Using the μC–Board, P051R01 Application Note 020

Rolf Lueck

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Rockland Scientific International Inc.
520 Dupplin Rd
Victoria, BC, CANADA, V8Z 1C1
www.rocklandscientific.com

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- 2010-12-07 RGL, Original, V1

1 Introduction

This document describes the usage of the micro–conductivity board, part P051R01, that has been specifically designed to work with the “low–power” line of instruments, such as the VMP–200 and the μRider–LP. These instruments operate on a unipolar power supply and handle analog signals that fall into the 0–5V range.

Other documents that may be useful include the calibration report for your specific board, and the calibration report for your specific sensor(s).

2 Board Description

The μC-board (Figure 1) consists of several sections (Figure 2).

2.1 Power

The board is energized by one of two methods. The usual method of powering the board is to apply 7–17 V to connector J2. The board will draw approximately 22mA at 14V. DC-DC converters provide the analog power rails of $\pm$ 5V, which is used by all analog sections, and also generates the 3.3V–rail that is used by all digital sections. The $\pm$ 5V–rail is available at connector J1 and can be used to energize other systems in an instrument. The current limit is 100 mA.

An alternative method of powering the board is to supply the $\pm$ 5V–rail directly to connector J1, and this requires an off–board source of clean power. Connector J2 is then not used and the DC-DC converters are automatically disabled. The 3.3V–rail is still generated.

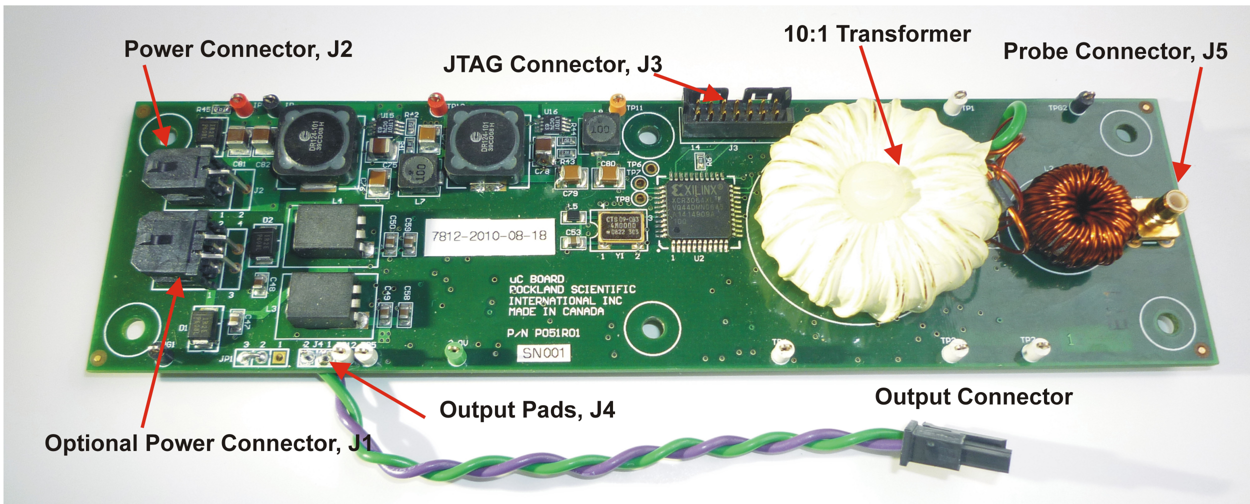

Figure 1: The micro–conductivity board (P051R01) with integrated anti–aliasing filter.

2.2 Driver–Detector

A direct digital synthesizer (DDS) produces a constant–amplitude ($2.5\mathrm{V_{PP}}$) and low-distortion sine wave that is used to pass a current through the pair of electrodes that form the micro–conductivity sensor. This drive voltage is coupled through a 10–to–1 transformer that reduces the voltage across the electrodes to approximately $0.25\mathrm{V_{PP}}$, and this voltage is smaller than the electro–chemical potential of almost all ions in seawater. The current through the primary winding of the transformer is then proportional to the conductance of the probe. The current flowing through the primary side of the transformer is converted into a voltage by the current–to–voltage preamplifier (I–to–V in Figure 2). An out of phase current is added to the primary current, via a 20 kΩ resistor, so that zero-current corresponds to about 4 S m^{-1}

