Analyzing the behavior of a Candidate SiPM and Signal Amplifier for MATHUSLA

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Abstract

MATHUSLA (MAssive Timing Hodoscope for Ultra-Stable neutraL pArticles) is a long-lived particle (LLP) detector which would be constructed on the surface above CMS and is currently in its planning stages [1]. This large-area detector would be composed of several layers of solid plastic scintillator, with wavelength-shifting fibers connected to silicon photomultipliers (SiPMs), allowing us to monitor an empty air-filled decay volume. The purpose of this research is to examine the behavior of a candidate SiPM and signal amplifier for this detection array. The SiPM in question is the SensL MicroFB-30035 and the amplifier is the Broadcom AFBR-S4E001 (displayed in figure 5). This goal was accomplished by simulating these components in SPICE, an electronic circuit simulator. Using this simulation method, we were able to measure the amplified signal output and produce voltage-time plots for it.

Introduction

The detection mechanism of MATHUSLA begins with plastic scintillator bars. Each bar is manufactured with a hole through the center into which wave-length shifting fiber (WLSF) is inserted. Figure 1 shows a sample of this. The WLSF is then affixed to SiPMs on either end. As a particle hits the bar, the emitted light travels through the WLSF and into the SiPMs. The position of a particle hit along the axis parallel to the bars can thus be determined by differences in light arrival times to these SiPMs. Figure 4 shows a baseline example setup of this. MATHUSLA will thus need a precise timing of approximately 1 ns for position reconstruction [2]. It is necessary to study the signal output to determine if a candidate SiPM-amplifier system satisfies this timing.

The schematics for the simulation models of the MicroFB-30035 SiPM and AFBR-S4E001 amplifier were each provided by their respective companies, SensL and Broadcom. The SiPM model is comprised solely of basic circuit components. It sends two outputs: a fast signal and a standard signal. In contrast, the amplifier circuit contains three subcircuits which represent operational amplifiers. Two of these components are AD8099 and the third is an AD8000, both of which are manufactured by Analogue Devices. The amplifier circuit also gives two outputs: a fast timing output and a photon counting output.

Methods

Using the schematics provided by SensL and Broadcom, the models for the SiPM and amplifier circuit were built within a SPICE based program. Specifically, LTSpice was used.

In order to build the amplifier circuit, SPICE model files for the AD8099 and AD8000 operation amplifiers were obtained from the Analogue Devices website. These were then modified for compatibility where necessary.

Next, the SiPM fast output was connected to the amplifier circuit input and the system was simulated. The simulation time was between 0 to 15 ns with a resolution of 5 ps. Finally, the voltage as a function of time was measured at four nodes within the circuit system. Meanwhile, figure 3 displays the SiPM constructed within SPICE. Meanwhile, figure 2 displays a schematic representation of the amplifier as well as the location of the measurement nodes. Notably, node 3 is the fast timing output and node 4 is the photon counting output.

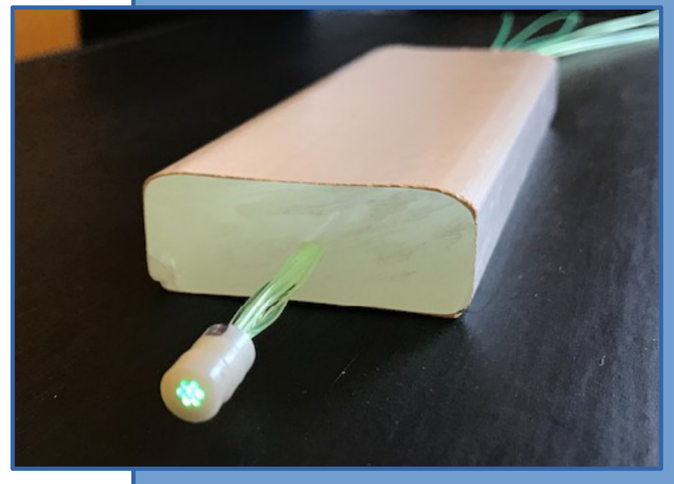

Figure 1: Solid plastic scintillator bar with inserted wave-length shifting fibre. [2]

