Gamma Spectrometer

Initial Project Proposal

Group 9

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Introduction

There are currently two main types of gamma radiation detectors used for gamma spectroscopy. NaI (TI) detectors use thallium doped sodium iodide crystals coupled to either photomultiplier tubes or photodiodes. Gamma rays transfer energy to these crystals through the photoelectric effect. The crystal then gives off photons in the UV range as the excited electrons fall back to the ground state. The photons emitted are measured and converted to a signal by the photomultiplier or semiconductor detector and amplified for processing.

The other type of gamma ray detector used is the germanium detector. This type of detector also operates on the photoelectric effect and has a better ability to distinguish between energy levels than NaI detectors. Germanium detectors must be cooled to low temperatures by liquid nitrogen and often require high voltages to operate (up to ~4kV).

Objective

The goal of this project is to design a gamma ray detector for the purpose of gamma spectrometry which aims to eliminate the shortcomings of NaI and germanium detectors. NaI crystals are not very sensitive to differences in gamma ray energy levels (low resolution). Different energy gamma rays can only be distinguished when there is a difference of at least 80keV. Furthermore, photomultiplier tube detectors can be expensive and require a high voltage to operate. Germanium detectors are expensive to produce and require special design considerations and equipment to operate (liquid nitrogen cooling).

We propose using a large surface area conventional silicon PIN diode (or array of smaller diodes) to detect incident gamma radiation for gamma spectroscopy applications. Unlike the NaI based detector, this detector would not require any specialty crystals and would directly convert the gamma ray energy captured to an electric signal to be amplified. Energy will be absorbed by the semiconductor through the photoelectric effect and Compton scattering. Essentially the PIN diode will be used to detect gamma ray photons instead of visible (or UV) light. The advantage of our approach is that no specialty crystals or liquid nitrogen is needed for operation. Additionally, it has been shown that certain PIN diodes will readily absorb energy from gamma rays in the 0-100keV range. Absorption efficiency is a problem above this range as this is dependent on the thickness of the diode. When charge is deposited onto the PIN diode due to gamma ray interaction a current that is proportional to the incident gamma ray energy will flow. With an appropriate pre-amplifier and pulse shaping circuit this current signal can be amplified and captured by a microcontroller for further processing. The gamma rays can then be binned according to energy and plotted like a histogram to produce the gamma spectrum. The energy range our device operates in offers several lucrative applications including X-ray fluoroscopy, which enables direct elemental analysis of a sample, a tool used in geochemistry, forensic science, and quality control of building materials.

While the direct use of PIN diodes for gamma ray detection has previously been investigated, the project will face several major challenges. An X-ray may only generate a few thousand electrons in the semiconductor depletion region. Since a photodiode does not provide any amplification, an extremely sensitive charge pre-amplifier must be designed, preferably at low cost. At the amplification levels required thermal and shot noise will also be a big problem. PIN diodes also have an intrinsic capacitance which will attenuate the signal. A low noise amplifier circuit must be designed and the entire circuit must be carefully shielded from electromagnetic noise. A pulse shaping circuit must also be designed, and a fast high resolution analog to digital converter will be required to accurately sample the pulse signal. The device may incorporate a thermoelectric cooler in an attempt to reduce noise. The gamma spectrum will be displayed on a (color?) LCD screen which will have a user interface with various additional functions, such as calibration and general gamma dosimetry. The spectrometer will most likely be powered by a single lithium ion cell, and have integrated power management for the cell offering USB charging capability and a DC boost converter to power the electronics. Calibration of the device will be a must, as specific semiconductor device structure will not be known, and so quantum efficiency will vary depending on the PIN diode chosen. The goal is to design a device which will have a linear response across the full range of measurement.

Moreover, the most critical component in this project is the PIN diode; there are many conflicting considerations when selecting a PIN diode. Detector sensitivity is one to be considered, the number of photons detected for any given radiation field depends on the size of the depletion region, which depends on the area of the diode and the amount reverse bias applied to it. The reverse bias needs to be large enough such that the depletion width is large enough to capture photons. However, if the depletion region is too large this will increase junction capacitance and the increased reverse bias will increase the chances of high field effects causing current leakage. Increasing junction capacitance and current leakage will cause noise and interference; one may not be able to see the distinct output created by the gamma ray. Studies show that capacitance as low as 25pF to 80pF will ensure minimal noise.

