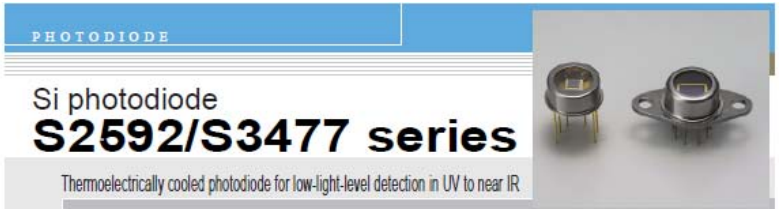
Photodiode, CMOS and CCD Arrays

- Cooling
- CCD vs. CMOS vs. PD
- QE, sensitivity
- Read noise
- EM-CCD

TE-Cooled Silicon Photodiodes

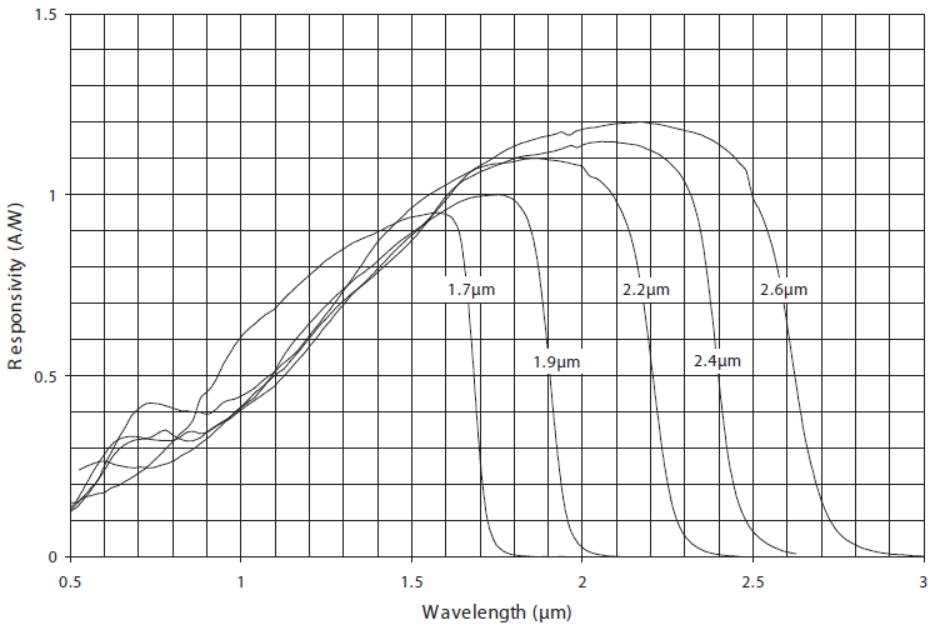


■ Electrical and optical characteristics (Typ. Ta=25 °C)

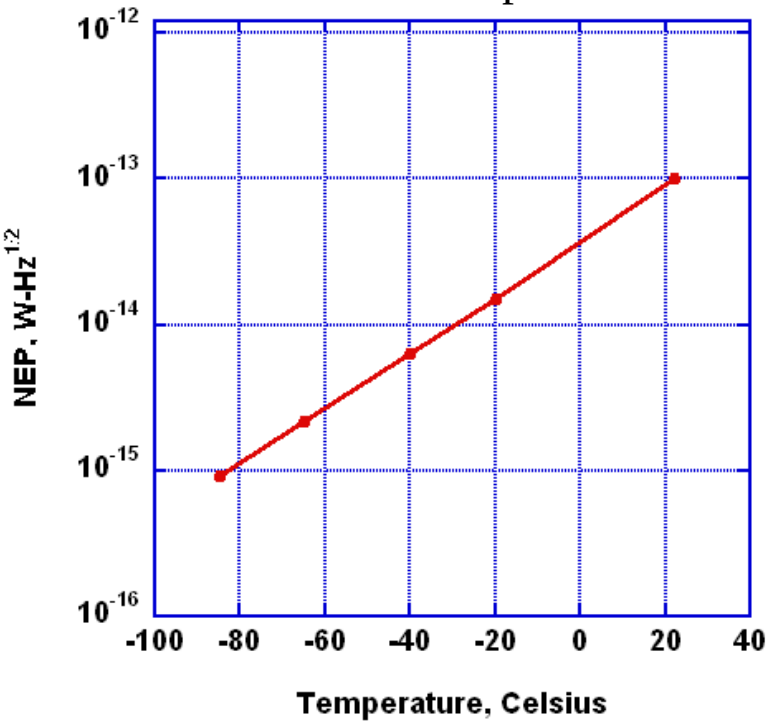
Parameter	Symbol	Condition	S2592-03	S3477-03	S2592-04	S3477-04	Unit
Spectral response range	λ		190 to 1100				nm
Peak sensitivity wavelength	λp		960				nm
Photo sensitivity	S	λ=λp	0.5				A/W
Short circuit current	Isc	100 lx, 2856 K	5		28		μA
Dark current	ID	VR=10 mV	10		25		pA
Temperature coefficient of dark current	TCID		1.15				times/°C
Rise time	tr	VR=0 V, RL=1 kΩ	0.2		1		μs
Terminal capacitance	Ct	VR=0 V	65		380		pF
Shunt resistance	Rsh	VR=10 mV	1		0.4		GΩ
Noise equivalent power	NEP	VR=0 V, λ=λp	8.1×10^{-15}		1.3×10^{-14}		$W/Hz^{1/2}$
Cooling temperature	ΔT		35				°C

