2023-24 Reverse Engineering Online Challenge

Medicine, Light, Technology: Disassembly of Finger Oximeter

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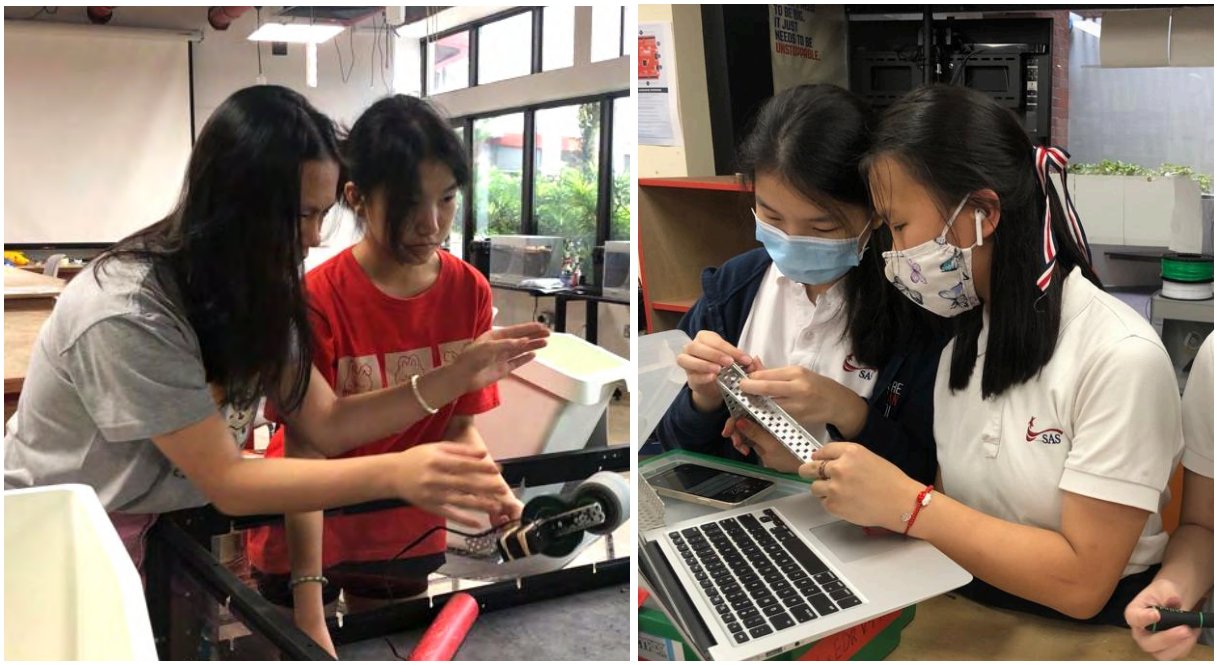
1. Introduction

"Hey isn't that the thing that shoots a laser through your finger?"

One of our team members curiously asked while we were trying to sort through a pile of old masks and COVID tests. We all started getting flashbacks of the pandemic; everyone had a different experience with the global emergency. Locked in rooms, strict quarantines, and the government tried to help by passing out these finger oximeters. Most of us tossed it to the side, overlooking the importance of a finger oximeter. After reaching out to healthcare workers in our community, we learned how crucial a finger oximeter could be in one's life.