Specifications / Requirements

- PIN diode (or array of PIN diodes)
    - Low capacitance under reverse bias to minimize noise (25pF-50pF)
    - No current leakage under reverse bias
- Analog board
    - Charge Sensitive Preamplifiers
        - A preamplifier is a device that typically helps improve the overall quality of the signal, which prepares the signal for the main amplifier. The PIN diode will emit a small amount of charge proportional to the photon's energy, typically, on the scale of eV. A comparator will be included in the configuration to output a high pulse when a gamma photon strikes the PIN diode.
    - Subtraction Circuit
        - Amplify the difference between the two inputs, this will account for any adjustments.
    - Pulse Shaper (Gaussian filter)
        - The impulse response will be a Gaussian function; this will ensure no overshoot and minimize rise and fall time. This will prohibit distortion of the input signal, giving a high signal to noise ratio.
    - Peak Stretcher (PDH, Peak Detect & Hold)
        - Each pulse that is inputted at the preamplifier stage will be held by the peak stretcher configuration and later fed into the Analog to Digital Converter.
- Digital Board
    - ADC (Analog-to-Digital Converter)
        - Converts the physical quantity (voltage) to a digital number that represents the original quantity's amplitude. Each pules that is held by the PDH is a continuous signal, the ADC will produce a digital signal.
    - CPLD (Complex Programmable Logic Device)
        - The data output from the ADC will be inputted to the CPLD and perform histogramming function.

  - Real-time Clock
    - Low power consumption IC will keep track of the current time
  - SRAM (Static Random Access Memory)
    - The data from the ADC are utilized and stored in 128KB SRAM
  - Flash Memory
    - The data stored in the SRAM will later be stored in the Flash memory for retrieval. Storage space maximum, 2MB.
  - Microcontroller
    - This will allow an interface and a few display functions for the user.
- Power Board
  - Voltage Regulators
    - Provide voltage regulation for necessary switching with analog and digital electronics.
  - Battery Gauge
    - Provides information about the remaining battery charge, which will be displayed on the LCD.
  - Charger
    - Rechargeable option.
  - USB Input
    - If the user chooses to interface with a personal computer.
- Power Supply (Battery)
  - A lithium ion rechargeable battery.
- Keypad
  - Enable the user to interface with a given options.
- LCD
  - Output display
- HV Supply
  - Generate the bias for the PIN photodiode, must be low power.

