

# EECE 2150 - Circuits and Signals: Biomedical Applications

## Lab 14: ECG Circuit 1 - The Instrumentation Amplifier

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### Introduction:

As discussed in class, **instrumentation amplifiers** are often used to reject common-mode signals and provide a stable gain with a high-impedance input over a modest range of frequencies. This is required for amplifying bio-potentials associated with electrocardiogram (ECG) signals.

Today, we will explore the operation of the instrumentation amplifier, observe ECG signals on the oscilloscope, and work to eliminate noise from our measurement circuit.

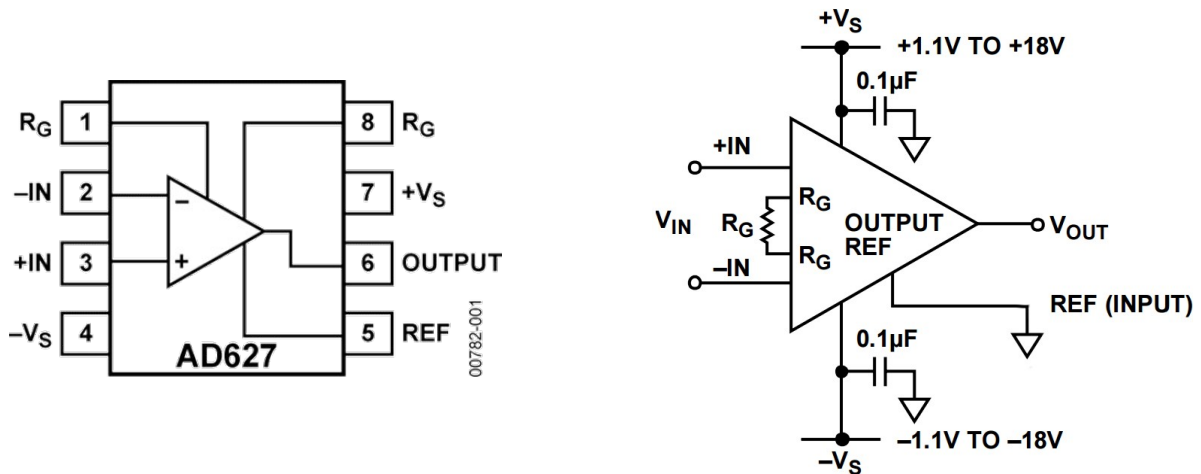
Unlike in the previous Operational-Amplifier lab, we will use two 1.5 V batteries to power our instrumentation amplifier circuit. This is to electrically isolate the circuit from the AC power for safe connection to students. In general though, single ended supplies are more common in “real” circuits, since they reduce the cost of production. We will explore this in the next lab. For this reason, **DO NOT** disconnect your circuit when you are finished today!!!!

### Part 1 - Connecting and Powering the AD627 Amplifier.

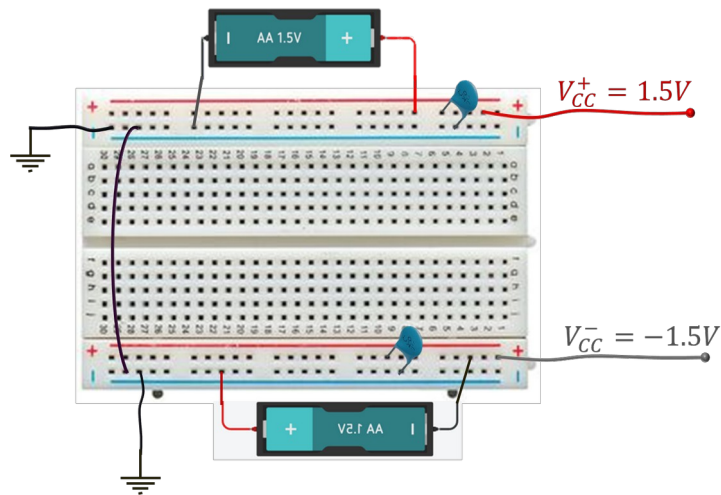
- 1.1 As discussed in class, the AD627 is a high quality, instrumentation amplifier integrated circuit with adjustable gain.
- 1.2 Like the LM741 and LT1490 Chips, the AD627 requires external DC power supplies for operation. It can be connected with one supply, but in this case we will use two 1.5 V batteries. Connect the AD627 instrumentation amplifier as shown in Figure 1 (page 15 of the spec sheet, posted on Canvas), in **double-ended power configuration, using ground for the REF input**. Use the provided 1.5 V battery connectors, being sure to provide a positive and negative 1.5 V supply (i.e. the two batteries must be connected with opposite polarity but common ground). Figure 2 shows the connection for the batteries to produce a positive and negative power source. **Note that, unlike the 1490 op-amp, you will destroy the AD627 chip if you connect the power supply wrong. So double/triple check your wiring before connecting the power!!!**

Also, be sure to use the capacitors as shown on the spec sheet. Q1: what do you think the capacitors are for?