NEP @ -10 ºC = 1.3E-14 $W\text{-}Hz^{-1/2}$

TE Cooled InGaAs Detectors



NEP vs. Temperature



Imaging Families

- Photodiode array
  - Si, InGaAs, HgCdTE
  - Fast, high noise floor
- CMOS array
  - Si only
  - Fast, moderate noise floor
  - Cheap
- CCD
  - Si only
  - Slow, very low noise
  - ~$10K

Photodiode vs. CCD Array

	InstaSpec™ II Silicon PDAs	InstaSpec™ IV Spectroscopy CCDs
Spectral response	180 to 1100 nm	180 to 1100 nm
Pixel size (binned)	25 µm x 2500 µm	26 µm x 26 µm
Saturation level (binned)	125 x 10^6 e^-	250 x 10^3 e^- (625 x 10^3 e^-)
Saturation exposure	>107 nJ cm^{-2} @600 nm	>250 pJ cm^{-2} @600 nm
Dark Current @min temp.	<6.4x10^{-15}A/pixel <1.03x10^{-14}A/cm^2	<1.6x10^{-20}A/pixel <2.4x10^{-15}A cm^2
Detection limit	<3.3 pJ cm^{-2} @600 nm <3750 e^-	<3.8 fJ cm^{-2} @600 nm <10 e^-
Max S/N ratio	10,000:1	900:1
Dynamic range	32,786:1 (@ 62 kHz)	65,536:1 (@ 62 kHz)
Electrons/count	1900	10
Usable for linear spectroscopy/ imaging	Yes	Yes
Usable for two dimensional spectro-scopy and imaging (shutter required)	No	Yes

