Handling Small Signals

Introduction

In many experiments, the signals that have to be measured are very small: millivolts, microvolts or even nanovolts (10^{-9} V). In this experiment, you will build some simple amplifiers that allow such signals to be seen, and which are able to separate the wanted signal from interfering signals (which may be much larger). You will use a signal generator, a strain gauge transducer and your own body as a source of test signals. If things go well, you should be able to record the electrical activity of your heart.

1 The isolation amplifier

In the final part of this experiment, you will need to make electrical contact to your skin. Although it is safe to touch the wires emerging from the front of the oscilloscopes, signal generators and power supplies in this laboratory, you will be using the isolation amplifier (figure 1) as an additional precaution. Additionally, it helps reject interference. All of the circuits you build will be connected to the oscilloscope and power supply via the isolation amplifier. Use a multimeter to measure the electrical resistance between various pairs of terminals of the isolation amplifier. In particular, verify that there **Q** is no electrical contact between any two terminals on different sides of the isolation barrier shown in figure 1. If this seems not to be the case, consult a demonstrator.

Figure 1: The isolation amplifier

Connect the flying leads that provide power for the isolation amplifier to the +15V (red) and 0V (black) terminals of the power supply. Be sure that the power supply is set to provide no more than 15 volts. Use a co-axial cable with BNC connectors to connect the signal output of the isolation

Q **Q** amplifier to one channel of the oscilloscope. These connections will remain in place for all the circuits that follow. Check that the power outputs of the isolation amplifier are at approximately their nominal +8V and -8V levels. All such voltages on the "isolated" side must be measured with respect to the green "isolated ground" terminals. Use the signal generator to apply a sine wave to the signal input of the isolation amplifier (100 Hz, 2V peak-to-peak is a good place to start), monitor both the input and output of the isolation amplifier with the scope (see figure 2), and determine what range of frequencies and amplitudes the isolation amplifier allows to pass unchanged[1]. Question: can you imagine how the isolation amplifier can pass power (in one direction) and signals (in the other direction) across the isolation barrier without there being any electrical connection bridging the barrier?

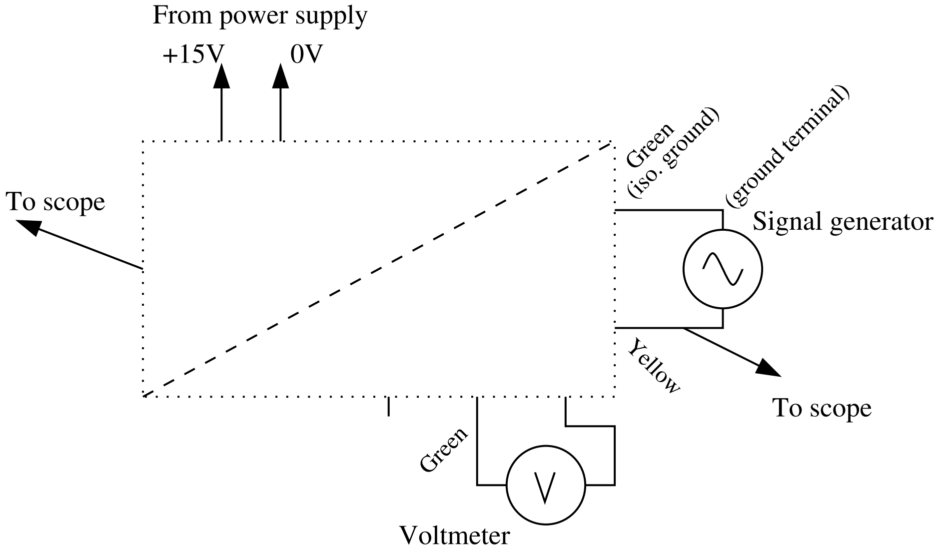

Figure 2: Testing the isolation amplifier

2 A differential amplifier

Q The amplifier discussed in this section is closely related to the inverting amplifier with which you may be familiar. Its special feature is that it amplifies the *difference* between the signals at its two inputs. This can be useful for cancelling out interference. Build the circuit shown in figure 3. The circuit takes its power from the isolation amplifier and sends its output signal via the isolation amplifier to the scope[2]. Because this amplifier is intended to have a large gain ($\equiv \frac{\text{output}}{\text{input}}$), the $10\ \Omega$ and $10\ \mathrm{k}\Omega$ resistors are used as a potential divider to attenuate the signal from the signal generator before it is applied to the amplifier. Verify, theoretically and by using the second channel of the oscilloscope, that the size of the signal at point B is approximately one thousand times smaller than that at point A. Why is it less clear at point B?

