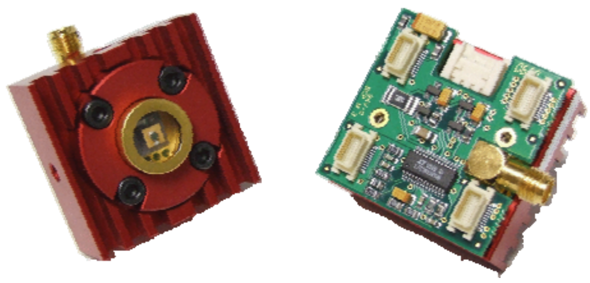
SPMMini
High Gain APD
Version 2.02

Overview



The SPMMini is the first solid state alternative to the analogue Photomultiplier Tube. It features SensL's novel and patented Silicon Photomultiplier (SPM) technology. The SPMMini is the first solid state alterative to the long established Photomultiplier Tube (PMT). It combines the high gain (10^6) and high quantum efficiency of the PMT with the well appreciated benefits of silicon including size, low operating voltage, robustness, reliability, magnetic field insensitivity, tolerance of excess/ambient light and suitability for miniaturisation. In addition, the novel design has high S/N light and a very fast pulse response.

The benefits of the SPMMini vs. the PMT are summarised in table below. Whether you are an OEM or a researcher and your application is a portable/miniature instrument, a large area radiation detection application or a high tier laboratory analysis instrument, the SPMMini will provide significant benefit over existing detector platforms.

The SPM technology is based on arrays of SensL's high gain photodiodes. The current from each high gain photodiode in the array is summed at the SPMMini output giving an analogue output signal which is proportional to the number of photodiodes detecting a photon at any given time. This is proportional to the incident light flux on the sensor.

The uniform high gain across the array allows the single photoelectron peaks to be clearly resolved permitting both single photon detection and accurate calibration of the photon number. The SPMMini has add-on modules available to enhance functionality, including a peltier cooler driver circuit to enable cooling to –20°C and a variety of amplifier circuits, including a trans-impedance option for CW applications, and pulse amplifier circuits for pulsed applications and applications where it is desirable to see the individual photon peaks.

The signal to noise of the SPMMini is better that a PMT for many typical applications. This is possible due to the superior excess noise of the Silicon Photomultiplier technology. A direct comparison of the S/N between a PMT and SPMMini is shown in Page 9.

Features

- High gain (10^6)
- Low bias voltages (30V)
- Fast rise time (<5ns)
- Low dark count rate (<1MHz)
- High S/N
- Not damaged by excess/ambient light
- Large area up to 9mm^2
- Minimal electronics requirement
- Compact, rugged and stable
- Insensitive to magnetic fields

Applications

- Fluorescence lifetime measurements
- Biological sensors
- Scanning microarrays
- DNA biochips/sequencing
- Proteomics/Protein Biochips
- Point-of-use biological agent detection
- Confocal microscopy
- Nuclear medicine
- Environmental monitoring
- Nuclear radiation detection
- Homeland security
- High energy physics
- Flow cytometry
- Capillary electrophoresis
- Range finding

Technology Comparison

SPM	Typical PMT
High gain (10^6)	High gain (10^6)
Low bias voltage (30V)	High bias voltage (kV)
Insensitive to magnetic fields	Sensitive to magnetic fields
Robust	Not robust - glass tubes
Tolerant of excess ambient light	Damaged by excess ambient light
Large area & arrays possible	Large size possible arrays impossible

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General Specifications

Parameter	Min	Typical	Max	Units	Test conditions
INPUTS					
Input Voltage 1 (+5V)	4.9	5.0	5.1	V	Typical Current 50mA
Input Voltage 2 (-5V)	-4.9	-5.0	-5.1	V	Typical Current 50mA
Input Voltage 3 - Detector Bias Voltage	28	31	31.5	V	Typical Current 10mA
Breakdown Voltage (V_{br})	27	28	29	V	At Room temperature
OTHER					
Spectral range	400		1100	nm	Peak λ = 520nm
Max Operating Temperature	-20	-	40	^{0}C	
Max Storage Temperature	-30	-	85	^{0}C	
CHANGES DUE TO OPTIONS					
Input Voltage 1 (5V)	4.9	5.0	5.1	V	**Cooling Board Option -** Typical Currents 200mA at normal operation 700mA at Startup
Cooling Time		10		sec	**Cooling Board Option** (from room temp)
Temperature Setpoint Stability	-20.1	-20	-20.1	°C	**Cooling Board Option**

