QED Analog Conditioning Board Manual

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QED Analog Conditioning Board Manual
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The Analog Conditioning Board
Hardware Documentation and User's Guide

Overview

The QED Analog Conditioning Board provides customized signal conditioning of the QED Board's 24 analog I/O lines. The QED Board's 8 analog outputs can be scaled up to a 0-10 Volt range, and the 16 analog inputs are conditioned by a combination of instrumentation amps, differential amps, and op amps with selectable gain, filtering and excitation. Two 0-20 mA inputs and outputs are supported, and onboard cold junction thermocouple compensation makes temperature measurement easy. The QED Analog Conditioning Board interfaces to the QED analog I/O connector via a 40-pin ribbon cable. The board can plug directly into the QED Industrial Control System Backplane Board to allow screw terminal access to all analog field connections.

Figure 1 is a block diagram of the board. The top of the diagram represents the direct 40-pin connection between the Analog I/O connector on the QED Analog Conditioning Board and the like-named Analog I/O connector on the QED Board. This connector identifies the 24 available analog I/O lines on the QED Board as an 8 channel 8-bit digital-to-analog converter (DAC), an 8 channel 12-bit analog-to-digital (A/D) converter, and an 8 channel 8-bit analog-to-digital (A/D) converter. The resolution of each converter is specified in bits; an 8-bit converter represents an analog signal as one of 256 (=2^8) levels, and a 12-bit converter represents an analog signal as one of 4096 (=2^{12}) levels.

Figure 1. Block diagram of the QED Analog Conditioning Board.

The Analog I/O Field Connector at the bottom of Figure 1 shows the conditioned input/output (I/O) signals that are connected to external analog sensors and actuators. The conditioning circuitry in the center of Figure 1 supplies programmable amplification, attenuation and filtering of A/D inputs, and voltage scaling and optional voltage-to-current conversion on the DAC outputs. The board enables direct connection to a myriad of sensors and actuators, including thermocouples, thermistors, RTDs, strain gauges, photodiodes, voltage inputs, voltage outputs, and 4-20 mA inputs and outputs. In most cases no external circuitry is needed; all that is required to interface an analog channel to a specified device is the selection of appropriate gain-programming resistors and filtering capacitors that plug into labeled sockets on the QED Analog Conditioning Board.

Let's examine Figure 1 more closely, working our way from left to right across the block diagram.

Power

The Analog Conditioning Board requires an external DC power source in the range 15 to 38 volts. On-board power regulators create +13 V and -6 V supplies for the operational amplifiers (op amps) on the board, a +5Vquiet supply and generate a nominal 4.096 V temperature-stable reference with 1 mA sourcing capability. The +5Vquiet supply is a noiseless 5V supply and it is not to be confused or connected with the +5V and +5VAN on the QED Board. The 4.096 V signal provides the reference voltages for the 12-bit and 8-bit A/D converters.

The Analog Conditioning Board uses +5V from the QED Board to generate V+Clamp. The 1.5Vref is used to generate the 4.096V reference and it is connected to the reference of all the DACs. V+raw from the QED Board is not used on the Analog Conditioning Board, but it is available at the power connector.

Thermocouple Cold Junction Compensation

A cold junction compensator makes it easy to acquire temperature data from thermocouples by supplying the required voltage correction at the "cold junction" leads of the thermocouple (that is, at the ends that are connected to the Analog Conditioning Board).

DAC Outputs

The QED Board contains an octal 8-bit digital-to-analog converter with a maximum output voltage of 3 volts. The Analog Conditioning Board contains 8 programmable-gain amplifiers that independently scale the full-scale voltage of each DAC in the range from 5.1 volts to 10.2 volts. Selection of one resistor per channel sets the full-scale voltage, and an optional filter capacitor in each output amplifier circuit allows smoothing of the step-like DAC output waveform.

0-20 mA and 4-20 mA Outputs

Two voltage-to-current converters are available on the Analog Conditioning Board to provide 0-20 mA output capability as indicated by the box labeled "Optional V/I Conversion to 0-20 mA Output" in the block diagram. Simple software can use this circuitry to achieve 4-20 mA signaling. These converters may be used on 8-bit DAC channels 1 and 3, or on the 12-bit DAC outputs discussed below. On-board jumpers (J3 and J4) select voltage or current output for these channels.

12-bit Resolution DACs

For applications that require 12-bit resolution and accuracy DACs, the Analog Conditioning Board includes hardware that combines pairs of 8-bit DACs to create 12-bit DACs. As shown in the box labeled "Optional Pairing for 2 12-bit D/A" in the block diagram of Figure 1, there are two of these circuits on the board, meaning that one or two channels of 12-bit DACs are available. All of the output conditioning options (gain scaling and optional filtering, as well as voltage-to-current conversion) that are available for the 8-bit DACs are also available for the 12-bit DAC outputs.

Calibration of 12-bit DACs

The 12-bit DACs are calibrated by monitoring their outputs using a 12-bit A/D input under the control of a software calibration procedure that builds a calibration table used to write to the 12-bit DAC channels. This is indicated by the box in Figure 1 labeled "Optional 12-bit D/A Calibration" which uses 12-bit A/D channel 12AN7, an on-board analog switch to route the signals, and the DAC8 output which controls the analog switch. The 12-bit output signals are set to zero ("taken off line") during calibration to prevent the calibration process from affecting external devices. The calibration can be performed once and the calibration table can be burned into ROM, or calibration can be performed periodically by the instrument to attain maximum performance and drift-immunity of the 12-bit outputs.

12-bit Resolution A/D Inputs

We continue our overview of the block diagram in Figure 1 with the signal conditioning circuitry for the 12-bit A/D inputs. These A/D channels are implemented by the LT1290 octal 12-bit A/D chip on the QED Board. The channels can be configured under software control to convert unipolar (0-4.096 V) or bipolar (-4.096V to +4.096V) voltage inputs.

Three of the eight channels are conditioned by "single-ended" amplifiers that supply programmable gain/attenuation (by selecting appropriate on-board resistor values), and filtering (by installing an appropriate on-board capacitor). Unattenuated single-ended inputs accept input voltages between -5 volts and +10 volts, referenced to Analog Ground on the QED Analog Conditioning Board.

Two of the 12-bit A/D channels are conditioned by differential amplifiers that supply programmable gain/attenuation and filtering. The differential circuits amplify the difference between a positive (+) and negative (-) input. The "common mode" voltage of the +/- inputs can range from -5 volts to +10 volts. Differential conditioning circuits can be made to act like single-ended inputs by simply grounding the - input.

Two of the 12-bit A/D channels are conditioned by instrumentation amplifiers that supply programmable gain and filtering. Well controlled gains of 10 and 100 are available by open circuiting or short circuiting a connection, and gains between 10 and 100 are resistor-programmable. These channels amplify the difference between a positive (+) and negative (-) input, and the circuit can accommodate common mode input voltages exceeding +/- 24 Volts. Each instrumentation amplifier has a socket for a precision 20 Ω sensing resistors to convert a 0-20 mA current loop signal into a 0-4.0 volt signal for conversion by a 12-bit A/D. As discussed later in this document, there are many possible configurations available for sensing 0-20 mA or 4-20 mA current loop signals from transmitters.

One 12-bit A/D input (12AN7) is not conditioned by an amplifier. This is the channel that is available for calibration of the 12-bit DACs. If the 12-bit DAC option is not used or if no runtime calibration is planned, this analog input can be used to convert unipolar (0-4.096 V) or bipolar (-4.096V to +4.096V) voltage inputs.

8-bit Resolution A/D Inputs

The final section of the block diagram in Figure 1 summarizes the signal conditioning circuitry for the 8-bit A/D inputs. These 8 channels are implemented on the 68HC11 chip on the QED Board, and accept voltages from 0 to 4.096 V. Three of the eight channels are conditioned by "single-ended" amplifiers that supply programmable gain/attenuation (by selecting appropriate on-board resistor values), and filtering (by installing an appropriate on-board capacitor). Single-ended inputs accept input voltages between -5 volts and +10 volts, referenced to Analog Ground on the QED Analog Conditioning Board.

Three additional 8-bit A/D inputs include sockets that accommodate an "excitation" resistor between the +5 Vquiet supply and the input. This makes it easy to create a voltage divider to measure resistive sensors such as thermistors. The two remaining 8-bit A/D inputs are not conditioned, and accept voltage inputs from 0 to 4.096 V.

All unused A/D inputs must be grounded.

Summary of Analog Channels and Potential Applications

The following table summarizes the available channels and some potential applications. The "Type" column specifies the resolution and whether the signal at the field connector is an input or an output. The "Conditioning" column lists the functions provided on the Analog Conditioning Board, and indicates the resistor, capacitor or jumper sockets that control the conditioning function. For example, to set the gain of 8-bit A/D channel CAN0, you insert a resistor in the socket labeled GL0. This is indicated as socket GLx in the table below; simply replace the "x" with the channel number to locate the appropriate socket on the board. The notes that follow the table explain some of the multi-purpose functions served by some of the channels.

Field Connector Names	Type	Conditioning	Applications
CVOUT2,[1] CVOUT4,[2] CVOUT5, CVOUT6, CVOUT7, CVOUT8,[3]	8-bit Output	0-5.1V to 0-10.2V scaling (GDx) Lowpass filtering (cap. in FDx) Programmable attenuation (FDx)	Voltage Output can source 10 mA
CV/IOUT1,[1] CV/IOUT2 [2]	12-bit Output	0-5.1V to 0-10.2V scaling (GDx) OR 0-20 mA output Lowpass filtering (cap. in FDx)	Voltage Output 0-20 mA or 4-20 mA Output at up to 5 V
C12AN0+ / C12AN0-, C12AN1+ / C12AN1-	12-bit Diff. Input	Instrumentation amplifier Gain = 10.0 (GHx = open) or 100.0 (GHx = shorted) or 10-100 (GHx = resistor) Lowpass filtering (cap. in FDx) Optional current sense resistor(SHx)	Differential voltage amplifier with wide +/-24 V common mode range 0-20 mA or 4-20 mA receiver Bridge sensors (strain, pressure, etc.) Thermocouples, RTDs Single-ended voltage input (ground V-)
C12AN2+ / C12AN2-, C12AN3+ / C12AN3-	12-bit Diff. Input	Differential amplifier Programmable Gain (GHx) Programmable Attenuation (AHx) Series input resistors (S+Hx, S-Hx) Lowpass filtering (cap. in FHx, AHx)	Differential voltage amplifier Bridge sensors (strain, pressure, etc.) Thermocouples, RTDs Photodiodes Single-ended voltage input (ground V-) 0-20 mA or 4-20 mA receiver ; requires external series sense resistor
C12AN4, C12AN5, C12AN6	12-bit Input	Single-ended amplifier Programmable Gain (GHx) Programmable Attenuation (AHx) Lowpass filtering (cap. in AHx)	Single-ended voltage input 0-20 mA or 4-20 mA receiver : requires external series sense resistor; requires 1 and only 1 ground-referenced receiver
C12AN7 [4]	12-bit Input	None	0 to +4.096V input or -4.096V to +4.096V input
CAN0, CAN1, CAN2	8-bit Input	Single-ended amplifier Programmable Gain (GLx) Programmable Attenuation (ALx) Lowpass filtering (cap. in ALx)	Single-ended voltage input
CAN3, CAN4, CAN5	8-bit Input	Resistive excitation (XLx) from +5Vquiet	0 to +4.096V input Resistive transducer (R_{XL} forms voltage divider)
CAN6, CAN7	8-bit Input	None	0 to +4.096V input
COLD JN COMP	Output	Jumpers select thermocouple type J (J5), K,T (J6), R,S (J7), E (J8), or +10 mV/^{o}C board temp. output	Tie one lead of thermocouple to this pin; other lead goes to amplified voltage input

Notes:

1. CVOUT2 is not available if a 12-bit DAC is configured at output CV/IOUT1.
2. CVOUT4 is not available if a 12-bit DAC is configured at output CV/IOUT3.
3. CVOUT8 is not available if a 12-bit DAC is configured at output CV/IOUT1 and 12-bit DAC calibration occurs during operation; this is because DAC8 controls the analog switch that routes signals during calibration.
4. C12AN7 is used to calibrate the 12-bit DACs, and is not available if a 12-bit DAC is configured at output CV/IOUT1 and 12-bit DAC calibration occurs during operation.

Single-ended Voltage Inputs

There are three 12-bit and three 8-bit channels of single-ended A/D inputs with programmable gain/attenuation and optional lowpass filtering. The Conditioned ANalog (CAN) inputs with 8-bit resolution are labeled CAN0, CAN1, and CAN3. The inputs with 12-bit resolution are named C12AN4, C12AN5 and C12AN6. The conditioning circuit is nearly identical for each of these inputs, and is shown in Figure 2.

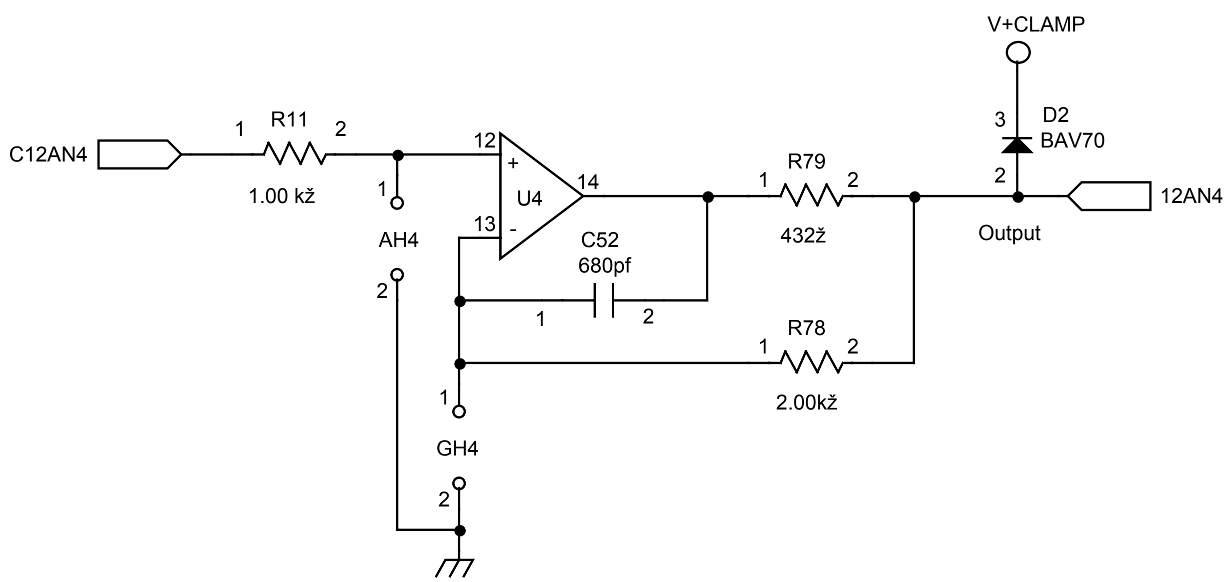


Figure 2. Input conditioning circuit for the single-ended 8-bit and 12-bit inputs. Note that the clamp diode is not present on the 8-bit resolution input channels. The labels refer to channel C12AN4 on the schematic.

