QUACKEMS 3-Input Test Board

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June 19, 2025

Contents

1 General Description

1.1 Introduction

The 3-Input Test board analyzes the output of the W1 Silicon Strip Detector for **QUACKEMS**[1]. The W1 Detector has 16 channels correlating to each silicon strip, and 3 of the channels may be tested at a time.

As of June 19, 2025, the 3 inputs on the board are soldered to channels 7, 8, and 9.

[1] Quantitative Charge Kinetic Energy Mass Sensor

1.2 Theory of Operation

W1 Detector: The W1 silicon strip detector has p-type strips and n-type bulk, with metallization on the top strips and bottom surface. This means that the detector behaves like a diode, and when the detector is reverse biased a depletion zone is made. When a charged particle crosses the depletion zone, it ionizes atoms along its track. In the depletion zone, there is no free sharge to accept the free electrons and holes. Therefore, they drift to the electrodes on opposing surfaces. The free holes get collected by the strip side of the detector, and generate a charge pulse.

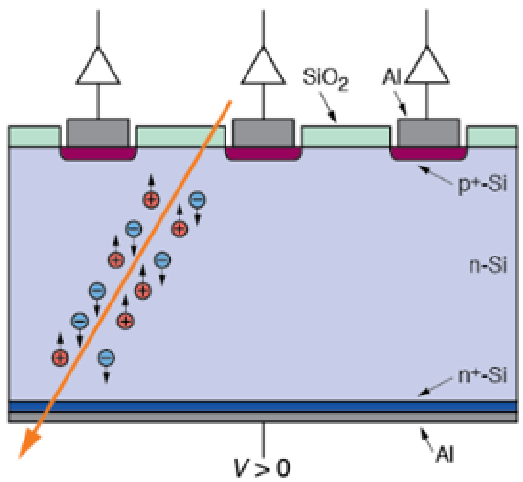


Figure 1: Basic Diagram of Silicon Strip Detector

Board: The purpose of the board is to take the input charge pulse of the W1 detector and convert it to a voltage pulse signal. This is done with a preamplifier and pulse shaper stage. The charge sensitive preamplifier stage integrates the charge pulse and produces a voltage pulse that decays exponentially. The gaussian pulse shaper stage takes the tail pulse from the preamplifier and produces a bell curve as the output. All 16 channels of the detector are AC-coupled. A low-pass filter maintains a steady bias voltage, the bias supplies current to the DC detector, and a capacitor between the preamplifier input and detector output blocks any DC current.

The test inputs simulate a charge pulse when a square wave is inputted. The board itself is encased in a grounded metal enclosure that functions as a Faraday cage.

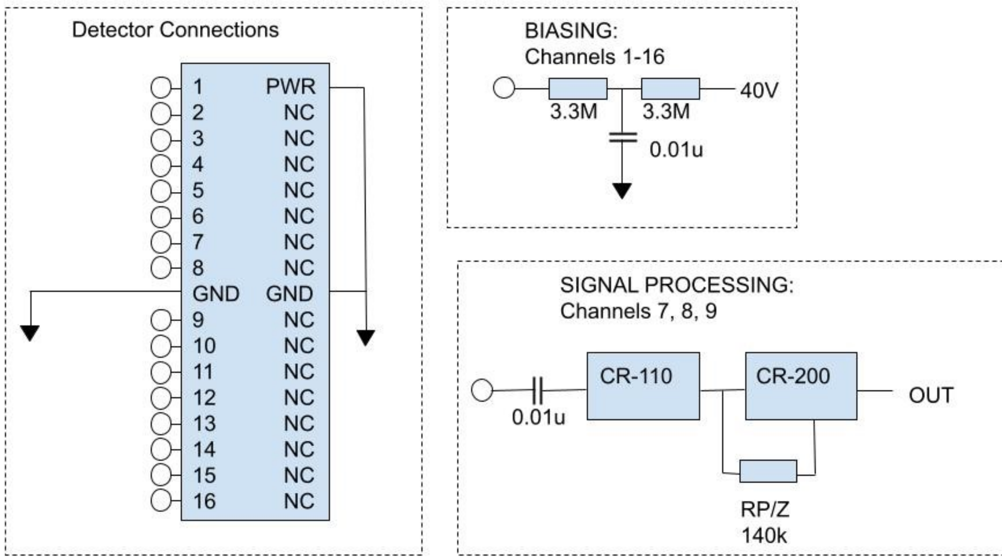


Figure 2: Basic Diagram of Front End System

1.3 Specifications

The following specifications are required for proper usage of the board:

- Amplifier Supply Voltage: 6 V–13 V
- Bias Supply: Dependent on W1 Detector, needs to be negative for detector to enter depletion.
- Grounding: Ensure the metal enclosure is properly grounded during operation to maintain signal integrity and reduce noise.

