

Biomedical Avalanche Photodiodes

C30902SH, C30921SH, C30902SH-TC, C30902SH-DTC

Si APD for biomedical, analytical and medical diagnostic instruments



Introduction

PerkinElmer Type C30902 family of Si avalanche photodiodes utilize a silicon detector chip fabricated with a double-diffused “reach-through” structure. This structure provides ultra high sensitivity at 400-1000nm.

The “S” series of the C30902 family of APD is designed for ultra-low light level applications (optical power less than 1 pW) and can be used in either their normal linear mode ($V_R < V_{BR}$) at gains up to 250 or greater, or as photon counters in the “Geiger” mode ($V_R > V_{BR}$) where a single photoelectron may trigger an avalanche pulse of about 10^8 carriers. In this mode, no amplifiers are necessary and single-photon detection probabilities of up to approximately 50% are possible.

This series is particularly well suited for ultra sensitive photon measurements in

biomedical, analytical and medical diagnostics instruments.

The C30902SH detector chip is hermetically-sealed behind a flat glass window in TO-18 packages. The C30902SH-TC and –DTC have thermoelectric cooler built-in in an TO-66 package to further reduce the noise. The C30921SH utilizes the same silicon detector chip as the C30902SH, but in a package containing a lightpipe which allows efficient coupling of light to the detector from either a focussed spot or an optical fiber up to 0.25 mm in diameter. The internal end of the lightpipe is close enough to the detector surface to allow all of the illumination exiting the lightpipe to fall within the active-area of the detector. The hermetically-sealed TO-18 package allows fibers to be epoxied to the end of the lightpipe to minimize signal losses without fear of endangering detector stability.

Features and Benefits

- High quantum efficiency
- Hermetically sealed packages
- Built-in TE cooler or lightpipe
- Linear or Geiger mode operation
- RoHS compliant

Applications

- Spectrophotometers
- Fluorescence Detection
- Luminometer
- DNA sequencer
- Particle sizing
- Confocal laser microscope
- Optical tomography
- Lidar

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Table 1. Electrical Characteristics

at $T_A = 22^\circ\text{C}$ unless otherwise indicated

	C30902SH, C30921SH			C30902SH-TC, C30902SH-DTC ³			Units
	Min	Typ	Max	Min	Typ	Max	
Package Type	902S: TO-18; 921S: Lightpipe TO-18 ⁶			TO-66 with Flange			
Breakdown voltage, V_{BR} ⁷		225			225		V
Detector active area diameter		0.5			0.5		mm
Temperature coefficient of V_R for constant gain	0.5	0.7	0.9				V/°C
Detector Temperature: ⁵							
- TC					0		°C
- DTC					-20		
Gain ⁷		250			250		
Responsivity:							
At 900 nm	92	108			108		A/W
At 830 nm	117	128			128		
Quantum efficiency:							
At 900 nm		60			60		%
At 830 nm		77			77		
Dark current, I_d		10	30				nA
- TC (0 °C)					2		
- DTC (-20 °C)					1		
Noise current, i_n : ²		0.11	0.2				pA/Hz ^{1/2}
- TC (0 °C)					0.04		
- DTC (-20 °C)					0.02		
Capacitance, C_d		1.6	2		1.6	2	pF
Rise time, t_r :							
$R_L = 50\Omega$, $\lambda = 830$ nm, 10% to 90% points		0.5	0.75		0.5		ns
Fall time:							
$R_L = 50\Omega$, $\lambda = 830$ nm, 90% to 10% points		0.5	0.75		0.5		ns
TEC max. current ³							A
- TC					1.8		
- DTC					1.4		
TEC max voltage ³							V
- TC					0.8		
- DTC					2		
Dark count rate at 5% photon detection probability (830 nm, case temperature of 22°C)		5,000	15,000		1,100 (-TC) 250 (-DTC)		cps
Voltage above V_{BR} for 5% photon detection probability (830 nm) (see figure 6)		2			2		V
After-pulse ratio at 5% photon detection probability (830 nm) 22°C ⁴		2	15		2		%
Maximum Reverse current at 22 °C :							
Continuous operation (Ave. value)			0.2		0.2		
Peak value for 1 second duration (non-repetitive)			1		1		mA
Maximum forward current at 22 °C :							
Continuous operation (Ave. value)			5		5		
Peak value for 1 second duration (non-repetitive)			50		50		mA
Max. total power dissipation at 22 °C			60		60		mW
Storage Temperature	-60		+100	-60		+100	°C
Operating Temperature	-40		+70	-40		+70	°C

