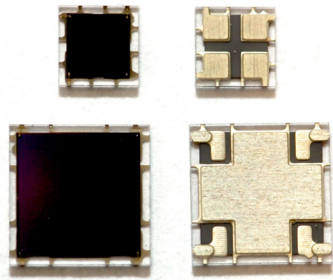


C-Series: Low Noise, Fast, Blue-Sensitive Silicon Photomultipliers



SensL's C-Series low-light sensors feature an industry-leading low dark-count rate, combined with high PDE and are available with SensL's proprietary fast mode output. Three sensor sizes are available; 1mm, 3mm and 6mm packaged in a variety of formats including TO-can, ceramic header and 4-side tileable surface mount technology (SMT) package. In addition, two evaluation boards are available with pre-mounted SMT sensors to facilitate rapid product evaluation.

This User Manual covers all aspects of using and understanding the C-Series range of sensors and evaluation boards. More details on the performance characteristics of the C-Series sensors can be found in the [C-Series datasheet](#).

Overview

The C-Series SiPM sensors from SensL are based on a P-on-N diode structure (Figure 1) that results in a high PDE (Photon Detection Efficiency) and sensitivity into the UV.

All C-Series SiPM sensors also feature SensL's proprietary *fast output* terminal (Figure 2), giving access to signals with extremely fast rise times and short pulse widths.

C-Series SiPM products are available in either MicroSC (2-pin) or MicroFC (3-pin) versions.

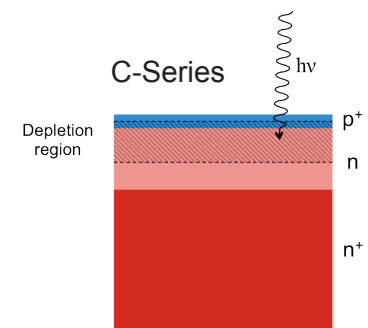


Figure 1, P-on-N sensor structure

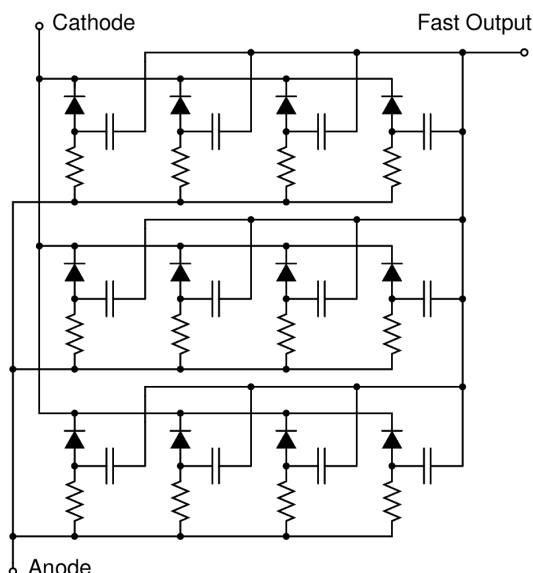


Figure 2, Simplified microcell level schematic of the C-Series SiPM.

MicroSC

Although all C-Series SiPM sensors have the architecture shown in Figure 2, MicroSC packaged products only have two pins giving access to the *anode* and *cathode*. The *fast output* is **not** accessible in MicroSC products.

MicroFC

MicroFC packaged products have three (or more) pins, giving access to the *fast output* as well as the *anode* and *cathode*. The *fast output* is the derivative of the internal fast switching of the microcell in response to the detection of a single photon.

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Glossary

C-Series - A family of SiPM products based upon a P-on-N structure, featuring sensitivity into the UV.

FC - C-Series SiPM product that has at least 3 pins (or pads) accessible that include *anode*, *cathode* and the *fast output* and can therefore be used in *fast mode* configuration.

SC - C-Series SiPM product that has only 2-pins accessible, giving access to the *anode* and *cathode*. The third terminal (fast output) is not accessible, and so SC sensors can only work in *standard mode*.

Fast mode - Using the *fast output* signal from an FC product for improved timing or photon counting applications.

Standard mode - Using the signal from the *anode* and *cathode* for the readout of an SC or FC product where timing performance is less critical.

Biasing and Readout

Fast Mode Biasing and Readout of MicroFC Sensors

Recommended Fast Mode Biasing

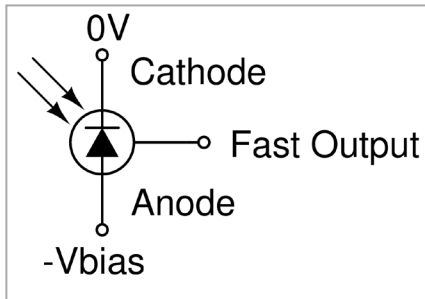


Figure 3, Recommended biasing

The fast output is referenced to the *cathode* (substrate) of the SiPM. Therefore the use of a negative bias voltage applied to the *anode* with *cathode* at 0V is recommended, as in Figure 3. The *fast mode* signal polarity is positive. (If an application requires the use of a positive bias, refer to the advice in Appendix A.) Please refer to the [C-Series datasheet](#) for the operating over-voltage range.

