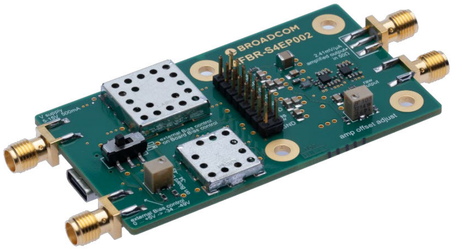
Application Note

AFBR-S4EP002

AFBR-S4P0102L3R Evaluation Kit

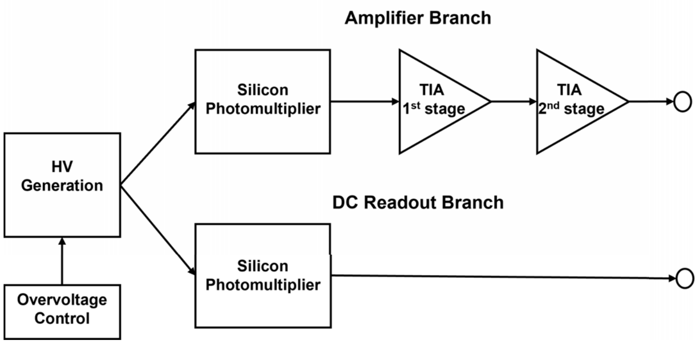


Overview

This application note introduces the AFBR-S4EP002 evaluation kit, a comprehensive platform designed to demonstrate the capabilities of our NIR-enhanced SiPM technology with advanced fast timing performance (NIR20Fast). Optimized specifically for the single-photon regime, this kit integrates low noise pre-amplification and high bandwidth, allowing engineers to bypass complex front-end design and focus immediately on sensor performance.

The AFBR-S4EP002 features an onboard high-voltage supply, an amplifier branch including a 1×1 mm^2 NIR20Fast SiPM (AFBR-S4P0102L3R), and a direct readout branch (unamplified), also equipped with an AFBRS4P0102L3R. A row of pin headers allows switching off one of the two SiPMs for the highest signal integrity in the other readout channel.

Block Diagram



Features

The AFBR-S4EP002 includes two AFBR-S4P0102L3R SiPMs (an amplified branch and a direct readout branch) and an onboard HV supply for fast testing and prototyping.

Features of the Amplifier Branch

- Amplified (2.4-kV/A) output
- 404-ps single-photon 80/20 fall time (leading edge)
- 50Ω matched output (SMA connector)

Features of the Unamplified Branch

- Unamplified DC channel output for high dynamic range requirements
- 50Ω load resistor

Applications

- Prototyping
- LiDAR
- Direct time of flight (dToF)
- Fluorescence detection

Onboard High-Voltage Generation and Bias Control

Accurate arrival-time measurements and excellent single-photon detection require a stable and low-noise bias voltage. The evaluation kit integrates a high-voltage circuit that generates the necessary bias voltage directly on the PCB and allows setting the optimal operation voltage point (overvoltage).

The evaluation kit is designed for flexibility in lab environments, and it supports two primary methods for powering the active components and the high-voltage generation circuit:

- **Standard DC Input:** The board accepts a DC voltage input via the SMA connector with a range of 5V to 15V.
- **USB-C Power:** Alternatively, the kit features a USB-C connector. Connecting this port to a standard USB power source (such as a PC port, laptop, or oscilloscope) supplies the necessary 5V rail.

Setting the SiPM Bias Voltage

The silicon photomultiplier operates in Geiger-mode, requiring a bias voltage V_{BIAS} above its breakdown voltage V_{BD}. The difference between these two is the overvoltage V_{OV}, which directly defines the SiPM optical performance parameters.

The AFBR-S4EP002 provides two methods to adjust the overvoltage, allowing for both quick manual setup and automated characterization.

Method A: Internal Potentiometer

For standalone testing and quick optimization, the bias voltage can be set using the onboard potentiometer (labeled “on Board Bias -34 … -49” on the PCB).

1. Ensure that the control switch is set to “on Board Bias control”.
2. Connect a multimeter to the jumper pins (GND and Bias Ampl or Bias raw) test point to monitor the actual voltage applied to the sensor.
3. Adjust the potentiometer until the desired bias voltage is reached.