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[1] Although it is called an amplifier, it has a voltage gain (output/input) of unity, so the output and the input should be equal.

[2] The TLC271 is a special low-power op-amp, chosen to run from the small amount of power available from the isolation amplifier. Care must be taken *never* to apply a total (positive plus negative) power supply voltage of more than 18 volts to it.

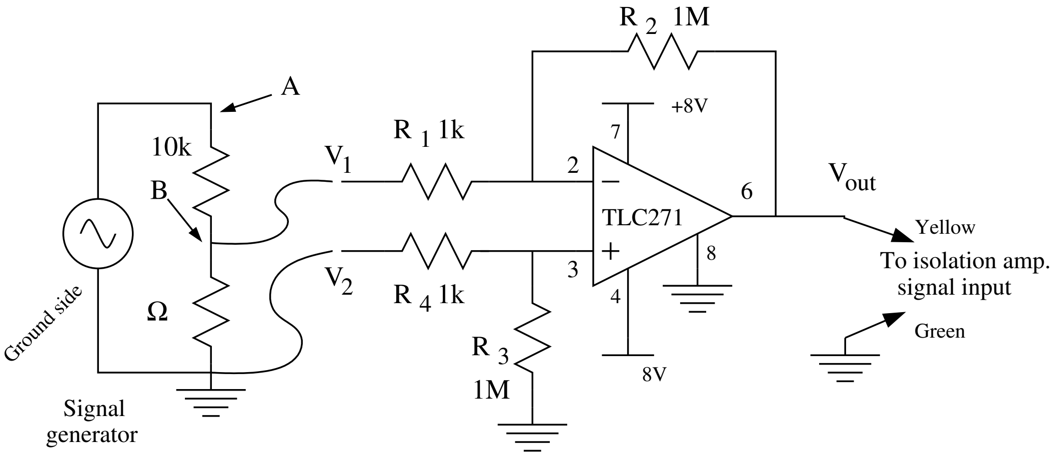

Figure 3: Differential amplifier. Note that the earth symbol refers to the green “isolated ground” terminals of the isolation amplifier. The curved lines represent possible connections made during testing.

Measure the gains of the circuit for its two inputs as follows: Set the signal generator to provide (roughly) a 2 volts peak-to-peak sine wave at 200 Hz. Connect point B of the 10 kΩ/10 Ω potential divider to input V_1 , ground input V_2 and measure the circuit output (via the isolation amplifier). The gain is defined as the output voltage (pin 6) divided by the input (point B). Then reverse V_1 and V_2 and repeat. In both cases, use a scope probe connected to the second input of the scope to monitor the input signal provided by the signal generator. Pay attention not only to the magnitude of the gain but also its sign, by comparing the phase of the input and output waveforms. **Q**

Finally, connect V_1 and V_2 together (this makes a “common-mode” signal) and measure the “common-mode gain” when they are both connected to the same signal. The common-mode gain should be small, so bypass the potential divider by connecting to point A instead of point B. Compare the resulting gain with what you expect from superposing the previous results, and with the theoretical result for this circuit[3]: **Q**

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1) \tag{1}$$

Why might you see deviations from this result in practice? **Q**

Investigate how the differential amplifier handles interference by disconnecting the inputs from V_1 and V_2 and touching V_1, then V_2, then both at once, with your finger. Examine the amplifier output in each case. What frequency is predominant? Where does it come from? Most importantly: why does touching both inputs at once reduce this interference? **Q**

3 Strain gauge bridge

A good use for the differential amplifier of figure 3 is to measure the out-of-balance signal of a Wheatstone bridge. You are provided with a flexible steel ruler that has a strain gauge glued to each

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[3] For the theoretically inclined: prove this by calculating the voltage at pin 3 of the op-amp in terms of V_2 and the R_3 / R_4 potential divider, the voltage at pin 2 by superposing V_1 and V_{out} using the R_1 / R_2 potential divider (both ways round) and then noting that the op-amp adjusts V_{out} to make pin 2 and pin 3 equal in voltage. In this circuit, $\frac{R_2}{R_1} = \frac{R_3}{R_4}$.

