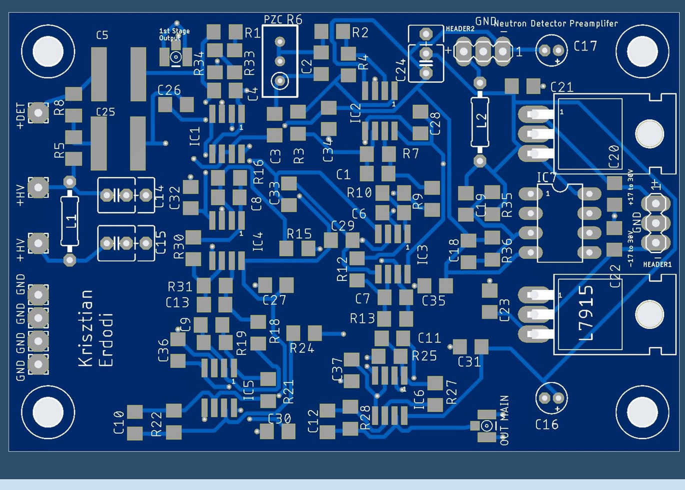

Low-Cost Electronics for Boron-Coated-Straw Neutron Detectors

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1 Introduction

The applications of neutron monitors extend to many critical fields such as leak detection in nuclear power plants, cosmic ray detection for space-weather monitoring, and homeland security in preventing the unauthorised transport of nuclear materials. The industry standard neutron monitor technologies are based on helium-3 but due to the volatile price and scarcity of this rare isotope, the production of these detectors, and scaling of projects involving them, is unsustainable and expensive. It is therefore valuable to explore and develop alternative technologies. Commercially available signal processing systems are costly and lack versatility, so this project aims to facilitate the scaling of neutron monitor networks by providing a platform for low-cost electronic systems for their operation. The project involves the final stages of development of a preamplifier and shaping amplifier system created for use with a PTI-110 boron-coated-straw neutron monitor and the verification and evaluation of its functionality with the use of a californium-252 neutron source.

2 Fundamental Operation

The PTI-110 is a neutron detector that works using boron-10 which can interact with low energy neutrons to produce charged particles. The detector consists of 30 sealed metal tubes that all have a thin wire running through the centre and the internal surfaces of the tubes are coated with boron-10 carbide. 1040 V is applied between the central wire and metal tube.

1) Incident neutron interacts with boron-10 to produce charged particles.
2) Charged particles ionise fill-gas atoms.
3) Electrons are accelerated by potential difference and cause further ionisation to cause a cascade.
4) Charge is deposited on anode wire and is passed through a DC-block capacitor to the preamplifier.
5) Charge is temporarily stored on the preamplifier's feedback capacitor to create a voltage pulse.
6) Voltage pulse is shaped and amplified to make it easier to measure.
7) Voltage pulse is compared to a threshold value in the discriminator.
8) If the pulse height is greater than the threshold, a pulse is sent to the counter.
9) Counter increments.