- 1.3 Select the  $R_G$  **value in Figure 1** to give a total circuit gain of about 25. **Q2: what R value can you use to produce this?** (according to the spec sheet)
- 1.4 Note that it is very important that **all grounds on your breadboard be connected together** to avoid ground loops. (*Reference voltage, scope, battery, AD627 grounds etc.*)



**Figure 1** - The AD627 Instrumentation Amplifier pin-out and connection diagram (see AD627 spec sheet online for details). Use 1.5 V batteries to power the circuit rather than the DC supply using the connectors provided. Connect the REF input, pin 5 on the AD627 to ground.

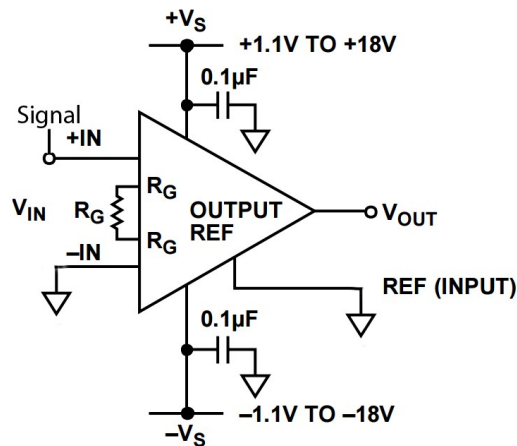


**Figure 2** Connections of two 1.5 V batteries to produce a positive and negative power sources with a common ground

## Part 2 - Testing the AD627

- 2.1 Generate a **test signal** to test the operation of the AD627 chip. As discussed in class, the AD627 amplifies small differences between the two input pins,  $+i$  and  $-i$

- 2.2 Use the signal generator to give a **sine wave with a peak-to-peak of 30 mV**
- 2.3 Use an appropriate value for the sine wave frequency that is in the middle of the expected frequency range of an ECG signal. Q4: Given our discussions in class, what frequency would this be?



**Figure 3** – Test signal circuit configuration

- 2.4 Connect this test signal to the input pins of the AD627 (one input should be the sine wave, the other should be ground)
- 2.5 Measure the output on the oscilloscope. Remember to adjust the **horizontal (time) axis** of the oscilloscope to an appropriate value given your sine wave.  
*You may want to use “AC coupling” at first to “find” your sine wave. You can do this by pushing the channel # button on the oscilloscope, and then switching between “DC coupling / AC coupling” using the button under the screen.*
- 2.6 What is the **gain** of the amplifier,  $\frac{V_{out}}{V_i}$ ? Record this in your lab-book. Is it as you expected from the spec sheet? This is also known as the **“differential mode gain”**  $A_{dm}$ .
- 2.7 To Measure the **“cut-off”** frequency of the amplifier, increase the frequency of the input signal and observe the gain. What frequency corresponds to 0.707 of maximum gain?
- 2.8 Try to measure the **common mode gain**,  $A_{cm}$  of your AD627 circuit. You can do this by connecting the signal generator to both inputs,  $+i$  and  $-i$  at the same time and measuring the size of the output signal. The input signal will need to be larger here, but should not approach the power supply voltage. In this case, use about a 500 mV Peak-to-peak sine wave at 100–200 Hz. Can you see any output at the input frequency? You may not be able to get a signal you can measure here, precisely because the AD627 is very good at “rejecting” common mode inputs like you have here. If you get a noisy signal, try to estimate its amplitude as well as you can. If you can measure a signal, the ratio of this output to the input amplitude (where the input amplitude is the amplitude of the signal coming from the signal generator) is  $A_{cm}$ .

- 2.9 The common mode rejection ratio  $CMRR$  is then given by  $20 \log_{10}(A_{dm}/A_{cm})$ . Note that the magnitude of the common mode gain will be much less than one. What value do you get? Does this agree with the spec sheet?