side. *Handle it gently,* because the strain gauge wiring is fragile. A strain gauge is a resistor made from a thin metal foil. When it is stretched, the change in length causes a change in resistance. The strain gauges, along with other resistors on the attached plug, form the bridge circuit shown in figure 4. Convince yourself that when the ruler is bent slightly, the resistance of one of the strain gauges will increase and that of the other will decrease. The changes in resistance may be only a few hundredths of an ohm in a resistance of 120Ω . Nevertheless, the differential amplifier will allow this small change to be seen. Connect the bridge to the differential amplifier as shown in figure 4. Clamp the end of the ruler from which the wires emerge, to a rigid support and balance the bridge by adjusting the potentiometer built into the bridge plug so that the output of the amplifier is zero volts dc. When the ruler is flexed slightly, the amplifier output voltage should change. Use the ruler to "weigh" some
Q coins. How much differential voltage change *at the bridge* is caused by the weight of a 10p piece?
Q How big is the common-mode voltage ($\frac{V_1+V_2}{2}$) in this circuit? (Measure V_1 and V_2 with a voltmeter.)
Q Estimate the smallest fractional change in resistance you could measure with the circuit. Why is the performance better than you could get with a single strain gauge an ohmmeter?

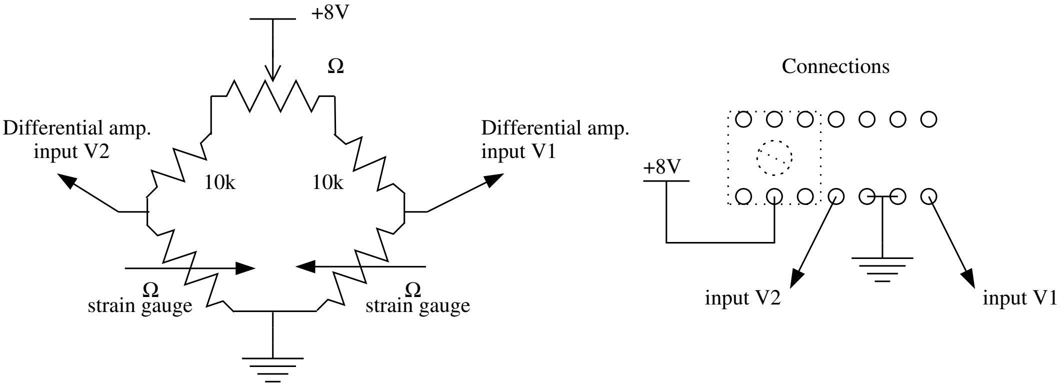

Figure 4: Strain gauge bridge

4 Instrumentation amplifier

The differential amplifier of figure 3 works reasonably well with the 120Ω resistance of the strain gauges, but if the resistance of the signal source becomes comparable with the 1 kΩ input resistors, then its performance will degrade. It is easy to see this from figure 3, by noticing that any resistance introduced in series with connection V_1 will affect the circuit just like an increase in the value of R_1. Equation 1 shows that the circuit gain will be reduced as a result. Use a battery-operated multimeter
Q to measure the resistance between two connections made to your arm. How badly would the gain of a circuit like that of figure 3 be affected by this resistance, if you were to look at signals originating inside your arm?

The solution to this problem is to use a special kind of differential amplifier circuit having a high input impedance, called an "instrumentation amplifier". The Burr-Brown INA121 chip contains a complete instrumentation amplifier[4]. Connect up this chip as shown in figure 5. The data sheet says

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[4] The first page of the INA121 data sheet is in the appendix.