Optical Characteristics

C30902SH (figure 7), C30902SH-TC, C30902SH-DTC (figure 9)

Photosensitive Surface:

ShapeCircular
 Useful area0.2 mm²
 Useful diameter0.5 mm

Field of View:

Approximate full angle for totally
 illuminated photosensitive surface100 deg

C30921SH (Figure 8)

Numerical Aperture of Light Pipe0.55
 Refractive Index (n) of Core1.61
 Lightpipe Core Diameter0.25 mm

“- TC” and “- DTC” TE Cooled version

TE cooled APD can be used for different reason. Most applications benefits from a TC (single) or DTC (dual) version for two reasons:

- To reduce the thermal noise for very small signal detection as described previously. The TC version has been design to operate the APD down to 0°C whereas the DTC version can be operated at -20°C when the ambient temperature is 22°C.
- To keep a constant APD temperature no matter the ambient temperature. Because APD breakdown voltage decreases with a decrease of temperature, the TE cooler allows a single operating voltage. Also, this configuration allows constant APD performance over an extended ambient temperature range.

The thermistor located inside the unit can be used to monitor the APD temperature and can be used to implement a TE cooler feedback loop to keep the APD at a constant temperature or/and to implement a temperature compensation on the APD bias voltage. A proper heat-sink is required to dissipate the heat generated by the APD and the TE cooler.

RoHS Compliance

This series of APDs are designed and built to be fully compliant with the European Union Directive 2002/95EEC – Restriction of the use of certain Hazardous Substances in Electrical and Electronic equipment.

Custom Designs

Recognizing that different applications have different performance requirements, PerkinElmer offers a wide range of customization of these APDs to meet your design challenges. Dark count selection, custom device testing and packaging are among many of the application specific solutions available.

Operating Notes

Note 1: At the DC reverse operating voltage V_R supplied with the device and a light spot diameter of 0.25 mm (C30902SH, C30902SH-TC, and C30902SH-DTC) or 0.10 mm (C30921SH). Note that a specific value of V_R is supplied with each device. When the photodiode is operated at this voltage, the device will meet the electrical characteristic limits shown above. The voltage value will be within the range of 180 to 250 volts.

Note 2: The theoretical expression for shot noise current in an avalanche photodiode is

$$i_n = (2q (I_{ds} + (I_{db}M^2 + P_O RM) F) B_W)^{1/2}$$

where q is the electronic charge, I_{ds} is the dark surface current, I_{db} is the dark bulk current, F is the excess noise factor, M is the gain, P_O is the optical power on the device, and B_W is the noise bandwidth. For these devices $F = 0.98 (2 - 1/M) + 0.02 M$. (Reference: PP Webb, RJ McIntyre, JJ Conradi, "RCA Review", Vol. 35 p. 234, (1974)).

Note 3: The C30902SH-TC has a one-stage thermoelectric cooler. The C30902SH-DTC has a two-stage thermoelectric cooler.

A 1-stage cooler will provide about a 3X performance improvement, and a 2-stage cooler will provide about a 6X improvement.

Selected C30902SH detectors with guaranteed 22°C dark counts <5,000 counts/sec are available on a custom basis.

Note 4: After-pulse occurring 1 microsecond to 60 seconds after main pulse. See "After Pulsing" on page 10 of this data sheet.

Note 5: A thermistor of 5KΩ @ 25°C and 43KΩ @ -25°C can be used to monitor the detector temperature.

Note 6: Lightpipe characteristics:

Numeric aperture of Lightpipe: 0.55
 Refractive Index (n) of core: 1.61
 Lightpipe core diameter: 0.25mm

Note 7: An APD breakdown voltage is temperature dependent and decreases with decreasing temperature. If the bias voltage is kept constant, APD gain will increase with decreasing temperature. A room temperature operating voltage is supplied with each unit. A TE cooler can also be used to maintain a constant APD temperature and thus keep the gain constant.

