PreLab 4: Optical Heart Rate Monitor (8 problems for 30 pts)

INTRODUCTION

An optical heart rate monitor is an example of photoplethysmography (PPG). The basic idea is to measure the change in light absorption by blood in your fingertip.

As shown in Fig. 1, we will use a REFLECTION-mode arrangement, which means the LED and photodetector are on the SAME side of the finger. This is easier to implement on a breadboard (or a Fitbit-like device).

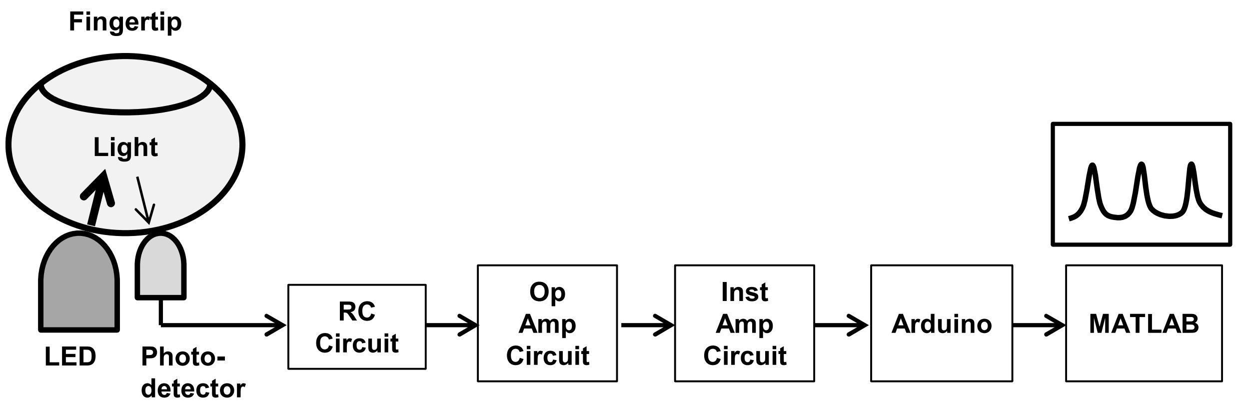

Fig. 1: Simplified diagram of the various stages in the PPG system.

LED

LED stands for "light emitting diode". How to use it in a circuit? When using an LED, the most important thing is to properly set the value of its ***current***. An LED is typically used with a current of 10 or 20 mA. This lab uses a higher power LED that can handle higher currents – we'll use 30 mA.

OK, so how to set the current? When an LED is conducting current, the voltage across the LED remains fairly constant, regardless of the current value! If you double the LED current, the LED voltage stays roughly the same. Weird! Yes, this means an LED does NOT obey Ohm's Law! Gasp!

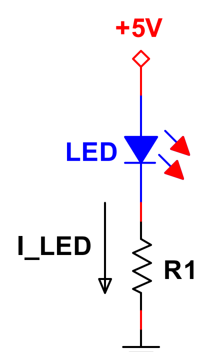

Fig. 2: LED circuit.

- **Problem 1**: Fig. 2 shows our LED circuit. It's really simple -- just a +5V power supply, the LED, and a resistor. A red LED typically has a "forward voltage" of V_F = 2.1V. Choose a standard 5% value for R1 that produces an LED current of 30 mA (slightly lower is fine).

  Hint #1: Remember that when the LED is on, its voltage is 2.1V.

  Hint #2: You should get around 100 ohm.

OPTICAL SENSOR

For this lab, the optical detector is a "phototransistor", which is a semiconductor device that converts incident light into a current. A phototransistor is like a photodiode, but its internal current gain produces a much higher output current. This sounds fantastic, but it does come at the expense of slower speed and somewhat noisier operation. However, a phototransistor is perfectly fine for this lab and results in a simpler circuit.

As shown in Fig. 3, the optical sensor circuit is quite simple. The phototransistor detects light and produces a current I_{SIG}, which is then converted into a voltage by a 1 kohm resistor. As discussed in class, the arterial pulsations in the fingertip produce very small changes in optical absorption. This means Vsig has a huge DC component (e.g. constant) with a tiny AC component due to arterial pulsation.

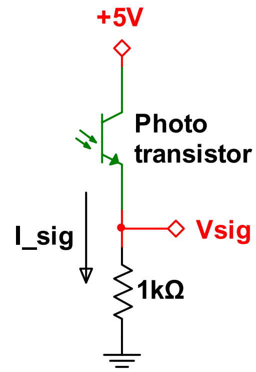

Fig. 3: Phototransistor circuit.

- **Problem 2**: Suppose the DC portion of Vsig is 2.5V, while the arterial pulsations produce a 0.2% change in the signal. Assuming a 60 bpm heart rate, sketch the photodetector signal over a 3 second interval. Label important features!