Specific Specifications

Typical Values	Part Number: SPMMini1000X03A1	SPMMini1000X03A3	SPMMini3000X03A1	SPMMini3000X03A3	Units	Test conditions
Chip Area	1.14x1.14	1.14x1.14	Pending	Pending	mm^2	-
Active Area	1x1	1x1			mm^2	-
Max Responsivity	130,000	130,000			A/W	+4V above breakdown, λ = 520nm
Pixel Gain	$1x10^6$	$1x10^6$			-	Bias = 32V
Pre-amp Board Gain	470	20			-	50Ω load
Max Output Voltage	0.220	1.5			V	50Ω load
NEP	$6.5x10^{-15}$	$6.5x10^{-15}$			$WHz^{-1/2}$	+4V above breakdown, λ = 520nm
Dynamic Range	10^3	10^3			-	Bias = 32V, λ = 650nm
Linear Range	0.0-4	0.5-14			nW/mm^2	Bias = 32V, λ = 650nm
Cut-off Freq	1	1			MHz	3dB point
Output Capacitance (source)	130	130			pf	-
Output Impedance	50	50			Ω	-
Number of Pixels	920	920			-	-
Pixel Quantum Efficiency (QE)	40	40			%	λ = 520nm, Bias = 32
Geometric Efficiency (F)	34	34			%	-
Photon Detection Efficiency (QE x F)	15	15			%	λ = 520nm, Bias = 32
Temp. dependence of Voltage Breakdown	23	23			mV/^{o}C	-
Single Photon Pulse - Leading Edge	23	5			ns	-
Single Photon Pulse - Falling Edge	25	20			ns	-

Notes:

SensL reserves the right to change all product specification and functionality without notification. Information on this datasheet is believed to be accurate. However, no responsibility is assumed for any inaccuracies or omissions.

The printed version of this datasheet is restricted to two pages. The full version is available on our website at www.SensL.com/Products

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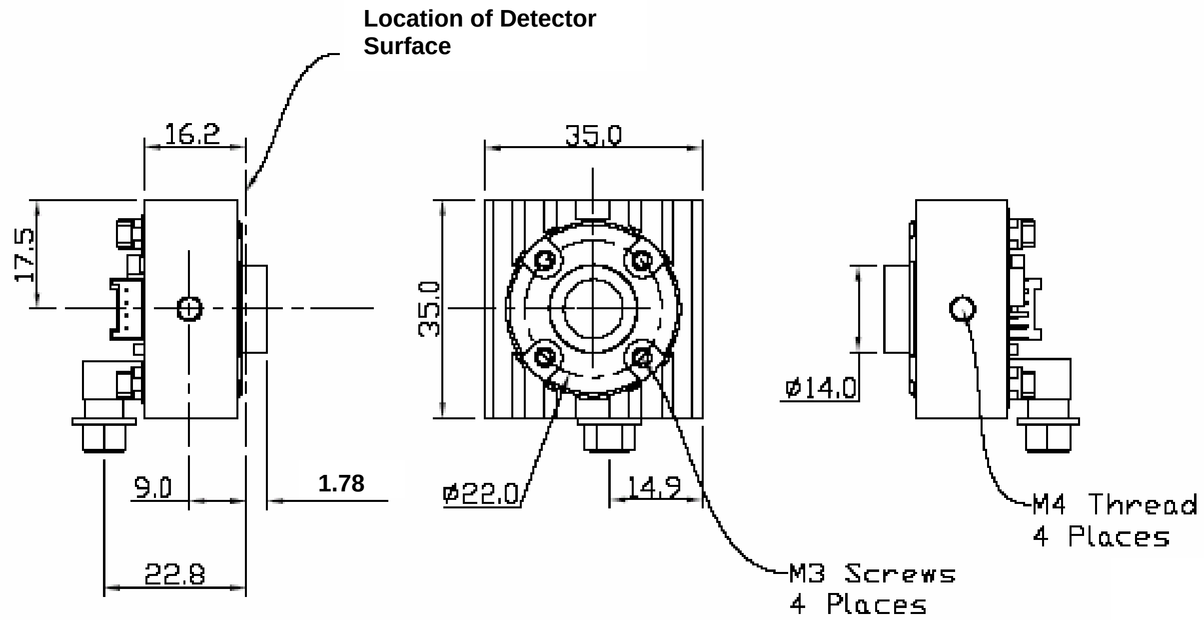
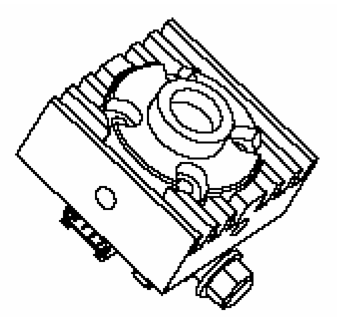
Mechanical Information:



All dimensions in mm



Drawings refer to Basic Module with no Cooling Board

Ordering Information

SPMMini1000X03A1	**Module Base: Transimpedance Amplifier & 1mm x 1mm sensor in T08 Can (with Peltier Cooler)**
SPMMini1000X03A3	**Module Base: Pulse Amplifier & 1mm x 1mm sensor in T08 Can (with Peltier Cooler)**
SPMMini3000X03A1	**Module Base: Transimpedance Amplifier & 3mm x 3mm sensor in T08 Can (with Peltier Cooler)**
SPMMini3000X03A3	**Module Base: Pulse Amplifier & 3mm x 3mm sensor in T08 Can (with Peltier Cooler)**

