Build and Test of A Gamma Radiation Detector

by

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I would like to thank Dr. Changzhi Li and Dr. Stephen Bay, not only for their guidance in this project, but also with my professional development. It is with my family, and friend's support that I have been able to complete my project. With their blessing, I can finish my master degree in Electrical Engineering at Texas Tech University and be ready for a professional career.

Table of Contents

Abstract

Gamma radiation detection has been part of research for a long period of time. Being able to detect gamma radiation when being exposed to radiation is a must. The gamma detector I have built will demonstrate that it is capable of detecting gamma radiation with a low budget. We were able to build and test a gamma detector. The circuit was tested with two different source types of gamma radiation. I will show that the detector is efficient with a 42mCi source and can detect a smaller source of up to 1uCi.

List of Figures

Chapter 1

Introduction

1.1 Motivation

The motivation for the building and testing of this particular circuit came from the idea from Dr. Jiang. Dr. Li and I had the idea on improving the overall effectiveness of the gamma detector that was used in Dr. Jiang's lab. We had the intention of trying to find a small and more effective detector. The main thing was to find the limitations of a specific gamma detector with some common parts for the detector. The commercial detector that is used is a highly developed and high functioning detector. We wanted to try and attempt to create a detector that could detect a similar amount of energy to that of the commercial detector with a small size and without a large bulky power supply.

The other vision of the project is to display the information onto an iPad or Android device. This is to display the detection spectrum from the detector on the iPad. Dr. Jiang's lab has a program that displays the spectrum through a piece of software on the computer. However, the information is not displayed on a iPad and not in real time. We wanted to be able to display the information from the detector in real time.

Chapter 2

Background Information

2.1 Gamma Radiation

Gamma radiation was discovered by the French physicist Henri Becquerel in 1896. [1] Gamma radiation is a "very high energy ionizing radiation and has about 10,000 times as much energy as the photons of the visible range of the electromagnetic spectrum."[1] Gamma radiation does not have any mass or electrical properties and is purely electromagnetic energy. Gamma rays are produced when there is a "disintegration of radioactive atomic nuclei and the decay of certain subatomic particles."[2] This means that the energy within the nucleus is unstable. Over time the nuclei starts to transform and starts to produce radiation.[3] This process is called radioactive decay. Radiation can be Alpha, Beta, Gamma or a combination of the three. [3] We see that for each gram of cobalt-60 there will be 50 Curies of radiation and 350 Curies per gram of iridium-192. [3] These elements are examples of radioactive material and have a larger amount of radioactive material than the material used for this experiment. Curies are the standard measurement for radioactive material.

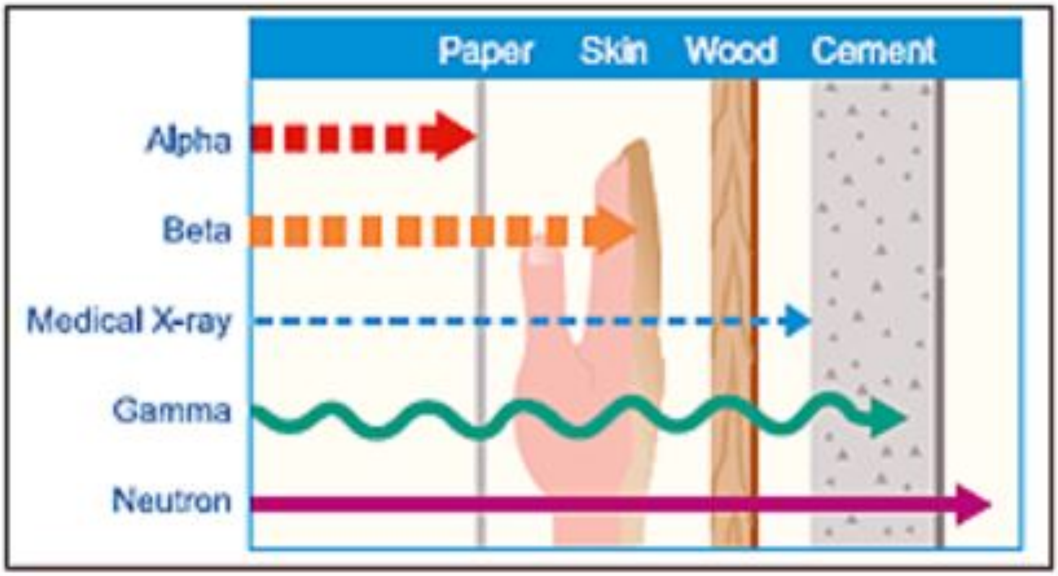

Figure 1. Radiation Penetration[4]

Gamma radiation is a hazard to the general public and can cause illnesses to those who are exposed for long periods of time. Most of the exposure to radiation is due to medical applications. Gamma radiation can travel through different types of materials. Figure 1 shows some of the materials that some forms of radiation can penetrate. We can see that some types of radiation are not strong enough to penetrate paper. However it has been demonstrated that gamma radiation can indeed penetrate up to a couple of inches of iron. Gamma radiation is absorbed with a greater efficiency by materials with a high density or atomic number. This is one reason why lead vests are used in hospitals for x-rays and radiation treatment. The half value layer is a table that displays the amount of material that is needed to reduce the incoming radiation by half. We can see in Table 2 the Half-Value Layer for certain peaks of voltage and how much material would be needed to reduce the incoming gamma radiation by half.

Table 1. Half-Value Layer[5]

	Half -Value Layer, mm (inch)	
Peak Voltage (kVp)	Lead	Concrete
50	0.06 (0.002)	4.34 (0.170)
100	0.27 (0.010)	15.10 (0.595)
150	0.30 (0.012)	22.32 (0.879)
200	0.52 (0.021)	25.0 (0.984)
250	0.88 (0.035)	28.0 (1.102)
300	1.47 (0.055)	31.21 (1.229)
400	2.5 (0.098)	33.0 (1.299)
1000	7.9 (0.311)	44.45 (1.75)

Though radiation is bad for human exposure in large amounts there are benefits to some of the applications for gamma radiation. Gamma radiation is used in sterilizing food to keep it fresh longer and to sterilize medical equipment. [1] Other applications for Gamma radiation are used in the medical field. Radiotherapy uses gamma radiation to kill the cancer cells that are unable to repair themselves. The Gamma rays are continuously injected near the small-infected area and help "arrest the development of the malignant cells."[2]

2.2 Silicon Photodiode and Characteristics

Silicon Photodiode detectors have been used in various fields such as medical imaging sensors, radiation detection, positioning detectors in space science and some experimental partial physics.[6] Photodiode diodes are used for high sensitivity applications. They are very handy and are able to detect traces of radiation.

When a photon is absorbed by the photodiode an electron hole pair is formed.[7] Current is then formed when the electron hole pairs are separated and the electrons move from the n-region and holes to the p-region.[7] There is a possibility that the holes and electrons connect and thus no charge displacement and no current occurs. The greatest chance of success for a charge is when the photon strikes within the depletion region where the electric field is the strongest. When the diode is in reverse bias almost all the charge carriers will be drawn away.[8] The charge is a small current pulse signal that will need to be processed through amplifiers. The sensitivity of the circuit can be increased by increasing the reverse bias voltage on the diode.[8] This will reduce the capacitance of the diode and increase the size of the depletion region while also improving the frequency performance. However with this decrease in capacitance noise is also generated by the photodiode under reverse bias that is due to shot noise, dark leakage current and shunt resistance. These parameters must be addressed at the design stage of the circuit.

2.3 Radiation Damage to Silicon Detectors

Radiation damage to the detector can be an important part in selecting a detector. The diode used in the experiments is a silicon based photodiode and some knowledge of the affects on radiation on silicon are needed. If silicon is damaged easily by the radiation it may be better to look elsewhere for a different material for a detector. There are two types of damaging radiation that can be inflicted on silicon and they are bulk damage and surface damage.

The damage to the silicon detector can lead to ionization and dislocation of atoms, thus causing damage to the silicon detector. [7] In other silicon detector experiments, the detectors have been submitted to environments that can expose it to "levels of up to several 10^{14} hadrons per cm^2".[9] This exposure can lead to changes in the "silicon bulk and will cause an increase of both the reverse current and the necessary depletion voltage as well as decrease the charge collection efficiency." [9] Bulk damage plays a significant role in radiation damage. It causes "change in the basic detector properties such as leakage current and effective doping concentration."[10] Here we can see that there are limitations for high exposures over time. If the component starts to emit larger amounts of leakage current this could affect the results of the entire circuit adding unwanted noise in the circuit. The high currents can lead to thermal runaway and unstable operational conditions. [10] The high leakage current is "mainly due to defect centers located close to the mid band gap."[10] The leakage current will then proceed to increase linearly with exposure.

Experiments done in [10] show that after irradiation the current diode behavior changes drastically. Figure 2 and Figure 3 show the results of the test to the current before and after irradiation. The diode was tested at 24 GeV protons for a total exposure of 3x10^{14} . We can see a huge difference in performance where the leakage current goes up from a few nano amps to around 60 micro amps. Although, this is with an extremely large amount of radiation and goes nowhere near the amount of radiation used in this experiment.

