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AND9795/D

A Brief Introduction to Silicon Photomultiplier (SiPM) Sensors

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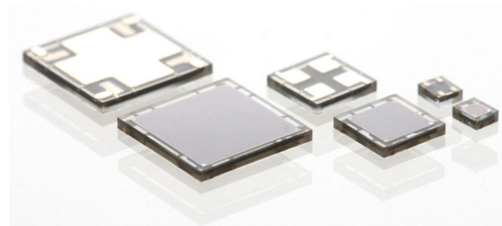
APPLICATION NOTE



The Silicon Photomultiplier (SiPM) is a low-light sensor that has performance characteristics comparable to a conventional PMT with the practical advantages of a solid-state sensor. The SiPM is well suited to a variety of applications including LiDAR, medical imaging, radiation detection and biosciences.

The SiPM is operated in Geiger-mode which enables high gain ($1x10^6$) at moderate bias (~30 V). This is achieved by creating a high field region in the diode that generates a self-perpetuating charge avalanche when a photon is absorbed. Once a current is flowing through the diode, it should then be stopped or 'quenched'. Passive quenching (i.e. no active circuitry), is achieved through the use of a series resistor which limits the current drawn by the diode during breakdown. This lowers the reverse voltage seen by the diode to a value below its breakdown voltage, thus halting the avalanche. The diode then recharges back to the bias voltage, and is available to detect subsequent photons.

In this way, a single photodiode device operated in Geiger-mode functions as a photon-triggered switch, in either an 'on' or 'off' state. Proportional information on the magnitude of an instantaneous photon flux is not available. A photodiode operated in the Geiger mode is referred to as a **SPAD (Single Photon Avalanche Diode)**.

The **SiPM** is formed of a dense array of small, independent SPAD sensors, each with its own quenching resistor, as shown schematically in Figure 1. Each independently operating unit of SPAD and quench resistor is referred to as a "microcell". When a microcell in the SiPM fires in response to an absorbed photon, a Geiger avalanche is initiated causing a photocurrent to flow through the microcell. It is important to note that the Geiger avalanche will be confined to the single microcell it was initiated in. During the avalanche process, all other microcells will remain fully charged and ready to detect photons. The sum of the photocurrents from each of these individual microcells combines to form a quasi-anlog output, and is thus capable of giving information on the magnitude of an instantaneous photon flux. The response to low-level light pulses is shown in Figure 2, and a charge spectrum of these pulses is shown in Figure 3.

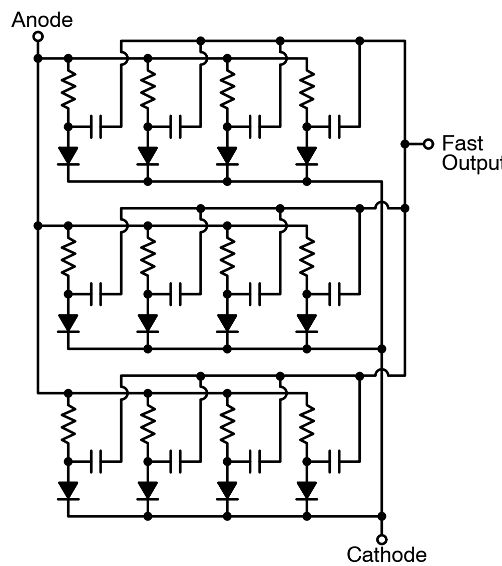


Figure 1. A SiPM Consists of an Array of Microcells (SPAD Plus Quench Resistor) with Summed Output

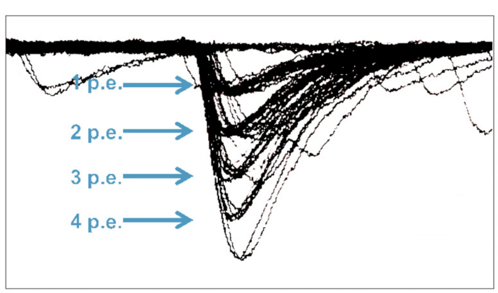


Figure 2. SiPM Output when Illuminated by Brief Pulses of Low-level Light, Showing the Discrete Photon Levels

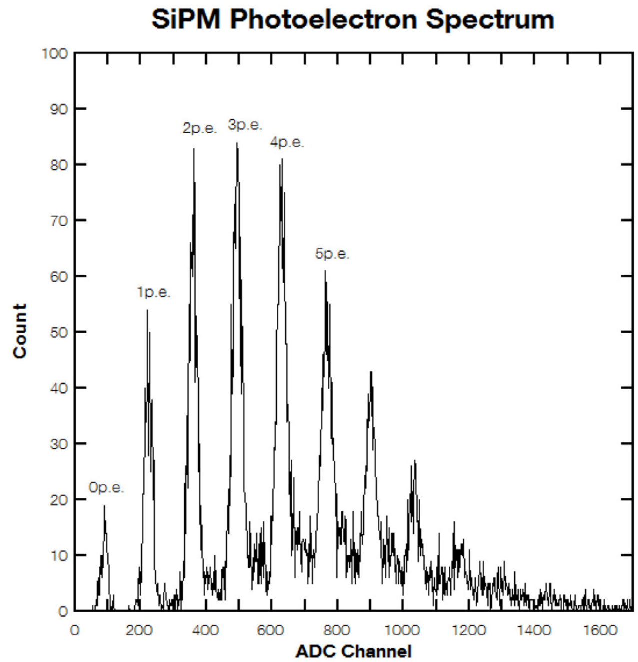


Figure 3. Charge Spectrum Showing the Well Defined Single and Multiple Photon Peaks

