Instrumentation Amplifiers

Introduction

In many applications of signal measurement it is necessary to measure a small signal that sits on top of a slowly varying background that is much larger. One such example is the measurement of the electrical activity of the heart by sensing the voltage changes on the skin as the heart goes through its cycle. Typical signals in this case are of the order of 1 millivolt whereas the potential difference across the body due to galvanic action may be as high as volts. The signal to noise ratio is thus ~1/1000 and any circuit we build must be capable of providing this kind of noise rejection. In addition, when the heart beats, the electrical activity changes rapidly in times as short as 10 ms. Thus our circuit must have frequency response in the range of 100 Hz. A natural solution is to try to use an opamp for this circuit. Unfortunately this will not work, as it is not capable of giving us the required common mode rejection ratio (CMRR) of 1000 or more. Thus we are led to consider a class of devices called instrumentation amplifiers. In this experiment we will build a circuit designed by Shawn Carlson.[1]

The Experiment

Electrical Circuitry

The Power Supply

You will be given a power supply that will provide the ± 9V needed for the circuit. Its construction can be seen in Figure 1. Note that it is constructed using two 9V batteries. Doing this eliminates any possibility of dangerous electrical shock as well as removing a source of possible noise that comes in at a frequency (60 Hz), that is important to our measurement. Ask your instructor for a power supply and familiarize yourself with its use.

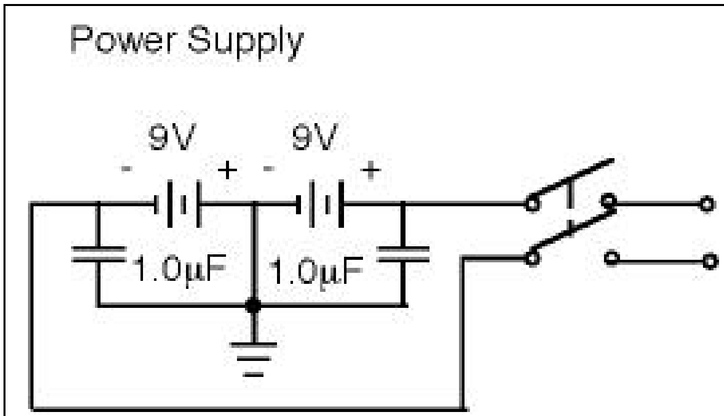

Figure 1: Power Supply

[1] Shawn Carlson, "Home is Where the ECG Is", Amateur Scientist, The Scientific American, June 2000.

The Amplifier

Our amplifier is built around the AD624AB instrumentation amplifier chip from Analog Devices. Please take some time to look at its data sheet, found in the

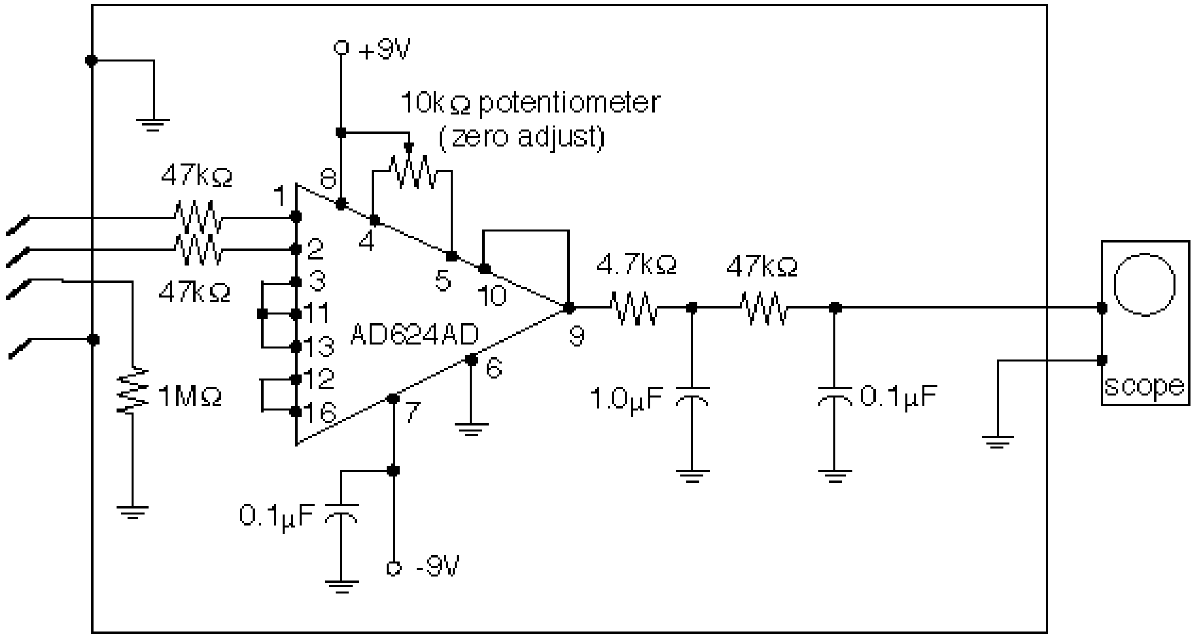

Figure 2: Amplifier circuit schematic.