The observed signals will be very fast, with rise-times ranging from 300ps to 1ns and pulse widths of 600ps - 3ns (depending on sensor size). A typical output pulse for a 3mm sensor (MicroFC-30035) is shown in Figure 4.

For all application circuits shown in this User Manual, it is recommended that a bias voltage filter, such as the one shown in Figure 5, is used.

Alternative biasing schemes are discussed in Appendix A.

Recommended Fast Mode Readout

Due to the extreme speed of the signals from the *fast output*, care should be taken in the routing of the signal. Common microwave/RF design rules, such as controlled impedance microstrip lines, should be used. The capacitance of the fast output electrode is much lower (of the order of 2-3pF for a 1mm device) than in a standard configuration. The lower output capacitance does not typically allow the use of a transimpedance amplifier, and instead one can use an RF style (50 Ω impedance) solution including direct connection to a coaxial cable. The 3mm and 6mm devices have higher capacitance, so for best operation when connecting to an oscilloscope or driving long wires, it is recommended that the fast output be connected to an RF transformer such as the RFXF9503 as in Figure 7. This provides impedance matching, to improve amplitude and timing characteristics of the pulse for 50 Ω impedance. For 1mm devices the capacitance is low enough to allow direct 50 Ω connection as in Figure 6.

Another feature of the *fast output* electrode is that it is AC-coupled, with no DC component. However, if needed, one can combine it with the standard output (see the next section) of the SiPM to incorporate DC information.

Fast Output Amplification

It is important to note that the signal charge injected into the fast output electrode is typically about 2% of the SiPM charge generated during the avalanche. However, the pulse duration is approximately 100 times shorter, so the current amplitude observed is about $0.02 \times 100 = 2$ times higher. This high current amplitude, in combination with the significantly lower output capacitance, make the device suitable for photon counting at very high speed (tens of MHz and higher has been demonstrated in the lab).

For amplification of the fast signal it is recommended that a low noise 50 Ω RF amplifier be used. As with standard readout, the level of gain required is dependent on the application. For applications with high photon counts it is recommended that the Mini-Circuits ZX60-43S+ be used. For photon counting applications it is recommended that the Mini-Circuits ZFL-1000LN+ be used. For PET applications it is possible to obtain both timing and energy resolution information from the fast output, with the anode and cathode only used for biasing.

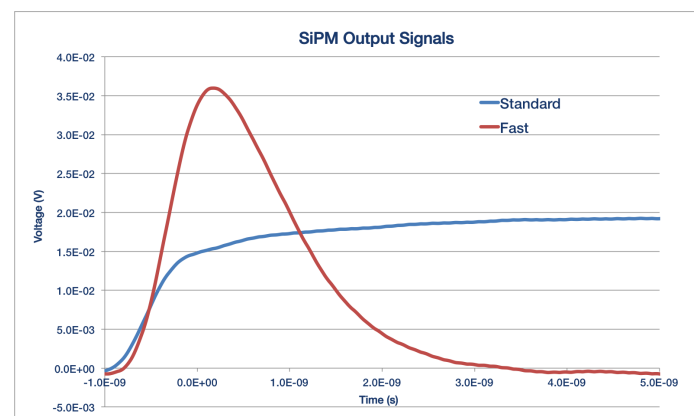


Figure 4, Fast mode output (red) of a MicroFB-SMA-30035 when illuminated with a 40ps laser pulse (Photek LPG-405). ~2.5% of microcells are fired in this pulse. Also shown is part of the standard output pulse, which is shown in full in Figure 9. Scope input = 50 Ω .

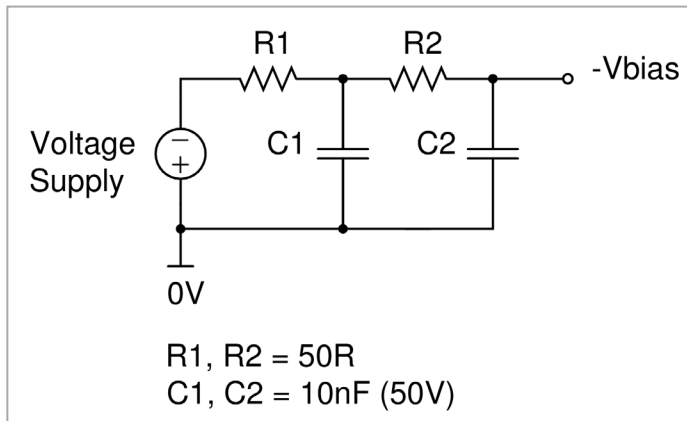


Figure 5, Generic biasing filter, recommended for all circuits given in this User Manual.