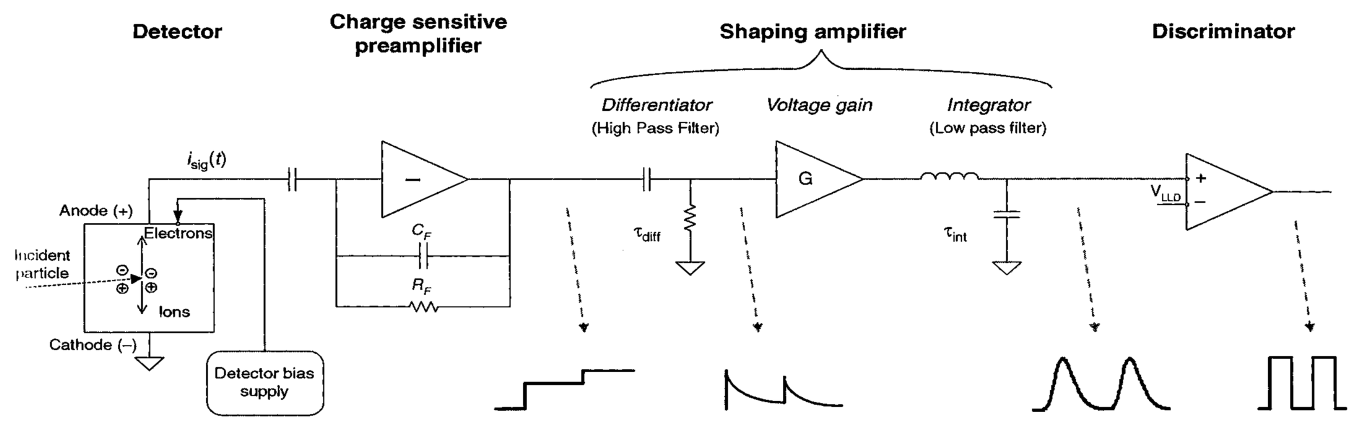


Figure 6– Schematic of simplified signal processing chain [1]

3 System Produced

A custom PCB was produced that allowed flexible configuration making it ideal for prototyping. This was housed in a diecast aluminium enclosure to reduce EMI. The internal enclosure houses a filtered boost converter unit used for power supply. The circuit implemented utilises successive op-amp-based analogue filters to achieve a gaussian pulse shape and has other features such as:

- Adjustable overshoot correction
- RC filter for high voltage input
- On-board rail splitter
- Space for linear voltage regulators for use with batteries

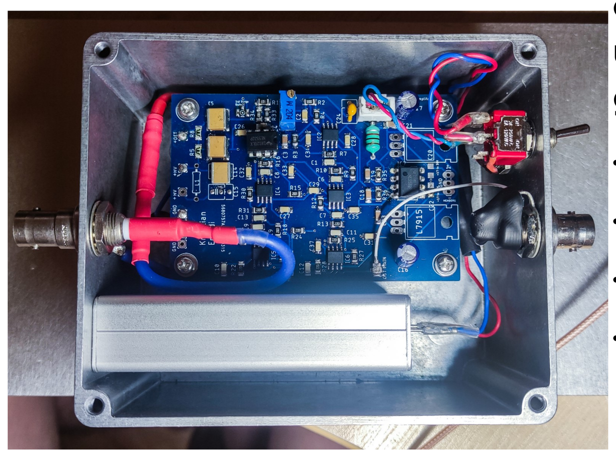


Figure 4– Preamplifier/Shaping Amplifier system

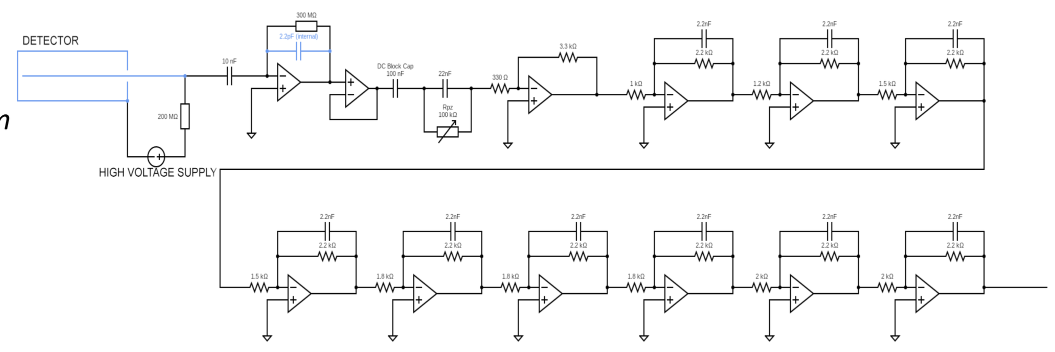


Figure 5– Schematic for circuit on PCB

A second version of the system was produced for high count rate applications (>1000 cps) utilising a novel shaping architecture. The op-amp's slew rate was used to limit the positive slope gradient instead of using successive integration stages. This utilises the full performance of the op-amps to produce the shortest possible pulse width. Another great advantage of this approach is that it requires very few components and minimises delay.

