

# AFBR-S4E001

## NUV-MT SiPM Evaluation Kit

### Overview

This application note introduces the Broadcom<sup>®</sup> AFBR-S4E001 evaluation kit, which has been designed to be used as an evaluation platform for the AFBR-S4NxxPyy4M SiPM family.

The document describes in detail the boards included in the evaluation kit and the test setup used for the evaluation of the optical and electrical characteristics of this SiPM family.

Figure 1 shows the front and back sides of the AFBR-S4E001 evaluation board.

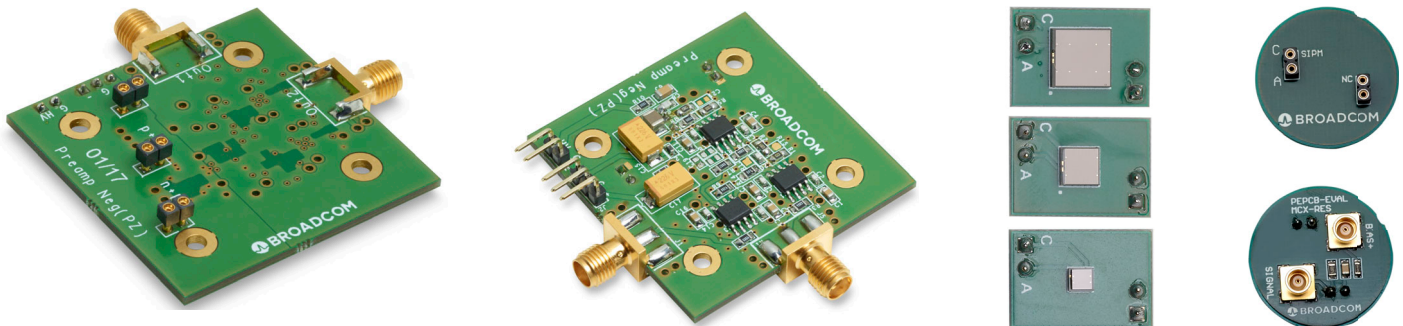
### Features of the Amplifier PCB

- Two 50Ω outputs
- Designed for single-photon and multiple-photon detection, such as scintillator readout
- Operating temperature range from -20°C to +50°C
- RoHS and REACH compliant

### Features of the DC Readout PCB

- Over 50Ω load DC
- No amplification stage
- Compatible with Thorlabs SM01 cage frames

**Figure 1: Components of the Evaluation Kit Including the Amplifier Board (Left, Center Left), the SiPMs on the PCB (Center Right), and the Round DC Readout PCB (Right)**



### Evaluation Kit

The evaluation kit includes the following:

- 1x evaluation board with amplified energy and timing output
- 1x round DC evaluation PCB (unamplified output)
- 1x AFBR-S4N22P014M SiPM (mounted on a test PCB)
- 1x AFBR-S4N44P014M SiPM (mounted on a test PCB)
- 1x AFBR-S4N66P014M SiPM (mounted on a test PCB)

The evaluation kit does *not* include the following:

- SiPM high-voltage source (up to approximately 50V)
- Dual power supply ( $\pm 2.5V$  to  $\pm 8.5V$ )
- Cables for readout

### Applications

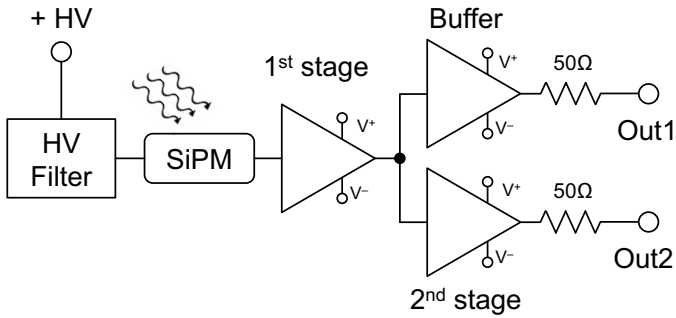
- Prototyping
- Device characterization
- X-ray and gamma-ray spectroscopy
- PET
- Fluorescence detection
- Cytometry

# Details on the Amplifier PCB

## Description

Figure 2 shows the block diagram.

