In-flight Radiation Detector Spring 2020 Update Report

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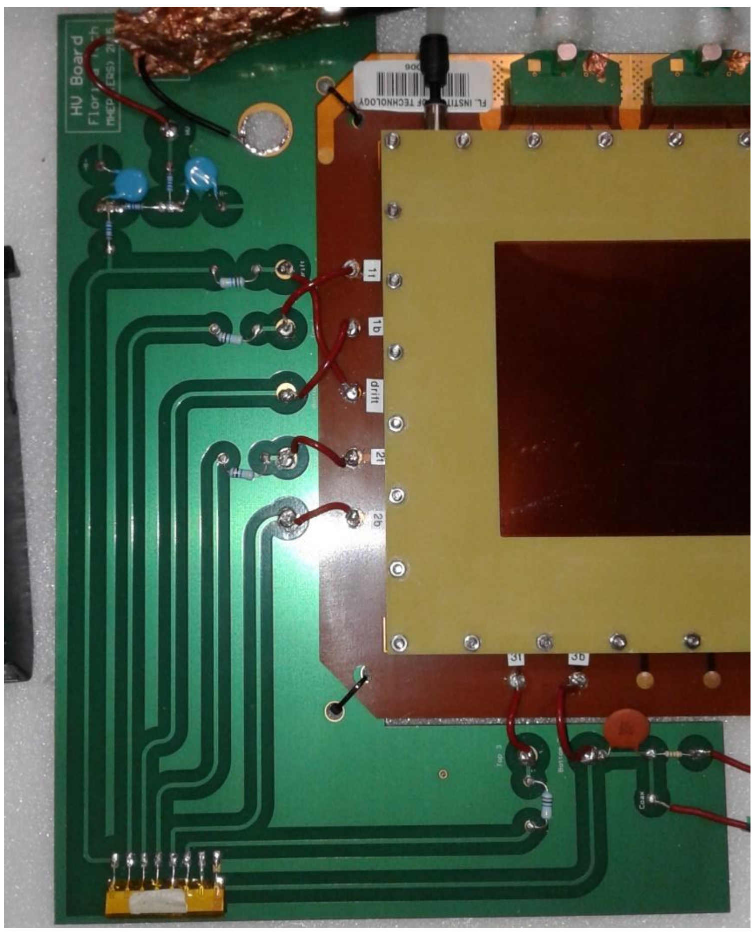

SUMMARY

The following document describes the testing procedures and processes conducted from Fall 2019 through Spring 2020 semesters on the In-flight radiation detector. The In-flight radiation detector is a 10 × 10 cm Gas Electron Multiplier (GEM) detector that is intended to be placed in either a high-altitude aircraft or spacecraft. The purpose is to determine the real-time directionality of incoming cosmic particles in the cabin of a high-altitude vehicle. As a result of this monitoring system, pilots and passengers will have a better indicator of the dynamic radiation environment during flights. The contents of this report are as followed: techniques for noise reduction and testing, test pulse into the detector system, detector source testing, and future studies.

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1. TECHNIQUES FOR NOISE REDUCTION AND TESTING

1.1 Overview of Noise Reduction and Testing

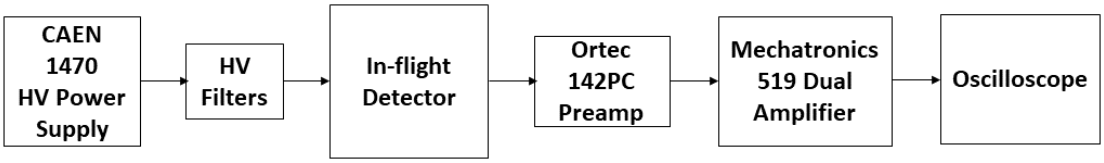

Figure 1. Simplified Block Diagram of In-flight Detector System

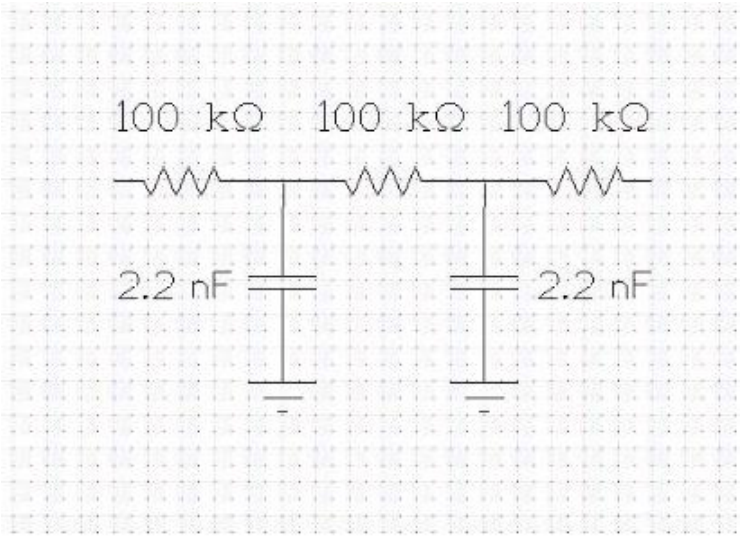

Figure 2. Circuit for HV Filter

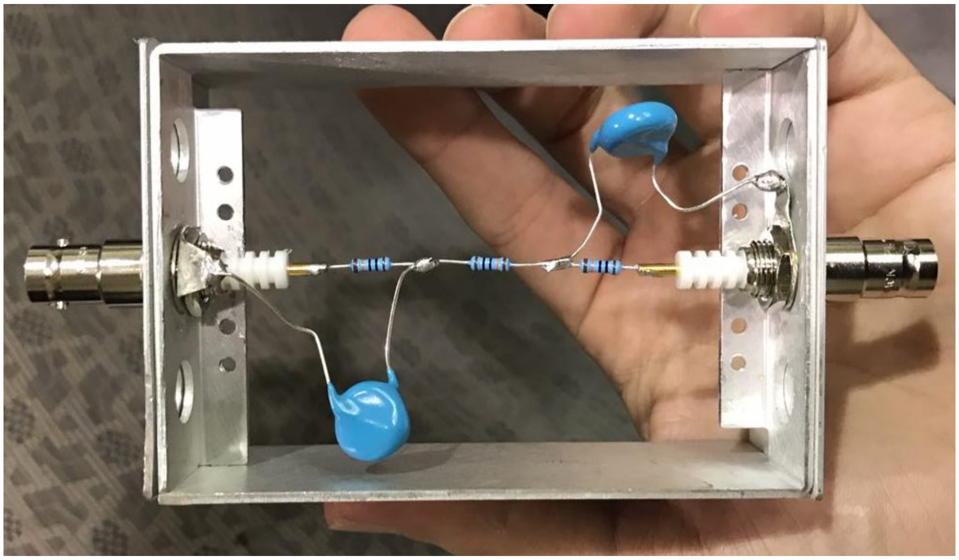

Figure 3. Image of HV Filter *[1]*

Figure 1 is a simplified block diagram of the In-flight detector system. A schematic of the HV filter configuration is depicted in Figure 2 and a photo of the HV filter is also presented in Figure 3. Three HV filters are included in the In-flight detector system to reduce the oscillation on the HV signal from the CAEN 1470 HV Power Supply.

For the detector to be able to identify signal pulses from a radiation source, the output noise level observed on the oscilloscope needs to be below a certain threshold. The output noise level needs to be less than 50 mV from the preamplifier signal and less than 200 mV from the amplifier signal. This is done to collect valid results for Quality Control (QC) tests 4 and 5. The two main factors that affect the noise levels are shielding and grounding. It should be noted for the In-flight detector this was an ongoing adjustment throughout 2019-2020 research years.

1.2 Shielding Techniques

The first factor that affects noise levels is shielding electronics. An effective material used for shielding electronic components is copper. The HEP lab has access to copper sheets, copper foil, and copper tape. The two important variations out of the list is the copper foil and copper tape. The copper foil is to be used to wrap large areas such as the detector, preamplifiers, or HV filters. The copper tape should be used to close small openings in the copper foil or secure the copper foil to the outside of the electronic filter or detector. The copper tape is also an important adhesive to use for grounding BNC coaxial cables as well. By encasing the electronics in copper foil and tape, essentially a Faraday cage has been constructed around the electronic device. The Faraday cage prevents static electric fields from passing through to the device and only allows charge to accumulate on the exterior of the Faraday cage [2]. Therefore, the copper foil/tape Faraday cage reduces the noise generated from static electric fields during the operation of the detector and related electronic filters. Figure 4 and Figure 5 are a couple of examples for properly shielded electronics.