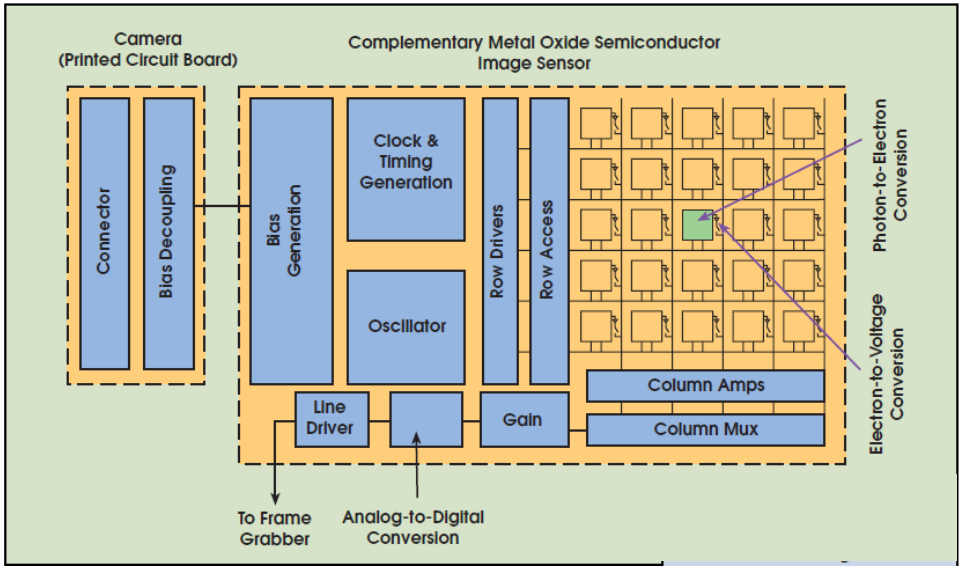
2D InGaAs PDA

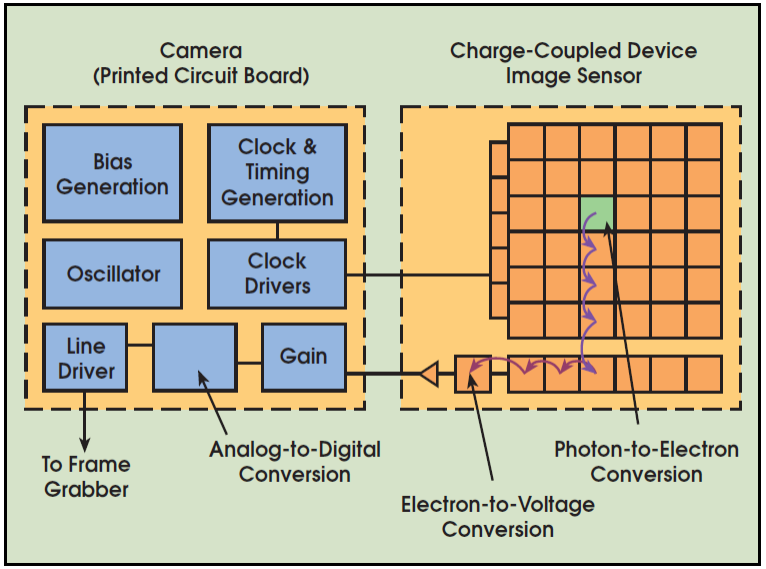
Sensor format	640 x 512
Pixel pitch	25 um
Max frame rate (full frame)	100 fps
Spectral sensitivity	0.9—1.7 μm
Optical fill factor	100%
Full well capacity	75,000 (HG), 2,500,000 (LG) electrons
Readout noise	70 (HG), 400 (LG) electrons
Windowing	Arbitrary region of interest
Integration modes	Snapshot, Integrate Then Read Snapshot, Integrate While Read
Quantum efficiency	> 70%
Operability	> 99.5%
Noise Equivalent Irradiance	< 8 x 10^8 photons/cm^2-s
Integration times	4 μs to 95% of frame time

aerius PHOTONICS, LLC

→ 3E3 e-/sec/pixel

CMOS vs CCD





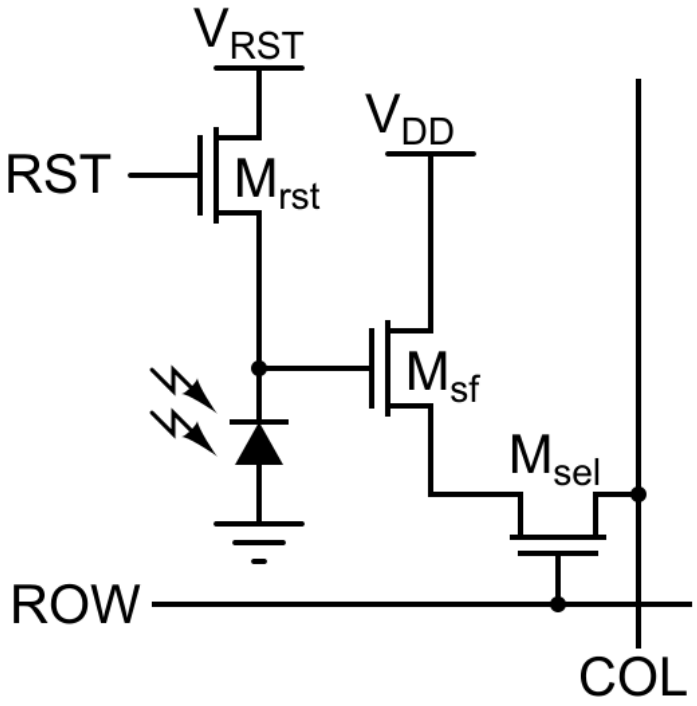
CMOS

- Amplifier at each pixel
- Low fill factor
- High noise from digital circuitry

CCD

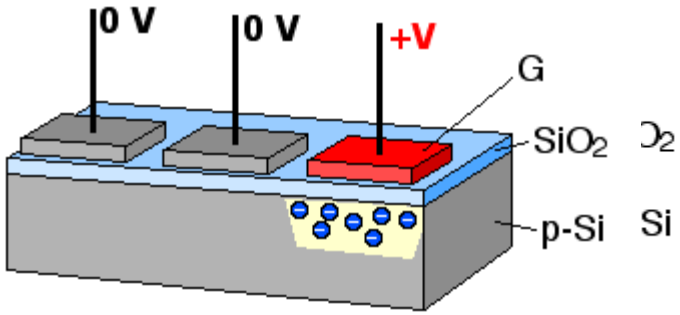
- Single amplifier at end
- High fill factor
- Lower noise from circuitry

CMOS Operation



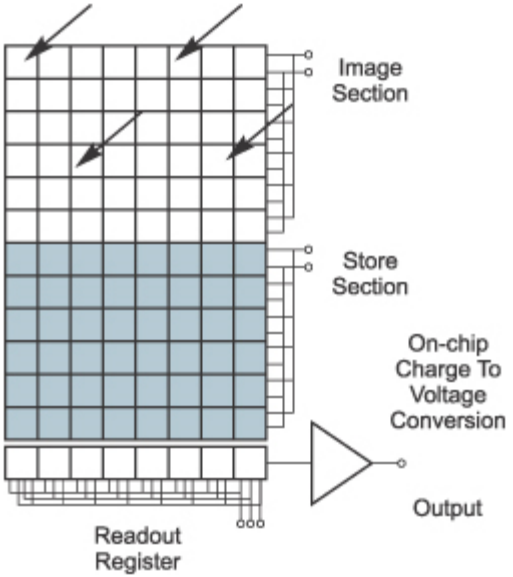
- Charge amplified at each pixel
- Clocked out like a memory chip
- Digital reset at each pixel