Figure 2: Block Diagram



The high voltage is filtered before being applied to the SiPM to minimize the fluctuations in the voltage source. The SiPM output signal goes into a first stage of amplification based on an operational amplifier in a transimpedance configuration. Its output is then split into two lines: the first goes through a buffer with unity gain and is connected to Out1; the second passes through a second stage of amplification including a Pole-Zero (PZ) filtering network and is connected to Out2. Given a flash of light, Out1 is used to estimate the number of detected photons, whereas Out2 gives a precise determination of the timing. Both outputs should be read through a 50Ω termination resistor.

## Inputs and Outputs

The board has three inputs (SiPM signal, SiPM high voltage, and power supply) and two outputs (Out1 and Out2). Two additional receptacles are included for mechanical stability only. Figure 3 and Figure 4 show a sketch of the board's front and back view.

Figure 3: Evaluation Board Front Side

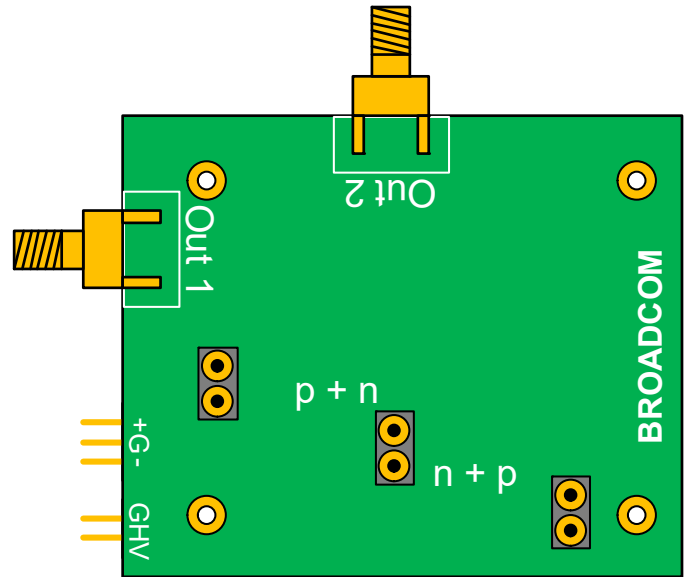
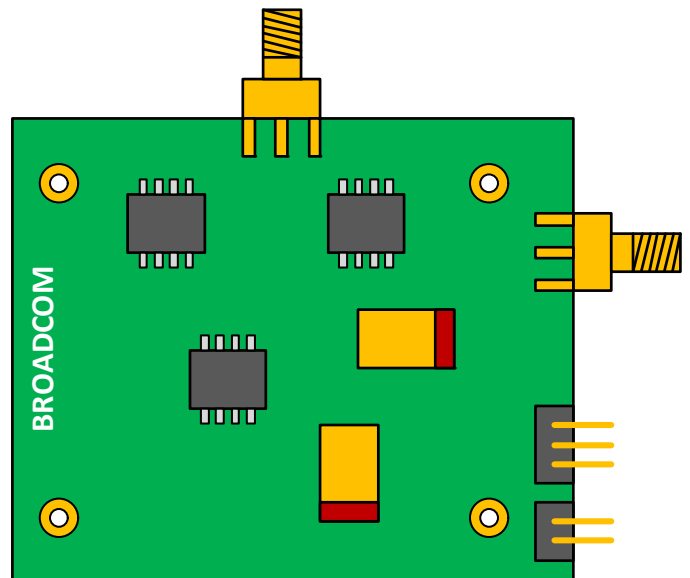


Figure 4: Evaluation Board Back Side

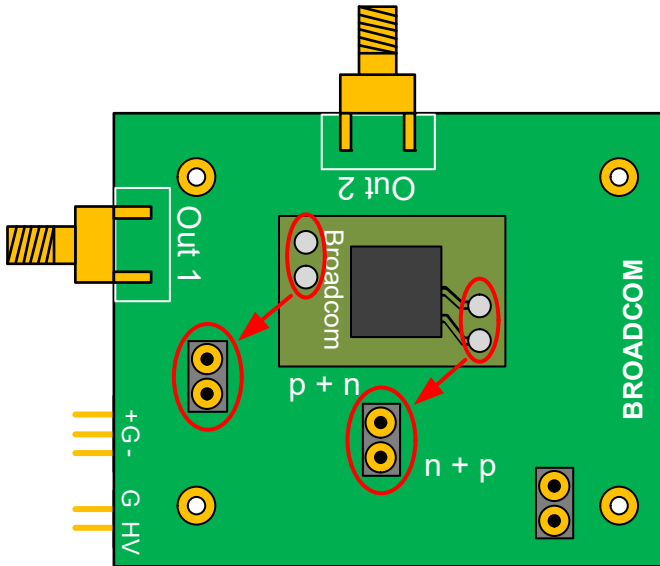


## Detailed Pin Descriptions

### SiPM Input

The detector must be connected as shown in [Figure 5](#).