1.4 Board Overview

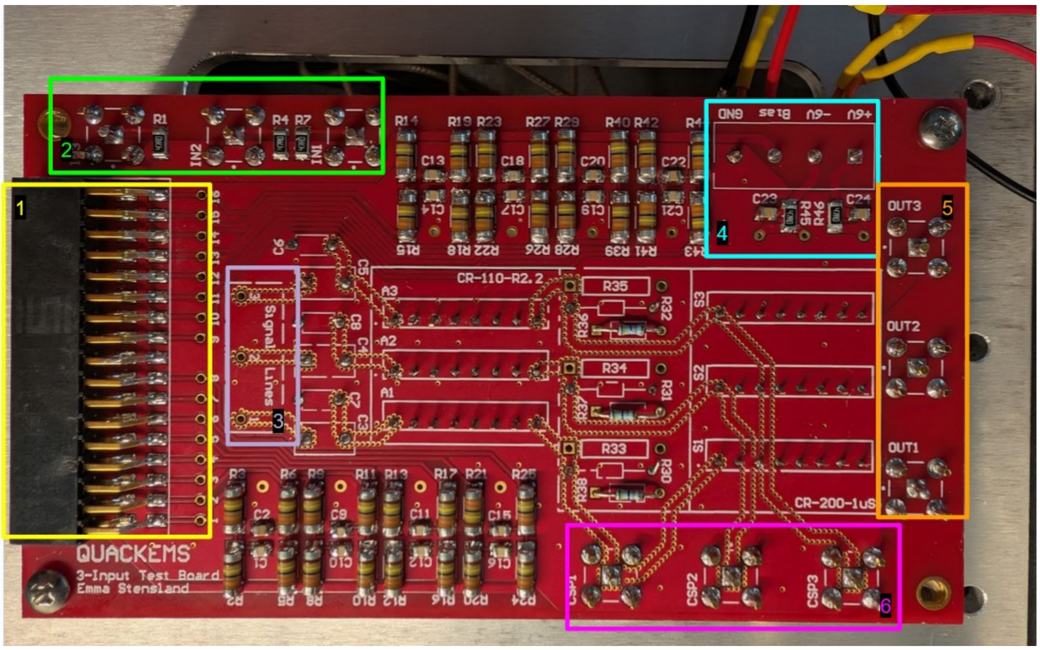


Figure 3: Top view of PCB

Each numbered box correlates to the following part of the board:

1. W1 Detector Pin Header
2. Input Test Signal SMA Connectors
3. W1 Detector Input Signal Jumper Connections
4. Screw Terminal for Power
5. Output Signals SMA Connectors
6. Preamplified Test Point SMA Connectors

2 Connections

2.1 W1 Detector

This gets attached at the pin header 1 seen in Figure 3. The strip side of the detector is oriented up with the top of the board, while the ohmic side faces down.

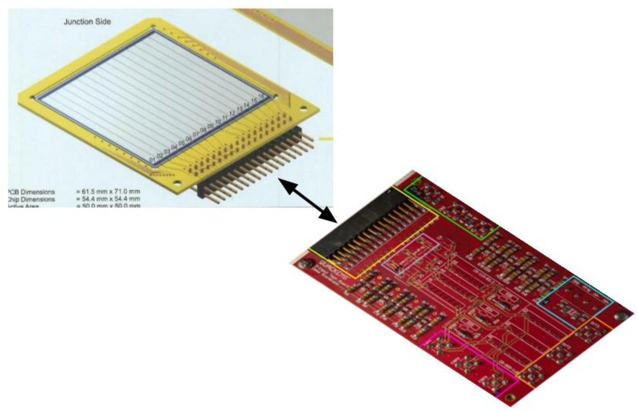


Figure 4: Detector connected to board

2.2 Input Test Signals

The SMA connectors supply test signals on the exterior of the enclosure as seen in Figure 5.

2.3 Output Signals

The SMA connectors read out the output signals on the exterior of the enclosure as seen in Figure 5.

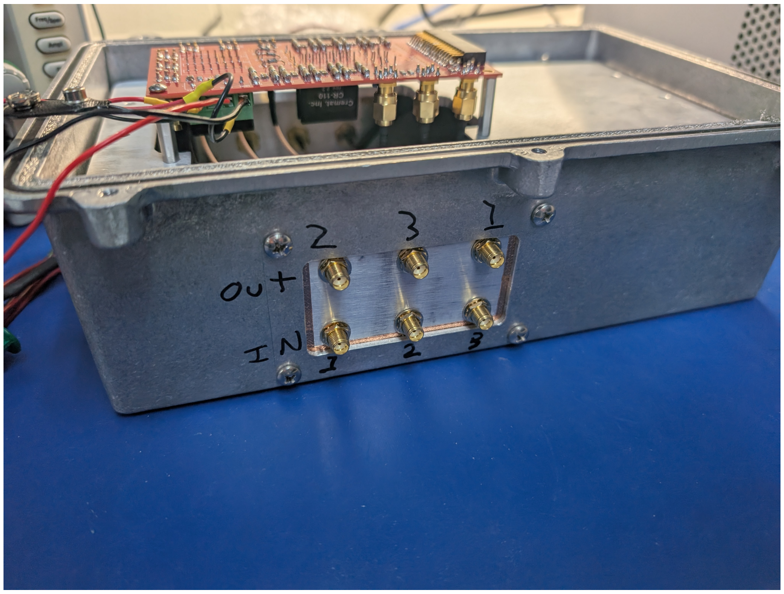


Figure 5: Input and Output Side View of enclosure

2.4 Detector Input Signals

These signals are soldered onto the detectors channels as described below:

Test Input	Detector Channel
Input 1	Channel 7
Input 2	Channel 8
Input 3	Channel 9

Table 1: Test Input to Detector Channel Mapping

2.5 Amp Power

To power the amplifiers, a positive power supply in the range of +6 V to +13 V should be connected to the +6 V terminal, and a negative supply from -6 V to -13 V to the -6 V terminal. For testing, 9 V batteries are to be connected as pictured in Figure 6.