Figure 4. Copper Foil and Tape Shielding on Preamplifier 5 Input Port Plate

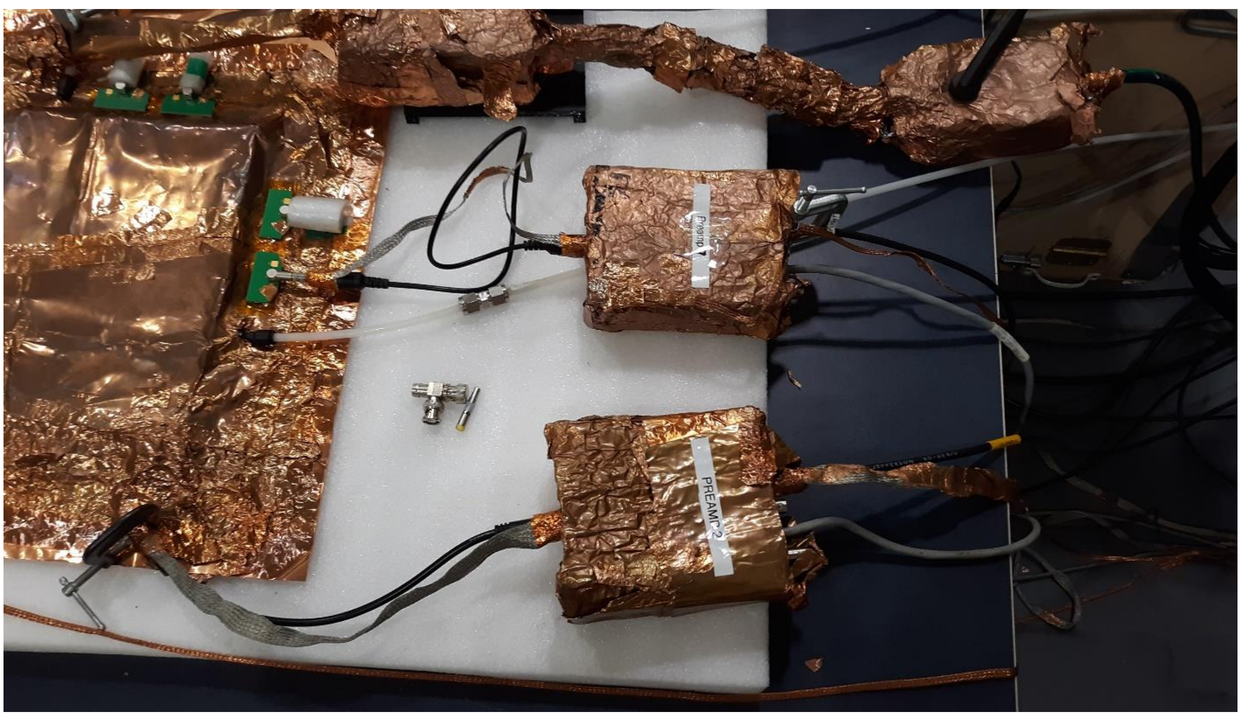

Figure 5. In-flight Detector System with Implemented Shielding Techniques

1.2.1 A Few Comments on Copper Foil

1. Copper is a conductive surface, proceed with caution when placing on electronics.
2. The copper foil used in the lab is recycled material from other projects. Inspect quality before use. Close any holes in the material with copper tape.

3. Try to stick with pure copper foil, avoid using sandwich foils with Kapton in-between layers of copper.
4. Try not to cut the available copper foil as it may be reused in the future for another project. If you need less material, work with smaller pre-cut sections and tape together with copper tape.
5. Use gloves to prevent paper cuts from the sharp corners, this also applies towards the copper tape as well.

1.2.2 A Few Comments on Copper Tape

1. A little goes a long way, only use what is necessary as the copper rolls are used for various projects around the HEP lab.
2. Use scissors to cut clean segments and to prevent paper cuts when tearing.
3. Instead of using a clamp, the copper tape can be used to make a grounding connection between the outside case of a preamplifier and a grounding cable.
4. Only remove if you are going to replace the tape. Unfortunately, the copper tape loses its adhesiveness after one use. Therefore, re-secure with new copper tape if adjustments are needed.

1.3 Grounding Techniques

The second consideration for reducing noise to the detector system is properly grounding the electronics. The In-flight detector has multiple components including: the HV power supply, HV filters, the detector, preamplifier, amplifier, and oscilloscope. Therefore, there are multiple areas where a section of the detector system may not be properly grounded.

1.3.1 Location of Earth Ground in High Bay Physics Research Hall

The earth ground is rack 1 in the High Bay Physics Research Hall (Figure 6). Rack 1 should be used as the central location for grounding all electronics in the HEP lab. However, if the detector is not in close vicinity to rack 1, ground straps can be attached to the grounding plate used by another detector that is already grounded to rack 1. Note this is the rack located outside the cleanroom in the HEP section of the High Bay Physics Research Hall.

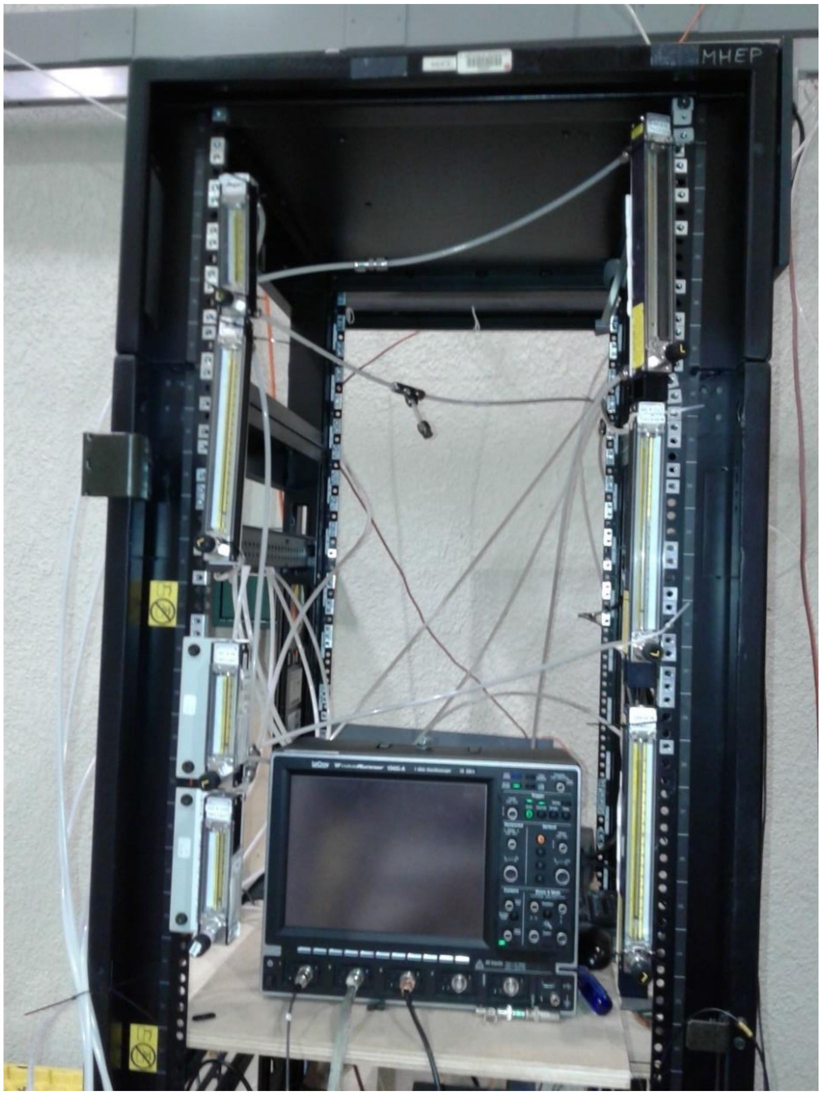

Figure 6. Image of MHEP Rack 1 in the High Bay Physics Research Hall

1.3.2 Grounding Electronic Filters and Cables

Ground straps are used for grounding the electronic filters and cables. These ground straps are used to provide the length and the connection needed to access the earth ground through rack 1. The primary focus is to ground all connections including the input and output ports of the HV power supply, HV filters, and preamplifiers. To ground the connection points, use either copper tape or metal clamps to make a connection between the input/output connections and the ground straps. See Figure 7 and Figure 8 for how the grounding straps are applied.

Figure 7. Image of Ground Strap Connection to GEM Bottom 3 Output

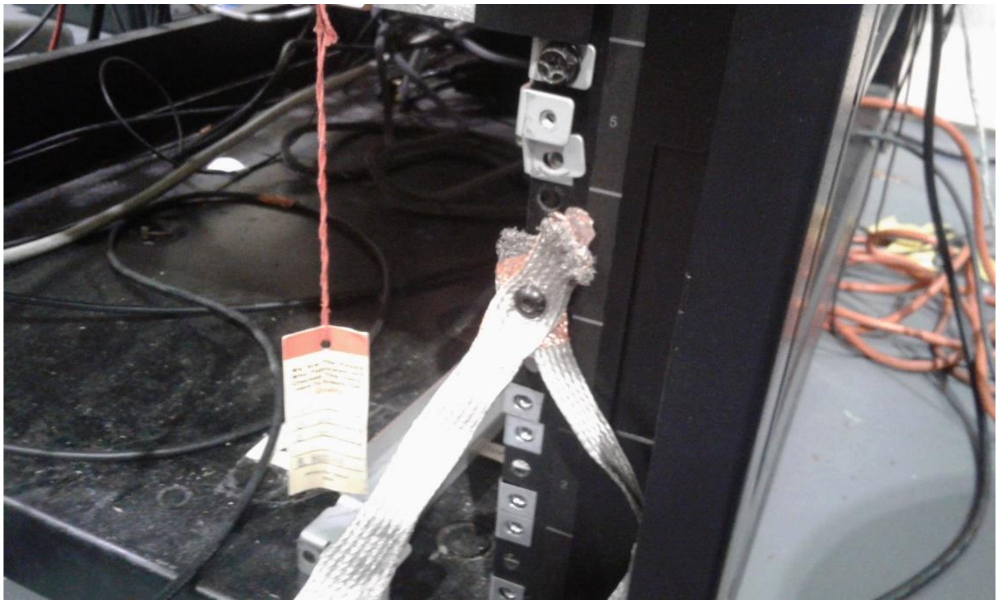

Figure 8. Image of Ground Straps Connected to MHEP Rack 1

1.3.3 Grounding the Detector

The In-flight detector is grounded using a sheet of copper metal as a grounding sheet. The grounding sheet discharges the HV board attached to the chamber section of the detector. A ground strap connects from the grounding board to rack 1. The copper foil that covers the top of the In-flight detector is also secured to the grounding plate. This is achieved by using copper tape to completely enclose the detector.

1.3.4 A Few Comments on Wiring

1. Make sure soldering connections for ground are secure. As a general note, double check that all wiring is secure as well. If the grounding connection is loose, the detector may not be properly grounded. As a result, excess charge will increase noise levels on the oscilloscope.
2. Ensure soldering connections are flat, round, and clean. If not, this may lead to higher amounts of noise and discharges when ramping up the HV power supply.

1.4 Noise Testing Procedure

The procedures listed are general instructions for noise testing a detector system. Therefore, little detail will be specified for the connections between the detector system, oscilloscope, and other electronic filters. The purpose of these procedures is to monitor the noise level from the detector system when the HV power supply is off.