CCD Operation

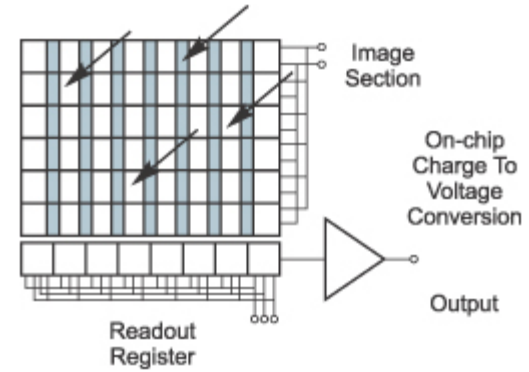


- Gate bias forms electrostatic well
- Multiple clock levels shift charge laterally
- Charge finally collected at sense amplifier

CCD Architectures



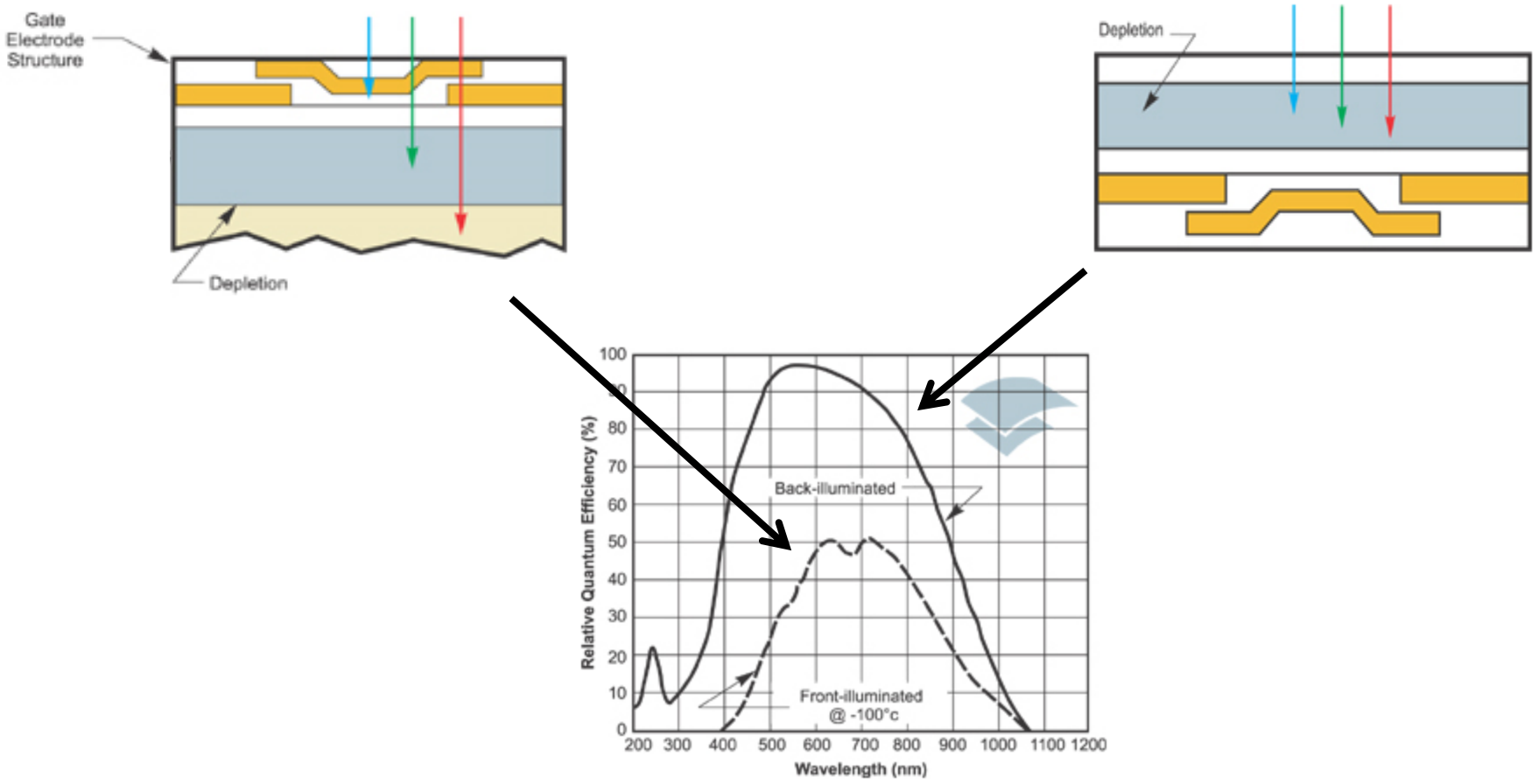
Frame transfer:
- High fill factor
- Moderate image smearing during transfer



