Testing the Ortec 142PC Preamplifier using a Koolertron DDS Signal Generator

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Chapter 1

Introduction

1.1 Summary

The following manual provides a procedure for testing the Ortec 142PC preamplifier and presents analyses of eight different preamplifiers according to the outlined procedure. Before describing the experimental setup and presenting the testing procedure, one needs to explore the importance of this test. In addition to this, the design of the preamplifier needs to be scrutinized to effectively test the device. This chapter aims to outline the motivation of this test and to analyze the 142PC preamplifier.

1.2 Motivation

As is highlighted in the maintenance instructions for the preamplifier [1], preemptively testing preamplifiers removes the possibility for errors when collecting data from a detector. In the case of High Energy Physics (HEP) Lab A, qualifying the performance of all available preamplifiers will allow for quicker quality control (QC) testing of micro-pattern gaseous detectors (MPGDs).

Certain QC tests require the use of a chain of devices to process the signal from an MPGD. In a general sense, the following chain of devices is utilized:

$$\text{MPGD} \rightarrow \text{Preamplifier} \rightarrow \text{Amplifier} \rightarrow \text{Discriminator} \rightarrow \text{Scalar Counter}$$

Since the preamplifier is the first device that receives the signal from the detector, it is critical to verify that it produces a consistent output amplitude per injected charge across a range of input signal amplitudes.

To test the preamplifier, it must be isolated from the other signal processing devices. A test pulse must be generated and injected into the device. This signal is compared to the output signal from the preamplifier across a range of test pulse amplitudes. The width of the input pulse is modified and the width of the output pulse is studied to verify that they are equivalent.

1.3 Nature of the Ortec 142PC Preamplifier

This preamplifier can be described in the following fashion. First, the device inverts whatever signal is injected into it. For instance, if a positive pulse of a certain amplitude is injected into the input port, the resulting signal that exits from the device will be negative. Second, the device is charge-sensitive. This means that an input voltage will be seen as the device as a certain amount of charge because a capacitor is at each input port (“Test” and “Input”). Figure 1.1 presents the circuit diagram of the preamplifier.

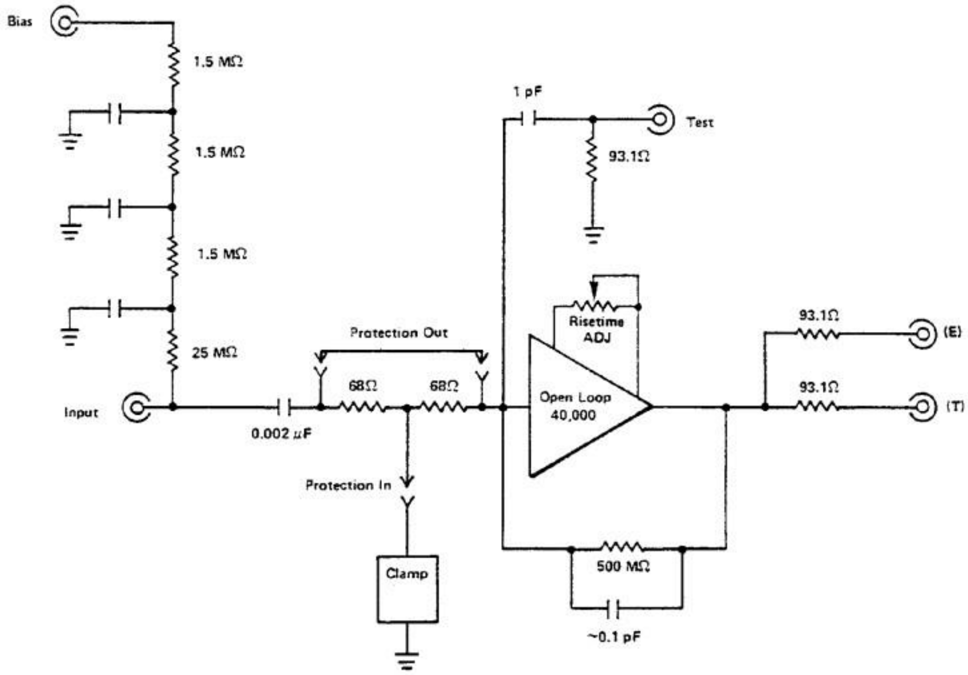

Figure 1.1: Schematic representation of Ortec 142PC preamplifier [1], showing input and output ports where physically located on the device as well as the operational amplifier used to invert the input signal

The charge-sensitivity of the 142PC preamplifier is dependent on which input port is used. Both ports utilize a capacitor to inject charge into the operational amplifier, so the injected charge can be found by the following relation, where Q_{in} and V_{in} are the injected charge and potential, respectively, and C is the capacitance the input pulse interacts with.

$$Q_{in} = CV_{in} \tag{1.1}$$

In the case of testing the performance of the operational amplifier, the “Test” connection is employed. This port immediately feeds voltage to a 1 pF capacitor, which injects charge into the operational amplifier. If a pulse with amplitude of 1 mV is passed through the capacitor, 1 fC of charge would be introduced to the operational amplifier, using Equation 1.1. Similarly, one can find that the injected charge from the “Input” connection is 2 pC, if the input pulse has the same amplitude.

Two statements about the injected charge may be made about the preamplifier.

1. As input pulse height is increased, the injected charge increases
2. As input pulse duration is increased, the injected charge does not increase once the capacitor reaches full capacity

From these, two conclusions may be made about the amplitude of the output pulse. Statement 1 would suggest that as the pulse height, or amplitude, is increased, the output amplitude is also increased. This is a trivial conclusion since the injected charge would be passed through the operational amplifier. The conclusion from the second statement is also trivial; changing the duration of the input pulse does not affect the amplitude of the output pulse. However, these conclusions lead to tests that verify the performance of this type of preamplifier.

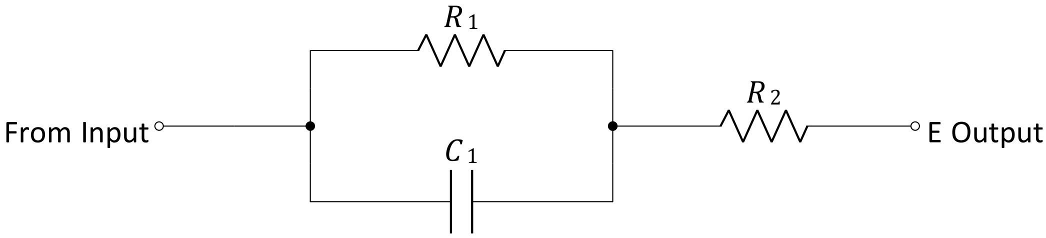

Figure 1.2: Elements involved in output of preamplifier, reduction from Figure 1.1; R_1 = 500 MΩ, C_1 = 0.1 pF, R_2 = 93.1 Ω

Another important aspect of this preamplifier is the rise-time of the output signal. To better analyze this, one output will be isolated, in this case "Energy," visualized in Figure 1.2. To determine the upper limit of the rise-time of the output pulse, one calculates the time constant for this circuit using the following formula.

$$\tau = (R_1 + R_2)C \tag{1.2}$$

Since the second resistance value is substantially lower than that for the first resistor, it can be ignored in this calculation. Using Equation 1.2 and the values for Figure 1.2, the time constant is found to be 50 μs. The significance of this value can be symbolically represented in the following way.

$$t_{goodrise} < \tau$$

If the rise-time of a preamplifier output is less than the value of the time constant associated with the output, then the preamplifier is considered to be in good shape [1].

Chapter 2

Equipment Setup

2.1 Summary

Testing the Ortec 142PC preamplifier requires isolation from the chain of signal processing devices. Once this is accomplished, the following setup is used to test the device. All connections are BNC and the connectors on the oscilloscope are connected via a BNC tee with 50 Ω terminators. Note that the preamplifier is connected to a preamplifier power supply serial connection on the back of an amplifier.