2.3 Demodulator & Pre–emphasis

A synchronous demodulator rectifies the AC–voltage that is produced by the current detector and a 4–pole Butterworth low–pass filter removes the carrier frequency and its harmonics. The

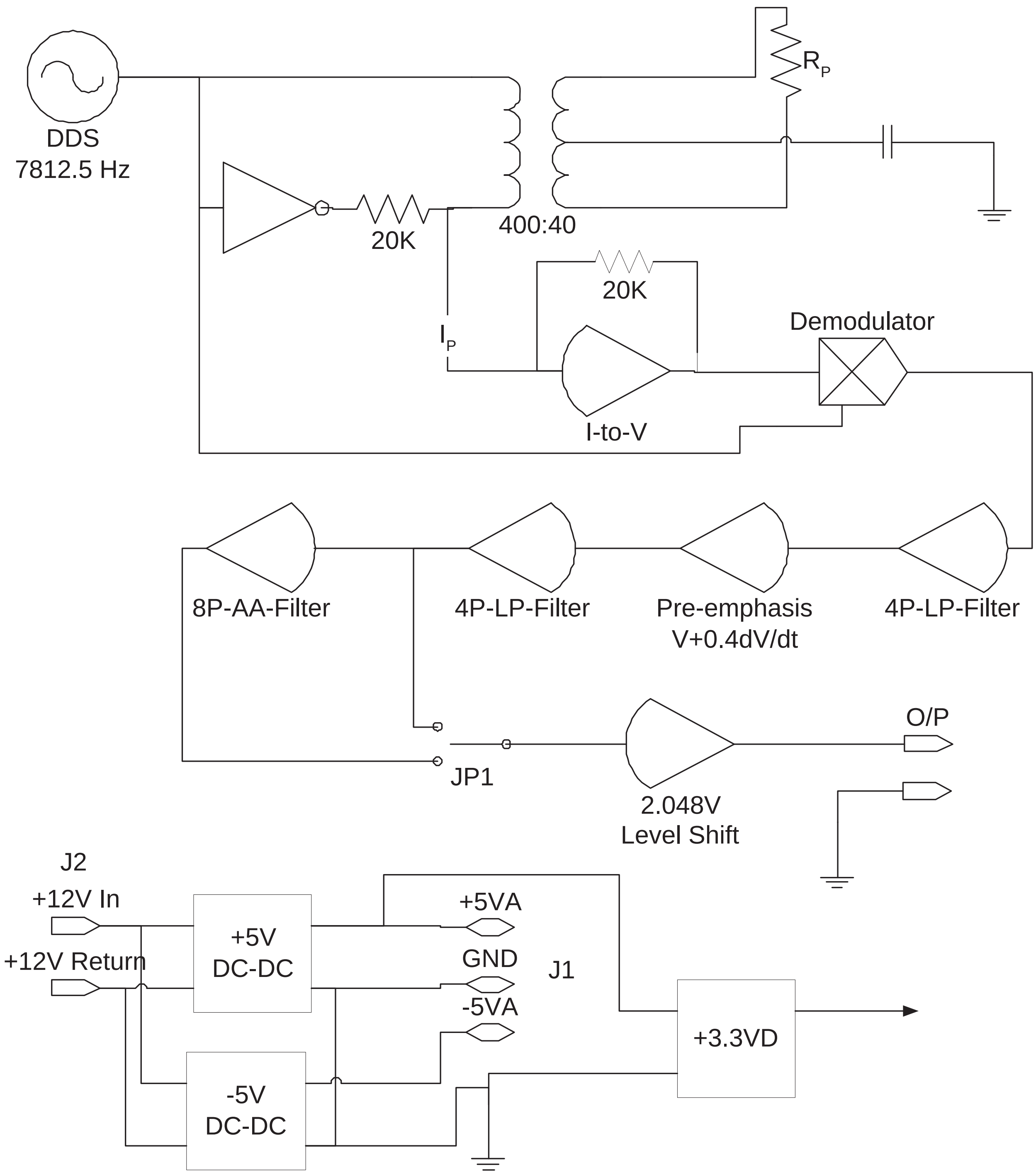

Figure 2: Block diagram of the P051R01 micro–conductivity board.

conductivity signal is then pre–emphasized with a derivative gain of 0.4 s. That is, 40% of the time-rate-of-change of the voltage is added to the signal. A second 4–pole low–pass filter removes remnants of the carrier frequency that have been boosted by the pre–emphesizer. This produces a conductivity signal with a bandwidth of about 1 kHz.