  Hint: Remember that more blood means more light is absorbed!

As shown in Fig. 4, the phototransistor circuit is followed by an RC circuit, an op amp circuit, and an instrumentation amplifier circuit.

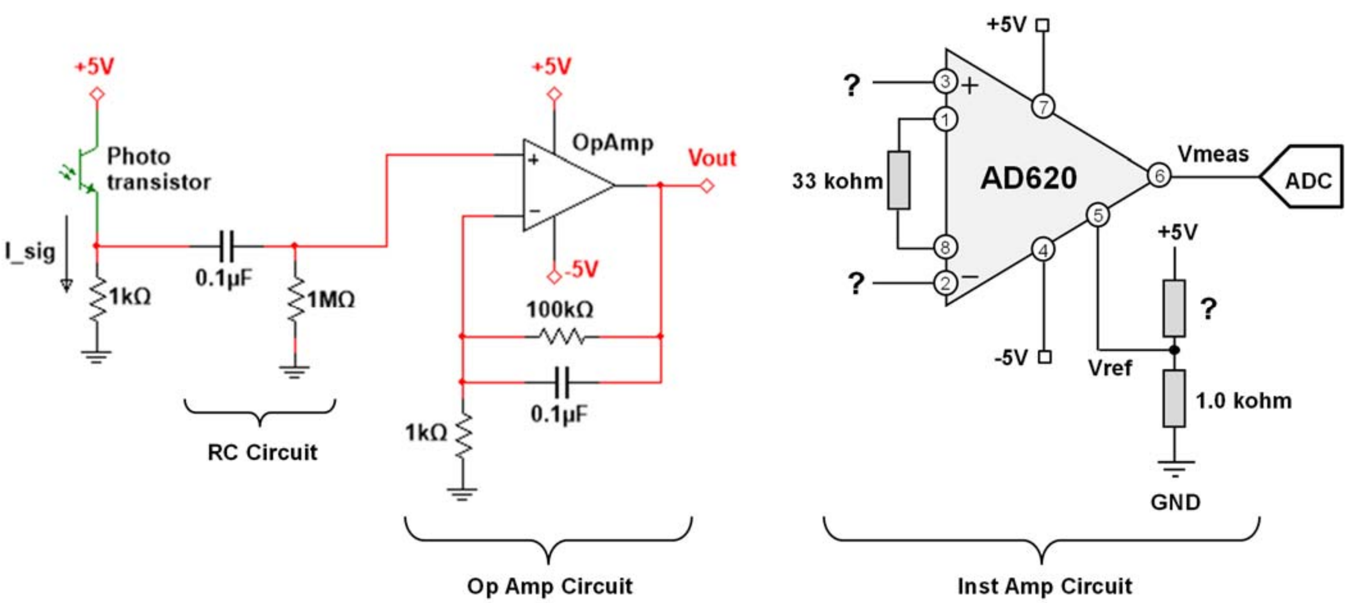

Fig. 4: The phototransistor output is sent through an RC circuit, an op amp circuit, and finally the instrumentation amplifier.

- **Problem 3**: Based on your experience with Lab 3, explain the purpose of the RC and op amp circuits. You don't need to use any equations. Just write about the concepts -- WHY is each circuit needed?

- **Problem 4**: Based on your answers to the previous problems, sketch the op amp output Vout over a 3 second interval. Keep in mind the op amp's voltage gain. Label important features (e.g. pulse amplitude)!

We're almost done! The voltage signal Vout needs to be amplified a little bit more. Plus, we want the measured voltage waveform Vmeas to consist of voltage *peaks* rather than dips. Furthermore, Vmeas should be between 0 to 5 V for Arduino compatibility. We can use the AD620 to do all three: (1) provide some additional gain (2) invert the signal (3) add a 1V DC offset. Nice!

- **Problem 5**: Fig. 4 shows an "incomplete" instrumentation amplifier circuit. Vref is made from a 1 kohm resistor (bottom) and a "mystery" resistor (top). Compute the appropriate standard 5% value for this upper resistor in order to produce V_{REF} close to 1V.

- **Problem 6**: Sketch a completed version of the instrumentation amplifier circuit. Make sure you clearly show the connections for the AD620 (+) and (-) signal inputs (pin 2 and 3).

  Hint #1: The AD620 can be used as a "single input" amplifier by grounding ONE of the signal inputs.

  Hint #2: The other AD620 signal input comes from the op amp output Vout.

- **Problem 7**: What is the overall voltage gain of the PPG circuit?

- **Problem 8**: Based on your answers to the previous problems, sketch Vmeas (the AD620 output) over a 3 sec interval. Label important features!

(End of PreLab 4)