

THE OHIO STATE UNIVERSITY

Pulse Detector

Using infrared light to detect a heartbeat

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Instructions for building a non-invasive pulse detector using easily available parts, such as an infrared light emitting diode, photodiodes, and operational amplifiers.

Introduction

Modern pulse oxymeters play an important part in modern medicine, specifically in the operating room. One of the most important people in an operating room is the anesthesiologist. They are in charge of keeping the patient alive within specified limits; therefore, they must monitor many vital statistics, two of which are pulse and oxygen content in hemoglobin in the blood.

The circuit presented here is a simplified version of a pulse detector. The pulse detector is noninvasive, easy to use, and made from items readily available. The instructions are presented in five parts:

- Parts list,
- Finger clip assembly and connections,
- The signal amplifier, and
- The comparator and the L.E.D. output.
- Testing and Suggestions

When testing the circuit, one must remember that it is designed to detect the heartbeat or the pulse using a person's finger; the difficulty arises in the fact that every body is different. Not only will the settings vary from person to person, but they will also vary from finger to finger.

Parts List

The following items are required to build this circuit:

Transmitter and Receiver (finger clip):

- ✓ 1 × infrared L.E.D. (Vishay Semiconductors Part No. TSHG8200, $\lambda = 830$ nanometers, 50mW at 100 mA, cone angle ($\pm 10^\circ$) and package T-1 3/4)
- ✓ 1 × photodiode (Advance Photonix, Inc., Part No. PDB-C158, silicon PIN, active area 3mm square, side-looking clear package)
- ✓ 1 × large clip (OXO SoftWorks is recommended).
- ✓ 1 × machine screw (#6-32, slotted round or truss head, length will depend on size of clip)
- ✓ Test leads with alligator clips (e.g. Digikey.com Part No. 461-1177-ND)
- ✓ Heat-shrink or electrical tape

Circuit:

- ✓ 1 × LM358 Operational Amplifier (low-power, dual op-amp, single supply operation possible, in an 8-pin DIP package)
- ✓ Resistors: 1 × 100 k Ω , 1 × 10 k Ω , 1 × 2.4 k Ω , 1 × 330 Ω , 1 × 100 Ω , all ¼ Watt carbon film such as Digikey.com 100KQBK-ND)
- ✓ 2 × 10 k Ω Potentiometers (e.g. Digikey.com 490-2875-ND)
- ✓ 2 × red L.E.D.'s (e.g. Digikey.com 754-1264-ND)
- ✓ 1 × 9 volt battery

Additional tools needed: power drill, glue gun, soldering iron, digital camera, or cellular phone with a digital camera, and a small screwdriver for adjusting potentiometer (e.g. Digikey.com SPTOOL-ND)

Finger Clip Assembly and Connections

Finger Clip Assembly

When searching for a clip, remembering several criteria will help decide which one is best for this application:

- The clip must be made from an opaque material (to help reduce the interference from ambient light)
- The clip must be able to open wide enough (the wider it can open, the wider variety of fingers it can accommodate)
- The clip must be made from plastic (easy to drill through, yet rugged)



Figure 1. Clips used for experiment.

Begin by drilling two holes on the same leg of the clip, the diameter of the holes will depend on the type of infrared L.E.D. and the machine screw that are used (see figure 2).

Note: For this application, a machine screw will be better than a wood screw for two reasons. First, the machine screw has more threads per inch allowing more control of the pressure on the finger, and second, machine screws usually have a blunt or flat end preventing drilling through the other leg of the clip.



Figure 2. Clip with holes for the placement of the infrared L.E.D. and the pressure adjusting screw.

To minimize even further the influence of ambient light, a black marker may be used to black out the top, bottom, and back part of the photodiode. Figures 3a and 3b show front and rear views of a clear photodiode and a photodiode blacked-out with a black marker.