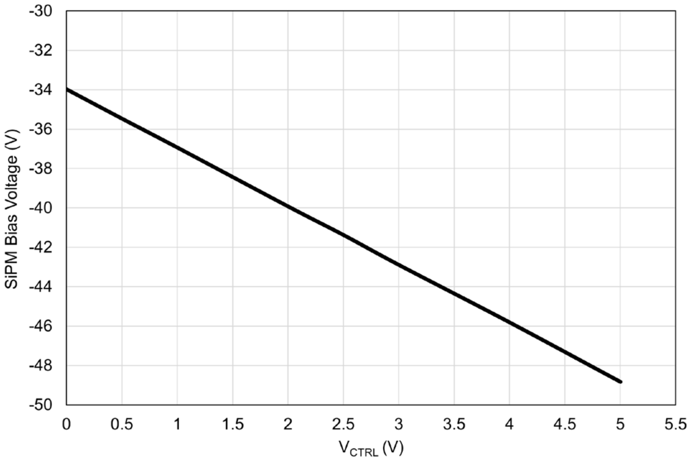
Method B: External Voltage

For advanced characterization, such as sweeping the overvoltage to plot PDE vs. Voltage curves or implementing temperature compensation loops, the bias can be controlled via an external analog voltage (V_{CTRL}).

1. Set the control switch to “external Bias control”.
2. Apply a control voltage V_{CTRL} to the “external Bias control” SMA connector.
3. The high-voltage output scales linearly with the input control voltage (V_{CTRL}) based on the correlation displayed in Figure 1, and it is described by the following equation:

$$V_{BIAS} = -2.97 \cdot V_{CRTL} - 34.97$$

Figure 1: SiPM Bias Voltage as a Function of the External Control Voltage (V_{CTRL})



NOTE: To bypass the onboard HV supply and provide the bias voltage to the SiPM directly, the GND and Bias Ampl/Bias raw pins can be connected to an external power supply.

Operating Conditions

Stresses greater than the absolute maximum ratings can cause damage to the devices. Limits apply to each parameter in isolation. Absolute maximum ratings are those values beyond which damage to the device can occur if these limits are exceeded for other than a short period of time.

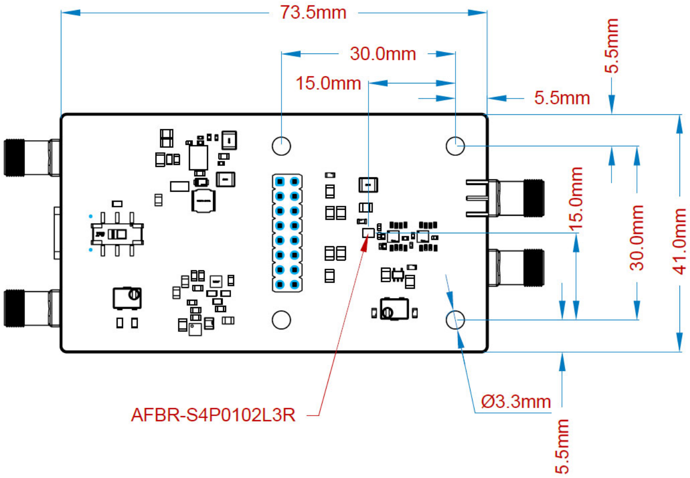
Parameter	Symbol	Min.	Typ.	Max.	Unit
Storage Temperature	T_{SG}	0	25	+60	°C
Operating Temperature[a]	T_A	0	25	+60	°C
Supply Voltage	V_{supply}	5	12	15	V
Control Voltage	V_{CTRL}	0	—	5	V
SiPM Overvoltage	—	—	10	12	V

a. At 1000-MHz oscilloscope bandwidth.

Mechanical Outlines

The mechanical outlines of the evaluation kit's PCB are according to Figure 2.

Figure 2: PCB Mechanical Outlines



The type of connectors for the supply voltage input, the control voltage, and the signal outputs is SMA.

Basic Schematics

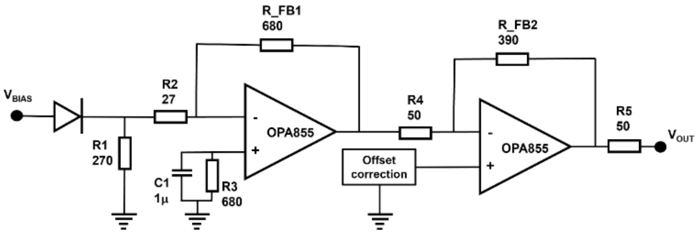
The amplifier circuit of the AFBR-S4EP002 evaluation kit is a two-stage transimpedance amplifier (TIA). The SiPM's signal is taken from the cathode and is fed into an amplification stage with a gain of 618 V/A.

The second TIA stage has a gain of 7.8 V/A and includes the option to set the baseline of the output via the potentiometer "amp offset adjust".

