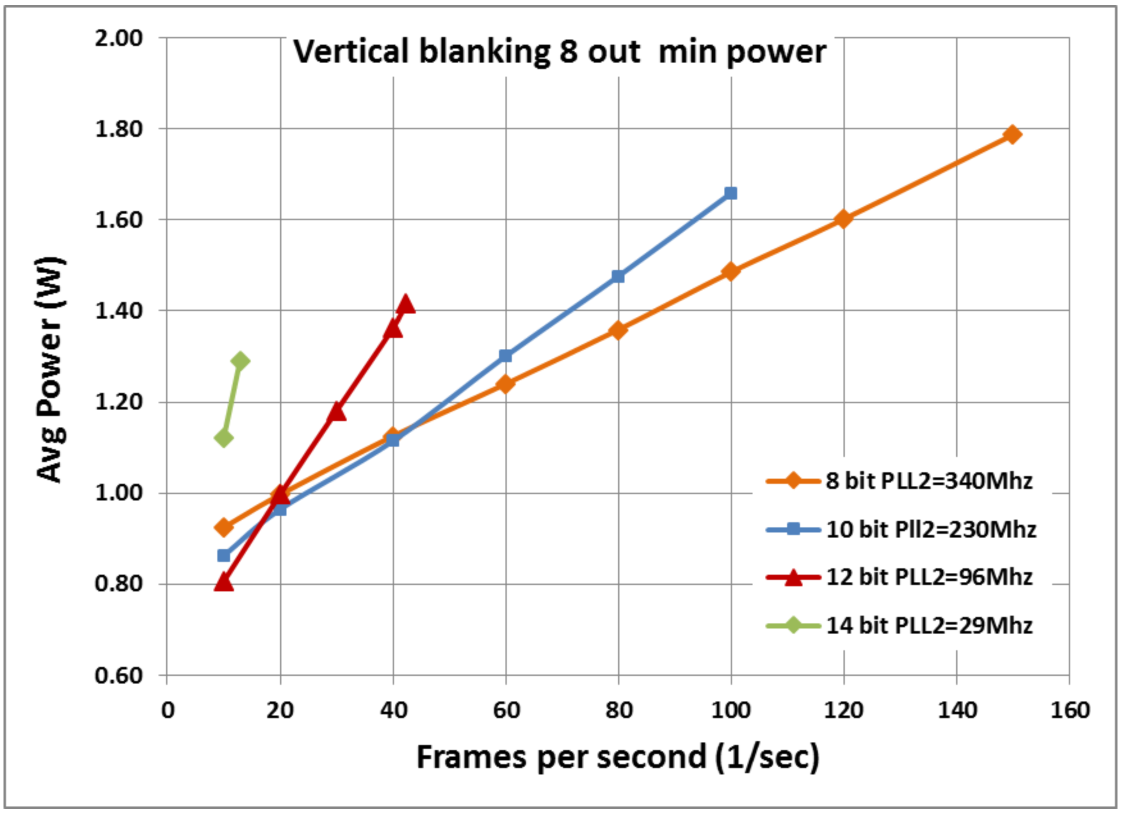


Figure 10: Dual-Scan ADC Bit Depth impact on Frame Rate and Power

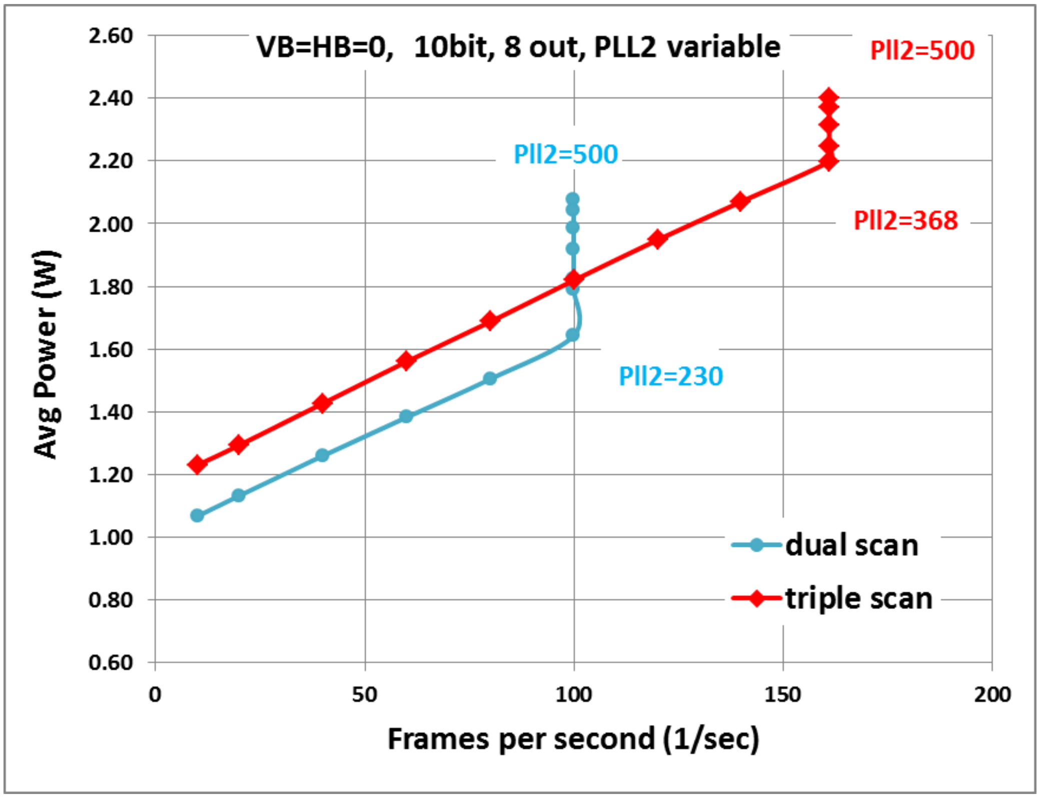


Figure 11: Tri-Scan vs Dual-Scan Power

Defect Definitions

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 Correction on, 1x Analog Gain, 1x Digital Gain	
Pixels Per Line	2832	
Lines Per Frame	2128	
Line Time	6.875 μsec	
Frame Time	8.25 msec	
Photodiode Integration Time	33 msec	
Storage Readout Time	7.85 msec	
Temperature	40 °C and 30 °C	
Light Source	Continuous red, green and blue LED illumination (green only for monochrome sensor)	
Operation	Nominal operating voltages and timing, PLL1 = 320 MHz, PLL2 = 410 MHz	

Defect Definitions for Testing

Description	Definition		Limit	Test	Notes
Dark Field Defective Pixel	29 °C RS: Defect ≥ 20 dn GS: Defect ≥ 180 dn	40 °C RS: Defect ≥ 30 dn GS: Defect ≥ 240 dn	60	4	3, 4
Bright Field Defective Pixel	Defect ≥ ±12% from local mean			5	1, 4
Cluster Defect	A group of 2 to 10 contiguous defective pixels, but no more than 3 adjacent defects horizontally		11		2
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	
Bright Field Faint Column/Row Defect	RS: 12 dn threshold GS: 18 dn threshold		0	18	

Notes:

RS = Rolling Shutter, GS = Global Shutter

1. For the color devices, all bright defects are defined within a single color plane, each color plane is tested
2. Cluster defects are separated by no less than two good pixels in any direction.
3. Rolling Shutter Dark Field points are dominated by photodiode integration time, Global Shutter Dark Field defects are dominated by the readout time.
4. 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

Test Definitions

TEST REGIONS OF INTEREST

Image Area ROI: Pixel (0, 0) to Pixel (2847, 2143)

Active Area ROI: Pixel (8, 8) to Pixel (2839, 2135)