supplementary reading section, to understand its function. At our gain of a 1000, this amplifier gives us a CMR of 110 dB. Our amplifier design is shown in Figure 2. Build this circuit on your proto-board. When handling the AD624AB chip be sure to wear the static strap properly grounded. The CMOS circuitry in the chip is extremely sensitive to static voltage discharges and is easily damaged. Take some care in laying out your circuit so that its function is more readily apparent. Place the chip near the center of the board and add other components around it. Have your instructor check your circuit before powering it up.

Questions

These questions should be answered before coming to the lab.

1. The amplifier circuit is similar to the instrumentation amplifier shown in Figure 9.10 in your text (DH). Its gain is given by:

$$G = \left[\frac{40{,}000}{R_G} + 1 \right]$$

The resistor R_G in the AD624AB plays the role of the resistor "R_2" in Figure 9.10. Consider the functional block diagram on page 1 of the Data Sheet. Show that the resistance R_G, between RG_1 and RG_2 obtained by shorting pin 16 (RG_1) to pin 12 and pin 2 (RG_2) to pins 11 and 13 yields a gain of 1,000.

2. The output (pin 9) of your amplifier is connected to the oscilloscope through a capacitor-resistor filter network. What is the frequency response of this filter? Sketch a Bode plot for this filter and include it in your lab notebook.

The Experiment

General

Your instructor will provide you with three electrodes to attach to your body, two to pick up the differential signals from your body and a grounding point to be attached to your ankle. Make sure that the electrodes are making good contact with your skin. It helps if the area of attachment is not too much encumbered with body hair. The output will be connected to your oscilloscope on which you will display the signal.

Muscle Contraction

For the first experiment, attach the signal electrodes on two ends of a muscle. Although a bicep will work, a stronger signal is obtained if a larger muscle such as the calf muscle is used. For this part of the experiment, observe the signal on the oscilloscope before and after a vigorous contraction of the muscle. What do you see? Make a sketch in your lab book.

Electrocardiogram

Attach the signal electrodes to corresponding points on your upper arms. An optimal placement of the electrode would be on both sides of your upper chest, but this is not practical in the laboratory setting. Observe the resulting signal on the oscilloscope and make a sketch for your lab notebook. What is the frequency of the main component of the signal?

In schematic form, a typical ECG trace is shown in Figure 3. The wave labeled "P" precedes atrial contraction; the "QRS" complex occurs at the start of the ventricular contraction and the T-wave comes at its end. Try to identify these features in your sketch.

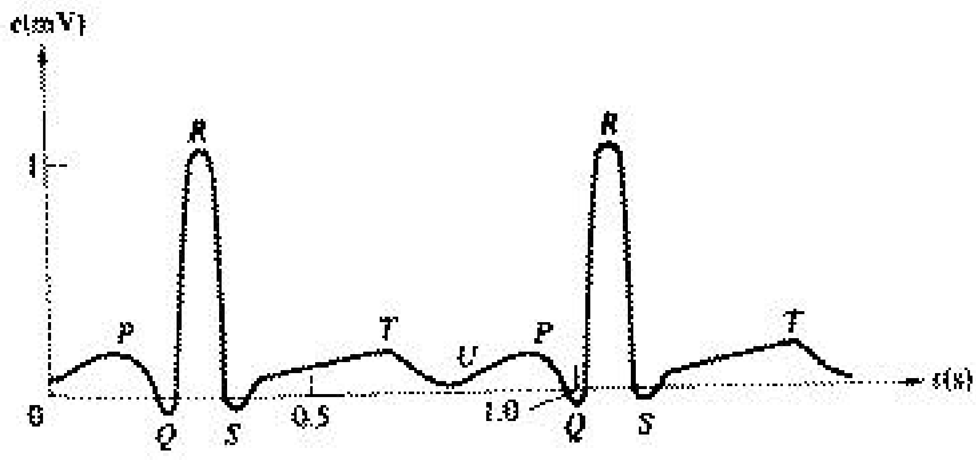

Figure 3: Schematic ECG trace.

Cardiac Recovery

If you are in good health, try to increase your heart rate by a factor of two over its resting rate. You might achieve this by running in place for a few minutes. Once you have done this, take a series of measurements of your heart spectrum noting carefully the time of each measurement. Do you notice anything unusual? Plot your heart rate as a function of time using for t = 0 the time when you stopped your exercise. How long does it take your heart rate to return to its resting state? (Use 10% as an estimate of the uncertainty here).