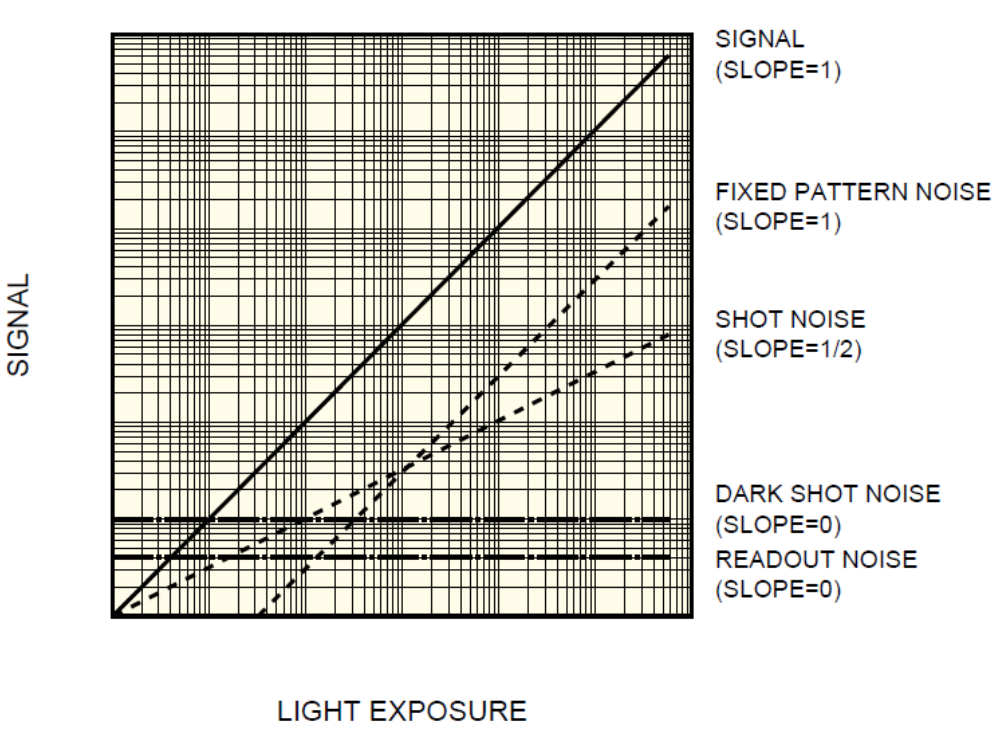
Interline transfer
- Low fill factor
- Little image smearing

