AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #36037

An Electronic-Circuit Platform for Comprehensive PSpice Simulation and PCB Troubleshooting

Dr. Wookwon Lee P.E., Gannon University

Wookwon Lee, P.E. received the B.S. degree in electronic engineering from Inha University, Korea, in 1985, and the M.S. and D.Sc. degrees in electrical engineering from the George Washington University, Washington, DC, in 1992 and 1995, respectively. He is currently a full professor in the Department of Electrical and Computer Engineering at Gannon University, Erie, PA. Prior to joining Gannon in 2007, he had been involved in various research and development projects in industry and academia for more than 15 years.

Dr. Nicholas B Conklin, Gannon University

Nicholas B. Conklin received a B.S. in applied physics from Grove City College in 2001, and a Ph.D. in physics from Penn State University in 2009. He is currently a professor and chair of the Physics Department at Gannon University, Erie, PA.

An Electronic-Circuit Platform for Comprehensive PSpice Simulation and PCB Troubleshooting

Wookwon Lee[1] and Nicholas B. Conklin[2]
[1]Department of Electrical and Computer Engineering
[2]Department of Physics
Gannon University
Erie, PA 16541
Email: {lee023, conklin003}@gannon.edu

Abstract

In this paper, we present an electronic circuit platform suitable to help students to further develop research skills through a full cycle of circuit design, PSpice simulation, and PCB troubleshooting. We also present brief details of a mathematical modeling for PSpice simulation, and technical issues encountered, and the methodology to troubleshoot the circuit utilizing both PSpice and PCB.

1. Introduction

In any electrical engineering curriculum for undergraduate students, at least one course is included to cover electronic devices and circuits with laboratory experiments, leading to a total of four credit hours of coursework. Typical topics covered in Electronics can be largely grouped into the following four categories: op-amp applications, diodes and applications, bipolar junction transistors (BJTs), field-effect transistors (FETs). Closely related to the electronic platform further discussed in this paper is op-amp applications. When op-amps are covered in the course, various op-amp circuits are discussed starting with inverting op-amps and non-inverting op-amps and then, comparators, integrators, differentiators, summing amplifiers, instrumentation amplifiers, and some other op-amp circuits. It is generally expected that students will be able to apply their knowledge of op-amps to real-world applications. As described in more details below, one example of the real-world applications is designing a high-altitude balloon payload of electronic instrument to measure the energy of cosmic rays. Due to the nature of amplification and integration of the current or voltage signal, the payload employs a set of op-amps in multiple stages of signal processing.

As an on-going undergraduate research project in an extracurricular setting, the payload design has gone through several cycles of circuit refinement, implementation, testing, and actual data collection in balloon flights, involving several cohorts of students over the past 8 years. Closely working with the students during that period, we as the faculty research advisors observed that there is room for improvement in helping students apply their knowledge from the Electronics course to real-world applications more effectively and successfully. In this paper, we present our perceptions on what could be done better with our payload design as an example providing specific areas of improvement. The remainder of this paper is organized as follows. In Section 2, an overview of our electronic circuit platform is provided, and key aspects of PSpice implementation and PCB design are described in relation to the traditional course coverage in Section 3. Section 4 presents technical issues encountered during the payload implementation. Finally, conclusions are made in Section 5.

2. Overview of the Electronic Circuit Platform

A balloon-borne payload was developed to measure cosmic-ray charge and energy as an undergraduate research project in a collaboration between the Electrical and Computer Engineering (ECE) and Physics departments. Cosmic rays are high-energy particles originating outside the solar system and interact with Earth's atmosphere[1], making balloon and satellite-based instruments ideal for studying them prior to this interaction. This payload employs a sampling calorimeter, composed of layers of tungsten and scintillator, to facilitate the energy measurement and a pixelated scintillator-based charge detector to achieve the charge measurement.

When a high-energy charged particle traverses scintillator, a fraction of the particle's energy is deposited in the material and converted into optical photons. These optical photons are detected using silicone photomultipliers (SiPMs) glued directly to the scintillator. The SiPMs convert the photons into a small current that is proportional to the amount of light detected, and therefore an indication of the energy deposited into the scintillator.