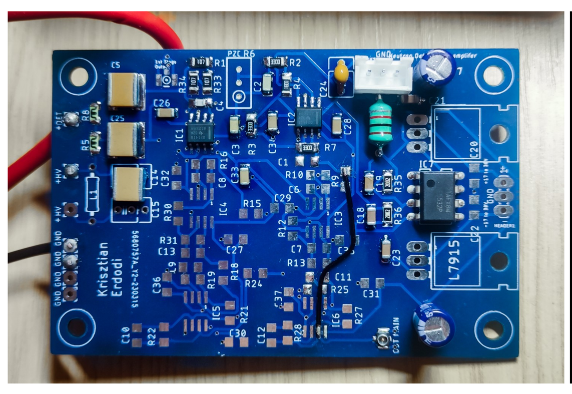
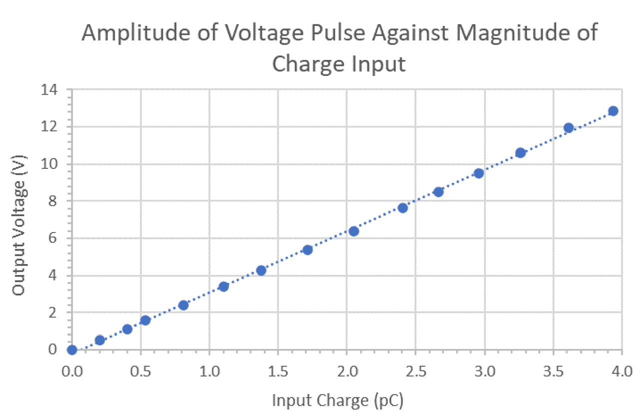


Figure 6– Second version of PCB

Figure 7– Output of second version (blue)

4 Primary Testing

Initial evaluation of the preamplifier was promising with very good, linear transfer characteristics and highly symmetrical gaussian pulse shaping.



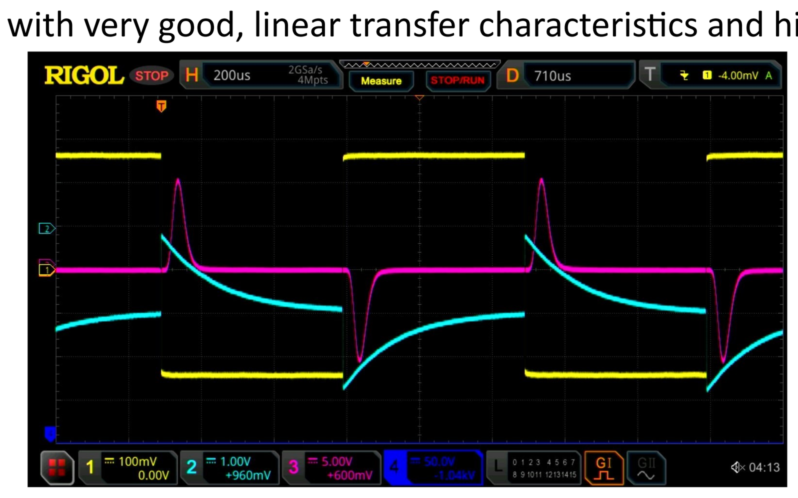


Figure 9-Output of first version of PCB (pink)

5 Problems and Solutions

The system was trialled with the detector attached. Testing with background radiation yielded no output initially. Consequent investigation using a circuit to superimpose a test pulse onto high voltage revealed that with the high voltage applied, the system did not function. This was remedied by changing feedback resistance in version one and using FET input op-amps in the slew-rate-limited version.