Options

SPMMiniC1	**Option: Add Cooling Board Option**
SPMMIniM1	**Option: Add C Mount Adaptor**

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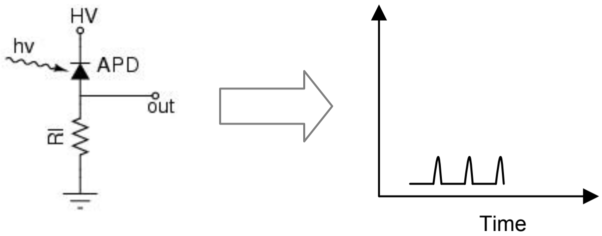
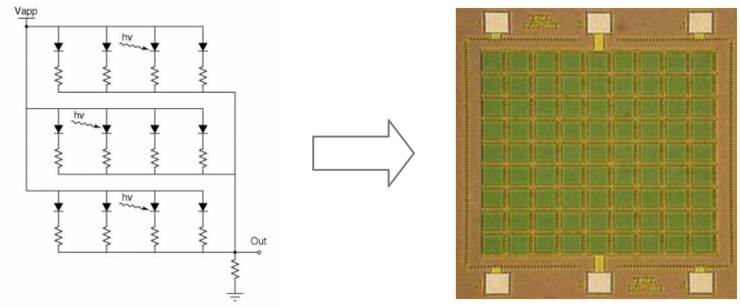
Technical Information - Silicon Photomultiplier Concept Overview

The core of SensL's SPM product line is a high gain photodiode array. SensL's photodiodes are specially designed to allow for operation above the breakdown voltage. Operation above breakdown is known to produce incredibly large gains (up to 10^6), which allow SensL's photodiodes to be sensitive to single photons of light. Internally, what allows a SensL photodiode to detect single photons is an ultra-high quality silicon diode coupled with a quenching resistor. The simplest way to view this concept is through the figure below. In this figure, a single diode is connected in series with a passive quenching resistor. When photons enter into the diode, they cause a very uniform avalanche breakdown to occur. This breakdown is then quenched by the series resistor. By carefully controlling the diode formation and resistor uniformity, a uniform pulse of current flows through the diode during each photon event. This process is the result of years of work into single photon counting diodes and allows high performance highly sensitive detectors in silicon to be realised.



In the Silicon Photomultiplier a large number of these high gain photodiodes are connected in parallel summing the output current from all the active pixels. Each photodiode operates on its own in response to photons entering into the detector. This is shown below as a schematic and also as an image from a manufactured SPM. The end result when illuminated is an analogue signal representing the current pulses from all the photodiodes within the array. This analogue output signal is therefore proportional to the light incident on to the active area of the sensor at any instant in time.

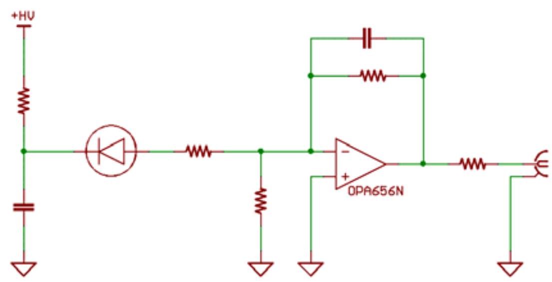


Technical Information - Pre-Amplifier Options

To benefit from the high gain responsivity it is required to use circuitry which can convert the current flowing through the array into a voltage which can be readily processed with standard electronics. Given the high gain inherent in the SPM, it is possible to use pre-amplifier boards of either current or voltage amplification. This has resulted in two different pre-amplifier configurations available from SensL.

Transimpedance Amplifier

The first of these is a transimpedance type pre-amplifier which can convert the raw current from the SPM into a voltage. The typical gain for a SensL transimpedance amplifier is 470V/A. The transimpedance pre-amplifier board is shown schematically in the Figure below. This board is ideal for applications that require detection of continuous signals where integration of the signal is done over time. One application is cell imaging or DNA microarrays where it is desired to integrate the optical signal from a sample for periods from 1us to 1ms in time. This can be accomplished easily with the SensL Transimpedance pre-amplifier.