A top-level block diagram for the payload is show in Figure 1. The payload consists of three main modules, the Data Collection Module (DCM) including the calorimeter and charge detector, the Trigger Logic Module (TLM) for discrimination between good and bad events, and the Data Management Unit (DMU) which handles communications with the ground and storage of data onto an SD card. Within the DCM, there is a Peak Detector Module (PDM) that employs a well-known peak detector design to read out each scintillator of the charge detector for a total of 25 channels. The DCM also includes a 30 channel Integrator Module (IM) to read out the calorimeter stack. The IM consists of 30 channels of multi-stage electronic circuits for processing of the analog signals from 30 Silicon Photomultipliers (SiPMs).

The IM is a custom design developed in house with the assistance of undergraduates, and the circuit for a single channel is shown in Figure 2[2]. Because the SiPM is a current output device, the first stage of preamplification would be ideally done by a transimpedance amplifier, which converts the current output of the SiPM into a voltage ($V_{O,TIA}$). Alternatively, the SiPM current

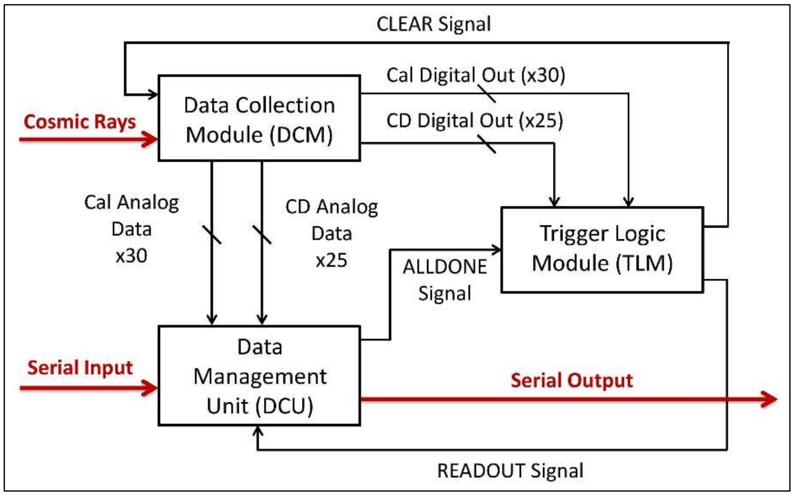


Figure 1 – Payload top-level block diagram

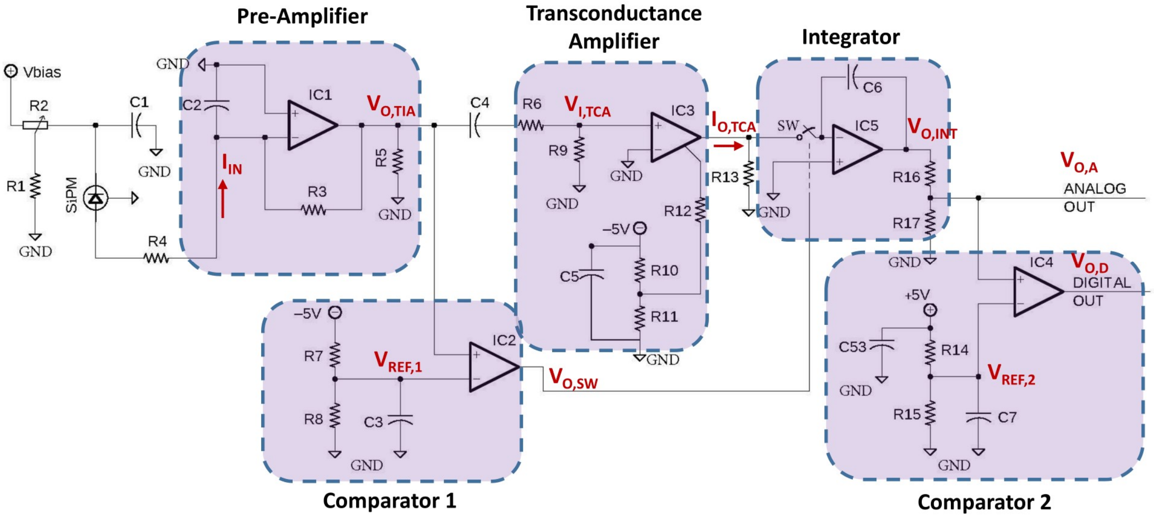


Figure 2 – Circuit schematic of a single integrator channel

output can be first converted to a voltage signal and then subsequently used as the voltage input to the preamplifier. Considering various factors affecting the performance of the overall circuit, we used the voltage signal in our design. This voltage is output to a comparator, which functions as a switch ($V_{O,SW}$) for a Burr-Brown IVC102 integrator[3]. As the integrator employs a transimpedance amplifier, it requires a current input, not a voltage input. Therefore, the design employs a transconductance amplifier between the output of the transimpedance amplifier and the input of the integrator ($I_{O,TCA}$). A second comparator on the output of the integrator ($V_{O,INT}$) is used to generate a digital signal ($V_{O,D}$) indicating that an event has occurred. The 30 channels of the IM are implemented on 8 printed circuit boards (PCBs), each processing 4 channels.