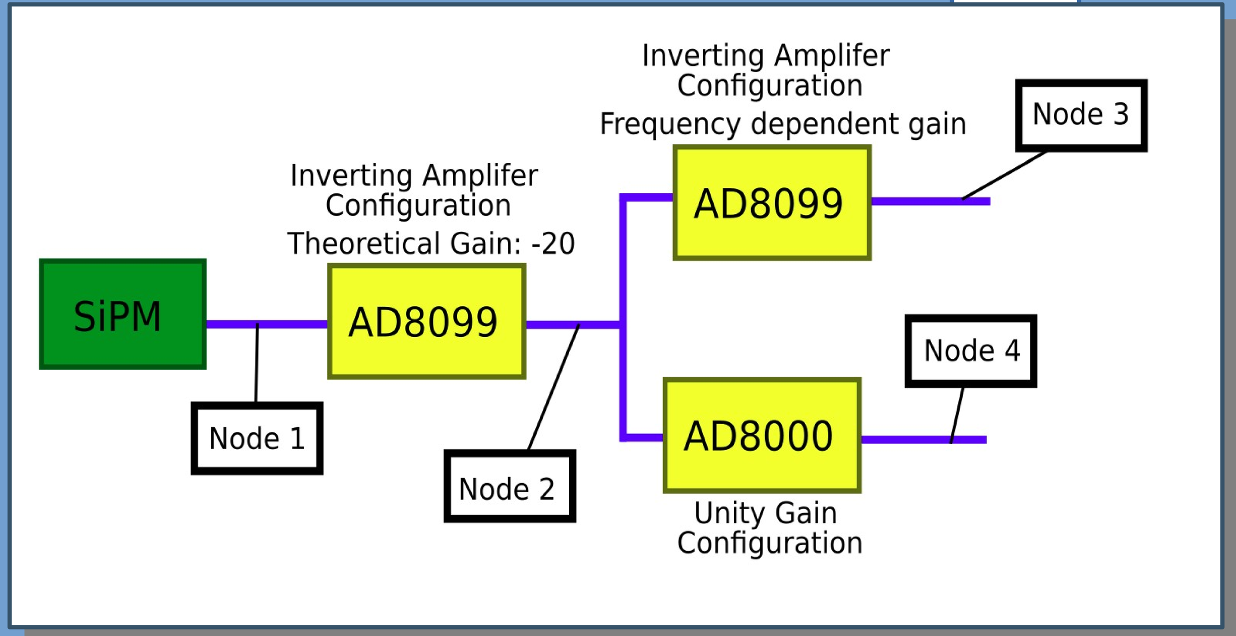

Figure 2: Schematic representation of the Broadcom AFBR-S4E001 simulation model. The location of the measurement nodes are also shown.