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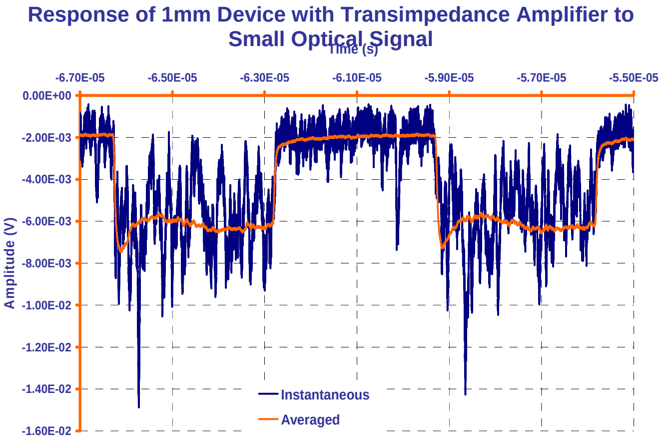
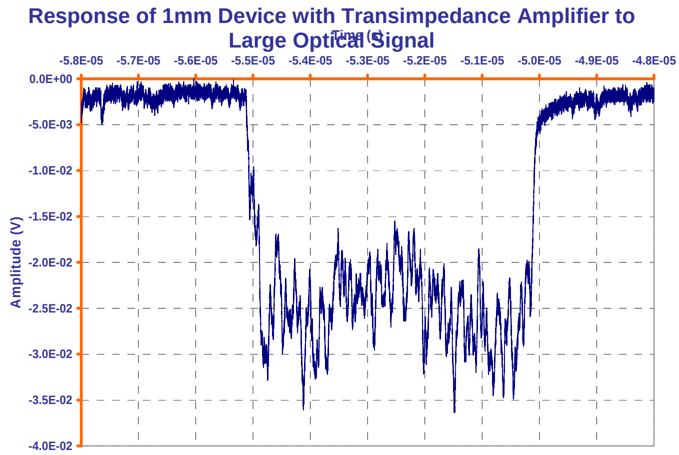
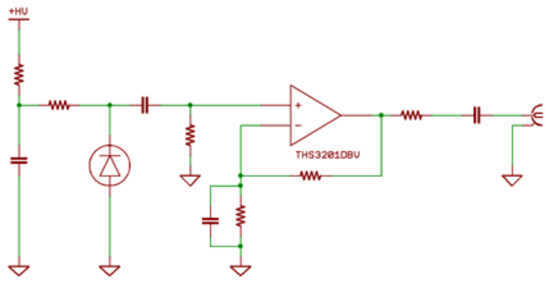
The typical response of the detector to a light signal with the transimpedance amplifier is shown in the images below. The image on the left shows the response of a 1mm SPMMini device with a transimpedance amplifier to a low photon level, i.e. small optical signal. The image on the right shows the response of the same device to a large signal (close to sensor saturation).



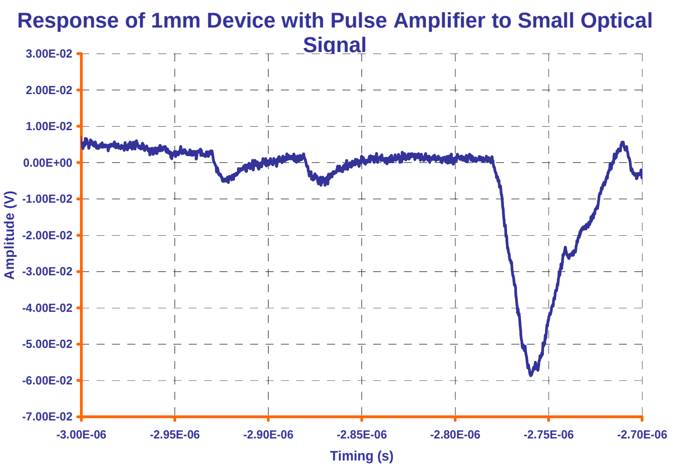


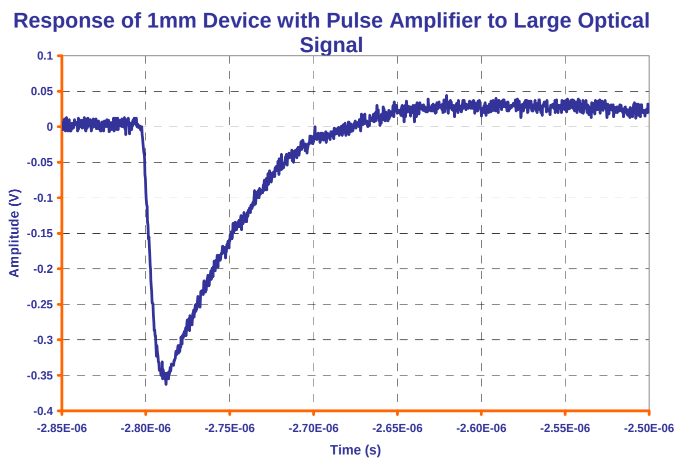
Pulse Amplifier

In situations where the signal is a pulse input, such a ranging applications, a scintillation experiment or in high energy physics, SensL have developed the pulse amplification pre-amplifier. This board is shown in the figure below. This allows the fast rise time of the detector to be exploited and provides for the simplest way to accurately bring pulse information to the user. The SensL SPM is coupled to a high speed pulse pre-amplifier which uses an internal gain of 20. This signal is then output to the user via a DC blocking capacitor to properly convey pulse information originating in the SPM.