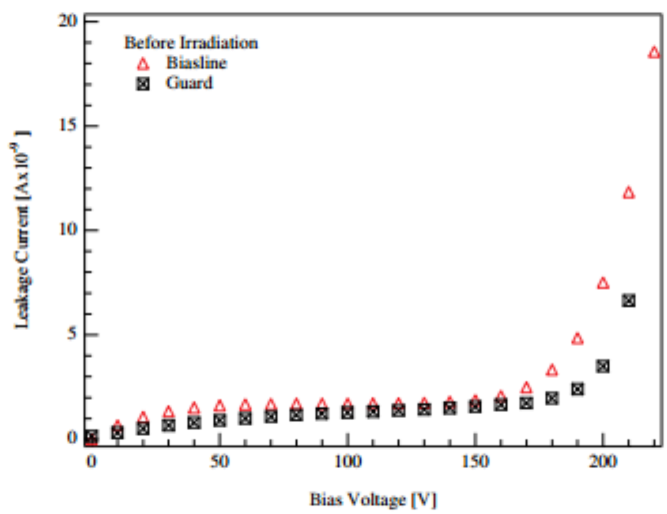

Figure 2. Diode leackage Current Before Irradiation at 20 C [10]

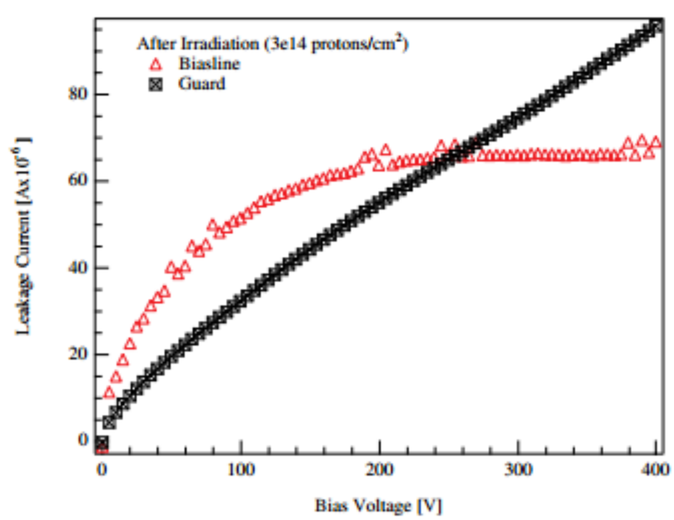

Figure 3. Diode Leakage Current After Irradiation at 20C [10]

After exposure to high doses of radiation, the surface effects to the active area become less important than those of the bulk effect.[10] Damage to the bulk contributes more noise to the diode over heavy radiation exposure. We can see that there are some effects of heavy radiation on the semiconductor diode. Based on the information from Dr. Jiang, the damaging threshold for silicon is about 145 keV. This threshold for silicon is a big difference from the magnitude of the exposures in the experiments above. This is a small amount of energy and when working with silicon one must be careful not to cross the damage threshold.

Chapter 3

Gamma Detector

3.1 Commercial Detector

In order to get a comparison for how well the gamma detector worked, I compared it with the detector in Dr. Jang's Lab. The detector that is used in the lab is the Amptek xr-100t. This producing is a high performance x-ray and gamma ray detector, preamplifier, and cooler system.[11] This system uses a Cadmium Telluride (CdTe) diode as the detector, a size 9 mm^2 and 1mm thick. The detector and the FET feedback components for the charge preamplifier are mounted to a two stage thermoelectric cooler. The preamplifier has a sensitivity of 0.82mV/keV with a negative signal output. The system is shielded by a light tight system with a vacuum tight beryllium window for the detector. The circuit diagram for the commercial detector is shown in Figure 4. The overall size of the case is 3x1.75x1.13 inches. This makes the device more attractive due to its small size and ease to carry and store.

The detector in the lab acts similarly to that of the detector that was built in this project. When the gamma rays strike the CdTe atoms the energy/charge is absorbed and converted to voltage. An average of one electron/hole pair for every 4.43eV of energy is lost in the CdTe.[11] However if the energy of the initial strike is sufficient enough, the loss of the energy is insignificant next to the photoelectric effect (Effect that metals discharge electrons when light is present) or the Compton scattering (The scattering of a photon by a free charge particle).The thermoelectric cooler cools the diode detector and the FET that is used before the preamplifier.

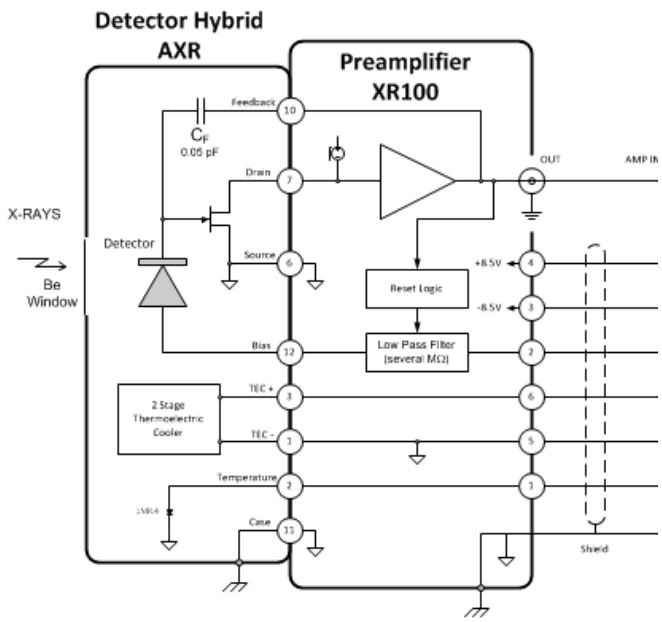

Figure 4. The internal Connections for Amptek Commercial Detector [11]

Figure 5 shows the efficiency of the detector. We can see that the detector has a 100% efficiency between the energy levels of 10 keV to 55 keV. There are chances of detecting values larger than 55 keV with a 60% chance of detecting values of up to 100 keV. After the 100 keV the detection values fall below 50%. This commercial detector has a good wide range of detection and has a very good efficiency.

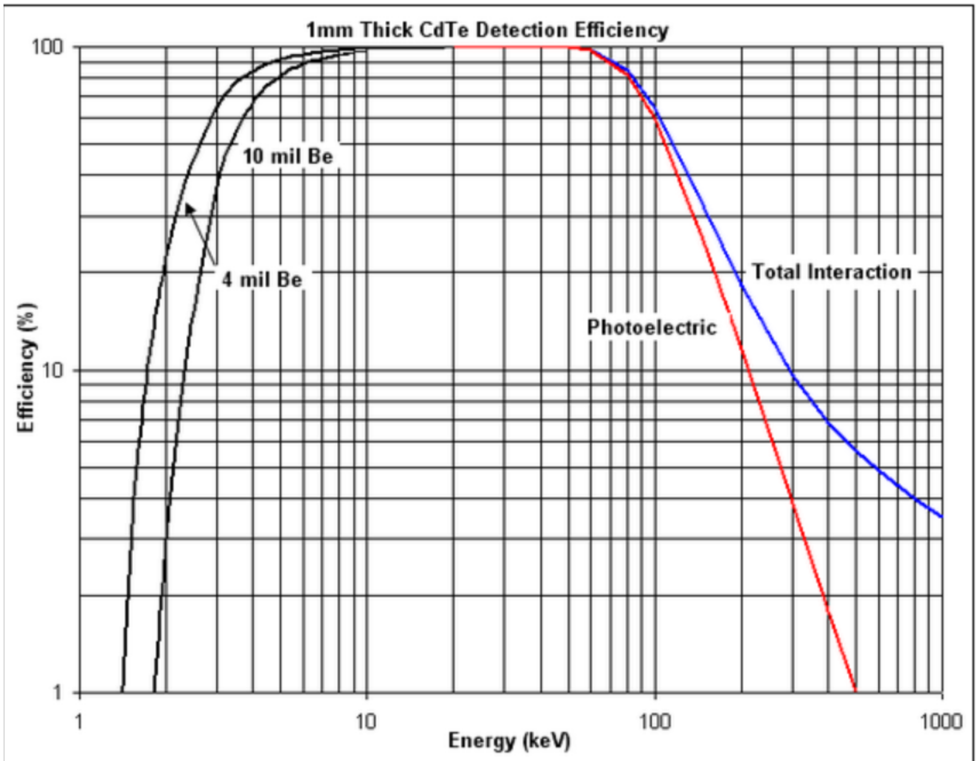

Figure 5. Log Plot of Detection Efficiency [11]

There are some different materials used for detectors. There are two different materials for detectors offered by Amptek that are of interest to me, a Silicon based detector and Cadmium Telluride (CdTe) based detector. Each of the materials for detectors has its own advantages. Generally, for lower energy levers below 25 keV, silicon is the material of choice. Silicon has a better energy resolution then CdTe at all energies, lower background counts, and has good efficiency up to 25 keV. [12] The Amptek website recommends purchasing the XR-100CR with is a Silicon detector for the energies less than 25 keV. Energy above 25 keV the CdTe is recommended. Although there are tradeoffs needed to be taken into account when selecting a detector. Silicon detectors will always have better spectral characteristics: better resolution and better peak to background ratios.[12] On the other hand, the CdTe will have better efficiency and operate at shorter shaping times. [12] So determining which commercial detector to choose from is dependent upon the application.

There have been other researcher who have done similar experiments to what I have done with a microwave based detector in [13]. Here they were able to design a working detector capable of detecting energy levels of < 100 keV. [13] Though they would eventually like to bring the detectors sensitivity to below 20 keV. Another interesting detector is the one in [14]. In this paper the authors use a stacked detector system made of the CdTe. This detector had some problems with resolution and peak detection due to the thickness of the detectors. The 5 mm thickness is needed to help with the detection of several hundred keV. [14] Overall, the results from the detector that was built for this project will display similar results to those mentioned above.

3.2 Gamma Ray Detector

The circuit that was used for the gamma detector is shown in Figure 6. A single pin diode is used to detect an incoming gamma source. When a gamma ray source passes through the diode, it collides with the electrons within the PN junction in the diode. This creates energy or charge that is released through the circuit. The circuit is designed to convert this charge into voltage with the use of capacitors. Once the signal is converted the signal is amplified and filtered through four different amplifiers and fed into a comparator circuit. The first stage of the circuit is the most important of all the other stages. The first stage is where the signal is amplified the most. The remaining stages act as band pass filters, filtering out unwanted frequencies. Each is combined for a better gain as well as a steeper roll of the frequency. The comparator at the end of the circuit helps distinguish between the actual signal and noise within the circuit. Setting the threshold voltage to just above the noise floor will help enable distension between the noise and signal. The final IC Max987 is a comparator that will output a pulse wave for each gamma photon that was successfully detected.