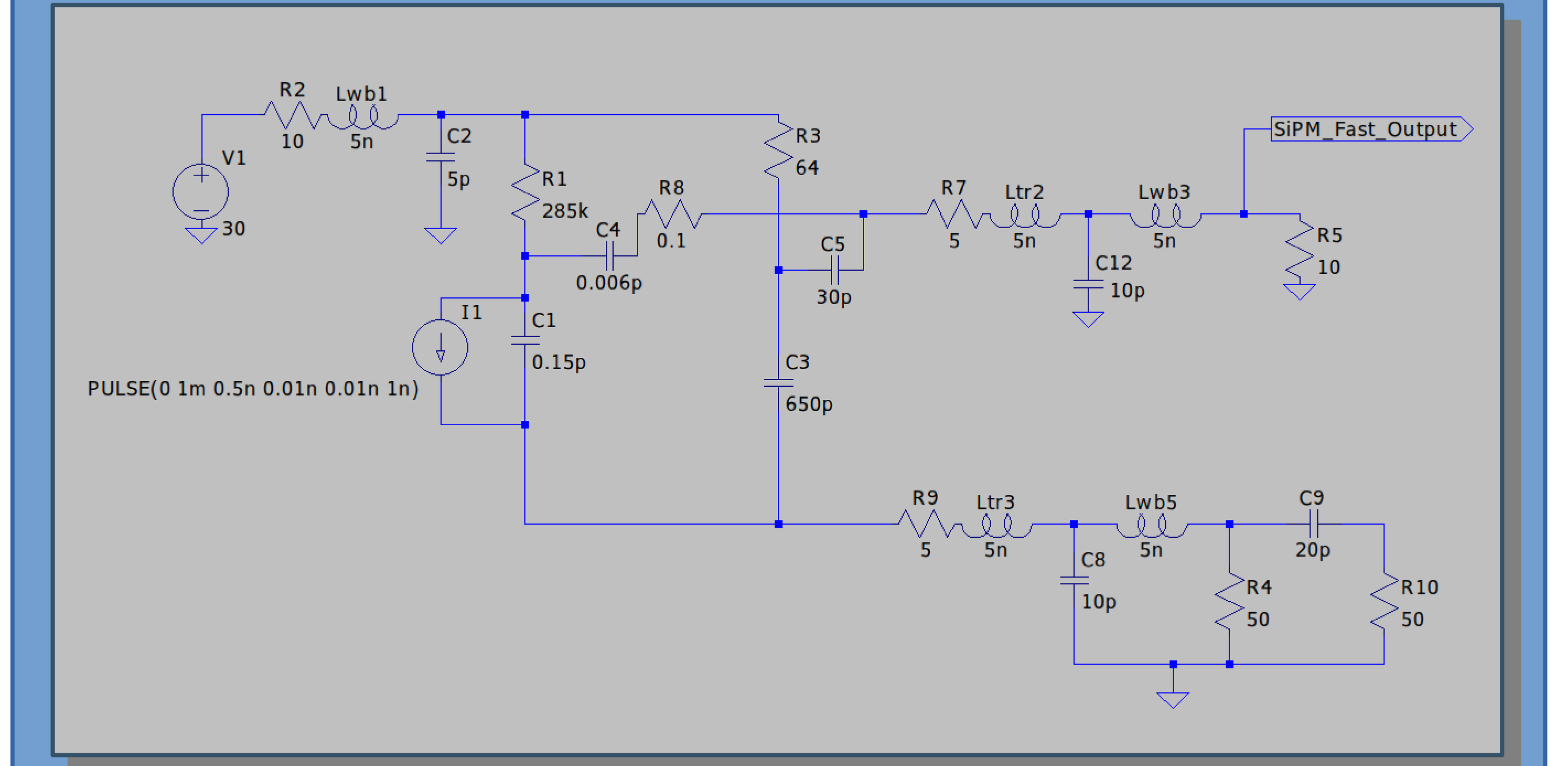

Figure 3: Circuit diagram of the simulation model for the SensL MicroFB-30035 SiPM. Here, displayed from LTSpice.

Results

Figure 6 shows the voltage-time plots for the nodes obtained from LTSpice at different voltage scales.

Discussion

From the results, it can be seen that the SiPM output (node 1) peaks at a bit less than 2 ns. In contrast, the first peak of the amplified photon counting signal (node 3) has a timing of a bit more than 3 ns.