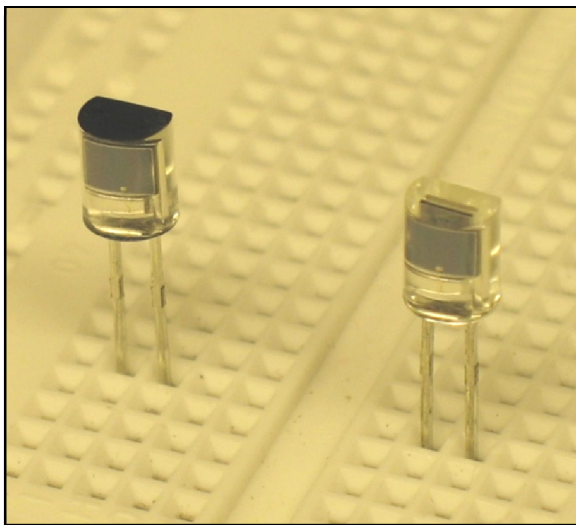


Figure 3a. Front view

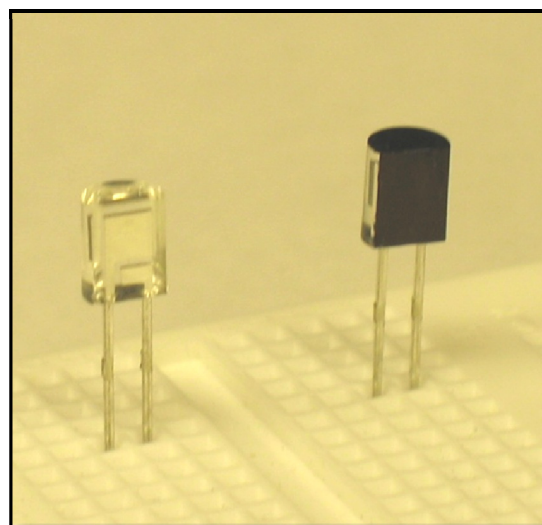


Figure 3b. Rear view

Next, solder extensions to the anode and cathode of the photodiode, this will allow easier connection to the circuit. It is important to use either wire wrap or electrical tape to cover the soldered connections since they will be in close contact with a metal screw (see figure 4).

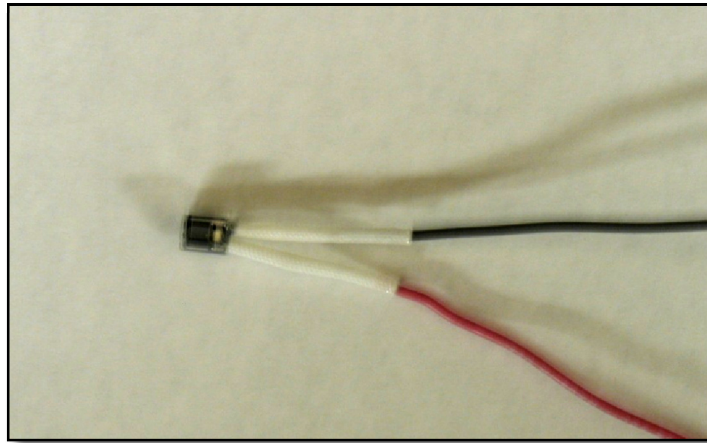


Figure 4. Front view of the photodiode after soldering extending wires.

Now that all the parts have been prepared, it is time to assemble the clip. First, screw in the machine screw to its limit so that the clip is completely open. Next, place the infrared L.E.D. in its hole, and use glue to keep it in place. Before applying the glue, it is important to aim the infrared L.E.D. toward the place where the photodiode will be placed.

Since the human eye cannot detect infrared light, one can use a digital camera (or a cellular phone with digital camera) to aim the infrared L.E.D. before applying glue. This is where a second pair of hands will be helpful with the aiming and gluing of the infrared L.E.D and the photodiode (see figure 5).

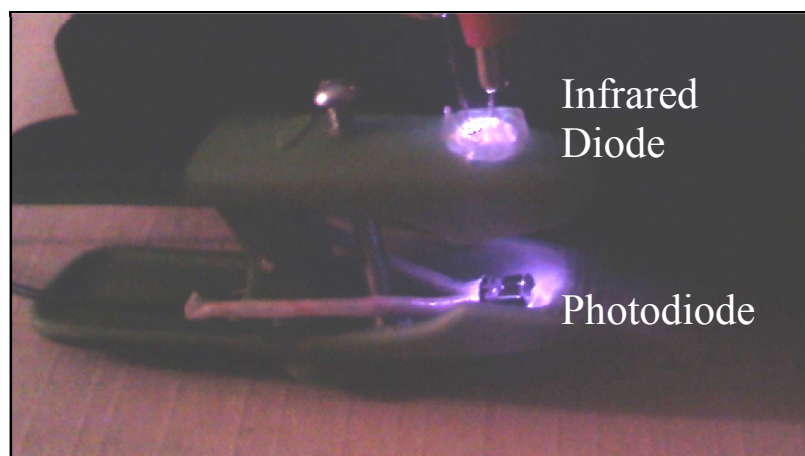


Figure 5. Photograph taken with a digital camera/cellular phone. Notice how infrared light appears as visible light.

This is how the final assembly of the finger clip should look:

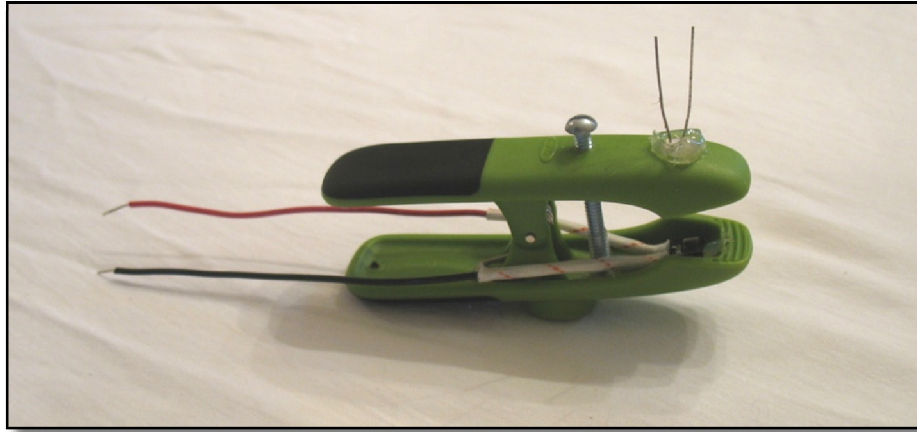
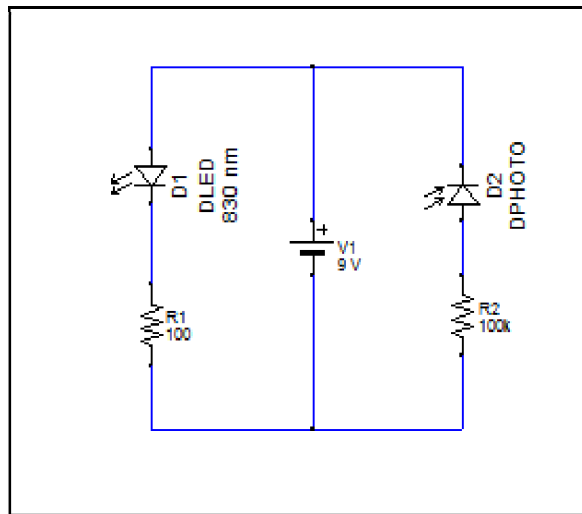