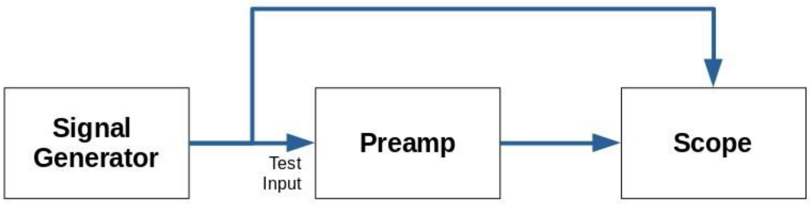

Figure 2.1: Flow chart displaying connections required for testing preamplifier

2.2 Required Equipment

Certain equipment are required to perform this test. The following table presents these devices. In addition to these devices, several BNC cables need to be procured to connect the signal generator, preamplifier, and oscilloscope according to Figure 2.1.

Table 2.1: List of equipment required to perform preamplifier test

Device	Make
NIM Crate	Nuclear Instruments
Amplifier Module	Ortec
142PC Preamplifier	Ortec
DDS Signal Generator	Koolertron
2-Channel Oscilloscope	Tektronix

The NIM crate supplies power to the amplifier module. This in turn powers the preamplifier via the serial connector attached to the preamplifier. The serial connector can be secured via clamps above and below the serial socket on the amplifier.

2.3 Setup Description

Before setting up the equipment to perform tests on the preamplifier, make sure that the crate is powered off. Follow the following procedure to set up the equipment properly.

1. Insert the amplifier module into the NIM crate and fasten via attachment screws if not done so already

2. Connect the preamplifier power cable (serial connection) to the corresponding power adapter on the back of the amplifier

3. Connect the signal generator to the preamplifier "Test" input and the first channel on the scope via a BNC tee; tee off the connection to the scope and connect a 50 Ω terminator to the other end of the tee

4. Connect the "Energy" output of the preamplifier to the second channel on the scope and terminate as in the previous step

Chapter 3

Testing Procedure

3.1 Summary

The testing procedure outlined in this section is based on that which is outlined in the preamplifier manual [1]. Before performing the tests, ensure that the preamplifier is connected as outlined in the previous section.

3.2 Procedure

1. Set up the signal generator to produce short pulses

   (a) Press $\boxed{\text{CH 1}}$ to make channel 1 active

   (b) Select $\boxed{\text{WAVE}}$: use knob to select Pulse

   (c) Select $\boxed{\text{FREQ}}$: use knob and arrow buttons to change to 150 kHz

   (d) Select $\boxed{\text{DUTY}}$: use knob and arrow buttons to change to 0.1%

   (e) Select $\boxed{\text{AMPL}}$: use knob and arrow buttons to change to 0.010 V

2. Measure and tabulate the *set signal generator amplitude*, *input voltage to preamplifier* and *output voltage from preamplifier*

3. Increase the set amplitude as follows and repeat the previous step at each point:

   (a) 10 - 100 mV by increments of 10 mV

   (b) 100 mV - 2 V by increments of 100 mV

4. Plot the output voltage versus the injected charge to calculate the output pulse amplitude per injected input charge of the preamplifier; calculate the ratio between output and input voltage and plot this versus set amplitude

5. Set the amplitude to 50 mV

6. Measure and tabulate the *duty cycle* and the *full width at half maximum (FWHM)* for input and output signals

7. Increase the duty cycle and repeat the previous step for the following intervals: 1%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%

8. Calculate the ratio between input and output FWHM and plot this versus the duty cycle; plot the output FWHM versus the duty cycle

9. Change the input connection to the “Input” connector; observe the rise-time of the output signal and compare to the time constant for the output circuit

3.3 Data Collection Tips

Take screenshots of input and output signals to compare amplitudes and calculate the rise-time of the output signal. Keep a log of types of measurements performed and changes made to the setup or procedure. Document and store, for future reference, the output amplitude per input charge for each preamplifier being tested and the ratio of rise-time of the output signal to the time constant of the output circuit.

Chapter 4

Sample Data and Analysis

4.1 Summary

This chapter presents results from testing eight preamplifiers. The only ones which presented issues were preamplifiers 3 and 4. These preamplifiers either did not have a discernible output amplitude per input charge or reached the expected nature of operation at a higher set amplitude, not across the full range of operation. Figure 4.1 displays the output amplitude per input charge for nominal preamplifiers when the “Test” input was used. While Figure 4.2 displays the output amplitude per input charge for nominal preamplifiers when the “Energy” input was used. Note the set amplitude was increased from 40 mV to 200 mV, in increments of 20 mV for the “Energy” input setup. In the worst case, a nominal preamplifier should not be less than 0.5 V/pC, since that would be too far from the accepted value of at least 1 V/pC. Note that for the first two preamplifiers, set amplitude ranged up to only 1 V. Only the section on the first preamplifier presents duty cycle results since these are almost identical for all preamplifiers.

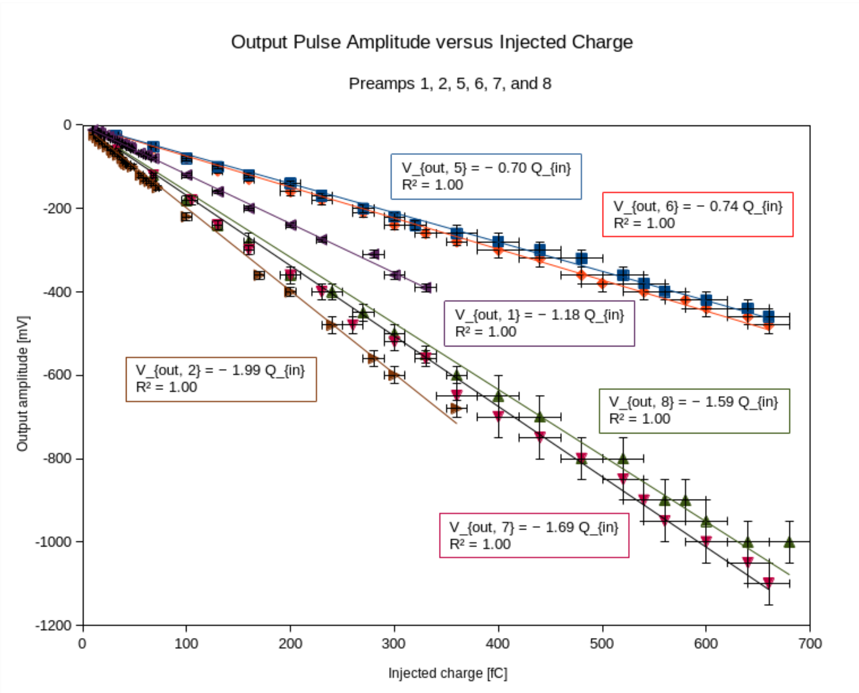

Figure 4.1: Output amplitude per input charge for preamps 1, 2, 5, 6, 7, and 8 using the "Test" input; Note the presence of inversion and a discernible amplification

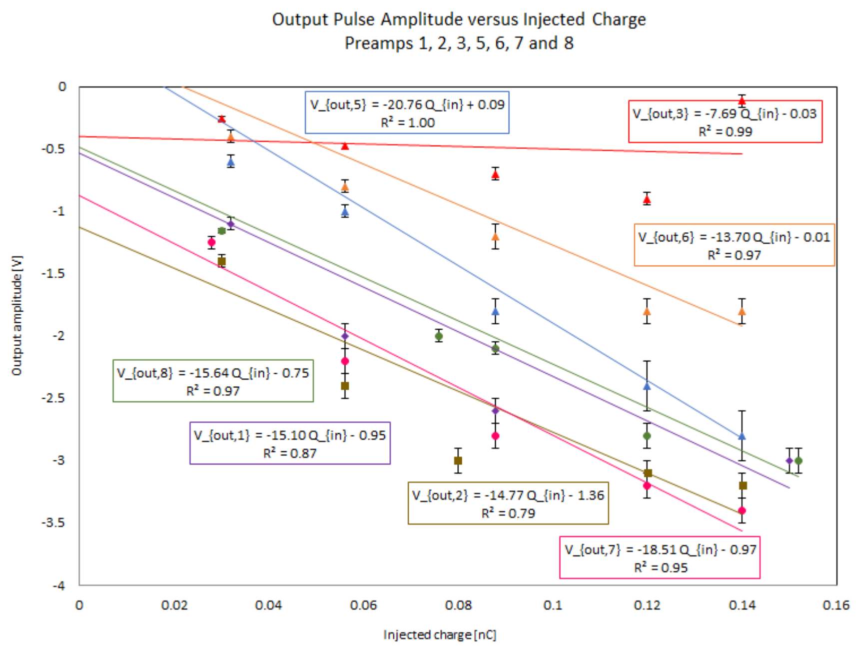

Figure 4.2: Output amplitude per input charge for preamps 1, 2, 3, 5, 6, 7, and 8 using the "Energy" input