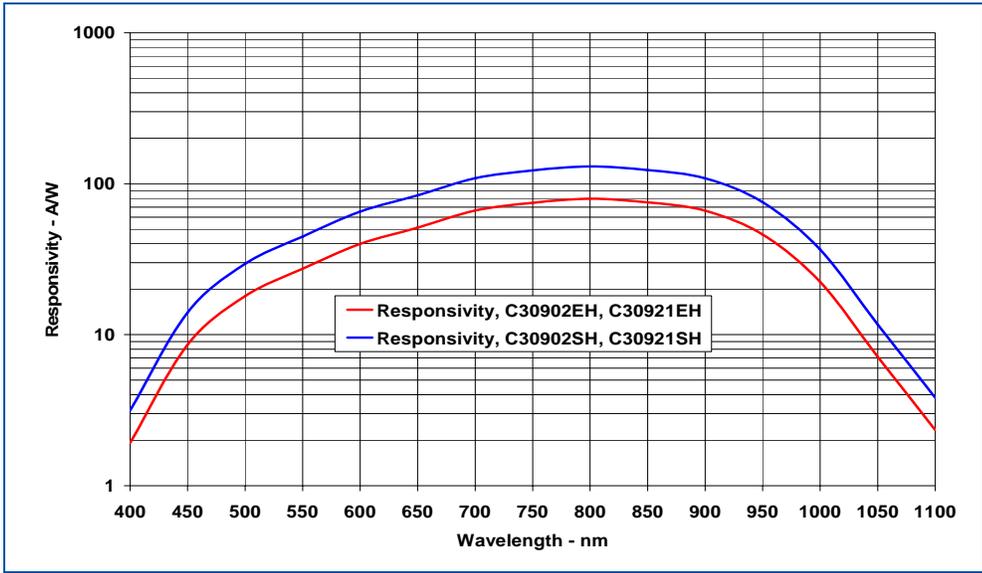


Figure 1. Typical spectral responsivity @ 22 °C

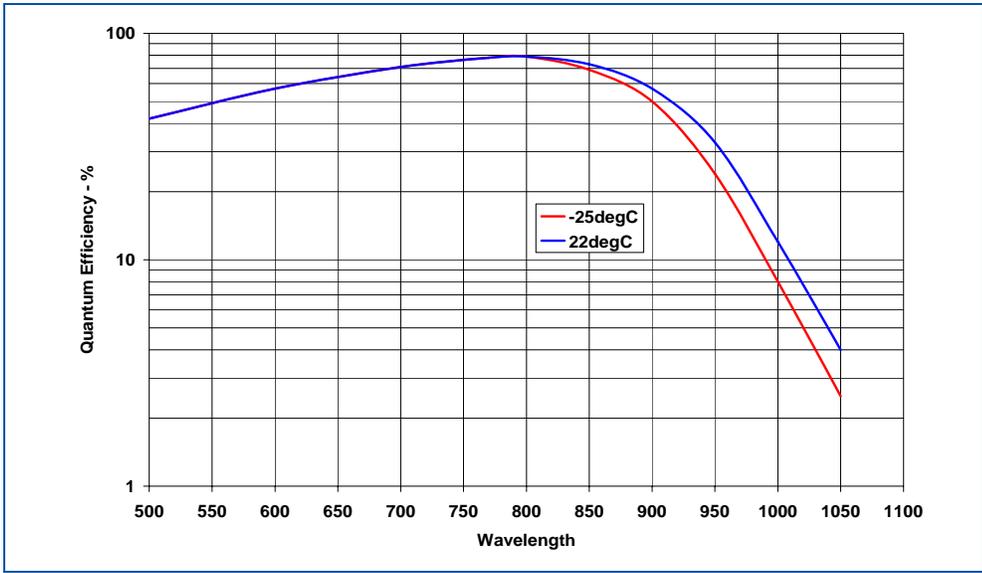


Figure 2
Typical quantum efficiency vs. wavelength

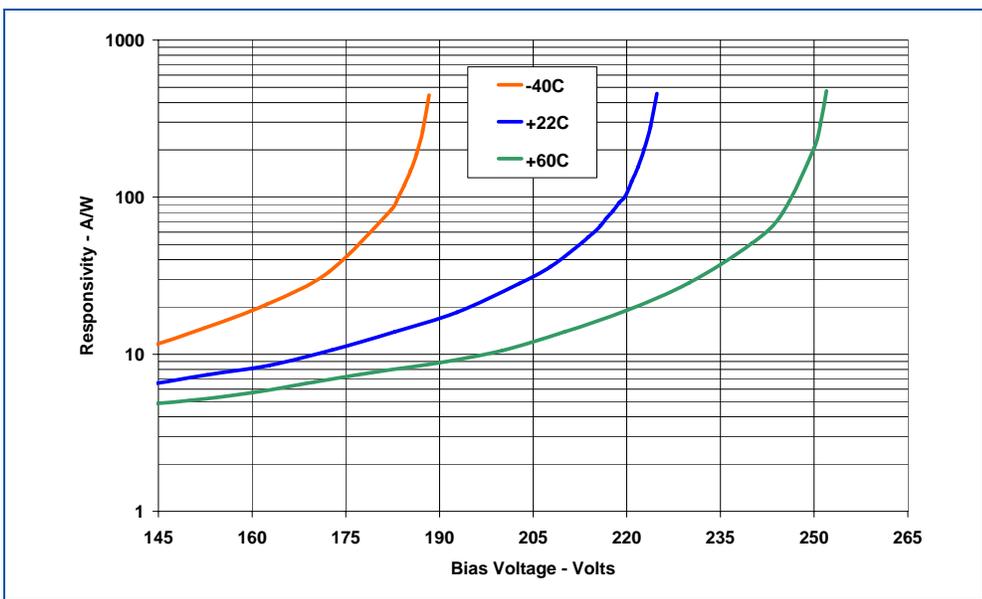


