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A Compact h-BN-Si Thermal Neutron Detector

NTR network

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Global Access to Medical Radionuclides

A modular, open-source particle accelerator using nuclear fusion to produce high-energy protons and neutrons is under construction at the University of Bristol. These particles can drive activation reactions that have the potential to produce radionuclides of interest to medical applications. [1]

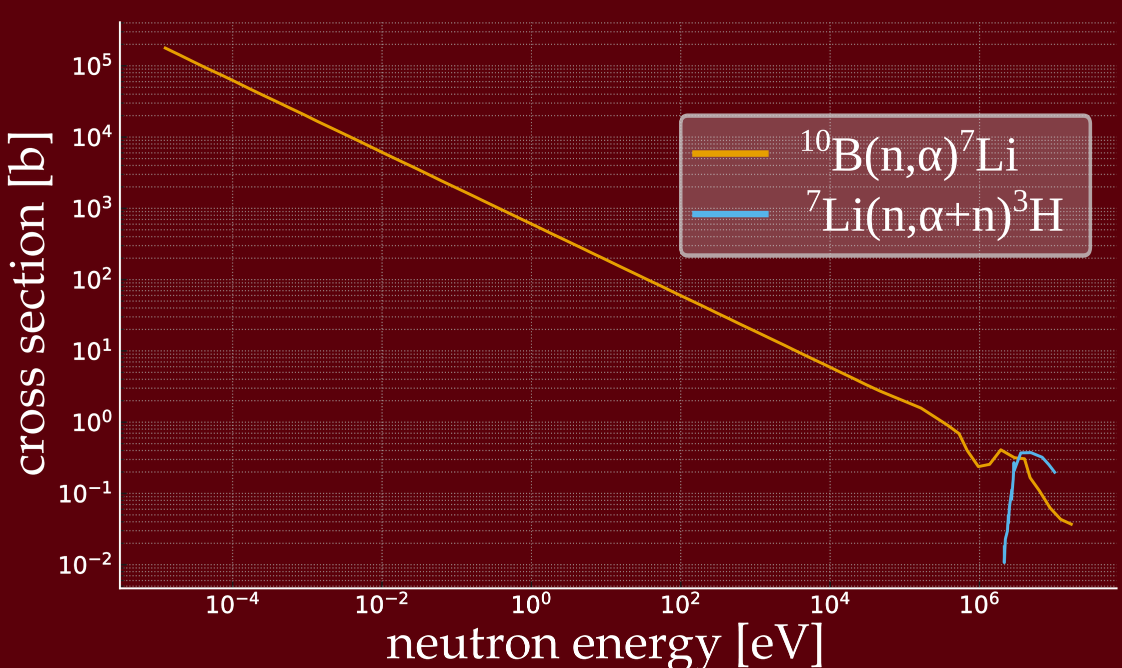
A low-cost and compact neutron detector is needed to measure the neutron flux, for QA, safety, and internal system monitoring. [2, 3]

Detection Principle

The detector relies on neutron interactions with stable ^{10}B to produce alpha particles, which are charged and can be detected:

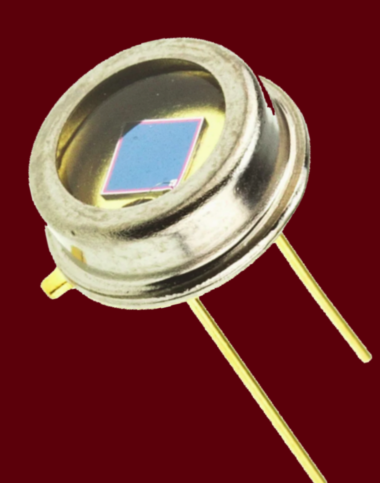
$$^{10}B(n,\alpha)^{7}Li \longrightarrow {}^{7}Li(n,\alpha+n)^{3}H$$

The (n,α) reaction on ^{10}B produces a 1.47 MeV alpha particle and stable ^{7}Li, which in turn can be fissioned by a fast neutron producing ^{3}H and another alpha particle. The ^{10}B cross section is orders of magnitude higher, making the detector most sentisive to thermal neutrons. The charged ^{3}H ion can be detected similar to an alpha particle, with the reaction energy Q split between them. [4, 5]