The input is presented through resistor R11 to the positive input of the high-performance LT1114C operational amplifier ("op amp"). If no additional components are inserted, the default configuration shown in Figure 2 yields a unity gain buffer (that is, the output voltage equals the input voltage) whose output is presented to the A/D converter on the QED Board.

Why is this a unity gain configuration? Briefly, this is because the op amp adjusts its output such that its + and - inputs are equal; this is what op amps with negative feedback do. The feedback resistor R78 ties the node labeled "Output" in Figure 2 (at pin 2 of R78) to the negative input of the op amp (at pin 1 of R78). There is essentially no current through R78 (because the input current of the op amp is extremely small), so the voltage drop across R78 is approximately zero, and thus the voltage at the + input equals the voltage at the - input which equals the voltage at 12AN4, the output of the overall circuit. The output voltage equals the input voltage, or, in other words, the circuit has unity gain. The standard input range is 0 to 4.096 volts for 8-bit and unipolar 12-bit channels, and -4.096 to +4.096 volts for bipolar 12-bit channels. The 12-bit A/D channels can be configured for unipolar or bipolar operation under software control.

Before discussing other configuration options, let's examine the other elements in the circuit of Figure 2 more closely. The input series resistor R11 has very little effect in the default configuration, because the input current of the op amp is negligible, so there is essentially no voltage drop across R11. Capacitor C52 is a compensation device that provides negative feedback at high frequencies to enhance the stability of the circuit.

Note that the series output resistor R79 is <u>inside</u> the op amp's feedback loop. The op amp is controlling the voltage at the node labeled "Output"; this "Output" voltage is what is being sensed and fed back by resistor R78. Thus, under normal circumstances the series output resistor R79 does not affect the output voltage. R79 serves two purposes:

1. it improves stability by isolating any capacitive loading from the op amp output; and,
2. it acts as a current limit resistor to avoid damaging the A/D input when overvoltage conditions occur.

If the input voltage at C12AN4 is greater than 4.8 volts, diode D2 begins to conduct and clamps the output voltage. This prevents an overvoltage condition at the input of the 12-bit A/D channel. If this diode were not present, the current limiting resistor R79 would prevent damage to the A/D input, but all channels of the 12-bit A/D would be susceptible to false readings. Clamping the A/D12 inputs to less than 5.0 volts avoids this problem. The 8-bit A/D inputs are not subject to this problem, so the clamp diodes are not used on their inputs.

<u>Amplifying a Single-ended Voltage Input</u>

To boost the gain of the conditioning circuit above unity, simply insert a resistor in the socket labeled GH4, where <u>G</u> stands for a <u>G</u>ain resistor, <u>H</u> means that this is a <u>H</u>igh Resolution (12-bit) channel, and <u>4</u> is the channel number. The voltage gain A_V is set by the ratio of the gain resistor Rg (GH4 in Figure 2) and the feedback resistor Rf (R78 in Figure 2) as:

$$A_V = 1 + Rf / Rg \qquad \textbf{Eqn. 1}$$

or, if the feedback resistor equals 2 kΩ,

$$A_V = 1 + 2000 / Rg \qquad \textbf{Eqn. 2}$$

where the gain resistor Rg is expressed in ohms. To calculate the value of Rg for a specified voltage gain, we can rewrite the equation as:

$$Rg = Rf / (A_V - 1) = 2000 / (A_V - 1) \qquad \textbf{Eqn. 3}$$

For example, suppose that we have an input signal that ranges from 0 to 0.4 volts, and we want the input signal to be multiplied by a gain of 10 to take advantage of the full resolution of the A/D converter. In this case,

$$Rg = 2000 / (10 - 1) = 222\ \Omega \qquad \textbf{Eqn. 4}$$

The nearest 1% resistor value is 221 Ω, and the nearest 5% resistor value is 220 Ω. Note that all of the pre-mounted feedback and series resistors on the board have a +/- 1% tolerance on their resistance values.

Attenuating a Single-ended Voltage Input

In some cases the input voltage swing is wider than the input range of the A/D converter. In these cases we need to attenuate the input signal by applying a gain less than one. In the circuit of Figure 2, this is accomplished by leaving the gain resistor socket labeled GH4 empty, and inserting a resistor in the attenuation socket labeled AH4. As you might suspect, the A stands for Attenuation, the H stands for High resolution (12-bit) channel, and 4 is the channel number. The combination of the series resistor R11 and the attenuation resistor AH4 forms a voltage divider that reduces the voltage at the positive input of the op amp in Figure 2, and this reduced voltage is buffered with unity gain by the op amp circuit.

To calculate the gain A_V as a function of the series resistance Rs (R11 in Figure 2) and the attenuation resistance Ra (socket AH4 in Figure 2), we use the standard voltage divider equation

$$A_V = Ra / (Rs + Ra) \qquad \textbf{Eqn. 5}$$

or, if the series resistor equals 1 kΩ,

$$A_V = Ra / (1000 + Ra) \qquad \textbf{Eqn. 6}$$

where the attenuation resistor Ra is expressed in ohms. To calculate the value of Ra for a specified voltage gain, we can rewrite the equation as:

$$Ra = A_V * Rs / (1 - A_V) = A_V * 1000 / (1 - A_V) \qquad \textbf{Eqn. 7}$$

For example, suppose that we have an input signal that ranges from 0 to 10 volts, and we want the input signal to be multiplied by a gain of 0.4 to attenuate it to a 0 to 4 volt range. In this case,

$$Ra = 0.4 * 1000 / (1 - 0.4) = 667\ \Omega \qquad \textbf{Eqn. 8}$$

<u>Lowpass Filtering the Input Signal</u>

Sometimes it is advantageous to pre-filter an input signal with a simple RC (resistor/capacitor) lowpass filter. This is easy to accomplish using the circuit in Figure 2 if you desire a voltage gain greater than or equal to 1. Simply insert a capacitor in the socket labeled AH4, and set the gain of the circuit by selecting the appropriate resistor for socket GH4 as described above. The combination of the series resistor Rs (R11 in Figure 2) and the parallel capacitor Cp in socket AH4 form a lowpass filter. The cutoff frequency fc of the circuit is given by:

$$fc = 1 / 2\pi RsCp \qquad \textbf{Eqn. 9}$$

where Rs is expressed in ohms (Rs = 1000 in Figure 2), Cp is expressed in farads, and fc is expressed in Hz (cycles per second). In simple terms, the lowpass filter attenuates frequencies above fc, and passes frequencies below fc. To specify the capacitor value as a function of the desired cutoff frequency, we can recast the equation as

$$Cp = 1 / 2\pi\ Rs\ fc = 1 / 2000\ \pi\ fc \qquad \textbf{Eqn. 10}$$

For example, assume that we want to sample a slow-moving temperature signal only once per second, and we want to filter out 60 Hz and higher frequency noise with a lowpass filter. We could specify a cutoff frequency of 6 Hz, leading to a calculated capacitance value of 26 microfarads. A 25 μF tantalum capacitor would work well in this case, attenuating 60 Hz noise by about a factor of 10, and attenuating higher frequencies by even higher factors. We recommend tantalum because aluminum electrolytic capacitors exhibit typical leakage currents of several microamps, which would lead to noticeable voltage offset errors in this application.

Differential Input Amplifiers

In many applications, the signal of interest is available as the difference between two related voltages. For example, the output of a bridge-type strain gauge, pressure sensor, or catalytic bead gas sensor is the difference between the midpoint voltages on the two legs of the bridge. For these applications, a differential amplifier (sometimes called a "diff-amp") like the one shown in Figure 3 works well.

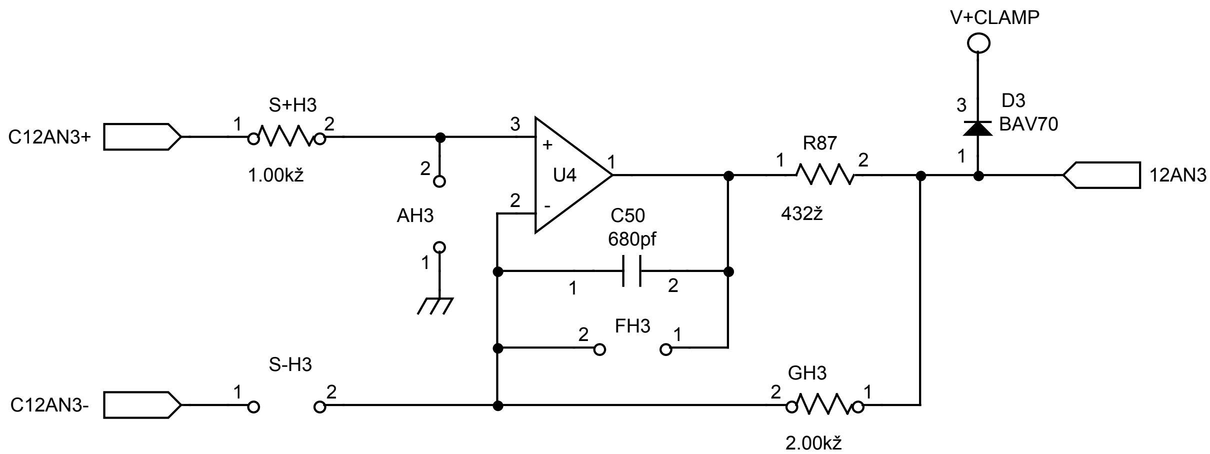


Figure 3. Differential amplifier input conditioning circuit for 12-bit A/D inputs. The component labels refer to channel C12AN3 on the schematic.

At first glance there are many similarities between the differential amplifier in Figure 3 and the single-ended amplifier in Figure 2. In fact, if we connect the signal labeled C12AN3- to ground, the circuits are nearly identical:

- they both behave as unity gain amplifiers in the default configuration;
- the resistor GH3 in Figure 3 provides negative voltage feedback just as R78 does in Figure 2;
- inserting a resistor in the S-H3 socket sets the gain in a manner analogous to inserting a resistor in the GH4 socket in Figure 2;
- the attenuation resistor socket AH3 in Figure 3 behaves the same as the corresponding socket AH4 in Figure 2, and each socket can optionally accommodate a filter capacitor to lowpass filter the input signal;
- the feedback capacitor C50 in Figure 3 provides the same stability enhancement as C52 in Figure 2; and,
- the series output resistor R87 in Figure 3 provides current limiting in overvoltage conditions just like R79 in Figure 2.

In other words, by grounding the negative input at C12AN3- and interpreting resistor socket S-H3 as the gain-setting resistor, we can make the amplifier in Figure 3 behave identically to the amplifier in Figure 2. Using this approach and consulting the sections presented above, we then know how to buffer, amplify, attenuate or lowpass filter a single-ended input using the differential amplifier.

Acquiring Data from Bridge Transducers Using Differential Amplifiers

The differential amplifier offers more capabilities than the single-ended amplifier. Figure 4 shows the circuit of Figure 3 interfaced to a standard bridge-configured sensor. In this example we assume that R2 is the active sensor element, sensing a physical parameter such as pressure, strain, combustible gas concentration, etc. The bridge is driven (excited) by a positive reference voltage such as +5Vquiet. In the quiescent state in which the sensor is not detecting a signal, the bridge is balanced and the + and - inputs to the differential amplifier (C12AN3+ and C12AN3-) are equal. If all of the resistors are of equal value, then the DC voltage at these inputs will be one half of the excitation voltage, or 2.5 volts.

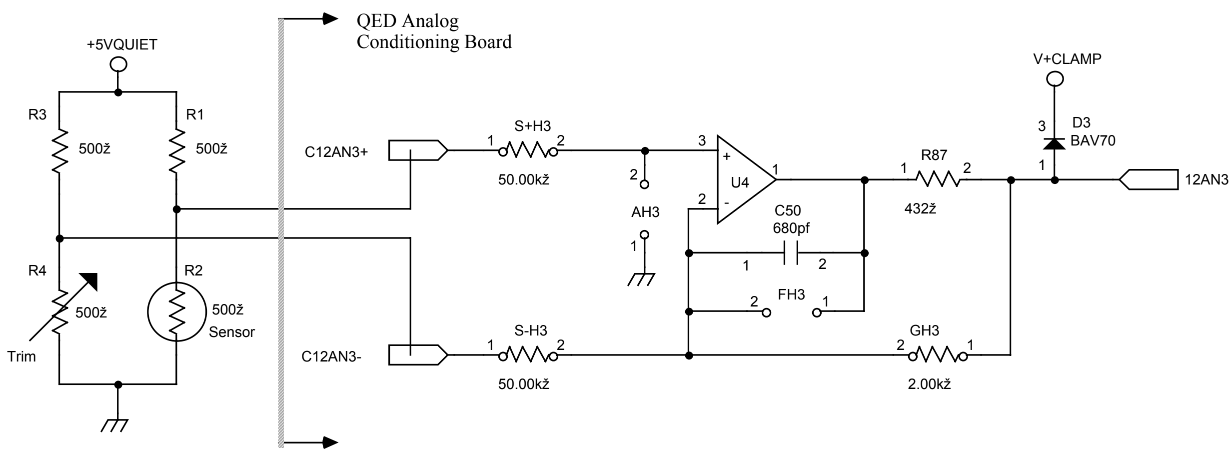


Figure 4. A differential amplifier interfaced to a bridge-type sensor such as a strain gauge or pressure sensor. The circuit amplifies the difference between the + and - inputs, ignoring the "common mode" DC offset.

Figure 4 illustrates a bridge with nominal 500 Ω resistors. We choose series resistors S+H3 and S-H3 to equal 50 kΩ, or 100 times the nominal bridge resistance. This prevents loading of the bridge circuit by the amplifier, and also prevents changes in the bridge resistances from significantly affecting the voltage gain of the amplifier. Note that the varying sensor resistance is placed in the side of the bridge connected to the + input of the differential amplifier; this enhances linearity by isolating the time-varying resistance from the negative feedback path that governs the gain equation.

Using the assumption that the S-H3 resistor is much larger than the bridge resistor, the voltage gain Av of the circuit is expressed as:

$$A_V = 1 + (Rf / Rg) = 1 + (GH3 / S\text{-}H3)$$ **Eqn. 11**

or, if the S-H3 resistor equals 50 kΩ as described above,

$$A_V = 1 + (GH3 / 50{,}000)$$ **Eqn. 12**

where the gain resistance in socket GH3 is expressed in ohms. To calculate the value of GH3 for a specified voltage gain, we can rewrite the equation as:

$$GH3 = S\text{-}H3 * (A_V - 1) = 50{,}000 * (A_V - 1) \quad [\,\Omega\,]$$ **Eqn. 13**

For example, suppose that we have a differential input signal that ranges from 0 to 0.1 volt, and we want the input signal to be multiplied by a gain of 40. In this case,

$$GH3 = 50{,}000 * (40 - 1) = 1.95\ M\Omega$$ **Eqn. 14**

A 2 MΩ resistor yields a gain of 41, which is close to our specified target.

An integrating amplifier can be created by installing a capacitor in the FH3 socket, where F indicates Filter, H indicates High resolution (i.e., a 12-bit channel), and 3 is the channel number. In addition, installing a capacitor in FH2 can sometimes help to improve the stability margin of the amplifier when very large feedback resistors are required as in the example above.

