engineeringworldhealth

Optical Heart Rate Monitor

Assembly Instructions

Contents

Overview

Devices that measure the heart rate can be found in almost all hospital areas and are important tools for diagnosing and monitoring health issues. Although doctors and nurses can hear cardiac sounds in a patient's chest with a stethoscope, the body's extremities are better location for continuous monitoring, for example, during thorax surgeries. This is possible because even small arteries in the body's extremities expand with the heart's contractions. The small volume variation can be detected with an optical sensor that measures the amount of red light absorbed by the arteries. Figure 1 shows how light reflectance in the human finger is measured by the EWH Heart Rate Monitor Kit to indicate the heart rate. After sampling the signal, the device amplifies the signal and displays the heart beats through outputs such as indicating lights.

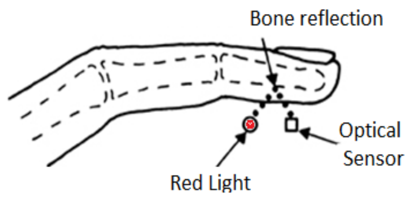
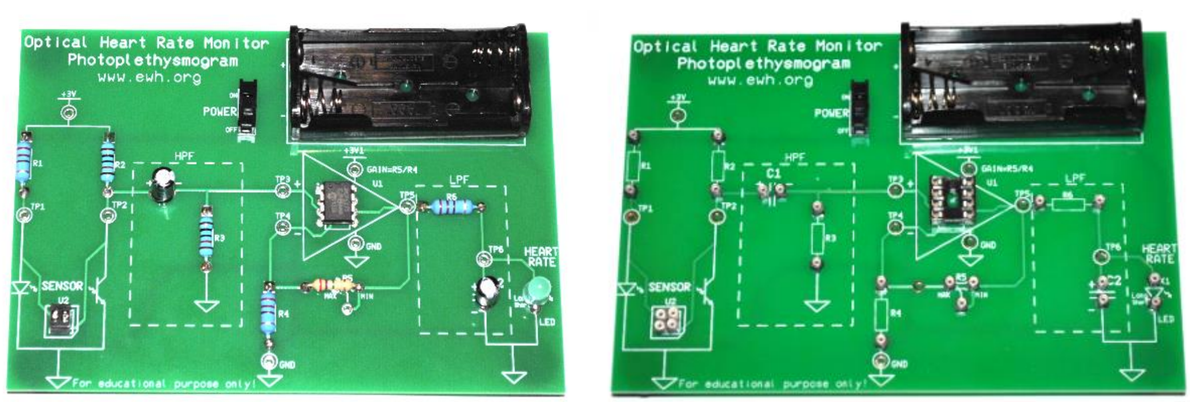


Figure 1 – Photoplethysmography measurement principle of the finger tip.

There are two possibilities to assemble the Optical Heart Rate Monitor kit. The first is to solder all the parts direct on the board as show in Figure 2 (a). The second is to solder only the battery holder, switches and sockets, seen in Figure 2 (b). This last approach allows users to connect and remove the components as many times as desired without soldering and is suitable for middle school, high school and college students activities that require the measure of each circuit block separately. If one loses some of the components, one can order a replacement package with only the resistors, capacitors, amplifier, LED and optical sensor from http://www.ewh.org/students/2013-12-06-15-44-37/stem-kits-prices



(a) (b)

Figure 2 – Optical Heart Rate Monitor kit assembled without sockets (a) for only one lecture and with sockets (b), which allows it be used many times.

Kit Disclaimer

Engineering World Health's Optical Heart Rate Monitor Kit is **an educational tool only and is not to be used for any other purpose, including any medical, diagnostic or other laboratory applications.**

EWH University Chapters may construct Optical Heart Rate Monitor Kits to give students an opportunity to practice hands-on technical skills.

Assembled kits (with or without sockets) can also be returned to EWH's office for re-use and re-assembly in BMET training programs in developing countries such as Rwanda, Cambodia, and Honduras.

EWH tried to choose low-cost components available in resource-poor areas, so that BMETs in training can repair their kits if necessary. Nevertheless, EWH Chapters are welcome to improve the equipment, for example, changing switches or building a case. Thank you for purchasing EWH Kits, which helps EWH improve health care in resource-limited settings by training biomedical engineering technicians and which gives STEM practice to the next generation of engineers.

Important Guidelines

1. Electrostatic discharges

Diodes and "integrated" circuits (ICs or chips) can be damaged by static electricity if not handled properly. This is a heightened concern in cold, dry climates. Even if you do not live in such an environment, you can prevent electrostatic discharge (ESD) by observing the following precautions:

- Keep components in their antistatic protection bags until you are ready to install them.
- Do not touch pins, leads, or solder connections on the boards with your bare hands; always use properly insulated tools.
- Handle the printed circuit board (PCB) only by its edges.
- If available in your laboratory, wear an ESD strap (Figure 3) connected to a proper ground when handling parts. If it is not available, touch some metal object just before handling the electronic components to discharge.

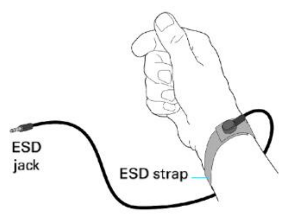


Figure 3 – Electrostatic discharge protection strap.