The typical response of the detector to a pulse light signal with the pulse amplifier is shown in the images below. The image on the left shows the response of a 1mm SPMMicro device with a pulse amplifier to a very low level photon pulse. The leading edge is ~5ns and trailing edge is ~20ns. The image on the right show the response of the same device to a large optical signal (close to sensor saturation).





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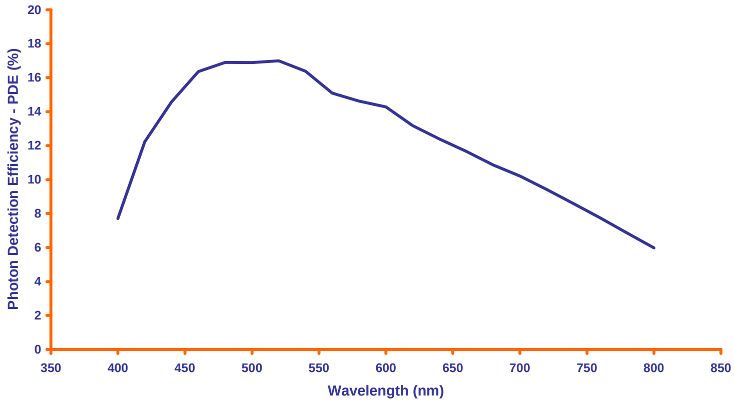
Technical Information - Photon Detector Efficiency

The Quantum Efficiency (QE) of the internal photodiode of an SPM is an important parameter to characterise. When taken in account with the fill factor, the QE dictates the overall Photon Detection Efficiency (PDE) of the SPMMini. The Photon Detection Efficiency gives you the percentage of photons that will be directly detected by the SPM. The equation for this is as follows:

$$PDE = QE \times FillFactor$$

Where QE is the quantum efficiency and the FillFactor is the geometrical efficiency of the SPM. The QE can be determined very accurately by measuring the QE of the individual high gain photodiodes in the SPM. Taking the QE dataof a single high gain photodiode allows you to extract the PDE for the entire array using the PDE equation above. The next graph shows the PDE measured in such a way.

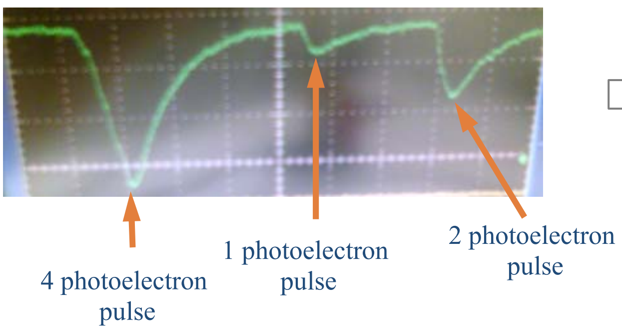
PDE vs. Wavelength (for all 1mm SPMMini products)

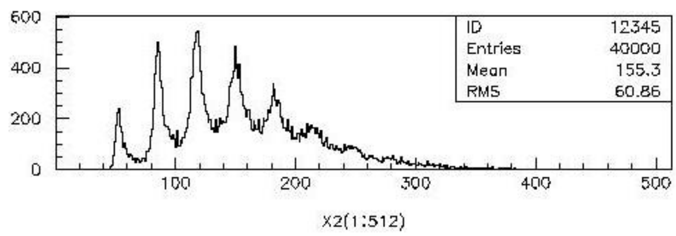


All measurements are made using a continuous light source, a monocromator and an integrating sphere. Calibration is via a calibrated PIN diode.

Technical Information - Single Photon Spectrum

It is possiblle to clearly indentify single and multiple photons in the SPMMini output. Using a multichannal analyser to profile the amplitude of pulses emmitted by the the detector the peaks indicating one, two, three, etc photons are clearly visible. The output from such a single photon peak measurment is shown below.





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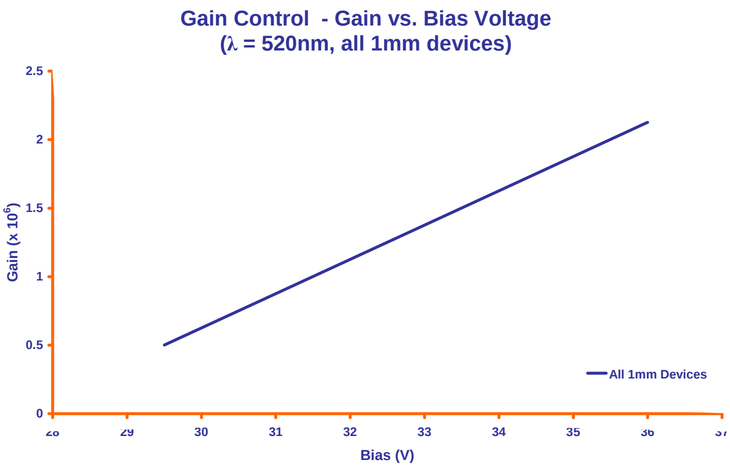
Technical Information - Gain Control

The gain can be varied by adjusting the over bias voltage (i.e. the over voltage or the voltage above the detector breakdown voltage).