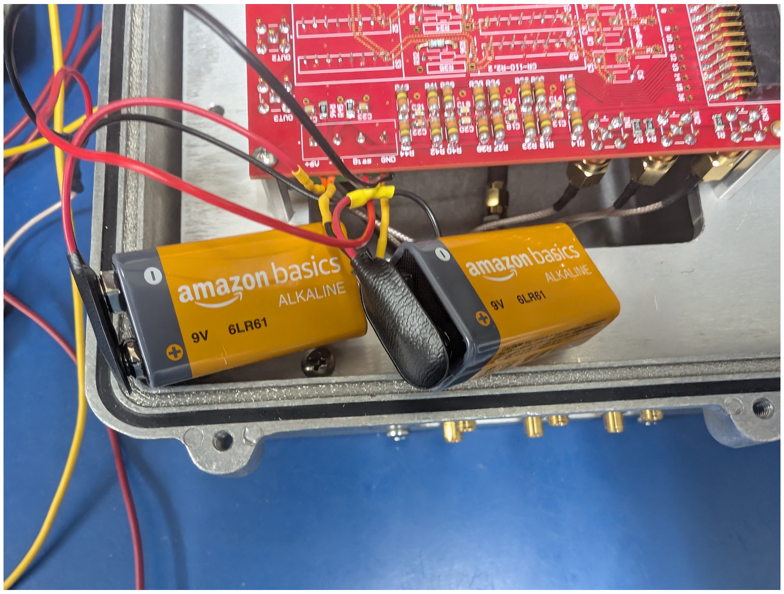


Figure 6: Batteries Connected to Board

2.6 Preamplified Test Points

The SMA connectors read test points after the signal has been preamplified at the location pictured in Figure 7.

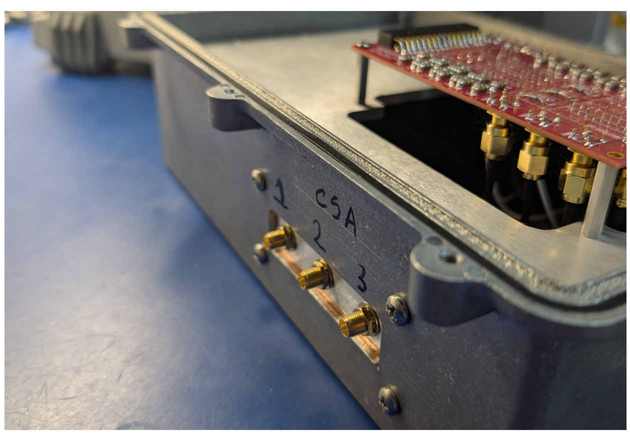


Figure 7: Test Point Side View of enclosure

2.7 Bias and Ground

The SMA connector on the top of the enclosure has a red and black wire. The black wire connects to ground and the red wire connects to bias, as shown in Figure 8.

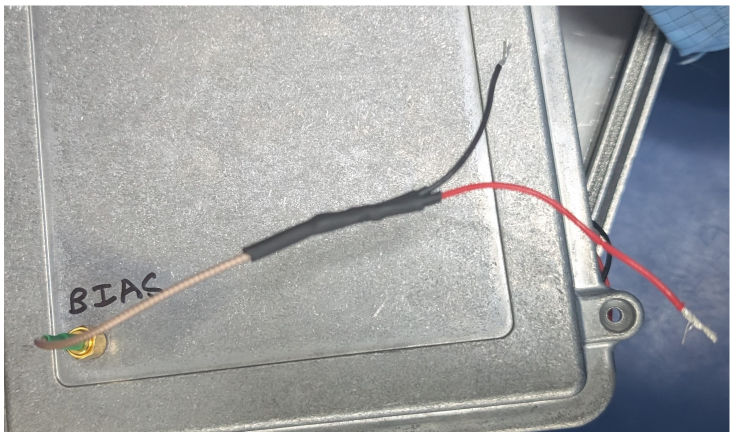


Figure 8: Bias Top View of enclosure

3 Testing Procedure

In order to verify successful operation of the board, the following procedure should be used for channels 1-3.

1. Connect the batteries to the board, as pictured in Figure 6.

2. Connect an SMA connector from the output of a function generator to the input of the channel desired to be tested. The input channels are the bottom row of SMA connections on the side of the enclosure, as pictured in Figure 5.

3. Set the function generator to 1 kHz, with 0 V offset, and 500 mV$_{pp}$, and turn the function generator on. This generates a impulse-like excitation after AC coupling, suitable for shaping circuit analysis.

4. Connect an SMA connector from an oscilloscope to the test point of the channel being tested. The test point connections can be found on the side of the enclosure, as seen in Figure 7. Adjust the scaling of the oscilloscope as necessary, and the following waveform should appear:

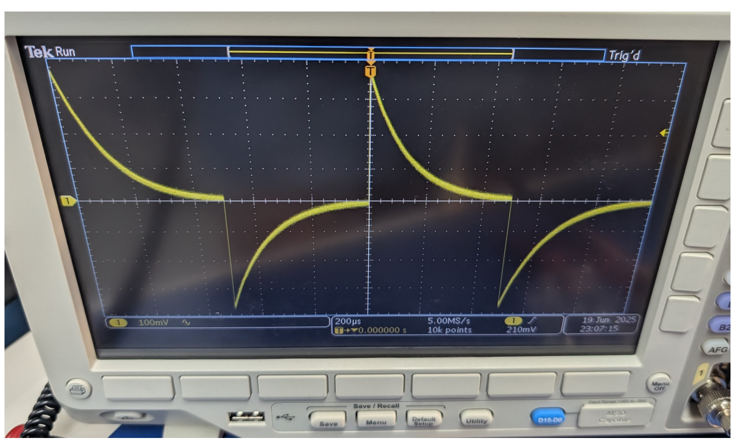


Figure 9: Preamplified Input as Seen on Oscilloscope

5. Connect an SMA connector from an oscilloscope to the output of the channel being tested. The test point connections can be found on the side of the enclosure, as seen in Figure 5. At the same scaling

as before the output will appear like Figure 10, and when zoomed in, the oscilloscope should display Figure 11