Figure 6. Finger clip with adjusting screw, infrared L.E.D. and photodiode.

Finger Clip Connections

The connections are straightforward: one 9-volt battery will be used to power both the L.E.D. and the photodiode.



Schematic 1 Finger clip connections.

Notice how the diodes are connected: the infrared L.E.D.'s (D_1) anode is connected to the positive rail or the positive terminal of the battery (also called *forward-biased*), and the photodiode (D_2) is connected with the cathode connected to the positive rail (also called *reversed-biased*).

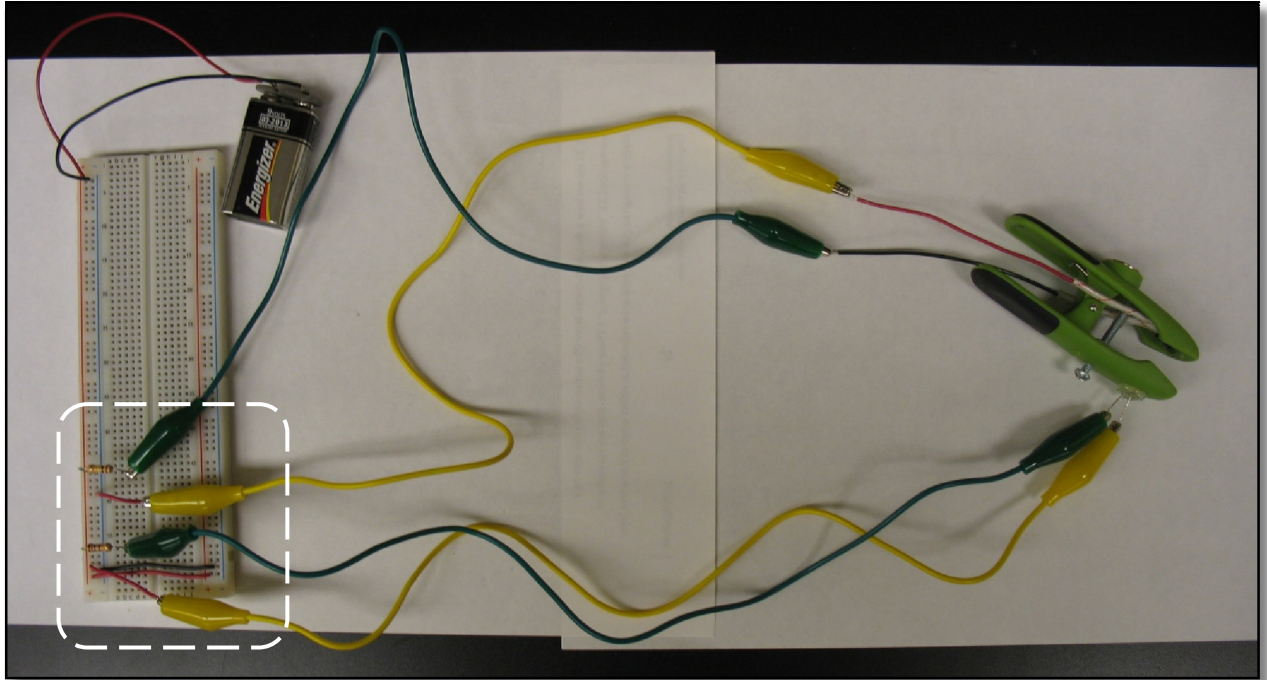


Figure 7. Connections for the finger clip.