2.4 Low–pass filter and level shifter

The wide bandwidth conductivity signal is routed along one of two possible paths, using jumper JP1 (Figure 2). The first path is through an 8–pole Butterworth anti–aliasing filter and then to the level shifter. The level shifter adds 2.048V to the signal to bring it into the 0–to–4.096V range, so that this output signal can be sampled by a device that accepts this, now quite common, voltage range. The second path leads directly to the level shifter and by-passes the anti-aliasing filter.

3 Conductivity and Output

3.1 Analog Processing

Your conductivity board will have been calibrated at RSI to establish its output in terms of probe conductance, to determine the gain of the pre–emphasis, and to measure the noise on its output. These are reported in a calibration certificate that accompanies every board.

It is important to understand that the board does not measure the fluid conductivity directly. The board measures the conductance, Y, of the probe. Conductance is the inverse of resistance and is measured in units if Siemens, while the fluid conductivity is a measure of the specific conductance and is expressed in units of Siemens m^{-1}, although the non–SI unit of mS cm^{-1} is frequently used by oceanographers, and μS cm^{-1} is preferred by limnologists. The conductance of the probe is given by

$$Y = K\sigma \tag{1}$$

where σ is the conductivity of the fluid expressed in units of S m^{-1}, Y is the conductance of the probe expressed in units of S, and K is usually called a "cell constant", and has units of length. The cell constant is determined by the physical dimensions of the probe and by its geometry, and is approximately $K = 1.2 \times 10^{-3}$ m, for the SBE7 micro-conductivity probe made by Sea–Bird Electronics. In seawater with a conductivity of $\sigma = 3$ S m^{-1} = 30 mS cm^{-1}, the probe conductance is 3.7×10^{-3} S, or 268 Ω.

The board is calibrated by replacing the probe with resistors of 0.01% accuracy that span a range equivalent to a conductivity of 0 to 70 mS cm^{-1}. The range of this static calibration (Figure 3) spans about one-half of the voltage output range of the board. This leaves the other half of the output range for the fluctuations which are added to the conductivity signal and this is discussed below (Pre–Emphasis section). For the example shown in Figure 3, upper panel, the output is given by

$$V_C = a + bY = 1.201 + 196.6 \times Y \tag{2}$$

where $a = 1.201$ V is the (intentional) offset and $b = 196.6$ V S^{-1} is the sensitivity to conductance and, hence, to fluid conductivity. The conductivity can then be derived using (1), or a calibration specific to the probe being used.The quality of the linear fit of output voltage to probe conductance is about 0.1% (Figure 3, lower panel).

3.2 Sampling

The output voltage from the micro-conductivity board is currently routed to the μASTP-LP (P049) board were it enters the path for the second FP07 thermistor (channel address 7). This means that a second thermistor is not supported if an instrument has a micro-conductivity board. The entry point is U19A, which is a precision difference amplifier. The micro-conductivity output signal goes to the positive input of this difference amplifier and the 2.048V reference signal goes to the negative input. This channel has its own 8-pole AA-filter. Consequently, the 8-pole AA-filter on the micro-conductivity board is not used.

The 16-bit AD-Converter on the μASTP board has an input range of 0 to 4.096 V. The digital output are 2's complement numbers, which means that they are signed integers and range from -2^{15} to $+2^{15}-1$ counts. The mid-point of zero counts is located at 2.048V. Thus, the relationship