Figure 3
Typical responsivity @ 830nm vs. operating voltage

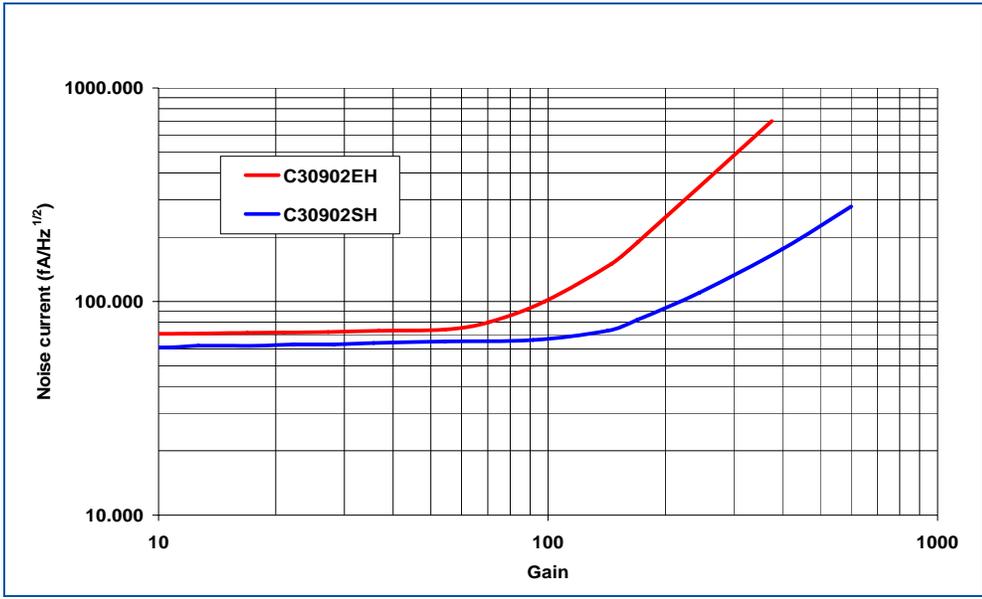


Figure 4
Typical noise current vs. Gain
@ 22 °C

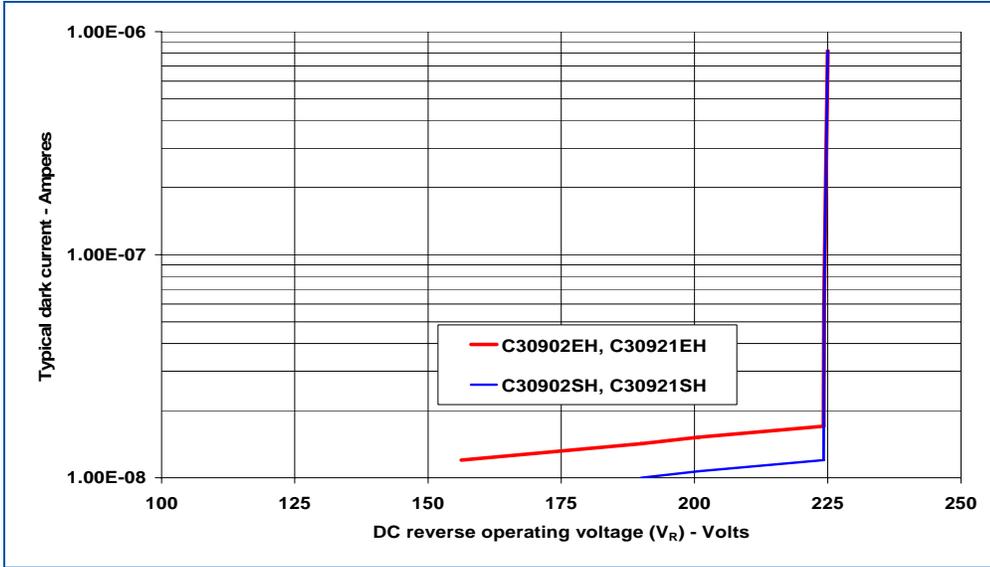