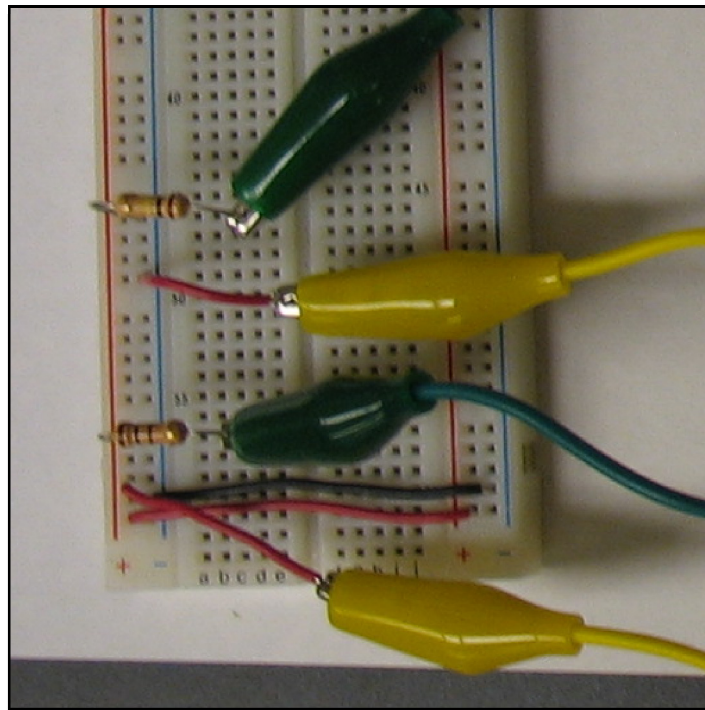
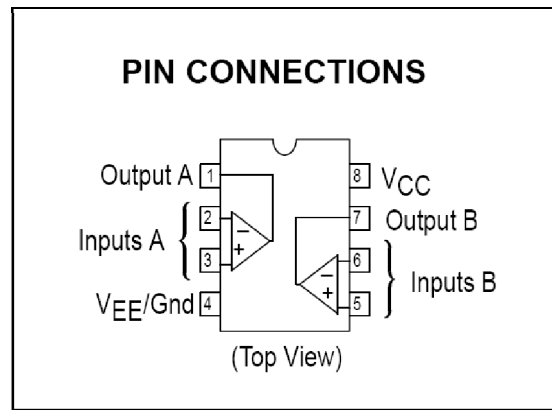


Figure 8. Close-up view of connections.

The Signal Amplifier

Operational amplifiers, or op-amp, are known as the workhorses of analog circuitry. Depending on how one is connected, it can perform many tasks. In this circuit, op-amps will be configured to do two tasks: first, to amplify a signal, then to compare two signals.

Now that there is a signal coming from the photodiode, that signal needs to be amplified if it is to be a usable signal. Since the LM358N has two op-amps in one integrated circuit, it is important to know how the pins are arranged (see schematic 2).



Schematic 2. Pin layout of the LM358N integrated circuit. (Motorola, Inc. LM358/D. Phoenix, Az: Motorola Literature Distribution, 1996.)

Op-amps' basic method of operation is to take the difference of the two incoming signals and to amplify the difference between the two signals. How much the signal is amplified, or *gain*, depends on the values of the resistors on the feedback loop. The feedback loop is the connection from the output fed back into the input; in the present case, it is the connection from pin 7 to pin 6 (see schematic 3). The gain is calculated by the mathematical formula:

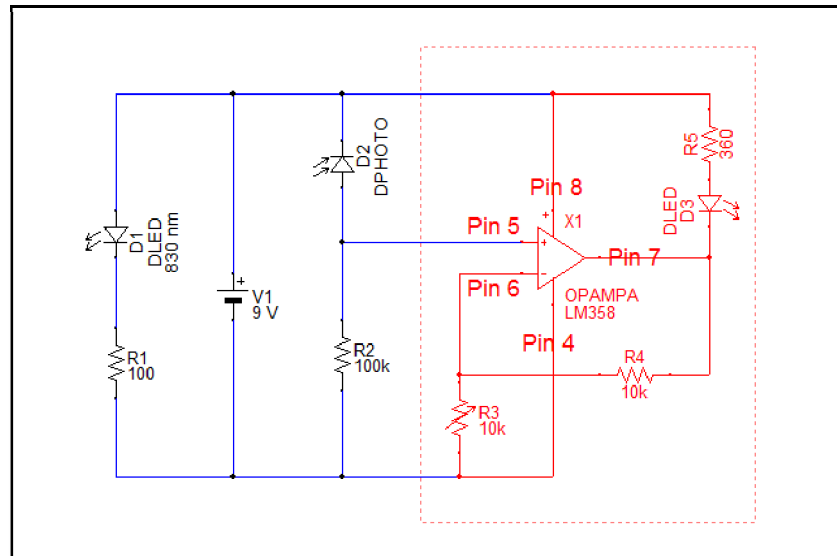
$$Gain = 1 + \frac{R_4}{R_3}$$

Notice that R_3 is a resistor with an arrow through it, this is the symbol for a potentiometer, or variable resistor. In this configuration, this will allow the gain to vary, similar to a volume control on an audio amplifier, for example:

$$Gain = 1 + \frac{R_4 \text{ (fixed)}}{R_3 \text{ (potentiometer)}} = 1 + \frac{10,000 \Omega}{5,000 \Omega} = 3$$

After placing a finger in the clip, the signal coming from the photodiode and going into pin 5 of the LM358 op-amp is approximately between 1.0 and 1.4 volts. This signal varies because it is dependent on the finger used; different fingers will give different levels.

After the signal is amplified, coming out of pin 7, it is in the 5 to 6 volt range. This signal carries the information desired: the human heart beat or pulse.



Schematic 3. The signal from the photodiode (finger clip), is amplified. (Note: Pin 4 is connected to the negative terminal of the battery, and is not connected to resistor R4, nor R3.)