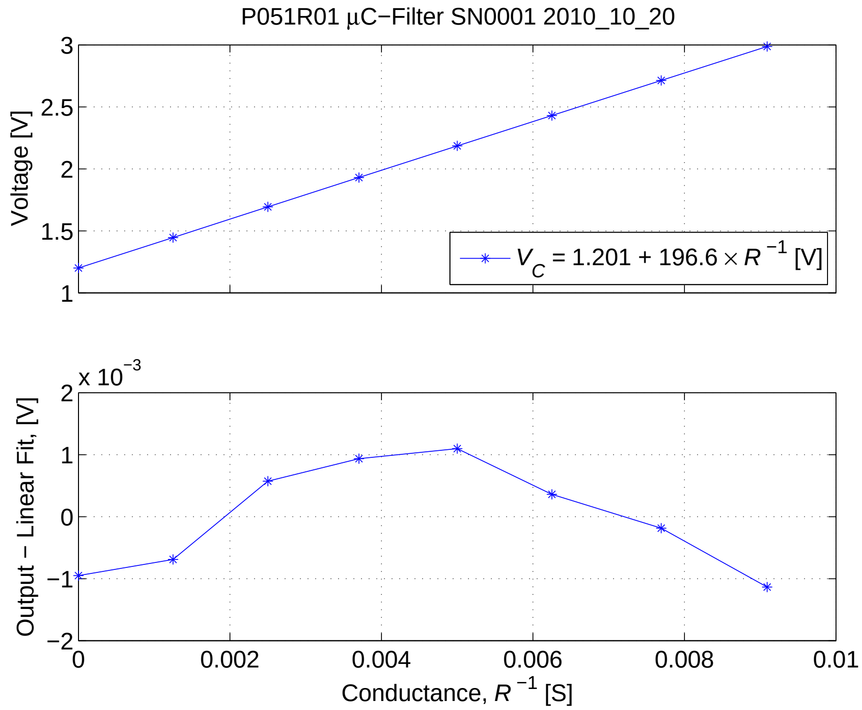

Figure 3: The static calibration of the micro–conductivity board using precision resistors.

of the the numeric integer data, N_C, recorded for the micro–conductivity channel, and the voltage, V_C, produced by the micro–conductivity board is

$$V_C = 2.048 + \frac{4.096}{2^{16}} N_C. \tag{3}$$

Then, using (2), we obtain the conductance of the probe, namely,

$$Y = \frac{1}{b}\left(-a + 2.048 + \frac{4.096}{2^{16}} N_C\right), \tag{4}$$

and finally, the fluid conductivity, using (1), is

$$\sigma = \frac{1}{bK}\left(-a + 2.048 + \frac{4.096}{2^{16}} N_C\right) \tag{5}$$

and has units of S m^{-1}. To convert the units of conductivity to mS cm^{-1}, simply multiply the results by a factor of 10.

4 Pre-emphasis

The spectrum of turbulent conductivity fluctuations is usually red, falling at a rate of $\sim f^{-5/3}$, and it is possible for the higher frequency content of the conductivity signal to fall below the sampling noise, even with a 16–bit analog–to–digital converter (ADC). Adding the derivative to the signal, before sampling, boosts the higher frequency components, and keeps the combined signal above the sampling noise of the ADC [1]. The spectrum of the pre-emphasized signal will rise slightly as $\sim f^{1/3}$ and this rise keeps the analog signal above the sampling noise of the ADC. We calibrate the derivative addition, as well as the response of the anti-aliasing filter, by injecting a pink–noise signal into the pre–emphasis section of the micro-conductivity board, and then calculate the transfer function of the output compared to this input.

For background information, consider that if a signal $x(t)$ has a fourier transform $X(f)$, then the fourier transform of the derivative of $x(t)$ is $2\pi jfX(f)$, where $j^2 \equiv -1$. The board has been designed to output a voltage that is proportional to conductivity plus 0.4 times its derivative. Therefore, if the input signal is $x(t)$ and the output is $y(t)$, then the fourier transform of the output, should be

$$Y(f) = X_C(f) + G_D 2\pi jfX_C(f) = X(f)\left(1 + 2\pi jfG_D\right). \tag{6}$$

where G_D is the derivative gain and is nominally 0.40 s. The transfer function is

$$H(f) = \left(1 + 2\pi jfG_D\right), \tag{7}$$

and the gain of the derivative is calibrated by dividing this transfer function by the gain of a differentiator,

$$\frac{H(f)}{2\pi jf} = \left(\frac{1}{2\pi jf} + G_D\right), \tag{8}$$

and this is plotted in Figure 4. The upper panel shows the magnitude of the transfer function, relative to the transfer function of a derivative, (8), while the lower panel shows the phase. At very low frequency ($f <$ 1 Hz), this function decreases proportional to frequency, and reaches a nearly uniform value of G_D, in the 1 to 100 Hz range. Above f = 100 Hz, the function then decreases sharply because of the 8–pole, Butterworth, anti–aliasing filter. The value of $G_D = 0.40$ s, in this example, is used in the data processing to deconvolve the pre–emphasized signal to obtain a time series of the conductivity which is not limited by sampling noise. A close–up view of the transfer function is shown in Figure 5. By pre-emphasizing the signal *before* sampling and deconvolving it *after* sampling, to undo the pre-emphasis, the resolution of the final signal is increased by the equivalent of about 7 bits [1].