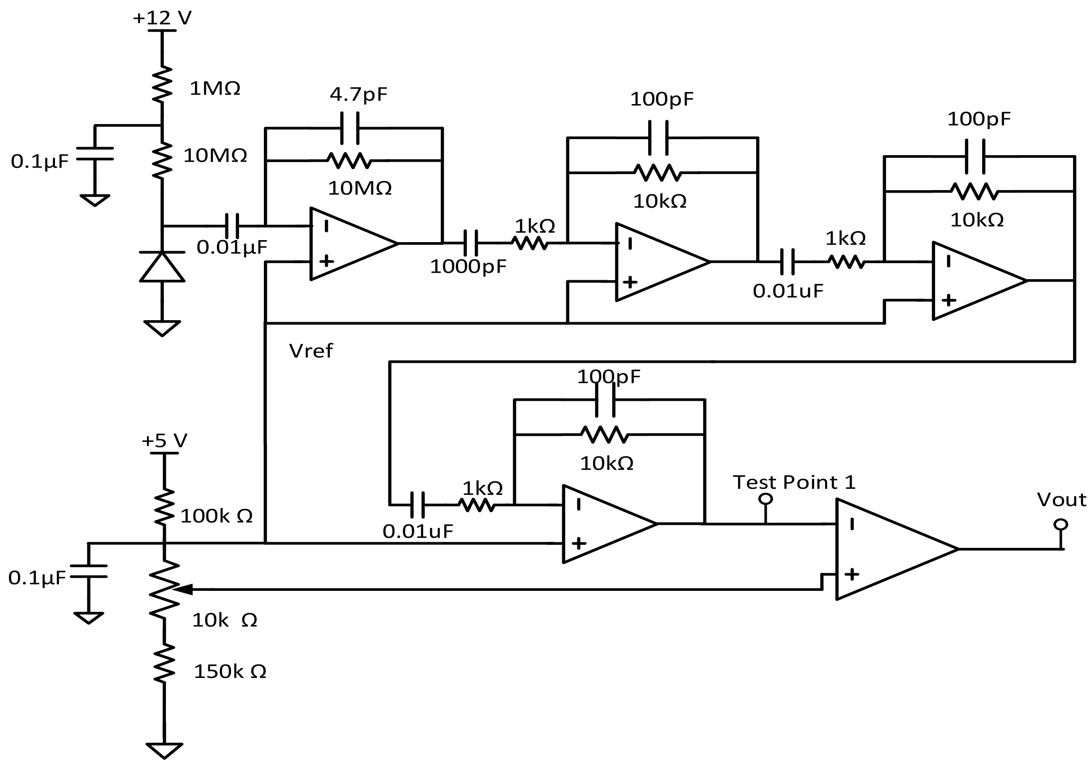

Figure 6. Gamma Detector Circuit

3.3 Component Selection

The design required very low noise components due to the small amount of charge that is generated by the gamma photons. This amount of charge being very small is also in need of low noise components to minimize the amount of overall noise in the circuit and lower the threshold for detecting gamma photons. The detector selection is one of the most critical components of the circuit. It is the vital component that detects the gamma source strike.

The sensitivity of the detector is based on the size of the depletion region. The larger the depletion region the more photons are able to strike the depletion region and result in a better charge and thus a better detection. This in turn is based on the actual size of the pin diode and the amount of reverse bias being applied to the diode. The larger the diode and the more reverse bias being applied, the more sensitive to detection it will be. As voltage increases, the depletion region increases. Thus the distance between the two plates increases and allows for a better detection.

However there are a few limitations to the size of the diode and the amount of reverse bias that can be applied. High capacitance tends to come with larger area detectors and thus increase the noise gain of the circuit. Leakage currents will come into play with a large value of reverse bias. If the diode capacitance is too large then the gamma strike is absorbed rather than detected.

As voltage increases, the depletion region increases. Thus the distance between the two plates increases, decreasing the capacitive of the diode. So in Figure 7, we can see that at the lower reverse bias voltages the capacitance increases because the plates are close together. When the voltage is higher, the plates are further away and the capacitance is lower. Based off of the actual circuit that was built, the reverse bias voltage that is being applied is roughly about 5.8V. So base off the graph in Figure 7, the capacitance that the circuit will see is about 30pF.

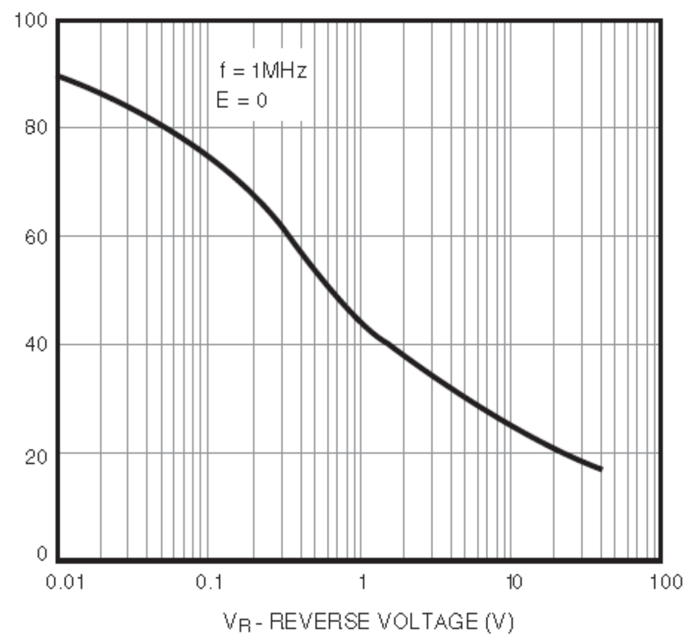

Figure 7. Capacitance vs Reverse Voltage [15]

The current detector that is used is a pin photodiode (QSE773). This is a plastic silicon pin photodiode. The chip size is 2.71 sq. mm.[15] The reverse bias voltage of the pin diode is 32V at 0.1mA of current.[15] This diode was recommended by others who have done similar experiments with gamma radiation. I think a better detector can be found, however, better detectors are a bit more expensive ranging about $100 or so. The actual cost for the detector used is about $1 per diode. This is nice for testing the circuit but for the final circuit and for more accurate results a more expensive detector with better quality should be used.

When building the circuit there needs to be some consideration in regards to shielding. This is due to the fact that the detector is very responsive to light. The circuit will trigger when the lights are turned on in the room. Some of the tests that were conducted were done with the use of a regular light source. The circuit acted just as a gamma source. Therefore, the circuit must have some type of shielding from any light source. Other experiments have used tin cans such as old cookie boxes or Altoid box as a shielding tool with a little hole in the top covered with aluminum foil to block out light. This would help to eliminate any type of detection of light.

3.4 Amplifier

Amplifiers in the electronic industry have become one of the more commonly used components for circuit design. Those the technology is improving and specifications for common amplifiers are improving there is always a need to improve upon current technology. The design of high performance analog integrated circuits with low noise, low power consumption, and smaller design has become a must for designers.[16] For the current design I am using we need to make sure that the amplifiers meet the lowest possible requirements for low noise, low power consumption, and overall size.

In the first stage of the circuit we will see where the input signal has come through. When the charge has struck the depletion region of the diode, the charge is then converted to voltage by the capacitor. The signal has been filtered with the 4 amplifiers. The first stage of the circuit will see the majority of the input noise and capacitance of the circuit. Based off some of the information from other studies, a photon strike can generate pulses from 50kHz to 100kHz . [17] A low current and low voltage input noise amplifier is need for this application. The circuit needs to filter as much of the noise as possible.

As mentioned previously, the first stage of the detector is the most critical of the circuit. A main issue is the signal to noise ratio (SNR) of the first circuit. This is where most of the noise will build up in the circuit. The SNR is defined as the ratio of signal power to noise power. This is the amount of signal that is desired versus the background noise in the circuit. The larger the gap between the signal and the background noise the better the ratio. So taking that into consideration we must first know the signal strength of the incoming signal (v_s) and the noise level (v_n). Once we know both of these number we can use the signal to noise ratio equation $\frac{v_s}{v_n} = 20 * log_{10}(\frac{v_s}{v_n})$. The voltage of the noise can be calculated with $v_n = \sqrt{4k_bTfR}$ where k_b is Boltzmann's constant, T is the temperature in Kelvin, f is the bandwidth frequency, and R is the resistance. The signal to noise ratio of the first stage is the most critical. The signal to noise ratio is a little difficult to calculate due to the small amount of signal from the first stage. I can say for certain that the signal to noise ratio is small. Although any actual calculations are not feasible for the first stage because we do not have an accurate signal for the noise or gamma strike. However, for the final stage of the system we are able to get a clear signal, we are able to get an idea of what the noise level is. Since each stage of the system not only amplifies the signal, it also amplifiers the noise from each amplifier. With the use of excel I was able to get value for the noise as means of the standard deviation and a value for the peak signal value. Through one cycle we have a peak to peak value of 0.563V. We must divide that value by 2 to get a peak voltage. So we get a value of 0.282V. The standard deviation for the noise is .02426V. Using the above equation to calculate the value for SNR we get for $\frac{v_s}{v_n}$ = 16.37 dB. This is not a particular large number for the SNR.

The input capacitance and input resistance of the op-amp play an important role because they do contribute to noise. First taking into consideration the input capacitance of the photodiode. The photodiode that we used has a input capacitance of roughly 30pF at the bias voltage of about 5.5V (Based off the graph in Figure 2). With this you can run some calculations to figure out the actual capacitance needed for the first stage transimpedance amplifier. The transimpedance amplifier shown in Figure 8 is a current to voltage converter and is a high gain amplifier. A high gain amplifier is needed for the small signal that was produced by the actual gamma photon strike. With this basically constructed amplifier we will get some oscillation. So we must add a capacitor in parallel with the R_f resistor to stabilize the signal and stop it from oscillating. The equation for the capacitor is $C_f = \frac{C_s}{2(\frac{R_f}{R_{in}}+1)}$. [18] The value that was calculated was 5pF, though in the circuit we used a 4.7pF capacitor. The 4.7pF capacitor that was used in the first stage helps stabilize the gain of the entire circuit as well as the noise.