To help regulate the output of op-amp, and to give a visual indicator of the voltage at pin 7, one of the red L.E.D.'s is connected in series with a $360\ \Omega$ resistor (R_5). This L.E.D. will light up when the voltage difference between the top rail and the voltage at pin 7 exceeds approximately 2 volts. Since the top rail is a fixed voltage, and the voltage at pin 7 is variable, the difference between them will vary. Therefore, if the L.E.D. is off, the gain is too high, hence, the voltage from pin 7 is too high, and if it is constantly lit, the voltage from pin 7 is too low, therefore, the gain is too low. Hence, the desired condition is to find just enough resistance from R_3 to find the on/off threshold for the L.E.D. This is done by adjusting the potentiometer until the L.E.D. is just barely on, with the finger in the clip.

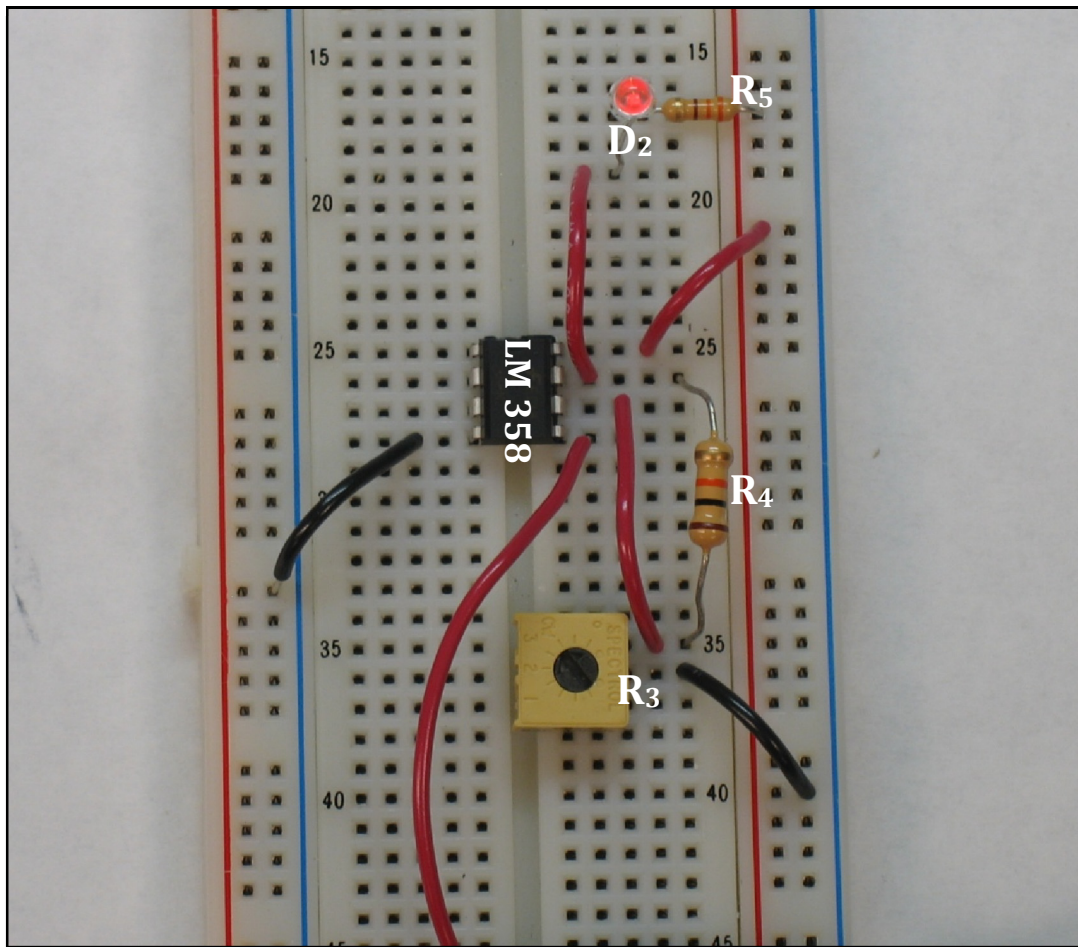


Figure 9. Connections for the amplifier.

The Comparator and L.E.D. output

When an op-amp is operated as a comparator, the gain is then automatically set to maximum; also called the *open-loop gain*. The name *open-loop* gain comes from the absence of a loop or connection going from the output of the op-amp to either input of the same op-amp.

The open-loop gain will vary depending on the op-amp model. The open-loop gain information is usually found on the datasheet of the specific op-amp being used (see figure 10). The LM358N has an open loop voltage gain of 100, which means that whatever the voltage difference between the signals at pin 2 and pin 3 will automatically be amplified by 100, when there is no connection between the output and either input of the op-amp. However, the output will still be limited by the voltage supply; no matter what the gain or input, the output (pin 7 and/or pin 1) cannot be larger than the voltage supply (battery).

