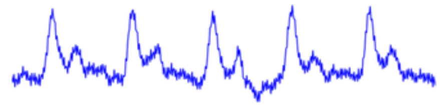
Lab 4 – Optical Heart Rate Monitor

GOALS

1) Build and test the electronics for an optical heart rate monitor.
2) Use the Arduino Uno and MATLAB to display the optical signal and heart rate.



GENERAL GUIDELINES

You know the guidelines by now …

REQUIRED MATERIALS

- Steady finger
- Lab kit
- Scope, probe kit, and computer, +/-5V benchtop power supply
- High brightness red LED (larger optoelectronic device)
- Phototransistor (smaller optoelectronic device)
- TL081 op amp (one), AD620 instrumentation amplifier (one)
- Resistors:

Resistors:	100 ohm (brown/black/brown) 5% resistor	(one)
	1 kohm (brown/black/red) 5% resistor	(three)
	3.9 kohm (orange/white/red) 5% resistor	(one)
	33 kohm (orange/orange/orange) 5% resistor	(one)
	100 kohm (brown/black/yellow) 5% resistor	(one)
	1 Mohm (brown/black/green) 5% resistor	(one)

- 0.1 µF capacitor (two)

LAB ACTIVITIES

1) Construct and test LED + phototransistor circuit, HPF, and amplifier + LPF
2) Construct and test AD620 circuit
3) Confirm your Arduino Uno and MATLAB programs still work.
4) Make a live PPG measurement.

INTRODUCTION

Your 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.

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).

The PPG system has five main parts:

(1) Red LED + phototransistor + High-pass filter

- Your fingertip rests on the LED and phototransistor
- The phototransistor produces a photocurrent, which is then converted into a voltage by a 1 kohm resistor
- The large DC offset is removed by the RC circuit (high-pass filter)

(2) Amplifier + Low-pass filter

- The op amp circuit amplifies the signal dips by 101.
- A low-pass filter rejects some noise.

(3) Instrumentation Amplifier

- This op-amp circuit does THREE things:
  - Amplifies the pulsed waveform a little bit more
  - Adds a roughly 1V DC offset
  - Inverts the pulse waveform to produce "positive" peaks.

(4) Arduino data acquisition

(5) MATLAB data processing and display.

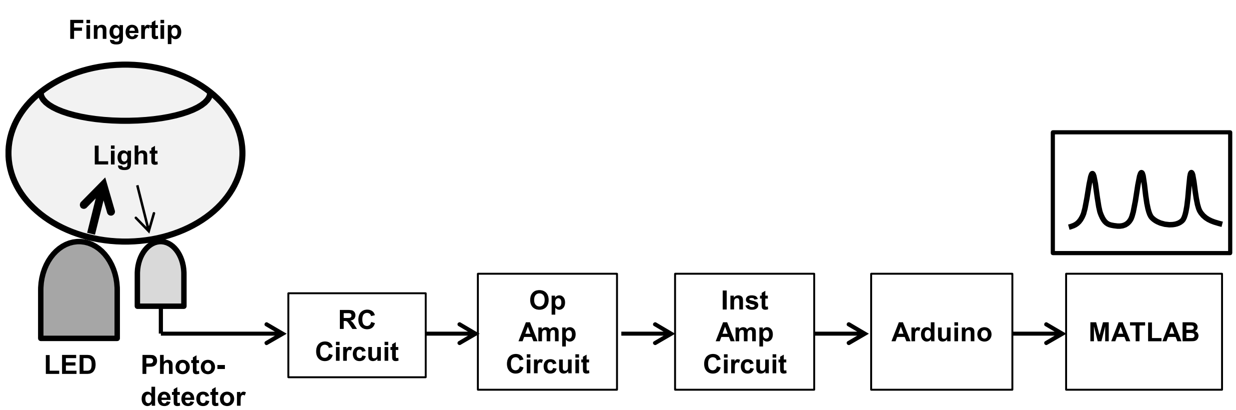


Fig. 1: Simplified diagram of the various stages in the PPG system.

