Large-area SiPM readout of timing and energy for plastic scintillator

TRIUMF — THE UNIVERSITY OF BRITISH COLUMBIA

TRIUMF's Neutral Atom Trap for Beta Decay (TRINAT)

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Acknowledgements

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Introduction

TRIUMF's Neutral Atom Trap for Beta Decay (TRINAT) is looking for evidence of right-handed neutrinos. By trapping an atom and looking at the recoiling particles, we can deduce properties of the neutrinos. For example, the beta asymmetry (how many betas recoil upwards or downwards) is related to the spin of the decaying atom, which is related to the helicity of the neutrino.

TRINAT has two beta detectors (Figure 7). These detect which direction the betas travel in. My role in this experiment is to improve the timing between these two detectors for improved timing resolution in our data acquisition system.

Objective & Specs

The main goals of this project are

- Diagnose the cause of large rise times in current set up
- Design a new printed circuit board (PCB)to improve summed signal 10-90% risetimes to improve timing resolution in data acquisition system

What does this mean in terms of design?

- Improve signal integrity and noise
- Capable of handling a large range of signals
- High bandwidth summing capabilities

Initial Tests

The PCB from AIT that was being used in the experiment set up had various problems

- Oversaturation due to low bandwidth
- Long rise time of 40ns

The likely cause of these issues were the operational amplifiers being used to sum the SiPM signals.

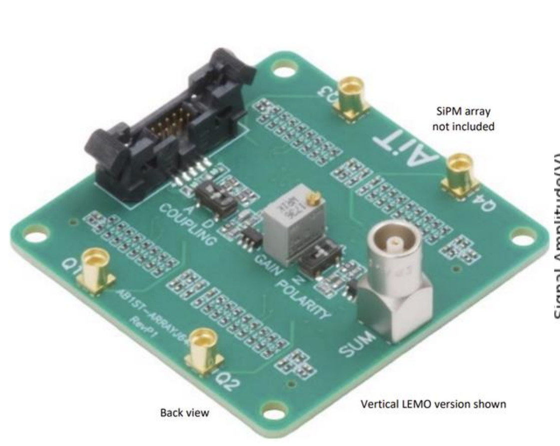

Figure 1: AIT summing board

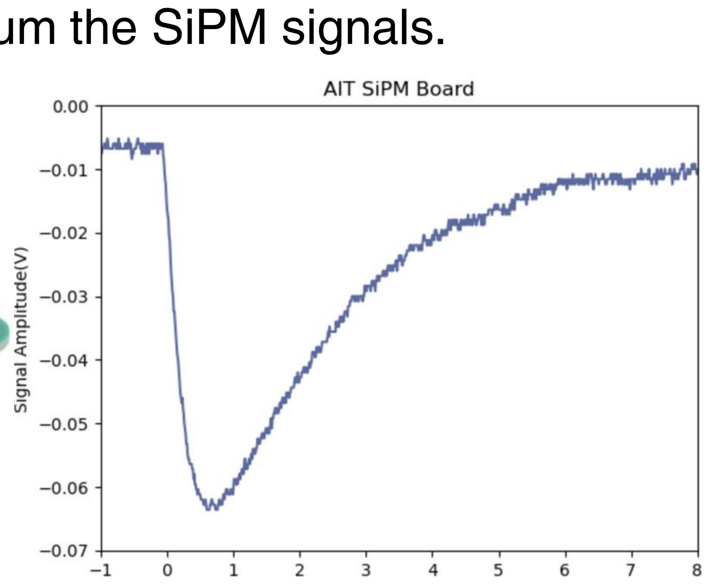

Figure 2: Rise time of 40ns

TRINAT had a PCB evaluation board from another company, Sensl, that provided access to each of the individual outputs of the SiPM array. I used this PCB to test various setups that I could use towards a future design.

Testing & Brainstorming

The evaluation board provided by the company Sensl allowed me to interact directly with the SiPM array.