2. Soldering Techniques

Soldering may be dangerous if you do not use the proper methods; therefore, follow these safety rules:

- Always wear safety glasses when soldering. The solder (the material heated with the iron) gets very hot. Occasionally an air pocket may form and pop as the solder is heated, sending bits of hot solder flying (beware of skin, clothing, eyes, and work surfaces).
- Never solder a live circuit (one that is energized).
- Solder in a well-ventilated space to prevent the mildly caustic and toxic fumes from building up and causing eye or throat irritation.
- Always put the soldering iron back in its stand when not in use. Be sure the stand is weighted or is attached to the worktable, so it doesn't topple over if someone brushes against the cord.
- To avoid the possibility of a fire, never place a hot soldering iron on the work surface.
- Never try to catch a hot soldering iron if it falls. Let it fall, then buy a new one if it breaks — just do not grab it!
- Give any soldered surface a minute to cool before touching it.
- Never leave flammable items (such as paper or clothing) near the soldering iron.
- Be sure to unplug the soldering iron when finished. Never leave a hot soldering iron unattended.
- Do not touch the solder too close to the pin connection; it may get hot and burn your finger.

There are some basic soldering techniques required to create good joints. Figure 4 shows some soldering problems that result in a bad electronic connection. Insufficient wetting may occur if there is not enough solder applied to the pin/pad. If all metal surfaces are not brought above the melting temperature of the solder in use, the result will be an unreliable "cold solder joint," which sometimes looks normal, but causes contact issues.

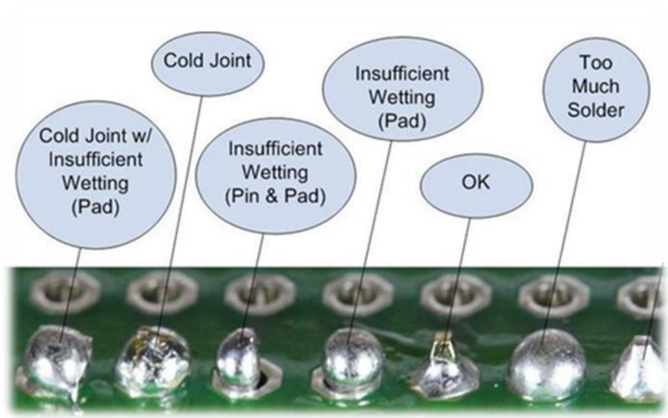


Figure 4 – Common soldering problems and their causes.

The first and most important rule when soldering is to ensure there is a secure mechanical connection to the Printed Circuit Board (PCB) before soldering the component to the board. The solder is for an electronic connection only and should not be depended upon for mechanical attachment.

The second rule is to heat the electronic connection first, NOT the solder. Once the joint is raised to a sufficient temperature, touch the pin side (opposite to the soldering iron) with the solder, so it will liquefy and flow into the hole (Figure 5).

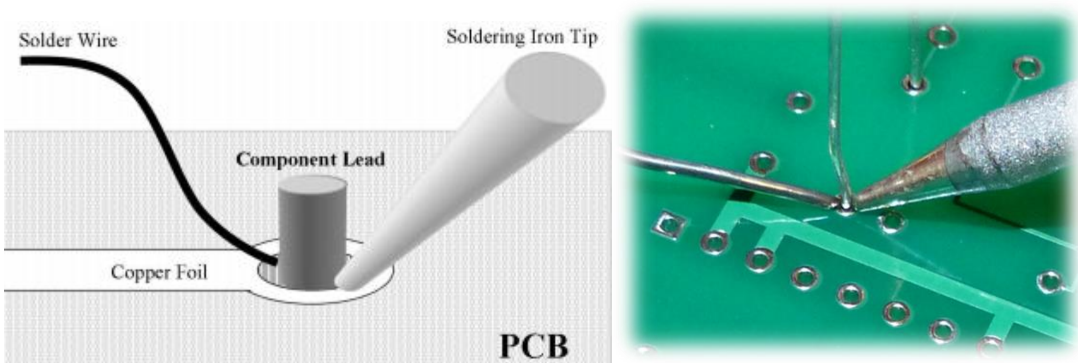


Figure 5 – Correct heating of component lead and hole, touching solder to joint and not the soldering iron.

Then gently pull the iron and solder away to allow this area to cool down. As the temperature lowers, the remaining solder changes from the liquid to the solid state. The resulting shape should be similar to a volcano, as shown in Figure 6.

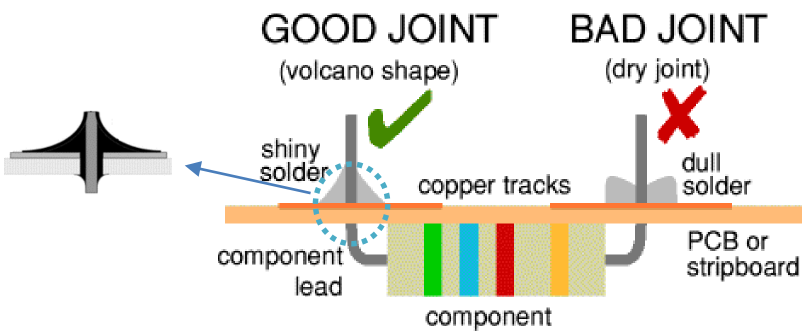


Figure 6 – Cross section view of the PCB in the soldering point.