PART 1: LED + PHOTOTRANSISTOR + HIGH-PASS FILTER

- **Step 1a**: Wire up the circuit in Fig. 2 and 3 (see Buma's breadboard for guidance, if necessary).
  - Use NEAT and COLOR-CODED wiring!
    - Red = +5V, Black = GND, Blue = -5V, Yellow = other
  - As shown in Fig. 2, the LED and phototransistor should be on either side of the breadboard gap (i.e. like the pins of the AD620 chip).
    - The high-brightness LED is the larger component. The LONGER pin is connected to +5V!
    - The phototransistor is the smaller component. The SHORTER pin is connected to +5V!
    - Clip the leads so that the LED and phototransistor are about the same height (Fig. 2).
    - Bend the LED and phototransistor so they are touching (Fig. 2).

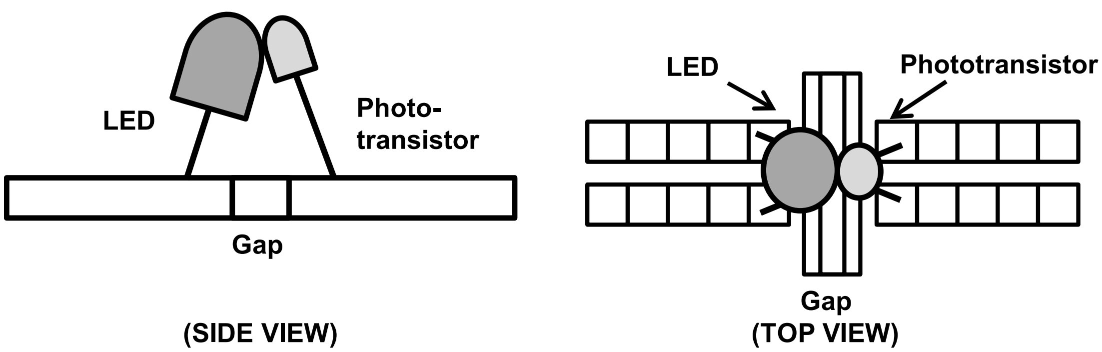


Fig. 2: The LED and phototransistor should be on either side of the breadboard gap (i.e. like an op amp chip). Trim and bend the leads of the LED and phototransistor so that they are touching.

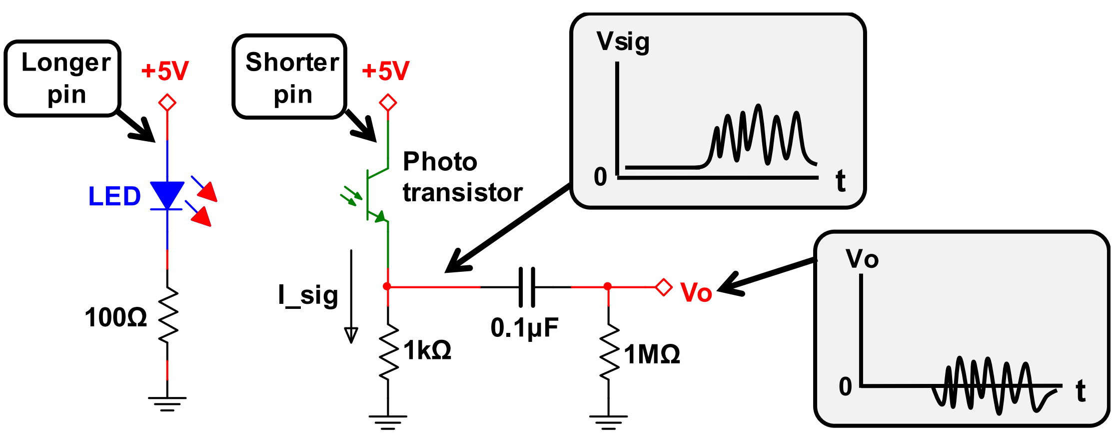


Fig. 3: LED and phototransistor circuit. +5V is connected to the LONGER pin of the LED and the SHORTER pin of the phototransistor!