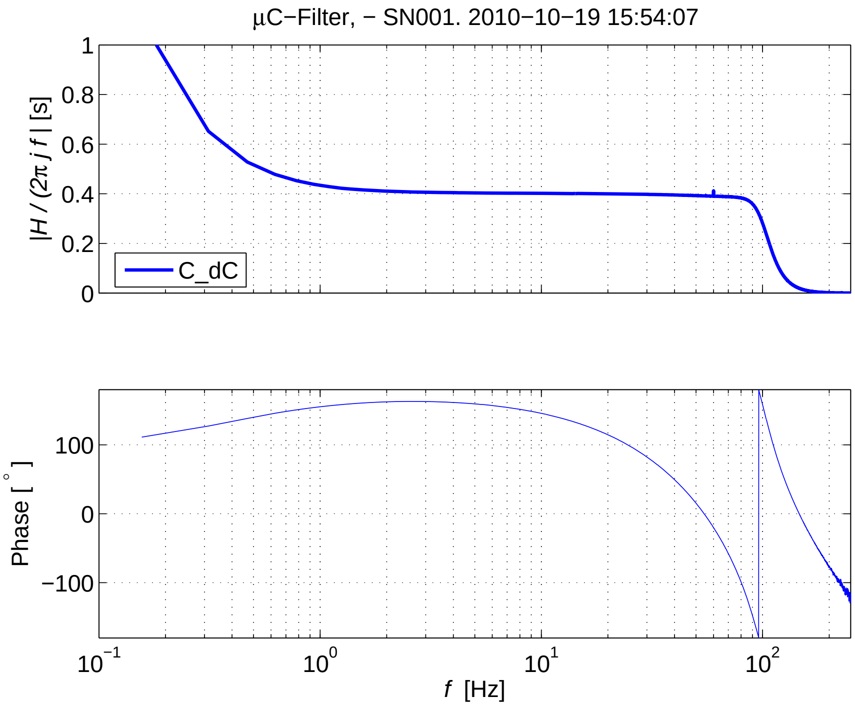

Figure 4: The transfer function of the micro–conductivity circuit relative to that of an ideal differentiator (8). The upper panel shows the magnitude while the lower one shows the phase.

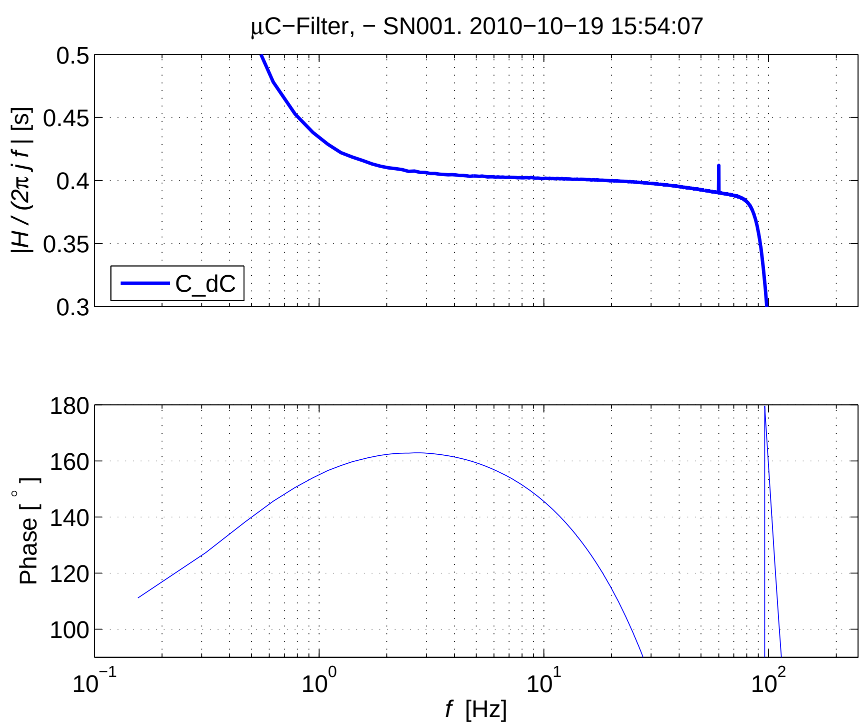

Figure 5: Close–up view of Figure 4.