LM358, LM258, LM2904, LM2904V														
ELECTRICAL CHARACTERISTICS ($V_{CC} = 5.0\text{ V}$, $V_{EE} = \text{Gnd}$, $T_A = 25^\circ\text{C}$, unless otherwise noted.)														
Characteristic	Symbol	LM258			LM358			LM2904			LM2904V			Unit
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage $V_{CC} = 5.0\text{ V}$ to 30 V (26 V for LM2904, V), $V_{IC} = 0\text{ V}$ to $V_{CC} - 1.7\text{ V}$, $V_O = 1.4\text{ V}$, $R_S = 0\ \Omega$ $T_A = 25^\circ\text{C}$ $T_A = T_{\text{high}}$ (Note 1) $T_A = T_{\text{low}}$ (Note 1)	V_{IO}	-	2.0	5.0	-	2.0	7.0	-	2.0	7.0	-	-	-	mV
Average Temperature Coefficient of Input Offset Voltage $T_A = T_{\text{high}}$ to T_{low} (Note 1)	$\Delta V_{IO}/\Delta T$	-	7.0	-	-	7.0	-	-	7.0	-	-	7.0	-	$\mu\text{V}/^\circ\text{C}$
Input Offset Current $T_A = T_{\text{high}}$ to T_{low} (Note 1)	I_{IO}	-	3.0	30	-	5.0	50	-	5.0	50	-	5.0	50	nA
Input Bias Current $T_A = T_{\text{high}}$ to T_{low} (Note 1)	I_{IB}	-	-45	-150	-	-45	-250	-	-45	-250	-	-45	-250	nA
Average Temperature Coefficient of Input Offset Current $T_A = T_{\text{high}}$ to T_{low} (Note 1)	$\Delta I_{IO}/\Delta T$	-	10	-	-	10	-	-	10	-	-	10	-	$\text{pA}/^\circ\text{C}$
Input Common Mode Voltage Range (Note 2), $V_{CC} = 30\text{ V}$ (26 V for LM2904, V) $V_{CC} = 30\text{ V}$ (26 V for LM2904, V), $T_A = T_{\text{high}}$ to T_{low}	V_{ICR}	0	-	28.3	0	-	28.3	0	-	24.3	0	-	24.3	V
Differential Input Voltage Range	V_{IDR}	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	-	-	V_{CC}	V
Large Signal Open Loop Voltage Gain $R_L = 2.0\text{ k}\Omega$, $V_{CC} = 15\text{ V}$, For Large V_O Swing, $T_A = T_{\text{high}}$ to T_{low} (Note 1)	A_{VOL}	50	100	-	25	100	-	25	100	-	25	100	-	V/mV

Figure 10. Electrical characteristics chart for the Motorola LM358 op-amp (Motorola, Inc. LM358/D. Phoenix, Az: Motorola Literature Distribution, 1996).

Since the signal coming out of pin 7, or the heartbeat signal is a transient signal, a flat, or DC signal needs to be created so that the comparator has a reference point. The DC signal will be used as a threshold to tell the comparator op-amp when to turn on and when to turn off. When the heart signal is below the threshold the comparator will turn off the L.E.D. and when the signal is higher than the threshold, the comparator will turn the L.E.D. on. With the subject's finger in the clip, and with the first L.E.D. barely on, adjust the second potentiometer (R_5) until the L.E.D. (D_4) begins to blink.

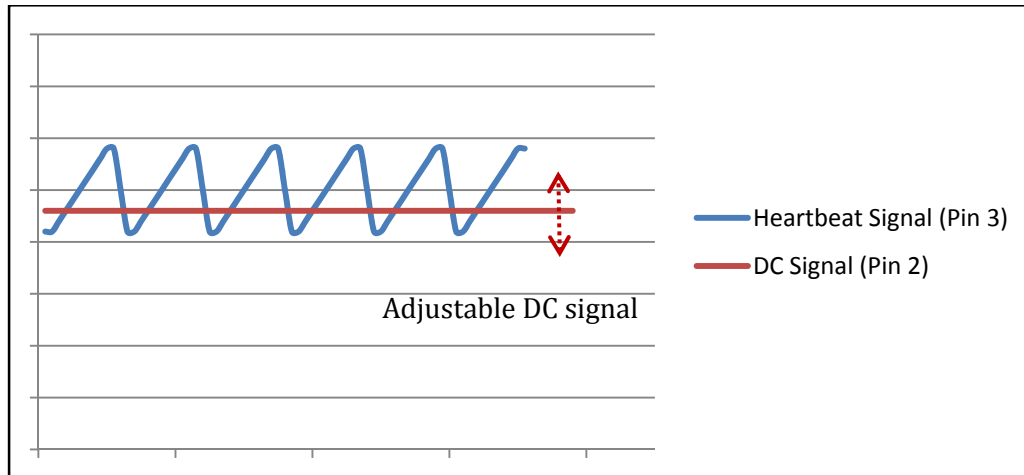
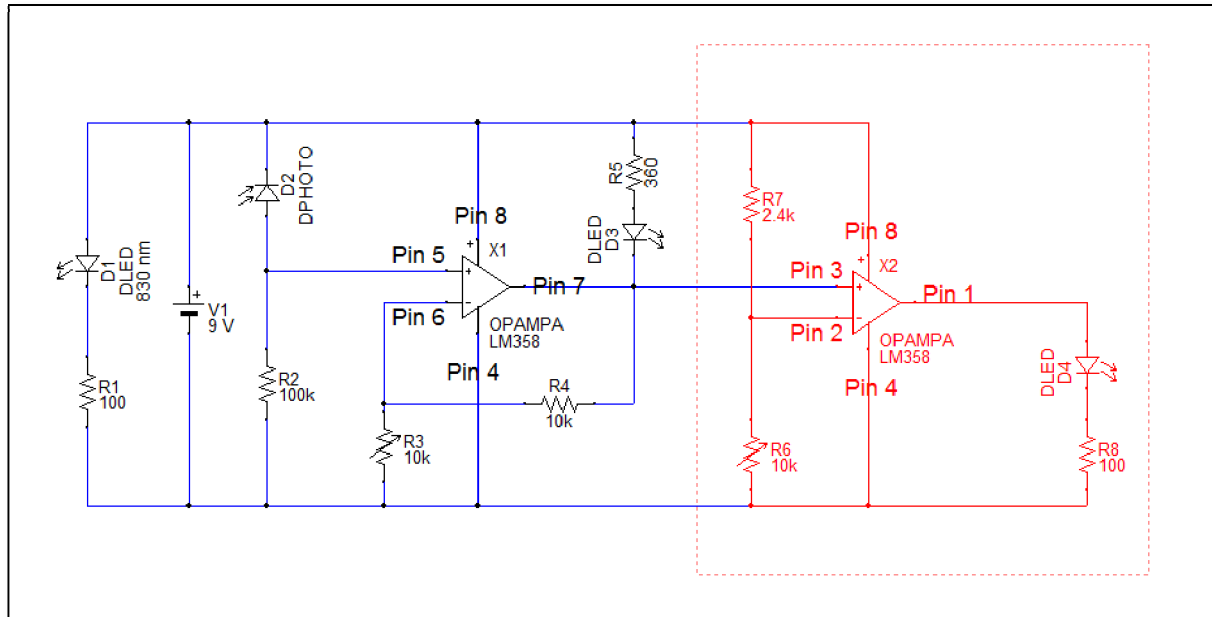