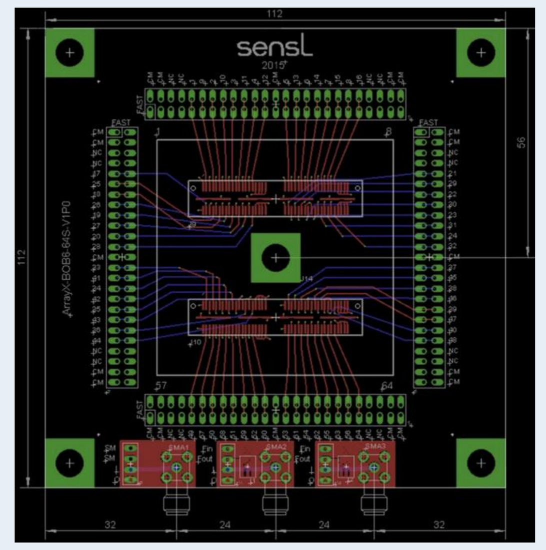

Figure 3 : 8x8 6mm Sensl PCB

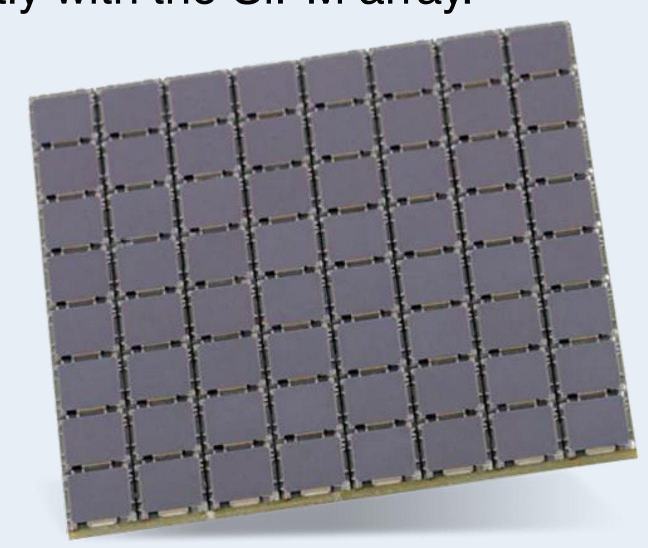

Figure 4 : 8x8 SiPM from Sensl

- Each quadrant can be represented by this equivalent circuit
- When these photodiodes are reverse biased, they cause an avalanching effect, which is when electrons rapidly multiply and cascade
- Our fast output provides an amplified electrical signal from the initial photon impact

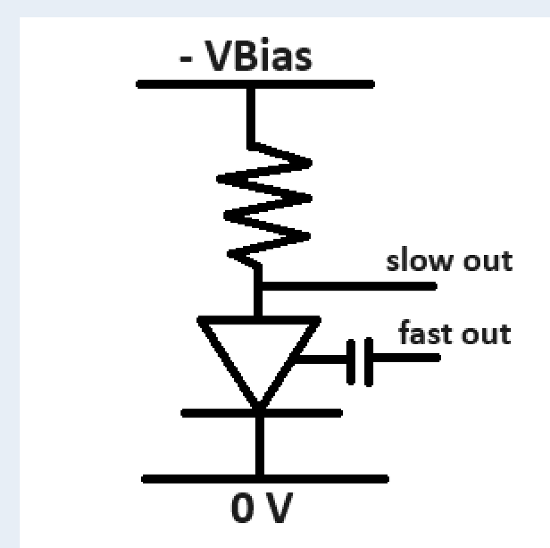

Figure 5 : quadrant equivalent

We can treat this output signal as a current source due to this effect. Thus, using basic principles, when two signals are connected at a node, their currents are summed. I wanted to use this idea to produce a passive sum design to avoid the use of active circuitry for an initial design.

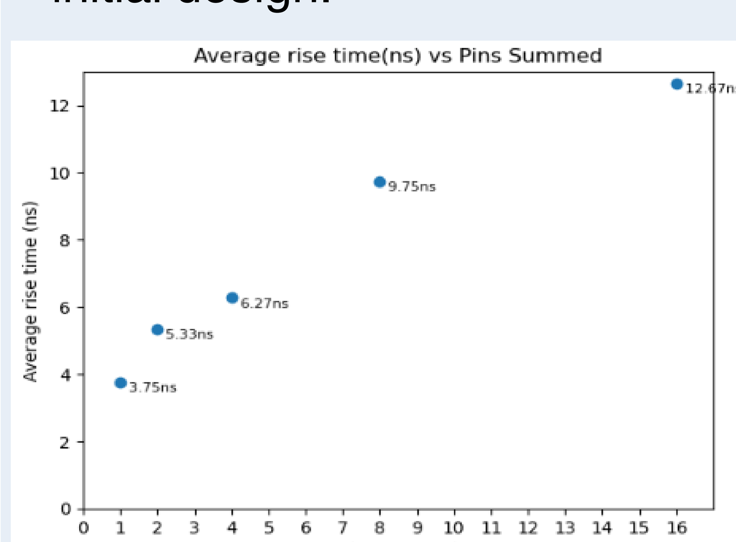

Figure 6: relationship of pins vs risetimes

*data from is 4x4 SiPM , the idea is the same with 8x8 SiPM

- Shorting the outputs sums the signals, but increased rise times
- The increase in rise time is due to increasing the capacitance of the system as each quadrant has a quench resistor and some capacitance