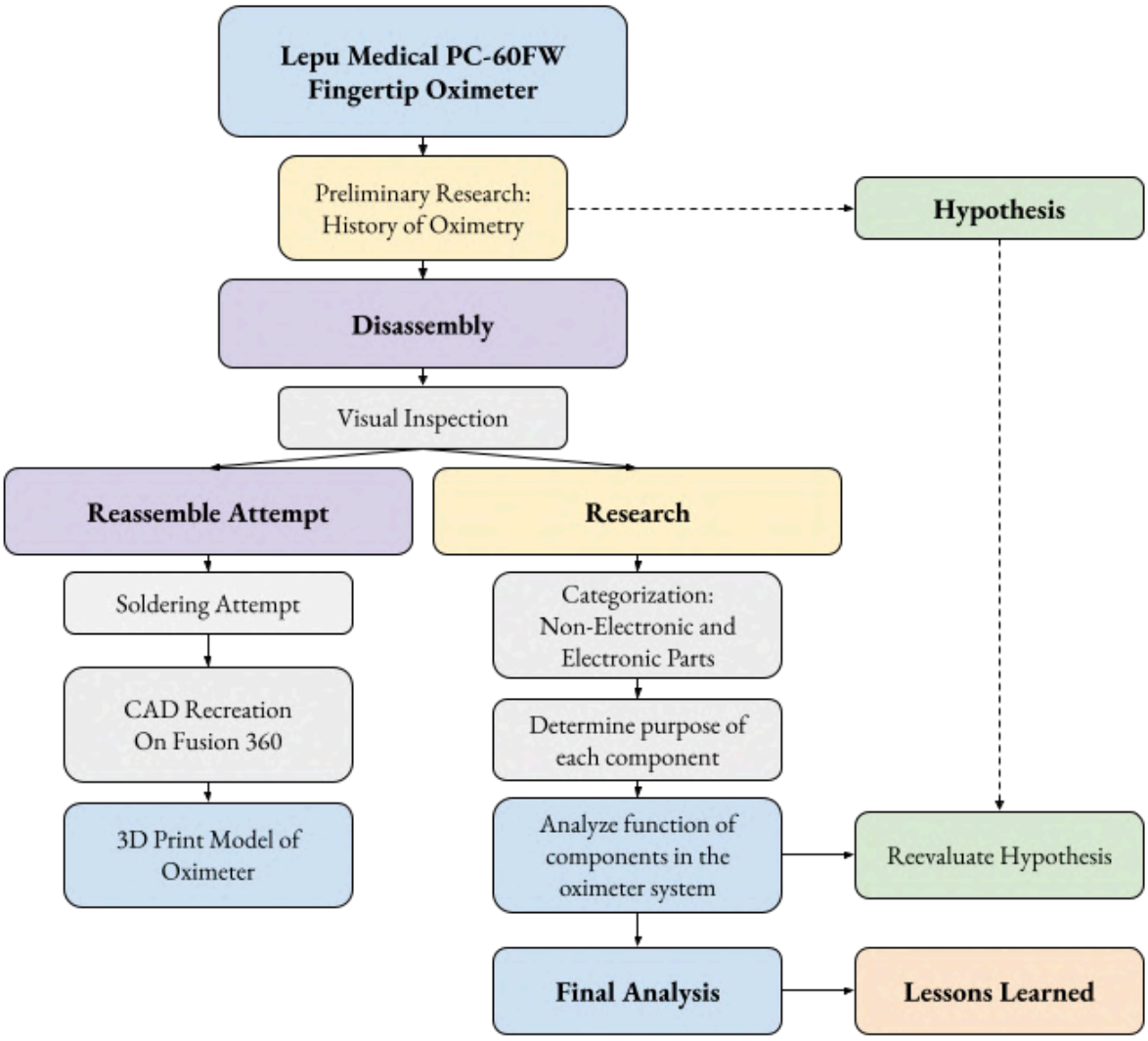
"It is the first step to see if a patient needs medical intervention."

Yet, we knew it as the thing that could "shoot lasers." If it is such a significant part of the medical field, we knew staying clueless was not the way to go. Together we formed a plan — one to figure out **how the finger oximeter works, and why it matters.**