Acquiring Data from Photodiodes Using Differential Amplifiers

A photodiode is a light-sensitive device used as a sensitive indicator of light levels. Figure 5 indicates how to interface a photodiode to the QED Analog Conditioning Board without the need for any additional external components. The feedback loop maintains zero bias voltage across the diode, and the output voltage indicates the light-induced current through the diode.

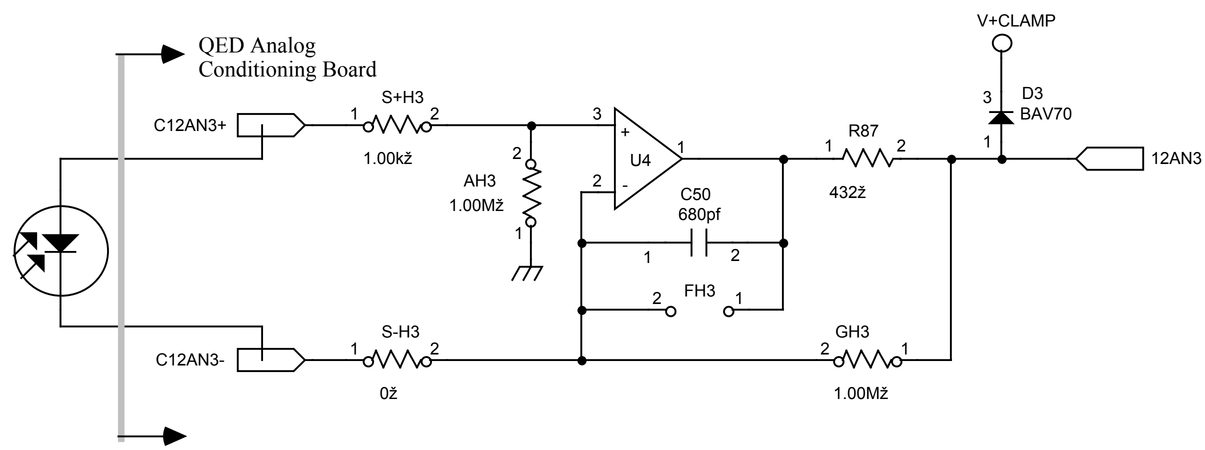


Figure 5. A differential amplifier interfaced to a photodiode. The values shown lead to an output of 2V/µA of current through the photodiode.

Instrumentation Amplifiers

The input pairs labeled C12AN0+ and C12AN0-, and C12AN1+ and C12AN1- are conditioned by two instrumentation amplifiers on the Analog Conditioning Board. An instrumentation amplifier (also called an "in-amp") is an integrated circuit comprising several op amps that amplifies a differential voltage input. There are many types of in-amps. The instrumentation amplifiers on the QED Analog Conditioning Board have several unique features. First, they sense and amplify voltages over a common mode input range exceeding +/- 24 Volts, even though the supply voltage range is only +5 to - 6 volts. This makes the in-amps useful for applications where a small signal rides on a relatively large common mode voltage, or for sensing 4-20 mA current loops where there may be a significant ground offset between the transmitter and the ground level at the QED Analog Conditioning Board. Second, each in-amp has very well controlled gains of 10.0 and 100.0, and the gain can be set to an intermediate value by proper selection of a programming resistor.

Figure 6 illustrates one of the two available instrumentation amplifier circuits. The circuit is simple: an Analog Devices AD626 in-amp senses the differences between the + and - input voltages, amplifies the difference by a specified gain factor, and passes the result to a unity-gain op amp buffer connected to a 12-bit A/D input. Pins 6 and 3 of the AD626 are the positive and negative supply inputs; they are filtered by RC decoupling networks to improve noise performance. The unity-gain op amp voltage follower is standard; this op amp configuration was discussed earlier.

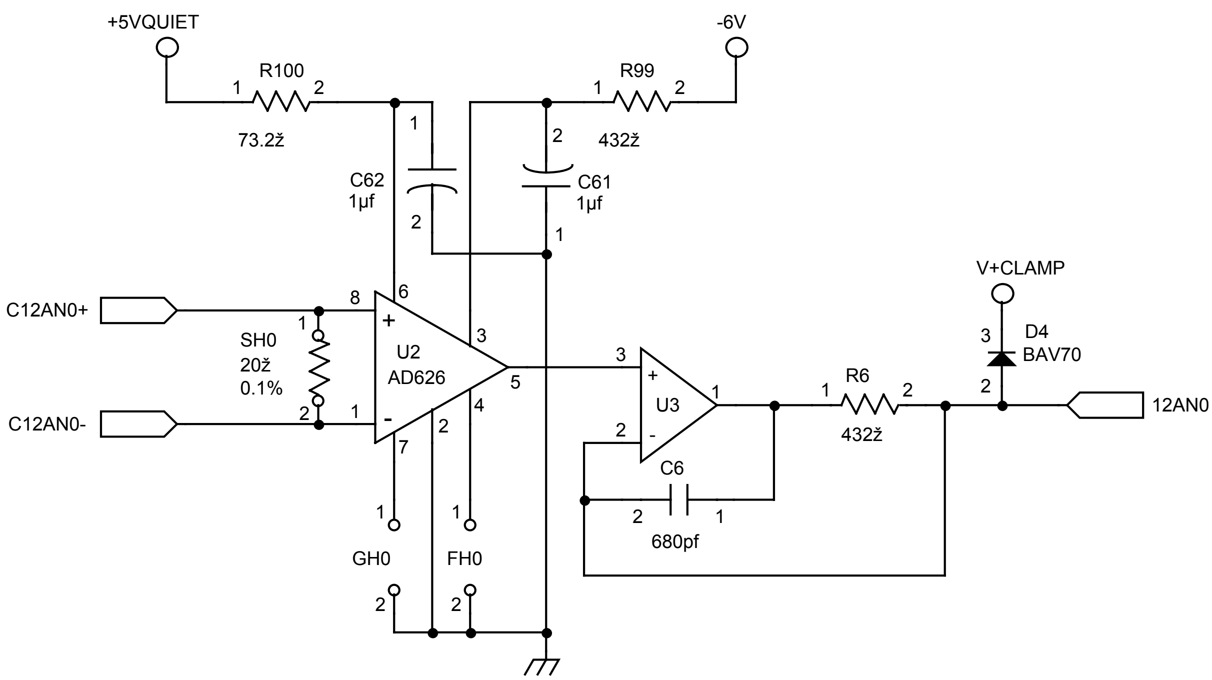


Figure 6. Instrumentation amplifier input conditioning circuit for 12-bit A/D inputs. The component labels refer to channel C12AN0 on the schematic.

The socket labeled GH0 sets the gain of the in-amp; if the socket is left empty, the gain equals 10.0. If a zero-ohm short is installed in GH0, the gain is 100.0. Installing a resistor between 100 kΩ and 100 Ω varies the gain over the range 11 to 99; refer to the following table as a guideline for selecting resistor values. Because the internal on-chip resistors in each in-amp have an absolute tolerance of ±20% (although they are ratio matched to within 0.1%), at least a 20% adjustment range must be provided for GHx.

Gain Range	Min. GHx	Max. GHx
11-20	5kΩ	105kΩ
20-40	802Ω	10kΩ
40-80	80Ω	1kΩ
80-100	2Ω	100Ω

We took a single in-amp, plugged in several resistors and measured the gain. The results are summarized in the following table, your gain resistors my vary by as much as 20%.

Resistor Value	Measured Gain
73.2Ω	89
100Ω	84
825Ω	45
1kΩ	40
2kΩ	28
5kΩ	18

Inserting a capacitor in the socket labeled FH0 (Filter for High resolution channel 0) lowpass filters the differential input signal. The cutoff frequency is given by:

$$fc = 1 / 2\pi * 100{,}000 * C \qquad [\text{ Hz }] \qquad \textbf{Eqn. 15}$$

where C is expressed in units of Farads. For example, to filter a very slow moving signal such as the output of a temperature transmitter, we could select a 10 µF tantalum capacitor which yields a cutoff frequency of 0.16 Hz. This would cut 60 Hz noise by approximately a factor of 360 while preserving the slowly varying temperature data.

Acquiring Data from Bridge Transducers Using Instrumentation Amplifiers

In a previous section we provided a detailed description of how to use a differential amplifier to acquire data from a bridge-type sensor such as a pressure or strain transducer. Notice that the instrumentation amplifier is itself a high performance differential amplifier, and can perform the same function. Figure 7 shows an instrumentation amplifier connected to a bridge transducer; compare this with Figures 4 and 6. The common mode input impedance of the in-amp is 100 kΩ, and the gain can be set to 10.0 or 100.0 or anything in between by configuring socket GH0 as described above.

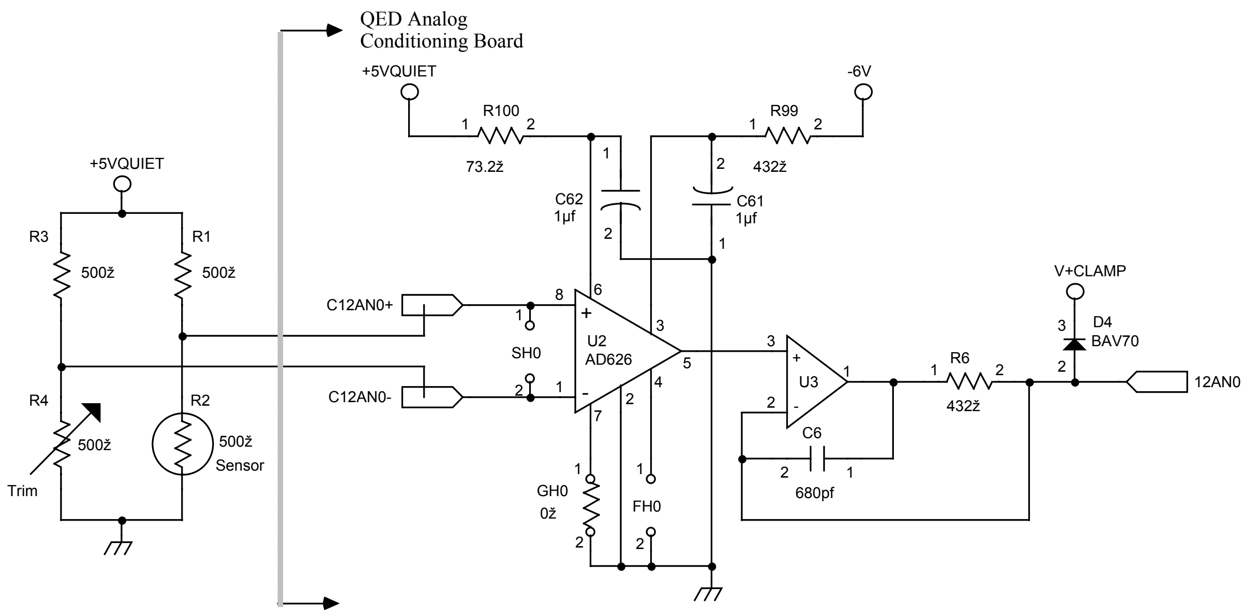


Figure 7. An instrumentation amplifier connected to a bridge transducer.

Receiving and Converting a 0-20 mA or 4-20 mA Signal

Receiving and Converting a 0-20 mA or 4-20 mA Signal Using an In-Amp

Many sensors transmit data as an analog signal varying between 0 and 20 mA or between 4 and 20 mA; these devices are called "transmitters". The analog conditioning board can detect and convert these signals in a number of ways, and the most flexible of these involves the in-amp circuitry as shown in Figure 8. If a 20 Ω 0.1% precision resistor is inserted in the socket labeled SH0 (a Series resistor on High resolution channel 0), then the current loop can flow in through the C12AN0+ terminal, through the series resistor, and out through the C12AN0- terminal. The current impresses a differential voltage across the 20Ω resistor that varies from 0 to 0.4 volts, and this voltage is amplified by a factor of 10 and converted by the 12-bit A/D input 12AN0. Thus, at the A/D input the 0-20 mA signal has been converted into a 0-4.0 volt signal referenced to the ground of the QED Analog Conditioning Board. This allows the 0-20 mA signal to be digitized and processed.

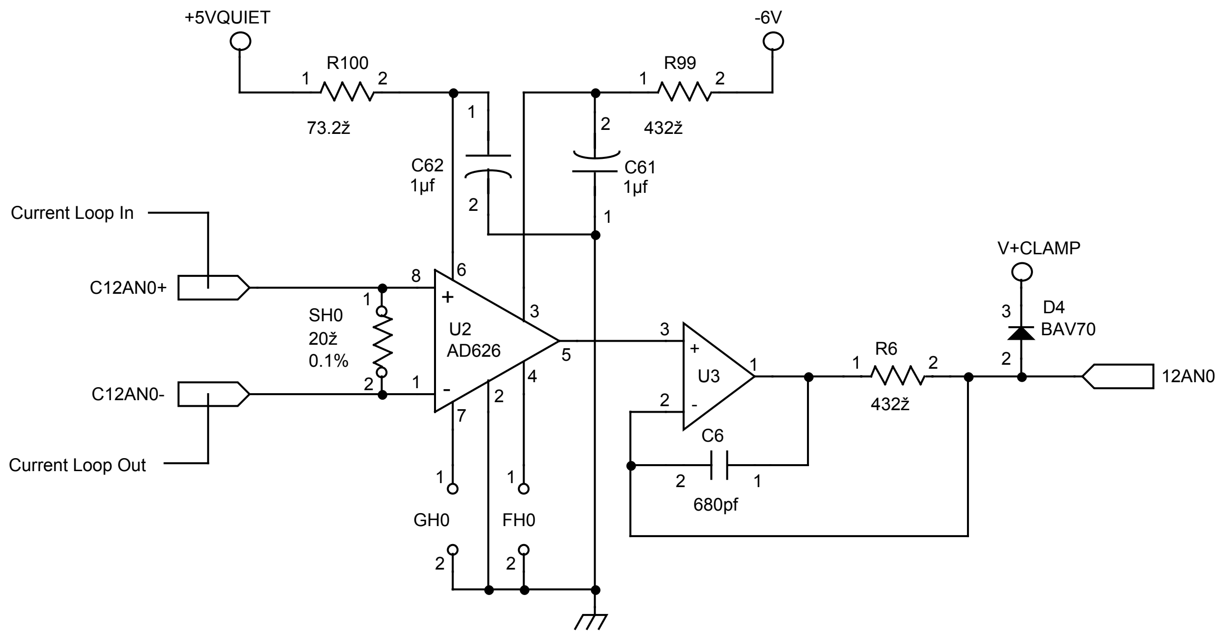


Figure 8. An instrumentation amplifier connected to a 0-20 mA or 4-20 mA current loop. This configuration can be used even if multiple "receivers" are sensing the current in the loop. If the QED Board is the only receiver and the transmitter sources current with respect to a shared ground, then the C12AN0- node can be grounded.

Receiving and Converting a 0-20 mA or 4-20 mA Signal Using a Differential Amplifier

We can also use the differential amplifier as shown in Figure 9 to acquire and convert a 0-20 mA or 4-20 mA signal; compare this configuration with Figures 3 and 8. The acceptable common mode range is not as wide as with the instrumentation amplifier circuits, but otherwise the performance is quite good.