For a neat appearance in your assembly, solder only one pin per component initially. Then turn the board over and check to see that the component is still mounted flush with the board. If there is a problem, you can carefully reheat the single pin and move the component.

In addition to these instructions, there are many tutorials online that can help improve your soldering technique, such as:

- http://www.youtube.com/watch?v=I_NU2ruzyc4
- http://www.youtube.com/watch?v=eU4t0Yko9Uk (for a more detailed explanation of the science behind soldering technique)

Tools List

To assemble the Kit, you will also need the tools and materials listed in Table 1. These items are not included in EWH's package and need to be purchased separately.

Table 1 – Tools and materials necessary to assemble the Optical Heart Rate Monitor (NOT included in the Kit package).

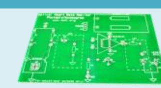
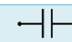
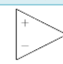
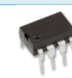
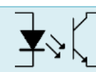
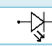
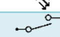
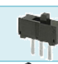
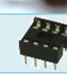
Description	Image
Soldering iron	
Solder	
Eye goggles	
Cutting pliers	
Long nose pliers	
2 x **1.5 V AAA batteries**	

Parts List

*** Do not remove parts from bags (especially the resistors). Remove each component from its bag when it is time to install each one individually.**

In addition to the printed circuit board, the EWH Optical Heart Rate Monitor package should contain 13 small bags with the parts listed in Table 2. This parts list is very helpful when assembling your kit. We suggest printing it out so you can easily reference it as you build the kit.

Table 2 – Optical Heart Rate Monitor Kit part list.

Description	Value	Quantity	Schematic ID	Schematic Symbol	Image*
Printed Circuit Board	N/A	1	N/A	N/A	
Resistor	220 Ω	3	R1, R4, R6		
Resistor	10 kΩ (10,000 Ω)	2	R2, R3		
Resistor	2.7 MΩ (2700,000 Ω)	1	R5		
Capacitor	10 µF (0.00001 F)	2	C1, C2		
Operational Amplifier	MCP6273	1	U1		
LED + Photodetector	OPB608R	1	U2		
LED	3 mm green	1	X1		
Switch	N/A	1	S1		
Battery Holder	N/A	1	N/A	N/A	
PCB Rubber Feet	N/A	4	N/A	N/A	
One Pin Socket	N/A	23	N/A	N/A	
Socket for Amp Op	N/A	1	N/A	N/A	

***Component color and shape may change according with supplier availability; images are for illustrative purposes only.**

Figure 7 shows how to identify the value of the components in each bag. Do not remove them from the package until you read the "Assembling steps" section. Each bag is carefully labeled for the parts that are inside, and removing them prematurely will make identifying them a challenge. Please contact EWH (+1 919 682 7788 or kits@ewh.org) if any parts are missing.

Figure 7 – Component description in value on the bag label.

Printed Circuit Board

1. Top layer

Figure 8 shows the top of the Printed Circuit Board, where all parts will be inserted. This PCB is a two-layer through-hole board with plated through vias, which are little holes where the component pins go through. To assist in placing the parts, there are silk-screened symbols and textual information printed in this layer. These references are also found in the schematic diagram and parts list.

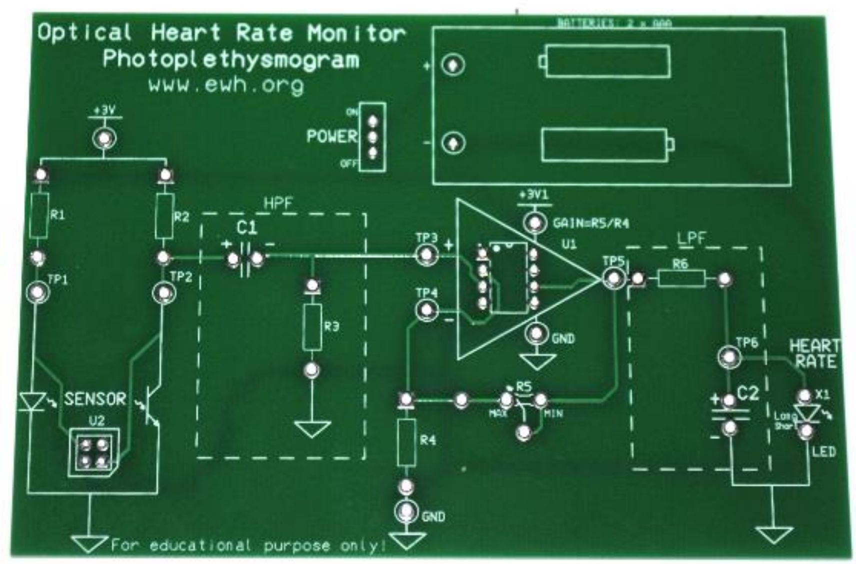


Figure 8 - Top of the bare printed circuit board with silkscreen marks to assist in placement of the electronic parts.