Problems	Solutions
Leakage current across capacitor causes saturation in the amplifier when high voltage is applied	• Use capacitors with low leakage dielectrics • Clean capacitors and board with alcohol to remove grease and remaining solder flux that may increase leakage current
Bias current rating of op-amp causes offset in base voltage and exacerbates the effect of capacitor leakage leading to clipping of signal and premature saturation of amplifier	• Decrease feedback resistor value since offset is directly proportional to its value • Choose op-amp carefully– FET input op-amps have very low bias currents • An alternative solution is to balance the bias current and capacitor leakage to cancel out but this can lead to manufacturing inconsistencies
Noise was coupled in fom high voltage power supply	Add a low pass filter to the high voltage power supply input line
Capacitor leakage current causes voltage drop across bias and filter resistors	Increase supply voltage to compensate for voltage drop

6 Experimental Method

To verify the ability of the system to detect neutrons, a water moderated Cf-252 source was utilised. The detector with the electronics connected was placed in front of the source and 2 experiments were conducted.

Firstly, the distance between the source and detector was varied.

Secondly, the threshold voltage on the discriminator was varied.

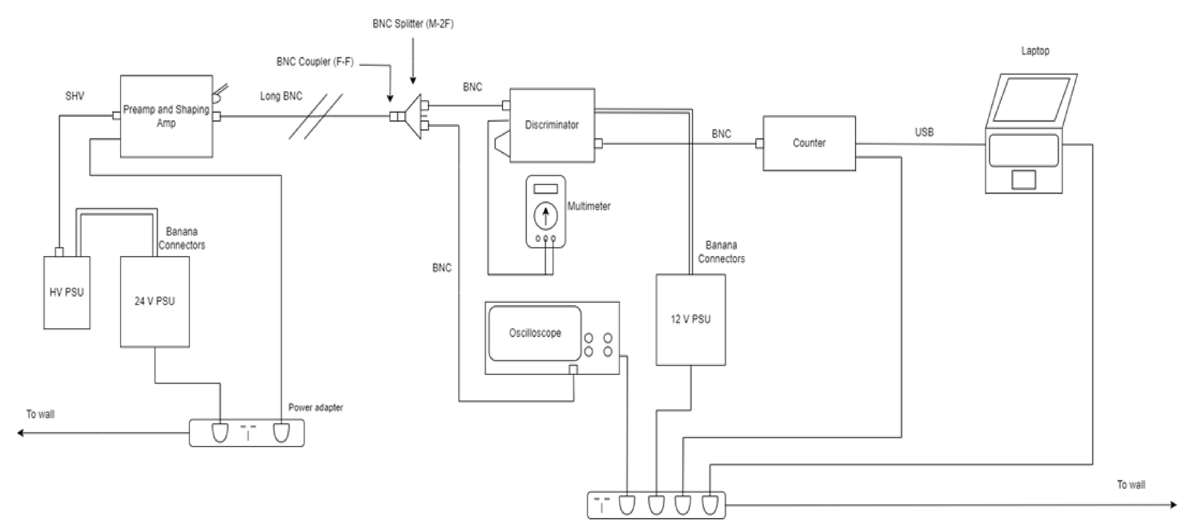
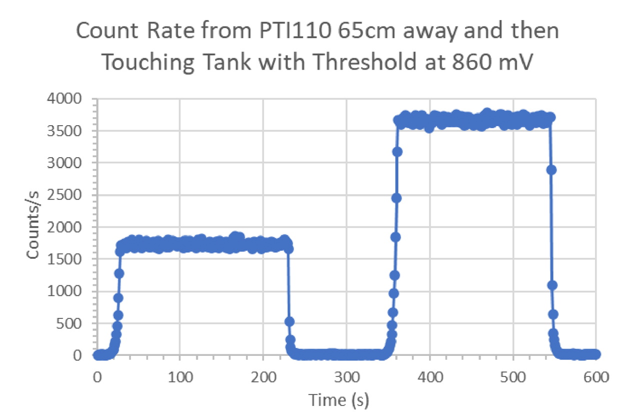
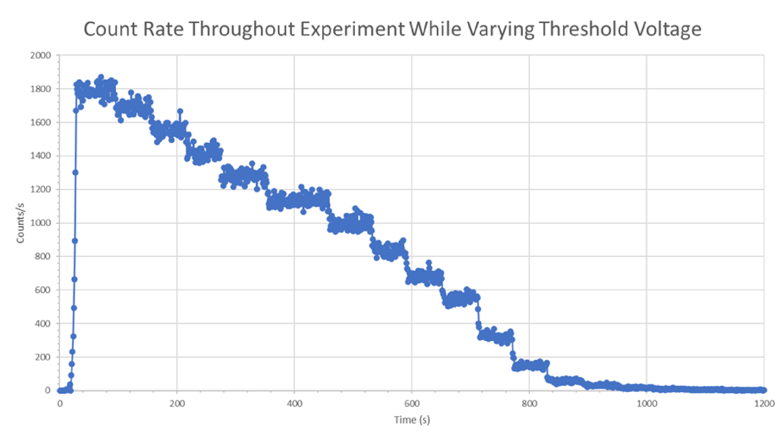