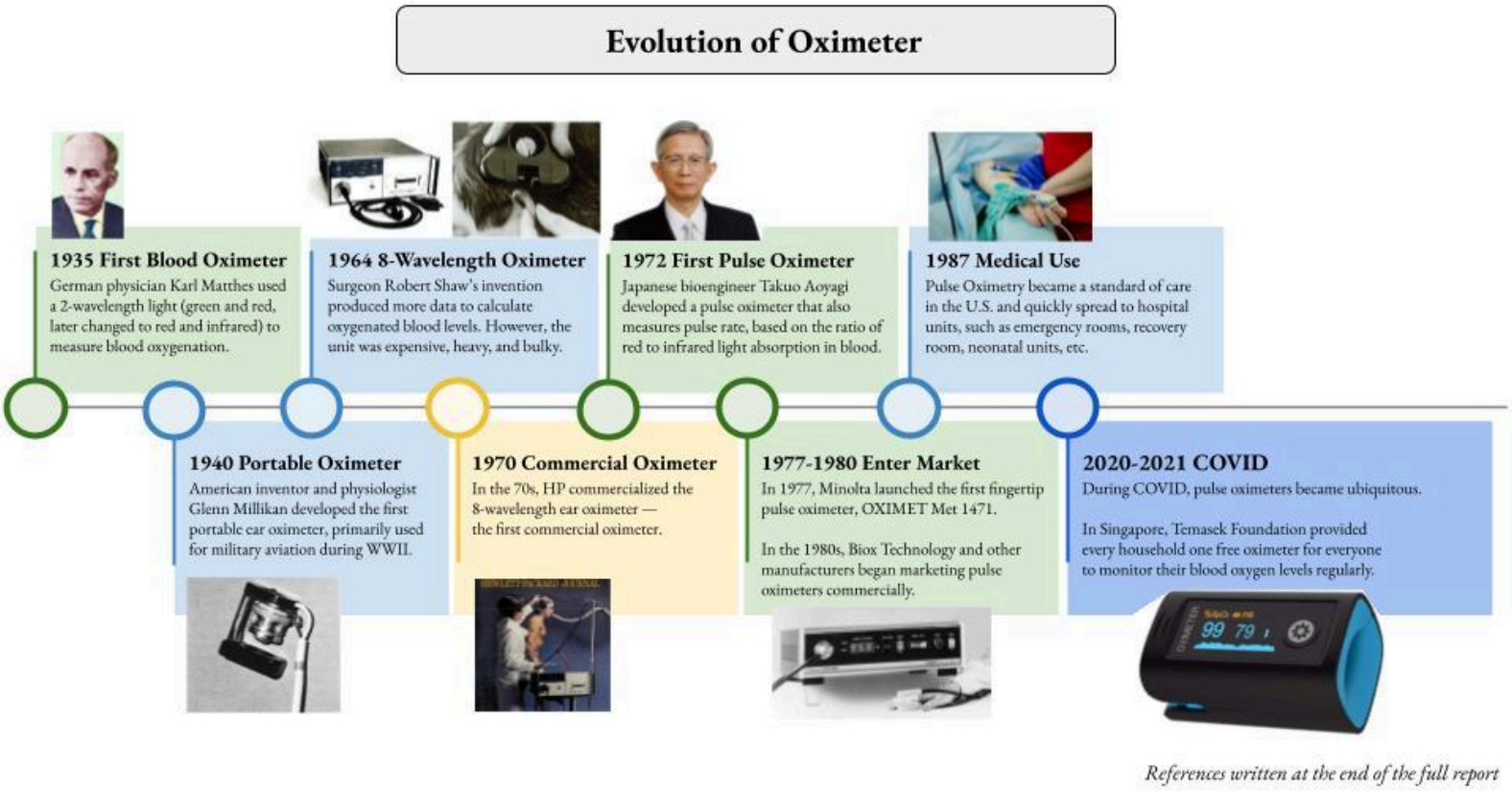


Photos of Adriana and Yoyo working together

2. Preliminary Planning and Research



Evolution of Oximetry



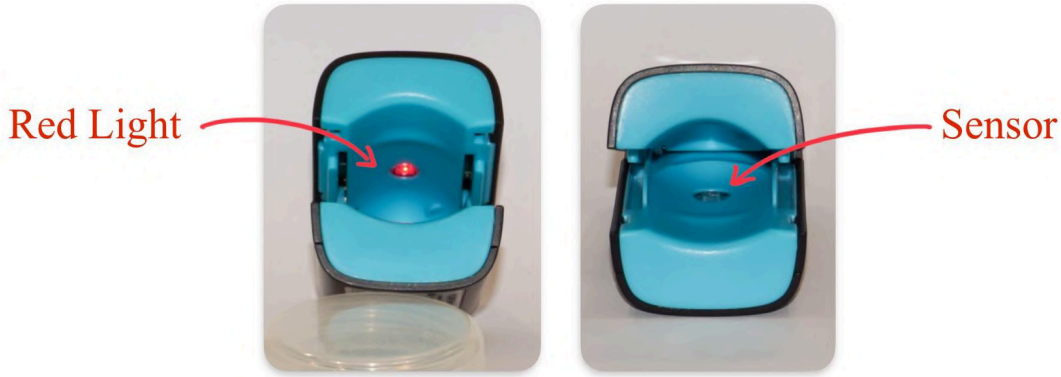
References written at the end of the full report

Our Product Model

Temasek Foundation Fingertip Oximeter PC-60FW by Lepu Medical
- Measures blood oxygen level and pulse rate
- Up to 12 groups of records can be stored in the record list
- Splash-proof and drop-resistant
- Four-direction display

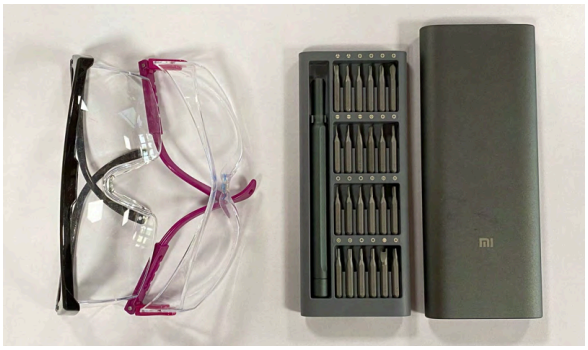
Hypothesis

We hypothesize that the red light shined on our fingers is detected by a sensor and used to determine our blood oxygen level and pulse.