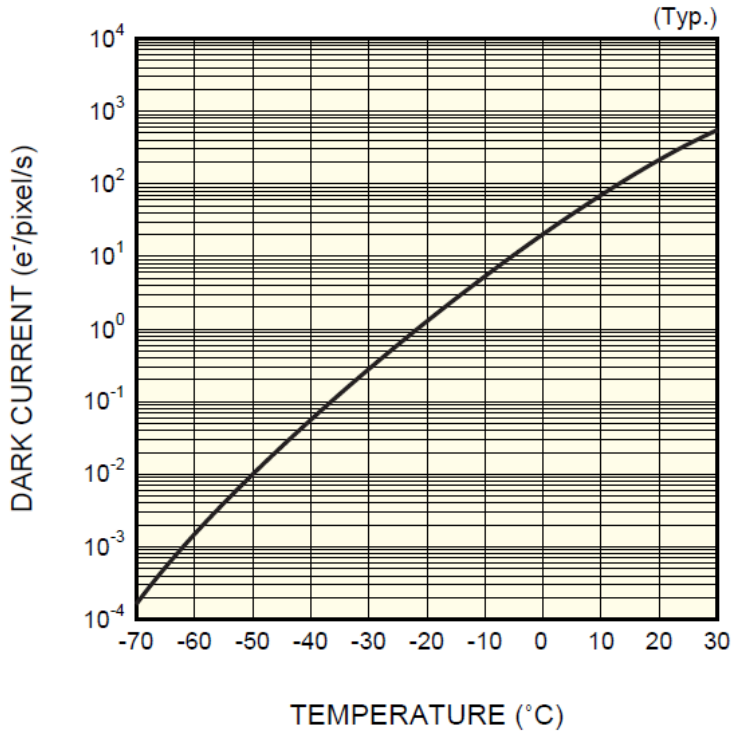
partially compensated by the use of

Spectral Response



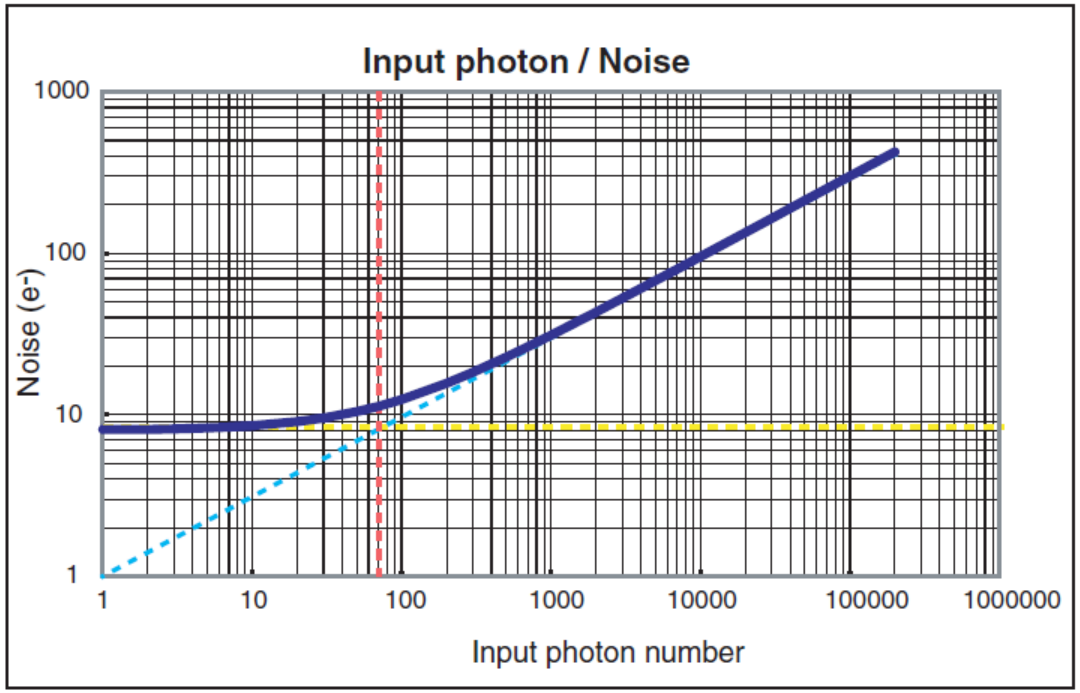
Noise Sources





- Cooling makes dark current negligible
- Fixed pattern noise can be compensated

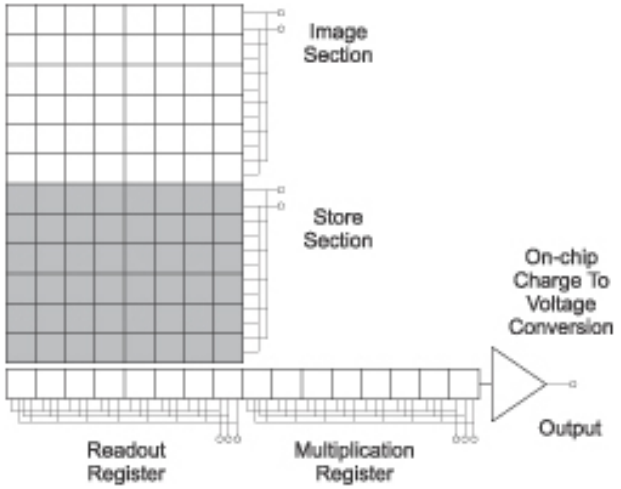
CCD Noise

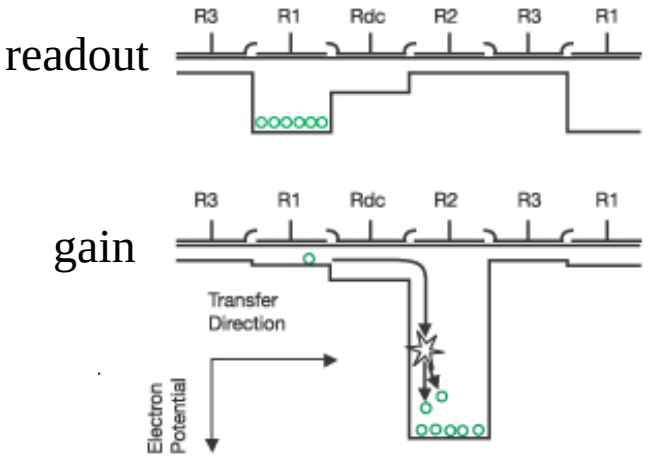


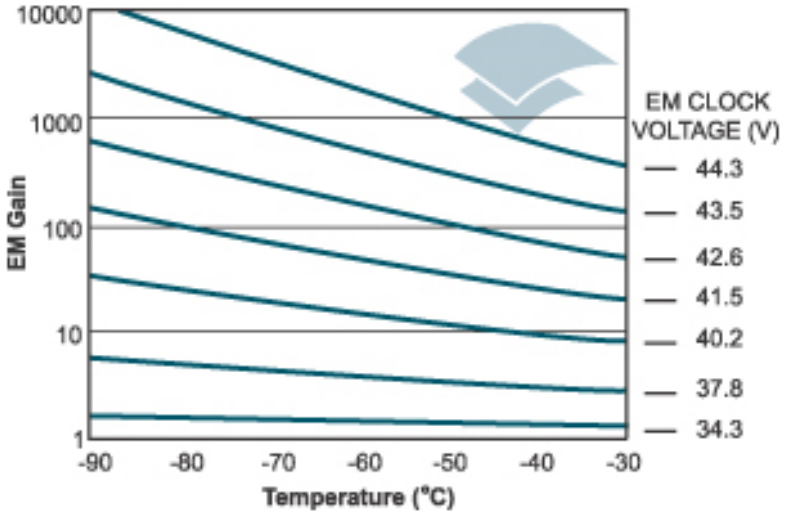
--- signal shot noise
--- readout noise
— total