5 Output Noise

The output noise of the micro–conductivity board is measured by connecting a resistor of approximately 270 Ω in place of the conductivity probe. This brings the mean output to approximately mid–range. Several minutes of data are then collected and used to compute the spectrum of the output (Figure 6). The green line serves as a reference and represents the thermal noise produced by a resistor of 27 kΩ which is the equivalent resistance of the probe as seen through the 10:1 transformer. A perfect electronics board would have a noise spectrum approximately three times larger than the green line, due to the additional contributions from the feedback resistor in the current–to–voltage converter and the resistor used to add an out–of–phase current. The measured noise spectrum is about ten times higher than the theoretical limit and this is due to electronic noise and remnant amplitude fluctuations of the constant–amplitude sine wave used to drive a current through the probe.

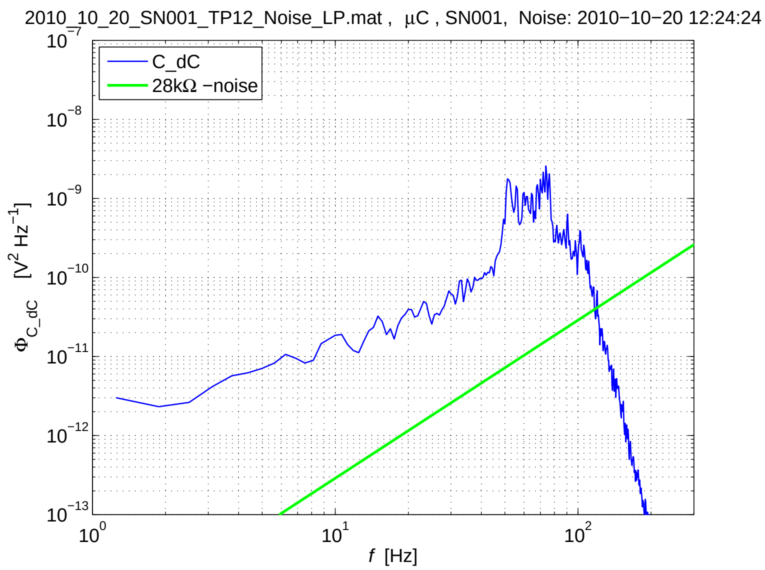

Figure 6: Spectrum of the output noise voltage from the micro–conductivity board (blue curve). The green lines is the noise spectrum that would result from thermal fluctuations of a 27 kΩ resistor.

The user will usually not have the ability to measure the noise spectrum in terms of voltage variance and must, instead, rely on the sampled data. The noise spectrum is expressed in units of counts variance in Figure 7, if it were sampled by a 16–bit ADC with a full–scale range of 4.096 V. The horizontal magenta line represents the sampling noise of an ideal ADC which has a variance of 1/12 counts^2, and is spread uniformly over the Nyquist band (0–256 Hz, in most cases). The ADCs made by RSI have a noise variance that is 3 times larger than that of an ideal converter, and this level is shown by the green line. The important point is that the pre–emphasis raises the analog signal noise above the sampling noise so that the analog signal is completely resolved.

The previous noise spectra provide the noise of the pre–emphasized signal which is a mixture of signal and its derivative. The spectrum of the noise output, after it has been deconvolved and converted in to the equivalent temperature signal (using a conversion of 1 mS cm^{-1} = 1 °C) is shown in Figure 8.