The amplifier branch of the evaluation kit is terminated with a 50Ω resistor, resulting in an effective overall gain of 2.4 kV/A when the signal is read over 50Ω input impedance.

Figure 3 shows a simplified schematic of the amplifier branch.

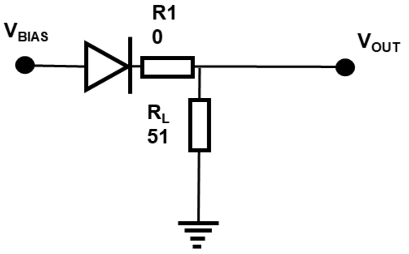
Figure 3: Simplified Schematic of the Amplifier Branch



A second AFBR-S4P0102L3R is mounted on the PCB's backside. This SiPM with its readout is referred to as the DC branch. Figure 4 shows a simplified schematic of the DC branch with its load resistor (R_L = 51Ω). If the signal is coupled into an oscilloscope with 50Ω input impedance, the effective load is 25Ω.

R_1 is 0Ω in the default configuration.

Figure 4: Simplified Schematic of the DC Branch



Key Performance Metrics

This section describes the key performance metrics of the evaluation kit and its signal.

Parameters given in this section are measured at 10V overvoltage and at 25°C unless stated otherwise.

Parameter	Symbol	Min.	Typ.	Max.	Unit
Active Area	AA	—	1.00 × 1.00	—	mm^2
Microcell Pitch	L_{CELL}	—	12.5	—	µm
Number of Microcells	N_{CELLS}	—	6334	—	—
TIA Gain	G_{TIA}	—	2.4	—	kV/A
Fall Time[a]	τ_{fall}	—	404	—	ps
Single-Photon Amplitude[a]	—	—	34.5	—	mV

a. At 1000-MHz oscilloscope bandwidth.

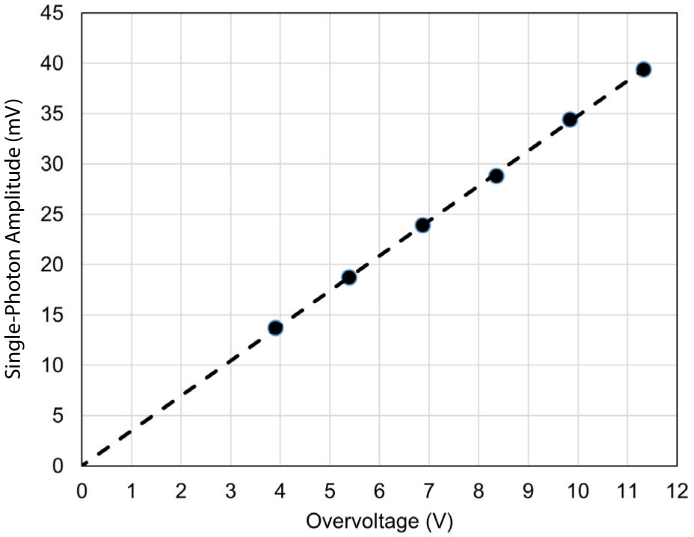
Pulse Characteristics

When the SiPM detects a photon, it produces a fast current pulse. The onboard transimpedance amplifiers convert this into a voltage pulse with a distinct shape: a fast rising edge followed by a slower exponential decay (Figure 8).

The two main pulse characteristics for fast timing applications are the signal amplitude and the fall time, resulting in the slew rate.

Amplitude: The peak voltage of a single photon depends on the overvoltage applied to the SiPM and the bandwidth. The typical single-photon amplitude at 10V overvoltage and 1000-MHz oscilloscope bandwidth[1] is 34.5 mV (Figure 5).

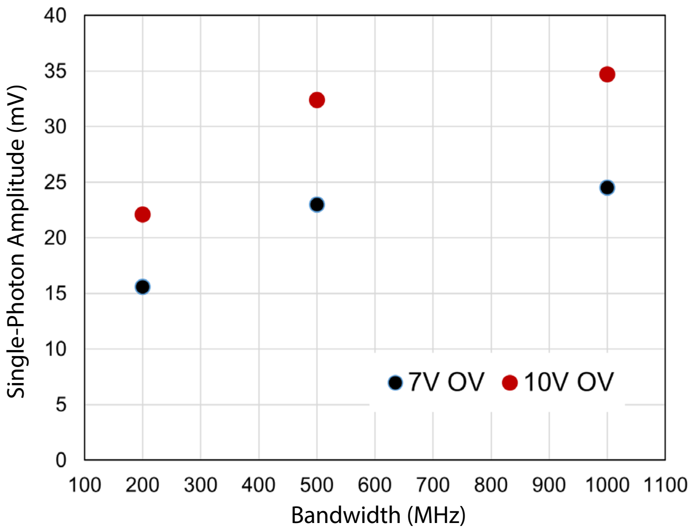
Figure 5: Typical Single-Photon Amplitude vs. Overvoltage



As evident from Figure 5, the SiPM's breakdown voltage (overvoltage = 0) is the point where the signal amplitude is 0. Together with the correlation in Figure 1, signal amplitude measurements at discrete V_{CTRL} steps can be used to derive the breakdown voltage of the SiPM.