4.2 Preamplifier 1

The following section provides calculations with respect to the performance of the first preamplifier. Following the outlined procedure, set amplitude was increased from 10 mV to 1 V. Afterwards, Figure 4.3 was produced to examine the output pulse amplitude per input charge of the preamplifier. The errors in each direction are half of the smallest voltage division on the oscilloscope.

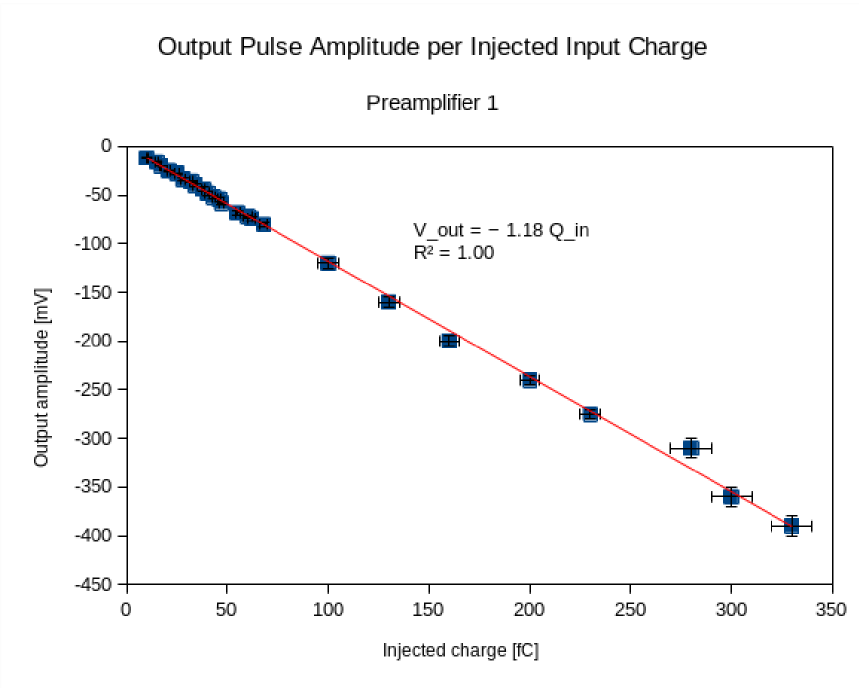

Figure 4.3: Output pulse amplitude plotted as a function of injected charge for the first preamplifier using the “Test” input; Note that the output amplitude per input charge is negative and its magnitude is greater than 1

Two aspects of this preamplifier can be extracted from Figure 4.3. First, the output amplitude per input charge is negative. This is indicative of the fact that the preamplifier inverts the input signal. Second, the magnitude of this factor is greater than one. This implies that the output signal amplitude will be larger than the input amplitude. To determine the goodness of fit for Figure 4.3, a normalized χ^2 test was performed on the output amplitude per input charge. If the resulting number is less than one, then the trend fits the data well. The standard formula for this calculation is as follows.

$$\tilde{\chi}^2 = \frac{1}{N-1}\left|\sum_{i=1}^{N}\frac{(O_i - E)^2}{E}\right| \tag{4.1}$$

In Equation 4.1, N is the number of data points (25 in this case), O_i is an individual observed output amplitude per input charge, and E is the expected output amplitude per input charge. The O_i's were calculated from the ratio of output amplitude and input charge at each set amplitude and E is the slope of Figure 4.3. This calculation is displayed below.

$$\tilde{\chi}^2 = \frac{1}{24}\left|\frac{(-1.20-(-1.18))^2}{-1.18} + \frac{(-1.07-(-1.18))^2}{-1.18} + \cdots\right|$$
$$= 1.55 \cdot 10^{-3}$$

Since this number is much less than 1, the output amplitude per input charge of -1.18 V/pC expected from Figure 4.3 sufficiently characterizes this preamplifier.

This output amplitude per input charge was calculated a second time by finding the ratio between output amplitude and input charge at each data point. The average of these values and the standard deviation of the mean were calculated in the standard fashion. This calculation yielded a value of -1.19 ± 0.01 V/pC. To properly compare this value to the slope of Figure 4.3, the error in the slope was calculated. Using these values, this second calculation was found to be 0.05σ from the expected result. Thus, it can be concluded that the test input of preamplifier 1 produces nominal readings.

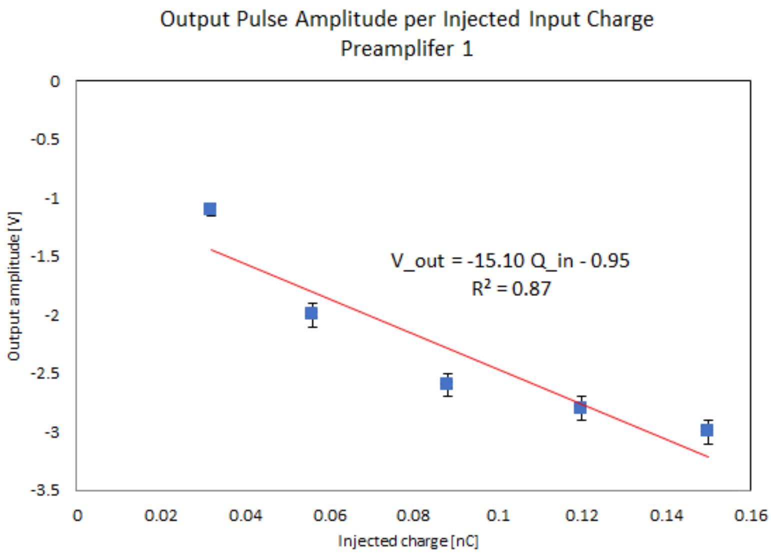

Figure 4.4: Output pulse amplitude plotted as a function of injected charge for the first preamplifier using the “Energy” input

Figure 4.4 represents the results from preamplifier 1 connected to “Energy” input. Unlike Figure 4.3, the graph above outputs -15.10 V per 1 nC of injected charge. Five data points were collected to create Figure 4.4. The equation of the line indicates when no charge is injected into the preamplifier, an output of -0.95 V is generated by the device. The R^2 value is 0.87 which is below the value for the “Test” input of 1.00, suggesting the data from the “Energy” input doesn’t fit the linear regression as well as the “Test” input data.

The second test performed involved increasing the duty cycle and observing how the full width at half maximum of the input and output signals changed in relation to each other. One would expect that the ratio between the full width at half maximum values would be one across the full scale of duty cycle. Figure 4.5 shows that the widths of the input and output pulses are equivalent across the full range of duty cycle modification, confirming what was expected.