- Summing 4 pins at a time significantly improves risetime, 6ns rather than 40ns
- TRINAT has an old module with high bandwidth op-amps, however only had 4 inputs. Using this module preserved the risetimes of just 4 pins summed together
- We repeated this test with the 8x8 SiPM and summed 16 signals at a time, resulting in 4 outputs being sent to the module. This resulted in a rise time of 10-13ns!

Passive PCB Design, Testing, & Active Design

After carrying out various tests on the evaluation board from Sensl, I was ready to begin designing a PCB. For the initial design we wanted to integrate with the 8x8 SiPM and use the external module since we were certain it was working as intended.

- This board needed to fit within the detector currently used in the experiment

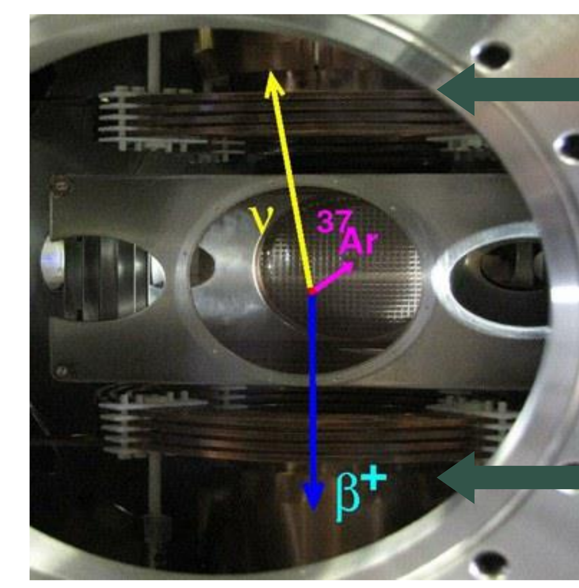

Figure 7 : Real atom trap chamber

*Beta detectors on top and bottom

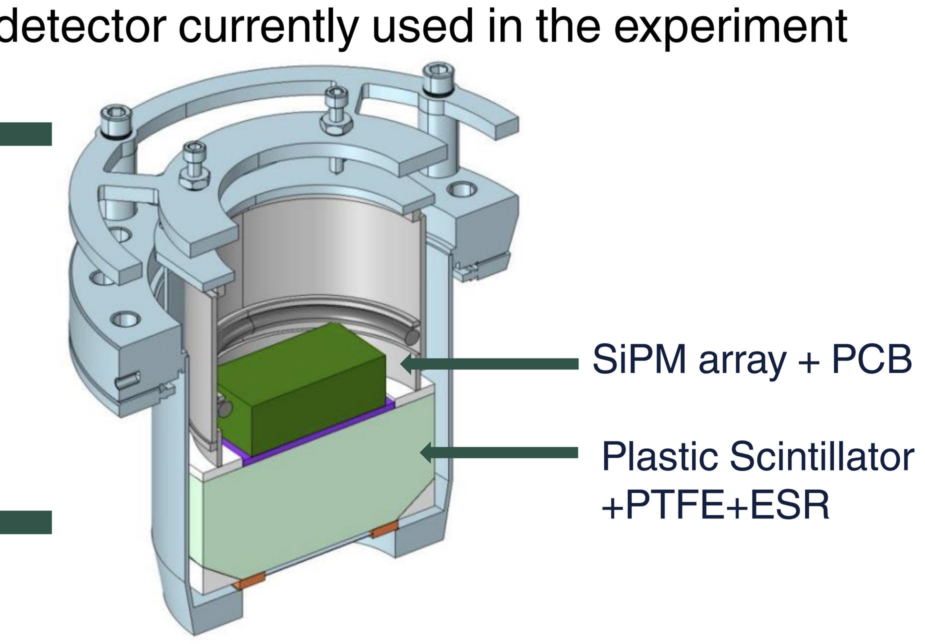

Figure 8 : CAD of Beta Detector

*Courtesy of Alexandre Gorelov

- The detector holds the SiPM and the plastic scintillator
- A scintillator emits light when it is exposed to ionizing radiation
- The SiPM detects this light and then turns it into an electrical signal that we can analyze