Figure 5
Typical dark current vs.
operating voltage @ 22 °C

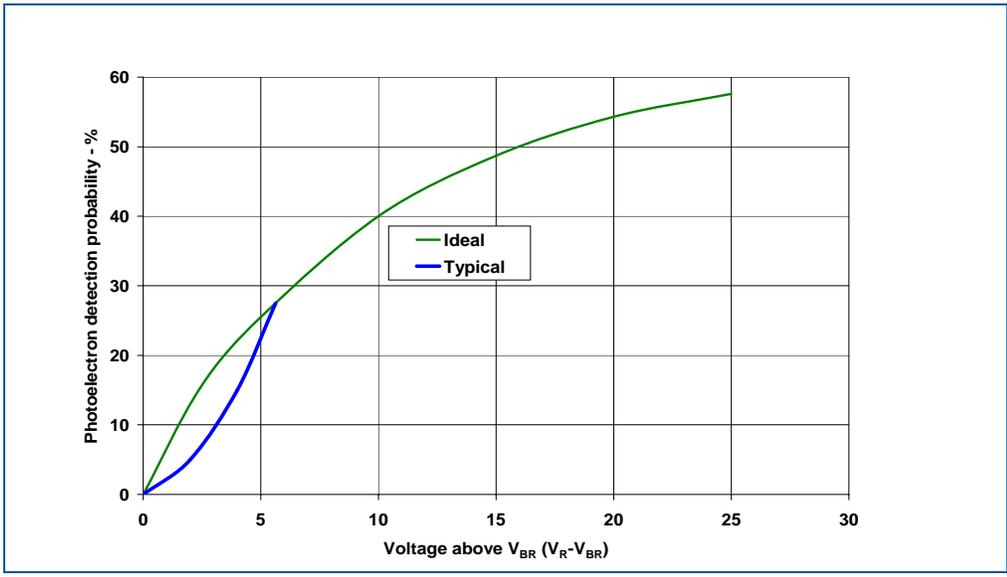


Figure 6
Geiger mode photon detection
probability vs. voltage above V_{BR}
(V_R>V_{BR}) @ 22 °C