1. Turn on the LeCroy Oscilloscope located in rack 1 and open the WaveRunner software.
2. Below the main trace display, 8 parameters are shown on the oscilloscope. Select one of the parameters and change the source to the current channel for the output of the detector system.
3. Choose the “Peak to Peak” function for the parameter. The oscilloscope will display both the instantaneous and average peak to peak voltage in the section below the main trace display.
4. Adjust the “Timebase” and the voltage per division as needed to compensate for the time sequence and voltage scale needed.
5. Select the “Trigger” box that is located in the lower right of the screen.
6. Select the same channel to trigger on that was chosen in step 3.
7. Select “Normal Trigger” from the controls and adjust the level to get a constant trigger output.
8. Ensure the trace displayed on the oscilloscope is the channel for the detector signal. The output seen on the scope is the current noise level from the detector system.
9. Take screenshots of the signal using the “Print” option on the controls.
10. Adjust shielding and grounding configuration until your average peak to peak voltage is within the limits specified in section 1.1.

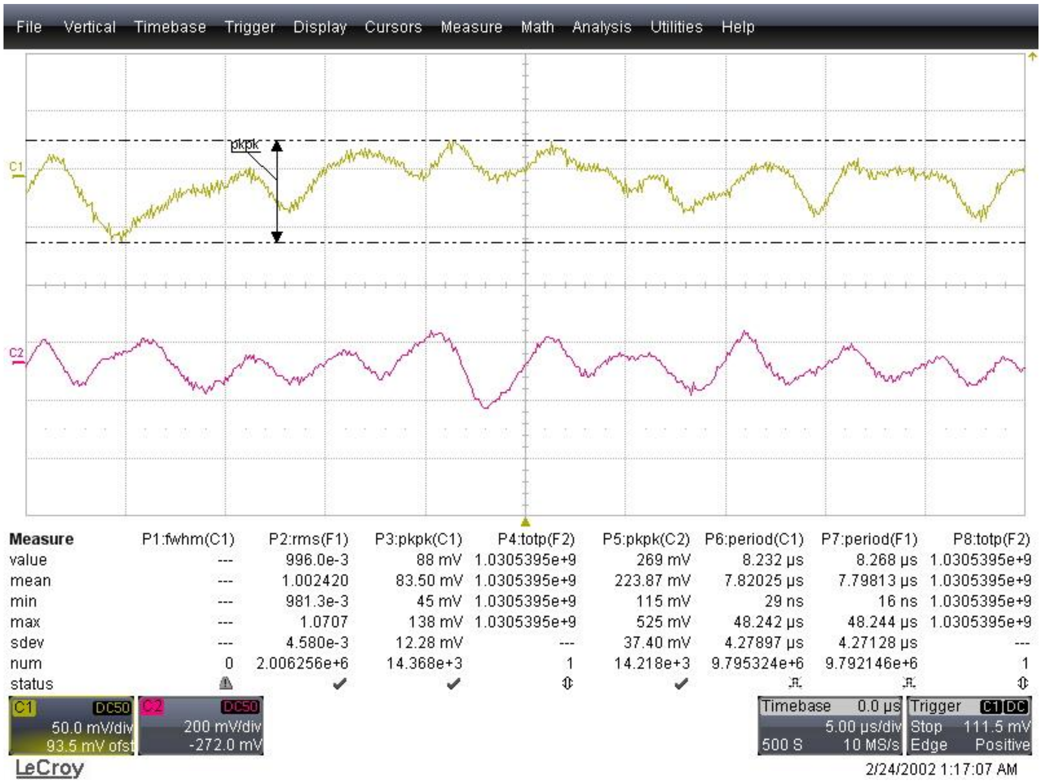

Figure 9. Oscilloscope Noise Signal Sample from GEM Bottom 3 (Yellow) and Readout Strip (Pink)

Figure 9 is a sample oscilloscope output for the In-flight detector when adjusting shielding and grounding to monitor the signal out of the preamplifiers attached to GEM bottom 3 foil (GEMB3) and readout strips. Channel 1 is connected to the Energy output of preamplifier 2 and channel 2 is connected to the Energy output of preamplifier 7. Preamplifier 2 input is connected to GEMB3 and preamplifier 7 is connected to the readout strips.

2. TEST PULSE INTO DETECTOR SYSTEM

2.1 Overview and Investigation Rationale

The desired signal from the detector system can be seen in Figure 10. However, when a source such as Strontium-90 (Sr-90) or Cadmium-109 (Cd-109) was introduced the In-flight detector was unsuccessful at generating a signal pulse. To investigate the In-flight detector system for defects, a test pulse was injected into the preamplifier using a pulse generator. The intent of the pulse testing is to determine if the In-flight detector electronics is able to respond to simulated signal pulse generated by the pulse generator. If this is successful, then the issue arises either within the radiation sources used in the High Bay Physics Research Hall or within a possibly faulty GEM detector. If the sources are found to be active, then further testing is required with the In-flight detector subsystems. This section will cover pulse testing the initial setup for the detector system, the preamplifier, the amplifier, and the final setup of the detector system.

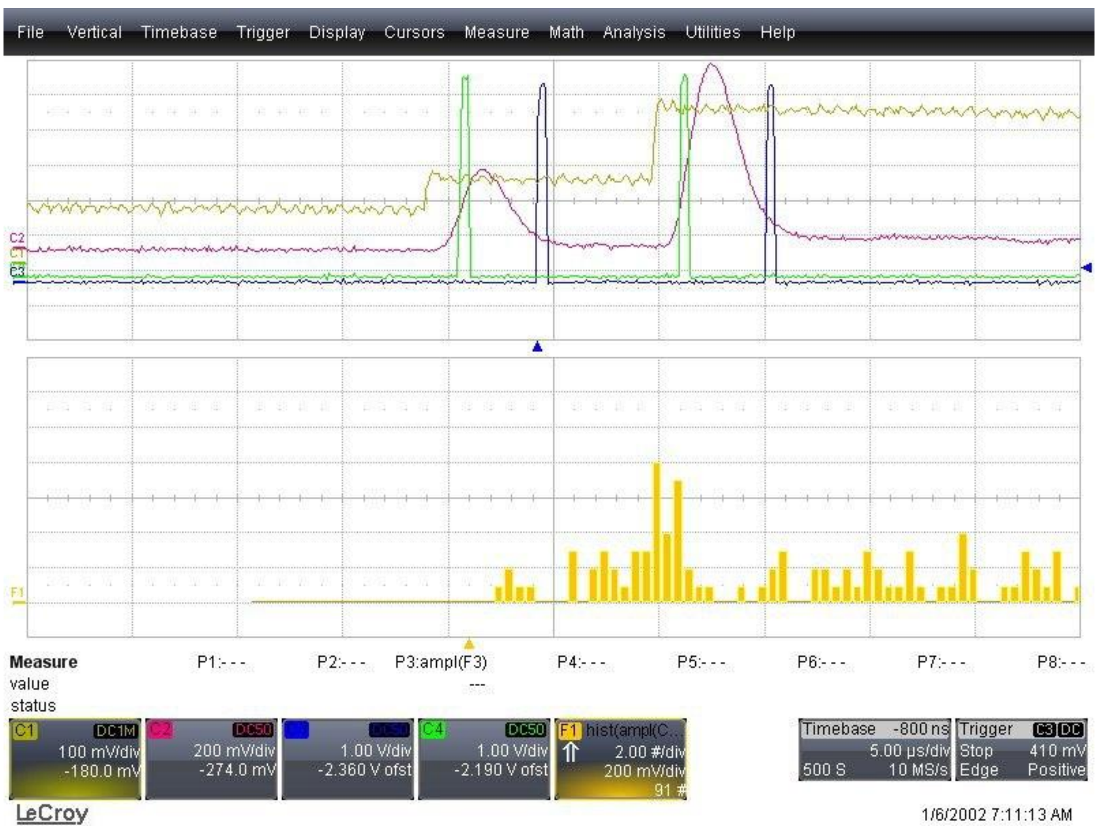

Figure 10. Desired Particle Detection Signal. (C1) Signal from the preamplifier. (C2) Signal from the amplifier. (C3) The LLD output at the rear of 551 SCA is generated when the set threshold is exceeded. (C4) The positive output of the SCA is generated at the constant fraction time recognition *[3]*.

A few notes on Figure 10 for the desired particle detection signal from a GEM detector system. This is a screenshot from Mehdi Rahmani of the accurate response from the detector when particle events occur [3]. It should be made clear that this is data from a different GEM detector project and not collected from the In-flight radiation detector. The two channels of interest for this report are channel 1 and channel 2. Channel 1, the yellow trace, is the preamplifier signal and channel 2, the pink trace, is the amplifier signal.

2.2 Pulse Generator Settings

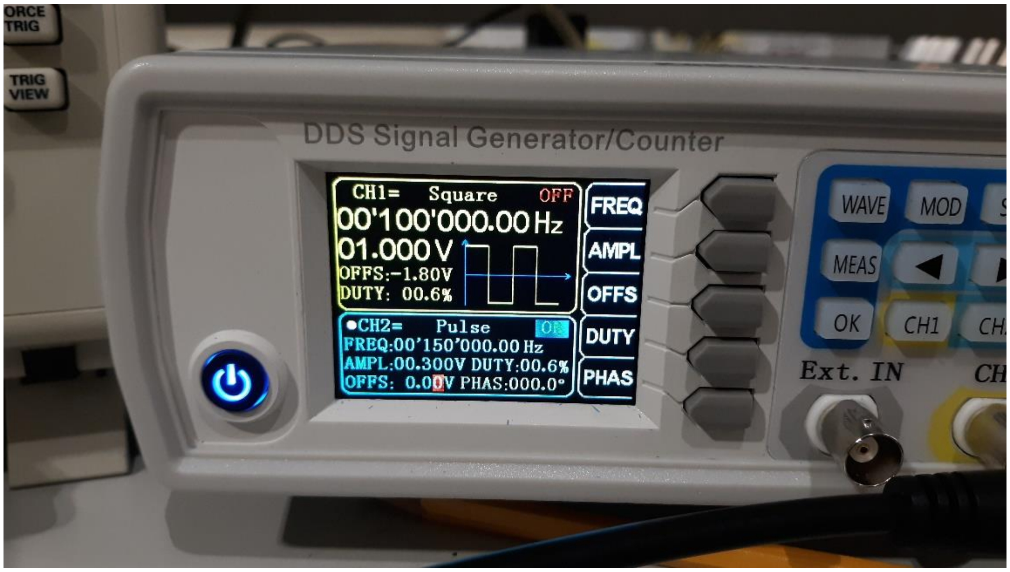

Figure 11. Picture of DDS Signal Generator

A few comments on Figure 11 which is an image of the signal generator used to test the In-flight detector system. The DDS Signal Generator can be used to produce different wave shapes, frequencies, amplitudes, and percentage duty cycle. For the application of the In-flight detector, the wave shape used is "Pulse" and the general settings for the oscilloscope screenshots collected are described below in Table 1. These settings are located in slot 2 of MHEP 1 DDS Signal Generator.