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

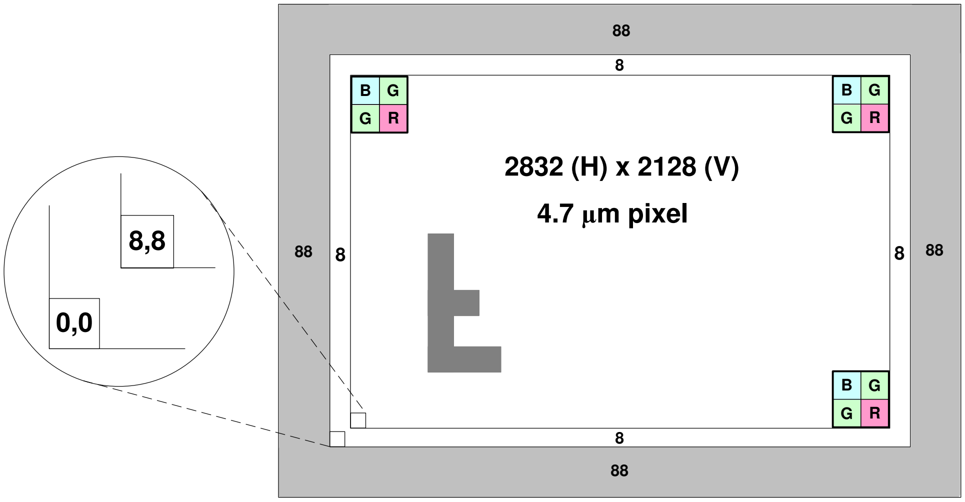


Figure 12: Regions of Interest

TESTS

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 180 subregions of interest, each of which is 190 by 178 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 Local Photoresponse Non-Uniformity (PRNU_1)

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.

$$PRNU\_1 = 100 * \left(\frac{\text{Active Area Standard Deviation}}{\text{Active Area Signal}} \right)$$

Units: %rms

3) Bright Field Global Non-Uniformity (PRNU_2)

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 180 subregions of interest, each of which is 190 by 178 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 PRNU_2.

$$PRNU\_2 = 100 * \frac{\text{Maximum Signal} - \text{Minimum Signal}}{\text{Active Area Signal}}$$ Units: %pp

4) Dark Field Defect Test

This test is performed under dark field conditions. The sensor is partitioned into 390 subregions 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 390 subregions 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 dn * 12 % = 84 dn
- A specific 128 x 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 ≤ (690 - 84 dn) in intensity will be marked defective.
  - Any pixel in this region of interest that is ≥ (690 - 84 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.

$$PLS = \frac{Photodiode\ Responsivity}{Storage\ Node\ Responsivity} \qquad \text{(unitless ratio)}$$

GSE (Global Shutter Efficiency) is a related unit. $GSE = \left(1 - \frac{1}{PLS}\right)\ \%$

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 550nm 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-06040 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-06040 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-06040 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 dn.

This illumination intensity at this ND filter is recorded (W/cm^2) as the Black-Sun Anti-blooming.
The 'xIlumSat' 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 (± 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. This Metric includes both temporal and FPN.

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. This Metric includes both temporal and FPN.

11) Maximum Photoresponse Non-Linearity

The photoresponse nonlinearity 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 Mavg and Lavg.

- The integration time is varied until the integration time required to reach the 70% saturation is determined. Mavg = the active array mean at the 70% saturation integration time.
- The integration is set to 1/14 (5% exposure point). Lavg = meant at the 5% exposure point
- PRNL (@ 5% saturation) =((Lavg/Mavg) * (14/1) -1) * 100

12) Maximum Gain Difference Between Outputs

The LVDS outputs contain no gain or offset error since these are purely digital segmentations. The predominant output mismatch comes from the pixel array readout segmentation. The sensor contains two ADC banks and four channels of analog line stores in its highest frame rate configuration, Tri-Scan. The sensor is factory calibrated to match the gain differences between all four possible gain channels. The gain variations are manifest as an every 4^{th} row gain pattern. In tri-scan, and an even/odd row gain difference in Dual-Scan. The sensor is factory calibrated to match the four possible row gains. This test is performed in Tri-Scan mode to test the worst case gain error including all possible 4 row gains after the calibration has been applied. The sensor is illuminated at 70% of saturation. The entire test frame ROI into 4 groups of every 4^{th} row. The first row group(average) is used as a reference and the following three row groups are compared to the first. The largest error is reported.

((Second Row Average/First Row Average) -1) * 100

((Third Row Average/Frist Row Average) -1) * 100

((Fourth Row Average/First Row Average) -1) * 100