Block Diagrams

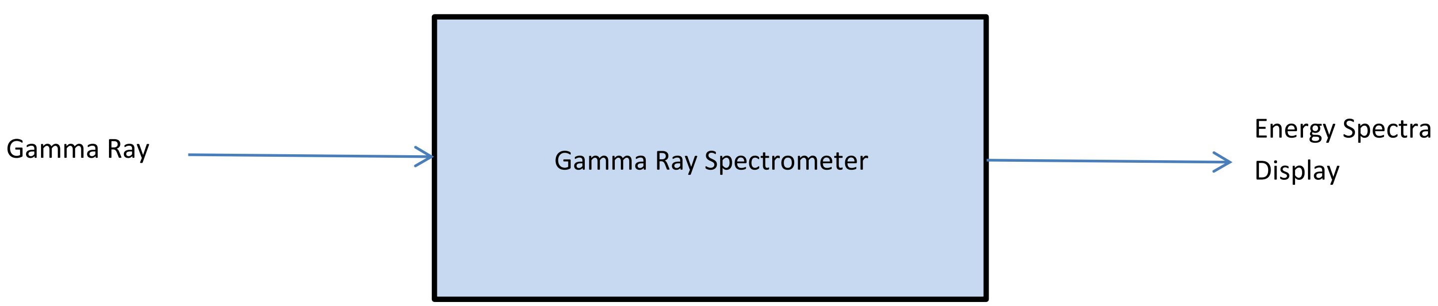

Figure 1

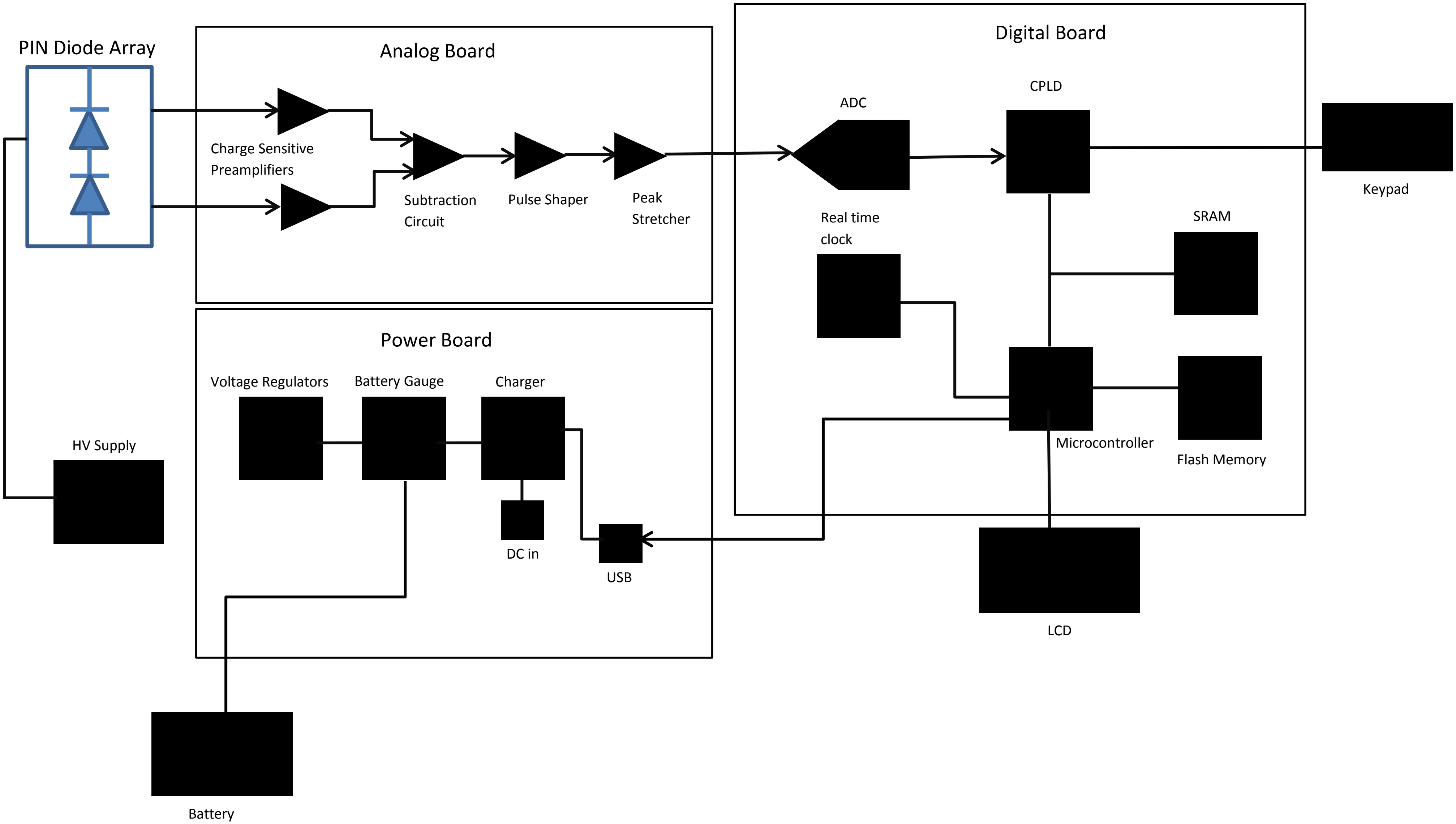
PIN Diode Array
Analog Board
Charge Sensitive
Preamplifiers
Subtraction
Circuit
Pulse Shaper
Peak
Stretcher
Digital Board
ADC
CPLD
Keypad
Real time
clock
SRAM
Microcontroller
Flash Memory
Power Board
Voltage Regulators
Battery Gauge
Charger
DC in
USB
HV Supply
LCD
Battery

Figure 2