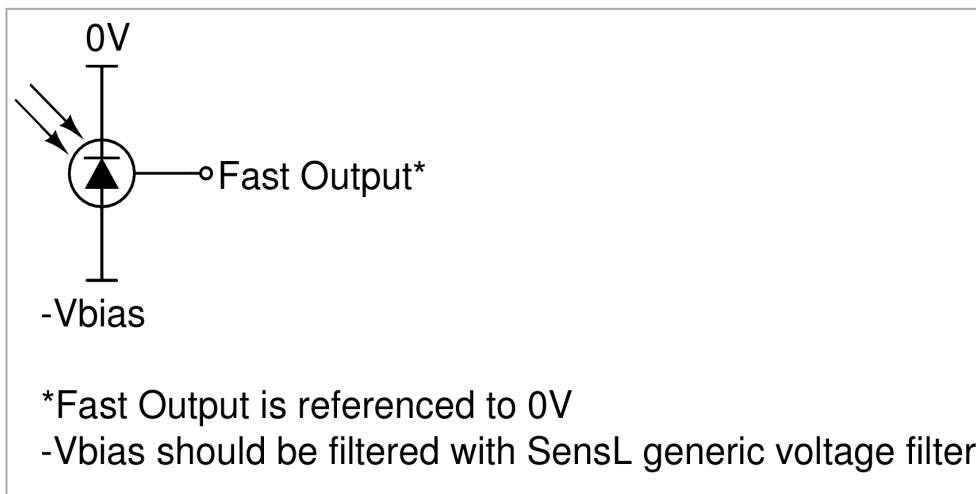


Figure 6, Recommended fast SiPM readout circuitry for 1mm MicroFC sensors.

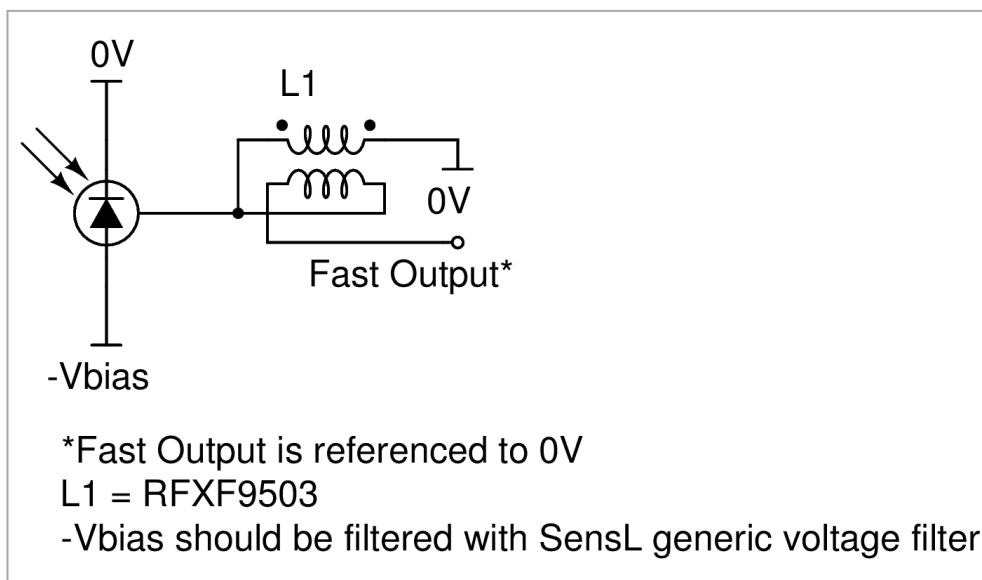


Figure 7, Recommended fast SiPM readout circuitry for 3mm and 6mm MicroFC sensors. Also shown is the recommended transformer part number and pin-out labelling.

Standard Mode Biasing and Readout of C-Series Sensors

For applications that do not require fast timing from the MicroFC, or for the MicroSC products that do not give access to the *fast output* signal, SensL's C-Series sensors will perform as a conventional SiPM. For MicroFC products the *fast output* terminal can be left open with no detriment to its *standard mode* performance. Standard mode signals may be more suitable for applications involving slow pulses or slowly-varying, continuous light levels, such as in luminometers or for gamma-ray spectroscopy with slow or low-light scintillators.

Recommended Standard Mode Biasing

Figure 8 below shows the *standard mode* biasing configuration. For MicroFC sensors the *fast output* electrode is left open (unconnected). For all C-Series sensors read out in standard mode, the cathode should be held at a positive bias with reference to the anode. It is recommended that the signal is taken from the side of the sensor held at 0V. Reading out in this way yields a pulse that has a rise time of 1ns-10ns and a decay time of several hundred ns (depending on sensor and microcell size). A typical standard mode output pulse shape is shown in Figure 9. Alternative biasing schemes are discussed in Appendix A.

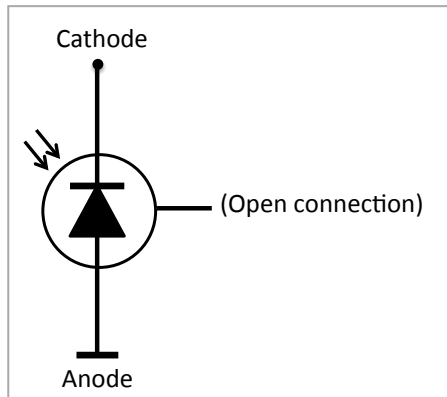


Figure 8, Biasing for standard mode. The cathode should be positive with respect to the anode, but either a positive or negative bias can be used.