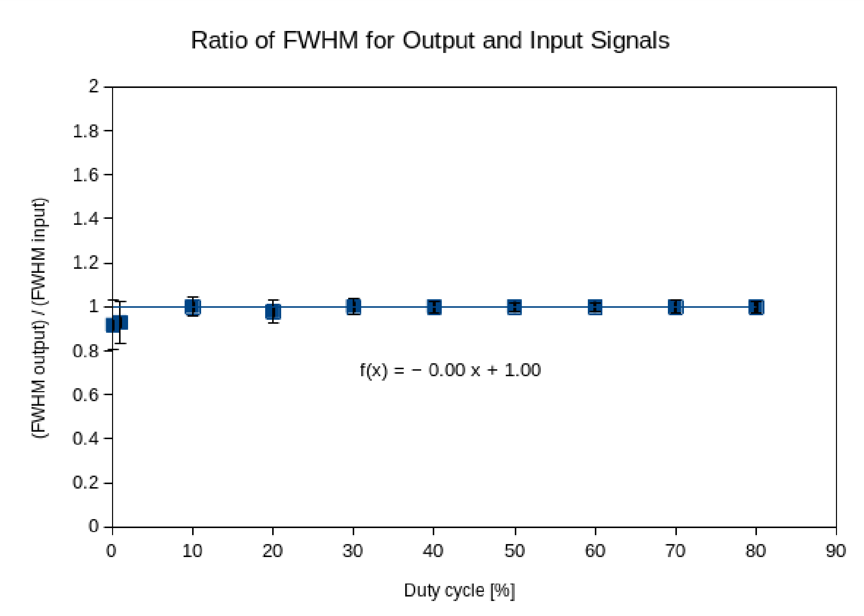

Figure 4.5: Ratio of full width at half maximum values from 0.1% to 80% duty cycle; As expected, the ratio stays the same and shows that the widths of input and output are equivalent

4.3 Preamplifier 2

A similar process was performed to test the second preamplifier. In this case, the magnitude of the output amplitude per input charge was larger, approaching 2 V/pC. Once again, this graphical calculation confirmed the inverting nature of this preamplifier. Figure 4.6 displays the output amplitude plotted as a function of input charge.

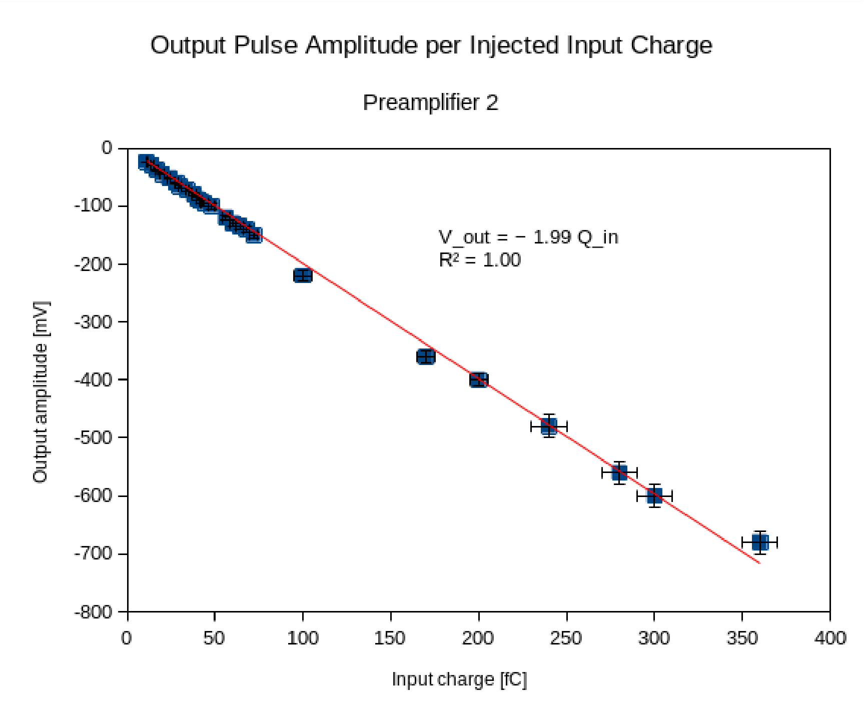

Figure 4.6: Output amplitude per input charge for the second preamplifier using the “Test” input, showing similar qualities to preamplifier 1

To gauge the accuracy of this value for the output amplitude per input charge, a normalized χ^2 test was performed on the data. Using Equation 4.1, the goodness of fit was calculated as follows. Note that there were 25 data points, as with the first preamplifier.

$$\begin{aligned}\tilde{\chi}^2 &= \frac{1}{N-1}\left|\sum_{i=1}^{N}\frac{(O_i - E)^2}{E}\right| \\ &= \frac{1}{24}\left|\frac{(-2.18-(-1.99))^2}{-1.99}+\frac{(-2.14-(-1.99))^2}{-1.99}+\cdots\right| \\ &= 0.01\end{aligned}$$

Since this number is dwarfed by 1, the expected value of -1.99 V/pC for the output amplitude per input charge accurately describes the second preamplifier.

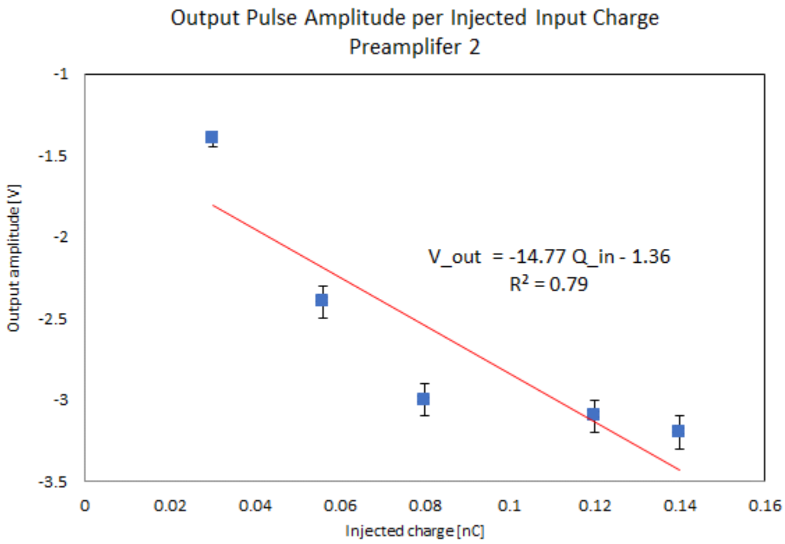

Figure 4.7: Output pulse amplitude plotted as a function of injected charge for the second preamplifier using the “Energy” input

Figure 4.7 represents the results from preamplifier 2 connected to “Energy” input. Unlike Figure 4.6, the graph above outputs -14.77 V per 1 nC of injected charge. Five data points were collected to create Figure 4.7. When no charge is injected into preamplifier 2, based on the equation of the line, an output of -1.36 V comes from the preamplifier. Once again, the R^2 value of 0.79 for Figure 4.7 is less than the value obtained from the “Test” input. This suggests the data doesn’t fit the linear regression as well as the results from Figure 4.6.

4.4 Preamplifier 3

In a similar way, the third preamplifier was tested. However, in this case, it wasn't until the set amplitude was ramped up to 400 mV that an expected output amplitude per input charge was observed. For all previous test amplitudes, this value was positive, contrary to the expected nature of the preamplifier. Another feature of this preamplifier that implies a malfunctioning device is the value of this output amplitude per input charge. Since it is less than 0.5 V/pC, Figure 4.8 displays the typical trend, in this case for preamplifier 3.