- **Step 1b**: Test your circuit.
    - The +/- 5V power comes from the benchtop supply.
        - When power is turned on, the LED should be very bright!
    - Set up the scope.
        - Press "Force" (to restore front panel control) and the press "Default"
        - Make sure the probe and scope are set to 1X
        - Set your scope to 1V/div (vertical) and 500 ms/div (horizontal).
    - Attach the scope probe to observe the Vsig of the phototransistor (see Fig. 3).
        - As you wave your hand just above the LED, the scope trace should respond to your hand waving. The Vsig waveform should be purely positive (see Fig. 3).
    - Move the scope probe to observe the output Vo of the high-pass filter (see Fig. 3).
        - As you wave your hand just above the LED, the scope trace should respond to your hand waving (see Fig. 3). The Vo waveform should be both positive and negative (see Fig. 3).

PART 2: OP AMP CIRCUIT (AMPLIFIER + LPF)

- **Step 2a**: Wire up the "Op Amp Circuit" circuit shown in Fig. 4.
    - This provides a gain of 101 and low-pass filter with fc = 15.9 Hz.

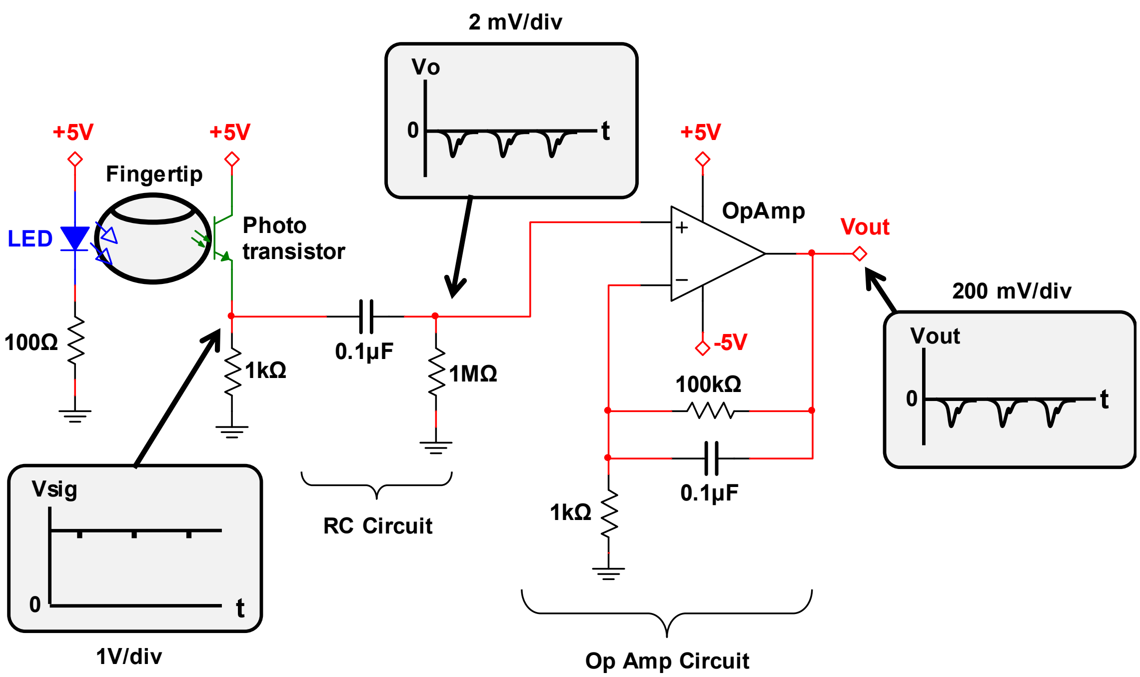


Fig. 4: After the high-pass filter, build the "Op Amp Circuit" that is a non-inverting amplifier with a low-pass filter (gain = 101 and f_C = 15.9 Hz). When you place your finger on the LED (be very still), observe the scope waveform for Vsig, Vo, and Vout.