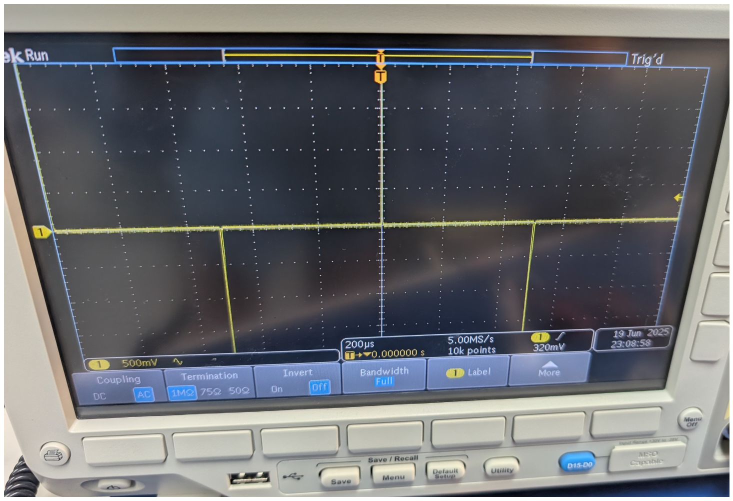


Figure 10: Output as Seen on Zoomed out Image of Oscilloscope

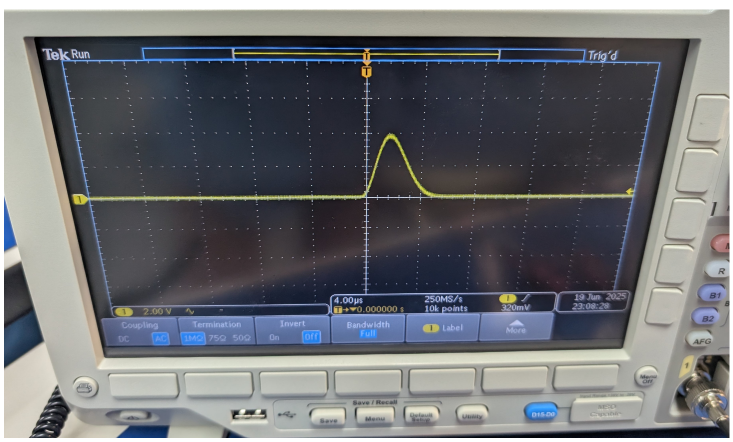


Figure 11: Output as Seen on Zoomed in Image of Oscilloscope

6. If all waveforms look as expected, the tested channel is working properly. If this test failed, verify all SMA connectors and wires are properly connected, and power is being properly supplied to the board.

4 Design Overview

4.1 PCB Layout

The PCB is a four layer board with each layer serving a purpose as listed:

1. Ground Plane, Bias Signals, Surface Mount Signals (Fig. 12)
2. Electrically Shielded I/O Signals of Preamp (Fig. 13)
3. Ground Plane (Fig. 14)
4. Power Lines for Preamp and Shaper (Fig. 15)