- Signal shot noise dominant above 70 photons/pixel
- Amplification before I-V conversion would lower shot noise limit

EMCCD Gain

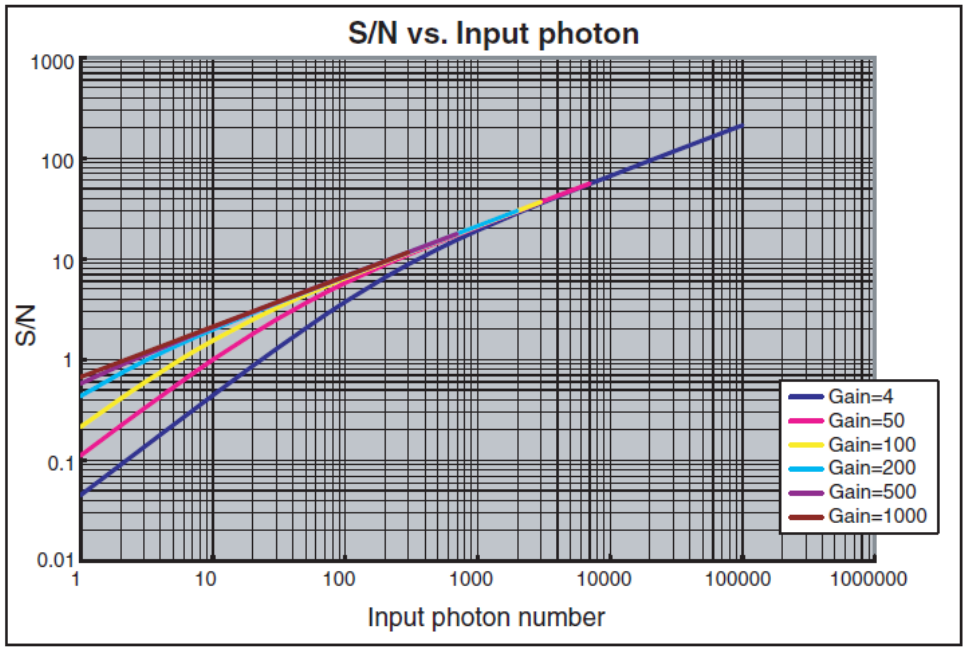






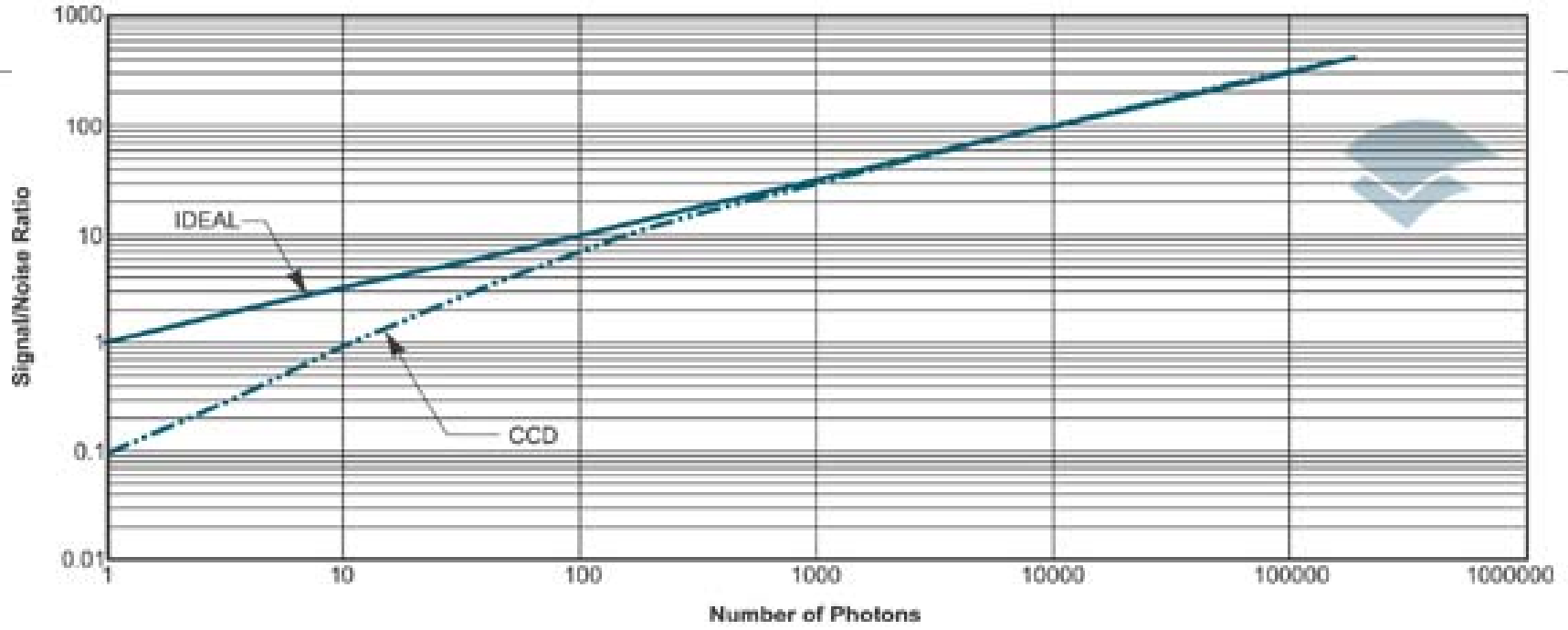
- Small avalanche gain in each cell
- Many multiplication cells
- 10^4 charge gain achievable