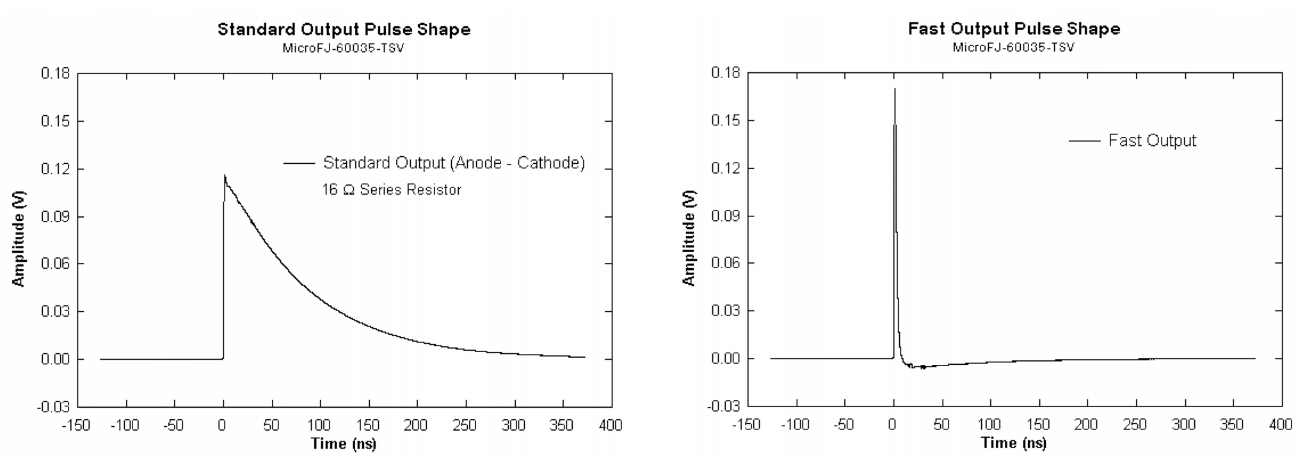


Figure 4. The Standard (Anode-cathode) and Fast Output Pulses

SIPM RESPONSE

The SiPM output pulses are shown in Figure 4. Reading out from the anode or cathode is referred to as the **standard output**. The recovery time of the sensor is determined by the microcell recharge time constant. This is dependent upon the various capacitances and resistances in the sensor system. Since the capacitance of the microcell will depend upon its area, the reset time will vary for different microcell sizes.

ON Semiconductor has developed a unique modification to the standard silicon photomultiplier structure that results in a third terminal (in addition to the anode and cathode). This is referred to as the **fast output** and is the sum of the capacitively-coupled outputs from each microcell, as illustrated in Figure 1.

The **dynamic range** is a function of the total number of microcells, the overvoltage used, and the wavelength of the incident photons. Figure 5 shows the typical dynamic range for 1mm, 3mm and 6mm sensors. It can be seen that the sensor has a linear response at lower photon fluxes, but as the number of incident photons increases, the sensor will start to saturate.

SIPM READOUT

Please consult the Biasing and Readout Application Note AND9782/D for guidance on the usage of SiPM sensors.

FURTHER INFORMATION

For a more in-depth introduction to the silicon photomultiplier including the various performance parameters, please see our Introduction to the Silicon Photomultiplier (SiPM) Application Note, AND9770/D.

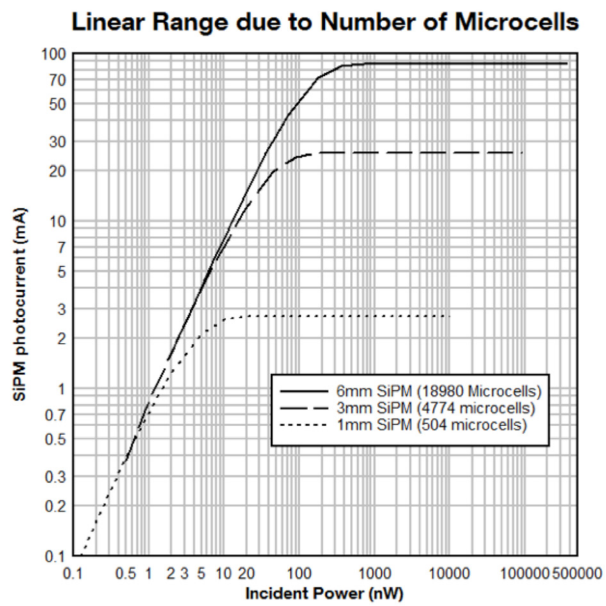


Figure 5. The SiPM Photocurrent as a Function of Incident Power on a Log-log Scale

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