Table 1. Pulse Generator Settings

Pulse Generator Settings	
Channel	2
Wave	Pulse
f (kHz)	40
V (V)	1.7
Offset (V)	0.85
Duty (%)	0.2

2.3 Initial Test Pulse Signal from Detector System

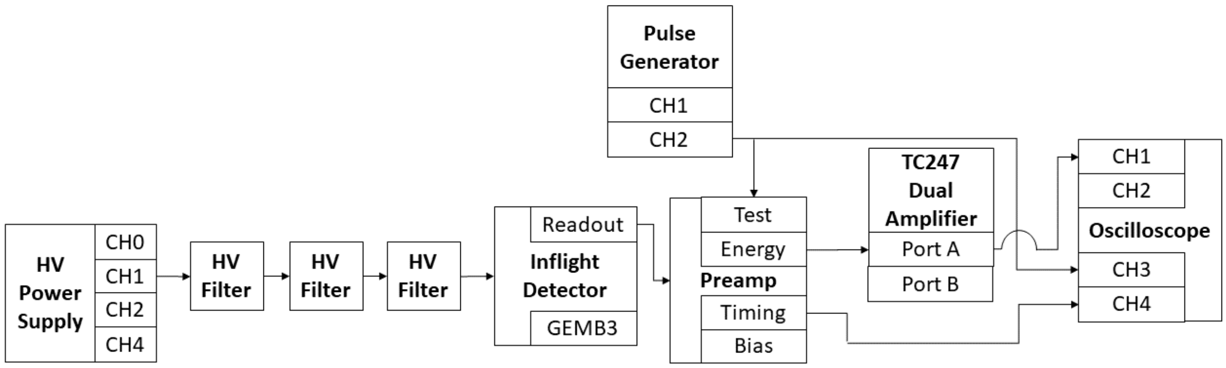

Figure 12. Initial Test Pulse into Detector System Setup Flowchart

This section provides details on the initial configuration used for the In-flight detector during pulse testing. The HV power supply is connected to the detector system but is turned off to inject a test pulse into the preamplifier. The pulse generator will replace the radiation source as the means to generate artificial signal pulses. During operation of the In-flight detector in a high altitude vehicle, the signal will be received from the Readout Strips. Therefore, one of the readout strip channels will be used for pulse testing the detector system. Channel 2 of the pulse generator was selected, as it was the only channel operational on the MHEP 1 DDS Signal Generator. The oscilloscope screenshots that follow are collected from three different sources: the raw signal from the pulse generator (test input signal), the signal from the amplifier and preamplifier, and the signal from the preamplifier (Table 2).

Table 2. Oscilloscope Channels Configuration for In-flight Pulse Test

Oscilloscope Channels Configuration for In-flight Pulse Test		
CH	Color	Connection Source
1	Yellow	Amplifier and Preamp
2	Pink	N/A
3	Blue	Pulse Generator
4	Green	Preamp

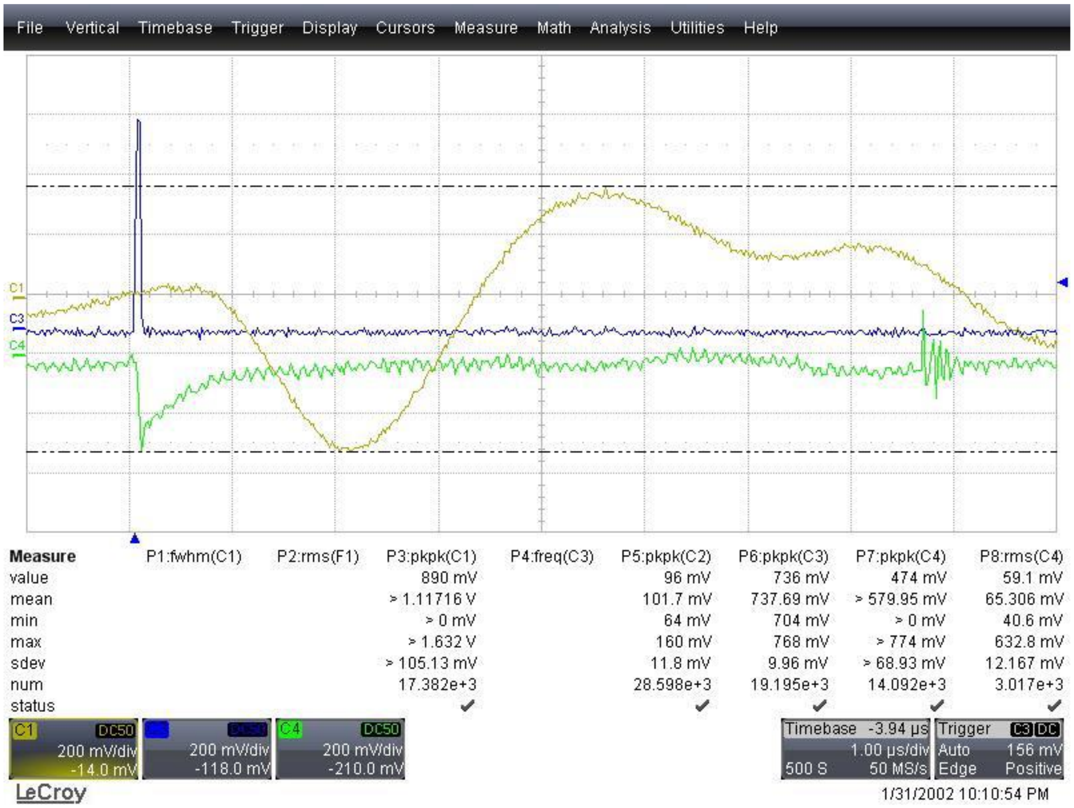

Figure 13. Oscilloscope Screenshot of Signal from Initial Detector System Setup. (C1) Signal from amplifier and preamplifier. (C3) Signal from the pulse generator. (C4) Signal from the preamplifier.

A few comments on Figure 13 which contains the initial signal seen from the detector system when a pulse wave is injected into test input port of the preamplifier. The focus of Figure 13 is the trace seen from the amplifier/preamplifier and the preamplifier. The signal from the preamplifier signal should be a single positive pulse as opposed to the wide bipolar signal seen in Figure 13. The signal from the preamplifier is also unusual due to the oscillation seen at the trailing end of channel 4's trace. The resulting signal shape first led to speculation of an issue from the preamplifier due to the repeating oscillation.

2.4 Test Pulse into Preamplifier

2.4.1 Investigation of Preamplifier Rationale

This section provides a brief explanation for the reasoning to look into pulse testing the preamplifier. Due to the oscillation seen in the signal trace produced in Figure 13, investigation continued with studying the operation of the preamplifier. It was discovered the oscillation would vary depending on the connection at the input of the preamplifier. To observe the behavior of the preamplifier, the detector was disconnected from the input of the respective device. This is the system represented in Figure 14. Not discussed in this report is the effect of the HV filters on the ripple seen from the preamplifier signal. See *Investigation of In-flight Preamplifier Ripple* by Michael Luntz and Devon Madden for more information [4].

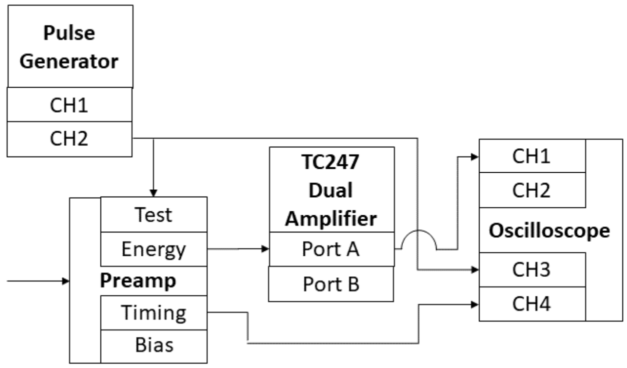

Figure 14. Preamplifier System Setup Flowchart

Figure 15. Picture of an Ortec 142 PC Preamplifier

This section provides a few comments on the preamplifiers used for the In-flight detector. The preamplifiers used for the In-flight detector are the Ortec 142 PC Preamplifier which is depicted in Figure 15 for reference. When using these preamplifiers, the plate for the input connection may vary. This makes no difference to the operation of the preamplifier, so long as the input connection is properly grounded using copper foil and tape. The plates made of ABS plastic will either be black or yellow. As a side comment, preamplifiers with ABS plastic plates are a result from modifying the input connection to a female BNC connector. The diameter of the orifice for the plate needed to be reduced to hold the female BNC connector. Therefore, ABS plastic plates produced at the Florida Tech MakerSpace was the quickest option to satisfy the HEP lab's requirement for additional preamplifiers with BNC input connections.