- **Step 2b: Test your circuit**.
  - Keep the scope probe on Vsig (vertical = 1V/div, horizontal = 500 ms/div) and place your fingertip on top of the LED + phototransistor.
    - The pad of your fingertip should be lightly pressed against the LED + phototransistor.
    - BE VERY STILL, since motion artifacts are significant in PPG!
    - The scope trace should be 1 or 2V at relatively flat (see Fig. 4).
  - Next, move the scope probe to the output Vo of the high-pass filter.
    - Change the vertical scale to 2 mV/div.
    - You should see a fairly noisy waveform (centered at 0V) with some tiny dips of 1 mV or so (see Fig. 4). BE VERY STILL, or else motion artifacts will swamp your pulse signal!
  - Finally, move the scope probe to the output Vout of the op amp circuit.
    - Change the vertical scale to 200 mV/div.
    - You should see some dips that are roughly a couple 100 mV in amplitude (see Fig. 5).
      - The size of the dips will be smaller if you have cold hands or poor circulation.
      - Be VERY STILL, since motion artifacts will swamp your desired pulse!
      - Buma or the lab assistant can help if you are having problems getting a reasonable signal.

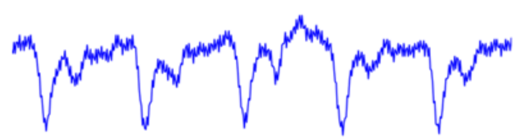


Fig. 5: The scope trace should look like this. The dips should be roughly 500 mV in amplitude, but it really depends on a lot of factors.

PART 3: AD620 circuit

The op amp output 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!

- **Step 3a**: Build the instrumentation amplifier circuit (see Fig. 6).
  - Use NEAT and COLOR-CODED wiring!

- **Step 3b**: Test your circuit.
  - Move the scope probe to the output of the AD620 and set the scope to 1V/div.
  - Place your fingertip on top of the LED + phototransistor.
    - You should see your PPG signal with an approximately 1V offset (see Fig. 7).

    - If your signal exceeds 5V (this does happen sometimes), think of a way to reduce the gain of your AD620 circuit
  - Demo your circuit to Buma.

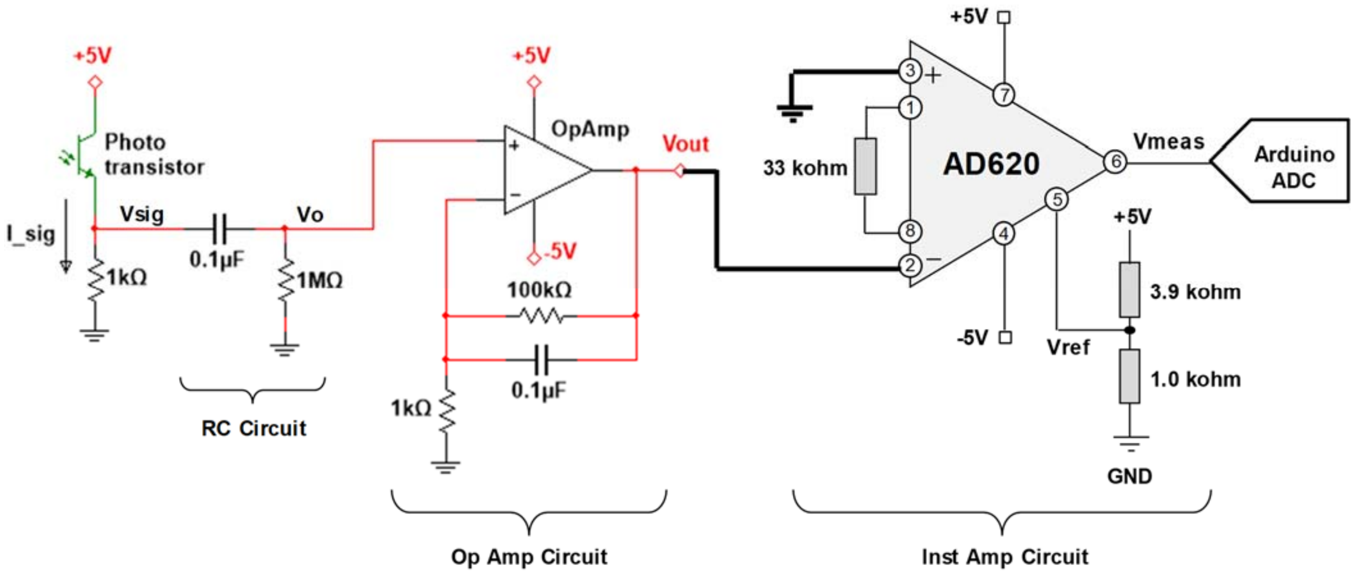


Fig. 6: The "Inst Amp" circuit provides additional gain, inverts the signal, and adds a 1V offset.