The circuit is powered by two AAA batteries of 1.5 V, which can be attached to the right-top region of the board in the holder. Figure 8 shows the + symbol on the left most circuit trace. This via runs from the positive side of the batteries to the board POWER switch. The - symbol connector corresponds to the negative polarity, which is the current return path. Although it is sometimes called ground (⏚), in reality, this device has no direct connection to the earth; therefore, it should be named (floating) common (▽).

2. Bottom layer

The bottom side of the board, shown in Figure 9, is where the components will be soldered. Note that the thicker via corresponds to the floating common ground track, which is connected to negative contact of the battery.

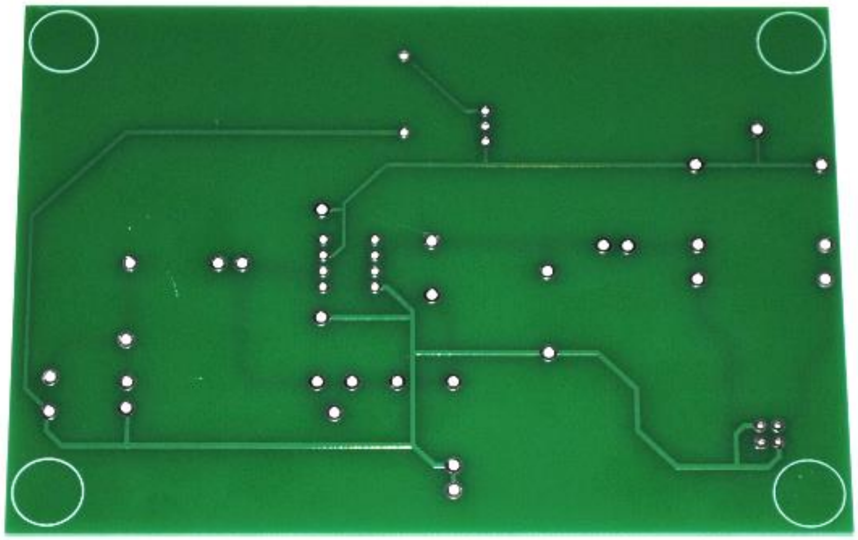
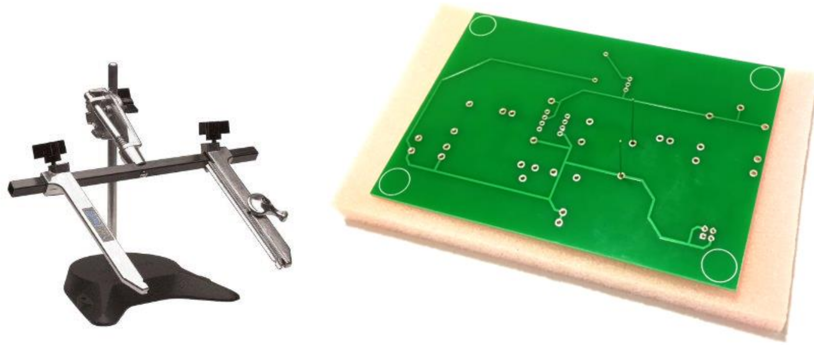


Figure 9 - Bottom layer of the bare PCB; the thicker via corresponds to the floating common, which is connected to the negative contact of the battery.

The physical layout of the PCB often must conform to other mechanical, thermal, electronic, or even electromagnetic requirements. Look carefully at the kit's bare board, to see that many of the digital signals cross analog signal lines at right angles. This physical layout helps decrease electronic noise coupling.

3. Board mechanical support

The clamp in Figure 10 (a) is called a "Panavise." It acts as a third hand to stabilize the board for soldering during assembly. If it is not available, a large, dry kitchen sponge will also give a good support; see Figure 10 (b). It presses the components flush with the board as their pins are soldered from the other side.



(a) (b)

Figure 10 - Panavise assembly circuit board holder (a) and PCB support on a dry sponge (b).

Schematic Diagram

Figure 11 shows a diagram of the Optical Heart Rate Monitor with the electronic interconnection of components. Notice that most drawings have identifiers (C1, C2, U1 etc.) next to them. The letter "C" followed by a number is mostly adopted for capacitors. Next to these designs, you will also see a numeric value such as 10 µF. These numbers provide the amount of capacitance in this particular element. For instance, C1 10 µF corresponds to the part whose identification is "C1" and has 10 micro farads of capacitance. All other components are described in the parts list section.