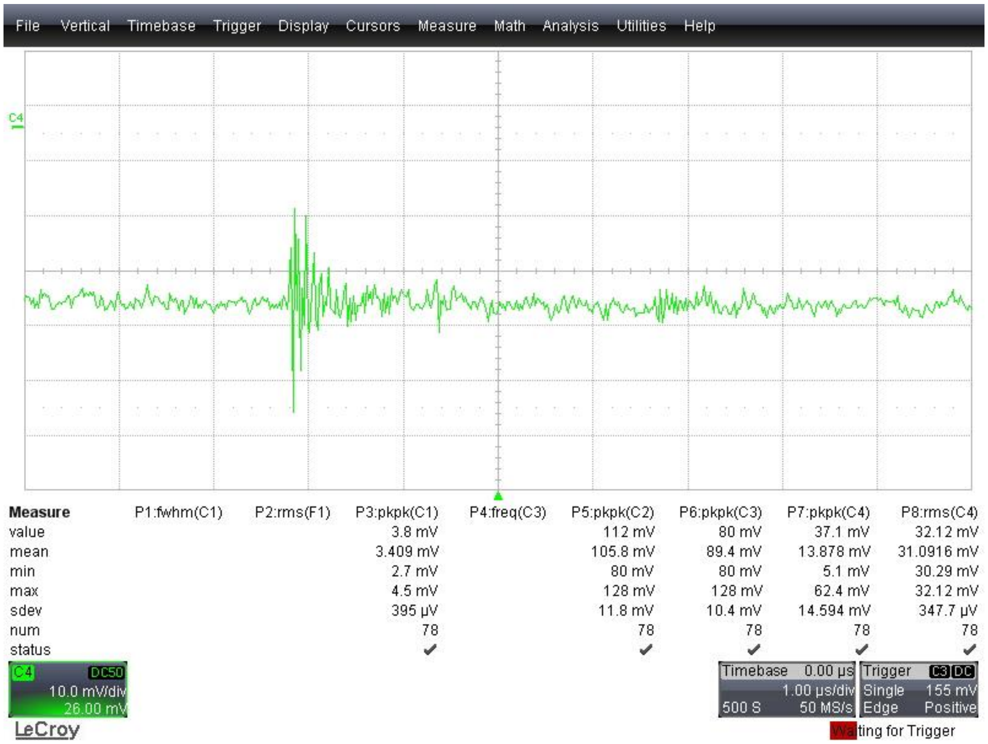

Figure 16. Oscilloscope Screenshot Oscillation on Preamplifier Signal

A few comments on Figure 16 which is a screenshot of only the signal seen from the preamplifier. The oscillation is present when the input of the preamplifier is attached to an unterminated BNC coaxial cable. The mean peak to peak voltage was 13.9 mV and the instantaneous peak to peak voltage was 37.1 mV. Therefore, the magnitude of the oscillation is below the 50 mV limit specified in section 1.1 of the report. However, investigation continued with the Capacitor test for the preamplifier signal.

2.4.2 Capacitor Test on Preamplifier Input

This paragraph provides a brief explanation of the Capacitor test and the test's purpose to section 2.4. The Capacitor test was conducted to determine how much capacitance is required to cause the oscillation or noise seen in Figure 16. The capacitor leads are attached at the input connection of the preamplifier. One lead is connected to the ground and the other lead is connected to the input as depicted in Figure 17. The results for the three capacitors are represented in Figure 18, Figure 19, and Figure 20 below. The signal was observed for three different ceramic capacitors: 5 pF, 10 pF, and 30 pF.

Figure 17. Capacitor Configuration on Preamplifier for Capacitor Test

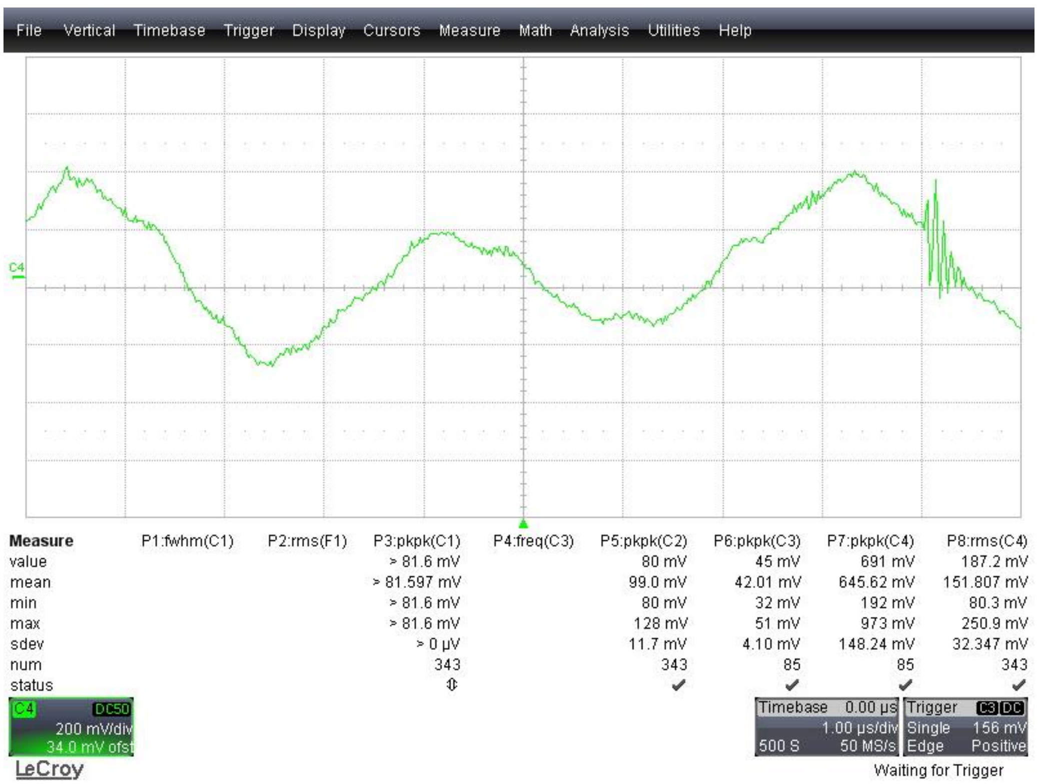

Figure 18. Oscilloscope Screenshot for Preamplifier Signal with 5 pF Capacitor at Input

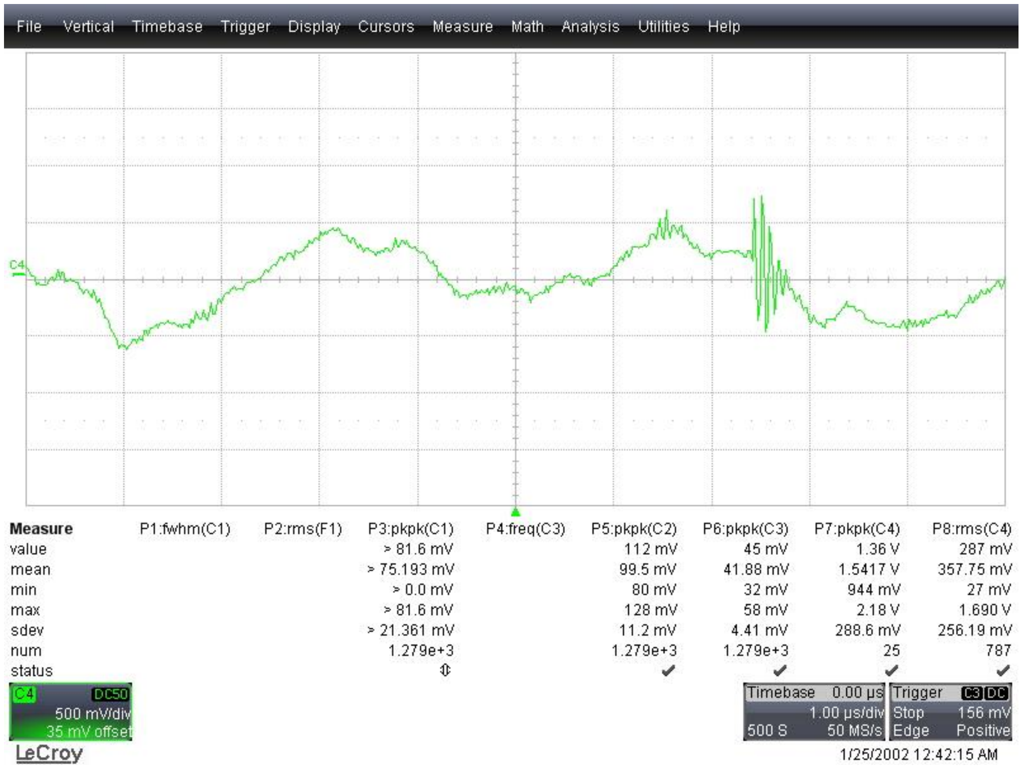

Figure 19. Oscilloscope Screenshot for Preamplifier Signal with 10 pF Capacitor at Input

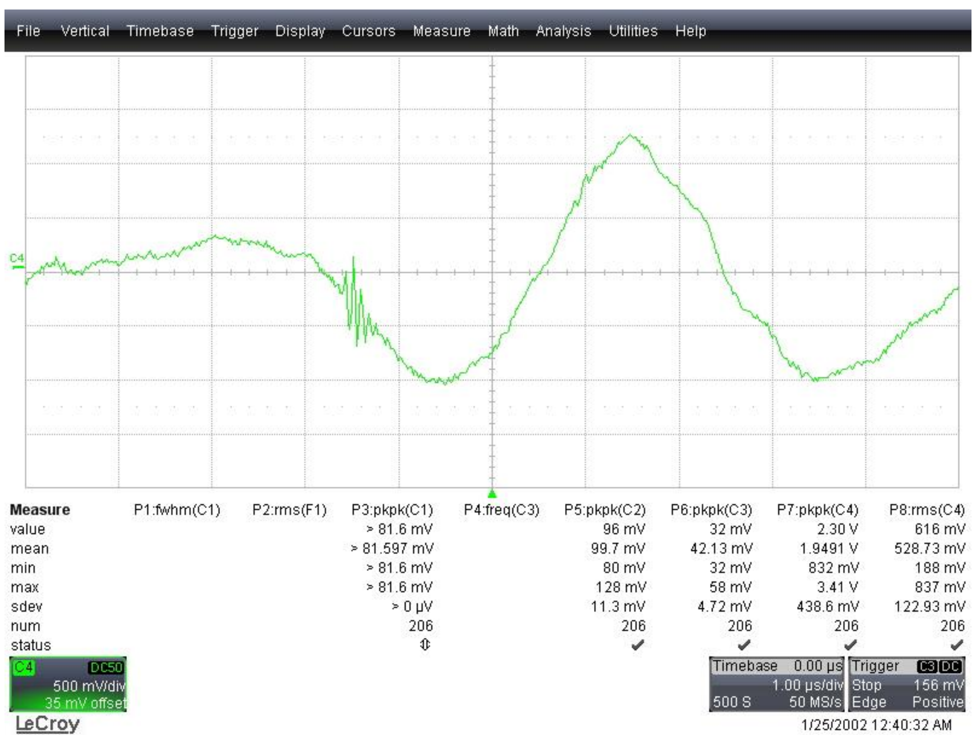

Figure 20. Oscilloscope Screenshot for Preamplifier Signal with 30 pF Capacitor at Input

This paragraph discusses the results seen in Figure 18, Figure 19, and Figure 20 for the Capacitor test. As a result of this test, it was evident only a small capacitor of value 5 pF was necessary to generate the oscillation and produce higher output voltage noise compared to the signal seen in Figure 16. Therefore, it can be stated a capacitance of less than 5 pF would be needed to remove the oscillation and reduce the magnitude of the output voltage noise. After talking to Dr. Marcus Hohlmann, the magnitude of the oscillation is small as mentioned in section 2.4.1. Therefore, investigation into the signal from the detector shifted from the preamplifier to the amplifier used for the detector system. As evident in Figure 13, the signal response of the amplifier is unusual compared to the traces seen in Figure 10.