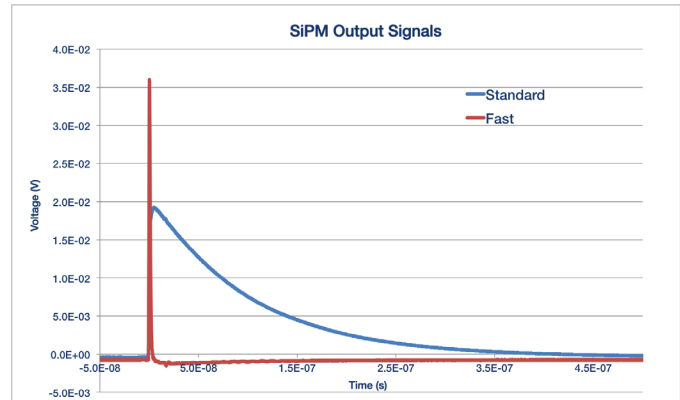


Figure 9, Standard output signal (blue) from a MicroFC-SMA-30035 when illuminated with a 40ps laser pulse (Photek LPG-405). ~2.5% of microcells are fired in this pulse. Also shown is the fast output (red) from the same pulse. Scope input = 50Ω.

When the *fast output* is not in use it should be left floating. Do not connect it to ground or have any wires or cables connected to it.

Recommended Standard Mode Readout and Amplification

Figure 10 shows how the C-Series devices can be connected to a standard high speed amplifier, such as the OPA656, to convert the standard mode output signal current to a voltage. This technique is recommended for standard mode readout of all SensL SiPM devices. In the case of MicroFC devices the fast output can be left open.

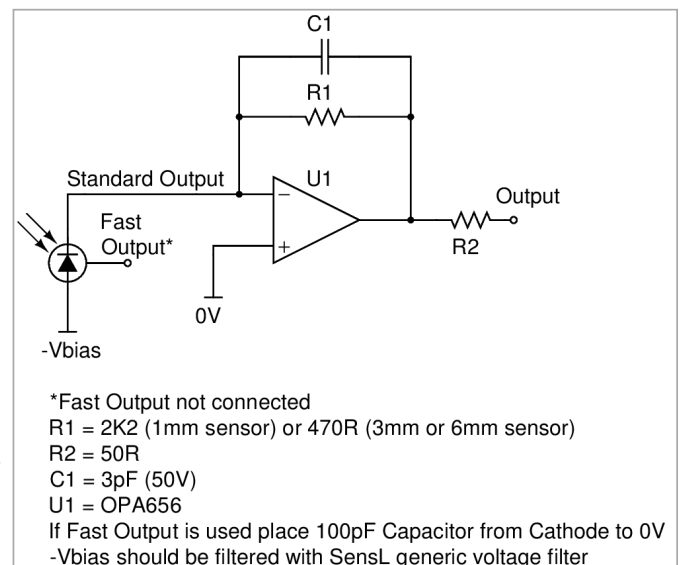


Figure 10, Example readout circuit for standard mode.

Dual Mode Readout of MicroFC Sensors

It is possible to read out both *fast* and *standard outputs* simultaneously from the sensor to obtain two separate signals. This can be used for obtaining timing (*fast output*) and amplitude information (*standard output*) from separate channels. This could be useful for applications such as PET (Positron Emission Tomography) where timing and energy information are required from each photon pulse. Note that this is only possible with MicroFC sensors. AC and DC coupled options for connecting the device for dual readout are shown in Figures 11 and 12.

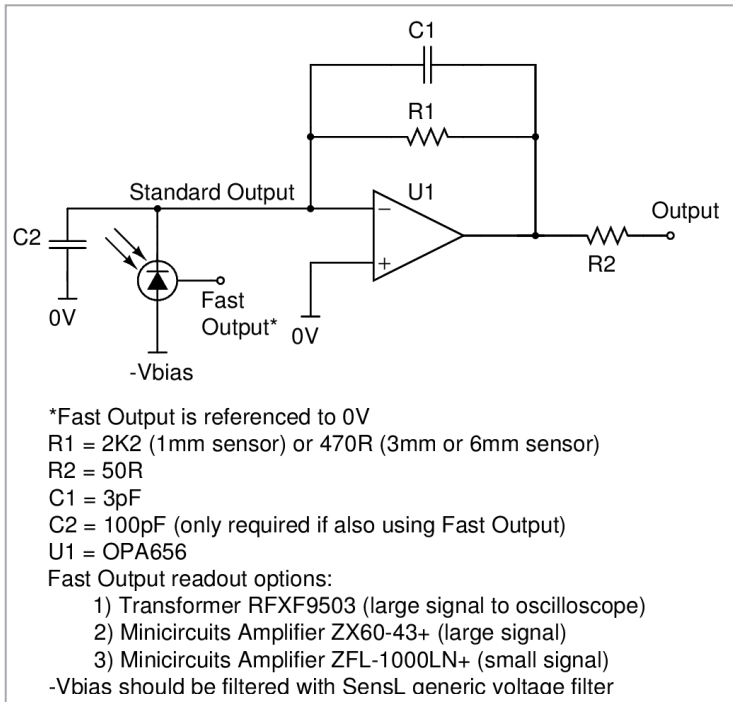


Figure 11, DC coupled readout option.
The standard output is amplified through a transimpedance amplifier (TIA).