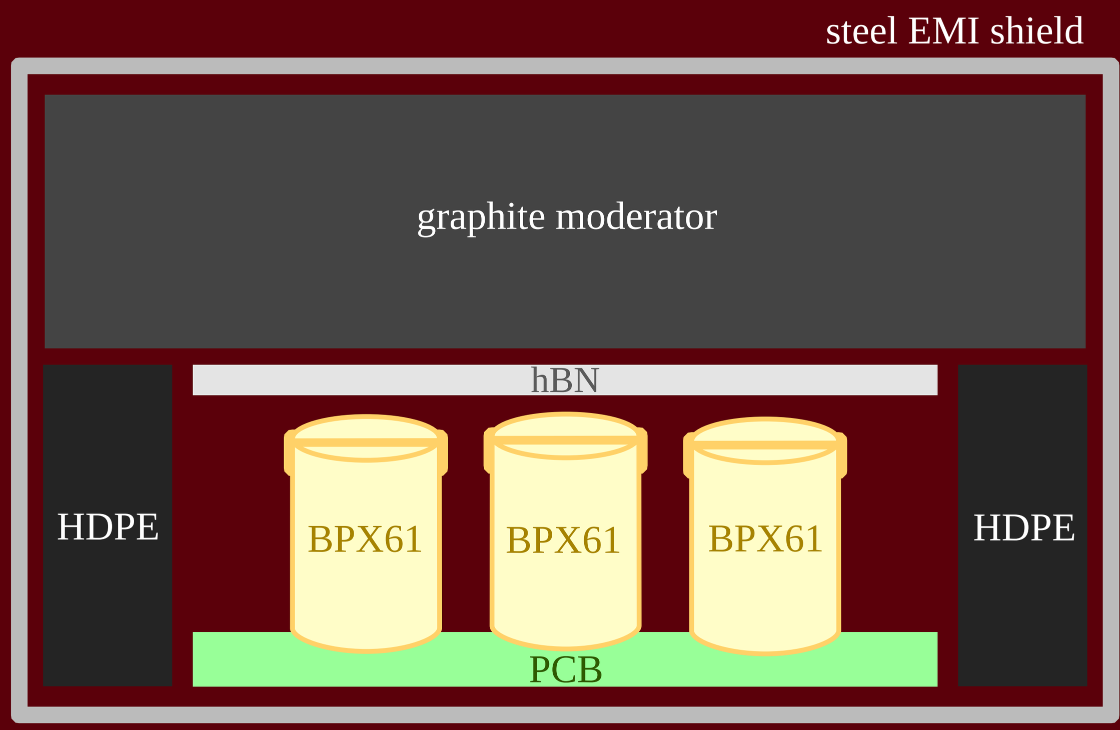
Silicon semiconductor detectors are well suited to the detection of light ions with MeV energies.

The BPX61 is a silicon PIN photodiode with 2 nA dark current and 40 - 70 pF junction capacitance. It is identical to a BPW34 in a metallic TO package.



Detector Design

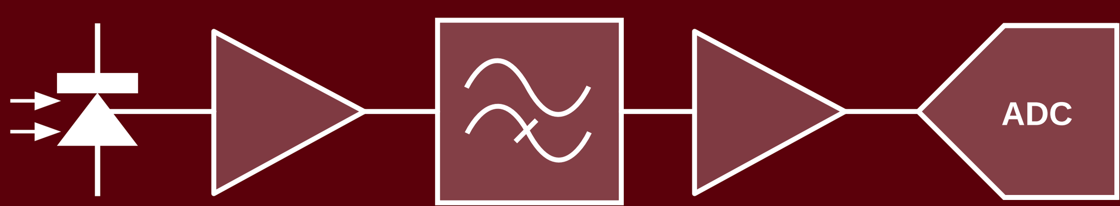
Because of the higher cross section at thermal neutron energies, fast neutrons must be moderated to increase detection efficiency. A layered approach is used. BPX61 PIN diodes are coated with 1 mm thick hexagonal boron nitride (h-BN). h-BN is a non-toxic, insoluble, white powder at room temperature. An array of 3 BPX61 pin diodes is used to increase sensitive area.