The resulting PCB has the following features

- Positively Biased (allows use of 30V low-current supplies)
- 4 Fast outputs to summing module
- Slow outputs used for energy of pulses
- Improved signal integrity by following industry highspeed PCB design
- AC and DC coupling option for energy signal

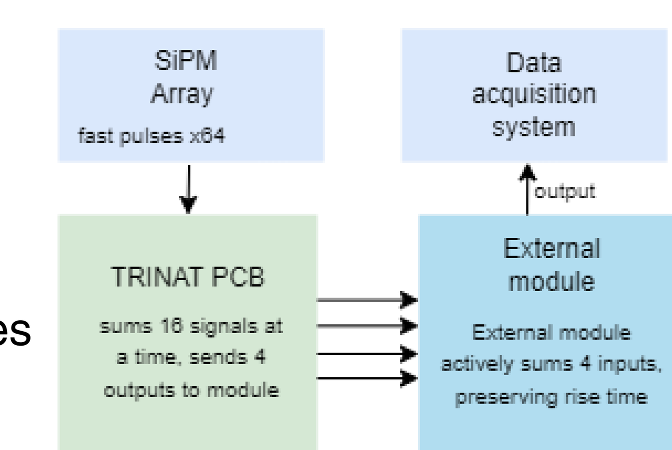

Figure 9 : Flow diagram of setup

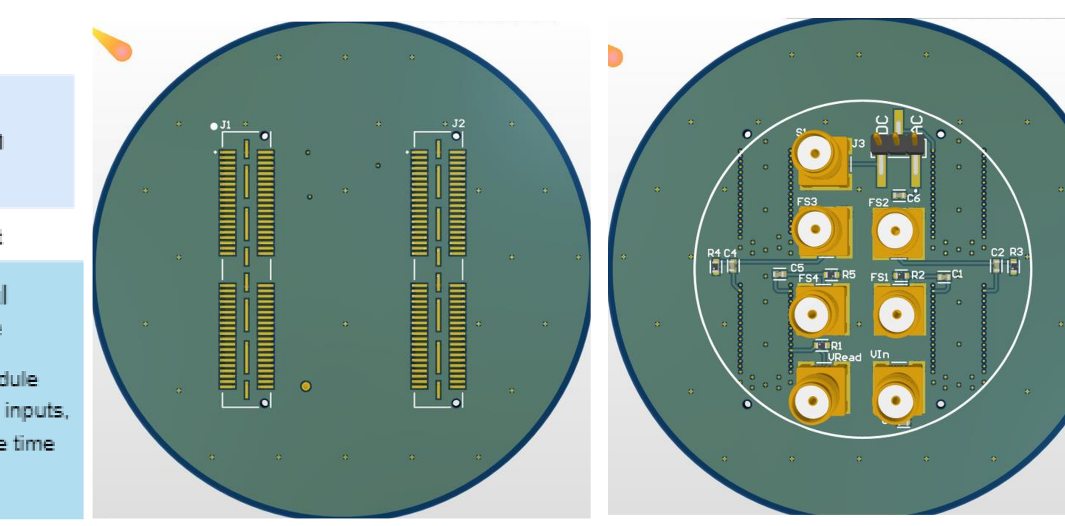

Figure 11 & 12 : 2 sides of PCB (SiPM and connectors)