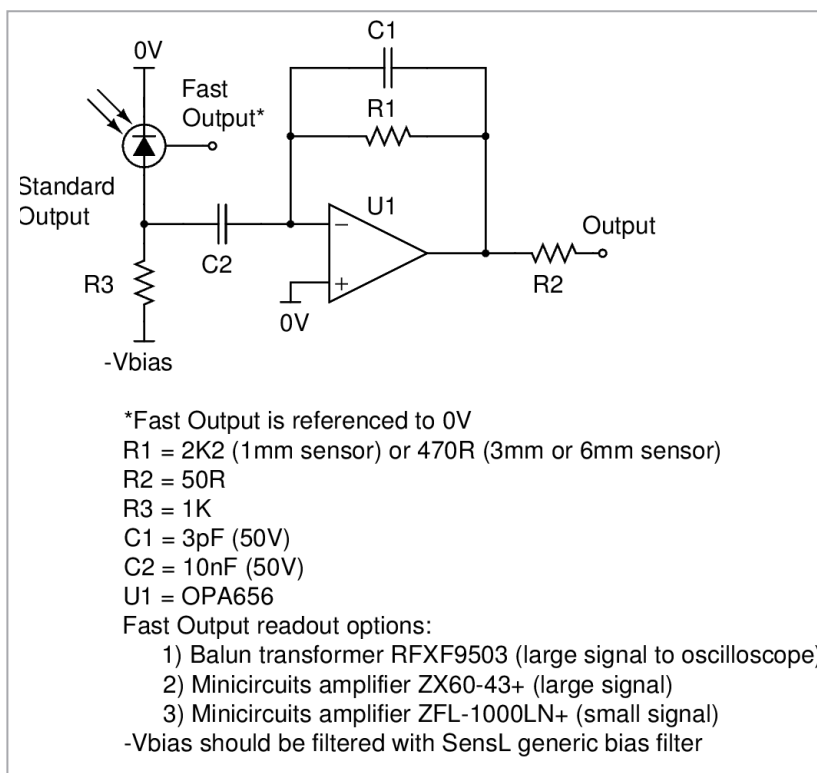


Figure 12, AC coupled readout option.
DC information from the SiPM is lost but the pulse amplitude is maintained through the transimpedance amplifier (TIA).

A third option for simultaneous readout of the standard and fast outputs provides a DC coupled standard output signal, and preserves the ability to read out the fast output. The decoupling capacitor from the cathode to 0V is critical to provide a return path for the fast output. This circuit is used on the SensL -SMA and -SMTPA evaluation boards. SensL recommend the -Vbias readout options from Figures 11 and 12 for most system designs. Alternative biasing schemes are discussed in Appendix A.

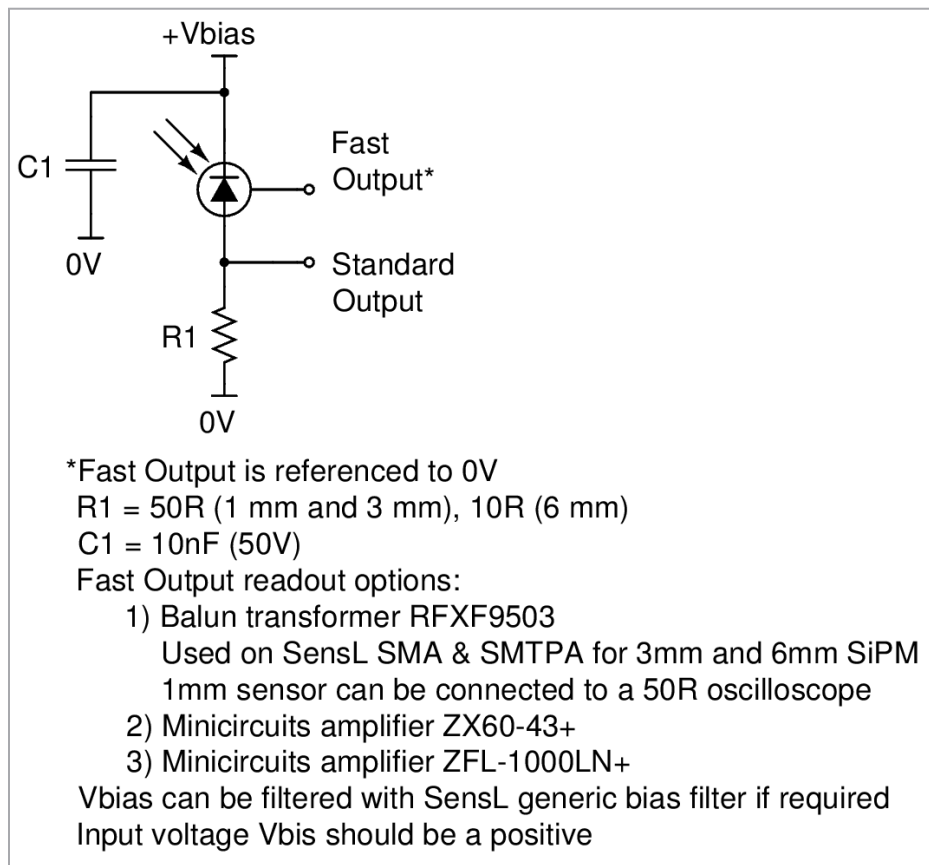


Figure 13, Third option for dual readout that is employed on the SensL -SMA and -SMTPA evaluation boards. Further information on using a positive bias is given in Appendix A.