As shown in Figure 2, the IM circuit employs op amps that are typically covered in an electronics course in electrical engineering at the sophomore level. While students are generally familiar with op amps by the time they begin research, concepts such as transimpedance and transconductance amplifiers are topics that even senior students do not routinely encounter. Furthermore, in beginning coursework, students typically focus on the behavior of a single op amp rather than using several to create a more complex circuit. Understanding and debugging a much more complex circuit provides students with a rich opportunity to learn beyond what is typically offered in the classroom. The tuning of each stage (through adjusting resistor and capacitor values) of the circuit requires careful planning to ensure proper operation (without clipping) over the entire desired dynamic range.

3. PCB Design and PSpice Simulation

In the early stages of the payload design, the single-channel circuit in Figure 2 was implemented on a breadboard for functional verification and troubleshooting. Software-based circuit simulation would have added more value to the breadboard-based troubleshooting. However, for a proper circuit simulation of this real-world application payload, accurate modeling of the SiPM signal and high-performance op-amp devices is critical for accuracy; unfortunately, these were challenges to students due to lack of understanding of the real-world signal and also

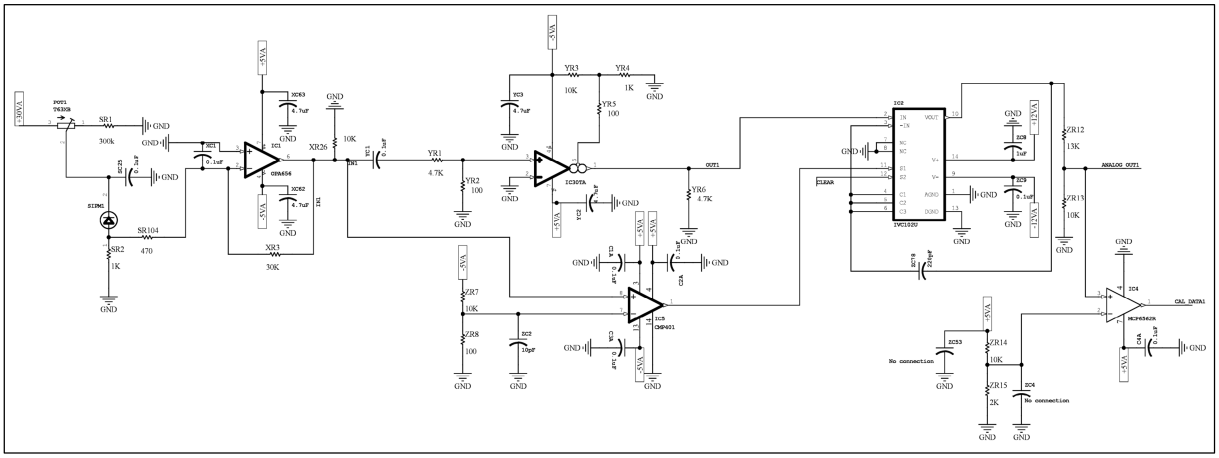


Figure 3 – Altium schematic of a single integrator channel

lack of availability of simulation models of the commercial IC products used for the payload.

After the initial circuit design was verified on a breadboard, it was implemented onto a printed circuit board (PCB) using Altium Designer, presenting students with another opportunity to develop hands-on skills that they do not necessarily encounter in the traditional course. Examples of such skills include finding component libraries online or creating them from scratch and learning to correct errors in the schematic revealed by running an error rule check (ERC) upon completing the design implementation. The Altium schematic implementation of a single IM channel is shown in Figure 3 (the actual PCB has four channels).