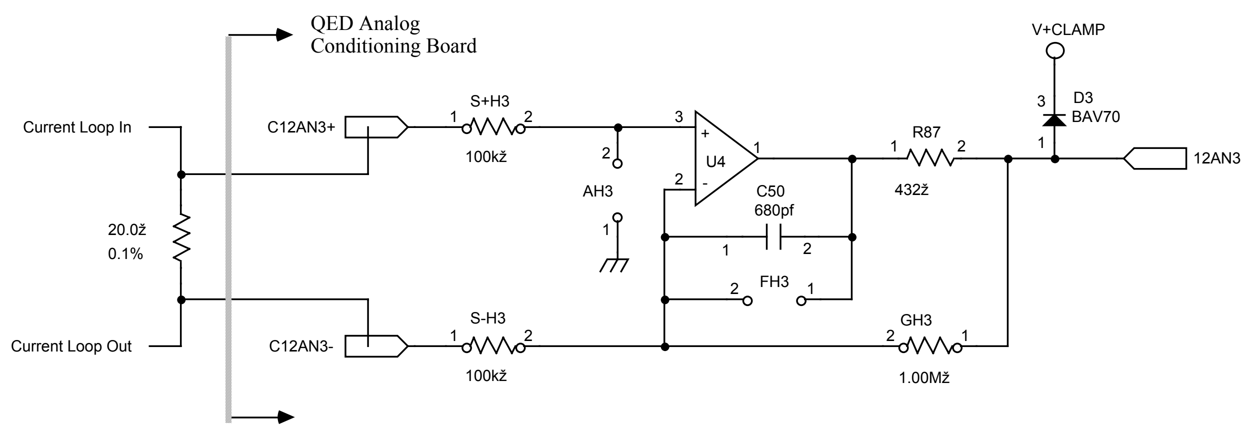


Figure 9. A differential amplifier connected to a 0-20 mA or 4-20 mA current loop. This configuration can be used even if multiple "receivers" are sensing the current in the loop, as long as the common mode voltage is within the range -5 V to +10 V. If the QED Board is the only receiver and the transmitter sources current with respect to a shared ground, then the C12AN0- node can be grounded.

<u>Receiving and Converting a 0-20 mA or 4-20 mA Signal Using a Single-ended Amplifier</u>

If the current loop transmitter and the QED Board share a common ground connection, and if the QED Board is the only receiver on the current loop, then the current can be simply passed through a 200 **Ω** resistor to ground to create a voltage that ranges from 0 to 4.0 volts. This voltage can then be sensed by any A/D input. Figure 10 shows the connection for a single-ended 12-bit channel. In fact, if 8-bit resolution is acceptable, any of the 8-bit A/D inputs can convert the 0-20 mA or 4-20 mA ground-referenced signal.

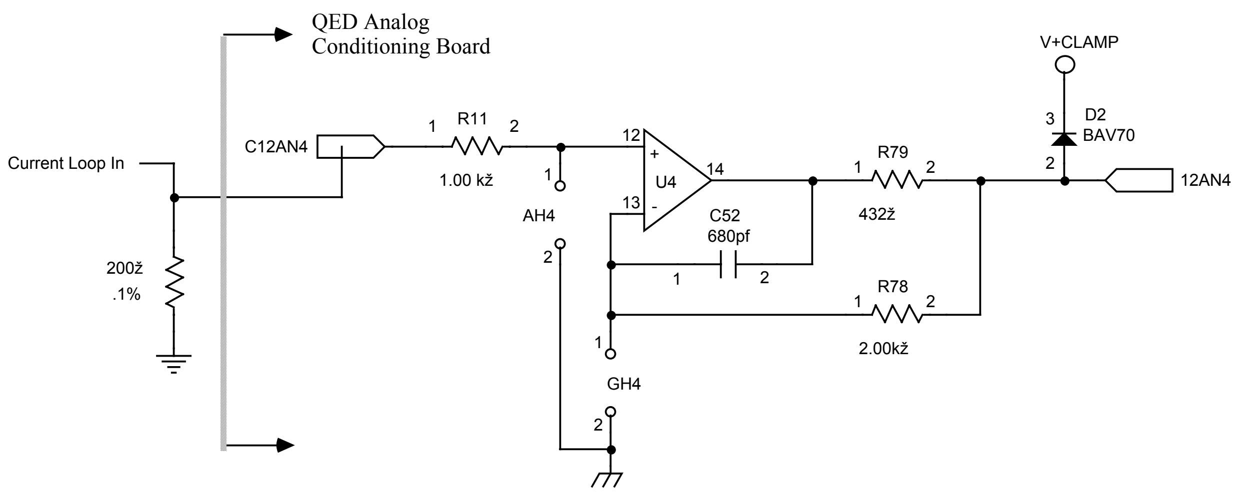


Figure 10. A single-ended amplifier connected to a 0-20 mA or 4-20 mA current loop. This configuration can be used if the QED Board is the only receiver, and the transmitter sources current with respect to a shared ground. Note that even un-amplified input channels such as CAN3 to CAN7 can detect the current loop signal under these conditions; only a single series 200 Ω resistor to ground is required.

Inputs With Excitation

The three 8-bit resolution Conditioned ANalog inputs named CAN3, CAN4, and CAN5 connect to 8-bit A/D channels through a 2 kΩ series protection resistor. These three inputs also offer a socket for an "excitation resistor" which is connected between the input and the +5Vquiet voltage. This configuration is ideal for purely resistive transducers such as thermistors; the combination of the excitation resistor and the sensing resistor forms a voltage divider. The result is that the voltage presented at the A/D input is monotonically related to the sensing resistance by a simple formula.

Note that if the excitation socket remains empty, the input accepts voltage inputs ranging from 0 to 4.096 volts and passes them to the 8-bit A/D converter.

Of course, you can provide external excitation to any input by attaching a pull-up resistor between the input signal and a suitable reference voltage such as +5Vquiet or +4.096VREF. This may be especially useful if you wish to measure a resistive sensor (such as a thermistor) with 12 bit resolution.

Connecting a Thermistor to the Input with Excitation

Figure 11 shows a thermistor interfaced to input CAN3. The 5 kΩ resistor Rx in socket XL3 (eXcitation for Low resolution channel 3) provides excitation, acting as the top half of a voltage divider between +5Vquiet and ground. The thermistor Rt has a nominal 5 kΩ resistance at room temperature, and is connected between the input and analog ground. The input voltage is given by:

Vin = 5.0 * Rt / (Rt + Rx) [volts] **Eqn. 16**

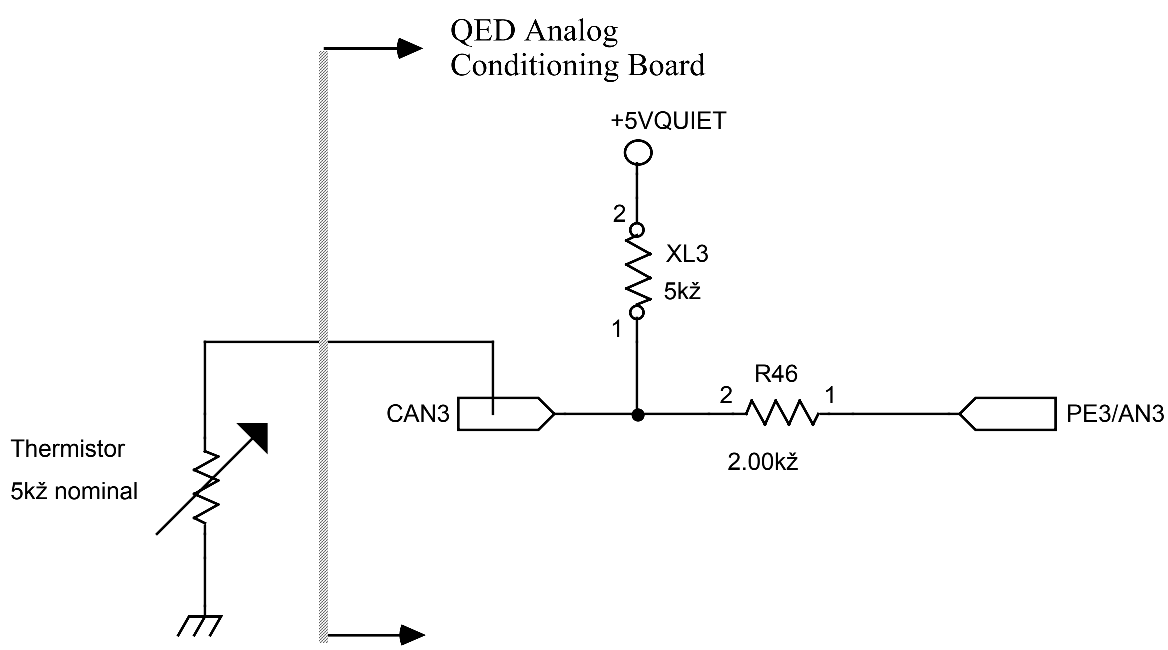


Figure 11. A thermistor interfaced to input CAN3.

If we measure a specific value of Vin using the A/D, the corresponding calculated value of the thermistor resistance Rt is:

Rt = Vin * Rx / (5.0 - Vin) **Eqn. 17**

To convert Rt into a temperature in degrees Kelvin, we use the standard thermistor formula:

T = A / (B + ln(Rt)) **Eqn. 18**

For the thermistor in this example, A = 3853.2 and B = 4.4162. Thus, if we measure an input voltage Vin equal to 2.0 volts, we can calculate the thermistor resistance Rt as:

$$Rt = 2.0 * 2000 / (5.0 - 2.0) = 1333\ \Omega \qquad \textbf{Eqn. 19}$$

The corresponding calculated temperature is

$$T = 3853.2 / (4.4162 + \ln(1333)) = 332\ K = 59\ C \qquad \textbf{Eqn. 20}$$

Single-ended Unamplified 8-bit A/D Inputs

The 8-bit Conditioned ANalog inputs named CAN6 and CAN7 directly present the input voltage to the 8-bit A/D converter through a 2 kΩ current-limiting protection resistor. Under normal conditions, less than 1 μA of current flows through the protection resistor, so it has negligible effect on the circuit. If an out-of-range voltage greater than 5 volts or below 0 volts is present, the resistor limits current to prevent damage to the A/D converter in the 68HC11 chip.

Acquiring Data from Thermocouples Using the On-board Cold-Junction Compensator

Thermocouples are used in many applications to sense temperature over a broad range. There are several families of thermocouples, each optimal for different resolutions and temperature ranges. The most popular thermocouples are designated as types E, J, K, R, S and T. The QED Analog Conditioning Board can accommodate all of these types.

The thermocouple comprises a small junction of two dissimilar metals. The device develops a small voltage potential across its leads that is related to the junction temperature being sensed. For example, a J type thermocouple develops about 51.7 μV/^{o}C (microvolts per degree Celsius) near room temperature. Unfortunately, the thermocouple's output depends not only on the junction temperature being sensed, but also on the temperature of the "cold junction" at the ends of the thermocouple leads. For example, on a QED Industrial Control System (ICS) that houses a QED Board and Analog Conditioning Board, this cold junction is located at the analog field screw terminals on the ICS backplane board. (Make sure that you run your thermocouple leads all the way back to the ICS or Analog Conditioning Board; otherwise, you may induce additional uncompensated thermocouple junctions that cause erroneous readings.) To calculate the actual temperature at the sensing junction, an electronic "cold junction compensator" measures the temperature on the Analog Conditioning Board and supplies the appropriate compensating offset voltage. The key assumption is that the temperature on the Analog Conditioning Board (specifically, the temperature of the LT1025 chip on the board) is equal to the temperature at the connection point of the thermocouple to the electronics (e.g., the ICS backplane board's screw connectors). For this reason it is wise to avoid the use of heat-generating components near the Analog Conditioning Board if high-resolution thermocouple temperature sensing is required.

Figure 12 shows a typical connection scheme for a thermocouple. One thermocouple lead is connected to "Cold Jn Comp" (pin 26 on the Analog Field Bus Connector), and the other is connected to a single-ended input configured with a typical gain of 50 to 100. Any of the amplified inputs on the board can be used; recall that differential amplifiers can be made to act like single-ended amplifiers by grounding the negative input. It is possible to terminate many thermocouples at the Cold Junction Compensator pin, as long as they are of the same or compatible types (that is, as long as they have the same voltage coefficient in the following table). The available types and the corresponding selection jumpers are as follows:

Thermocouple type	Voltage Coefficient	Jumper
J	51.7 µV/^{O}C	J5
K, T	40.6 µV/^{O}C	J6
R, S	5.95 µV/^{O}C	J7
E	60.9 µV/^{O}C	J8
Cold Junction Temperature	10 mV/^{O}C	J9

Note that if J9 is installed, the output at the "Cold Jn Comp" is 10 mV/^{O}C, reflecting the temperature of the LT1025 chip which we assume is closely related to the board temperature and the temperature of the thermocouple leads. That is, this output is zero volts at 0 C, and 0.25 V at 25 C. Using the appropriate algorithms, this temperature reading can be used to provide software cold junction compensation for a variety of thermocouple types.

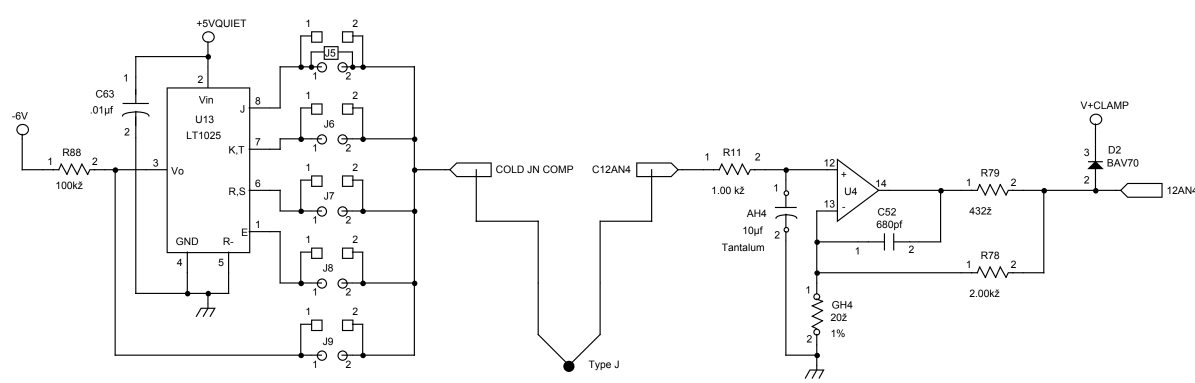


Figure 12. A J-type thermocouple interfaced to the Analog Conditioning Board. One thermocouple lead is connected to the "Cold Jn Comp" pin, and the other is connected to an amplified single-ended 12-bit A/D input at C12AN4. Jumper J5 is installed to configure the LT1025 cold junction compensator for J-type

thermocouples, and the C12AN4 amplifier is configured for a gain of 100 and includes a lowpass filter for noise reduction. Low leakage filter capacitors such as tantalum, ceramic or film capacitors should be used to avoid offset errors.