Figure 5: Connection with SiPM PCB



The anode and cathode of the detector are connected to the amplifier's input, whereas the other receptacle has no electrical connection and is used only for mechanical stability.

### SiPM High Voltage

SiPM high voltage is provided with the 2-pole connector displayed in [Figure 6](#). The supply voltage must be positive.

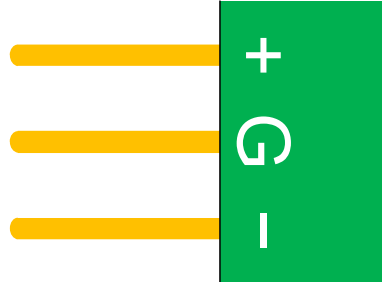
Figure 6: SiPM High-Voltage Connector Detail



### Board Power Supply

Power for the board is provided by the 3-pole connector displayed in [Figure 7](#).

Figure 7: Board Power-Supply Connector Detail



Suggested starting values:

- $V^+$ : +5V
- $V^-$ : -5V

With the suggested values, the absorbed current in each line is approximately 40 mA. The output signals can range from -3.8V to + 3.8V ( $\pm 1.2V$  is used by the op-amp and is unavailable). Since Out1 is negative and Out2 is positive, the user might want to shift the output dynamic to avoid saturation in one of the outputs. Typically, it is crucial to avoid saturation on the Energy channel rather than the Timing channel. The reason for this is that the Timing signal carries the most useful information in the very beginning of its rising edge, where saturation is not an issue.

To shift the output range, adjust the bias voltages and keep the overall difference within 11V max. (10V is suggested for safety). Additionally, each voltage cannot be lower than  $\pm 2.5V$  or higher than  $\pm 8.5V$ .

In summary:

- $+2.5V \leq V^+ \leq +8.5V$
- $-2.5V \geq V^- \geq -8.5V$
- $V^+ - V^- \leq 11V$

## Out1: Energy

Out1 is the output of the first stage of amplification.

The polarity is negative. The gain of the amplification stage (also accounting for termination) is  $G = 83 \text{ V/A}$ . An offset of a few tens of millivolts with respect to ground is common and is due to the operational amplifier chip. The exact value changes from sample to sample and can be positive or negative.

Out1 preserves the signal shape and can thus be integrated to obtain the delivered charge, a quantity that is proportional to the number of detected photons. In a typical application with a scintillator, this quantity is also proportional to the energy of the detected X or gamma ( $\gamma$ ) ray. Hence, Out1 is referred to as the Energy signal.

## Out2: Timing

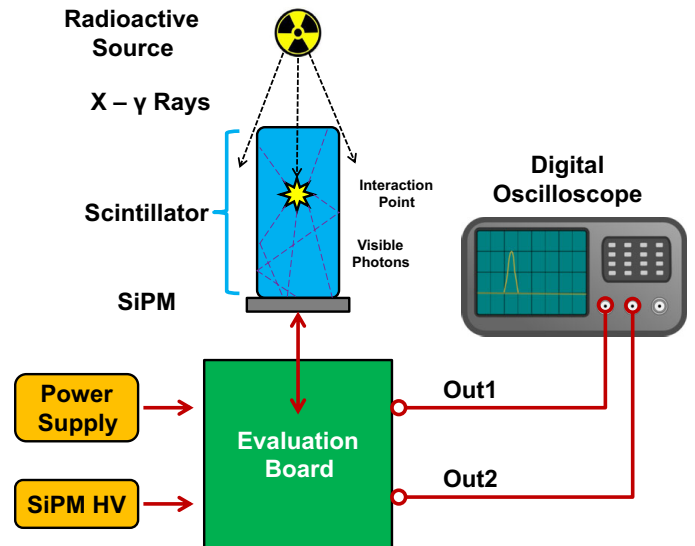
Out2 is the output of the second stage of amplification. The polarity is positive. The gain of the amplification stage is not defined because of the presence of the PZ network.