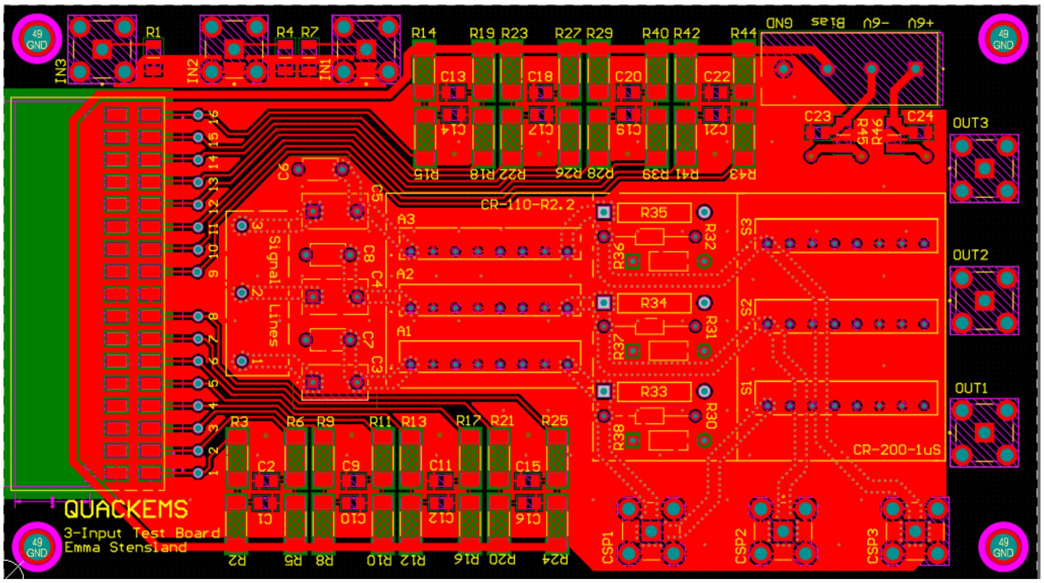


Figure 12: Layer 1 of 3-Input Test Board

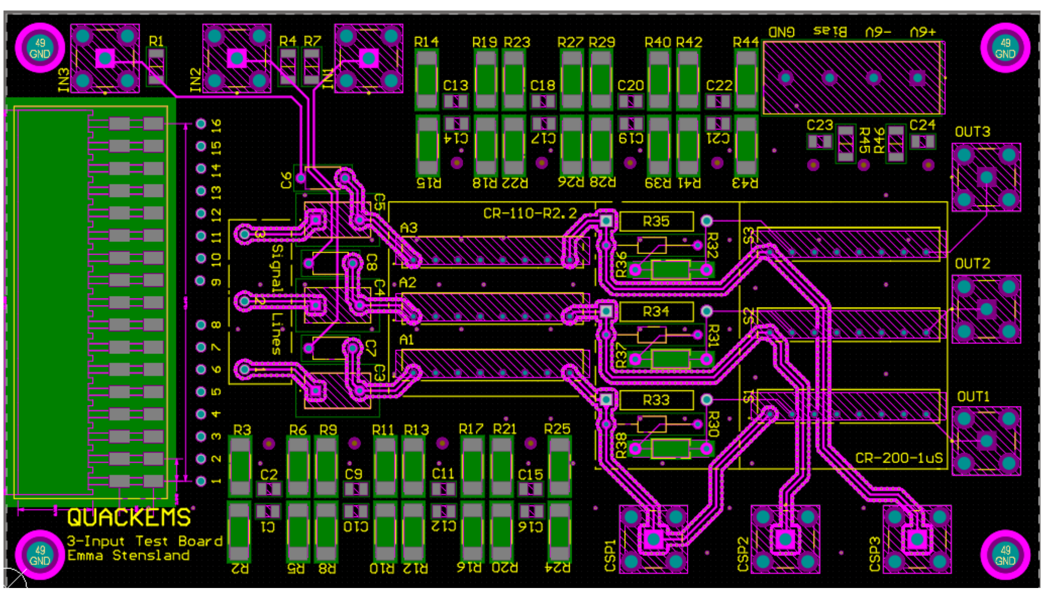


Figure 13: Layer 2 of 3-Input Test Board

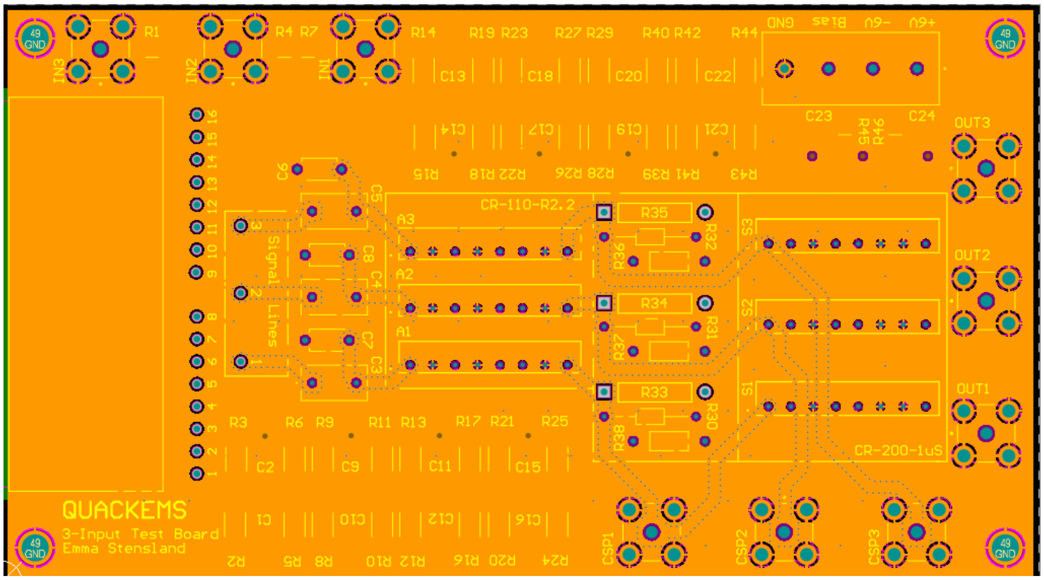


Figure 14: Layer 3 of 3-Input Test Board

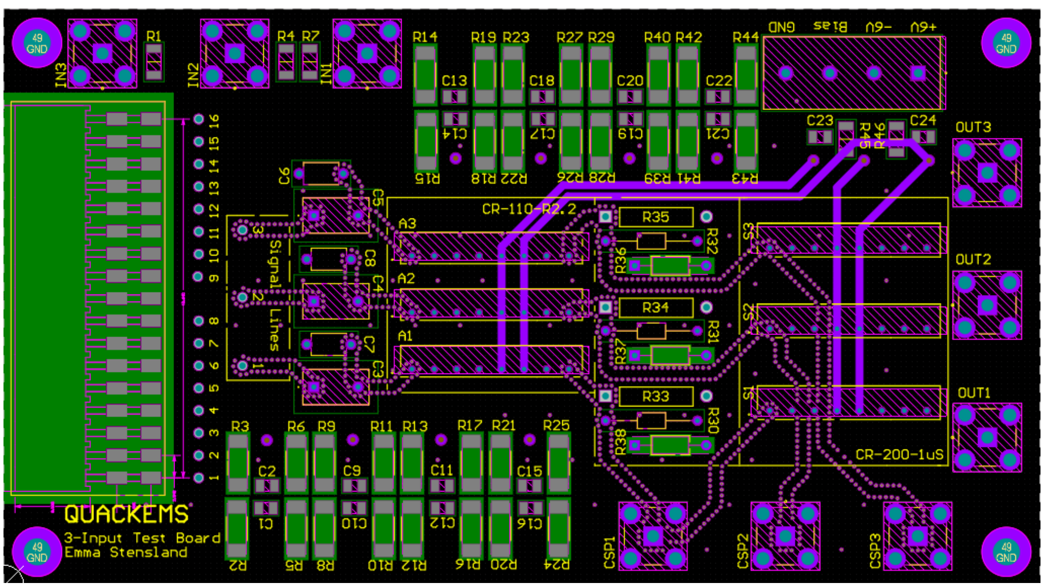


Figure 15: Layer 4 of 3-Input Test Board

5 References

The following resources were used:

- Cremat Inc Website (cremat.com)
- CERN Silicon Strip Detector Slide Show
- CR-110-R2.2 Datasheet
- CR-200-R2.1 Datasheet
- W1 300um Documentation