Readout of Arrays of SiPM Devices

Many applications require the use of multiple sensors in the form of an array, such as the SensL ArrayC line of products. Large arrays can pose a readout challenge due to the many channels of amplification and processing that are required. Therefore, methods of reducing the number of channels are often employed in order to reduce the readout requirements. Many examples of this can be found in the literature, and SensL has extensive experience in developing solutions for array readout, as demonstrated by the Matrix family of products. A [Tech Note](#) is available on the subject of large area array readout.

C-Series Mounted Sensors

Some C-Series sensors are available ready mounted on test boards, to allow for easy evaluation. The SMA and SMTPA were designed for evaluation of fast output with a DC-coupled standard output. The SMA board is configured for use with the circuit shown in Figure 13 and the SMTPA can also be configured in this way with the use of an external decoupling capacitor and sense resistor. Note that the 3mm and 6mm versions of the SMA and SMTPA have baluns at their fast outputs for signal shaping and impedance matching. The use of these boards is detailed in the following sections.

MicroFC-SMA

The MicroFC-SMA-XXXXX product line (Figure 14) features either an SMT or X18 packaged SiPM sensor (type specified by the XXXXX digits) soldered onto a small PCB board. The board is simple to use, having just three SMA (female) connectors: one delivers the bias voltage (V_{bias}) and the other two provide the output signals: standard output from the anode (S_{out}) and the fast output (F_{out}). The circuitry on the board is designed to bias the sensor in such a way as to retain the optimum high-speed performance. A typical output pulse is shown in Figure 4 which was taken from a MicroFC-SMA-30035. The circuitry used is as given in Figure 13 with the addition of a bias filter (Figure 5) and transformer on the fast output of the 3mm and 6mm versions (Figure 7). For the complete circuit schematics, please consult the [SMT Board Reference Design](#) document. For links to the full CAD files, see page 11.

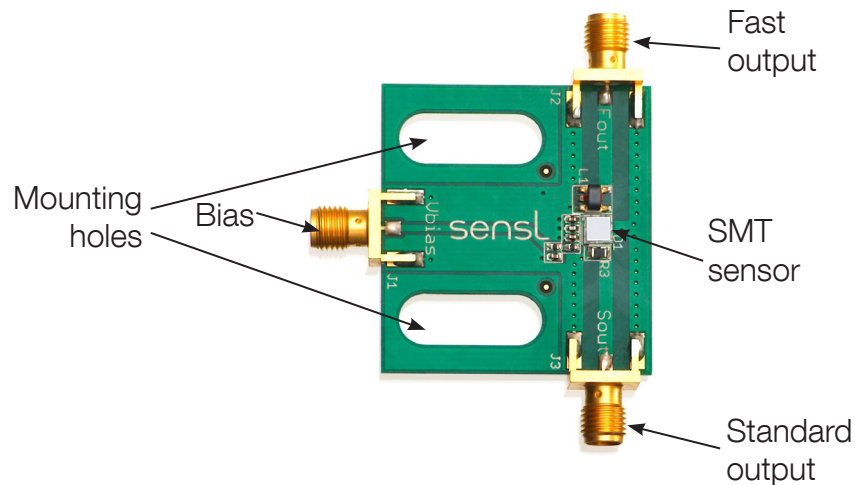


Figure 14, The MicroFC-SMA board: 3mm SMT version

Output	Connector	Function	Comments
Vbias	Standard female SMA connector	bias input (cathode)	positive bias input
Fout		fast output	if unused can be left open
Sout		standard output (anode)	if unused can be left open

Table 1, SMA Connections

The MicroFC-SMA is recommended for users who require a plug-and-play set-up to quickly evaluate MicroFC sensors with optimal timing performance. The board provides outputs which can be connected directly to the oscilloscope or measurement device. The board also allows the standard output from the anode to be observed at the same time as the fast output. Table 1 summarizes the connections to the SMA board. Each board has two mounting holes to allow secure placement during testing, with sensors located at the edge of the board. This allows two sensors to be placed in close proximity for coincidence timing measurements.

MicroFC-SMTPA

The C-Series SMT Pin Adapter board (SMTPA) is a small PCB board that houses the sensor and has through-hole pins to allow its use with standard sockets or probe clips. This product is useful for those needing a quick way to evaluate the SMT packaged sensors without the need for specialist surface-mount soldering. While this is a ‘quick fix’ suitable for many evaluations, it should be noted that the timing performance from this board will not be optimized and if the best possible timing performance is required, the MicroFC-SMA-XXXXX is recommended. The pinout numbering is shown in Figure 15 and defined in Table 2. Please consult Appendix A for information on biasing.