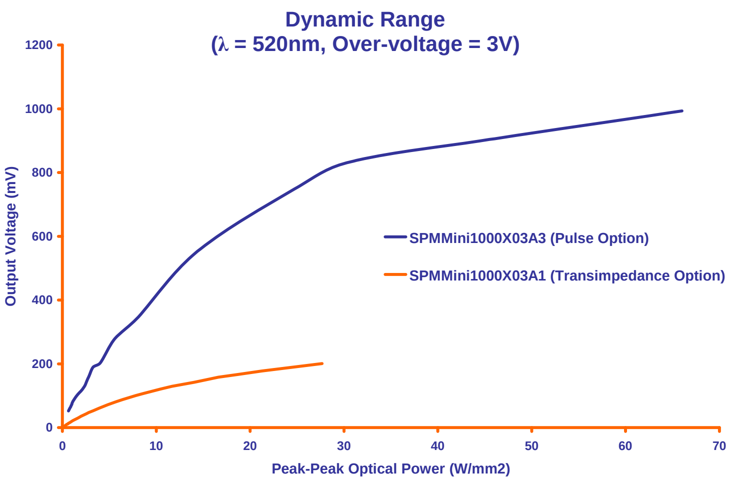


Technical Information - Dynamic Range

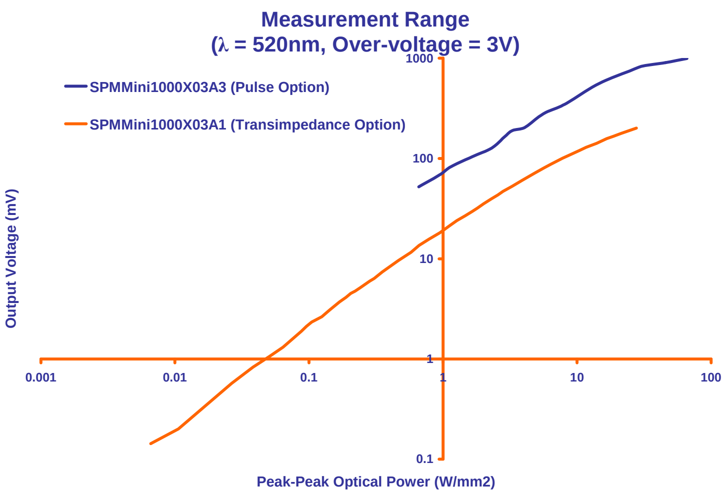
The SPM response as a function of input optical power is shown for all the SPMMini product variations.

The Dynamic Range is the range of optical input power signals which the detector can measure. This is measured by measuring the detector output response to varying optical input signal power.

The upper limit of the Dynamic Range is the power level at which the detector is saturated, i.e. all the photodiodes are continuously firing.



From the data on the left side it can be seen that the Measurement Range of the SPMMini is four orders of magnitude.



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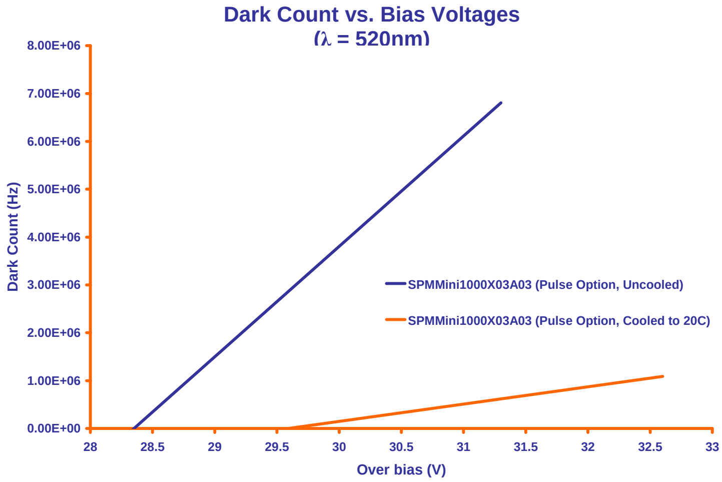
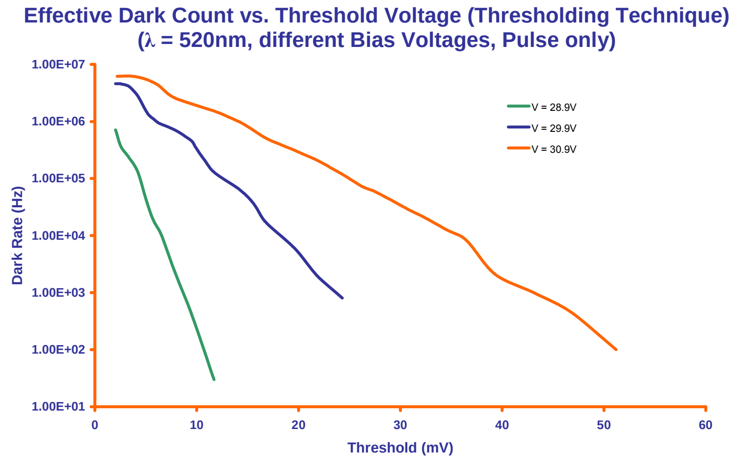
Technical Information - Noise