- **Step 3c**: Connect the Arduino to your circuit.
  - Use a YELLOW wire to connect the level-shifter output to the **A0 pin** of the Arduino.
  - Use a BLACK wire to connect the breadboard ground to the **GND pin** of the Arduino.

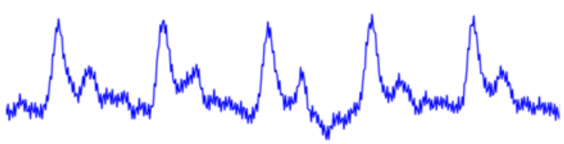


Fig. 7: The scope trace should look something like this. Your finger must be VERY still to avoid motion artifacts!

(End of Part 3)

PART 4: DATA ACQUISITION AND DISPLAY

This week's Arduino program is basically the same as last week (ECG system). The Arduino acquires 300 samples and then sends them to the computer. The sampling interval is dt = 10 ms. You can re-use your Lab3 code (nice!), but a couple of tweaks need to be made.

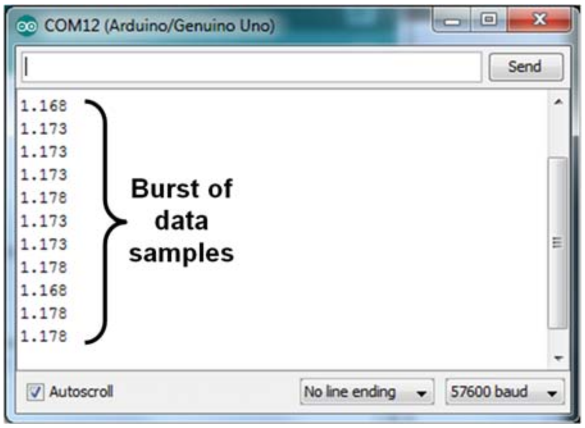


Fig. 8: Sending 'y' to the Arduino should result in a rapid burst of data.

- **Step 4a**: Update your Lab3 Arduino code.
  - Make sure the correct serial port is selected before uploading!
  - Upload your Lab3 Arduino code to the Uno and run the **Serial Monitor** on the computer.
  - Make sure the bottom right of the window is set to "57600 baud".
  - You should notice the letter "**a**" on the first line.
  - Type in the letter "**y**" in the command line and press the **Send** button.
    - You should see a rapid burst of voltage values appear (see Fig. 8).
    - Every time you send 'y', a new burst of data should appear.

- **Step 4b**: Make sure your MATLAB program works OK.
  - Make sure the correct COM port is specified!
  - Run your code -- an initial plot should appear showing a flat line with amplitude near 1.
  - After a few seconds, a new plot should appear showing your amplified PPG signal.
  - Keep your program running.

- **Step 4c**: Record your PPG waveform.
  - When your plot has settled down to a nice looking trace, click just outside the white plot area to stop the program.
  - **Save the figure for your lab report** (e.g. as jpeg file).
  - **Demo your system to Buma**.
  - **Take a photo of your awesome PPG system for your lab report (Buma can help you with this)**!

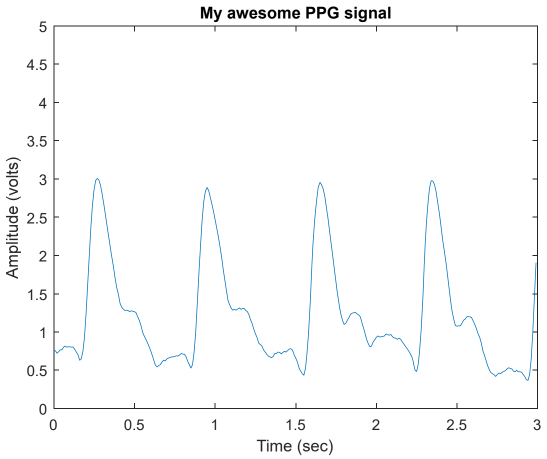


Fig.9: Hopefully you see something like this for your MATLAB plot! Remember to edit the plot title in your MATLAB code!

(End of Lab 4)