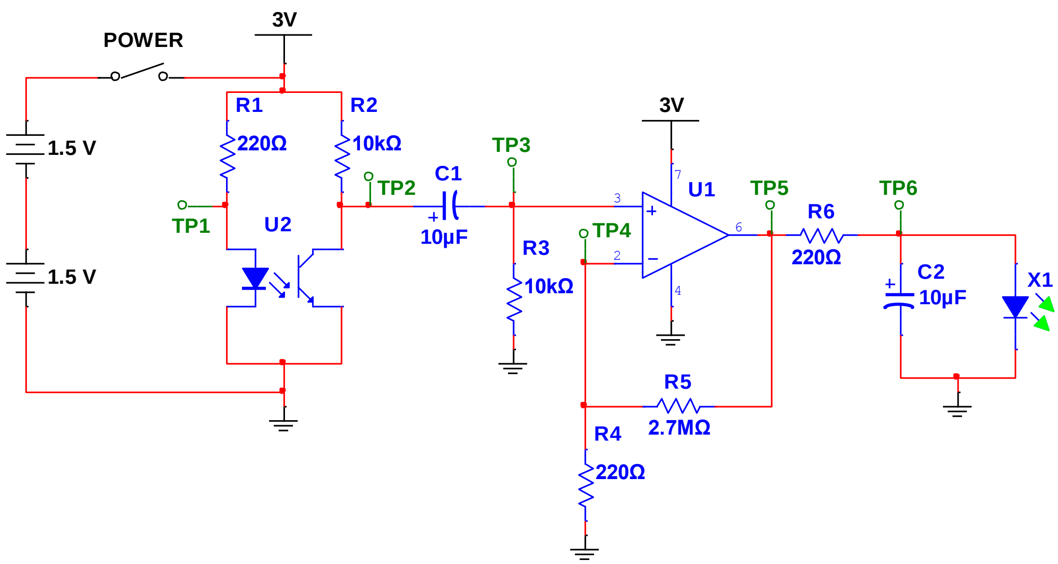


Figure 11 – Optical Heart Rate Monitor electronic schematic diagram.

Electronic elements such as capacitors (C) and resistors (R) are classified as "discrete," for they can perform only one function. On the other hand, there are "integrated" circuits (ICs or chips) that contain many individual parts within them that can perform complex processes. The Optical Heart Rate Monitor board has two of these chips: U1 and U2.

Frequently on a schematic diagram, supply voltages are on top of the page or component, and common or reference returns are on the bottom of the page or component. Signal flow is often left to right across the board's schematic.

Notice: there is a difference between the schematic diagram and the actual physical layout of the PCB itself. For example, on the schematic, the batteries appear in the left corner of Figure 11, near the POWER switch. On the board, the actual battery connector is in the upper right corner. This practice is common. The schematic is meant to show the logical, electrical, or electronic interconnection of the components to help explain the function of the circuit.

Sockets Assembling Steps (Reusable kit option)

Using sockets allows instructors to teach students about each circuit block separately. After the sockets are soldered to the board (a one-time task), components can be placed and removed from the board as many times as necessary without the need for additional soldering.

First, solder all the sockets in the positions shown in Figure 12.

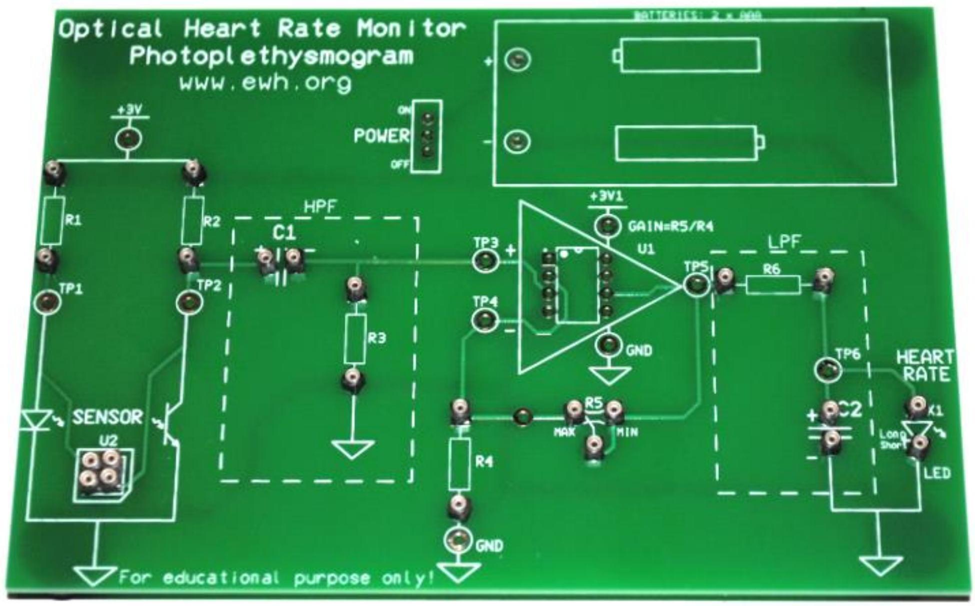


Figure 12 – Sockets placement on board.

Next, solder the amplifier socket in position U1, as shown in Figure 13.

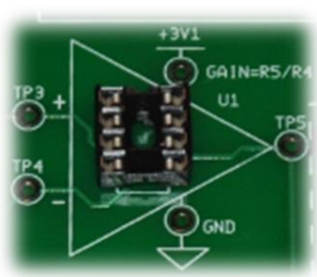


Figure 13 – Amplifier socket placement on board.

In order to finish the reusable board assembling, please solder the electromechanical components (battery holder, switch and rubber feet) as shown in item 3 of the "One-time Assembly Steps" section. This option allows instructors to reuse the board many times, teaching how each block works separately since students can remove each part and see the changes in the circuit behavior.

One Time Assembling Steps

Before beginning to assemble the Optical Heart Rate Monitor, organize your workspace and components. Do not remove parts from bags. Remove each part from its bag when it is time to install each one individually.

A physical assembly constraint to think about would normally include the order in which components are soldered to the PCB. With this kit, there is plenty of room, so there should be no issue placing the components, no matter which parts you start with. However, it is still a good idea to have some logical plan and pre-identify all of the parts before installation.