After completing the schematic, students needed to layout the components on the physical PCB. One thing noticed by the authors is that students tend to over rely on the auto-router rather

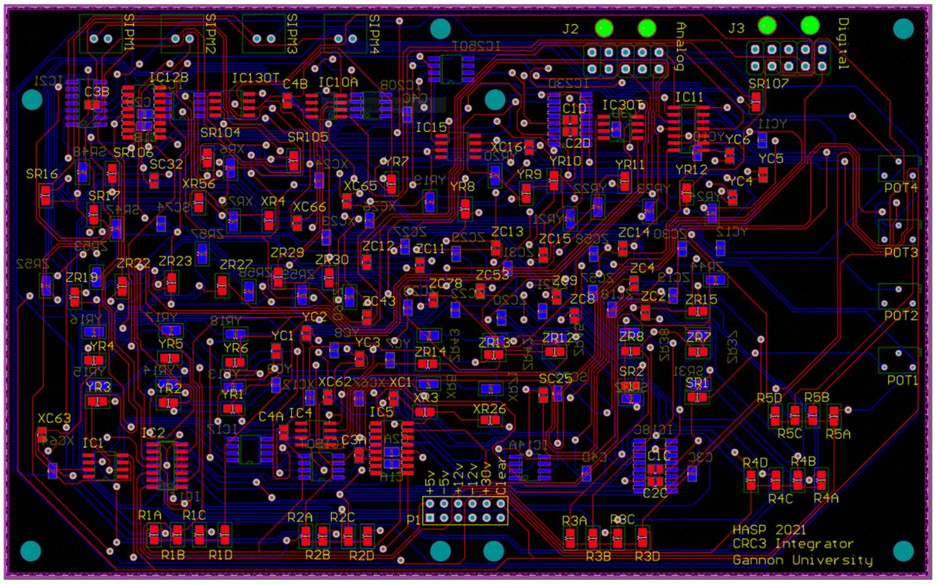
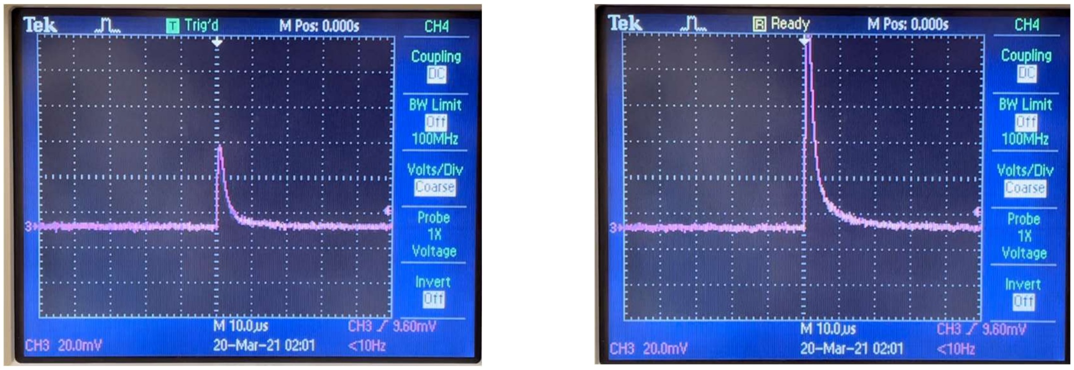


Figure 4 – Altium PCB layout view of a single board



(**a**) (**b**)

Figure 5 – SiPM voltage output waveform measured across a 1 kΩ resistor: a) ~46mV peak voltage; ~110mV peak voltage

than considering good part placement. For example, some of the IC filter capacitors were placed very far from the ICs, reducing their effectiveness. The PCB for a single IM board, containing four integrator channels, is shown in Figure 4. As a dual layer PCB, the top and bottom layers have a similar level of complexity.

At a later stage of the payload design, the project has evolved to be able to capture images of the SiPM signals for mathematical modeling purposes. Shown in Figure 5, the SiPM output voltages measured across a 1 kΩ resistor resemble an exponentially decaying function with a different peak voltage. A more accurate empirical model can be derived with additional terms although not discussed in this paper for brevity. Approximating the SiPM signal using an exponential voltage-source model in PSpice based on the empirical mathematical model, a PSpice simulation schematic of the preamplifier can be completed as shown in Figure 6. Also, PSpice from OrCAD had all device models available for the circuits while some models were not available