SPMMini detectors provide an analogue output in response to an incident photon flux. In an ideal SPMMini the output node would be zero volts when un-illuminated. However, there is a dark current signal that is present in the SPMMini detectors. This dark signal can be seen as a series of pulses that are at the single photoelectron level, i.e. the pulses are at the level of the SPMMini output in response to a single photon of light. The dark count has its origins in the individual photodiodes where the spurious output pulses are the result of thermally generated carriers. As the dark count is random the chance of having two photodiodes fire at a single time is very small.

The dark count is also impacted by the extent to which the bias voltage is set over the break-down voltage. This relationship is shown in the graph on the right. It is generally quoted as the number of dark counts per second (cps) or Hz. It is measured by keeping the sensor in total darkness and measuring the average number of pulses per second.

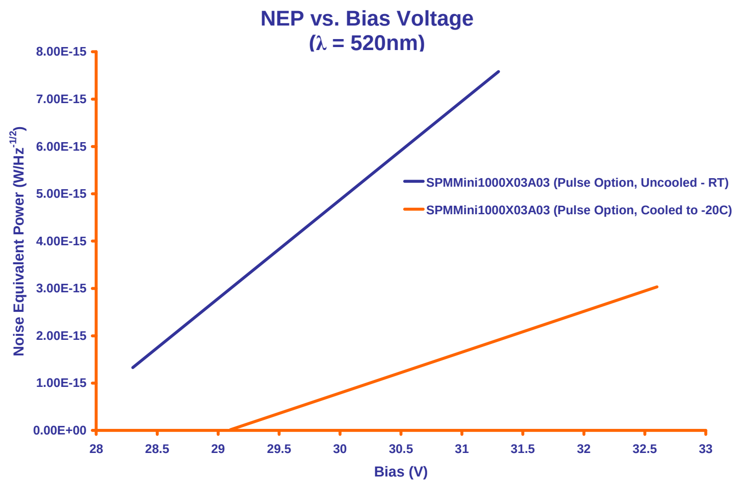


A thresholding technique, which is similar to that used in photomultiplier readout circuitry, can also be implemented. By setting the triggering threshold of the output circuitry to different levels above the single photon electron level the effective dark noise can be significantly suppressed in the output signal. The effect is shown in the chart on the right.



Noise Equivalent Power (NEP) is derived from dark rate data. This is when the signal rate is equal to the dark rate, i.e. the signal to noise is 1.

Cooling the SPMMini reduces the dark rate and allow a lower NEP to be achieved.



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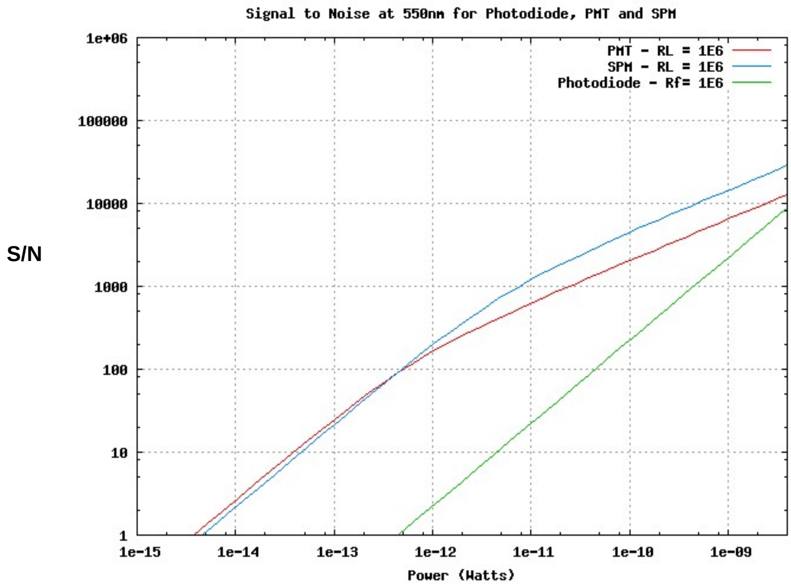
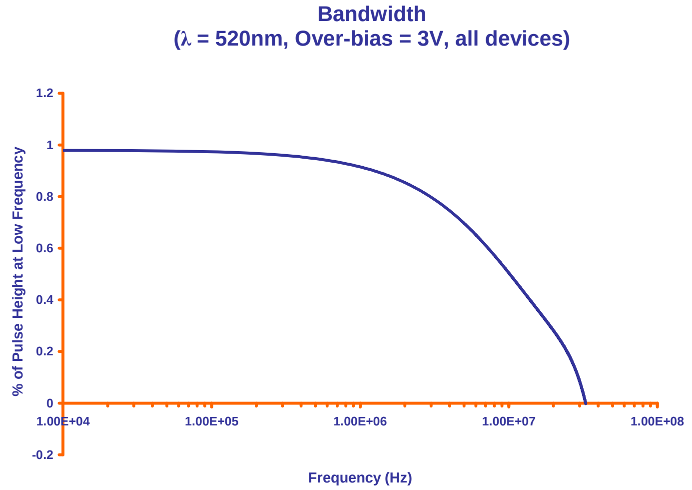
Technical Information - Signal to Noise

The following chart compares the S/N for a PMT, a photodiode and the SPMMini at various light levels.