2.5 Test Pulse into Amplifier

2.5.1 Investigation of Amplifier Rationale

Figure 21. Picture of TC247 and Mechatronics 519 Dual Amplifiers

This paragraph identifies a few notes on the amplifiers used for the detector system. Depicted in Figure 21 are the dual amplifiers used for the In-flight detector. The Tennelec TC 247 dual amplifier was used for this section. However, in section 2.6 the Mechatronics 519 dual amplifier was used for testing.

The following paragraph specifies the rationale for pulse testing the TC 247 dual amplifier. The expected response for the amplifier signal is a single positive pulse (Figure 10). However, a bipolar response is evident from the current configuration of the In-flight detector system (Figure 12). Therefore, the signal from the amplifier needs to be investigated with the pulse generator. For this section, the signal was observed from the two ports of the TC 247 dual amplifier and the signal from only the amplifier.

2.5.2 Results with TC 247 Ports

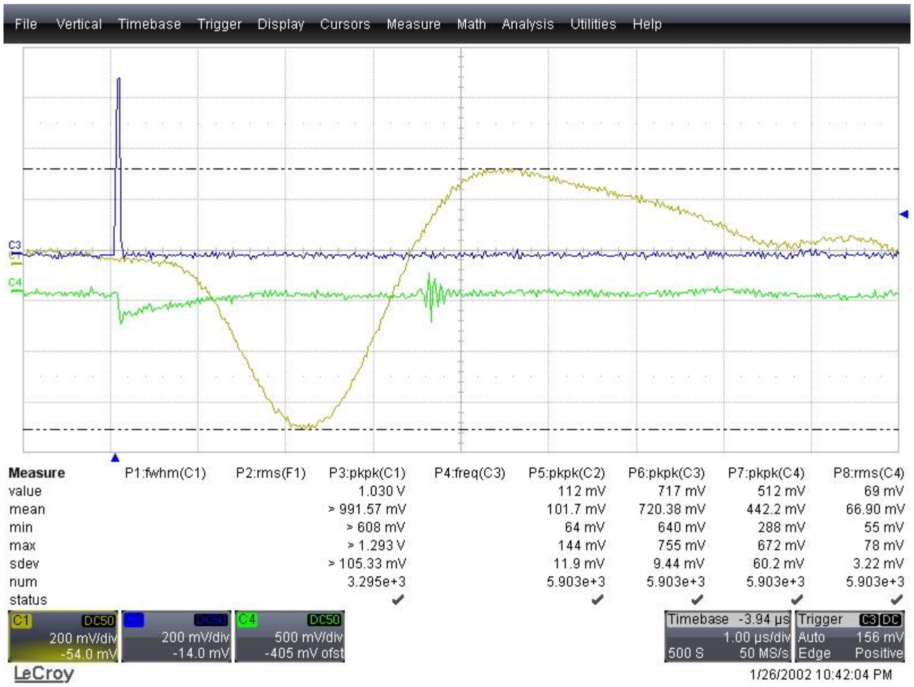

Figure 22. Oscilloscope Screenshot Detector System Signal through Port A of TC247 Amplifier. (C1) Signal from amplifier and preamplifier. (C3) Signal from the pulse generator. (C4) Signal from the preamplifier.

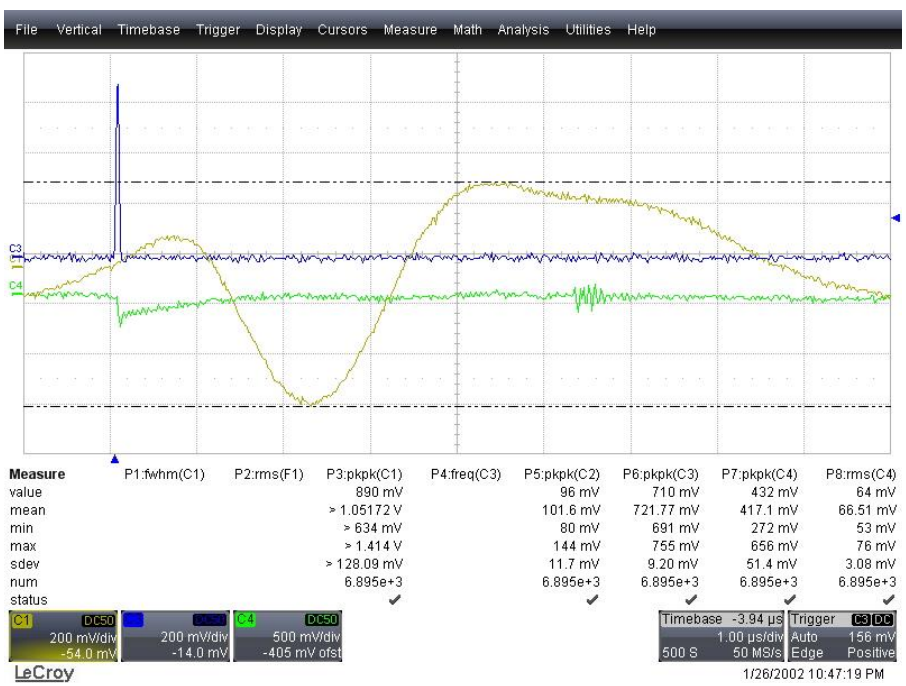

Figure 23. Oscilloscope Screenshot Detector System Signal through Port B of TC247 Amplifier. (C1) Signal from amplifier and preamplifier. (C3) Signal from the pulse generator. (C4) Signal from the preamplifier.

This excerpt provides a few comments on the results seen in Figure 22 and Figure 23. Figure 22 and Figure 23 are the oscilloscope screenshots for port A and B of the TC 247 dual amplifier. The response seen with the two ports did not change substantially. As the mean peak to peak voltage from port A and port B was ~102 mV and the trailing section of the bipolar pulse shape has a slow decay back to ground in both cases.

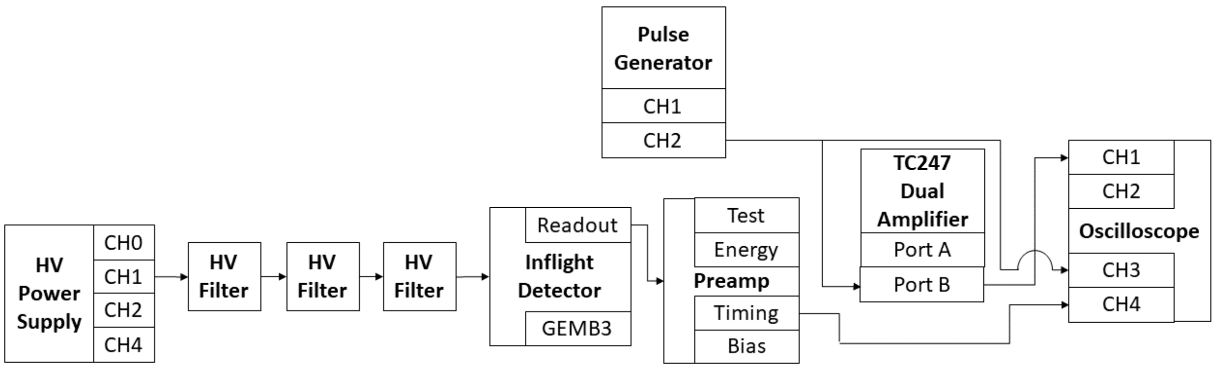

Figure 24. Detector System Bypassing Preamplifier Setup Flowchart

This section provides a few comments on Figure 24. The above flowchart is the configuration of the detector system to observe the signal when the test pulse is injected into the amplifier directly. This was done to isolate the signal from only the amplifier and to verify it is operating correctly for the detection of a signal pulse.