CR-110-R2.2 charge sensitive preamplifier: application guide

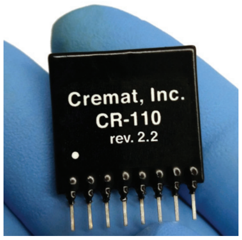
July 2023

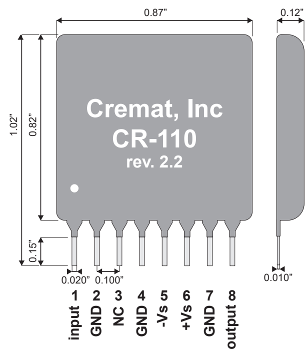
General Description

Cremat's CR-110-R2.2 is a single channel charge sensitive preamplifier module intended for use with various types of radiation detectors including semiconductor detectors (e.g. CdTe and CZT), p-i-n photodiodes, avalanche photodiodes (APDs), and various gas-based detectors. The CR-110-R2.2 is one of a series of four charge sensitive preamplifiers offered by Cremat, which differ from each other most notably by their gain. As with all Cremat's preamplifier modules, the CR-110-R2.2 is small (less than one square inch in area), allowing for compact multichannel detection systems to be constructed using a modular design.

Package specifications

The CR-110-R2.2 circuit is in an 8-pin SIP package (0.100" spacing). Pin 1 is marked with a white dot for identification.

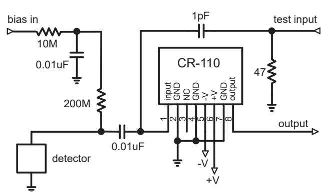




Detector coupling

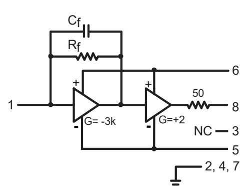
The CR-110-R2.2 can be used either in a direct coupled (DC) mode or an AC coupled mode. If the detector current exceeds 1 nA, it is recommended that an AC coupled mode be used to prevent the resulting DC offset of the preamplifier output from saturating. more information can be found at: **https://www.cremat.com/applications/csp-application-notes/**

Typical setup



The CR-110-R2.2 is often AC-coupled to a detector in the way shown here. This circuit is available in the form of Cremat's CR-150-R6 evaluation board, providing a socket for the CR-110-R2.2 module, BNC connectors, and circuitry for powering the preamplifier. For more information see: **https://www.cremat.com/CR-150-R6/**

Equivalent circuit diagram



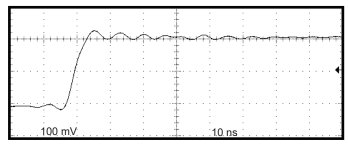
This figure shows a simplified equivalent circuit diagram of the CR-110-R2.2, which is a two stage amplifier. The first stage is a high gain, charge sensitive preamplifier and the second stage is low gain voltage amplifier. Pin numbers corresponding with the CR-110-R2.2 preamplifier are shown. R_f (100MΩ) and C_f (1.4pF) are the feedback resistor and capacitor respectively. An LTspice model of the CR-110-R2.2 is available on the Cremat web site. LTspice is freeware computer software implementing a SPICE simulator of electronic circuits, produced by semiconductor manufacturer Analog Devices.

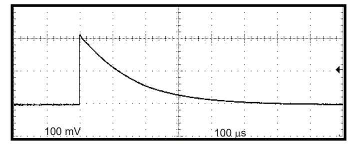
Input and output waveforms

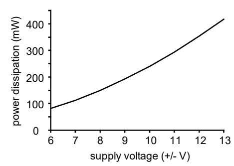
Charge sensitive preamplifiers are used when radiation is detected as a series of pulses of current. These pulses of current flow into (or out of) the preamplifier input. Depending on the type of detector, these pulses are typically in the range of a few ns to a few µs in duration. Each current pulse is integrated by the feedback capacitor within the preamplifier resulting in a voltage pulse at the output that is proportional to the total charge in the pulse. The feedback resistor (in parallel with the feedback capacitor) slowly discharges (resets) the feedback capacitor, producing an exponential decay of each pulse with a time constant = 1.4pF x 100Mohms = 140µs. For this reason the pulses of current from the detector should be limited in duration to only a few microseconds as longer pulses see a distortion due to this exponential decay.

The rise time of the CR-110-R2.2 output pulses is approximately 3 ns, however the rise time may be further slowed by a couple of factors. Added capacitance at the preamplifier input (i.e. detector capacitance) slows the rise time at a rate of 0.22 ns/pF. The output rise time will also be limited by the speed of the detector. For example, the detection current pulse from a CsI(Tl)/photodiode scintillation detector has a duration of approximately a couple µs, so in this case the rise time of the charge sensitive preamplifier output will be at least that long.

The output waveform of the CR-110-R2.2 using a capacitively-coupled fast square wave pulser at the input is shown below in two figures. The rise time of the preamplifier is evident in the figure on the left. At long time domains, the 140 µs output decay is evident in the figure on the right. **Both figures below show the same preamplifier output.** They differ only in the time domain.







The power dissipation of the CR-110-R2.2 is shown to the left as a function of supply voltage. The minimum supply voltage for good operation is +/- 6V. Any supply voltage applied in excess of this figure does not change or improve CR-110-R2.2 performance, but instead results in unnecessary power dissipation.

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https://www.cremat.com

Specifications

Assume temp =20 °C, V_s = ±6V, unloaded output

	CR-110-R2.2	units
Preamplification channels	1	
Equivalent noise charge (ENC)*		
ENC RMS	200	electrons
	0.03	femtoCoul.
Equivalent noise in silicon	1.7	keV (FWHM)
Equivalent noise in CdZnTe	2.4	keV (FWHM)
ENC slope	3.8	elect. RMS /pF
Gain	1.4	volts /pC
Rise time **	3	ns
Decay time constant	140	µs
Unsaturated output swing	-3 to +3	volts
Maximum charge detectable per event	1.3 x10^7	electrons
	2.1	pC
Power supply voltage (V_s)		
maximum	V_s = ±13	volts
minimum	V_s = ±6	volts
Power supply current (pos)	9	mA
(neg)	6	mA
Power dissipation with no load	85	mW
Operating temperature	-40 to +85	°C
Output offset	+0.2 to -0.2	volts
Output impedance	50	ohms

* Measured with input unconnected, using Gaussian shaping amplifier with time constant =1 µs. With a detector attached to the input, noise from the detector capacitance, leakage current, and dielectric losses will add to this figure.