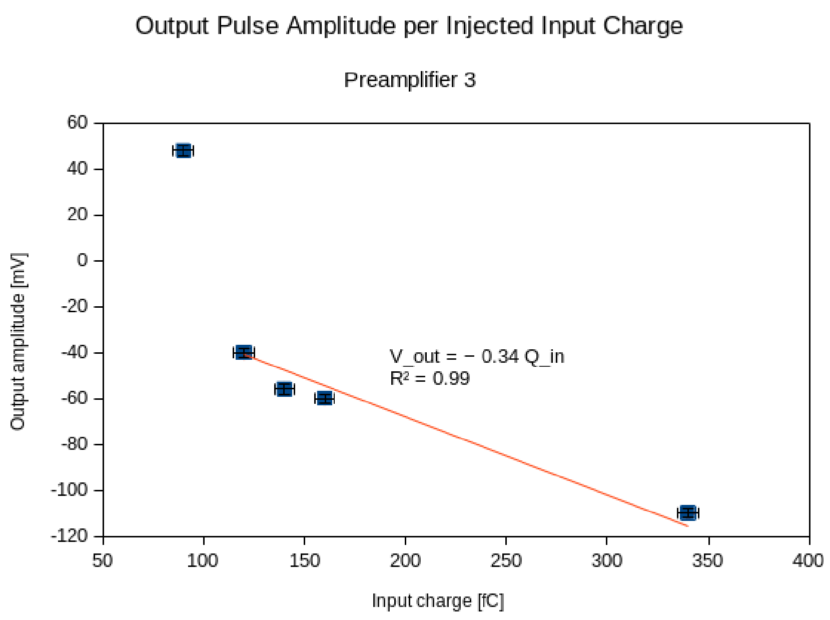

Figure 4.8: Output amplitude per input charge for the third preamplifier using the "Test" input; Prominent issues with the preamplifier are clear from the discontinuity before 100 fC of input charge and the small output amplitude per input charge magnitude

Clearly, this preamplifier does not follow -0.34 V/pC because of some internal electronics issue. However, to quantitatively verify this accusation, a normalized χ^2 test was performed on the data. in this case, there were 14 data points.

$$\begin{aligned}\tilde{\chi}^2 &= \frac{1}{N-1}\left|\sum_{i=1}^{N}\frac{(O_i-E)^2}{E}\right| \\ &= \frac{1}{13}\left|\frac{(0.53-(-0.34))^2}{-0.34}+\dots+\frac{(-0.33-(-0.34))^2}{-0.34}+\dots\right| \\ &= 1.73\end{aligned}$$

Since this number is greater than one, the trend in Figure 4.8 is not accurate across the full range of set amplitudes. This indicates that the preamplifier is faulty. Currently, this issue is being investigated by research assistants.

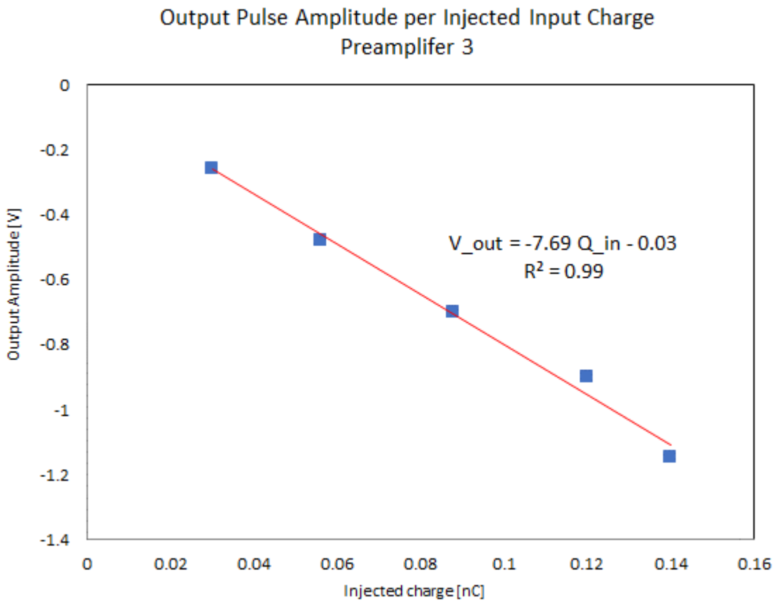

Figure 4.9: Output pulse amplitude plotted as a function of injected charge for the third preamplifier using the “Energy” input; Note this data was collected after research assistants repaired the internal circuit connections

Figure 4.9 represents the results from preamplifier 3 connected to “Energy” input after repairs were made to the internal electronics. Unlike Figure 4.8, the graph above outputs -7.69 V per 1 nC of injected charge. Five data points were collected to create Figure 4.9. The y-intercept from the above plot indicates that the preamplifier still generates a small voltage of 0.03 V when no charge is provided. The R^2 value is close to 1, which suggest the data from Figure 4.9 closely fits the linear trendline.

4.5 Preamplifier 4

Results are not compiled for preamplifier four because this device displayed no discernible output. This presented obvious issues for collecting data, and since no useful data was generated from this device, it was not quantitatively analyzed. As with preamplifier 3, this device is currently being investigated by research assistants.

4.6 Preamplifier 5

The next four preamplifiers were recently purchased at the end of Summer 2019. This device, labeled as preamplifier 5, was found to be in nominal condition, as the following analysis will show. Note that the output amplitude per input charge is less than one but inverted, as can be seen in Figure 4.10. One thing to note is that for preamplifiers 5, 6, 7, and 8, the set amplitude ranged from 100 mV to 2 V.

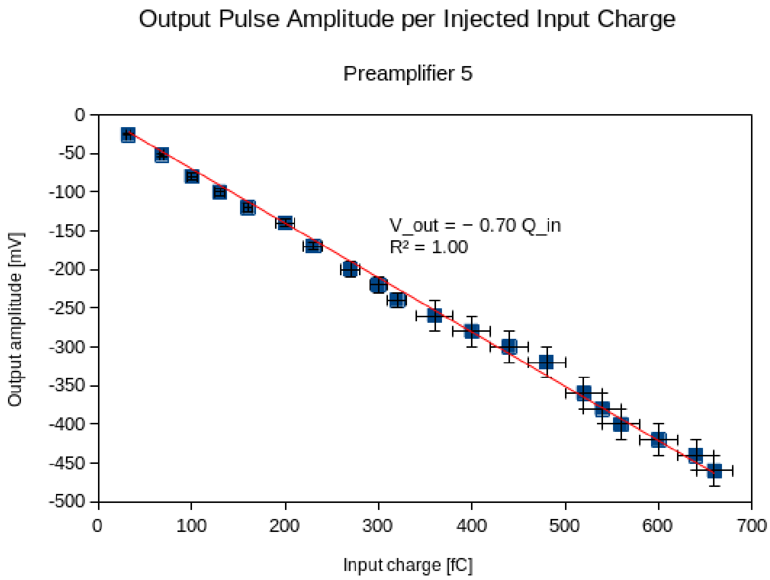

Figure 4.10: Output amplitude as a function of injected charge across the range of set amplitudes from 100 mV to 2 V for the fifth preamplifier using the "Test" input

To determine how well the output amplitude per input charge fit the data, Equation 4.1 was used to compare the expected value of -0.70 V/pC to each point in Figure 4.10. This calculation is performed below, with 20 data points.

$$\begin{aligned}\tilde{\chi}^2 &= \frac{1}{N-1}\left|\sum_{i=1}^{N}\frac{(O_i-E)^2}{E}\right| \\ &= \frac{1}{19}\left|\frac{(-0.81-(-0.70))^2}{-0.70}+\frac{(-0.76-(-0.70))^2}{-0.70}+\cdots\right| \\ &= 3.26\cdot 10^{-3}\end{aligned}$$

Evidently, this expectation describes the performance of the preamplifier through the test input quite accurately.

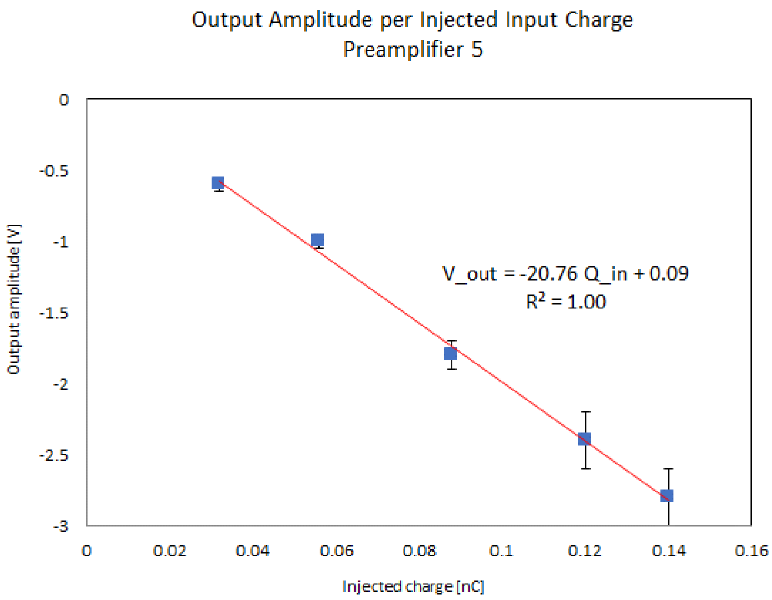

Figure 4.11: Output pulse amplitude plotted as a function of injected charge for the fifth preamplifier using the "Energy" input

Figure 4.11 represents the results from preamplifier 5 connected to "Energy" input; unlike Figure 4.10, the graph above outputs -20.76 V per 1 nC of injected charge. Five data points were collected to create Figure 4.11. When 0 nC of charge is injected into the preamplifier, the device generates +0.09 V. The data from Figure 4.11 fits the trendline as the R^2 value is 1.00, this is the same as the results from the "Test" input seen in Figure 4.10.