The PZ filter is designed to change the signal shape. Specifically, it suppresses the recovery tail of the SiPM signal, thus reducing the baseline fluctuations due to dark counts. As a consequence, the extraction of the timing information (when using a simple leading edge discriminator [LED], as an example) is more accurate and allows for improved timing resolution performance. Hence, Out2 is referred to as the Timing signal.

## Example of Operation and Sample Signals

Figure 8 shows the typical test setup.

Figure 8: Typical Test Setup Scheme



The scintillator converts the energy from the X -  $\gamma$  ray into many visible photons, which are then detected by the SiPM. The interaction between the radiation and the scintillator can be of two types: photoelectric effect or Compton scattering. In the first case, the X -  $\gamma$  ray is absorbed and all the energy is deposited. With Compton scattering, however, the X -  $\gamma$  ray is not absorbed and only a fraction of its energy is released into the scintillator.

Each detection event is randomly a Compton scattering or a photoelectric effect, according to a distribution that strongly depends on the atomic number of the scintillator and the radiation energy. Different materials have different characteristics in terms of density, number and wavelength of produced photons, and emission time. The choice of the material strongly depends on the energy of the radiation that must be detected.

The following example signals can be obtained with a typical test setup. The scintillator is a commercially available LYSO crystal with dimensions of 4 mm x 4 mm x 20 mm. The employed radioactive source is  $^{22}\text{Na}$  and emits two primary gamma lines at energies of 511 keV and 1274 keV. The setup is completed by the digital oscilloscope from LeCroy (model WavePro 760Zi-A with 6 GHz of bandwidth and a 40-GS/s sampling rate).

Figure 9 shows a persistence of signals on Out1. The displayed waveforms represent the gamma counts in a LYSO scintillator from the scintillator's internal activity background.

Figure 9: Example Output Signals from Out1

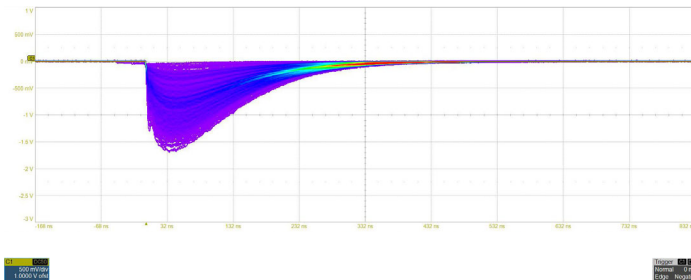
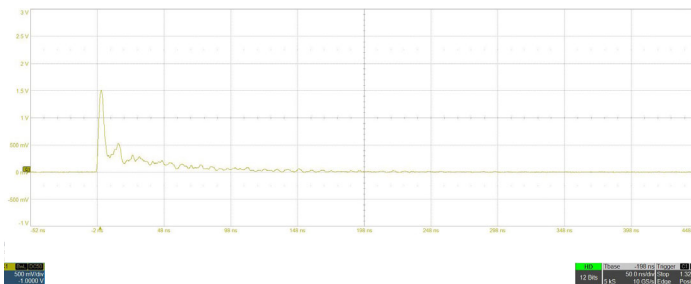


Figure 10 shows one example signal from Out2. It can be seen that Pole-Zero filtering produces a much steeper signal that is optimized for the extraction of the timing information. The oscillations after the first peak are due to photons reaching the detector after the first bunch and oscillations of the op-amp. They do not deteriorate the performance because the best information about the time of arrival of the gamma ray is carried by the very first photons that contribute to the very first part of the first rising edge. For optimal operation, it is thus suggested to set a low threshold (as close as possible to the baseline fluctuation level) and to consider only the first threshold crossing.

Figure 10: Example Output Signal from Out2



## Absolute Maximum Ratings

Stresses in excess of the absolute maximum ratings can cause damage to the circuit. Limits apply to each parameter in isolation. Absolute maximum ratings are those values beyond which damage to the board may occur if these limits are exceeded for more than a short period of time.