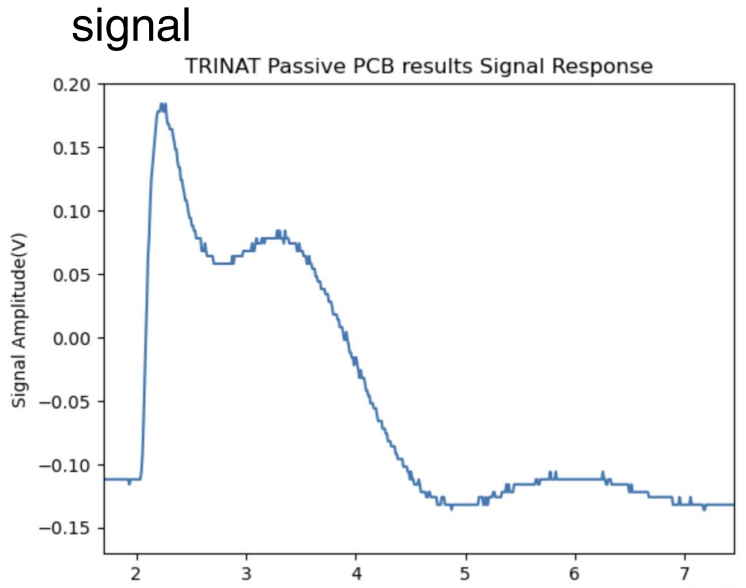

Figure 13: Result of passive PCB

TRINAT PCB results

- Have rise time of 9ns, which is faster than we thought
- A ripple appeared, working to identify issue, not critical
- Can move on to active design

I am now working towards incorporating active summation on our next iteration since this will

1. Improve rise times
2. Reduce use of an external module
3. Reduce cables to PCB, 3 cables instead of 7

To actively sum these signals, I learnt it was best to use a current-feedback operational amplifier.
These were chosen because

- Lower gain minimum
- High bandwidth
- Responds to difference in current, not a difference in voltage

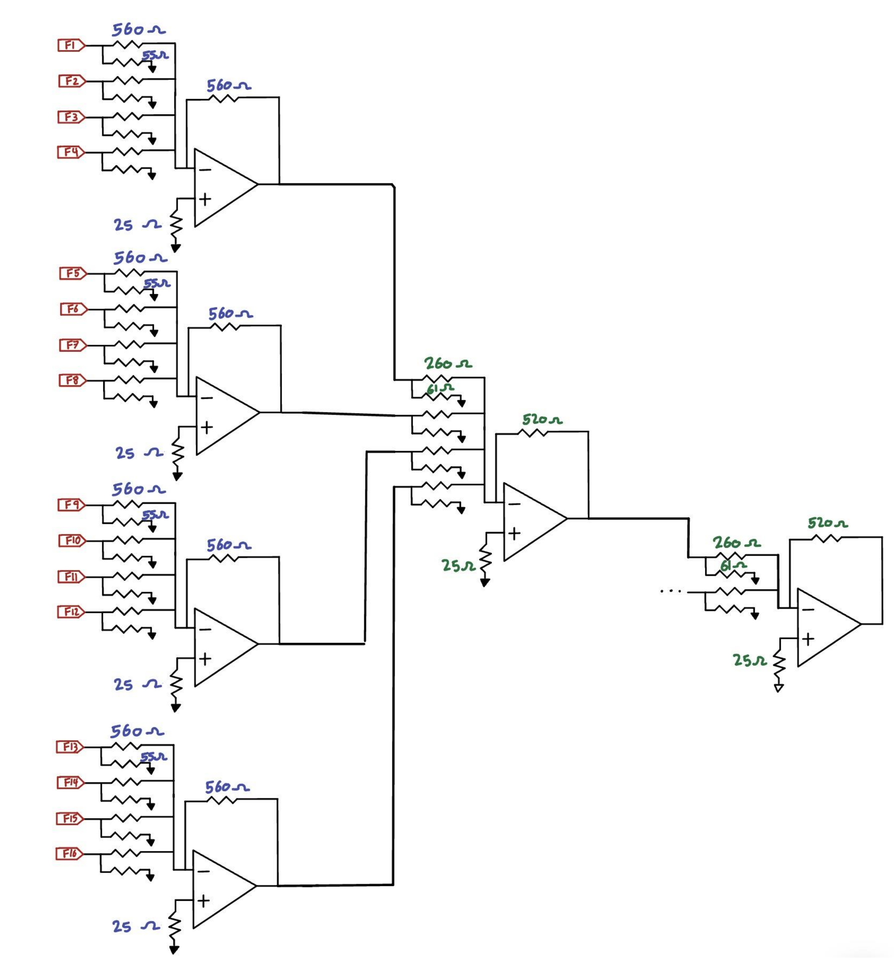

Figure 14: Schematic design for active summing

Summary

This project has allowed me to deepen my knowledge not just in Physics, but in Electrical Engineering. Despite having previous experience in PCB design, I have never had to work with high-speed signals and attempt to have minimal noise in my final design. This gave me an opportunity to research highspeed design practices and talk with experienced professionals, physicists and electrical engineers, at TRIUMF.

This projects aligns with TRIUMFs mission as it allowed me to make a positive contribution to research and scientific discovery. I am grateful that I have had the opportunity to learn from such great individuals.