4.7 Preamplifier 6

The sixth preamplifier proved to be as operational as the previous preamplifiers, disregarding preamps 3 and 4. As with preamplifier 5, the output amplitude per input charge is less than one but is inverted. The inversion of the input signal is critical since this device is an inverting preamplifier. Figure 4.12 displays the trend of output amplitudes across a range of injected charges.

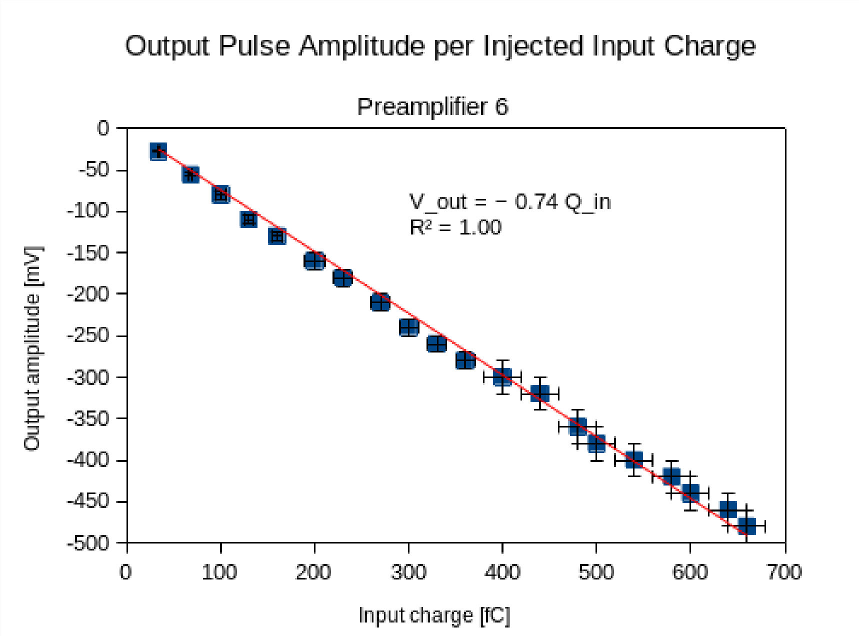

Figure 4.12: Output amplitude across a range of injected charges for preamplifier 6 using the "Test" input, resulting in a "gain" of -0.74 V/pC

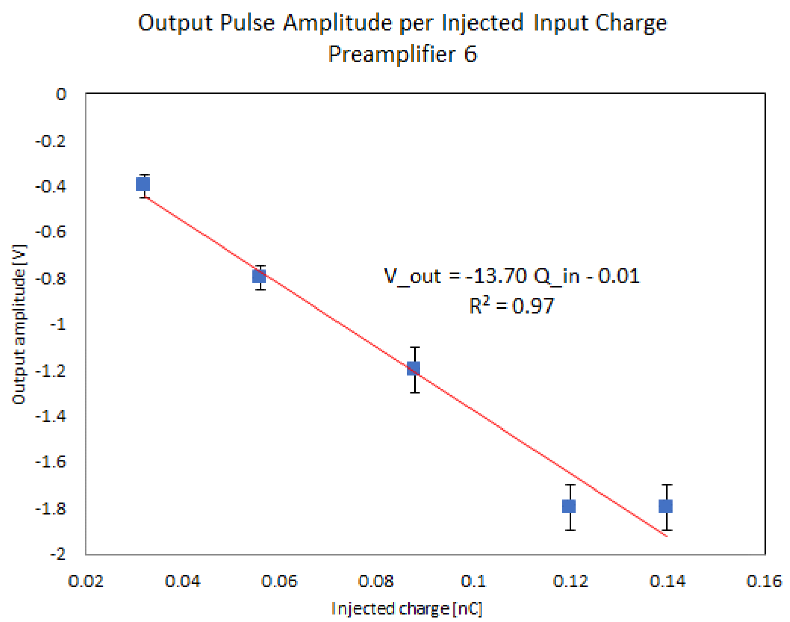

Figure 4.13: Output pulse amplitude plotted as a function of injected charge for the sixth preamplifier using the "Energy" input

Figure 4.13 represents the results from preamplifier 6 connected to "Energy" input; unlike Figure 4.12, the graph above outputs -13.70 V per 1 nC of injected charge. Five data points were collected to create Figure 4.13. When no charge is injected into the preamplifier, -0.01 V are generated by the device. This is small in comparison to preamplifiers 1 and 2 for "Energy" input. The R^2 value is 0.97, a difference of 0.03 from the results seen in Figure 4.12. This implies the results from the "Energy" input closely fit the linear trendline.

4.8 Preamplifier 7

As far as the seventh preamplifier is concerned, the device operates in a nominal fashion. As opposed to previous preamplifiers, the output amplitude per input charge is greater than one and is also inverted, two features that align with a sound preamplifier. Figure 4.14 shows the linear fit of output amplitude as a function of injected charge, producing a slope of -1.69 V/pC.

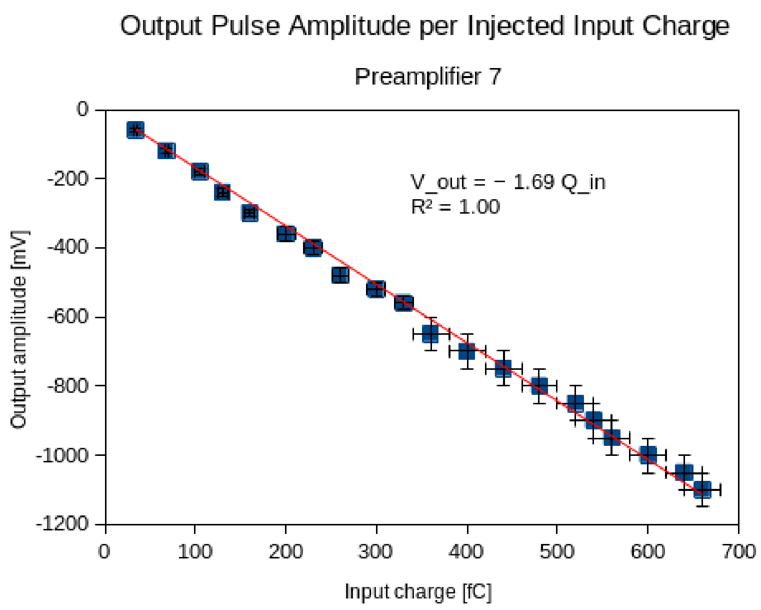

Figure 4.14: Output amplitude across a range of injected charges for preamplifier 7 using the “Test” input