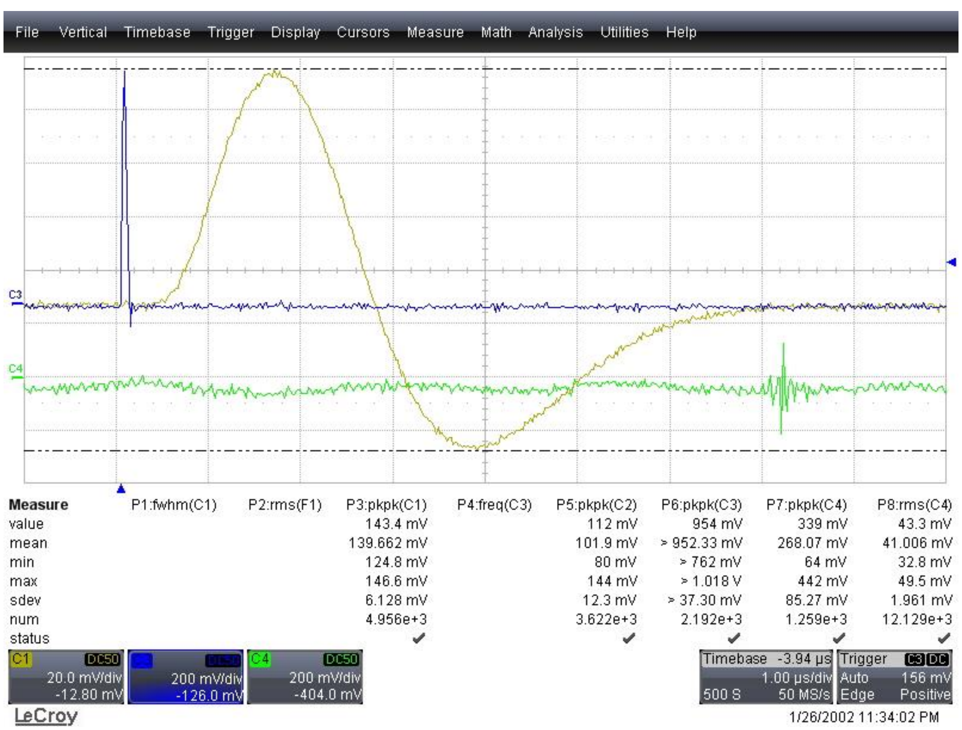

Figure 25. Oscilloscope Screenshot of Detector System Bypassing Preamplifier Setup. (C1) Signal from the amplifier. (C3) Signal from the pulse generator. (C4) Signal from the preamplifier.

A few comments on the results when the test pulse is injected into the amplifier. Based on Figure 25, the signal seen from the amplifier trace is incorrect still. As the trace generated is a bipolar response, where the expected response is a single positive pulse as depicted in Figure 10. Therefore, the settings on the TC 247 amplifier may be incorrect or there is a defect with the amplifier.

2.6 Final Test Pulse Signal from Detector System

2.6.1 Changes to Detector Setup

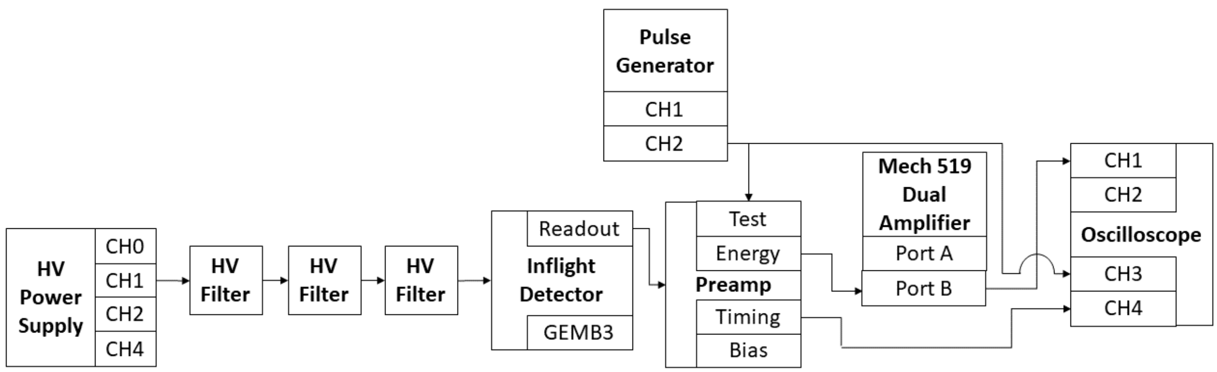

Figure 26. Final Test Pulse into Detector System Setup Flowchart

The following section discusses the changes to the In-flight detector setup for pulse testing. These changes were made possible with the assistance of Michael Luntz and Mehdi Rahmani. The key differences between Figure 26 setup and Figure 12 setup deals with the amplifier. Port B was chosen arbitrarily as both port A and B provides the same response. Instead of using the TC 247 amplifier, the Mechatronics 519 amplifier is now in use. This is because the Mechatronics 519 dual amplifier has a polarity option. The settings for the Mechatronics 519 dual amplifier are located below in Table 3. Additionally, the settings for the pulse generator were adjusted as well. The most important change was the pulse width was increased from 100-200 ns range to 13 ms on the pulse generator. These settings used for the pulse generator are located in slot 4 of MHEP 1 DDS Signal Generator.

Table 3. Mechatronics 519 Dual Amplifier Settings

Mechatronics 519 Dual Amplifier Settings	
Fine Gain	0
Course Gain (Switch 1)	1
Course Gain (Switch 2)	10
Polarity	Negative

2.6.2 Test Pulse Results for Final Detector System Setup

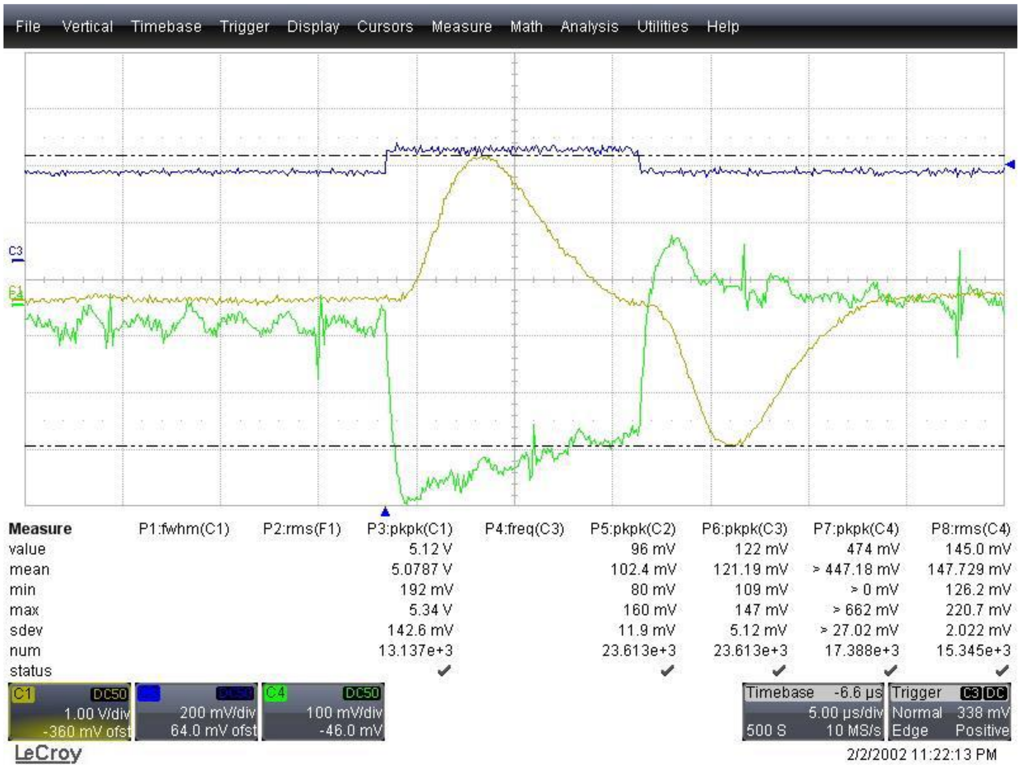

Figure 27. Oscilloscope Screenshot of Final Detector System Setup Signal. (C1) Signal from amplifier and preamplifier. (C3) Signal from the pulse generator. (C4) Signal from the preamplifier.

These are comments on the experimental results seen in Figure 27 from the changes made to the setup of the In-flight detector. After making the changes to the setup discussed in section 2.6.1, a signal similar to what is seen in Figure 10 was obtained. Figure 27 is the correct response by the detector system. Between -5 µs and 5 µs is the same response seen in Figure 10. However, the trailing response after ~6 µs mark is the impulse response to the particle detection. Therefore, the response determined by the In-flight detector is not a bipolar response, but instead a combination of a particle detection pulse and the impulse response to the particle detection.

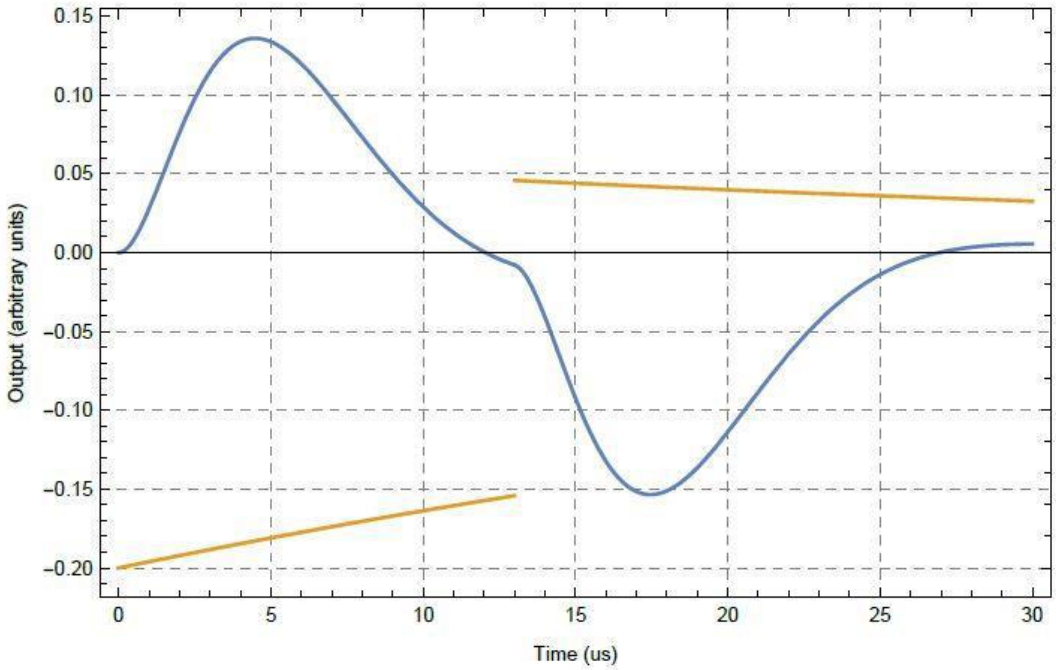

Figure 28. Simulated Preamplifier (Orange) and Amplifier (Blue) Response to Test Pulse *[5]*

These are comparisons between the analytical results to the experimental results for injecting a test pulse into the In-flight detector system. The response collected experimentally with the pulse generator is similar to the shape generated by Michael Luntz's simulation of the preamplifier and amplifier response to a test pulse [5]. Note the orange trace is the preamplifier response and the blue trace is the amplifier response. Therefore, it can be stated the In-flight detector is now properly setup to detect a signal pulse from a radiation source.