8-Bit DAC Outputs

The QED Board contains an 8 channel multiplying DAC (digital to analog converter) with 8-bit resolution and 0-3 volt maximum output range. The QED Analog Conditioning Board includes circuitry to program each of these output ranges to 0-5.12 V, or 0-10.24 V, or any intermediate range. Thus, you can have 8 Conditioned Voltage OUTputs (outputs CVOUT1 to CVOUT8), each with 8-bit resolution and a programmable output voltage range anywhere from 5.1 to 10.2 V. The output op amps run on +13V/ -6 V supplies, and are able to source up to 10 mA at up to 10.2 volts output, or sink 2 mA at 0 volts output.

If you need higher resolution outputs, you can configure two pairs of DACs to yield two calibrated 12-bit resolution DACS with either voltage outputs (0-5.12 or 0-10.24 V, or anything in between) or with 0-20 mA current outputs.
The simplest of the DAC conditioning circuits is the 8-bit resolution scaled voltage output as shown in Figure 13. The field connections for these outputs are labeled CVOUT5, CVOUT6, CVOUT7, and CVOUT8. (CVOUT8 optionally shares another use, controlling the calibration of the 12-bit DACs.) See the glossary entries for >DAC (a Forth routine) and SetDAC() (a C function) for details regarding how to control the DAC outputs.

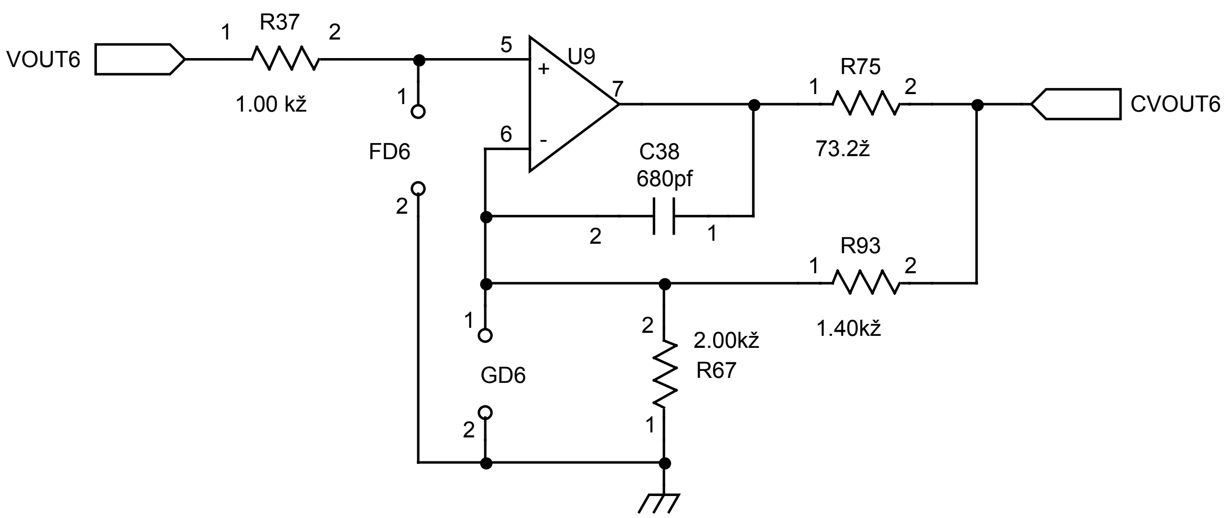


Figure 13. Voltage output amplification circuit for CVOUT6. In the default configuration, the output voltage range is 0-5.1 volts, corresponding to about 20 mV per DAC step. Insertion of an 825 Ω 1% resistor in the GD6 socket boosts the output range to 0-10.2 volts, corresponding to about 40 mV per step.

The output voltage amplification circuit in Figure 13 is very similar to the input amplifier illustrated in Figure 2 and described in detail above. The input to the amplifier is VOUT6 from the octal DAC on the QED Board; this signal ranges from 0 to 3.0 V. In the default configuration (i.e., socket GD6 is empty/open circuited), the amplifier scales the signal with a voltage gain equal to

$$Av = 1 + R93 / R67 = 1.7 \qquad \textbf{Eqn. 21}$$

Thus the voltage output range is 3.0 * 1.7 = 5.1 volts, corresponding to approximately 20 mV for each one of the 255 steps of the 8-bit DAC. If an 825 Ω resistor is placed in socket GD6 (the

Gain resistor for DAC channel 6), it appears in parallel with R67, resulting in an effective resistance of 584 Ω between the op amp's negative input and ground. The resulting gain is

$$Av = 1 + 1400 / 584 = 3.4 \qquad \textbf{Eqn. 22}$$

Thus the voltage output range is 3.0 * 3.4 = 10.2 volts, corresponding to approximately 40 mV for each one of the 255 steps of the 8-bit DAC.

To specify an output voltage range between 5.1 and 10.2 V, use the following formula to choose the R_{GD} resistance (the resistance installed in the GD6 socket) as a function of the output voltage Vmax:

$$R_{GD} = 2.8 \times 10^6 / [(667 * Vmax) - 3400)] \qquad [\ \Omega\ ] \qquad \textbf{Eqn. 23}$$

To filter the step-like output of the DAC, each output circuit contains a capacitor socket labeled FDx where F stands for Filter, D stands for DAC, and x represents the channel number. The cutoff frequency of the lowpass filter resulting from the installation of a capacitance C is

$$fc = 1 / 2\pi * 1000 * C \qquad [\ Hz\ ] \qquad \textbf{Eqn. 24}$$

because the series resistance is 1000Ω. In general, a good choice is to choose fc to be approximately equal to the frequency at which the DAC is updated by the software. For example, if the software writes to a DAC 160 times per second (i.e., 160 Hz), then a 1 μF capacitor would be appropriate.

If a finer resolution output is required and a smaller output voltage range is allowable, an attenuating resistor instead of a capacitor can be installed in FDx. To size the attenuation resistor, refer to Equation 7.

High Resolution 12-bit Voltage Outputs

Figure 14 illustrates the conditioning circuit that combines two 8-bit DACs to create a single DAC with 12-bit resolution. DAC channels 1 and 2 can be combined in this way, as can DAC channels 3 and 4. In this section we discuss the voltage output version of these high resolution outputs, and in a subsequent section the current output option is described.

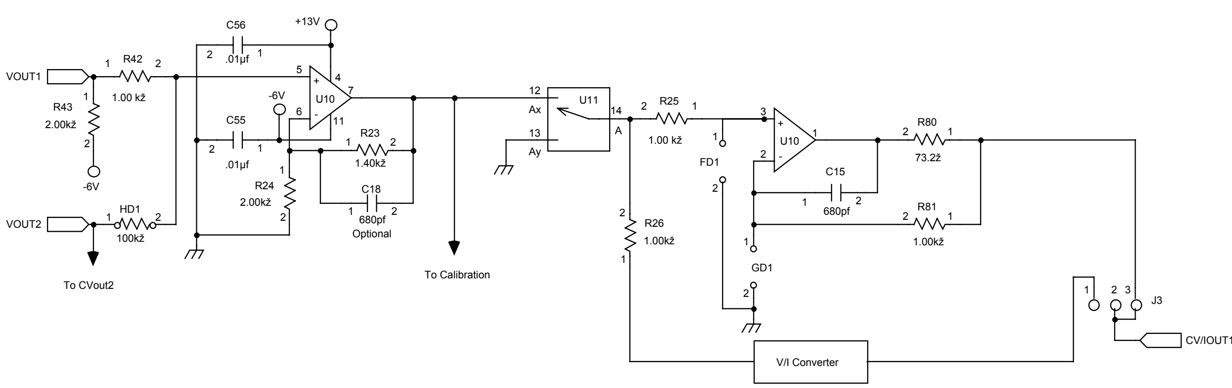


Figure 14. This output conditioning circuit combines DAC channels 1 and 2 to create a single high resolution 12-bit output voltage. The output voltage range in the default configuration is 0-5.1 volts, corresponding to about 1.25 mV for each of the 4096 DAC steps. Insertion of a 1000Ω 1% resistor in the GD1 socket boosts the output range to 0-10.2 volts, corresponding to about 2.5 mV per step.

If socket HD1 (next to the VOUT2 signal in Figure 14) is left open circuited, then DAC1 and DAC2 operate independently with 8-bit resolution as described above. If a 100 kΩ resistor is inserted in socket HD1, then the outputs of DAC1 and DAC2 (named VOUT1 and VOUT2 on the QED Board's Analog I/O connector) are summed through resistors R42 and HD1. Because R42 equals 1 kΩ and HD1 equals 100 kΩ, the effect of DAC1 is 100 times stronger than DAC2. The result is that DAC1 provides a "coarse" input which is augmented by a "fine" input from DAC2. In other words, DAC2 provides much smaller steps to fill in the gaps between the coarse steps of DAC1. Working in combination with the appropriate software (which is available on diskette from Mosaic Industries), the two DACs can achieve 12 bit resolution and accuracy after calibration by 12-bit A/D channel 12AN7.

The summed inputs are buffered and amplified, and then pass through an analog switch to another amplification stage whose gain is set by resistance GD1. The analog switch allows the voltage output to be taken "off line" during calibration as discussed below. In the default configuration, GD1 is an open circuit, and the voltage output range is 0-5.1 V. If a 1.00 kΩ resistor is inserted in GD1, the voltage range doubles to 0-10.2 V. To select the voltage output option, jumper J3 should be installed between the center post and the post labeled "V" on the silk-screen. To select the current output option, jumper J3 should be installed between the center post and the post labeled "I" on the silk-screen

To smooth the step-like output of the DAC, a filter capacitor can be inserted in socket FD1 as explained in the previous section.

In summary, the circuit comprises a summing amplifier, an analog switch which can take the output "off line" during calibration, and a gain and filtering stage.

<u>Calibrating the 12-bit DAC Outputs</u>

To use the 12-bit calibration feature, jumpers J1 and J2 must be installed, the socket labeled GD8 (the gain setting resistor for DAC8) must be empty and there must not be any resistor installed in FD8. This configuration dedicates the 12-bit A/D channel 12AN7 to the calibration process, and also dedicates the DAC8 channel to control the calibration process. If 12-bit DACs are not required in a given application, J1 and J2 may be left as open circuits, and this makes the 12-bit A/D input 12AN7 and the 8-bit voltage output CVOUT8 available for general purpose use.

The remainder of this section explains how the hardware accomplishes the calibration process; it is not necessary to master this material to use the calibrated 12-bit DACs, so you may skip to the next section if you wish.

By feeding the output of the summing amplifier through an analog switch (74HC4053 at U11) via jumper J1 to the 12-bit A/D input 12AN7, appropriate software can create a calibration table for the 12-bit DAC. Whenever we want to create an output voltage (or current) based on a 12-bit DAC count ranging from 0 to 4095, the software consults the lookup table and writes the appropriate 8-bit counts to DAC1 and DAC2 to generate the desired output. In essence, the calibration process makes the 12-bit DAC have the same step size and accuracy as the on-board 12-bit A/D.

During calibration, we will be manipulating the DAC outputs, and we don't want this to affect any machinery that the DACs may be driving. To avoid problems, we use an analog switch to disconnect the DAC signal from the output and keep the CV/IOUT1 output at zero while the summed signal is being calibrated by A/D input 12AN7.

The 74HC4053 triple SPST (single-pole single-throw) analog switch properly routes the analog signals during calibration and operation. The switches are labeled A, B, and C; a digital input of 0 at control input A connects the output to pin Ax on the device, and a digital input of 1 at control input A connects the output to pin Ay. Three digital signals are required to select which analog switch is active. Because the QED Analog Conditioning Board does not have access to any digital I/O signals (it connects only to the QED Board's Analog I/O Bus), the voltage output of DAC8 is used to control the analog switch. The Analog Conditioning Board's schematic shows how DAC8 controls the analog switch U11 via jumper J2 and a resistive divider network. The following chart on summarizes the control scheme:

DAC8 Voltage	A	B	C	Function
0.0	0	0	0	On line Channel 1
3.0	1	1	0	Off line Calibrate 1
5.1	1	1	1	Off line Calibrate 2

The standard operating mode occurs with DAC8 set to a count of zero, with its output at zero volts. In this case:

- analog switch A is connected at Ax, so the 12-bit combination of DAC1 and DAC2 is gated to the voltage or current output at CV/IOUT1;
- analog switch B is connected to Bx, so the 12-bit combination of DAC3 and DAC4 is gated to the voltage or current output at CV/IOUT2;
- analog switch C is connected to Cx, so the output of the DAC1/DAC2 summing amplifier is connected to the A/D input 12AN7 .

Thus both 12-bit DAC outputs are available at their respective CV/IOUT pins (assuming that the required 100 kΩ resistors are installed in HD1 and HD3, and that jumpers J3 and J4 are appropriately set.)

To calibrate the 12-bit combination of DAC1 and DAC2, we set DAC8 to a count of 150, corresponding to an output voltage of 3.0 Volts at CVOUT8. Because jumper J2 is installed, this voltage drives the input pins of the analog switch via a resistive divider network. In this case:

- analog switch A is connected at Ay, so the voltage or current output at CV/IOUT1 is held at zero;

- analog switch B is connected to By, so the voltage or current output at CV/IOUT2 is held at zero;
- analog switch C is connected to Cx, so the output of the DAC1/DAC2 summing amplifier is connected to the A/D input 12AN7.

In this configuration, the DAC outputs are safely "off line" with zero output so that external devices will not be disturbed during the calibration, and the DAC1/DAC2 12-bit pair is connected to the 12-bit A/D to enable the building of the calibration table.

To calibrate the 12-bit combination of DAC3 and DAC4, we set DAC8 to a count of 255, corresponding to an output voltage of 5.1 V at CVOUT8. Because jumper J2 is installed, this voltage drives the input pins of the analog switch via a resistive divider network. In this case:

- analog switch A is connected at Ay, so the voltage or current output at CV/IOUT1 is held at zero;
- analog switch B is connected to By, so the voltage or current output at CV/IOUT2 is held at zero;
- analog switch C is connected to Cy, so the output of the DAC3/DAC4 summing amplifier is connected to the A/D input 12AN7.

In this configuration, the DAC outputs are safely "off line" with zero output so that external devices will not be disturbed during the calibration, and the DAC3/DAC4 12-bit pair is connected to the 12-bit A/D to enable the building of the calibration table.

0-20 mA Current Outputs

Current loop signaling is a standard means of transmitting analog signals in industrial control and data acquisition systems. The QED Analog Conditioning Board can source two current outputs at 0-20 mA with up to 5 volts output drive capability. Each current output can be driven by an 8-bit DAC (DAC1 and DAC3), or by a 12-bit combination DAC (DAC1/DAC2 and DAC3/DAC4) to achieve higher resolution. Most 0-20 mA and 4-20 mA systems specify 12-bit resolution.

Note that software determines whether the full-scale output signal maps onto a 0 to 20 mA range or a 4 to 20 mA range. By setting the DAC outputs to 4.0V, the current output will be 20mA. Be careful not to set the voltage above 4.0V when using the current outputs.