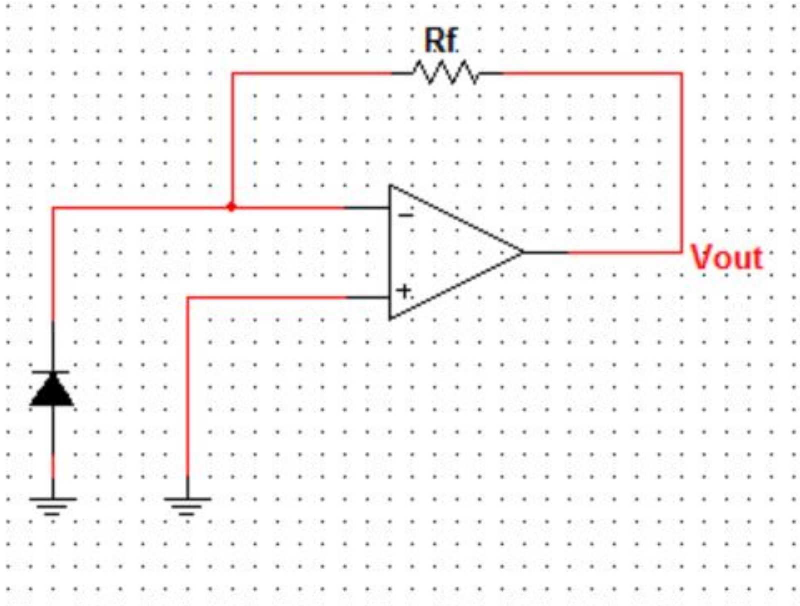

Figure 8. Basic Transimpedance Amplifier

3.5 Low Noise Amplifiers

A low noise amplifier is needed for this application. In building the detector we need to look for amplifiers that can satisfy the low noise condition. There have been several research topics with low noise op-amp application. The research done in [19] was with low noise and low power amplifiers. With an ultra low noise of 2nV/√Hz and a power consumption of 140 uW at a 32um process, we can see that it is possible to develop an op-amp with such a small noise level and power.[19] Another requirement is to find a op-amp that can withstand large amounts of radiation. In [20] the op-amp was tested under sever radiation and was still capable of performing at a top level. This may be something to consider for the future. To find components that will not be effected by the high radiation will be a great improvement from the op-amp that was used in this project.

The amplifier selected is the Max4477 op-amp. The is a low-noise, low-distortion, wide-band op-amp. The Max4477 has a low input voltage noise of 4.5nV/√Hz at 1kHz and 3.5 nV/√Hz at 30kHz.[21] There is a negligible input current noise of 0.5fA/√Hz due to its small amplitude. [21] The input capacitance (Cin) for the amplifier is 10pF and the input resistance (Rin) 1000 GΩ.[21] We can see based on the information that this is a really good amplifier and will work well in the current set up.

We decided to implement a 4 stage amplifier system for the circuit. If there were any more stages this would create distortion within the system and we would get some cut off of the signal. The 4 stages gives us enough gain to amplify the signal without getting a lot of distortion and helps from keeping the signal from capping off at the supply rails. I set the amplifier rails from +5V to ground. This is useful because I am using a reference voltage for the positive input of the op-amp. If I wanted the output of the op-amp to be centered around zero I would change the negative rail to -5V and the positive input to the amplifier to be ground. We will see later in the paper that the signal from the experiments is centered on 3.5V or 3.0V rather then ground as explained above. This is due to the reference voltage for the op-amp.

3.6 Other Detector Circuits

There have been other examples of gamma ray detectors. Each circuit that we have looked at has very similar constructions and employ similar ideas. The first circuit we looked at was that of Alan Yates in Figure 9. His detector used a BPW34 photodiode as its detector. This diode size is $7.5mm^2$ and has high photo sensitivity and radiant sensitivity.[22] The diode having a reverse bias voltage is 60V. This is very good because you can apply high voltages and lower the capacitance. When reverse bias voltage is applied, the diode can have up to 9pF of capacitance.[22] Although when simulated, the actual voltage seen by the diode would actually be about 8.5V and the resulting capacitance would actually be around 19pF. The circuit like all others was tested with an Americium-241nsource that emits approximately 59 keV of energy.[23] It is stated on Alan Yates website that he thinks this is about the practical limit of this detector. The measurements from the video Alan provided on his website show that his average detections is about 400mV to 600mV. It is not stated whether the probes are 1x or 10x because of this we may not have a good measure of what the actual amplitude is. This was a really good detector but still had some flaws such as temperature problems.

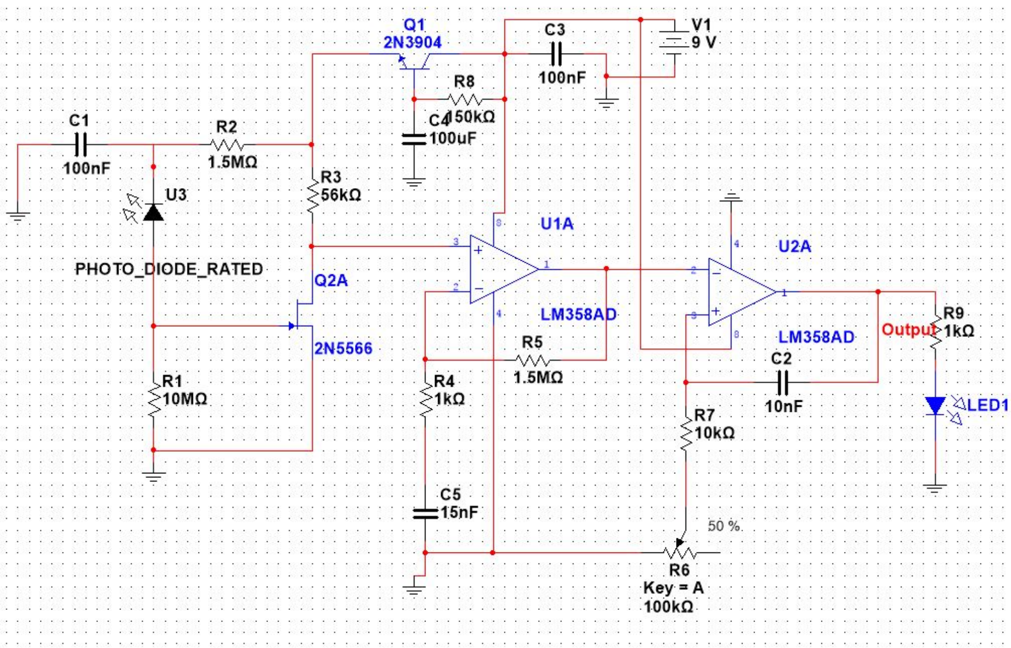

Figure 9. Alan Yates Prototype Circuit [24]

Another circuit of interest was that done by a few people who constructed and tested their version of a gamma detector. The circuit behaves similar to that of a classic Geiger Counter. The designers of this circuit used a large photodiode, making it more sensitive to detecting strikes in the depletion region. The diode is a PS100-7-CER-PIN. This diode is 10mm x 10mm and has a capacitance of about 80pF under a 12V bias.[8] The amount of leakage current is roughly 2-4nA making this a low to mid range for a detector.[25] Figure 10 has the circuit that was used for the Solid State Photodiode Gamma radiation detector. We can see that in Figure 10, the first stage looks very similar to the design that I used for my detector. However the designer decides to use two resistors in parallel for the gain stage to be able to use a larger value for the compensation capacitance. This is mainly because his calculated value for the C_f capacitor was around 0.2pF and the value was not practical. What is needed is to increase the compensation capacitor to improve the oscillation in the circuit.

The second stage of this system acts as a filter for low frequencies. This is due to the capacitor C9 and resistor R13. This system consists of the LM358 op-amp which in the second stage is being used as a low pass filter. The Lm358 have a typical noise level of about 40nV√Hz.[26] With this the amplifier will not be a great amplifier for the first stage of the system. If there is too much noise in the first stage the signal can be lost. This is why the inexpensive Lm358 is used for the second and third stages of this design. The third stage of the system is a comparator for the system to generate the output pulse wave to signify a detection. There is an LED and noise counter to signify detection by visual and audio means. These would be good options for improving the current detector that was built for this project.

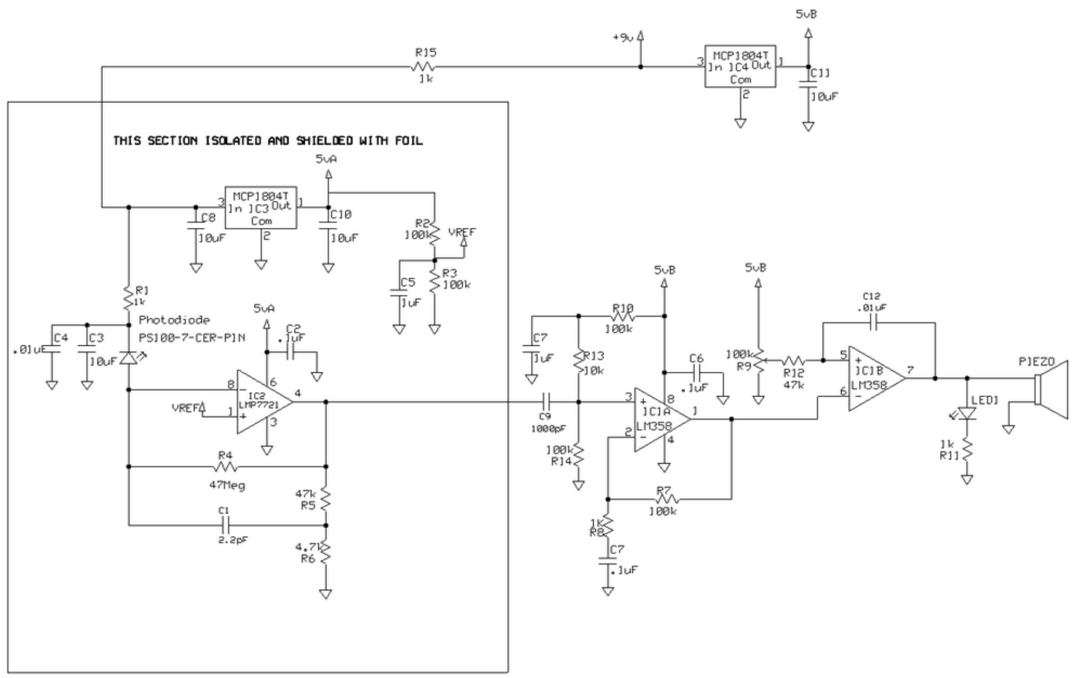

Figure 10. Solid State Photodiode Gamma Radiation Detector [17]

Chapter 4

Testing and Results

4.1 Test Results

The test results from the detector are displayed in the figures below. I was able to get really good results when it came to gamma radiation detection. Figure 11 shows the actual circuit that was tested. The board was milled using the milling machine in the pulse power lab. The use of a LM7805 5V regulator to supply the Max4477 op-amps as well as the Max987 Comparator was used. The Max987 is a low voltage rail to rail comparator that is used for signal recognition. [27] The LM7805 is a 5V regulator with up to 1A of output current to supply the op-amps and comparators with voltage.[28] This makes testing the board easier since only one power supply is needed. The detector circuit needs 12V power supply to supply the circuit with the needed voltage. The 12V power supply was needed to bias the photodiode. As high as voltage as possible is needed at the diode to reduce the capacitance of the diode.