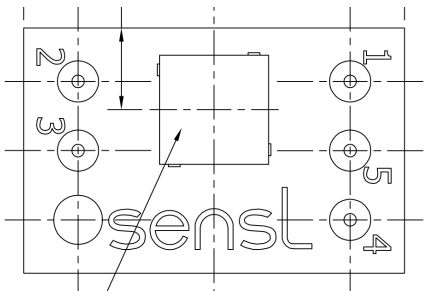
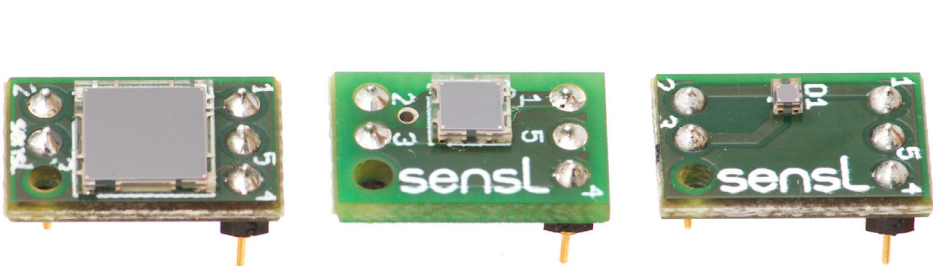


Figure 15, SMTPA pin numbering

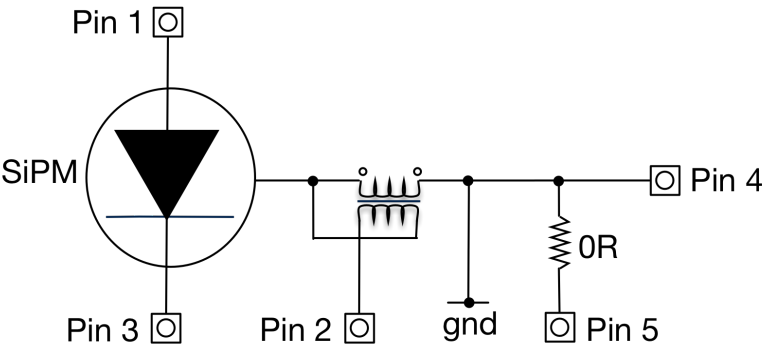


Figure 16, SMTPA circuit schematic for the 3mm and 6mm board. The 1mm version does not have the balun.

MicroFC-SMTPA-XXXXX	
Pin No.	Connection
1	anode
2	fast output
3	cathode
4	ground
5	no connect

Table 2, SMTPA board pin-outs

The circuit schematic for the 3mm and 6mm versions is shown in Figure 16 and does not contain any on-board decoupling on the bias line. Therefore, a bias filter, such as that in Figure 5, should be included on the bias line before connecting to the relevant bias input pin (see Table 2). The output can be connected directly to an amplifier or 50Ω load oscilloscope. The full electrical schematics are available to download in the [SMT Board Reference Design](#) document.

Due to the presence of the pins on the SMTPA board, it is not optimal for evaluation testing where timing with the *fast output* signal is critical. For evaluations where the timing performance of the *fast output* is critical, the use of the SMA board is recommended.

The connectors from Samtec used are:

- BBL-103-G-E
- BBL-102-G-E

Compatible sockets from Samtec are:

- SL-103-G-10
- SL-102-G-10

CAD and Solder Footprint Files

[MicroFC-60035-SMT-C1](#) CAD and solder footprint, C1 revision (see the [PCN](#) for details).

[MicroFC-300XX-SMT-C1](#) CAD and solder footprint, C1 revision (see the [PCN](#) for details).

[MicroFC-300XX-SMT-A1](#) CAD and solder footprint, A1 revision (see the [PCN](#) for details).

[MicroFC-100XX-SMT-A1](#) CAD and solder footprint, A1 revision (see the [PCN](#) for details).

[MicroFC-100XX-SMT-C1](#) CAD and solder footprint, C1 revision (see the [PCN](#) for details).

[MicroFC-SMA-60035](#) CAD.

[MicroFC-SMA-300XX](#) CAD.

[MicroFC-SMA-100XX](#) CAD.

[MicroFC-SMTPA-60035](#) CAD.

[MicroFC-SMTPA-300XX](#) CAD.

[MicroFC-SMTPA-100XX](#) CAD.

MicroFC-100XX-X18 CAD: Please refer to the package drawings in the [C-Series datasheet](#)

MicroFC-300XX-X13 CAD: Please refer to the package drawings in the [C-Series datasheet](#)

MicroFC-600XX-X13 CAD: Please refer to the package drawings in the [C-Series datasheet](#)

Handling and Soldering

Safe Handling of Sensors

- When unpacking, care should be taken to prevent dropping or misorienting the sensors. The specific items contained in the package and the type of packaging will depend on the parts ordered.
- Remember that the SiPM is a sensitive optoelectronic instrument; always handle the sensor as carefully as possible.
- The sensor should be disconnected from the bias supply when not in use.
- SiPM sensors are ESD sensitive. The following precautions are recommended:
 - Ensure that personal grounding, environmental controls and work surfaces are compliant with recommendations in JESD625.
 - Ensure that all personnel handling these devices are trained according to the recommendations in JESD625.
 - Devices must be placed in an ESD approved carrier during transport through an uncontrolled area.