Neutron moderation is achieved using 25 mm thick graphite. The unit is made directional by shielding neutrons from non-acute angles with polyethylene. The detector is packaged in a steel tube with BNC feedthrough as EMI shield. BPX61 PIN diodes are mounted on a PCB with integrated 9V battery power supply.

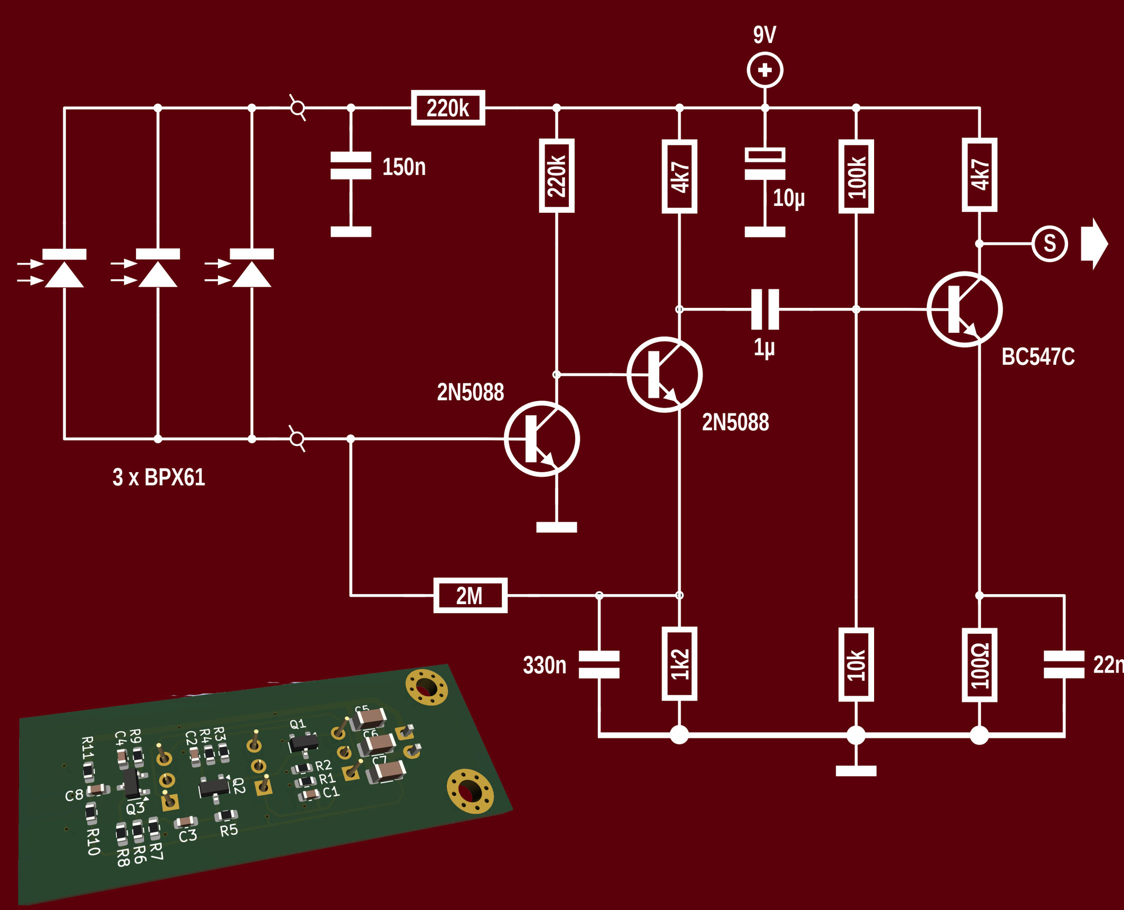
Signal Processing

Analog front-end consists of a transimpedance amplifier, high-pass filter, pulse shaping circuit, and analog-to-digital converter (ADC). The front-end circuits remain inside the EMI shield, the ADC is external.