** Pulse rise time (defined as the time to attain 90% of maximum value) has a linear relationship with input capacitance. Value cited in the table assumes zero added input capacitance. To calculate pulse rise time for practical situations, use the equation: t_r =0.22 C_d + 3 ns, where t_r is the pulse rise time in ns, and C_d is the added capacitance (e.g. detector capacitance) in pF. Others factors within the detection system may further limit this value.

CR-200 Gaussian shaping amplifier: application guide

rev. 2.1, Jan. 2017

General Description

The CR-200 is a Gaussian shaping amplifier module, and is used to read out the “tail pulse” signals such as from charge sensitive preamplifiers, PMTs, and other similar detection circuits. Gaussian shaping amplifiers are also known as ‘pulse amplifiers’, ‘linear amplifiers’, or ‘spectroscopy amplifiers’ in the general literature. They accept a step-like input pulse and produce an output pulse shaped like a Gaussian function (bell curve). The purpose of these amplifiers is not only to transform the shape of the event pulse from a tail pulse to a bell curve, but also to filter much of the noise from the signal of interest. Use of shaping amplifiers will reduce the fall time of the pulse signals, reducing the incidence of pulse ‘pile up’, and improve the signal-to-noise of the detection system.

The CR-200 is available in 8 different shaping times, from 50 ns to 8 µs. The gain and shaping times of these amplifiers are fixed. If additional gain is desired, it is recommended that this be done with the application of an additional broadband amplifier between the preamplifier and the CR-200 shaping amplifier. Cremat offers an evaluation board (CR-160-R7) which includes a multi-stage variable-gain amplifier, as well as all necessary connectors. More information on the CR-160-R7 evaluation board can be found at http://cremat.com

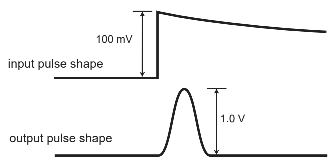


Figure 1. Comparison of sample input and output pulse shapes

The shaping time is defined as the time-equivalent of the "standard deviation" of the Gaussian output pulse. A simpler measurement to make in the laboratory is the full width of the pulse at half of it's maximum value (FWHM). This value is greater than the shaping time by a factor of 2.4. For example, a Gaussian shaping amplifier with a shaping time of 1.0 µs would have a FWHM of 2.4 µs.

Equivalent circuit diagram

Figure 2 shows an equivalent circuit. Pin numbers corresponding with the CR-200 shaping amplifier are shown. Input components C_{in} and R_{in} form a differentiating circuit. The following circuitry consists of two Sallen and Key filters, providing 4 poles of integration and signal gain. The numerous integration stages produce an output pulse that approximates a Gaussian function.

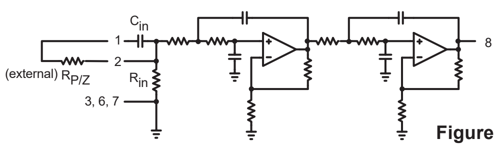


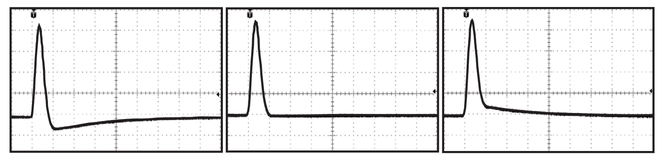
Figure 2

part #	shaping time	output pulse width (FWHM)	R_{in}	C_{in}	gain
CR-200-50ns	50 ns	120 ns	220 Ω	220 pF	8
CR-200-100ns	100 ns	240 ns	220 Ω	470 pF	10
CR-200-250ns	250 ns	590 ns	240 Ω	1000 pF	10
CR-200-500ns	500 ns	1.2 µs	510 Ω	1000 pF	10
CR-200-1µs	1 µs	2.4 µs	1.0 kΩ	1000 pF	10
CR-200-2µs	2 µs	4.7 µs	2.0 kΩ	1000 pF	10
CR-200-4µs	4 µs	9.4 µs	1.2 kΩ	3300 pF	10
CR-200-8µs	8 µs	19 µs	2.4 kΩ	3300 pF	10

Pole/Zero Correction

The long decay time of the input pulse creates a small overshoot in the shape of the output pulse unless a pole/zero correction is utilized. This can be done by connecting a resistor ($R_{P/Z}$) between pin 1 (input) and pin 2 (P/Z). This resistor is in parallel with the input capacitor (internal to the CR-200 circuit) and creates a 'zero' in the amplifier's transfer function which cancels the 'pole' created by the charge sensitive preamplifier's feedback resistor. To achieve proper pole/zero cancellation, $R_{P/Z}$ should be selected so that $R_{P/Z}*C_{in}$ is equal to the decay time constant of the preceding charge sensitive preamplifier output signal. Use the equation $R_{P/Z} = R_f*C_f/C_{in}$ where R_f and C_f are the feedback resistor and feedback capacitor of the charge sensitive preamplifier and C_{in} is the value of the input capacitor in the CR-200. The value of C_{in} for the CR-200 circuit can be found in the provided table.

You may wish to realize $R_{P/Z}$ as a potentiometer so to adjust the value precisely. The effect of $R_{P/Z}$ on the pulse shape can be seen in the pulse waveforms shown in Figure 3.