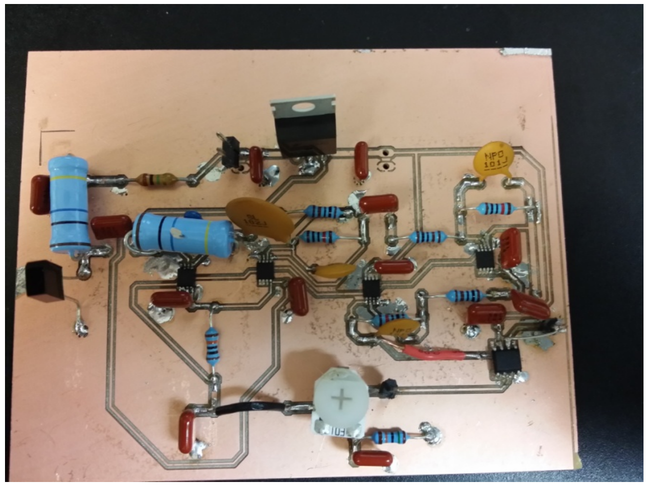

Figure 11. Milled Detector Circuit

The detectors test point 1 output is shown in Figure 6. Figure 12 shows the results of the gamma source from Dr Jiang's Lab. This was the main source that was used when testing the device. Here we can see that when there is a strike on the photo detector the output before the comparator has a slight wave indicating that there was a detection. Compared to Figure 13 where the lights were off and the gamma source is off. We can see that there is a big difference in the actual noise figure versus the gamma source detection figure. Dr. Jiang's gamma source has a 42m Ci of radiation and 330 keV of energy. This is a large amount of radiation and power but the detector is able to detect this source with ease.