Table 1: Absolute Maximum Ratings

| Parameter                       | Symbol      | Min.      | Max.      | Unit |
|---------------------------------|-------------|-----------|-----------|------|
| Storage Temperature             | $T_{STG}$   | -20       | +60       | °C   |
| Operating Temperature           | $T_A$       | -20       | +50       | °C   |
| Op-amp Dual Voltage             | $V_{\pm}$   | $\pm 2.5$ | $\pm 8.5$ | V    |
| Op-amp Total Voltage Difference | $V^+ - V^-$ | —         | 11        | V    |
| Supply Current                  | $I_{\pm}$   | —         | 100       | mA   |

## Details on the Round DC Readout PCB

This section provides an overview on the DC readout PCB of the AFBR-S4E001.

### Description

The circular DC SiPM readout PCB is designed for maximum dynamic range readouts, allowing access to the SiPM signal without the potential restrictions of an amplifier circuit (for example signal amplitude or bandwidth).

The DC PCB is equipped with a low-pass filter on the bias supply line to reduce voltage ripples from the voltage source and with a load resistor ( $50\Omega$ ) in the signal line. This  $50\Omega$  load causes an effective load of  $25\Omega$  when the signal is read using a  $50\Omega$  input impedance on an oscilloscope or DAQ.

The mechanical dimensions of the circular DC readout PCB are designed such that it is compatible with Thorlabs SM01 cage mount systems. The circular form factor allows the PCB to be inserted in the Thorlabs cage frames or lens tubes such that the SiPM is aligned with additional optics used in customer setups.

### Inputs and Outputs

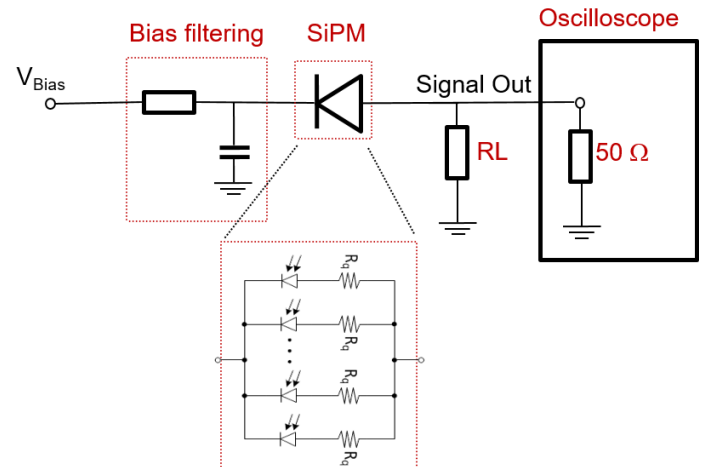
The DC PCB uses MCX connectors (jack,  $50\Omega$ ) for signal and bias connections.

The positive bias voltage is supplied via the “BIAS+” input. With a SiPM breakdown voltage of  $32.5\text{V}$  (at  $25^\circ\text{C}$ ) and a maximum allowed overvoltage of  $16\text{V}$ , the range of applicable bias voltages is between  $32.5\text{V}$  and  $48.5\text{V}$ .

The SiPM signal is retrieved via the “SIGNAL” connector and can be directly connected to an oscilloscope.

Figure 11 shows a block diagram when connecting a SiPM to an oscilloscope using the circular DC readout PCB.

**Figure 11: Block Diagram of SiPM Readout Using the Circular DC Readout PCB and an Oscilloscope**



### Connecting the SiPM

The SiPM (on the interposer PCB) is connected to the pin headers on the top side. The pin headers for the SiPM anode and cathode are labeled with “A” and “C”, respectively, on the circular PCB and the SiPM interposer PCB. The second pair of pins (header) is not connected. These two pins increase mechanical stability and ensure alignment of the SiPM front side with optics.

## Outputs and Example of Operations

**ATTENTION:** Before applying a bias to the SiPM, a completely dark operation environment must be ensured. To prevent the SiPM from damage, a current compliance limit of 5 mA should be used.

The expected pulse shape using the circular DC readout PCB depends on the SiPM and readout electronics settings that are used. Figure 12 (left) shows the expected pulse shapes (averaged over several hundred pulses) using a 500-MHz bandwidth and a 50Ω input impedance on an oscilloscope with the SiPM biased at 12 VOV (44.5V bias). Figure 12 (right) shows a zoomed-in view of the first 20 ns of the pulse.