EM-CCD Noise



- EM doesn't buy much above 500 photons/pixel
- EM accompanied by spurious noise- grainy image

CCD SNR


1000
100
10
1
0.1
0.01
Signal/Noise Ratio
IDEAL
CCD
1
10
100
1000
10000
100000
1000000
Number of Photons

Dynamic Range

Full Well Capacity & Dynamic Range of Various Cameras

Camera	Pixel Size μm^2	Full Well Capacity e^-	Read noise e^-	Dynamic Range	Decibels dB	Bits	Notes
DU-885K-VP	8 x 8	30000	20 (x3 pre-amp)	1500	64	11	EM Amplifier with No Gain (dynamic range higher with EM gain)
DL-658M-TIL	10 x 10	25000	15	1667	64	11	EM Amplifier with No Gain
DU-897-CSO-BV	16 x 16	180000	9 (x1 pre-amp)	20000	86	15	Conventional Amplifier @ 1MHz (dynamic range higher with alternative pre-amp)
DU-920N-BV	26 x 26	510000	10	51000	94	16	50kHz Readout Rate

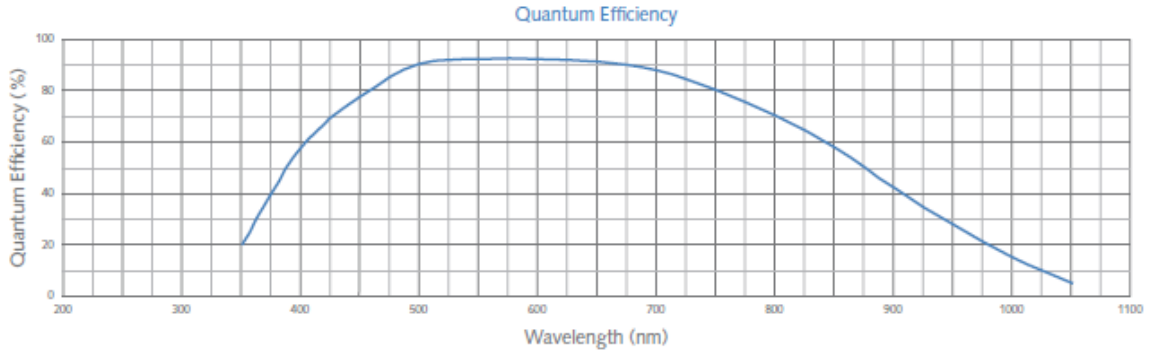
Larger pixel = larger well capacity but poorer resolution

EM-CCD Specs

Specifications

Read noise (e- rms @ Gain State 3)		
10 MHz EM Port	45e-	
5 MHz EM Port	32e-	
5 MHz non-EM Port	12e-	
1.25 MHz non-EM Port	6e-	
Pixel Well Depth		
Active area	200,000e-	
Gain register	800,000e-	
Bias stability		
A measurement of the camera stability when no light hits the sensor. A slope of zero would be ideal. *See footnote #1.*	≤0.0006	
Gain stability		
A measurement of Ideal value would measuring the slop EM Gain applied.		
Field uniformity		
The image quality of any gradient (i.e *footnote #3.*		
Baseline bias value		
Cooling temperature	Air cooled (@ ambient air 20°C)	-85°C
	Chilled liquid (@ 10°C)	-100°C
Dark current	0.001 e-/pixel/sec (*See footnote #4.*)	
Background events		
(10 MHz, 1000X EM gain) Standard operation	0.0045 events/pixel (@ 1000X EM gain)	
(10 MHz, 1000X EM gain) BERT operation	not detectable (*See footnote #5.*)	

Photometrics
512 x 512 pixels
16 um x 16 um



Credits

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