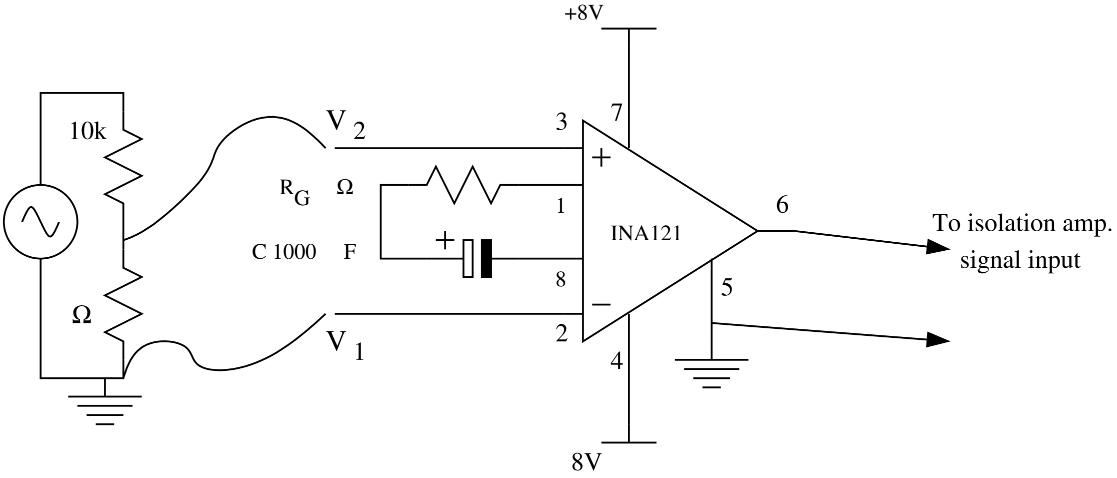

Figure 5: Instrumentation amplifier. The INA121 is an integrated instrumentation amplifier, not an ordinary op-amp. The curved lines represent connections for a test input.

that the gain G of this circuit is given by

$$G = 1 + \frac{50k\Omega}{Z} \tag{2}$$

In figure 5, Z is the sum of R_G and the reactance of capacitor C, $\frac{1}{2\pi fC}$. What will be the value of G (i) at d.c. (zero frequency)? (ii) at a frequency so high that the capacitor can be neglected? How high is high enough? **Q**

Using the signal generator and potential divider as before, check that this circuit behaves the same as the previous one. Disconnect the signal generator and potential divider from the amplifier, and use two insulated wires of length 0.5 to 1 metre and crocodile clips to connect the amplifier inputs to two self-adhesive electrodes on your arm. One near the elbow and one near the wrist works nicely. With the scope in MEM and ROLL modes, you are ready to look for signs of life. Since, unlike a signal generator, you are not always connected to ground, you will also need to hold on to a wire connected to your amplifier's (isolated) ground. This will provide the few picoamps of current that the amplifier's inputs need. Clench your fist and look for signals. Record your results using the hardcopy facility of the scope. Even though the instrumentation amplifier does a good job, well-attached (low resistance) electrodes and a good ground connection are necessary for good results. Record your trials and results. How big are the voltages you are measuring (before amplification)? Why is it helpful for the circuit's gain to be reduced at d.c.? **Q**

Figure 6 shows a typical result.

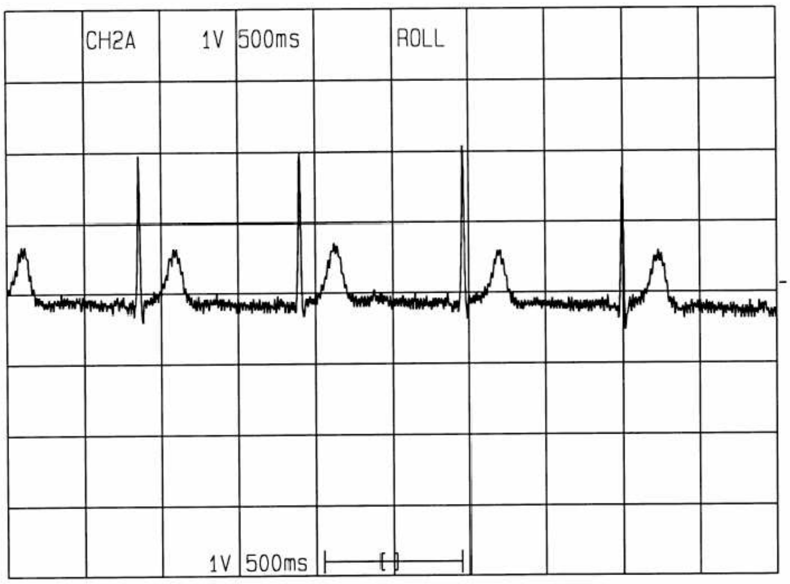

Figure 6: Heart of demonstrator