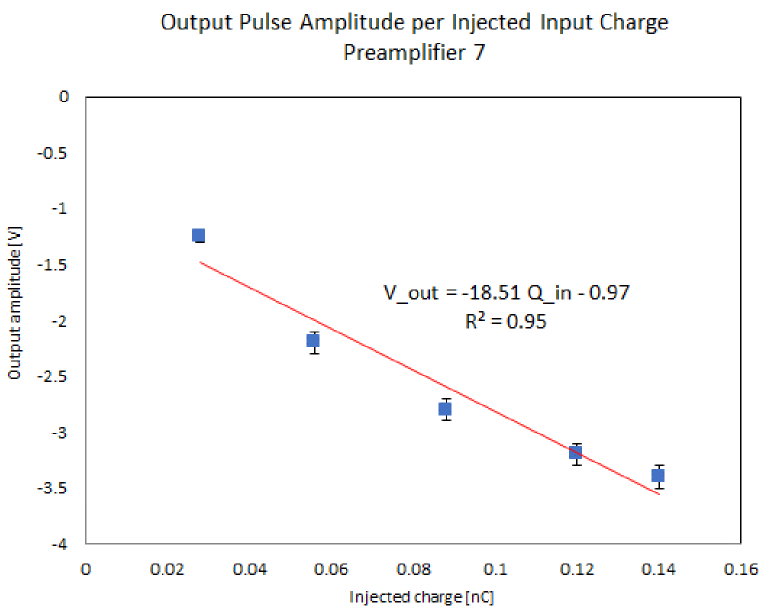

Figure 4.15: Output pulse amplitude plotted as a function of injected charge for the seventh preamplifier using the “Energy” input

Figure 4.15 represents the results from preamplifier 7 connected to "Energy" input; unlike Figure 4.14, the graph above outputs -18.51 V per 1 nC of injected charge. Five data points were collected to create Figure 4.15. Similar to the first two preamplifiers, when no charge is injected into the preamplifier, about -1 V is generated by the device. A small difference of 0.05 between the R^2 value from the "Test" and "Energy" input, suggesting the results in 4.15 closely fits the linear trendline.

4.9 Preamplifier 8

The final preamplifier is labeled preamplifier 8. In this case, the device operates in a similar fashion to preamp 7. The output signal is inverted and the output amplitude per injected charge is greater than one. As previous analyses have shown, this indicates that preamplifier 8 operates in a nominal fashion. Figure 4.16 displays the output amplitude across a range of injected charges from 34 to 660 fC.

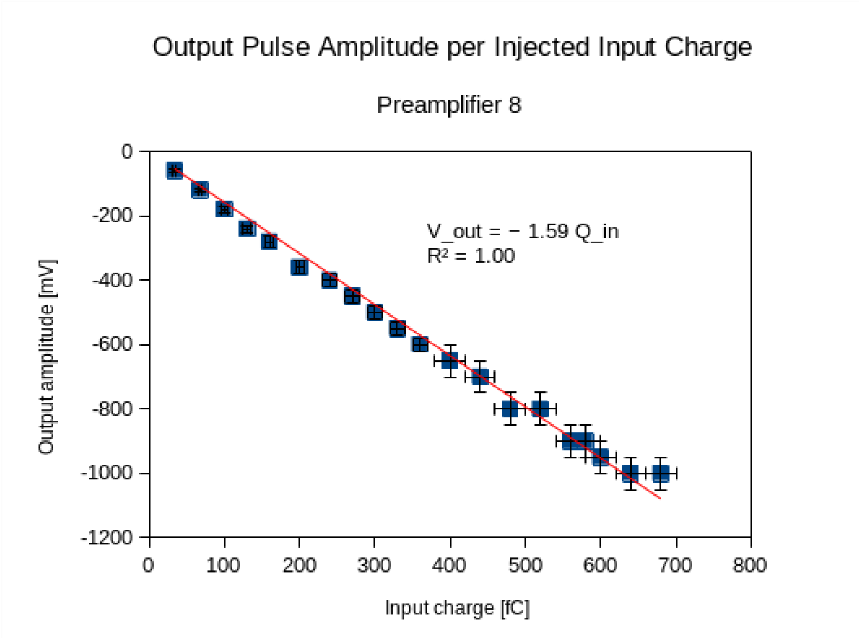

Figure 4.16: Output amplitude across a range of injected charges, 34-660 fC, for preamplifier 8 using the "Test" input, resulting in a "gain" of -1.59 V/pC

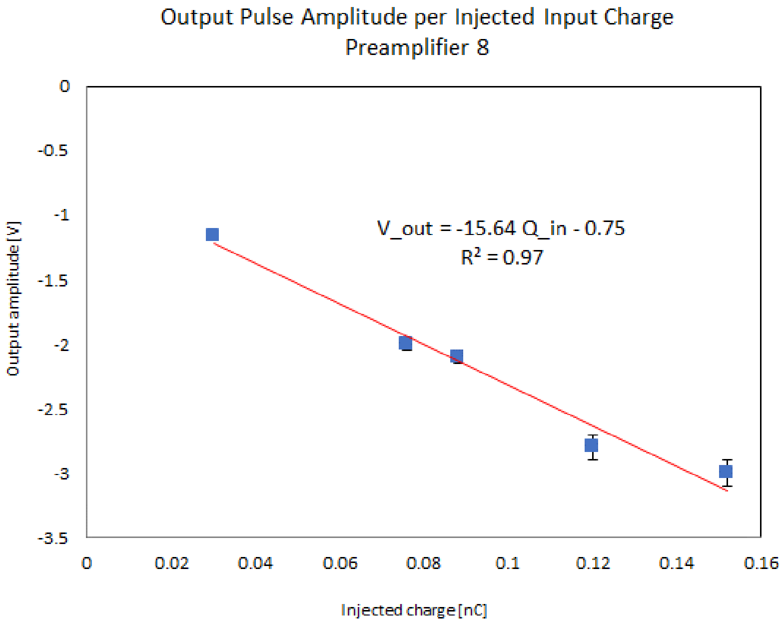

Figure 4.17: Output pulse amplitude plotted as a function of injected charge for the eighth preamplifier using the “Energy” input

Figure 4.17 represents the results from preamplifier 8 connected to “Energy” input; unlike Figure 4.16, the graph above outputs -15.64 V per 1 nC of injected charge. Five data points were collected to create Figure 4.17. When no charge is injected into preamplifier 8, -0.75 V is the output from the preamplifier. The data presented in the Figure above fits the trendline and is close to the R^2 value seen in Figure 4.16.

Chapter 5

Conclusions

5.1 Summary

In conclusion, the majority of preamplifiers in the laboratory operate nominally. Determining factors for a working preamplifier are the inversion of the input signal, a slow rise-time that is no greater than the RC time constant of the output, and a discernible amplification. As was found in Chapter 1, this time constant was determined to be 50 μs. Note that preamplifier 4 did not produce an output, which is why no results for this preamplifier are present in this document. This preamplifier and preamplifier 3 are currently under investigation to determine the root cause of these preamplifiers malfunctioning.

5.2 Nominal Preamplifiers

Most of the preamplifiers tested were found to be nominal. These are listed in Table 5.1 with corresponding output amplitude per injected charge when “Test” input was used. Table 5.2 lists output amplitude per injected charge when “Energy” input was used.

Table 5.1: List of all nominal preamplifiers as labeled in the laboratory for “Test” input

Preamplifier Number	Output amplitude per injected charge [V/pC]
1	-1.18
2	-1.99
5	-0.70
6	-0.74
7	-1.69
8	-1.59

Table 5.2: List of all nominal preamplifiers as labeled in the laboratory for “Energy” input

Preamplifier Number	Output amplitude per injected charge [V/nC]
1	-15.10
2	-14.78
3	-7.69
5	-20.76
6	-13.70
7	-18.51
8	-15.64

Appendix A

Sample Data

The data presented in this section is associated with that collected for determining the output amplitude per input charge. Tables A.1 – A.7 represents the data collected when utilizing the “Test” input and tables A.8 – A.14 represents the data collected when utilizing the “Energy” input. To obtain the input charge, one simply employs Equation 1.1. The following tables are associated with all nominal preamplifiers in ascending order of labeling.

