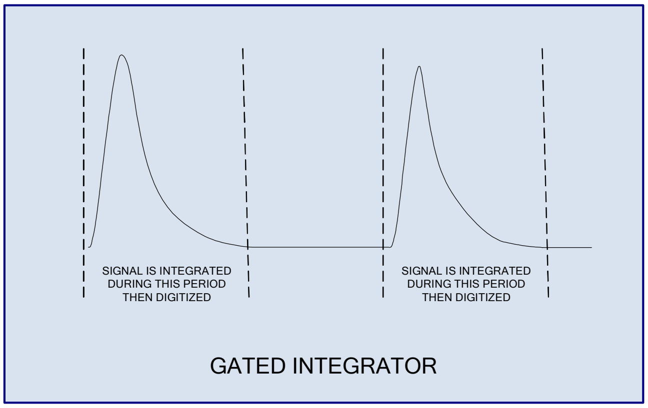
Readout Techniques for Silicon Photomultipliers

Application Note

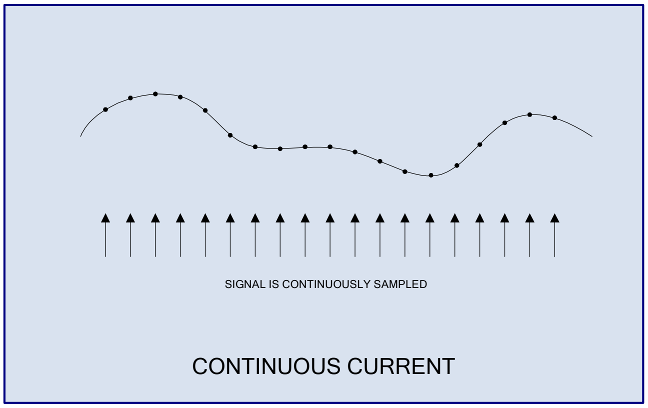
The process of measuring the output from a silicon photomultiplier and converting it into a digital data signal is called SiPM readout. Applications such as PET, SPECT, flow cytometry, LIDAR, fluorescence detection, confocal microscopy, and radiation detection require signal processing techniques specific to the types of signals encountered when using SiPMs. Depending on the application, various SiPM readout methods can be employed to maximize signal to noise ratio, dynamic range, and data throughput.

The three most common SiPM readout methods are *gated integrator*, *continuous current*, and *photon counting*. Each method is suited for a very specific type of signal produced by the SiPM. The types of SiPM signals normally encountered are illustrated below.

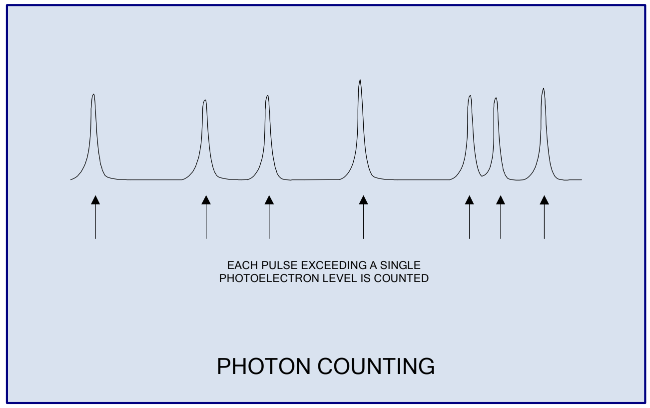
The *gated integrator* method is used for readout of SiPM signals that appear as short pulses of charge. These pulses typically coincide with the firing of an excitation source such as a laser in fluorescence detection systems, or the arrival of radioactive particles such as in a PET or gamma camera system. In both cases the arrival of the pulse from the SiPM is known in advance — or very soon after it first arrives — so that the *gated integrator* can be precisely timed to integrate only the charge pulse and blocked from integrating during all other periods.



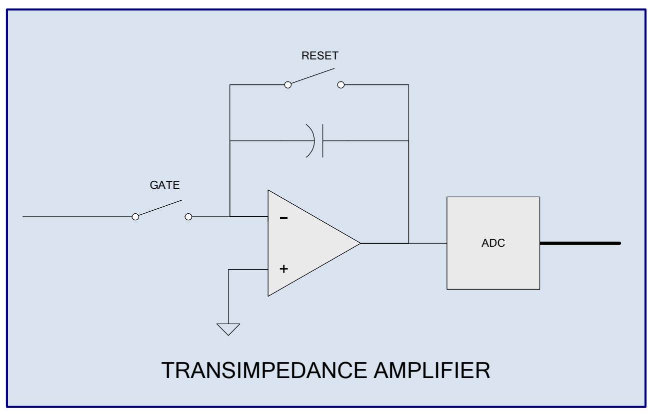
When the SiPM is illuminated with more or less a steady level of light, the device is said to be operating in current mode as shown in the second example. Readout of the SiPM under these conditions is best performed using the *continuous current* method. Here, the SiPM and associated readout circuit are performing like a picoammeter or electrometer by continually measuring the low level of light and sampling the result over time.