Figure 6 displays the single-photon amplitude (for 7V and 10V overvoltage) at three bandwidth values.

Figure 6: Single-Photon Amplitude vs. Bandwidth



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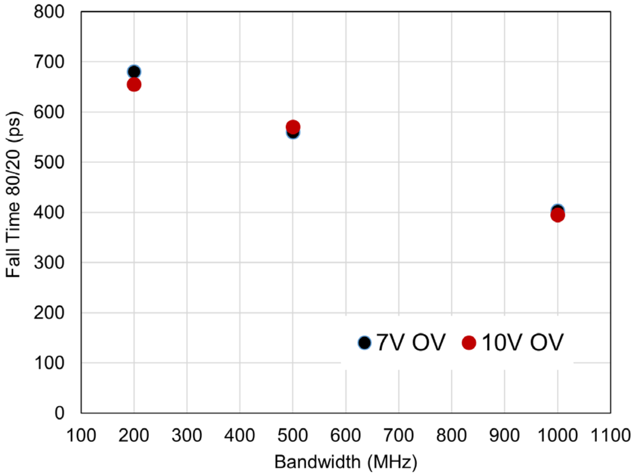
[1] The bandwidth of the amplifier circuit is smaller than 1000 MHz. Hence, measurements at 1000-MHz oscilloscope bandwidth show the undistorted pulse characteristics of the evaluation kit.

Fall Time (Leading Edge): The observable signal fall time depends on the bandwidth. The typical intrinsic fall time (80/20) at 1000 MHz of the SiPM's signal in the amplifier branch is 404 ps (Figure 7).

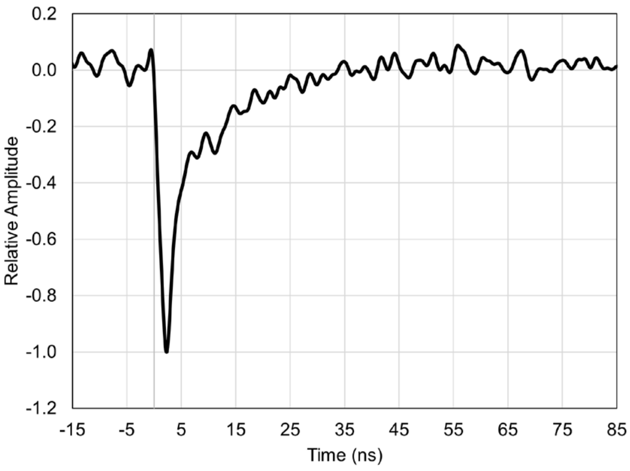
Figure 7: Signal Fall Time (80/20) vs. Oscilloscope Bandwidth



Recharge Time Constant: Another important SiPM pulse characteristic is the recharge time constant (τ). It is the time that it takes to recharge the SPAD over the quenching resistor and characterizes the slow signal decay component.

Figure 8 shows a typical waveform of a single-photon pulse and clearly shows the two characteristic pulse components of an SiPM: the fast component with a duration of a few nanoseconds and the actual recharge tail determined by the recharge time constant. The signal returns to its baseline after approximately five times the recharge time constant.

Figure 8: Typical Single-Photon Waveform at 10V Overvoltage

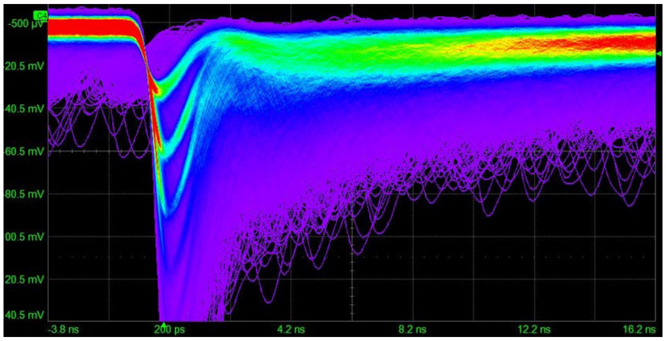


Photon Number Resolution

One of the defining strengths of the SiPM technology is the ability to resolve the number of detected photons on a single-pulse basis. Because the SiPM is composed of thousands of microcells (SPAD and quenching resistor) operating in parallel, the output signal is the sum of all simultaneously firing microcells. If multiple photons arrive at the same time at the SiPM, the output amplitude will quantize to discrete multiples of the single-photon amplitude.