An electronic component may be classified as passive, active, or electromechanical. Electromechanical components can carry out electrical operations by using moving parts or by using electrical connections. Active components, such as diodes and ICs, rely on a source of energy and usually can inject power into a circuit. Passive components cannot introduce net energy into the circuit. They include two-terminal components such as resistors and capacitors and are easier to assemble.

1. Passive components

Resistors are a good choice to start with, if the person assembling is practicing soldering for the first time. They are relatively flat and close to the board, easy to identify, and will tolerate a large amount of heat. In case you mixed these parts, you can identify the resistance value through color bands printed around their body, shown in Figure 14.

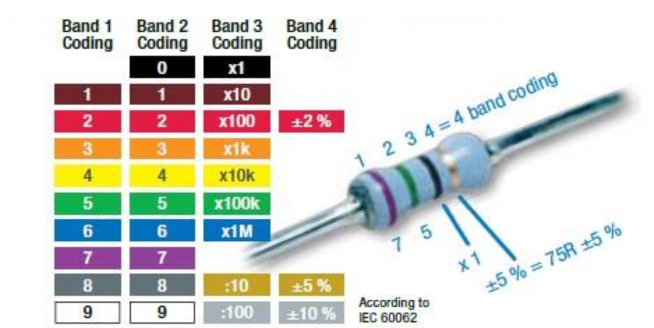


Figure 14 – Resistor color code identification chart.

Note: resistors R1, R4, and R6 are all 220 Ohms. Thus, all will have the same colored bands printed on them.

After identifying each component position on the PCB, you can assemble the part following instructions.

Table 3 – Components assembling steps for Optical Heart Rate Monitor parts.

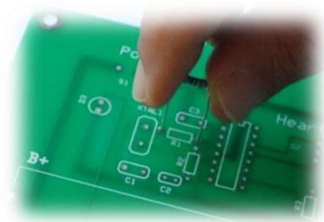
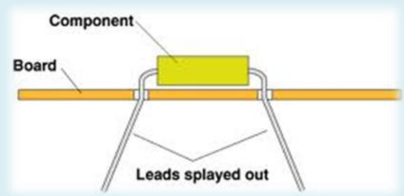
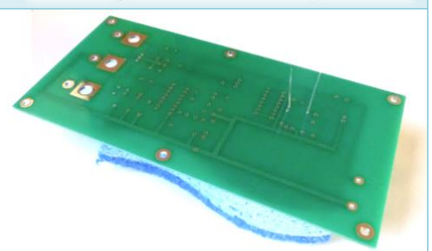
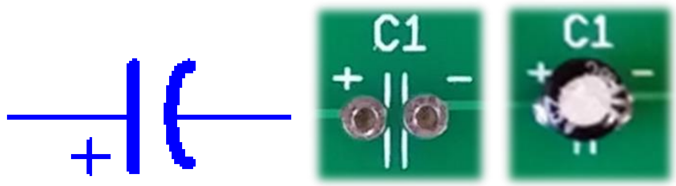
Component Assembly Steps		
1	**Bend the component wires 90º.**	
2	**Insert component pins into corresponding holes on circuit board. The resistor must rest on the top, labeled side of the board.**	
3	**Gently bend the leads under the board when installing to get a good mechanical connection.**	
4	**Turn the PCB over so that the component is face down and the wires are exposed.**	
5	**Solder each component leg to the board.**	
6	**Using the wire cutters, cut the excess length of resistor wires as close to the board as possible.** ***Protect your eyes from wire pieces that may fly from the board!***	

Figure 15 shows the resistor's symbol, silk screen drawing and the correct placement on the PCB.

(a) (b) (c)

Figure 15 – Resistor (R6) schematic symbol (a), silk screen (b) and chip placement (c).

After assembling all the resistors, the next step is placing the capacitors (Figure 16). These components have electrolytic technology and, therefore, only work properly if connected in the right polarity. Pay special attention to connect the longest wire of the capacitor in the positive (+) contact.



(a) (b) (c)

Figure 16 – Electrolytic capacitor (C1) schematic symbol (a), silk screen (b) and chip placement (c); these kind of capacitors have polarization restrictions.

2. Active components

Now install the Light Emitting Diode (LED). Figure 17 shows its symbol, silk screen drawing and placement. If an LED is installed with the wrong polarity, it will not turn on or might even burn out. Be careful to install this component correctly on the "X1" position of the board. The anode (positive voltage) should be placed toward the upper side of the board and the cathode (negative reference) toward the lower side.