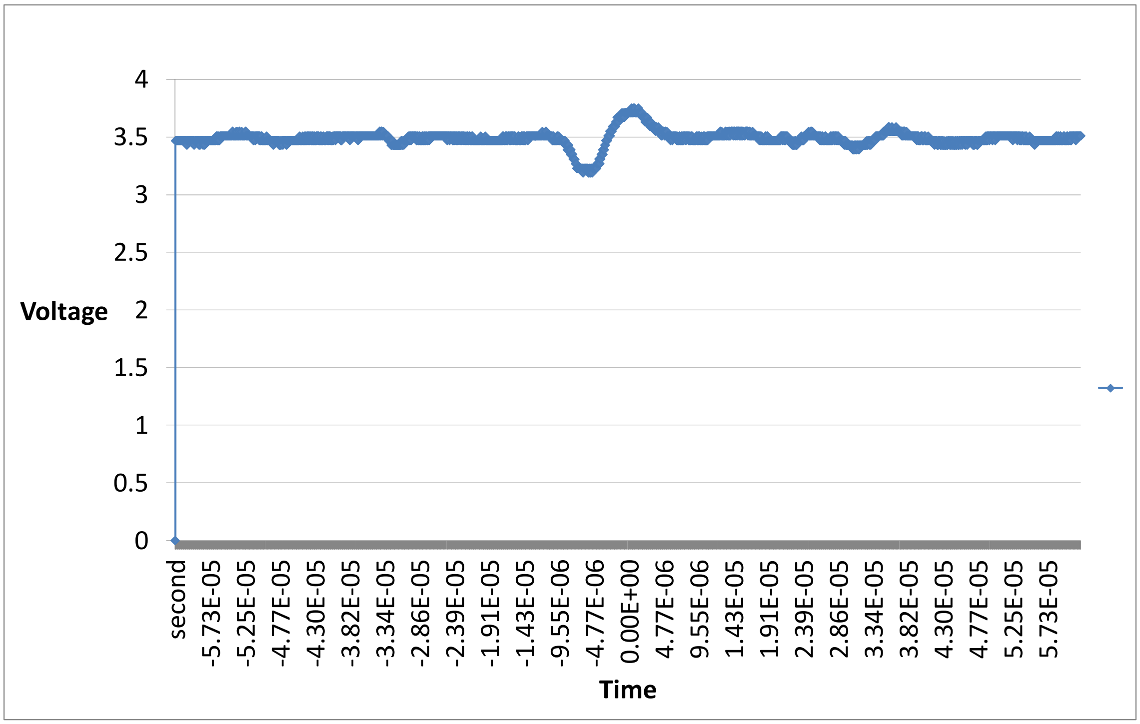

Figure 12. Gamma Source Test with 42mCi

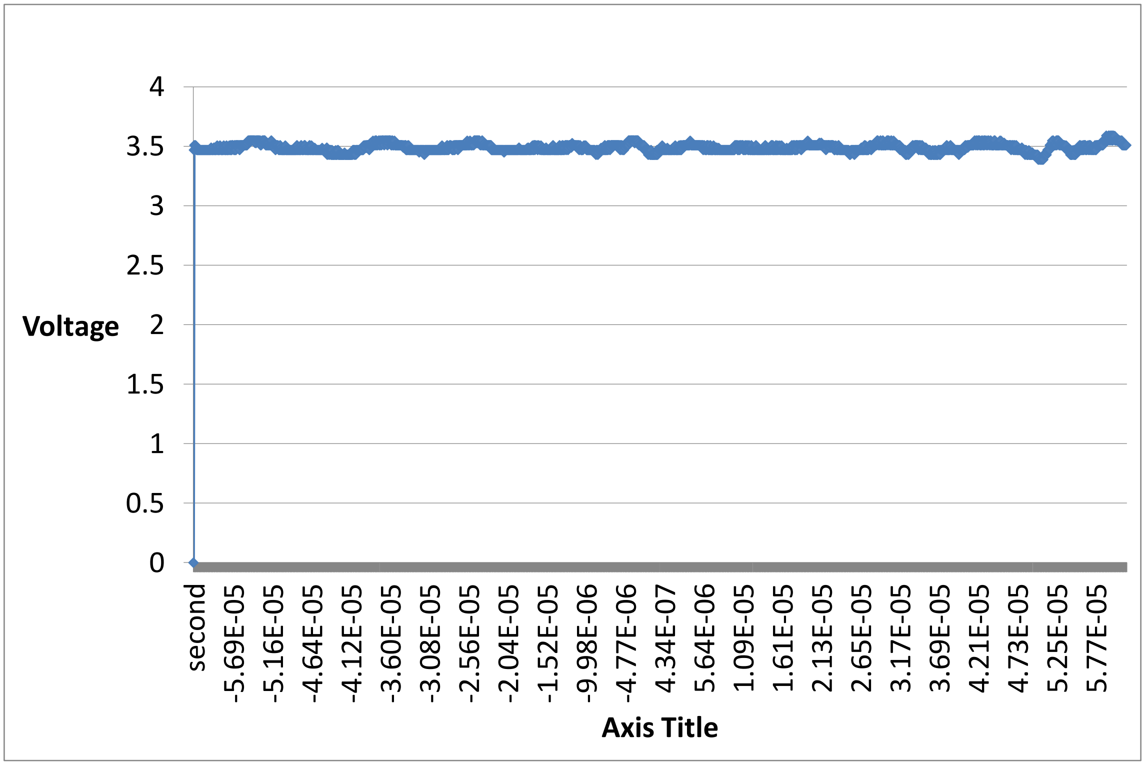

Figure 13. Detector Output with Lights off and no Gamma Source

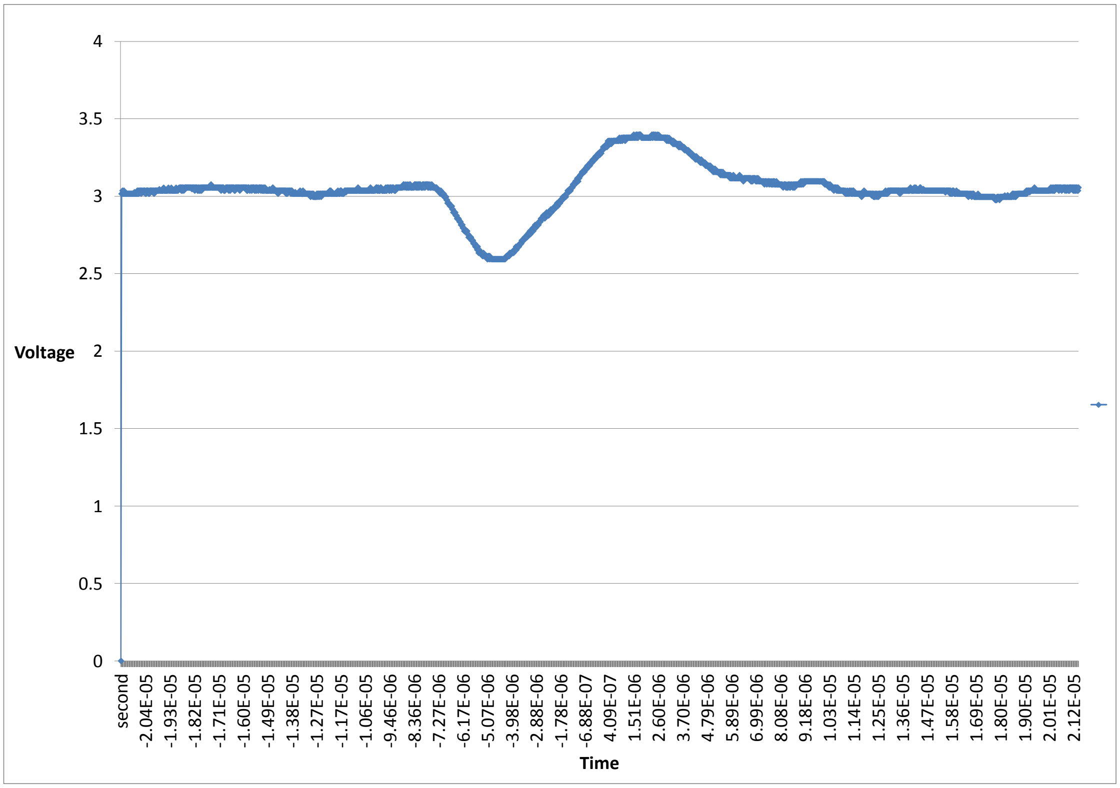

Figure 14. Detection of Gamma Source 42mCi

Figure 15 is the result of the gamma detector with the light source in the lab. The graph displays the reason as to why we stayed with a 4 stage amplifier system rather than go into further stages. We can see that with the end result of the 4 amplifiers, the signal is being caped off by the supply voltage to the op-amp. Note that the signal was taken with op-amp scope probes with a different magnification. So we must multiply the signal by ten to get the true magnitude of the photon strike. This graph demonstrates why a 4 amplifier stage is the best option for the system. We need to make sure that there is no distortion or cutoff of the signal.

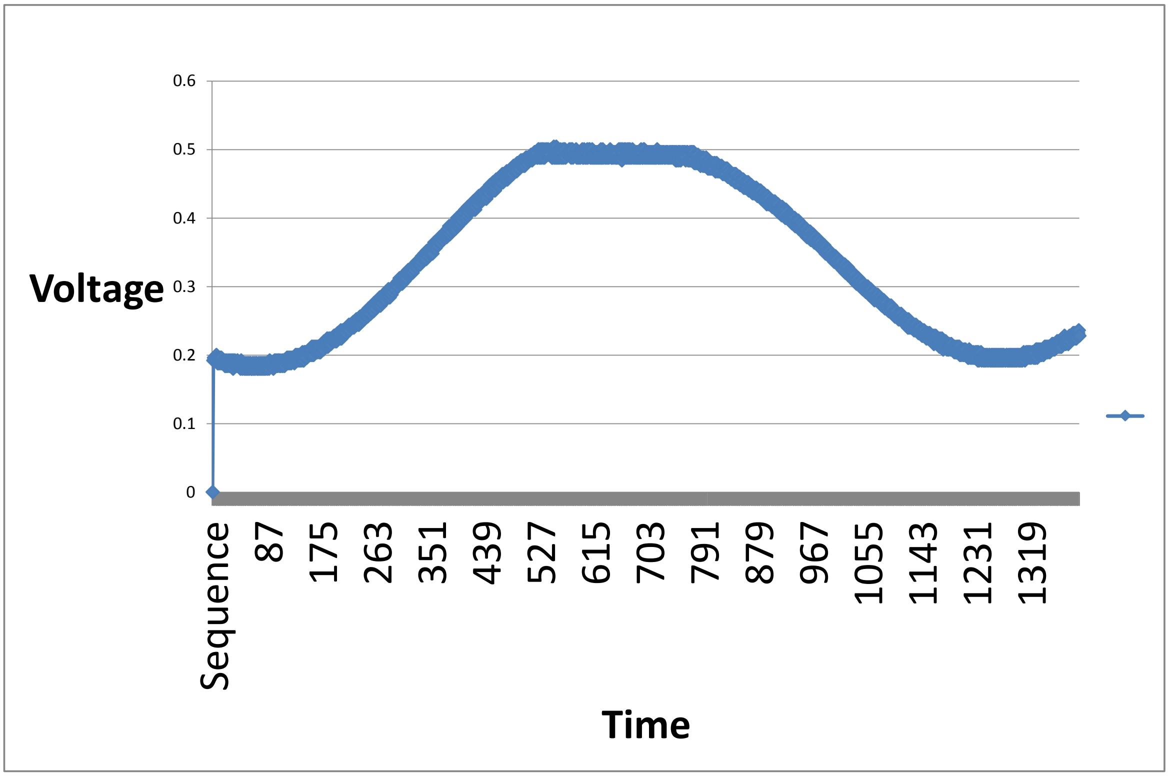

Figure 15. Detector Output with light sensitivity

Figure 16 is the results of the detector with the very small Americium-241 source applied to the detector. The Americium-241 contains 1.0µ Ci of radiation. This is a very small amount of radiation compared to that of the source used in Dr. Jiang's lab. This could possibly be the practical limit for the detector, however, I am unsure because we do not have a gamma source of smaller magnitude to test with. The amount of energy that is produced by the Americium-241 is roughly about 60eV. The signal from the Americium source is fairly small and has a weak signal of about 0.25Vpp compared to that of the gamma source from Dr. Jiang's lab. The signal from the other source is about 1Vpp. The value is very close to the noise level of the circuit. We can see that signal from Am-241 appearance to that of the value of the noise level in Figure 13. When testing the value from the americium, I set the trigger of the oscilloscope just above that of the noise signal. We left the oscilloscope black to make sure that the noise does not trigger when noise is high in the circuit. Once we were sure that there was no false trigger, we applied the Americium source and produced the signal.

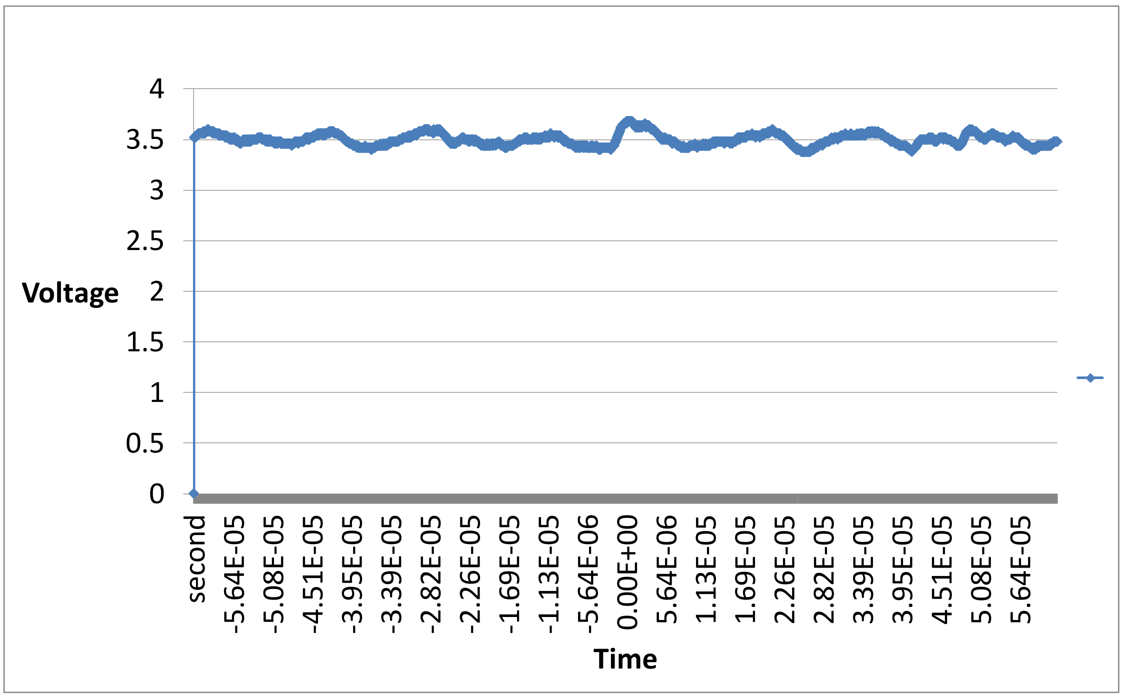

Figure 16. Value from Am-241

4.2 Layout

The layout is an important part of the construction of the detector. The layout in Figure 17 is a simple test layout laid out with through hole components. The reason for this circuit was due to the incredible noise produced by the breadboard test. The circuit was first constructed on a breadboard for testing, however, this was not a good measure of how the circuit worked due to the amount of noise being produced. The noise was so large it consumes the charge signal and no accurate signal was produced to measure if the circuit was working. So I had to search for a better way to test the board. The first try was to use a chemical etch for this layout. This process would involve printing the circuit on some photo paper and apply heat to apply the ink to an FR-4 copper material.[29] The ink would act as a shield for the traces, and the chemicals would eat away the copper that was not covered in ink. This process did not work as well as expected due to the small amplifier packages as well as the printout of the circuit on the photo paper. This is mainly due to the photo paper that was used. There are specific paper that can be used to better transfer the ink. In Figure 18 we can see a few traces that were not etched or were etched together on the FR-4 board. As a result the board was unusable and I had to seek other means of building the board.

The board was finally milled with the machine down in the lab. This was a better way of laying the board out on copper then the chemical etch. After this process there were still a few problems with the milled board. The milling machine still missed a few holes and traces for some of the components. Special care and attention to the traces is needed when using the milling machine because there could be a few missing traces or connected traces. Another problem I found is in regards to the small components that were used. With The amplifiers being very small the milling bit had some problems getting traces that were so small. So making sure that the drill bit cuts into the copper top of the board and not cut into the other traces and make the other traces smaller. This would make it hard solder the components on the board if the traces were to small.