Our Hypothesis: ***The Red light*** *above shines on our finger, and then* ***The Sensor*** *below detects the light*

3. Disassembly Process

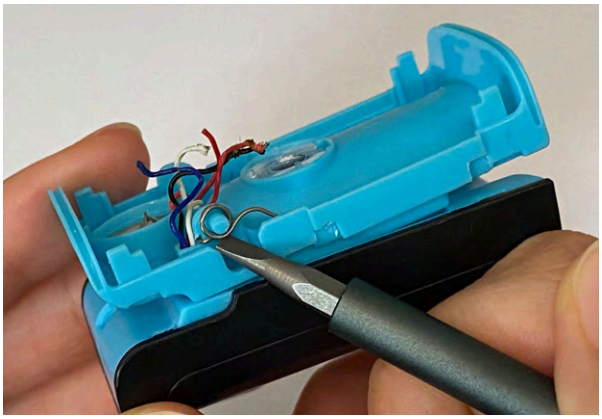


Tools: Safety Glasses and Screwdriver Kit

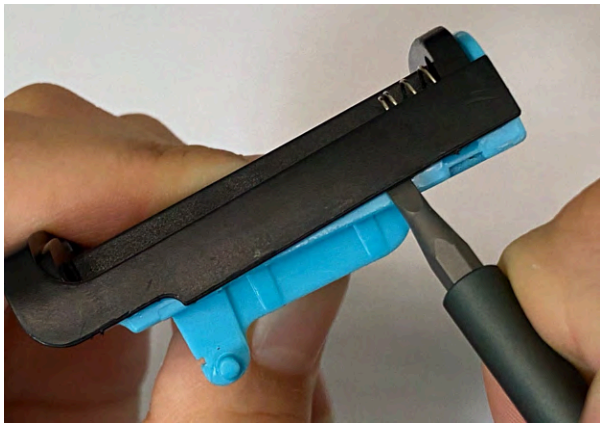
Step 1: Remove all batteries

Step 2: Remove the top lid of the oximeter

Step 3: Remove the motherboard

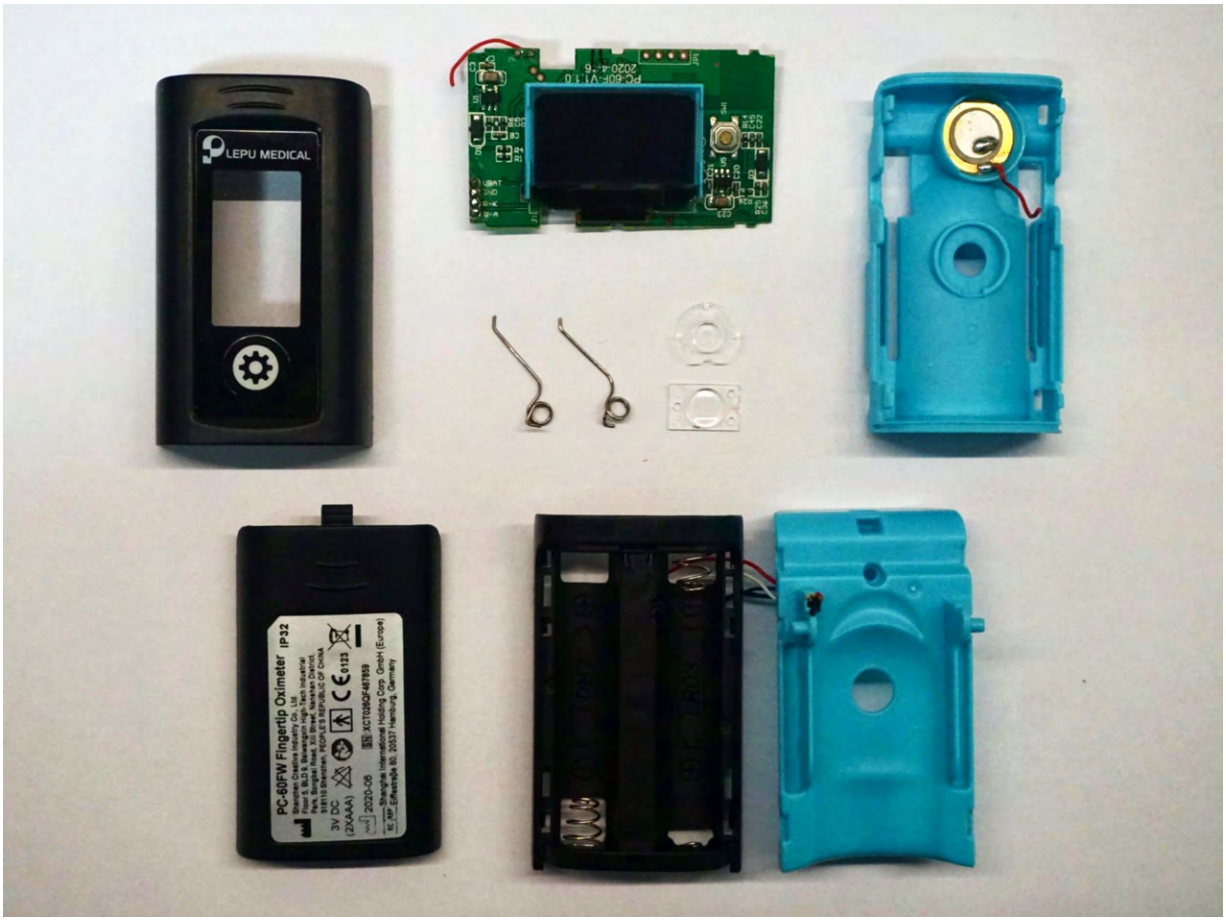


Step 4: Unhinge the top compartment



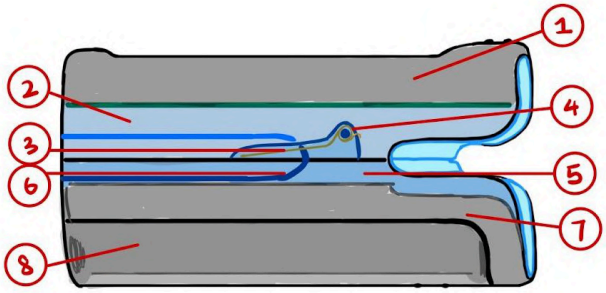
Step 5: Remove the bottom lid/Battery holder

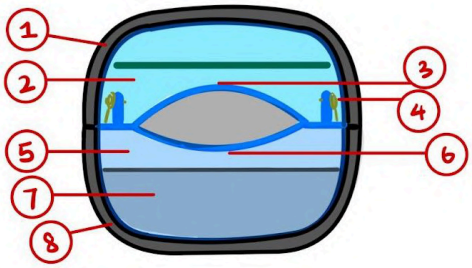
After Disassembly:



4. Parts List