Technical Information - Bandwidth

The chart below shows the bandwidth of the SPMMini.



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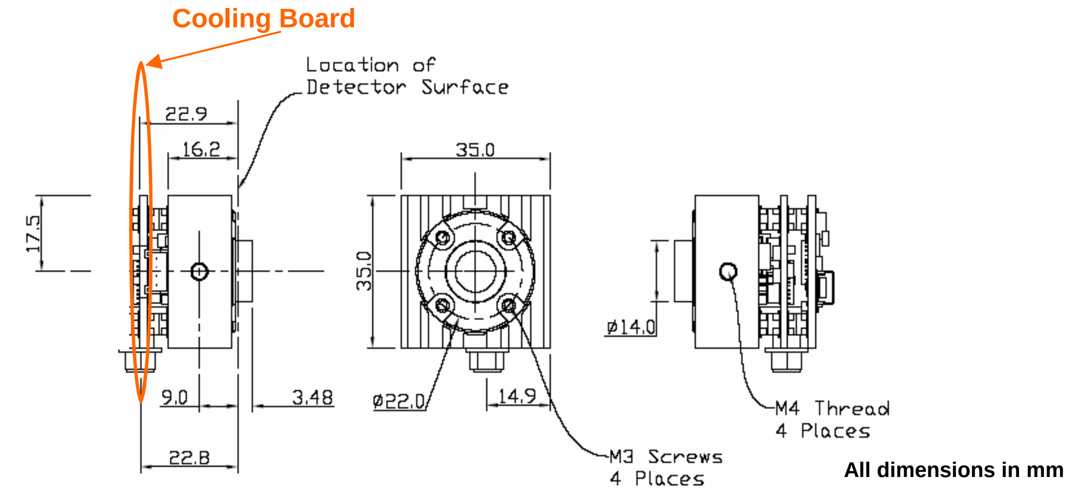
Option 1 - Cooling Board

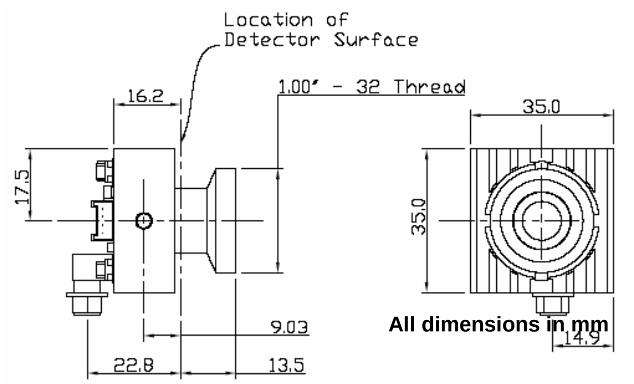
The SPMMini has a cooling option for reducing the temperature of the sensor to -20°C. Cooling is achieved with a two stage TEC Peltier cooler controlled by the add-on board which connects directly onto the SPMMini or main module. A pulse width modulator is used to maintain a stabilised temperature to within 0.1 degrees centigrade based upon feedback from a thermistor situated beside the SPMMini in the hermetically sealed TO8 can. The module features current soft-start for controlled start-up to prevent high current in-rush and an output slew rate limiter to reduce system noise.

The cooling board snaps onto the main module quench board. The drawing shows the dimensions of the main module combined with the cooling board. The addition of the cooling board increases the current drawn on the main 5V power supply. See the table on Page 2 for full details.



Option 2 - C Mount Adaptor

A C Mount Adaptor option is available which attaches to the collar around the T08 can and facilities the attachment of various standard C Mount fittings, including filters and lenses. This an ideal solution for attaching light collection lenses.



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About SensL

SensL's vision is to become the brand and partner of choice for users (particularly OEMs) of low light detectors and imaging systems. Our disruptive products facilitate the improvement in the performance of our customers' systems and enable new applications by overcoming the limitations of existing low light detector technologies. This is particularly relevant when compared to the vacuum based Photomultiplier Tube (PMT).

This breakthrough in low light detection solutions has been achieved by leveraging our core Geiger Mode Photodiode technology to create three distinct low light detector platforms. Our Photon Counting, Silicon Photomultiplier and Low Light Imager products enable the development of new systems for applications such as Bio-diagnostics, Medical Imaging, LIDAR, Environmental Monitoring and High Energy Physics.

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