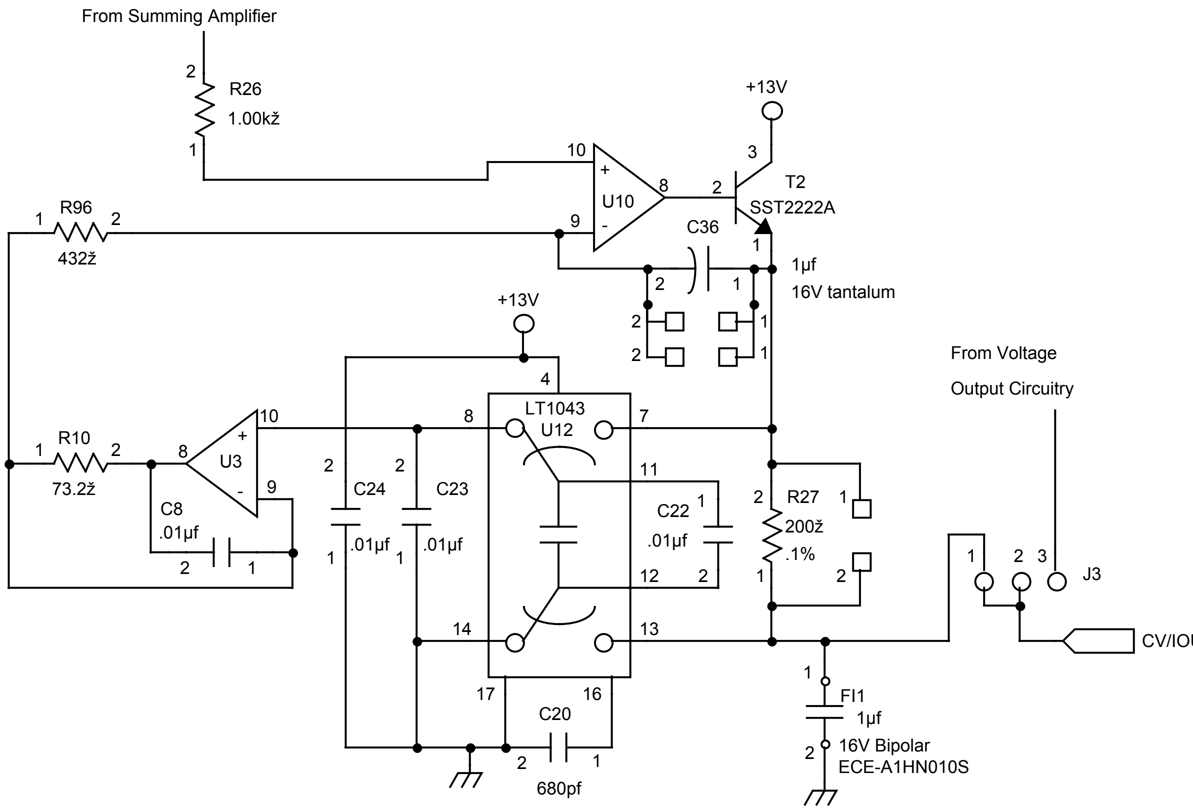


Figure 15. This voltage-to-current converter transforms a 0 to 4.0 volt input signal (from DAC1 or the high-resolution combination of DAC1 and DAC2) into a current output of 0 to 20 mA at CV/IOUT1.

In simple terms, the switched capacitor LT1043 chip in Figure 15 impresses the 0-4 V input voltage across the 200 Ω precision resistor R27 to generate a well-controlled 0-20 mA output. The input voltage is taken from the calibrated output of the summing amplifier as discussed above, so the output current is a 0-20 mA signal calibrated to 12-bit accuracy and resolution. The voltages on the left side of the LT1043 switched capacitor chip in Figure 15 are referenced to the analog ground on the Analog Conditioning Board, while the voltages on the right side of the LT1043 at the precision 200 Ω resistor R27 are set by the external current loop ground and the load resistance in the current loop. The switched-capacitor architecture of the LT1043 allows the feedback network to work properly despite ground offsets. The circuit works properly as long as the output voltage at CV/IOUT1 is above -5V and less than +5V with respect to the analog ground on the QED Analog Conditioning Board.

The optional 1 µF output filter capacitor at socket FI1 is recommended for improved noise performance. Removing the capacitor improves the output response time for signals that vary at greater than 100 Hz, but results in higher switching noise.

Using the QED Analog Conditioning Board

The QED Analog Conditioning Board is easiest to use with the Industrial Control System which provides easy connection to all the field connections and power connections. If all the A/D input channels are not being used, the unused inputs should be connected to ground.

Connectors

There are two 40 pin male quarter-square post connectors on the QED Analog Conditioning Board. The "Analog I/O" connector is wired directly to the connector by the same name on the QED Board; this connection can be made via ribbon cable.

The other 40 pin connector on the QED Analog Conditioning Board is called the "Analog Field Connector". It brings out all of the "Conditioned" inputs and outputs, which is why most of the signal names on this connector start with "C". For convenience, the Analog Ground signal is present at 10 different pins on this connector. Another convenient feature is that pins 1-26 are compatible with Gordos™ 8- and 16-channel non-multiplexed isolated analog I/O boards. This compatibility can be used to add a few channels of modular isolated analog I/O.

When the QED Analog Conditioning Board is used with the Industrial Control System, the board can be plugged into the Industrial Control System's backplane board to give screw terminal access to all the field connections. This provides an easy way to connect to the analog inputs and outputs.

The power connector is a 6 position screw terminal connector. Power is supplied to the board at the 15-38VDC and GND connections. V+Raw is also available at the connector, although it is not used on the QED Analog Conditioning Board. The +13V, +5Vquiet, and -6V supplies are available for external low current, analog circuitry. Drawing excessive current or using them for digital circuitry will degrade the performance of the board.

Power Supplies and References

The QED Analog Conditioning Board requires an input voltage in the range 15 to 38 volts DC. An on-board regulator then generates all other required voltages. The following table summarizes all of the voltages and their purposes:

Supply Name	**Function**
+15-38 VDC	External supply voltage
+13 V	Positive supply for op amps
-6 V	Negative supply for op amps
+5 Vquiet	Supplies excitation and several chips (in-amps, cold jn, etc.)
+5 V	Used to generate V+CLAMP
+4.096	Vrh reference for A/D converters, not available to user
+4.096VREF	Available reference, can source 1 mA
V+CLAMP	Clamp overrange voltages to about 4.8 V
V+RAW	From QED Board, not used on Analog Conditioning Board
Analog Ground	Shared analog ground for QED and Analog Conditioning Boards

In some applications it may be possible to power both the QED Board and the QED Analog Conditioning Board from a single external +15 V regulated supply. Simply connect the 15V regulated supply to the QED Board, connect the Analog Conditioning Board with a 40 pin ribbon cable and install a wire on the Analog Conditioning Board power connector from V+RAW to +15-38 VDC. These two signals are located next to each other on the connector. You do not need to add any ground connections from the QED Board to the Analog Conditioning Board.

When using two supplies, one for the QED Board and one for the Analog Conditioning Board, do not connect the grounds together, they will be connected through the Analog Ground. By connecting the grounds together, you will be creating a ground loop.

Installing Configuration Resistors, Capacitors, and Jumpers

This section describes the configuration options for user-installed resistors, capacitors and jumpers. Figure 16 shows the silk-screen legend on the QED Analog Conditioning Board. At the lower right, jumpers J1 and J2 should be installed to enable calibration of the 12-bit DACs, and should not be installed if the 12-bit DAC option is not used. If J1 and J2 are installed, 12AN7 and DAC8 are devoted to controlling the 12-bit DAC calibration. J1 and J2 are not installed in the default configuration.

Jumper J3 controls whether CV/IOUT1 is a current (I) or a voltage (V) output, and J4 performs the same function for channel CV/IOUT3.

Jumpers J5 through J9 select which of the LT1025 cold junction compensation outputs is tied to the "COLD JN COMP" pin on the field connector. Only one jumper can be installed in jumpers J5 through J9. The following table summarizes the effect of the jumpers:

Thermocouple type	Voltage Coefficient	Jumper
J	51.7 μV/°C	J5
K, T	40.6 μV/°C	J6
R, S	5.95 μV/°C	J7
E	60.9 μV/°C	J8
Cold Junction Temperature	10 mV/°C	J9

In the default configuration (when the board it is shipped from Mosaic Industries), no user-installed resistors or capacitors are on the board, jumpers J1 and J2 are open circuited (12-bit DAC calibration is not enabled), and J5 is installed (J-type thermocouple compensation).

The legend in Figure 16 provides a key to interpreting the resistor and capacitor labels. This legend is printed right on the board to make it easier to use the configuration options, and the device names are also present in the schematic of the QED Analog Conditioning Board. The first letter indicates the function of the resistor or capacitor:

First Letter Code	Channel Type
A	Attenuation resistor (optional: filter capacitor)

F	Filter capacitor
G	Gain-setting resistor or jumper
S	Series resistor (S+ for + input; S- for - input)
X	EXcitation resistor

The second letter indicates the type of channel:

Second Letter Code	Channel Type
D	8-bit DAC output
H	High resolution 12-bit A/D input
HD	High resolution 12-bit DAC output
I	I (Current) output
L	Low resolution 8-bit A/D input

The final number indicates the channel number. For example, the component at the upper left of the user-installable component block on the board is labeled SH1. According to the tables above, we know that this is a Series resistor on the High resolution 12-bit A/D input channel 1 associated with inputs C12AN1+ and C12AN1-. A check of the schematic shows that this socket can accommodate a 20Ω 0.1% precision resistor to enable reception of 0-20 mA current loop signals. The device just below SH1 on the board is labeled GH1, telling us that this is a Gain-setting resistor or jumper for the same channel. Below that is device FH1, telling us that this is a Filter capacitor for the same channel. Note that there is a box drawn around these three devices on the legend in Figure 16 to suggest that they are all associated with the same analog I/O channel.

The detailed explanations of the conditioning circuitry presented earlier in this document provide formulas that specify the proper choice of resistors and capacitors for each channel.

Before Using The Board

Before you use the board, we recommend you read through the documentation and understand all the features of the board. You should install the supplied required resistors in the appropriate sockets. The 1.00kΩ resistors should be installed in S+H2 and S+H3. The 2.00kΩ resistors should be installed in GH2 and GH3. Make sure all unused A/D inputs are tied to ground.

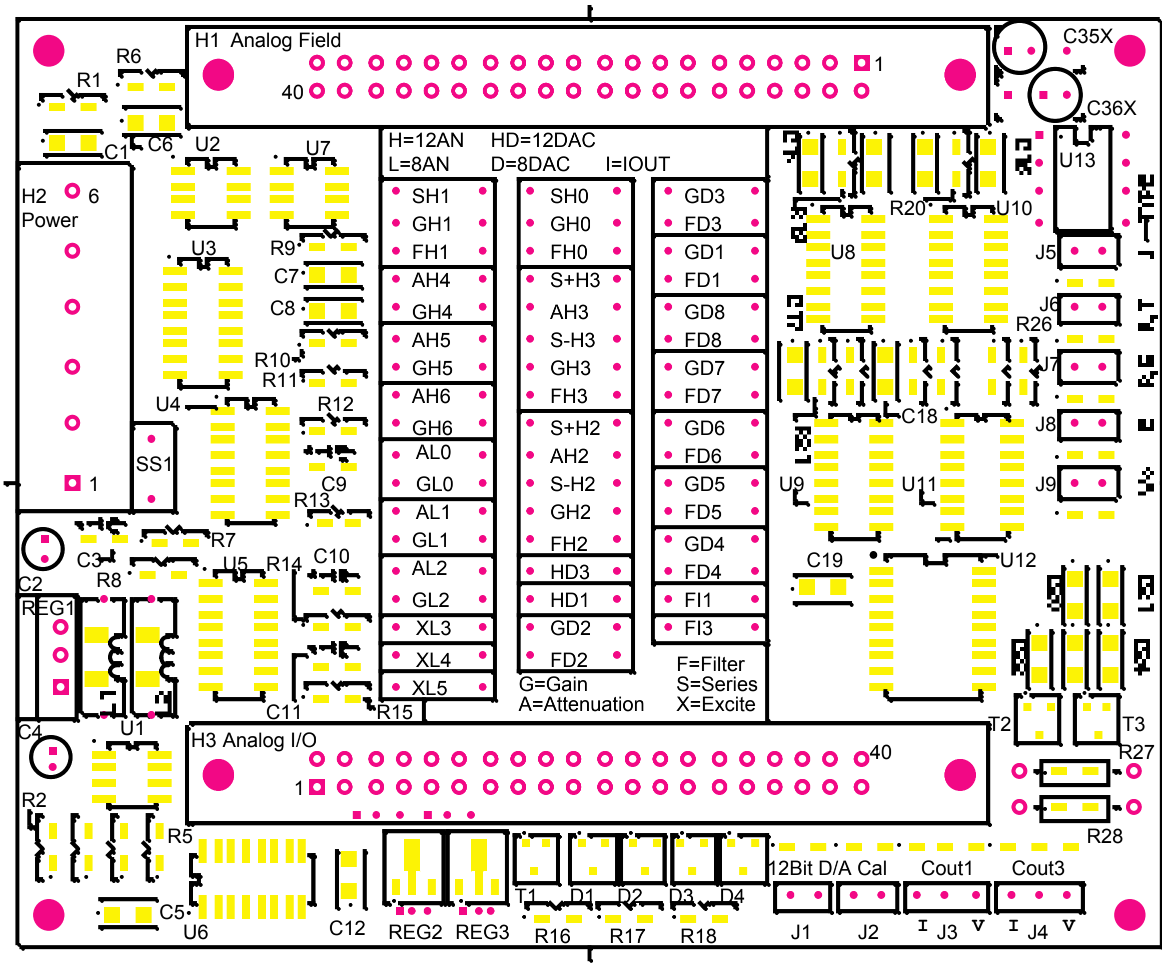


Figure 16. The silk-screen legend on the QED Analog Conditioning Board. This legend labels the sockets in the middle of the board that accommodate the configuration resistors and capacitors. Jumpers J1-J4 are located at the lower right, and cold junction compensator jumpers J5-J9 are located near the upper right corner of the board.

Summary

The following table summarizes the key components, relevant equations, and corresponding QED Board signal name that relate to each channel on the QED Analog Conditioning Board. Together with the first table presented in this document, this provides a cogent overview of the capabilities of the Analog Conditioning Board.