On an oscilloscope with "infinite persistence" or "color grading" turned on, a distinct pattern results, allowing for easy calibration of the single-photon gain (Figure 9). The prominent pulses represent the different photon levels starting with the 1-p.e. (photo-electron) pulses. In Figure 9 the signal levels of one to five photons can be clearly observed.

Figure 9: Oscilloscope Screenshot of Distinct Photon Signal on Color Grading



Dark Counts: Due to the physical nature of silicon, you will observe random pulses even in complete darkness. This is the *dark count rate (DCR)*. These dark pulses are identical in shape and amplitude to real single-photon pulses.

Although observing pulses on an oscilloscope provides a time-domain view, the full performance of the SiPM is best analyzed by integrating the output charge of each detected event. By integrating the current pulse over a fixed time gate, the total charge (Q) of every event is calculated and binned into a histogram.

This results in a *single-photon spectrum*, commonly referred to as a *finger plot*. Figure 10 shows a single-photon spectrum acquired using a 905-nm laser (PW < 70 ps) following the well-known Poisson distribution. The SiPM signal was integrated for 15 ns, and the oscilloscope input impedance was set to 50Ω.

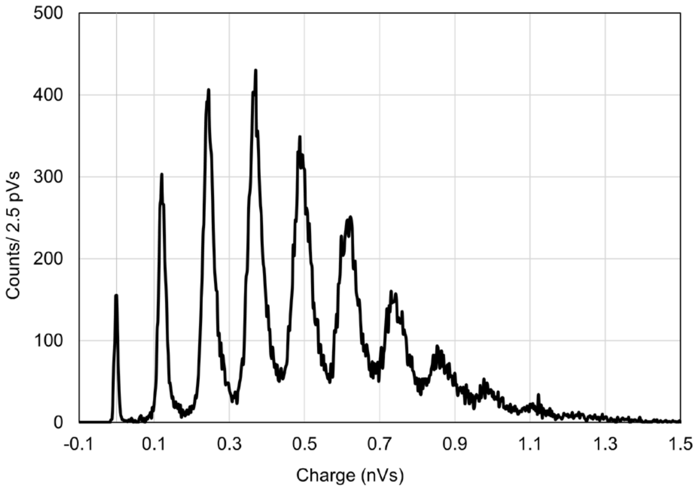
Interpreting the Finger Plot

The spectrum reveals the quantized nature of the SiPM signal composed of the signal from multiple microcells. Because the device gain is highly uniform across its microcells, the charge histogram displays a series of clearly resolved Gaussian-like peaks:

- **The Pedestal (0 p.e.):** The first peak (here at 0 nVs) represents the electronic noise floor of the system where no microcells fired during the integration gate.
- **1st Finger (1 p.e.):** The first signal peak corresponds to the charge generated by a single microcell firing (one detected photon or one dark count event).
- **2nd Finger (2 p.e.):** The second peak corresponds to two microcells firing simultaneously.

The ability to clearly distinguish these peaks—specifically the “valley” between the 0-p.e. noise pedestal and the 1-p.e. signal—is an indicator of a high signal-to-noise ratio (SNR).

Figure 10: Single-Photon Spectrum



Single-Photon Time Resolution

In many applications such as LiDAR and fluorescence lifetime imaging (FLIM), the arrival time of a photon is just as critical as its detection. The ability to resolve single photons clearly above the noise floor enables precise measurements of the photon’s arrival times.

Single-photon time resolution (SPTR) is the parameter that characterizes the time jitter on repeated single-photon arrival time measurements. It is an integral measure of multiple contributions such as signal transit time spread (TTS) and the signal’s slew rate.

SPTR is defined as the full width at half maximum (FWHM) of the distribution of time differences between the arrival of the photon and a reference signal (like the electrical trigger).

The SPTR tends to improve with the applied overvoltage of the SiPM as the slew rate increases. Limits can be imposed by the increasing noise and the maximum slew rate of the amplifier.

Figure 11 shows the arrival time difference between the single-photon signal of a 905-nm laser (with a pulse width < 70 ps) and a reference signal measured at 11V overvoltage. The calculated SPTR of the AFBR-S4P0102L3R and the amplification circuit on the AFBR-S4EP002 is 426 ps.

Figure 11: Arrival Time Distribution