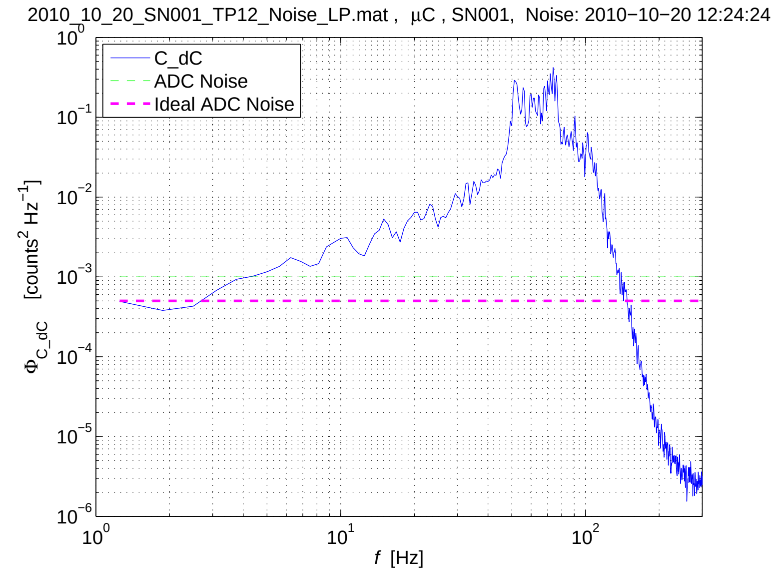

Figure 7: Spectrum of the output noise voltage from the micro–conductivity board, expressed in terms of counts of an analog–to–digital converter with 16-bit resolution and an input range of 4.096 V.

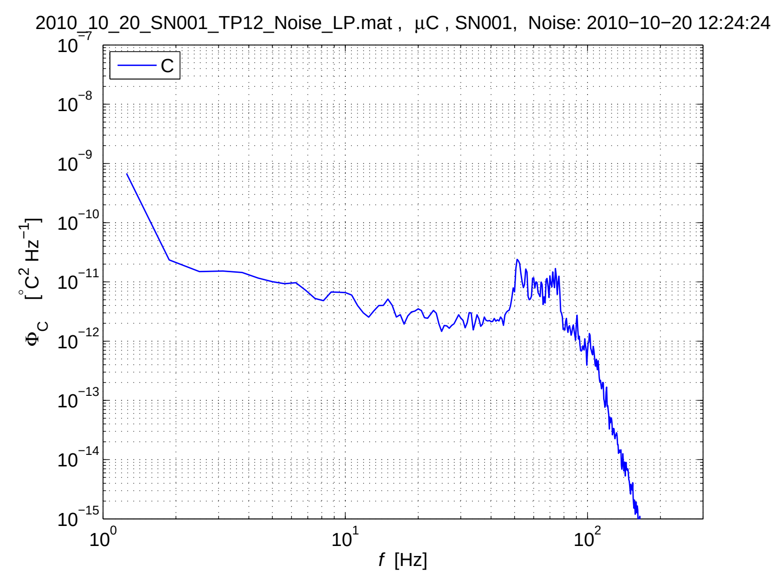

Figure 8: Spectrum of output noise converted to equivalent temperature fluctuations in a fluid with a conductivity of 30 mS cm^{-1}.