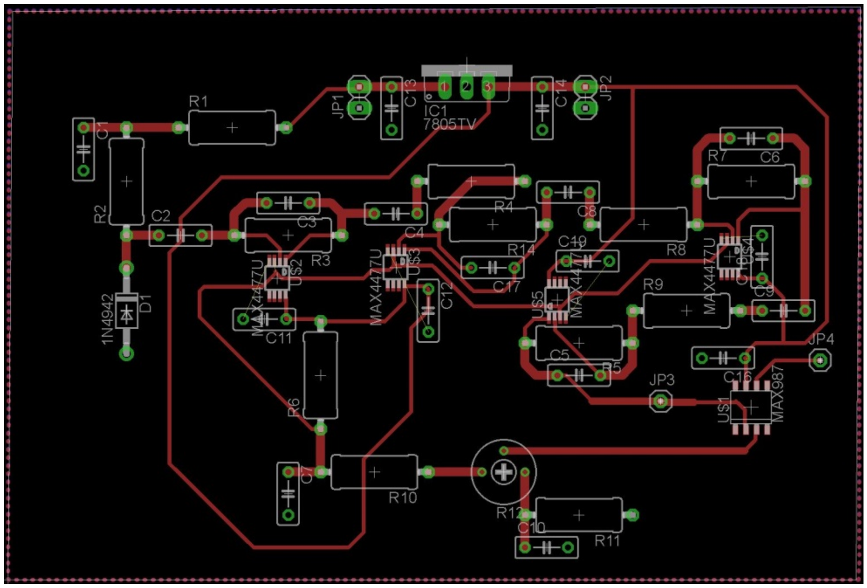

Figure 17. Current Layout of Detector in Eagle Cad

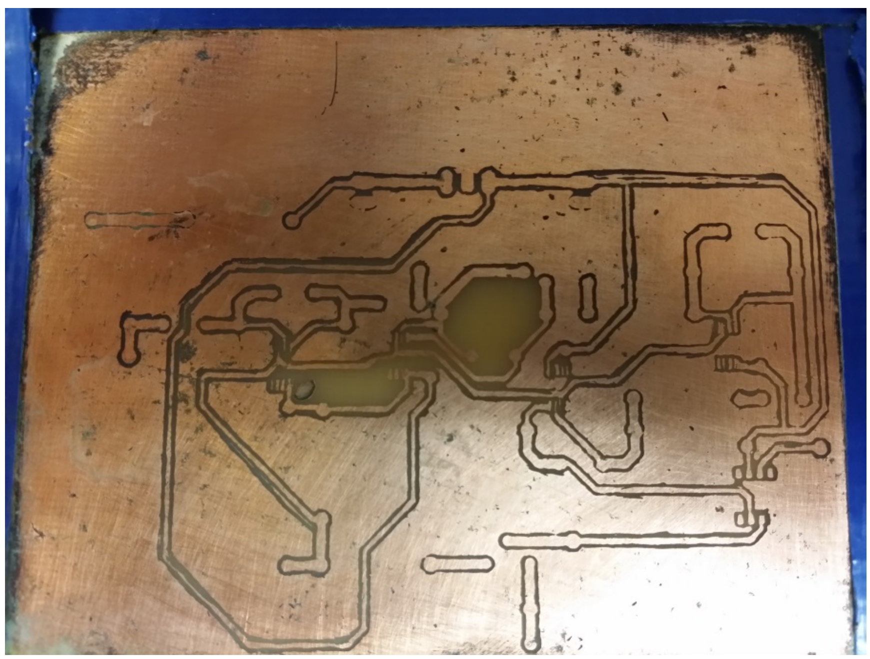

Figure 18. Attempt at Chemical Etch

Figure 20 is the board that was laid out with surface mount components. This helped improve the overall functionality of the circuit board. This will also helped to reduce the overall size of the circuit, add resistance, and add inductance from the connection.

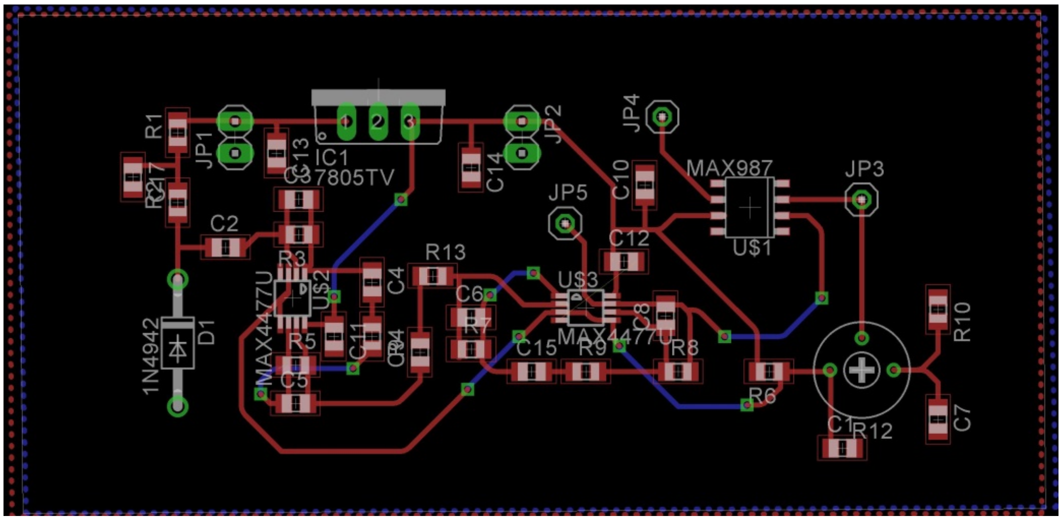

Figure 19. Surface Mount Component Layout

4.3 Future Improvements

There are a few suggestions for improvements to the board. One of the suggestions is to combine both the microcontroller and the xbee device into one system. With this adjustment it will be much easier to use the board. The three boards will be combined into one, making the detector more portable. The only thing that will have to be taken into consideration is whether the microcontroller and the xbee can stand up to gamma radiation. The second is shielding. A better system of shielding light from the detector would be needed. Rather than using a cookie tin, one could fabricate a suitable shield for the detector. Third, using a larger diode and finding a diode that has lower input capacitance. A diode with lower input current and a larger area for detection would be a good start for improving the efficiency of the system. Fourth, is to have the board fabricated. The use of a green board will allow for the boards area to be smaller and more reliable then the milled board that was used. With the use of a green board smaller Surface mount components can be used. This will help with the overall noise. Lastly, finding a better and faster analog to digital converter (ADC). The current microcontroller (Atmeg328P) is not fast enough for the current signal. The gamma detection signal is roughly about 5 micro seconds and the ADC on the microcontroller is about 13 micro seconds at its fastest. So, when we try to get a spectrum for the incoming signal, the device only catches a few parts of the signal. The output is not a regular input but rather a spread of random detections that it can catch. This is troublesome because we do not know when a signal will be detected or if the ADC will be able to convert the signal fast enough.

Chapter 5

Labview and Xbee Integration

The vision for the labview program was to display the information gathered from the gamma detector and display it on labview as well as on an iPad. Figure 20 shows the overall block diagram and the flow of the system that has been built. Here we can see each component of the device and how each one interacts with the other.

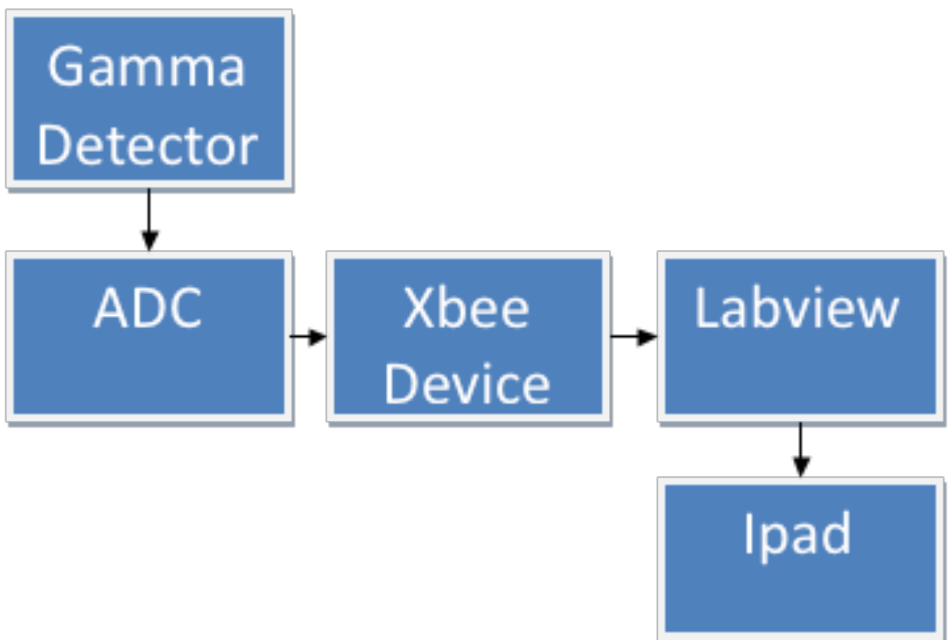

Figure 20. System Block Diagram

The final idea was to get a spectrum from the data and plot it in real time. I was to take each peak of the signal and plot the information in a histogram. The program uses a basic VISA connection to connect to the Xbee wireless devices.[30] The program continues to take the input string and convert the value into an integer value and passing the values into a histogram. The program also counts all the detected values for the gamma source when it passes through the program.

The Xbee devices that were used for the system are the Xbee Pro 900 system. This system will make the data transfer wireless. The devices operate at a baud rate of 9600.[31] This is the slowest rate the devices can operate at. Though the devices can operate at higher rates, 9600 baud rate is a good starting point for data transfer. Figure 21 displays the connection from the arduino board that was used as the ADC to the xbee devices. The information is then passed to the second xbee device and transferred via USB cable. Although regular jumper cables were used, it might be better in the long run to use a better connection system rather than just jumpers because the jumper wires contribute to some noise in the system. I also used an xbee adapter kit that I bought to make the connection of the ADC to the xbee easier. All that is needed for the adapter kit is a 5V power supply, ground, and the signal to the receive and transfer pin (RX) to transfer the data that is collected. The adapter has two LED's that flicker to indicate when data has been/is being transferred and received.