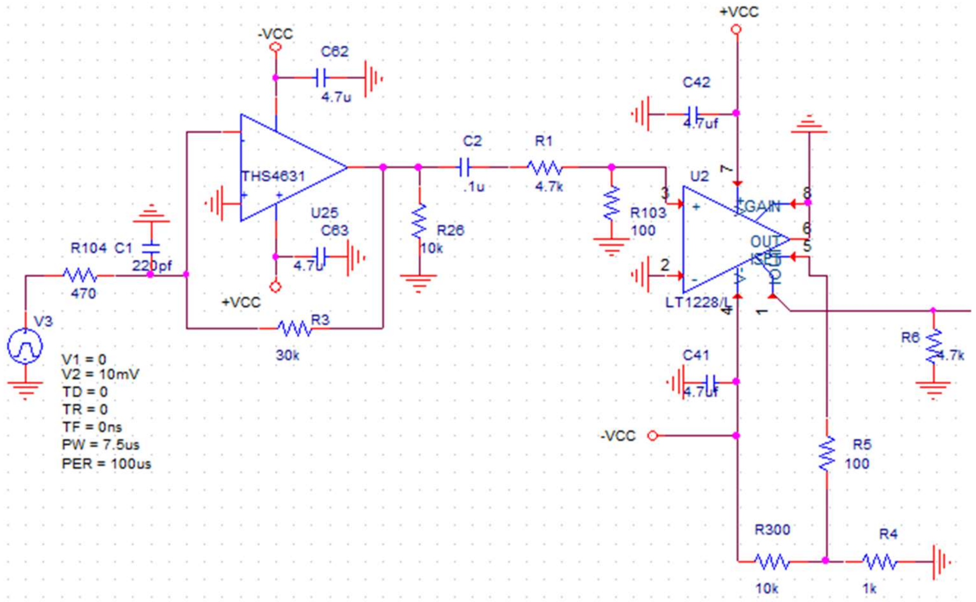


Figure 6 – PSpice schematic of a single integrator channel

in Altium PSpice, leading to separate PSpice simulation and PCB design with different software tools. Also, a desired backward compatibility of several versions of PCB design files developed over the past several years played a role in part for the decision to use separate software tools, as conversions between PCB design tools presented unexpected complications of what was thought to be a straightforward conversion from one to the other, vice versa.

4. Technical Issues and Challenges

There are several challenges that typical EE students would face in development of the circuit and implementation on a PCB. First, each channel has five op-amp stages, and the gains of these stages must be set carefully to ensure the circuit operates correctly over the entire dynamic range (for example, not clipping). The complex interrelation between each of the stages presents significantly more complexity than what students learned from their coursework for DC biasing and AC analysis. Furthermore, the op amps operate at a much higher frequency than those encountered during their coursework. The typical pulse duration from the SiPMs is 1 μs ~3 μs (or the signal frequency of 300 kHz ~ 1 MHz), and the transimpedance amplifier gain is ~63 in the circuit shown in Figure 6. Op amps typically used in coursework, such as the LM741, do not have sufficient bandwidth or slew rate to keep up, giving students the opportunity to learn about the departure of op amps from ideal behavior and review data sheets to evaluate more suitable choices.

After evaluating the completed PCB, it was discovered that the common ground for all four channels presented performance issues with parasitic effects between channels on dc biasing and ac signal processing. Furthermore, the circuit is composed of both digital and analog components, and the failure to separate digital and analog grounds also appears to have created performance issues. A proper grounding for electronic circuits is one of the known challenges to undergraduate students.

5. Conclusions

We have presented a real-world application of electronic circuits that has been used as an educational platform to help students develop research skills. Beyond the importance of the proper initial circuit design, when constructed PCBs experience various technical problems, successful troubleshooting of the electronic-circuit can be best facilitated with the use of both PSpice simulation and PCB troubleshooting. While research opportunities may be limited and available only to a few select students in general, we believe that more complex real-world applications, if covered within the curriculum for all students, will better facilitate student learning.

References

[1] S. Swordy, “The energy spectra and anisotropies of cosmic rays,” *Space Science Reviews*, vol. 99, pp. 85-94, 2001.

[2] W. Lee and N.B Conklin, “An electronic instrument for measurement of the charge and energy of cosmic-rays in high-altitude balloons,” in *Proc. 2018 IEEE Ubiquitous Computing, Electronics & Mobile Communication Conf.*, Nov. 2018, pp. 752-757.

[3] Burr-Brown, “IVC102 Precision Switched Integrator Transimpedance Amplifier,” *PDS-1329A*, June 1996.