Figure 11. Simulation of signals entering the comparator op-amp.



Schematic 4. After the signal is amplified, a comparator configuration with a "flat" d.c. signal to make the L.E.D. flash. (Note R7 is connected to R6, and not connected to neither pin 3 nor pin 7).

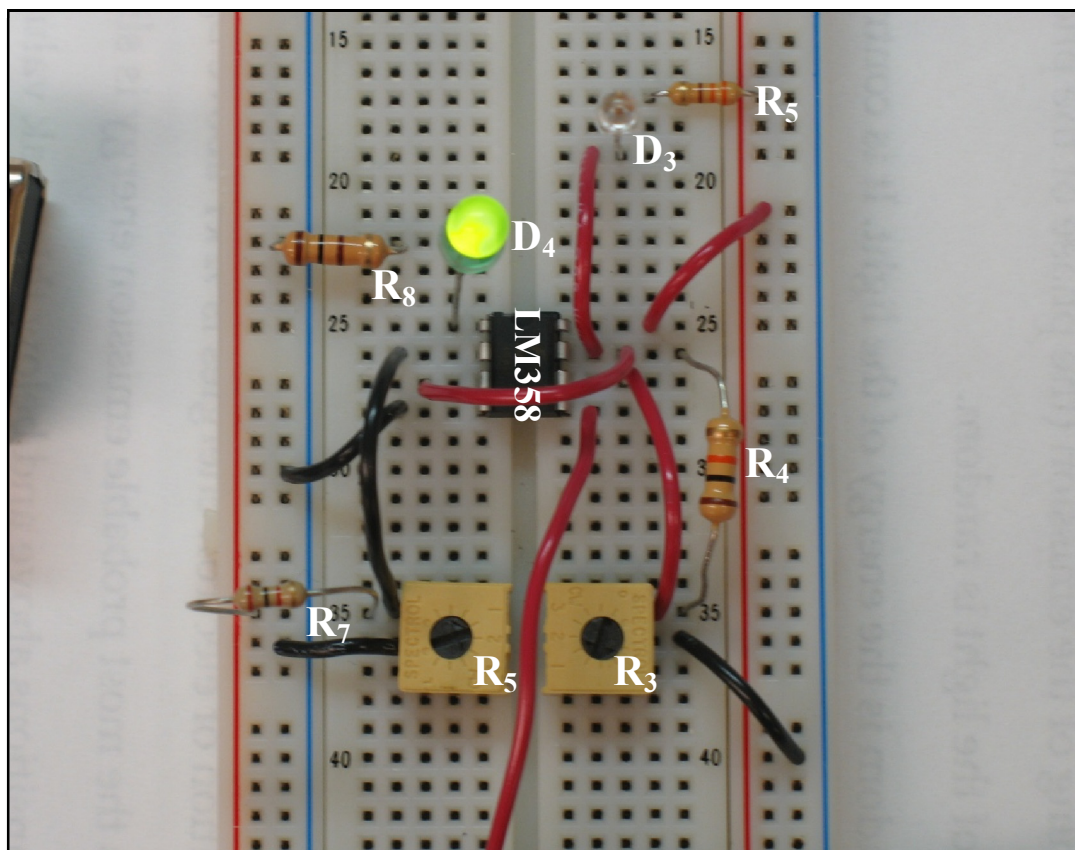


Figure 12. Connections for finished circuit.