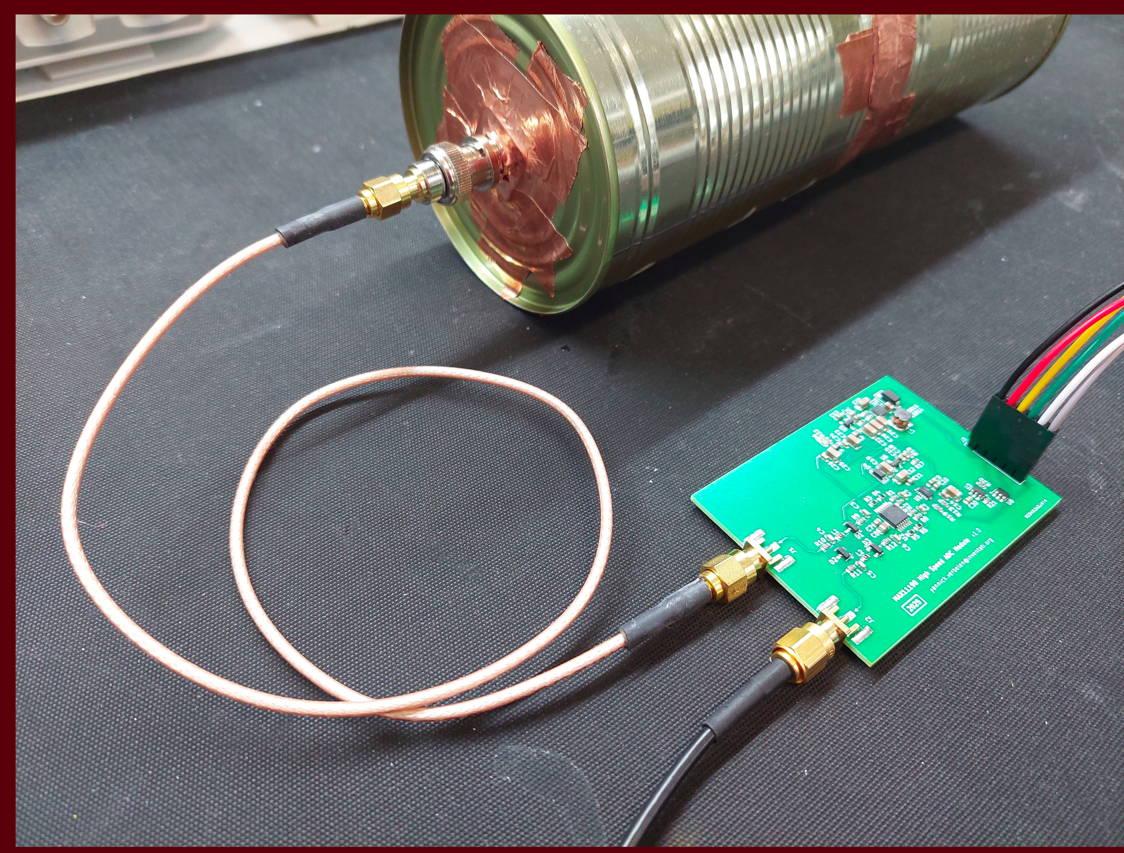
For the TIA stage, a class A cascade amplifier is composed of two low-noise 2N5088 NPN transistors [6]. A 2 MΩ feedback resistor is used for self-biasing of the TIA stage. The PIN diodes are biased via a filtered 9V supply. A 330 nF capacitor bypasses the emitter resistor to increase small signal gain.

A high-pass filter shapes the signal and feeds it into a class A power amplifier stage with a BC547C NPN transistor. The output signal has an amplitude of ca. 500 mV/MeV as measured on a DS1054Z oscilloscope.