Package Summary

Table 3 summarizes packages and product type. In the following sections, handling and soldering advice is given for each package type.

Package type	Delivery option code	Product type	MSL*	Reflow Solder?
SMT - Tape & Reel	TR	FC	3	Y
SMT - Cut Tape	TA	FC	4	Y
SMT - Other	WP, GP	FC	N/A	Y**
X18	PK	FC	N/A	N
X13	PK	SC	N/A	N

Table 3, Summary of which package types are associated with which product type.

* See Table 4 for definition

** Sensors shipped in either a waffle pack (WP) or gel pack (GP) require a bake according to J-STD-20, prior to reflow soldering

SMT Package

A dedicated [SMT Handling and Soldering Tech Note](#) is available that contains in depth information on the storage and use of the SMT parts, including the CAD for the tape and reels.

The SMT package is compatible with standard reflow solder processes (J-STD-20) and so is ideal for high volume manufacturing. The recommended solder footprints are included in the downloadable CAD files that are listed on page 11. If the SMT part is being assembled into an array, the advice below and in the [SMT Array Tech Note](#) should be followed.

SMT SiPM sensors are shipped in moisture barrier bags (MBB) according to the J-STD 033 standard. An unopened MBB should be stored at a temperature below 40°C with humidity below 90%RH. After the MBB has been opened, the devices must be reflow soldered within a period of time depending on the moisture sensitivity level (MSL). SensL SMT Tape & Reel are MSL 3, cut tape SMT are MSL 4 and SMT sensors shipped in trays require a bake prior to reflow soldering. See Table 4 for details.

Delivery Format	MSL	Exposure time	Condition
Tape and reel	3	168 hours	≤30 °C/60% RH
Cut tape and partial reels	4	72 hours	

Table 4, MSL definitions applicable to SensL products (reference J-STD 020).

All SMT shipped on tray do not have an MSL rating and should be baked prior to placement on PCB. Please discuss this with your contract manufacture for their recommended baking cycle which adheres to IPC/JEDEC J-STD-20 MSL Classification. Note the temperature of the bake should not exceed the recommended operating temperature of the product listed in product's datasheet.

Exposure to solvents such as **concentrated** isopropyl alcohol (propan-2-ol) or commercial flux removal fluids such as Fluxene will cause severe, irreversible damage to the MLP packages. If cleaning is necessary, a 20% solution of isopropyl alcohol can be used. Further details on cleaning can be found in the [SMT Handling Guide](#).

Creating Arrays of SMT Sensors

If multiple SMT parts are to be mounted in close proximity (e.g. 1D or 2D arrays), the following recommendations may be helpful. By following this recommendations, a planarity of 0.09% to 0.53% can be achieved.

- Minimum spacing between SMT parts of 200µm.
- Use of FR4 PCB as the substrate material
- Use commercial automatic placement machines to achieve the necessary placement accuracy to give the above spacing and planarity.
- Take into account the MSL 3 specifications of the SMT devices when assembling.
- Hold the PCB board in a rigid frame to avoid warping due to the heat process.
- The user can refer to the additional [Tech Note](#) on this subject.

X18 Package

The X18 (TO-18 can) package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X18 products. A maximum temperature of **260°C for no more than 10 seconds** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

X13 Package

The X13 ceramic package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X13 products. A maximum temperature of **260°C for no more than 5 seconds, applied at a distance of 2mm from the ceramic base** is recommended. More details can be found in the [Hand Soldering Guide Tech Note](#).

‘Not Connected’ (NC) Pads and Pins

Common PCB design practice is to ground any floating pins or pads such as those labelled ‘NC’. Grounding the pin helps shielding and can reduce noise interference from external sources (EMI/RF).

Further Help

If more help is required in the set-up or operation of C-Series sensors, there are several SensL resources that can help.

- The [C-Series Datasheet](#) contains more detailed information on the physical and performance characteristics of the sensors.
- A variety of Tech Notes are available on the website, www.sensl.com, such as:
 - A guide to [handling and soldering SMT packages](#).
 - A guide to [hand soldering](#) through-hole SensL sensor products.
 - Reference design document for the [SMA and SMTPA boards](#).
 - A guide on creating [arrays of close-packed SMT sensors](#).
 - An extensive [library](#) of technical and scientific papers on the use of SensL SiPM sensors.
- If additional help is needed, please contact support@sensl.com

Appendix A - Biasing Alternatives & Signal Polarity

This Appendix lists all of the possible ways in which a C-Series SiPM can be biased. For each biasing arrangement, the standard and fast signal polarities are given. A and B are the recommended configurations. C and D will work, but are not recommended for use with the fast output. The following abbreviations are used throughout:

V_{bias} = bias voltage

S_{out} = standard output

F_{out} = fast output

R_s = load resistor for the standard output

R_f = load resistor for the fast output

V_s = standard output voltage

V_f = fast output voltage

R_Q = quench resistor (included on the SiPM die)