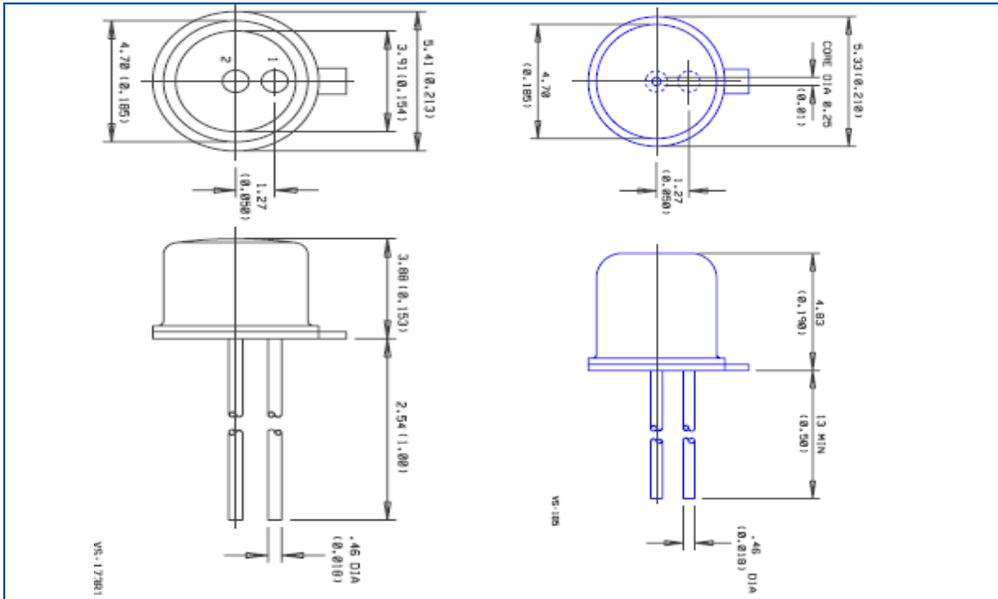


Figure 7

C30902SH (left)
C30921SH (right)
TO-18 Package outline

Dimensions in mm (inches)

Pinout:

1. Positive Lead (Cathode)
2. Negative Lead (Anode)

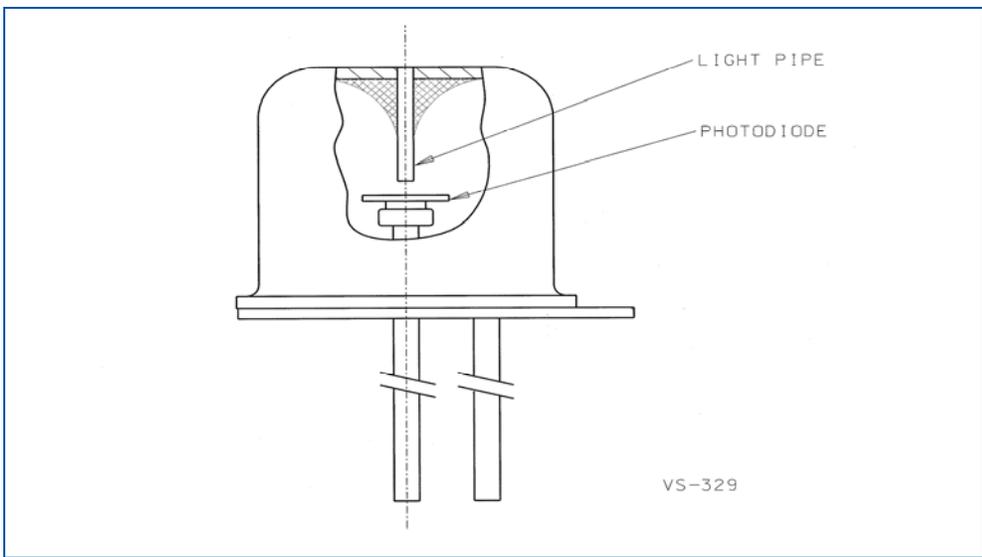


Figure 8

C30921SH, cutaway of the lightpipe package outline

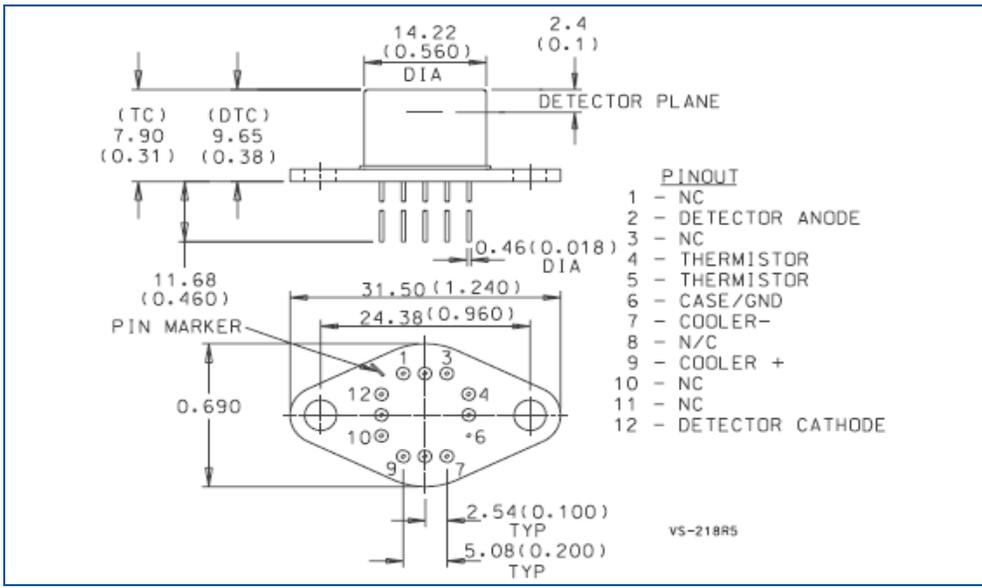


Figure 9

C30902SH-TC, C30902SH-DTC,
TO-66 with flange package outline

Dimensions in mm (inches)

Geiger mode operation Introduction

When biased above the breakdown voltage, an avalanche photodiode will normally conduct a large current. However, if the current is such that the current is limited to less than a particular value (about 50 μ A for these diodes), the current is unstable and can switch off by itself. The explanation of this behaviour is that the number of carries in the avalanche region at any one time is small and fluctuating wildly. If the number happens to fluctuate to zero, the current must stop. If subsequently remains off until the avalanche pulse is retriggered by a bulk or photo-generated carrier.

The “S” versions are selected to have a small bulk-generated dark-current. This makes them suitable for low-noise operation below V_{BR} or photon-counting above V_{BR} in the Geiger mode. In this so-called Geiger mode, a single photoelectron (or thermally-generated electron) may trigger an avalanche pulse which discharges the photodiode from its reverse voltage V_R to a voltage slightly below V_{BR} . The probability of this avalanche occurring is shown in Figure 8 as the “Photoelectron Detection Probability” and as can be seen, it increases with reverse voltage V_R . For a given value of $V_R - V_{BR}$, the Photoelectron Detection Probability is independent of Temperature. To determine the Photon Detection Probability, it is necessary to multiply the Photon Detection Probability by the Quantum Efficiency, which is shown in Figure 2. The Quantum Efficiency also is relatively independent of temperature, except near the 1000 nm cut-off.

The “S” versions can be used in the Geiger mode using either “passive” or “active” pulse quenching circuits. The advantages and disadvantages of each are discussed below.

Passive-Quenching Circuit

The simplest, and in many case a perfectly adequate method of quenching a breakdown pulse, is through the use of a current limiting load resistor. An example of such a “passive” quenching is shown in figure 10. The load-line of the circuit is also shown in the same figure. To be in the conducting state at V_{BR} two conditions must be met:

1. The Avalanche must have been triggered by either a photoelectron or a bulk-generated electron entering at the avalanche region of the diode. (Note: holes are inefficient at starting avalanches in silicon.) The probability of an avalanche being initiated is discussed above.
2. To continue to be in the conducting state a sufficiently large current, called the latching current I_{LATCH} , must be passing through the device so that there is always an electron or hole in the avalanche region. Typically in the C30902SH and C30921SH, $I_{LATCH} = 50\mu$ A. For currents $(V_R - V_{BR})/R_L$, much greater than I_{LATCH} , the diode remains conducting. If the current $(V_R - V_{BR})/R_L$ is much less than I_{LATCH} , the diode switches almost immediately to the non-conducting state. If $(V_R - V_{BR})/R_L$ is approximately equal to I_{LATCH} , then the diode will switch at an arbitrary time from the conducting to the non-conducting state depending on when the number of electrons and holes in the avalanche region statistically fluctuates to zeros.

When R_L is large, the photodiode is normally conducting, and the operating point is at $V_R - I_{DS}R_L$ in the non-conducting state. Following an avalanche breakdown, the device recharges to the voltage $V_R - I_{DS}R_L$ with the time constant $R_L C$ where C is the total device capacitance including stray capacitance. Using $C = 1.6$ pF and $R_L = 200.2$ k Ω a recharge time constant of 0.32 μ s is calculated. The rise-time is fast, 5 to 50ns, and decreases as $V_R - V_{BR}$ increases, and is very

dependent on the capacitances of the load resistors, leads, etc. The jitter at the half-voltage point is typically the same order of magnitude as the rise-time. For timing purposes where it is important to have minimum jitter, the lowest possible threshold of the rising pulse should be used.