$R_{P/Z}$ resistance too high | $R_{P/Z}$ resistance proper | $R_{P/Z}$ resistance too low

Figure 3

Baseline Restoration (BLR)

The CR-200 does not contain active baseline restoration circuitry. For this reason there will be a negative 'baseline shift' (change in the output DC offset) at high counting rates. In order to determine whether this will be a problem for your application, use the equation (valid for small baseline shifts):

$$S/H = R * \tau * 2.5 \times 10^{-6}$$

where S is the negative baseline shift, H is the pulse height, R is the count rate (counts/sec), and τ is the shaping time of the shaping amplifier (in µs). For example, using a 1 µs shaping amplifier we would predict a 0.025 (2.5%) shift in the baseline at a count rate of 10,000 counts per second.

To address this potential problem, Cremat offers the CR-210 baseline restorer. More information on this circuit can be found at the cremat.com web site.

Package Specifications

The CR-200 circuit is contacted via an 8-pin SIP connection (0.100" spacing). Pin 1 is marked with a white dot for identification.

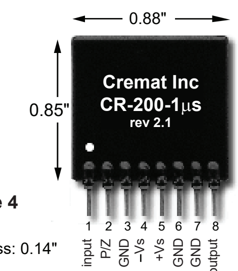


Figure 4

Typical Application

Figure 5 shows the CR-200 in a typical application, coupled to a detector via a CR-110 charge sensitive preamplifier. Depending on the requirements of your application, an AC-coupled amplifier may be added between the preamplifier and shaping amplifier to further increase the signal size. An optional CR-210 baseline restore circuit has been added as well.

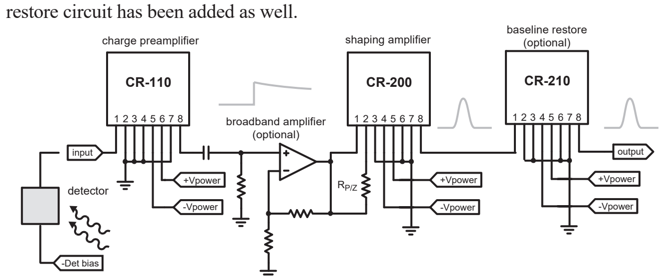


Figure 5

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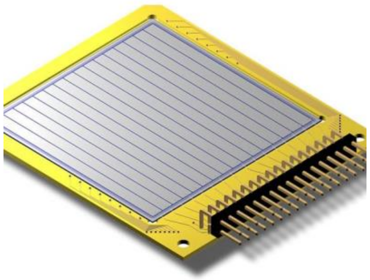
cremat

Design W1



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Detector Description

DC Strip Detector without Bias Resistors

All double sided devices can be fabricated as single sided devices using either the double sided junction or ohmic side

Junction Implant Window:	Type 2 / 7 / 9 / 9.5
Junction Metal Options	M / G / P / T
Ohmic Implant Window:	Type 2
Ohmic Metal Options	M
Single or Double Sided	All double sided devices can be fabricated as single sided devices using either double sided junction or ohmic
Application	Nuclear, Research, High Energy and Ion Beam Physics
Package	PCB/PCB Kapton/Ceramic. Transmission designs and headers.
Package Comments	Various - Can typically be modified onto FR4, ceramic, polyamide and kapton. With various connector types (straight or 90 degree) to suit requirements.

Dimension Parameter	Value
Chip Dimensions - Flat to Flat (mm)	53.78 x 53.78
Chip Number of Sides	4
Active Area Width (mm)	49.50
Active Area Height (mm)	49.50
Active Area nom. (mm2)	25
Junction Pitch (µm)	3125
Ohmic Pitch (µm) *	3125
Junction Number of Strips	16
Ohmic Number of Strips *	16
Minimum Acceptance Level	100% Operational

* Applicable only to Double Sided Devices

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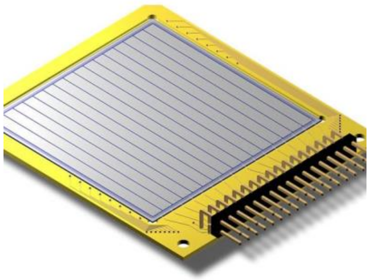
Design W1



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Parameter	50um	65um	140um	300um	500um	1000um	1500um
Device Thickness (µm)	50	65	140	300	500	1000	1500
VFD Typical (V)	10	10	20	50	75	150	250
Total Leakage Typical at VFD (nA)	70	50	60	65	360	600	550
Total Leakage Typical at VFD +30% (nA)	85	70	130	100	465	730	630
V_B at 10 µA (V)	>50	>50	>100	>100	>150	>200	>300
V_f at 10 mA (V)	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Junction Strip Capacitance Typical VFD (pF) **	4	3	2	1	1	1	1
Alpha Resolution Junction Side Typical (5.48 MeV ^{241}Am)	3%	3%	2%	2%	1%	1%	1%
Isolation (Ohmic Side)	100 K Ohm Minimum						
Isolation (Junction Side)	10 Megaohm Typical						
Acceptance Level	100% (All Channels Operational)						

Measurements taken at 20°C on N-Type Float Zone material,
Total Alpha Resolution will be measured on both sides of the detector,
At time constants of FWHM with 241 Americium Source 5.48 MeV line.

* Applicable only to Double Sided Devices ** Excludes 1pF /cm for Cable Readout and Capacitance on packaging

Parameter	Value
Maximum Operating Voltage (V)	VFD + 30V
Operating Temperature (°C) *	-55 to + 70

* If higher temperature of operation required, then gold contacts may need to be added (TBC).
Heating/ Cooling will half or double leakage current every 7°C for high resistivity silicon