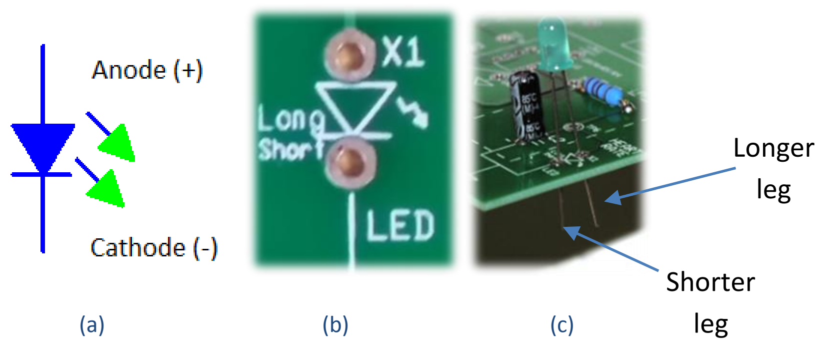
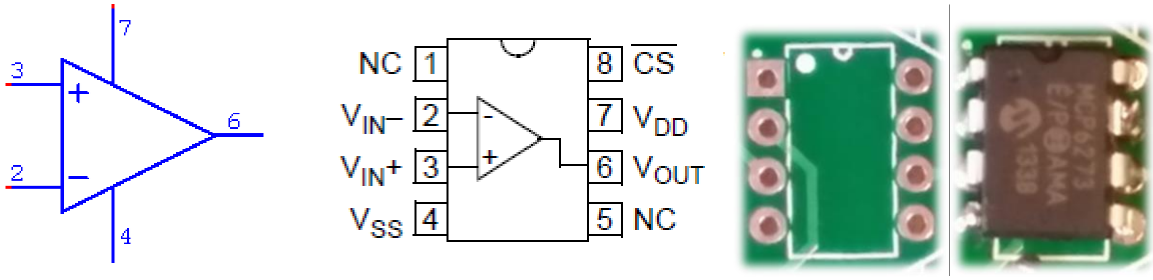


Figure 17 – Light emission diode (LED) schematic symbol (a), silk screen (b) and placement (c).

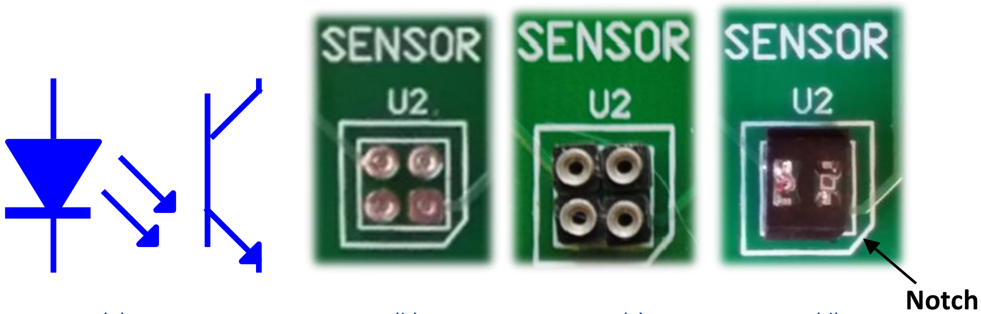
Next, install the amplifier integrated circuit (U1) on the board; Pay attention to place these components in the right polarity! The wrong pin layout on the PCB may burn the part since VDD (+ 3 V) and VSS (0 V) would be inverted. Figure 18 shows the amplifier symbol, silk screen drawing and the correct placement on the board.



(a) (b) (c)

Figure 18 – Integrated Circuit schematic symbol (a), silk screen drawing (b) and chip placement (c).

The next integrated circuit (U2), in the same package, has an LED that serves as an optical sensor. Therefore, it is important to insert it with the right polarity. One corner of the sensor is notched, so it does not form a sharp, right angle corner, as shown in Figure 19. The notched corner must match the diagonal, trimmed corner of the silk-screened box on the board. If the sensor legs are bent, it may be difficult to place in the board holes. One option is to solder the four sockets.



(a) (b) (c) (d)

Figure 19 – Optical sensor symbol (a), silk screen outline drawing (b), socket (c), and chip placement (d).

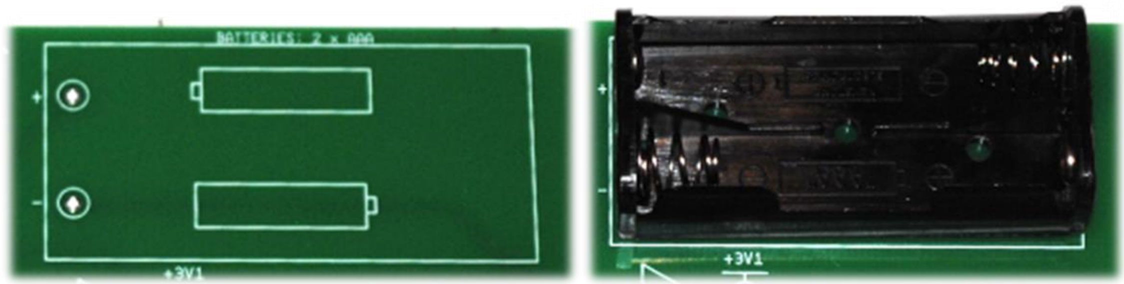
3. Electromechanical components and PCB Support

The only parts left to solder are electromechanical. The first is the power slide switch in Figure 20.

(a) (b) (c)

Figure 20 –Slide switch symbol (a), silk screen drawing (b) and placement (c) in the power position.

The final part that needs to be soldered is the holder for the AAA batteries, shown in Figure 21.



(b) (b)

Figure 21 – Battery holder (a) silk screen and (b) placement.

The kit also includes four rubber feet to be placed underneath the corner holes as shown in Figure 22.

Figure 22 - Rubber feet to be placed underneath the corner holes.