**Figure 12: Single Photon (1 p.e.) Waveform Using the Circular DC Readout PCB**

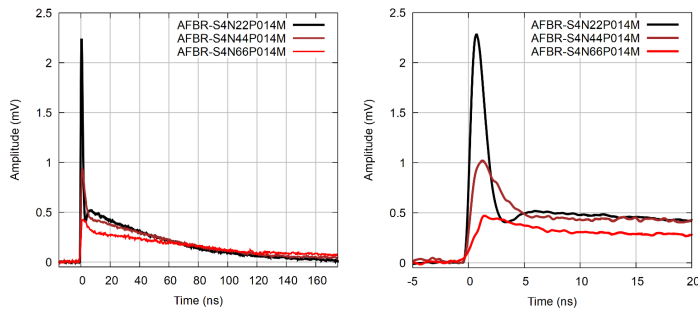


Figure 13 shows a typical pulse train obtained from an AFBR-S4N44P014M (at 12 VOV) measured on an oscilloscope with a 50Ω input impedance and a 500-MHz bandwidth. The primary dark counts are visible with an amplitude of 1 mV. Events with amplitudes over 1 mV are crosstalk events of various orders.

**Figure 13: Pulse Train of AFBR-S4N44P014M at 12V Overvoltage**

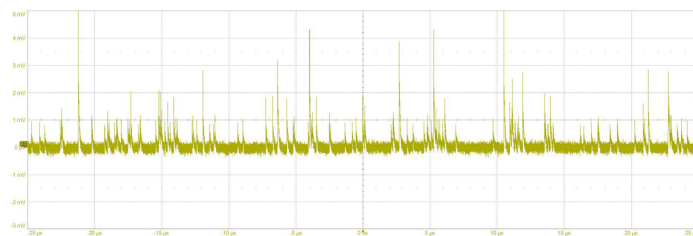
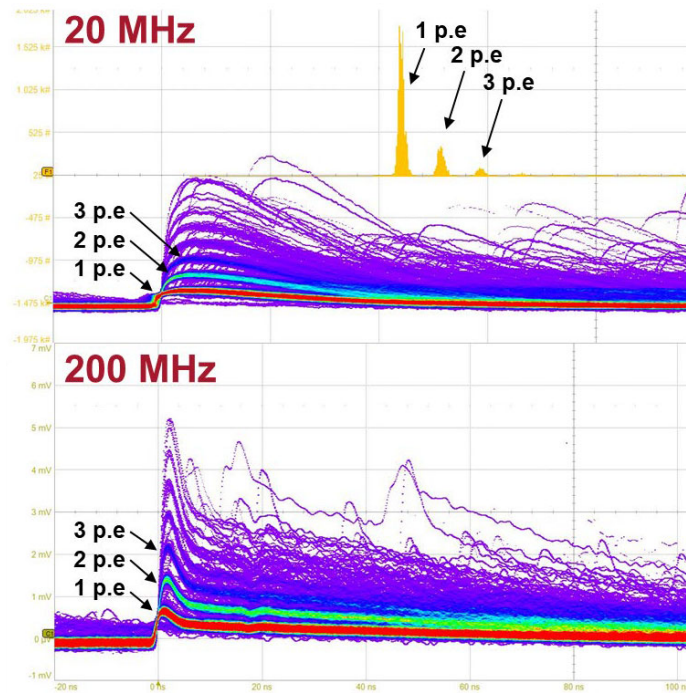


Figure 14 shows two screenshots taken from a measurement of the AFBR-S4N44P014M at 12V overvoltage. The screenshots demonstrate the signal shaping effect of a band-pass (low-pass) filter on the SiPM signal. For both settings, the single-photon response of the AFBR-S4N44P014M is clearly visible without amplification. Furthermore, the different photon levels (1 p.e., 2 p.e., and so on) can be clearly separated from each other, resulting in excellent single-photon resolution even without a dedicated amplifier and shaping circuits, while still allowing detection of bright signals up to the full SiPM saturation without limitations.

**Figure 14: Dark Pulses of AFBR-S4N44P014M in Persistence Mode**



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