Analog Field Bus Connector Name	Type	Relevant Components	Relevant Equations	QED Board Signal Name
CV/IOUT1	8-bit scaled voltage/current output	GD1, FD1, FI1, J1, J2, J3	21, 23, 24	Vout1
CVOUT2	8-bit scaled voltage output	GD2, FD2	21, 23, 24	Vout2
CV/IOUT3	8-bit scaled voltage/current output	GD3, FD3, FI3, J1, J2, J4	21, 23, 24	Vout3
CVOUT4	8-bit scaled voltage output	GD4, FD4	21, 23, 24	Vout4
CVOUT5	8-bit scaled voltage output	GD5, FD5	21, 23, 24	Vout5
CVOUT6	8-bit scaled voltage output	GD6, FD6	21, 23, 24	Vout6
CVOUT7	8-bit scaled voltage output	GD7, FD7	21, 23, 24	Vout7
CVOUT8	8-bit scaled voltage output	GD8, FD8, J2	21, 23, 24	Vout8
C12AN0+, C12AN0-	12-bit differential input; instrumentation amp	SH0, GH0, FH0	15	12AN0
C12AN1+, C12AN1-	12-bit differential input; instrumentation amp	SH1, GH1, FH1	15	12AN1
C12AN2+, C12AN2-	12-bit amplified differential input	S+H2, S-H2, AH2, GH2, FH2	1 - 14	12AN2
C12AN3+, C12AN3-	12-bit amplified differential input	S+H3, S-H3, AH3, GH3, FH3	1 - 14	12AN3
C12AN4	12-bit amplified input	AH4, GH4	1 - 10	12AN4
C12AN5	12-bit amplified input	AH5, GH5	1 - 10	12AN5
C12AN6	12-bit amplified input	AH6, GH6	1 - 10	12AN6
C12AN7	12-bit un-amplified input	J1		12AN7
CAN0	8-bit amplified input	AL0, GL0	1 - 10	PE0/AN0
CAN1	8-bit amplified input	AL1, GL1	1 - 10	PE1/AN1
CAN2	8-bit amplified input	AL2, GL2	1 - 10	PE2/AN2
CAN3	8-bit input with excitation	XL3	16 - 20	PE3/AN3
CAN4	8-bit input with excitation	XL4	16 - 20	PE4/AN4
CAN5	8-bit input with excitation	XL5	16 - 20	PE5/AN5
CAN6	8-bit un-amplified input			PE6/AN6
CAN7	8-bit un-amplified input			PE7/AN7
COLD JN COMP	Thermocouple cold junction compensator	J5, J6, J7, J8, J9		

Appendix A
QED Analog Conditioner Board Connector Pinouts

Analog I/O Connector

Vrl	-	1	2	-	Vrh
PE7/AN7	-	3	4	-	PE6/AN6
PE5/AN5	-	5	6	-	PE4/AN4
PE3/AN3	-	7	8	-	PE2/AN2
PE1/AN1	-	9	10	-	PE0/AN0
12AN7	-	11	12	-	12AN6
12AN5	-	13	14	-	12AN4
12AN3	-	15	16	-	12AN2
12AN1	-	17	18	-	12AN0
AGND	-	19	20	-	+5VAN
Vin1	-	21	22	-	Vout1
Vin2	-	23	24	-	Vout2
Vin3	-	25	26	-	Vout3
Vin4	-	27	28	-	Vout4
Vin5	-	29	30	-	Vout5
Vin6	-	31	32	-	Vout6
Vin7	-	33	34	-	Vout7
Vin8	-	35	36	-	Vout8
1.5Vref	-	37	38	-	+5V
Analog Bus V-	-	39	40	-	V+Raw

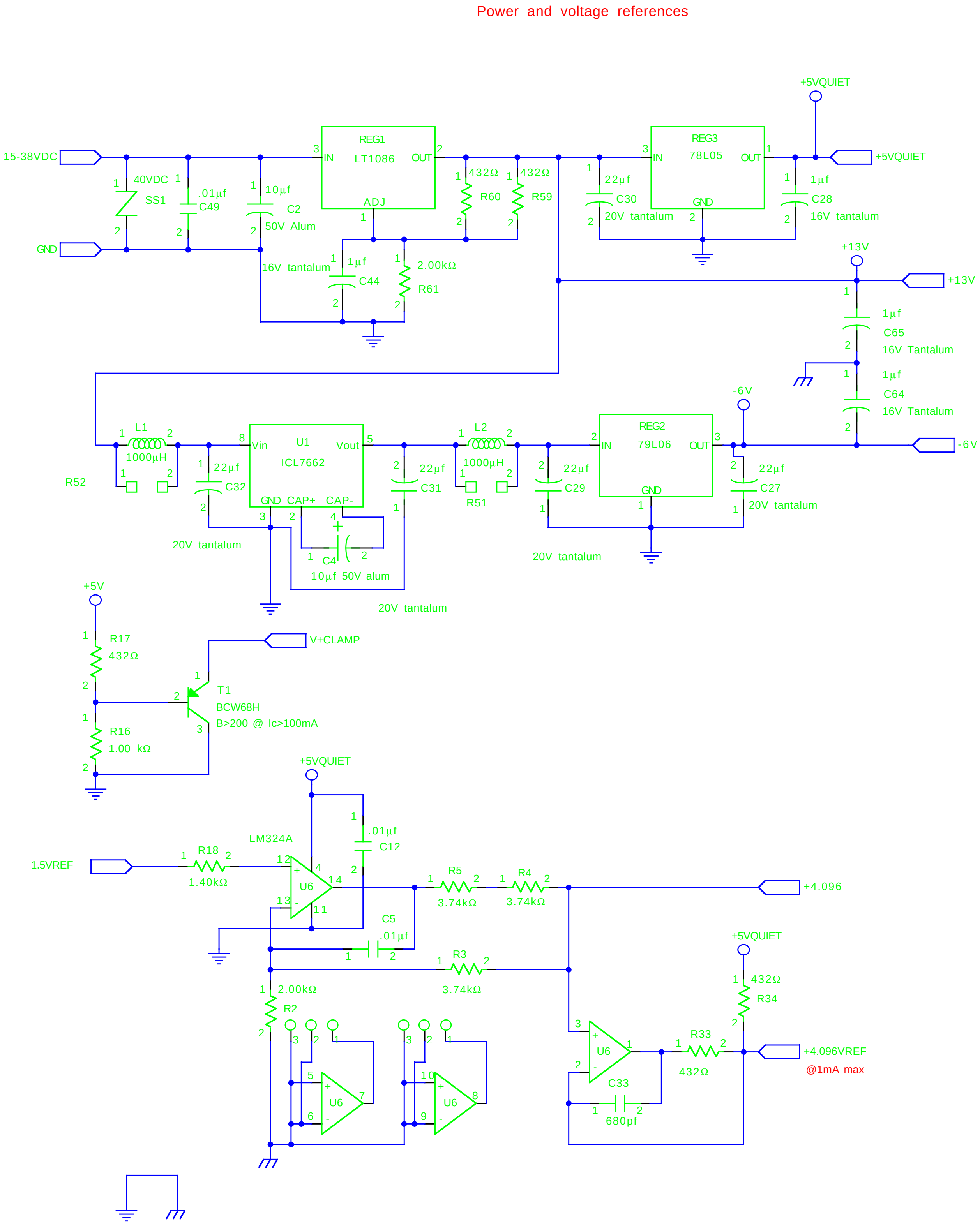
Analog Field Bus

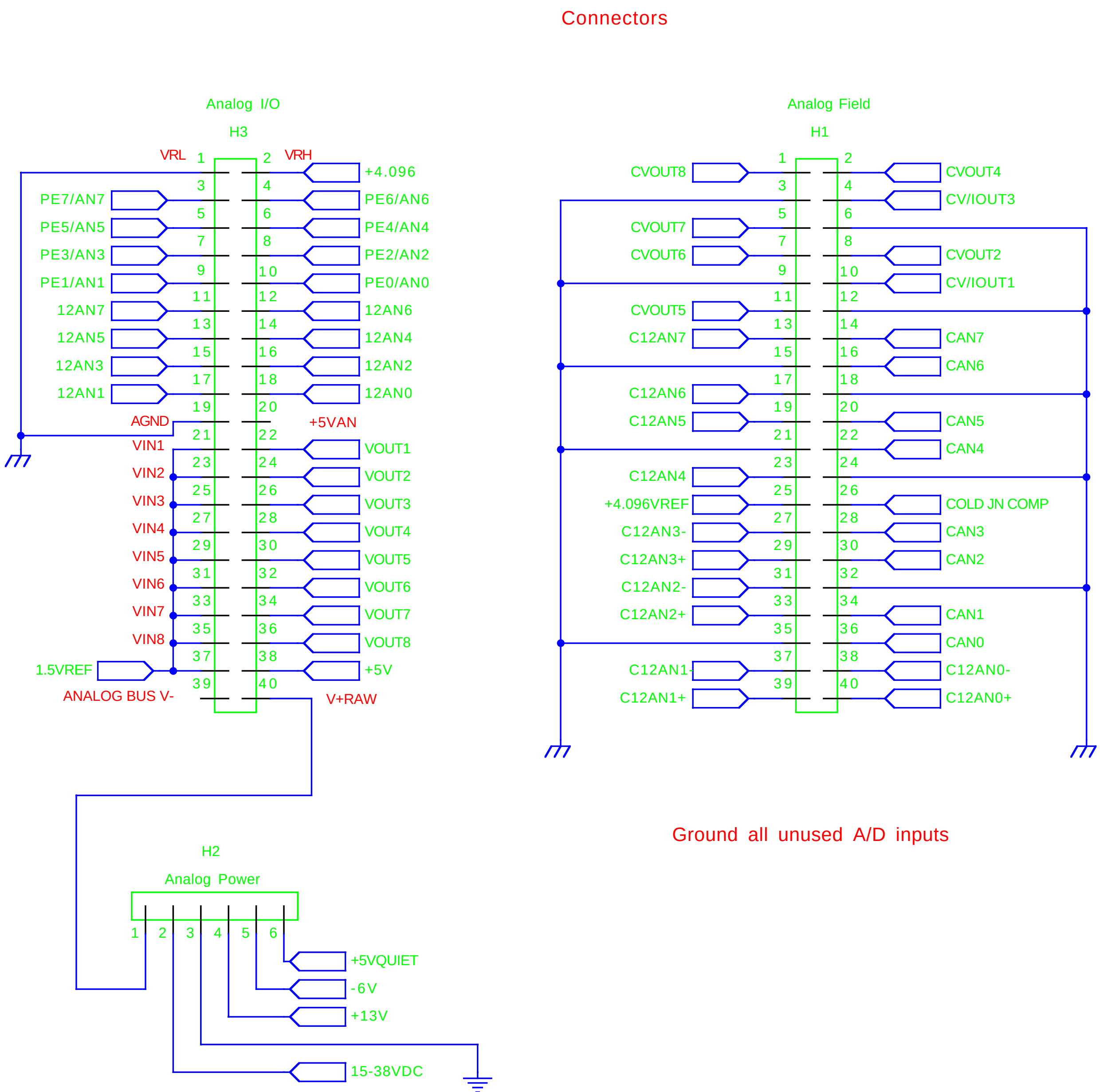
CVOUT8	-	1	2	-	CVOUT4
GND	-	3	4	-	CV/IOUT3
CVOUT7	-	5	6	-	GND
CVOUT6	-	7	8	-	CVOUT2
GND	-	9	10	-	CV/IOUT1
CVOUT5	-	11	12	-	GND
C12AN7	-	13	14	-	CAN7
GND	-	15	16	-	CAN6
C12AN6	-	17	18	-	GND
C12AN5	-	19	20	-	CAN5
GND	-	21	22	-	CAN4
C12AN4	-	23	24	-	GND
+4.096 Vref	-	25	26	-	COLD JN COMP
C12AN3-	-	27	28	-	CAN3
C12AN3+	-	29	30	-	CAN2
C12AN2-	-	31	32	-	GND
C12AN2+	-	33	34	-	CAN1
GND	-	35	36	-	CAN0
C12AN1-	-	37	38	-	C12AN0-
C12AN1+	-	39	40	-	C12AN0+

QED Power Connector

V+RAW	-	1
15-38VDC	-	2
GND	-	3
+13V	-	4
-6V	-	5
+5VQUIET	-	6

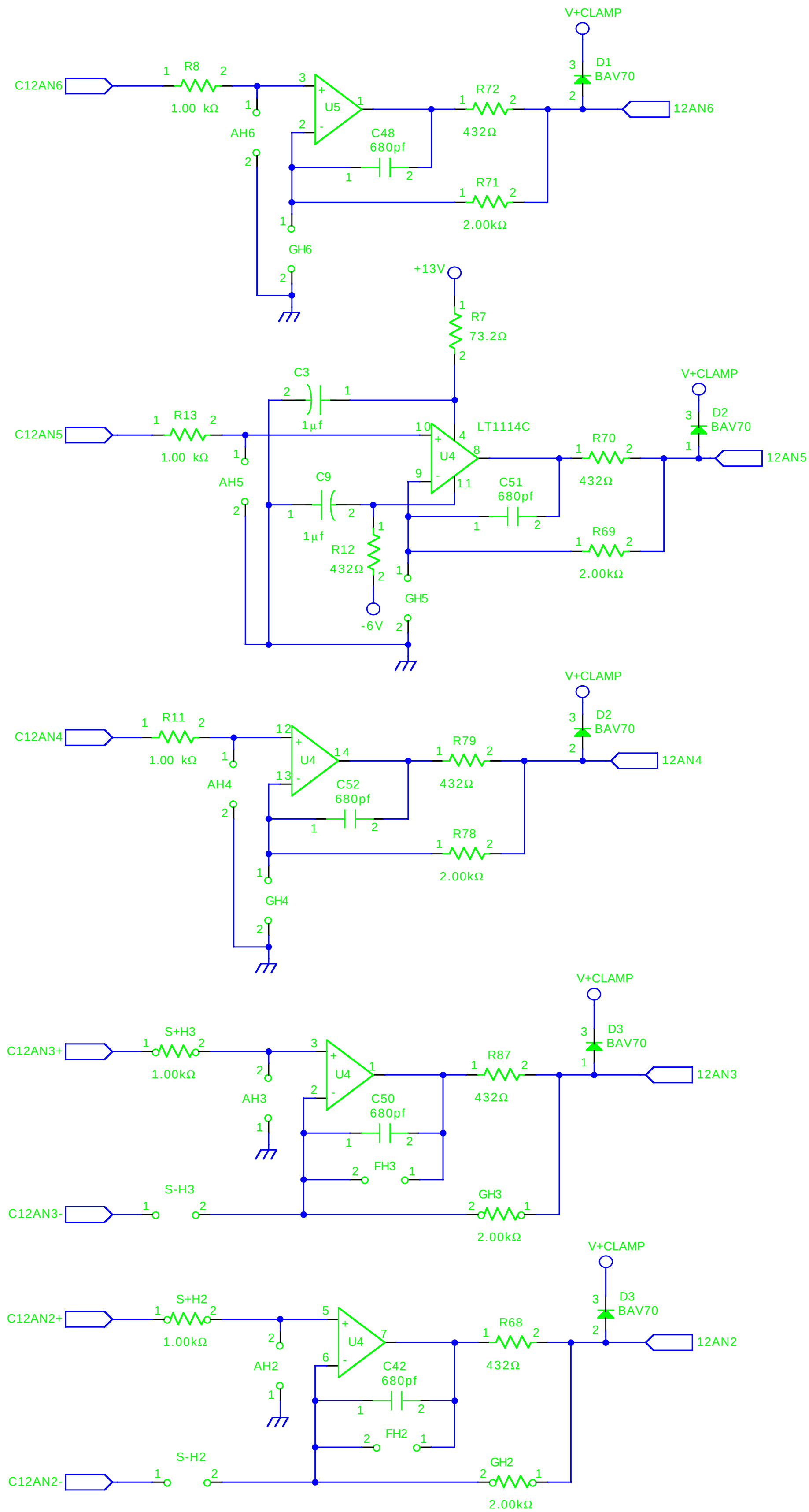
Appendix B
Analog Conditioning Board Schematics