The third example shows the *photon counting* mode where the SiPM and readout circuits operate in a quasi-digital mode. *Photon counting* is typically used when the light level is extremely low. Here the SiPM sees discrete single photon events rather than large bursts of photons or the continuous flow of multiple overlapping photons. The corresponding charge output from the SiPM is thus many single short duration pulses consisting of the charge from single photons hitting the SiPM at random intervals. Under these conditions, the light is measured by counting the number of events over a time period. Since this SiPM readout technique is more like a digital readout mode, it is not covered here but instead described in Vertilon's MCPC618 eight channel photon counting systems user's manual.
MCPC618 Eight Channel Photon Counting System



Silicon photomultipliers are inherently charge output devices and therefore require a means to either collect charge over a fixed period of time or continuously measure current. In Vertilon's PhotoniQ data acquisition systems this operation is performed by a transimpedance amplifier that effectively converts the charge or current signal from the SiPM into a voltage that can be readily digitized by an analog to digital converter. Since different applications require different SiPM readout techniques, the transimpedance amplifier is software configurable to accommodate any number of uses.



The diagram at right shows the transimpedance amplifier configuration for a PhotoniQ data acquisition system. Circuit performance is optimized by using a capacitor in the amplifier feedback path and controlled switches to selectively enable the integration of the charge signal and resetting of the integration capacitor. This configuration increases the dynamic range by keeping the amplifier from saturating and improves the SNR by limiting the bandwidth in the signal path. In *gated integrator* applications where the charge integration period is precisely timed relative to a trigger signal, the *gate* switch is used to selectively connect the SiPM to the integrator during the desired time interval. Special cancellation circuitry and processing algorithms ensure that the charge injection from the switch remains below the noise level and does not negatively impact the measurement of the signal. After the integration period has expired, the capacitor voltage is sampled and then reset by the *reset* switch. The *gated integrator* is then re-armed so that the process can be restarted when triggered again. This gating technique is used when one of the PhotoniQ's *analog* gate modes is selected. A different gating scheme is used for the PhotoniQ's *digital* gating modes. Here the *gate* switch remains closed for all time, and the integration period is set using digital techniques. While this mode allows the DAQ system to acquire charge pulses that occur in time prior to the trigger signal, it does have the risk that the integrator will saturate because of constant optical background signals and electrical bias currents. However, this risk is minimized by a proprietary algorithm in conjunction with specialized circuitry that ensures that the integrator remains well in its linear region thus maintaining virtually all of its dynamic range. Silicon photomultiplier readout in *continuous current* mode also operates with the *gate* switch closed. Similar background and bias current cancelation techniques are employed to offer the highest sensitivity possible.

In *gated integrator* mode, SiPM readout can be synchronous when it is known when the event is likely to occur — example applications are laser induced fluorescence or confocal microscopy — or asynchronous such as when a particle arrives randomly like in PET systems or gamma cameras. In these applications the SiPM delivers a burst of charge coinciding with the fluorescence event or a radioactive particle hitting a scintillator-coupled SiPM. For fluorescence detection systems, the event is usually triggered by a laser which in turn induces a decaying fluorescence signal that the SiPM detects. The event is short lived and its occurrence in time is synchronized with the firing of the excitation source. Nuclear particle detection is similar to fluorescence detection in some respects in that charge from particle events is delivered by the SiPM in short duration pulses. However, unlike fluorescence systems where the events can be captured by synchronizing to the excitation source, nuclear particle events occur randomly and therefore must be synchronized by alternate means. Typically this is done using the common cathode from the SiPM which generates a signal when any one of its anodes from the SiPM array detects a signal. A preamplifier and discriminator on the cathode are used to create a signal that triggers the collection of charge from the SiPM. Most Vertilon sensor interface boards include this circuitry so that the trigger signal is automatically generated when a particle exceeding a preset energy threshold hits the SiPM.

Silicon photomultiplier readout using the *continuous current* method is best employed when the light signal is present over a long period of time and is relatively steady. Variations in the magnitude of the light are measured by sampling the SiPM's current output over an appropriate interval. The same integrating transimpedance amplifier is used but the sampling switch is always closed so that the output of the amplifier is simply the integral of the SiPM current over the sampling period. Configured in this way, the integrator acts like a low pass filter removing unwanted higher frequency components from the signal before it is sampled. Unlike common sample and hold circuits that simply take a "snapshot" measurement of the signal level at one point in time, the PhotoniQ's integrating transimpedance amplifier effectively performs an integrate and hold function. Hence aliasing effects from noise or other interference present on the SiPM output at frequencies much higher than the reciprocal of the sampling interval will be suppressed. Low frequency noise performance can be further improved by post processing the digital samples by averaging them over time.

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