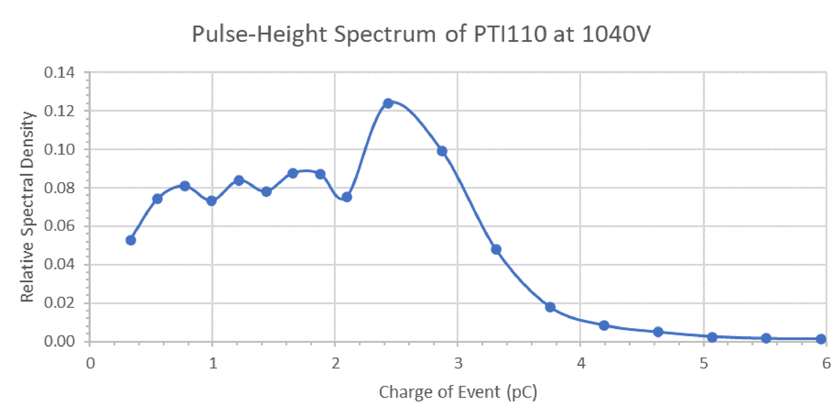
Figure 10- Connection diagram for experimental setup

7 Results

It is clear from the first test that the system is successful at detecting neutrons even at higher count rates than it was originally designed for. The data from the second experiment was used to produce a pulse height spectrum by averaging the rates at different thresholds and then taking the differences between them and correlating them to the voltage value interpolated between the threshold values. The spectrum acquired is consistent with and remarkably similar to externally acquired spectra for boron-coated-straw neutron detectors [2].







8 Opportunities for Improvement

This project marks only the beginning of optimisation and development. The functionality of the system has been proven and understood in detail, allowing future versions to be specialised for the use case. This may mean low power consumption for remote areas, ultra compact form factor for portable applications, or low cost for mass manufacture.

It is entirely possible to integrate the discriminator, counter and high voltage supply directly onto the PCB to allow extremely convenient use. This could be further improved by adding a microcontroller with local storage and wireless network connectivity to the device. It is conceivable that one could add local power generation such as a solar panel or small wind turbine and have a completely self sufficient neutron monitoring station that requires no auxiliary hardware other than what is included on a 5 x 10 x 15cm box, allowing cheap operation and low maintenance, all for a price comparable to the cost of only a commercially available preamplifier.

Figures

Figure 1 (top left corner): Image of top side of un-populated custom PCB

Figure 2 (top right corner): Image of preamplifier/shaping amplifier unit mounted to detector front plate

References

[1] [1] G. F. KNOLL, *Radiation Detection and Measurement*, 4th ed. JOHN WILEY, 2010.

[2] J. L. Lacy et al, "Boron coated straw detectors as a replacement for 3He," in - 2009 IEEE Nuclear Science Symposium Conference Record (NSS/MIC), 2009, . DOI: 10.1109/NSSMIC.2009.5401846.

[3] K. Erdodi, "The Design and Manufacture of a Signal Processing System for Use with a PT-110 Boron-Coated-Straw Neutron Detector," 2023.

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