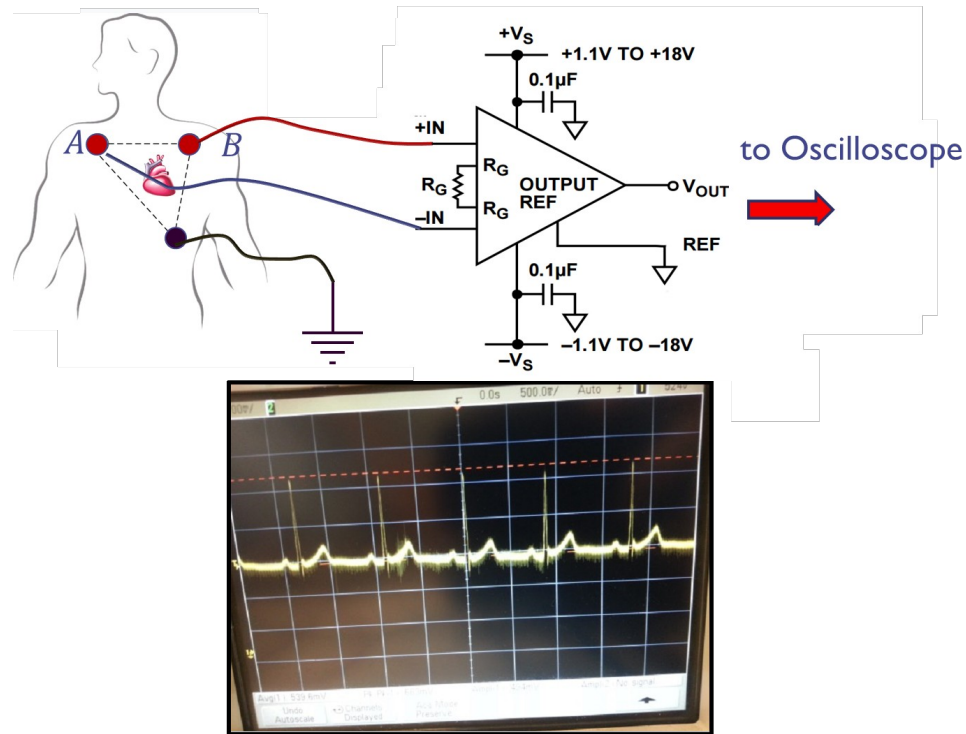


Figure 4 - ECG Measurement Configuration

### Part 3 - First attempt at measuring your ECG signal.

Making an ECG measurement is challenging and requires some patience and trial and error. **In all probability will not work well on the first try**, but this is part of developing the circuit/technique. With a little patience and adjustment, you can get a very clean ECG signal. Use the Biopac EL503 electrodes provided. The Electrode placements in Figure 4 are suggested for the optimum signal, but simply using the right and left forearm may be more convenient for testing, and is also fine as far as acquiring an ECG.

### Some considerations - Read before attempting!

1. **Electrode placement:** electrodes can be placed across your chest (upper right and lower left as shown above) or on your forearms. Be sure to attach a **third electrode to your body connected to ground**. This is very important.
2. **Connectors:** You may use the specialized electrode connectors provided. Somewhat surprisingly, many students have better results by making lead wires and attach them to the conductor by stripping a ~1" length from the end and wrapping it around the

conductor tightly a few times and crimping with pliers. Do not solder since this will damage the electrode.

3. Try to keep your muscles still when you are acquiring your data (why?). It is suggested that **one student wear the electrodes and hold still**, while the other student adjusts the equipment.
4. Observe the EKG signal on the oscilloscope. If it looks perfect, you are very lucky!! However, you will probably have some noise or a lot of noise or a small signal. Describe the signal that you get.
5. This is one occasion where the “**auto scale**” button on the oscilloscope **will probably not work**. Set an appropriate **horizontal (time) axis**, such as **(200- 500)ms/division**. Also set an appropriate **vertical axis** based on your anticipated ECG signal amplitude. You will need to turn on “AC coupling” to find your ECG wave if there is a substantial DC offset. We will remove this DC offset in the next lab.
6. One source of noise is your body acting as an antenna and picking up low frequency signals, largely from the 60 Hz power lines. We try to eliminate this as much as possible by using the difference amplifier feature of the instrumentation amplifier, assuming that the potential of your entire body is changing at the same time due to external influences. Another potential source of noise is that any loop of wire acts as a transformer as the magnetic field changes inside it. You may have seen this in your physics course and you will see it in the future in your electromagnetics course. The way we can eliminate loops of wire is by twisting the wires together. This is used in Ethernet cables – they contain “twisted pairs.” Here, you may be able to do the same thing by twisting the three wires going to the body together. Try this and describe the results.
7. In future labs, we will filter out the dc potentials that are superimposed on the time-varying cardiac signal (one method is shown on page 19 of the spec sheet (Figure 46)), and we will build filters to eliminate high-frequency noise before acquiring the signal.
8. You may want to adjust the  $R_G$  **resistor** value for the right amount of gain.

Observe the ECG signal on the oscilloscope. Describe your signal in your report.

You can also take a snapshot of your oscilloscope screen for your report.

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Last updated: 8/25/2021 Iman Salama, 11/11/2015 Mark Niedre