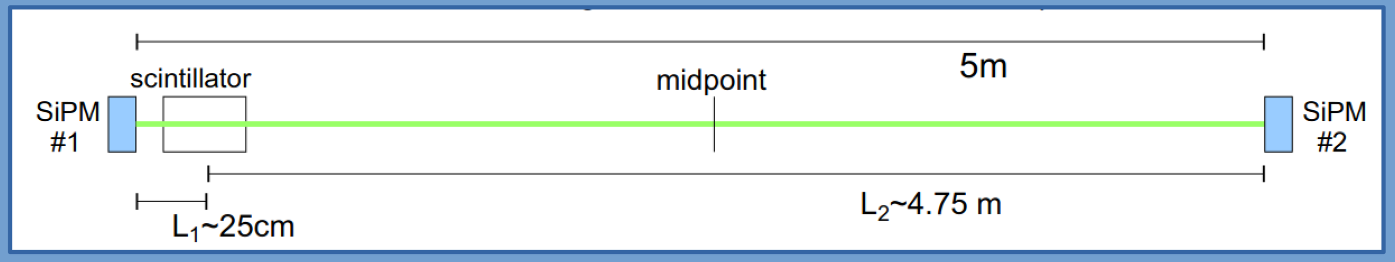

Figure 4: A baseline setup of a scintillator bar, WLSF, and two SiPMs which could be used to study the timing resolutions for the proposed system. [2]

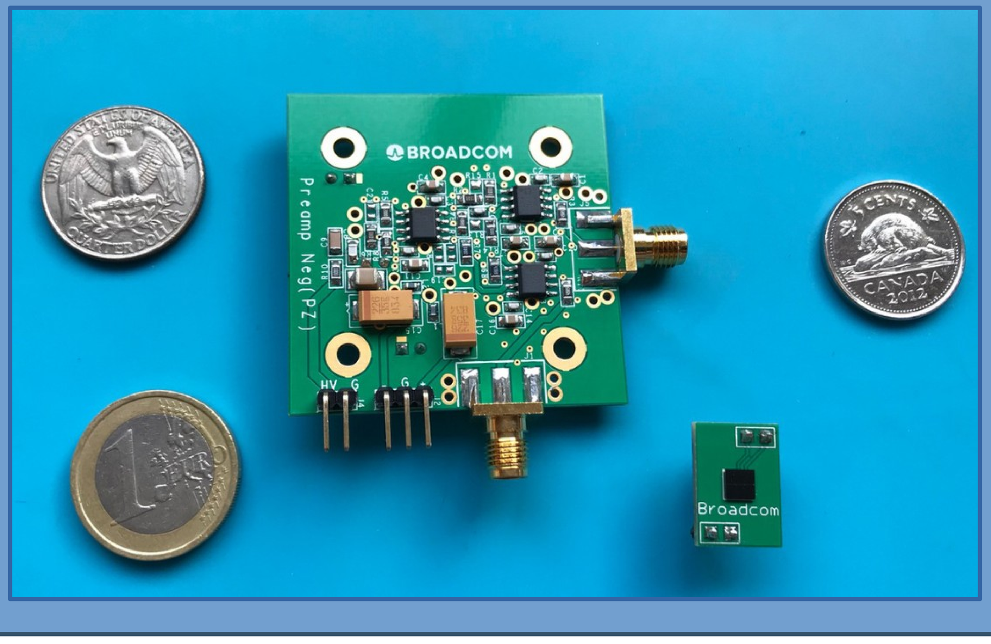

Figure 5: Center image: The Broadcom AFBR-S4E001 alongside various currencies for scale. Bottom right: An example of another SiPM, the Broadcom AFBR-S4N44C013 (not the candidate SiPM of this work). [2]