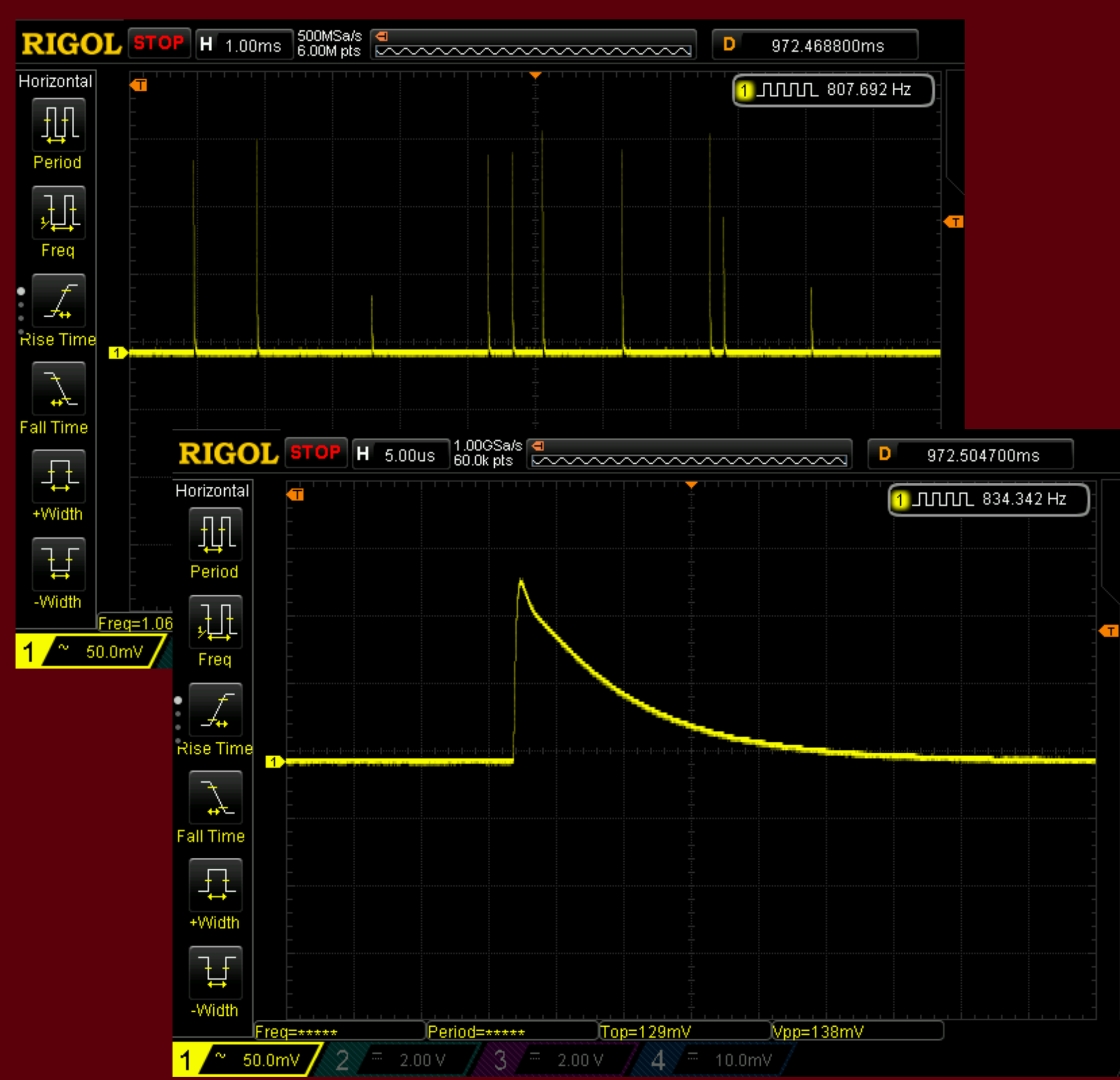


Experimental Results

The University of Bristol lacks a neutron source, and the particle accelerator is still under construction, which prevented experiments under neutron irradiation. Instead, a 30 kBq ^{241}Am check source was used to inject alpha particles into the BPX61 PIN photodiodes directly to validate the amplifier design.



A high-speed ADC of type MAX11198 was used to acquire pulses, with a resolution of 16 bits and sampling rate of 2 MS/s. Pulses were synchronised on an external clock signal.



The captured pulse sequence shows alpha particles with different amplitudes captured by the BPX61 array. The period is variable due to randomness of radioactive decay. The detailed graph shows a single pulse with amplitude 130 mV and half maximum width of 15 µs. The noise is < 5 mVpp.

To validate the neutron detector design, the search for a well-characterised neutron source is ongoing. The authors are looking for collaboration with organisations that could provide access to a source.

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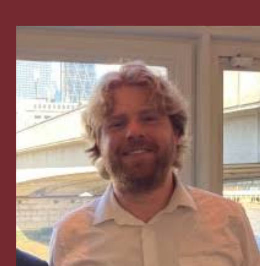

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