Power and voltage references
15-38VDC
GND
40VDC
SS1
.01µf
C49
10µf
C2
50V Alum
REG1
LT1086
IN
OUT
ADJ
432Ω
R60
432Ω
R59
2.00kΩ
R61
1µf
C44
16V tantalum
22µf
C30
20V tantalum
REG3
78L05
GND
1µf
C28
16V tantalum
+5VQUIET
+13V
1µf
C65
16V Tantalum
1µf
C64
16V Tantalum
-6V
L1
1000µH
R52
22µf
C32
20V tantalum
U1
ICL7662
Vin
Vout
GND CAP+ CAP-
C4
10µf 50V alum
22µf
C31
20V tantalum
L2
1000µH
R51
22µf
C29
20V tantalum
REG2
79L06
22µf
C27
20V tantalum
+5V
R17
432Ω
R16
1.00 kΩ
V+CLAMP
T1
BCW68H
B>200 @ Ic>100mA
1.5VREF
R18
1.40kΩ
LM324A
U6
.01µf
C12
R5
3.74kΩ
R4
3.74kΩ
+4.096
C5
.01µf
R3
3.74kΩ
2.00kΩ
R2
432Ω
R34
R33
432Ω
C33
680pf
+4.096VREF
@1mA max

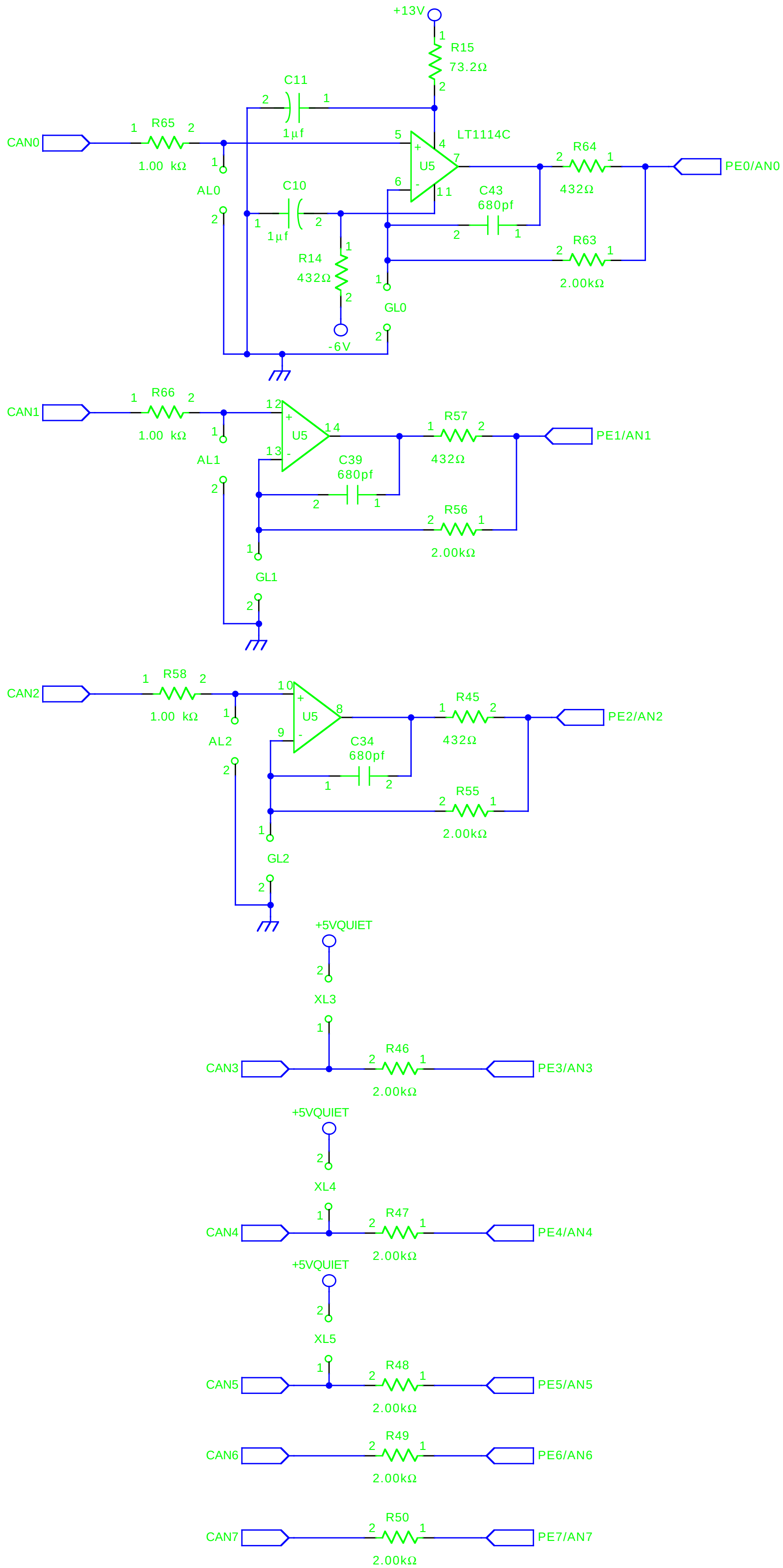


Connectors
Analog I/O
H3
VRL
VRH
+4.096
PE7/AN7
PE6/AN6
PE5/AN5
PE4/AN4
PE3/AN3
PE2/AN2
PE1/AN1
PE0/AN0
12AN7
12AN6
12AN5
12AN4
12AN3
12AN2
12AN1
12AN0
AGND
+5VAN
VIN1
VOUT1
VIN2
VOUT2
VIN3
VOUT3
VIN4
VOUT4
VIN5
VOUT5
VIN6
VOUT6
VIN7
VOUT7
VIN8
VOUT8
1.5VREF
+5V
ANALOG BUS V-
V+RAW
Analog Field
H1
CVOUT8
CVOUT4
CV/IOUT3
CVOUT7
CVOUT6
CVOUT2
CV/IOUT1
CVOUT5
C12AN7
CAN7
CAN6
C12AN6
C12AN5
CAN5
CAN4
C12AN4
+4.096VREF
COLD JN COMP
C12AN3-
CAN3
C12AN3+
CAN2
C12AN2-
C12AN2+
CAN1
CAN0
C12AN1-
C12AN0-
C12AN1+
C12AN0+
H2
Analog Power
+5VQUIET
-6V
+13V
15-38VDC
Ground all unused A/D inputs

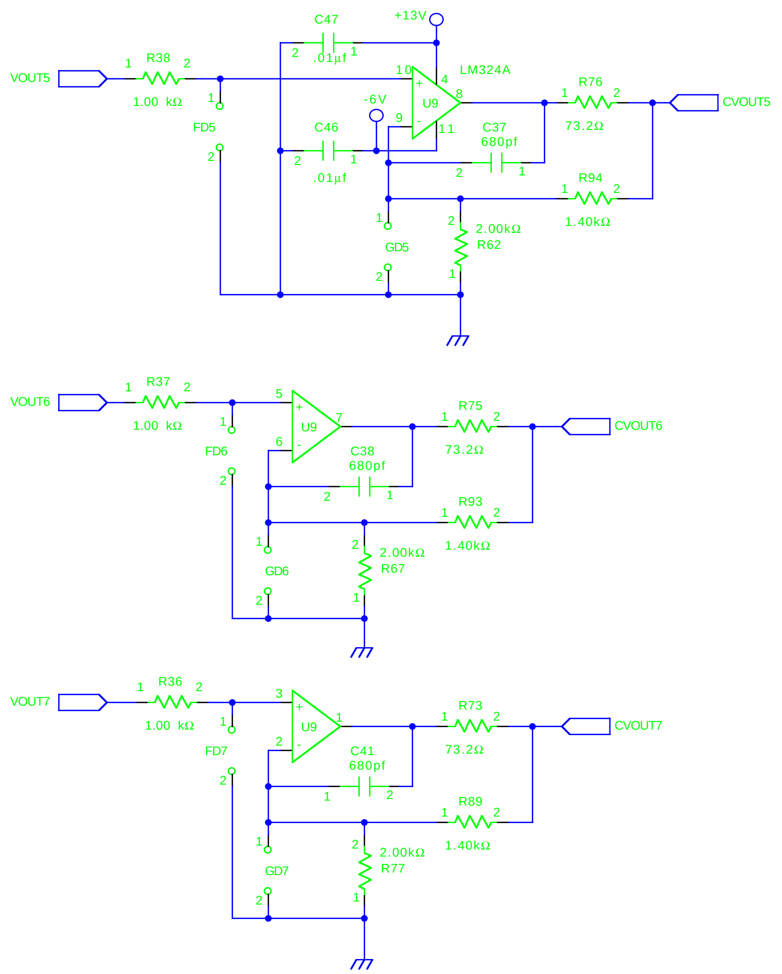
12 Bit A/D inputs



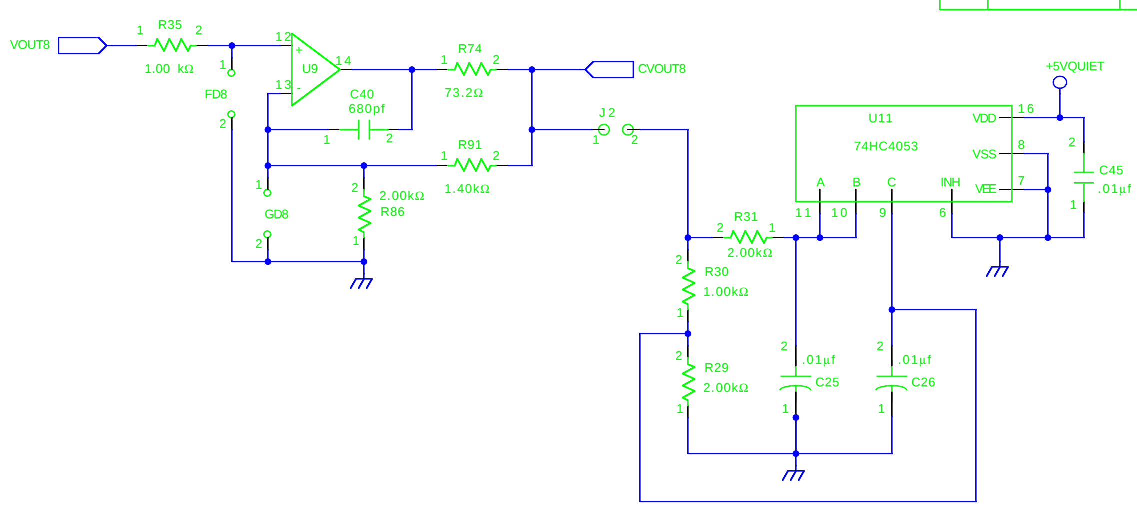
8 Bit A/D inputs



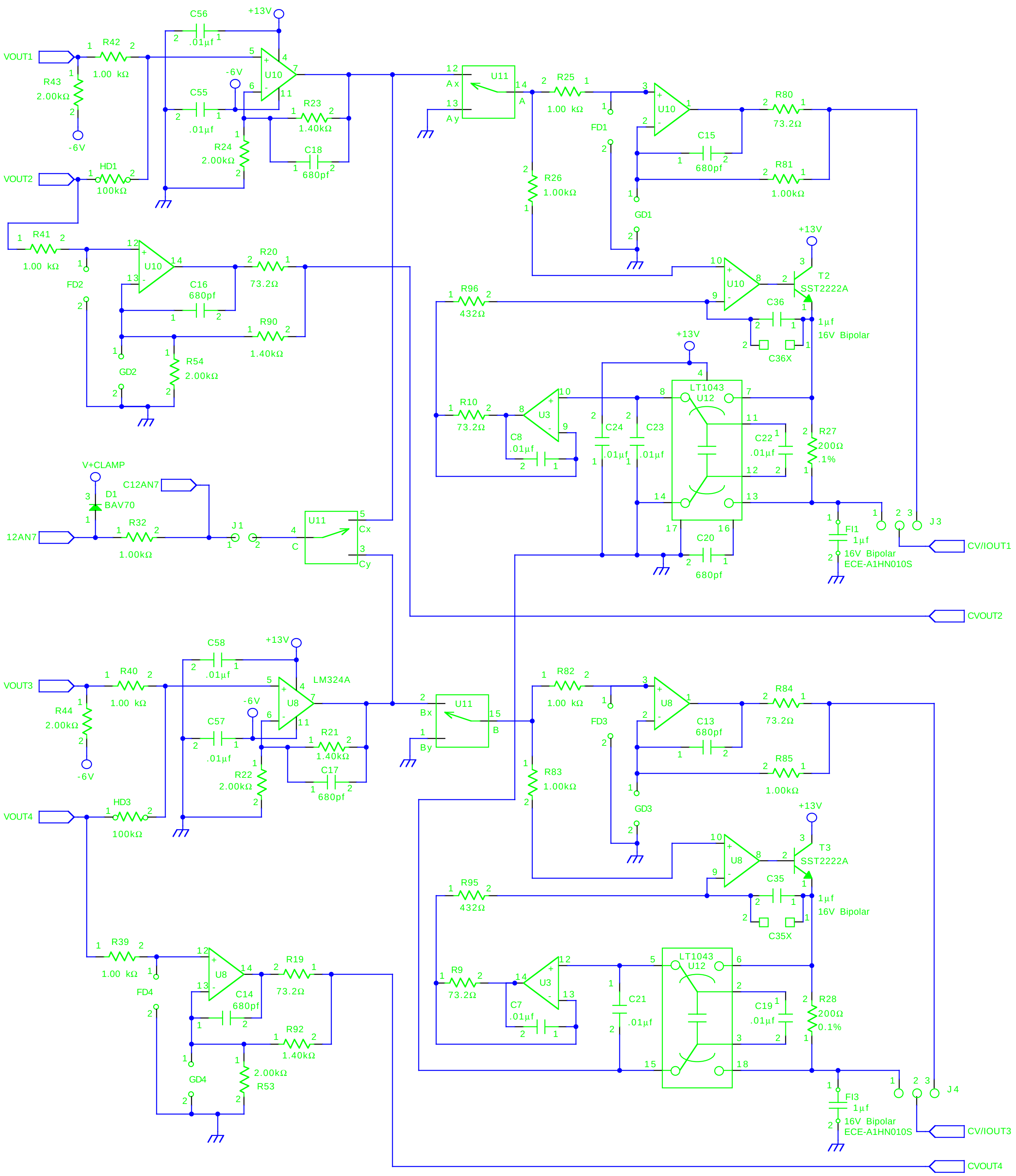
8 Bit DACS voltage outputs



DAC	VOLTAGE DIVIDER	A B C	
0.0	0.0	0 0 0	ONLINE CH1
3.0	2.0	1 1 0	OFFLINE CAL1
5.1	3.4	1 1 1	OFFLINE CAL2



8 Bit DACS voltage & current outputs



In amps and cold junction comp.