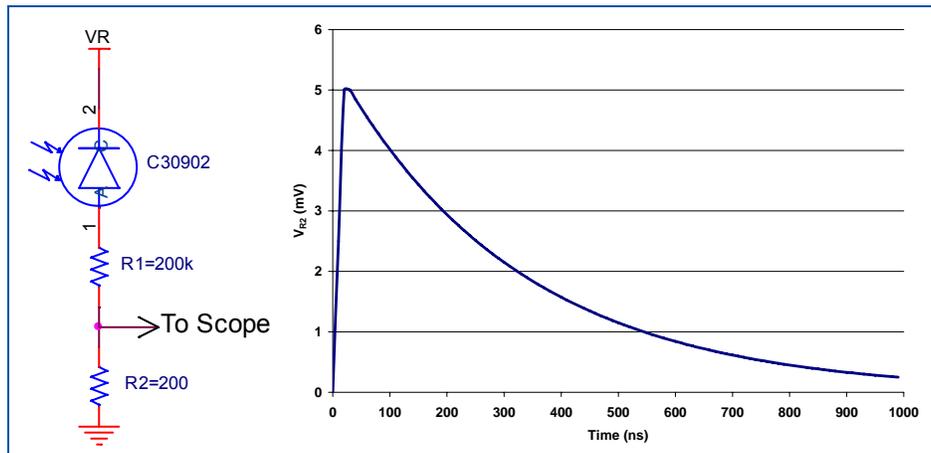


Figure 10
Sample of passive quench circuit

Active-Quenching Circuit

Until the C30902SH is recharged, the probability of detecting another incoming photoelectron is relatively low. To avoid an excessive dead-time when operating at a large voltage above V_{BR} , an “actively quenched” circuit can be used. The circuit temporarily drops the bias voltage for a fraction of a microsecond following the detection of an avalanche discharge. This delay time allows all electrons and holes to be collected, including most of those temporarily “trapped” at various impurity sites in the silicon. When the higher voltage is reapplied, there are no electrons in the depletion region to trigger another avalanche or latch the diode. Recharging can now be very rapid through a small load resistor. Alternatively, the bias voltage can be maintained but the load resistor is replaced by a transistor which is kept off for a short time after an avalanche, and then turned on for a period sufficient to recharge the photodiode.

Timing Resolution

For photon counting application, the time of the TTL triggered pulse after detecting a photon, when plotted on a curve, take the FWHM averaged, is the timing resolution or time jitter. The jitter at the half-voltage point is typically the same order of magnitude as the rise-time. For timing purposes where it is important to have minimum jitter, the lowest possible threshold of the rising pulse should be used.

After-Pulsing

An after-pulse is an avalanche breakdown pulse which follows a photon-generated pulse and is induced by it. An after-pulse is usually caused by one of the approximately 10^8 carriers which pass through the diode during an avalanche. This electron or hole is captured and trapped at some impurity site in the silicon, as previously described. When this charge-carrier is liberated, usually in less than 100ns but sometimes several milliseconds later, it may start another avalanche. The probability of an after-pulse occurring more than one microsecond later is typically less than 1% at 2 volts above V_{BR} , using the circuit shown in Figure 7.

After-pulsing increases with bias voltage. If it is necessary to reduce after-pulses, it is recommended that one keep $V_R - V_{BR}$ low, use an actively-quenched circuit with a long delay-line, or a passively-quenched circuit with a long $R_L C$ constant. Stray capacitances must also be minimized. Electronic gating of the signal can be performed in certain situations. Should after-pulses be a serious complication in a particular applications, operation below V_{BR} with a good amplifier might be considered.

Dark Current

“S” versions have been selected to have a low dark-count rate. Cooling to -25°C can reduce this by a factor of 50, since the dependence of dark-count rate on temperature is exponential.

The dark-count increases with voltage following the same curve as the Photoelectron Detection Probability until a voltage where after-pulsing is responsible for a feedback mechanism which dramatically increases the dark-count rate. This maximum voltage is circuit dependant, and is not warranted other than the values listed on page 3. In most cases, with a delay time of 300 ns, the diode can be used effectively at V_R up to $V_{BR} + 25\text{V}$.

The C30902 should not be forward biased or, when unbiased, exposed to strong illumination. These conditions result in a greatly enhanced dark-count, which requires up to 24 hours to return to its nominal value.

“Your Partner of Choice”

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