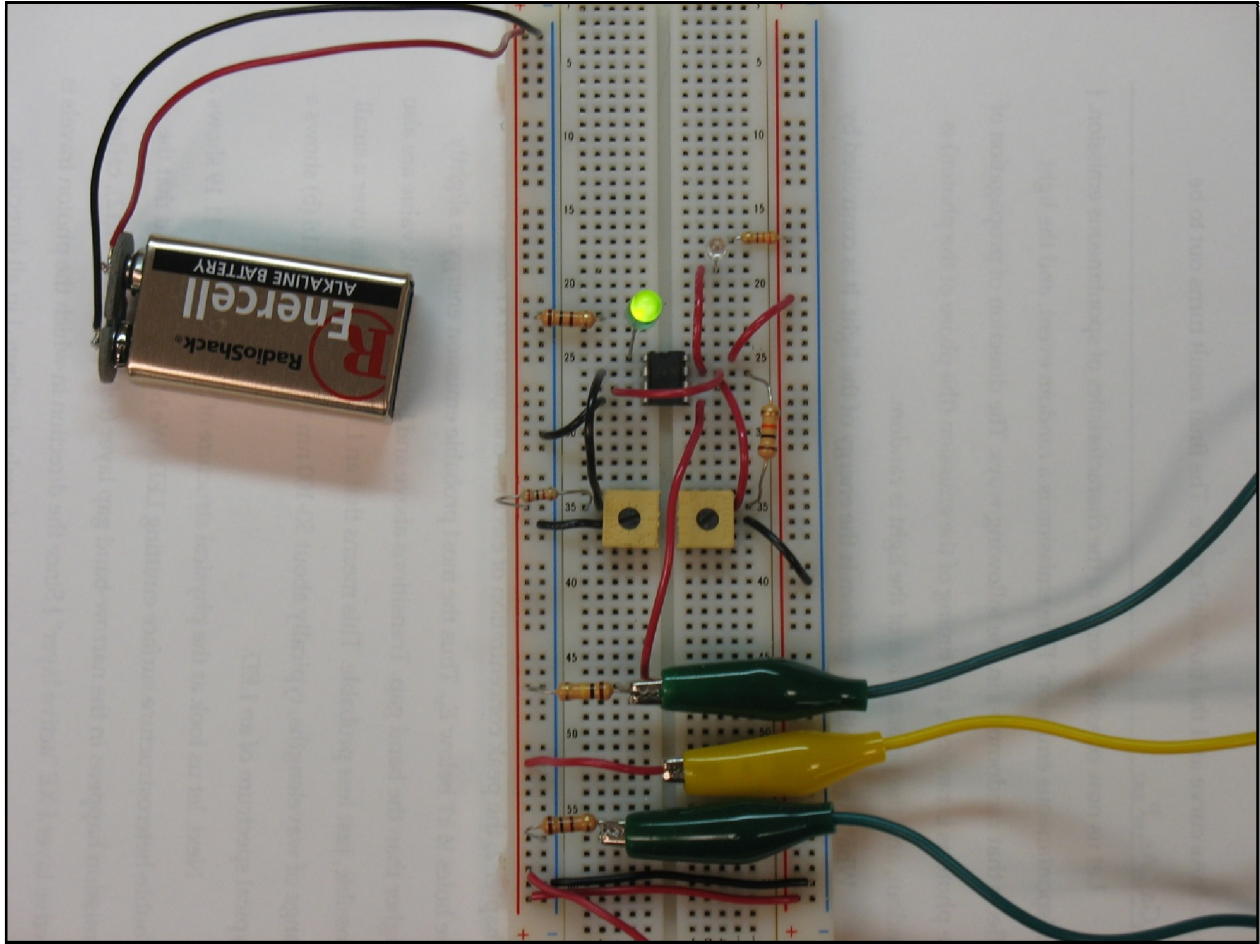


Figure 13. Finished circuit.

Testing and Suggestions

When testing, remember to adjust the pressure on the clip, each finger needs a different amount of pressure: too much pressure, and it will reduce blood flow; not enough pressure the infrared signal will not reach the photodiode. One might find that the index finger might give a stronger signal than the pinky finger, or vice-versa. These are some suggestions prior to testing the circuit:

- Wash your hands with soap and warm water, in addition to cleaning your hands, the warm water and the scrubbing action will stimulate blood flow
- Avoid wearing false nails and nail polish, they block infrared light.
- Another way to stimulate blood flow is by massaging your hands and fingers, or even clapping your hands.

Summary

This experiment was designed and written with the high school senior or college freshman in mind. The pulse sensor is noninvasive, easy to use, and made from items readily available. As a standalone, the pulse detector can be a way to introduce students into electrical engineering, spectrophotometry and to biomedical studies.

This circuit was designed with the intent of accommodating as many body types and finger types as possible; however, one thing to remember is that everybody and every *body* is different.

As a fun experiment, recruit a subject to use the pulse detector, observe the L.E.D. while the subject listens to different types of music of different tempos. What types of music will make their pulse increase and decrease? How will practicing yoga or meditating affect a person's pulse? What about doing exercise?

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Schematic 4. The complete schematic (*highlighted: a comparator configuration with a "flat" d.c. signal to make the L.E.D. flash.*)