Figure 23 shows the assembled Optical Heart Rate Monitor Kit. The next section shows the steps to follow in testing your circuit.

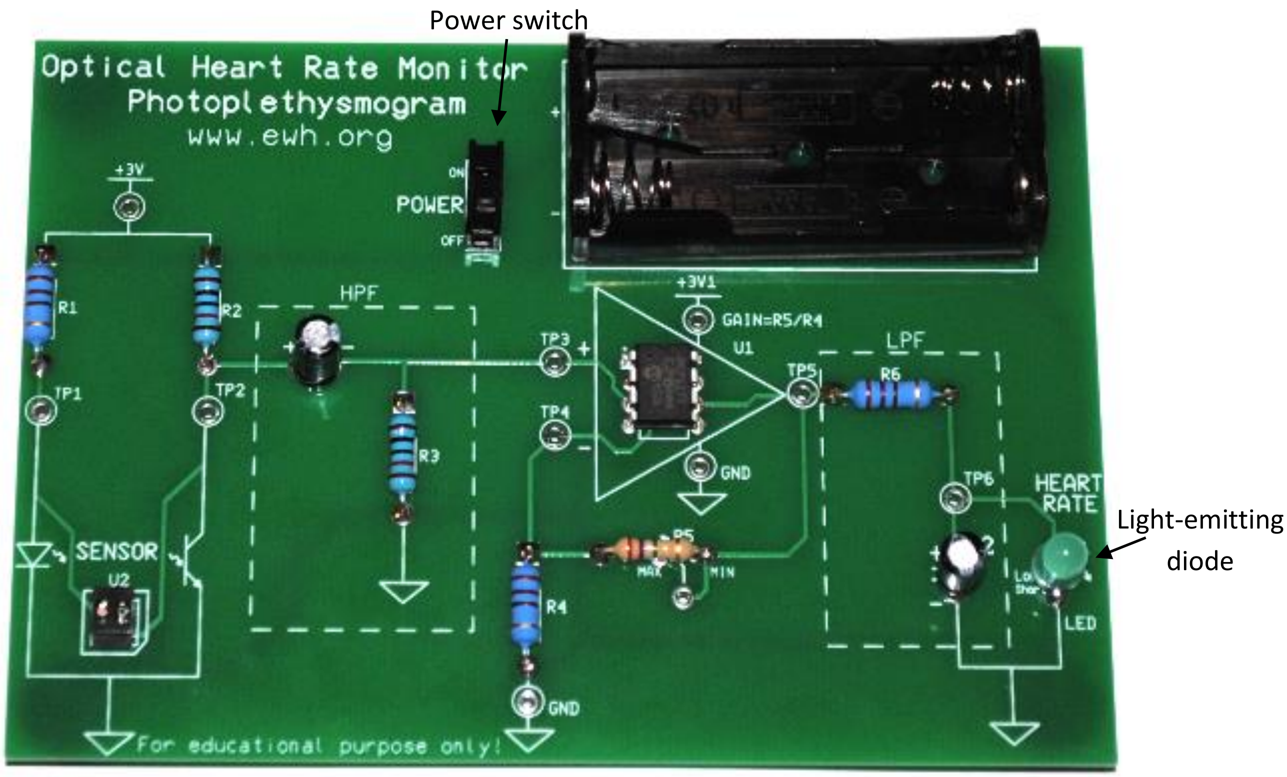


Figure 23 – Optical Heart Rate Monitor Kit after assembly.

Testing Instructions

Figure 24 shows the kit block diagram and signals. The sensor measures optical information from many tissues such as skin and muscle, but only the small arteries volume change is important for our measurement. Therefore, one needs to separate the small waves through the detector (filter) and increase the pulse level with an amplifier. The resulting signal is strong enough to make a green light blink every time the heart beats.

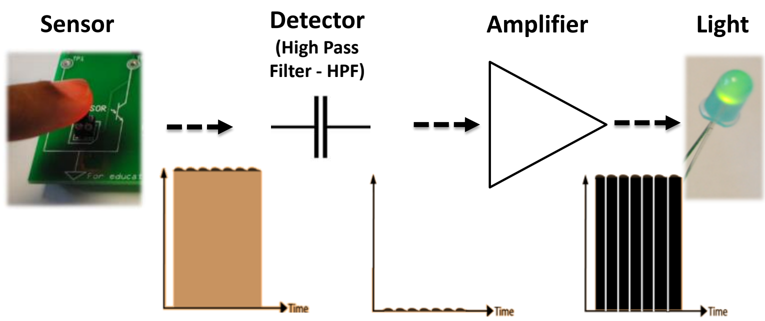


Figure 24 – Heart Rate Monitor block diagram and signals.

To test the circuit, connect the two AAA batteries in the holder and turn ON the board. Place the index finger of your left hand on the sensor (Figure 25). The circuit works better if your elbow and all fingers lay on the table. Use your right hand index finger to feel your heart pulse in your neck. When the heart beats, the sensor detects the volume change in the small arteries of the finger tip. This information (wave) goes through the detector (filter) and is amplified, lighting the green LED with each cardiac pulse.

Figure 25 – Heart Rate Monitor fingertip measurement, the circuit works better if your elbow and all fingers lay on the table.