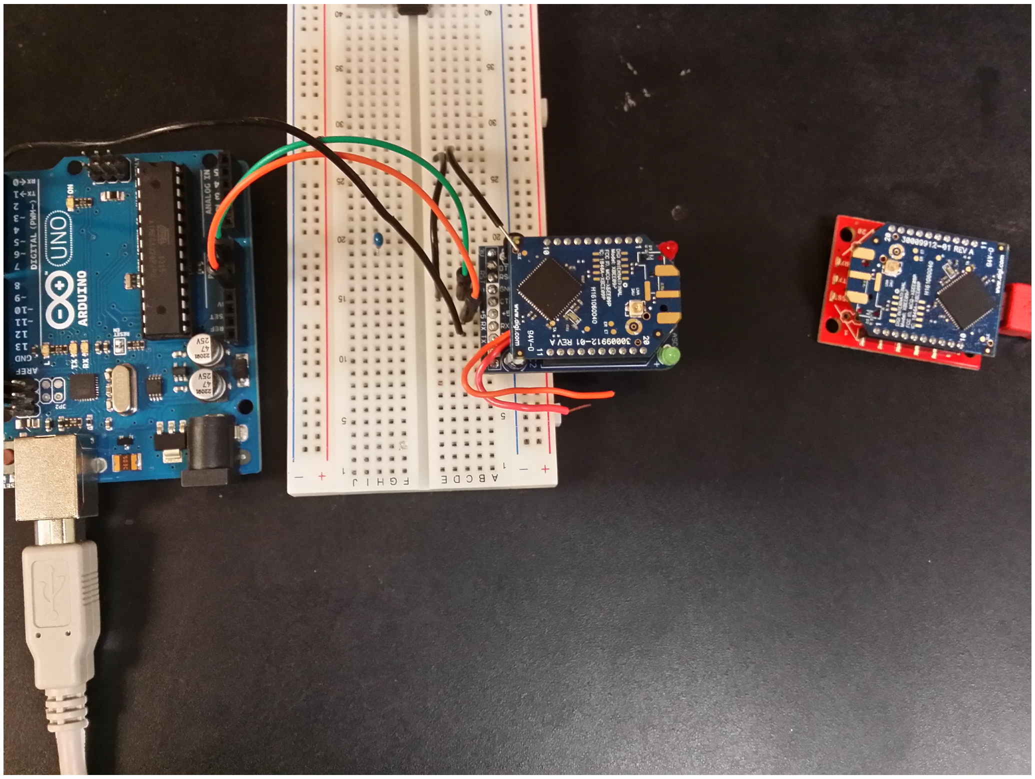

Figure 21. Xbee Connection

In Figure 23 displays the labview block diagram program for counting the signal inputs and transferring the information to the iPad. The program uses a comparison function in labview to see if the value of the incoming signal is greater than 3.2V. This value was obtained by observing the noise level of the output amplifier. If the incoming value is less than 3.2V we know that it is most likely noise. I can include the noise counts in the histogram but we will get a large value of counts around the noise floor and the graph will then show mostly noise counts rather than the signal counts. The labview program displayed all the information in a histogram form and displays the histogram on the iPad app. Figure 23 shows how the data will be displayed in labview and on the iPad. However when tested with the gamma source, the gamma source spikes were too fast for the current ADC chip that was used. The atmeg328p microcontroller chip has an ADC conversion time of about 13us-270us.[32] The signal spikes are about 6us in total length. So there will not be an accurate display of data in labview. The data points were sporadic and not in regular intervals. The data would miss up to two gamma strikes because of the speed of the ADC. It will detect a gamma strike however, the final output would not be a correct spectrum due to the missing data that is missed due to the lack of sampling points from the ADC.

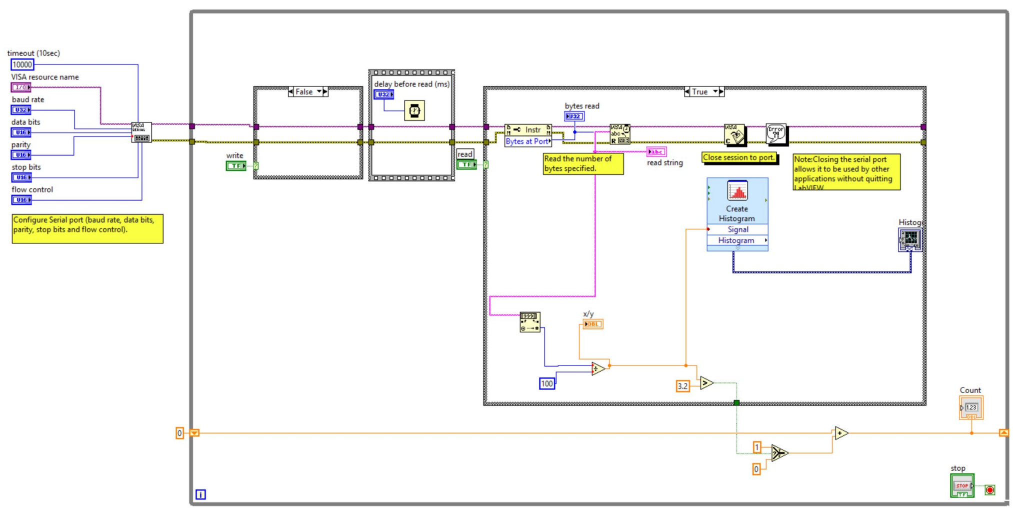

Figure 22. Labview Block Diagram

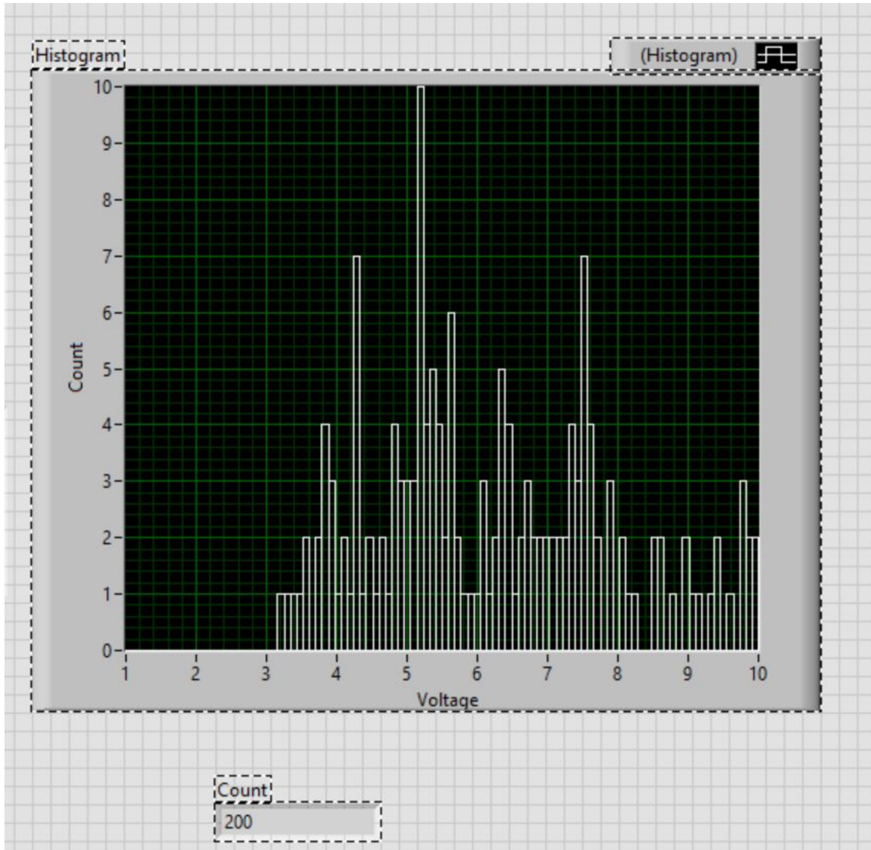

Figure 23. Labview Histogram Data

At the beginning there were a few problems getting the Data Dashboard app to work, due to some of the regulations in labview as well as the display options in the app. The iPad app also has limited display options for graphing data. There are only a few options for graphing within this app and before the data is passed through to the app it must be in a specific data type. [33] This was difficult due to my limited knowledge in labview and limited understanding of the data type within labview. Finally, after further research and outside assistance I was able to correctly display the data on the app and get clear data. This was done by creating my own custom variable within labview in order to use the app. It took some time and adjustments to get the data variable right and in the proper format but I was finally able to get the data to pass through labview and display on the iPad. Originally we had wanted to be able to use android devices as well but there were too many limitations with the android app. The specific graph that I had in mind of using was not available on the android version of the app and only had a linear graph for displaying data in real time but not able to convert to a histogram form. The version of the app on the iPad was 2.0 and the version on the android was 1.0. Therefore, some of the functions were not available on the android app.

Chapter 6

Conclusion

Finally, the circuit was a success. The circuit was proven to detect gamma radiation and display the information on an iPad just as I had been striving for. Though there were some problems along the way regarding limitations with circuitry, the final product and overall functionality was good. Although we only had two gamma radiation sources in which to test the limits of the circuit, the limit to energy the circuit could detect was a small disappointment. Once a suitable ADC is found that is capable of detecting the full gamma signal the output counting and full spectrum will be more accurate. Though these were limitation of the circuit I have shown that it is indeed possible to get a spectrum of the gamma strikes and display the information on a wireless device. The detector is capable of detecting gamma rays with energies of greater than 59 kev. It may be possible to manipulate the circuit to achieve a smaller detection level of energy. By adding more detectors or getting a larger detector it will be possible to detect smaller amounts. Careful care must be taken to the noise within the first stage to make sure that the signal is not absorbed. A smaller overall layout, a careful selection of components, power connections, and jumper wires should help to reduce some noise in the circuit. Overall, after many difficulties I was able to amplify the gamma strike signal and display the information from the detector on an iPad and achieve the final outcome of the project.

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