6 Appendix

6.1 Layout

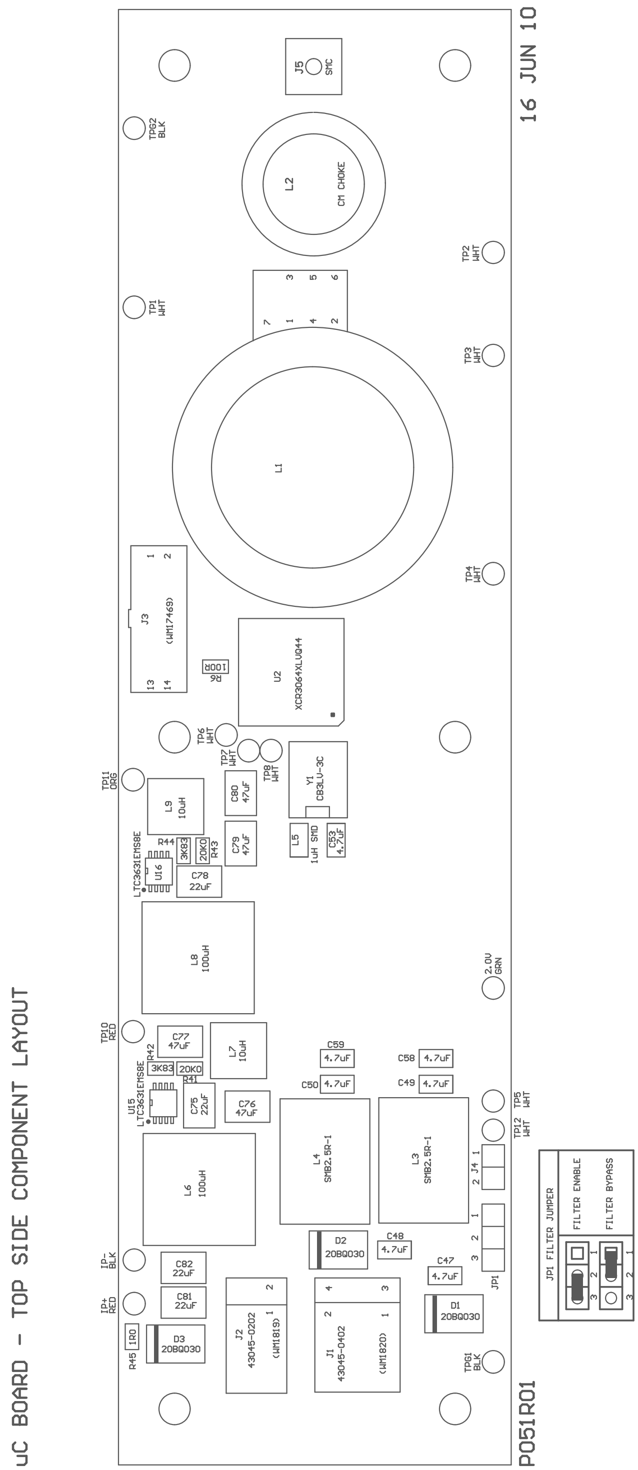

Figure 9: The physical layout of components on the micro–conductivity board.

6.2 Connectors

Table 1: **J1**. Optional External Power. These pins can be used as inputs or outputs. If a good quality ±5V power source is available, then use this input and do not put 7–18V power on to connector J2. The internal DC–DC converter modules will be automatically disabled. Alternatively, if power is applied to J2, then this connector can be used to route ±5 V power to other devices. The limit is about 100 mA.

Pin #	Function
1	+5VA, Positive analog power
2	GND, Analog ground
3	−5VA, Negative analog power
4	GND, Analog ground

Table 2: **J2**. Primary power connector. The board will operate with an input voltage in the 7–18V range. This connector is not required if there is a source of good quality ±5 V power available in a system, see Table 1. Normal current draw is 22 mA.

Pin #	Function
1	7 – 18V, Positive power.
2	GND, Power return (ground).

Table 3: **J3**. JTAG connector. For factory use only.

Pin #	Function
1	DGND, Logic ground.
2	+3.3VD, Logic power.
3	DGND, Logic ground.
4	TMS
5	DGND, Logic ground.
6	TCK
7	DGND, Logic ground.
8	TDO
9	DGND, Logic ground.
10	TDI
11	DGND, Logic ground.
12	NC
13	DGND, Logic ground.
14	NC

Table 4: **J4**. Output connection pads.

Pad #	Function
1	Output signal, $0 - 5$ V range.
2	Analog signal ground.

Table 5: **J5**. Micro–conductivity probe connection. SMC-style coaxial cable.

Pin #	Function
1	Center conductor of coaxial cable.
2	Shield of coaxial cable.

Table 6: **JP1**. Filter-selection pads. Shorting Pad 2 to either Pad 1 or Pad 3 selects the desired function

Pad #	Function
2–1	By-pass of 8–pole anti-aliasing filter. Nominal filtering at 2 kHz.
2–3	98 Hz 8–pole anti-aliasing filter applied to signal.

6.3 Specifications Summary

The specifications of the micro–conductivity board are summarized in Table 7.

Table 7: Specifications of the micro–conductivity board, P051R01.

Parameter	Value
σ range	$0-8$ S m^{-1}, for $1-3$ V
dσ/dt	< 4 S m^{-1} s^{-1} peak.
Bandwidth	$0-1000$ Hz, 1-pole, or $0-98$ Hz 8-pole Butterworth.
Pre-emphasis [1]	$\sigma + 0.4 \cdot d\sigma/dt$
Noise	$< 10^{-13}$ (S $m^{-1})^2$ Hz^{-1}, 2–100 Hz band.
Power [2]	$7-18$ V, 22 mA, primary.
	± 5 V, auxiliary .
Dimensions	$140 \times 40 \times 30$ mm (L $\times$ W $\times$ H).
Mass	0.10 kg

[1] The exact derivative gain is provided in the calibration report.
[2] $\pm$5V power can be an input or an output, see text.

References

[1] T. D. Mudge and R. G. Lueck. Digital signal processing to enhance oceanographic observations. *Journal of Atmospheric and Oceanic Technology*, 11:825–836, 1994.