3. IN-FLIGHT DETECTOR SOURCE TESTING

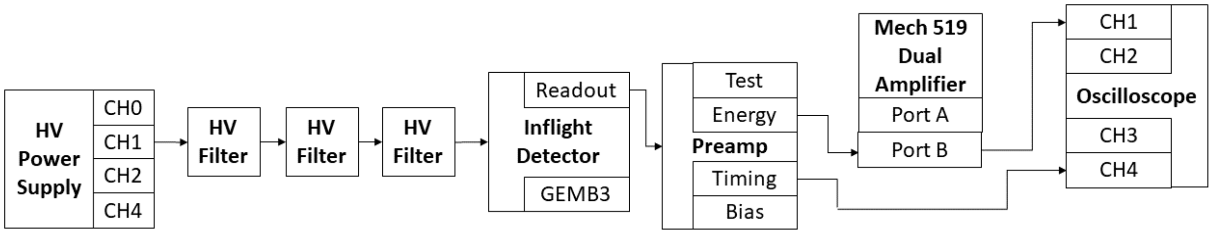

Figure 29. In-flight Detector Setup for Source Testing Flowchart

This section is an overview of the current setup for source testing with the In-flight detector as of March 2020. Figure 29 is the detector setup for testing with radiation sources. The main difference from section 2 of the report is the pulse generator has been removed from the flowchart. Now the detector will be powered by the HV power supply and signal will be generated from the radiation source. The radiation source used for the latest testing of the In-flight detector was a 10 μCi Cadmium-109 (Cd-109) disk from Spectrum Techniques added to the High Bay Physics Research Hall safe on March 2, 2020. This source should not be confused with the two Cd-109 disks from the Physics Graduate Laboratory. The detector is ramped to 4320 V, which is at the operating current for the In-flight detector. The operating current for the In-flight detector is 763 μA. The Cd-109 source is placed inside of a source holder and the source holder is placed above the chamber section of the In-flight detector.

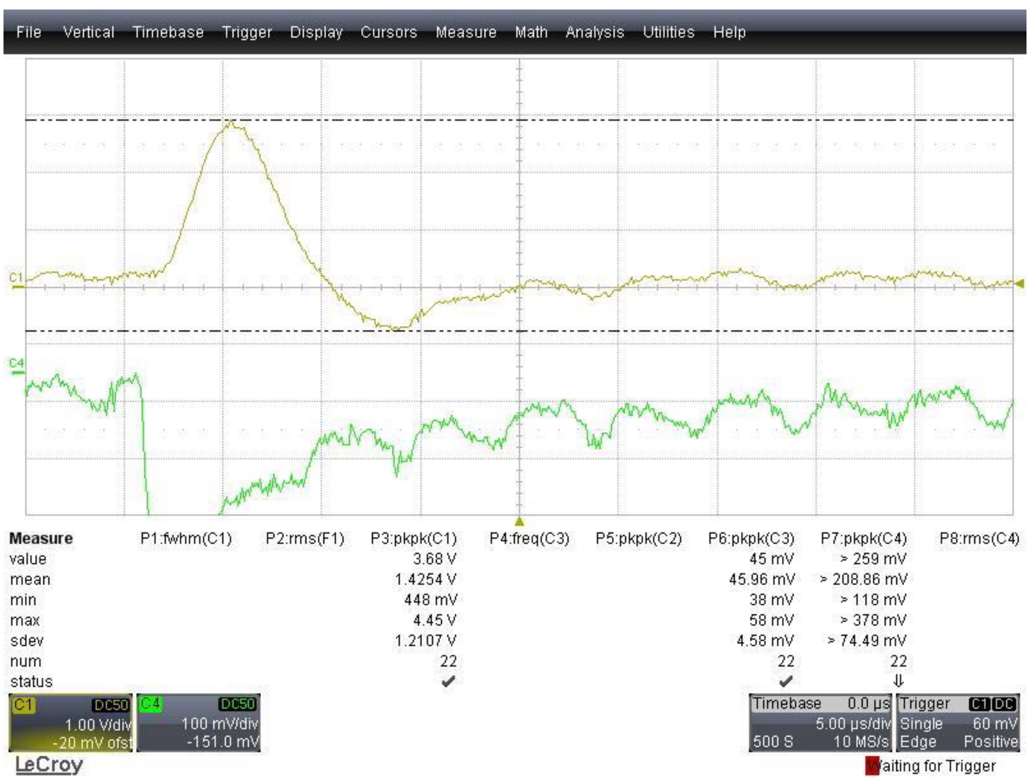

Figure 30. Oscilloscope Screenshot Cd-109 Source Detector Response. (C1) Signal from amplifier and preamplifier. (C4) Signal from preamplifier.

The next three paragraphs will discuss the results and conclusions from source testing the detector with the Cd-109 disk. Figure 30 is a screenshot from the oscilloscope of the response of the In-flight detector when the Cd-109 source is introduced at operating current. As a reminder, the yellow trace is the signal from the amplifier and the green trace is from the preamplifier. Unfortunately, the trace for the preamplifier signal was cut off by the limits of the voltage divisions. However, the correct signal response is visible from the two channels when using the Cd-109 source. It should be noted that the signal from the preamplifier is inverted, therefore unlike Figure 10 the polarity is in the negative direction.

Unfortunately, further investigation is still required. As the trace shape is accurate, the rate at which signal pulses are detected was relatively low. The rate was 10-20 signal pulses per minute, however the desired rate with the Cd-109 source should be on the order of magnitude of 10^4 or higher. Additionally, the time constant of the preamplifier relaxation after the transition is shorter compared to Figure 10. Therefore, an issue still exists with the detector system's ability to generate a signal pulse from a radiation source.

Future studies for the In-flight detector have been outlined in section 4. A potential cause of this response may be occurring in the HV filters. Therefore, test 2 will be performed to evaluate the connections, conditions of the circuit elements, and test the operation of the HV filters with a pulse generator.

4. FUTURE STUDIES

4.1 Overview

In the Fall 2020 semester, the following four electronic tests are to be conducted. These are done to continue the investigation into the In-flight detector's ability to identify a signal pulse. The tests include: ground Bias input, AC vs. DC couple, HV filter check, and SHV cable to BNC coaxial cable shielding test. Each test's objectives are listed below.

4.2 Test 1: Ground Bias Input

- Observe oscilloscope signal of detector system
- Ground Bias Input connection on preamplifier
    - Disconnect input connection to Bias circuit
    - Solder 10-30 MΩ resistor to input port and ground
- Observe oscilloscope signal of detector system after change

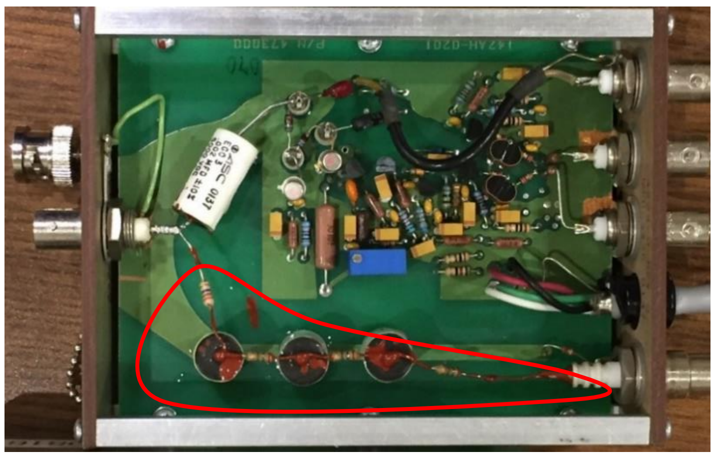

Figure 31. Preamplifier 8 Circuit with Bias Circuit Circled in Red

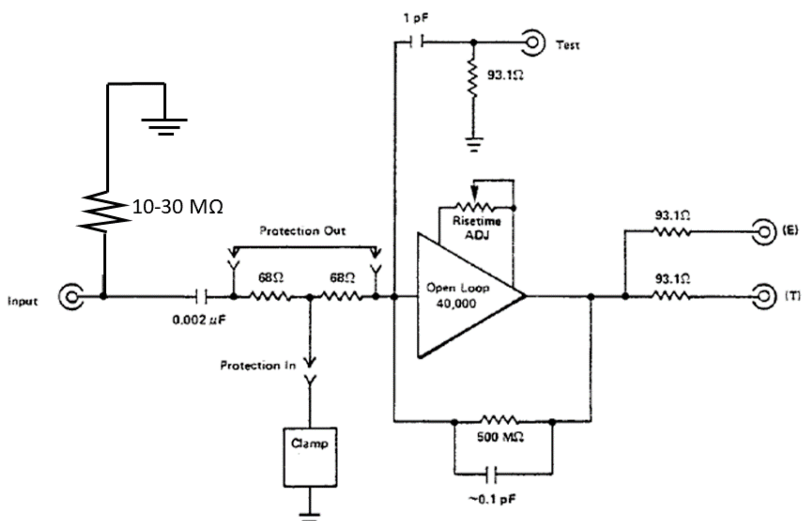

Figure 32. Test 1 Simplified Block Diagram of the 142PC Preamplifier Modified from *[6]*.

4.3 Test 2: AC vs. DC couple

- Apply 50V from HV supply directly to oscilloscope
- Record oscilloscope trace with AC couple selected in trigger controls
- Record oscilloscope trace with DC couple selected in trigger controls

4.4 Test 3: HV filter check

- Open HV filters and take pictures of interior circuitry
- Inspect open HV filters for bad connections or burnouts
- Use multimeter and check connections
- Connect HV filter to pulse generator and apply a sinusoidal wave
    - Measure attenuation
    - Create bode plots

4.5 Test 4: SHV to BNC coaxial cable shielding

- Test SHV to BNC coaxial cable without alterations and record oscilloscope screenshot
- Cover with copper foil, test, and record oscilloscope screenshots

5. REFERNCES

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