Table A.1: Table of “Test” input and output amplitudes for preamplifier 1

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
10.0 ± 0.5	-12.0 ∓ 0.5	55 ± 1	-68 ∓ 2
15.0 ± 0.5	-16.0 ∓ 0.5	60 ± 2	-72 ∓ 2
17.0 ± 0.5	-20.0 ∓ 0.5	62 ± 2	-74 ∓ 2
21.0 ± 0.5	-25.0 ∓ 0.5	68 ± 2	-80 ∓ 2
25 ± 1	-28 ∓ 1	100 ± 5	-120 ∓ 5
28 ± 1	-34 ∓ 1	130 ± 5	-160 ∓ 5
32 ± 1	-36 ∓ 1	160 ± 5	-200 ∓ 5
34 ± 1	-40 ∓ 1	200 ± 5	-240 ∓ 5
38 ± 1	-44 ∓ 2	230 ± 5	-275 ∓ 5
40 ± 1	-48 ∓ 2	280 ± 10	-310 ∓ 10
43 ± 1	-52 ∓ 2	300 ± 10	-360 ∓ 10
46 ± 1	-54 ∓ 2	330 ± 10	-390 ∓ 10
47 ± 1	-58 ∓ 2		

Table A.2: Table of “Test” input and output amplitudes for preamplifier 2

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
11.0 ± 0.5	-24.0 ∓ 0.5	56 ± 2	-120 ∓ 5
17 ± 1	-38 ∓ 1	60 ± 2	-130 ∓ 5
20 ± 1	-45 ∓ 1	64 ± 2	-135 ∓ 5
24 ± 1	-52 ∓ 2	68 ± 2	-140 ∓ 5
28 ± 1	-60 ∓ 2	72 ± 2	-150 ∓ 5
30 ± 1	-66 ∓ 2	100 ± 5	-220 ∓ 10
34 ± 1	-72 ∓ 2	170 ± 5	-360 ∓ 10
38 ± 1	-80 ∓ 2	200 ± 5	-400 ∓ 10
40 ± 1	-88 ∓ 2	240 ± 10	-480 ∓ 20
42 ± 1	-92 ∓ 2	280 ± 10	-560 ∓ 20
44 ± 2	-95 ∓ 5	300 ± 10	-600 ∓ 20
48 ± 2	-100 ∓ 5	360 ± 10	-680 ∓ 20
48 ± 2	-100 ∓ 5		

Table A.3: Table of “Test” input and output amplitudes for preamplifier 3

Input Amplitude [mV]	Output Amplitude [mV]
90 ± 5	48 ± 2
120 ± 5	-40 ∓ 2
140 ± 5	-56 ∓ 2
160 ± 10	-60 ∓ 5
340 ± 10	-110 ∓ 5

Table A.4: Table of “Test” input and output amplitudes for preamplifier 5

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
32 ± 2	-26 ∓ 1	360 ± 20	-260 ∓ 20
68 ± 2	-52 ∓ 2	400 ± 20	-280 ∓ 20
100 ± 5	-80 ∓ 5	440 ± 20	-300 ∓ 20
130 ± 5	-100 ∓ 5	480 ± 20	-320 ∓ 20
160 ± 5	-120 ∓ 5	520 ± 20	-360 ∓ 20
200 ± 10	-140 ∓ 5	540 ± 20	-380 ∓ 20
230 ± 10	-170 ∓ 5	560 ± 20	-400 ∓ 20
270 ± 10	-200 ∓ 10	600 ± 20	-420 ∓ 20
300 ± 10	-220 ∓ 10	640 ± 20	-440 ∓ 20
320 ± 10	-240 ∓ 10	660 ± 20	-460 ∓ 20

Table A.5: Table of “Test” input and output amplitudes for preamplifier 6

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
34±1	-28∓1	360±10	-280∓10
68±2	-56∓2	400±20	-300∓20
100±5	-80∓5	440±20	-320∓20
130±5	-110∓5	480±20	-360∓20
160±10	-130∓10	500±20	-380∓20
200±10	-160∓10	540±20	-400∓20
230±10	-180∓10	580±20	-420∓20
270±10	-210∓10	600±20	-440∓20
300±10	-240∓10	640±20	-460∓20
330±10	-260∓10	660±20	-480∓20

Table A.6: Table of “Test” input and output amplitudes for preamplifier 7

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
34±2	-60∓5	360±20	-650∓50
68±2	-120∓5	400±20	-700∓50
105±5	-180∓10	440±20	-750∓50
130±5	-240∓10	480±20	-800∓50
160±5	-300∓10	520±20	-850∓50
200±10	-360∓20	540±20	-900∓50
230±10	-400∓20	560±20	-950∓50
260±10	-480∓20	600±20	-1000∓50
300±10	-520∓20	640±20	-1050∓50
330±10	-560∓20	660±20	-1100∓50

Table A.7: Table of “Test” input and output amplitudes for preamplifier 8

Input Amplitude [mV]	Output Amplitude [mV]	Input Amplitude [mV]	Output Amplitude [mV]
34±2	-60∓5	360±10	-600∓20
68±2	-120∓5	400±20	-650∓50
100±5	-180∓10	440±20	-700∓50
130±5	-240∓10	480±20	-800∓50
160±5	-280∓20	520±20	-800∓50
200±5	-360∓20	560±20	-900∓50
240±10	-400∓20	580±20	-900∓50
270±10	-450∓20	600±20	-950∓50
300±10	-500∓20	640±20	-1000∓50
330±10	-550∓20	680±20	-1000∓50

Table A.8: Table of “Energy” input and output amplitudes for preamplifier 1

Input Amplitude [V]	Output Amplitude [V]
0.016±0.001	-1.10∓0.05
0.028±0.002	-2.0∓0.1
0.044±0.002	-2.6∓0.1
0.060±0.005	-2.8∓0.1
0.075±0.005	-3.0∓0.1

Table A.9: Table of “Energy” input and output amplitudes for preamplifier 2

Input Amplitude [V]	Output Amplitude [V]
0.015±0.001	-1.40∓0.05
0.028±0.001	-2.4∓0.1
0.040±0.002	-3.0∓0.1
0.060±0.005	-3.1∓0.1
0.070±0.005	-3.2∓0.1

Table A.10: Table of “Energy” input and output amplitudes for preamplifier 3

Input Amplitude [V]	Output Amplitude [V]
0.015±0.001	-0.26∓0.02
0.028±0.001	-0.48∓0.02
0.044±0.002	-0.7∓0.05
0.060±0.002	-0.9∓0.05
0.070±0.005	-0.115∓0.05

Table A.11: Table of “Energy” input and output amplitudes for preamplifier 5

Input Amplitude [V]	Output Amplitude [V]
0.016±0.001	-0.60∓0.05
0.028±0.002	-1.00∓0.05
0.044±0.002	-1.8∓0.1
0.060±0.005	-2.4∓0.2
0.070±0.005	-2.8∓0.2

Table A.12: Table of “Energy” input and output amplitudes for preamplifier 6

Input Amplitude [V]	Output Amplitude [V]
0.016±0.001	-0.40∓0.05
0.028±0.001	-0.80∓0.05
0.044±0.002	-1.2∓0.1
0.060±0.005	-1.8∓0.1
0.070±0.005	-1.8∓0.1

Table A.13: Table of “Energy” input and output amplitudes for preamplifier 7

Input Amplitude [V]	Output Amplitude [V]
0.0140±0.0005	-1.25∓0.05
0.028±0.001	-2.2∓0.1
0.044±0.002	-2.8∓0.1
0.060±0.005	-3.2∓0.1
0.070±0.005	-3.4∓0.1

Table A.14: Table of “Energy” input and output amplitudes for preamplifier 8

Input Amplitude [V]	Output Amplitude [V]
0.0150±0.0005	-1.16∓0.02
0.038±0.001	-2.00∓0.05
0.044±0.002	-2.10∓0.05
0.060±0.002	-2.8∓0.1
0.076±0.002	-3.0∓0.1

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[1] "Model 142PC Preamplifier Operating and Service Manual." Advanced Measurement Technology, Ortec Part No. 717600. Revision B. 2002.

[2] "Operating Manual: CJDS66 Series Digital Control Dual-channel DDS Signal Generator." Koolertron. Revision 1.0. 2017.