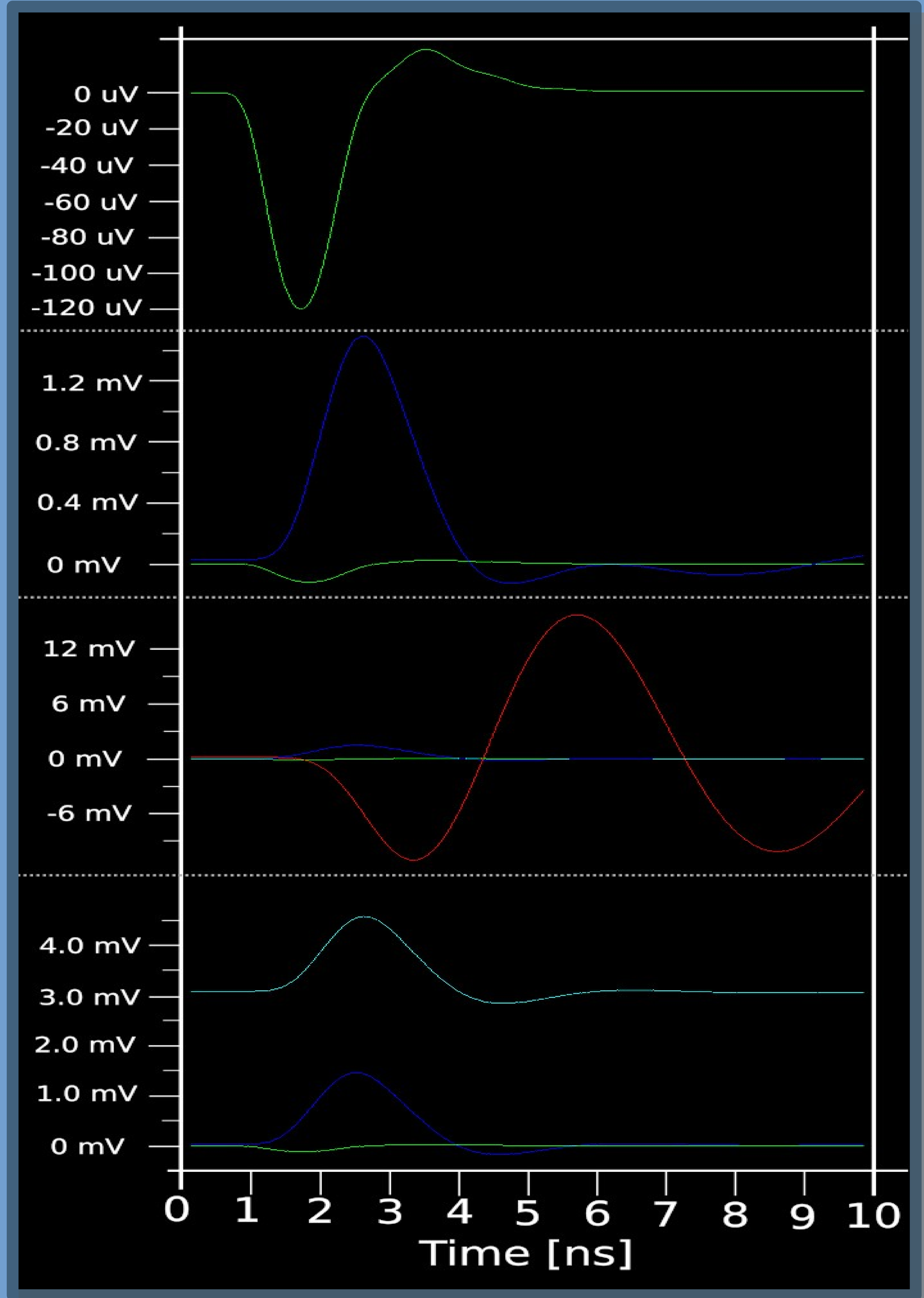

Figure 6: A comparison between different voltage-time plots of the four measurement nodes. Ordered from top to bottom: node 1 (in green) alone, node 1 with node 2 (in blue), nodes 1 and 2 with node 3 (in red), nodes 1 and 2 with node 4 (in cyan). Results were obtained via LTSpice simulation.

Next Steps

Using simulation methods, the goal to examine the behavior of the candidate SiPM in connection to the amplifier was achieved.

We will next build this setup in the lab and compare our results to other candidate SiPMs.

References

[1] Cristiano Alpigiani, Juan Carlos Arteaga-Velazquez, Austin Ball, Liron Barak, Jared Barron, and Brian Batell et al. An update to the letter of intent for mathusla: Search for long-lived particles at the hl-lhc, 2020.

[2] Steven Robertson. R&D status. MATHUSLA weekly meeting, Jan 2021.