Non-Electronic Components

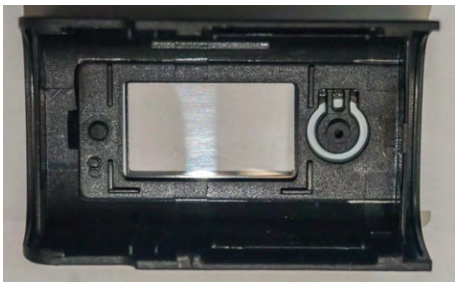




Top Compartment

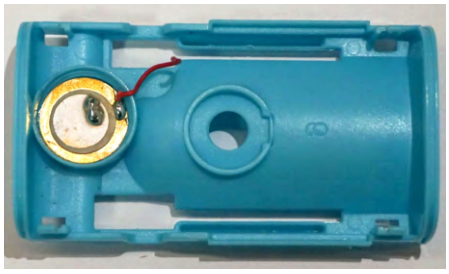
1. Casing #1

The top case encloses the motherboard and holds the display. Users interact with the menu button on this piece to change the mode.



2. Casing #2

Within the top compartment, this piece supports the motherboard; it's exterior provides a space for the user to place their finger to test oxygen level.



3. Plastic Window

On casing #2, this window provides an opening for the red and infrared LED to shine through.

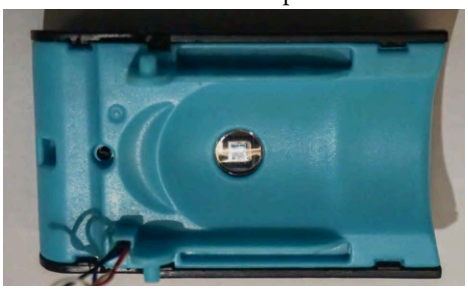
4. Torsion Spring

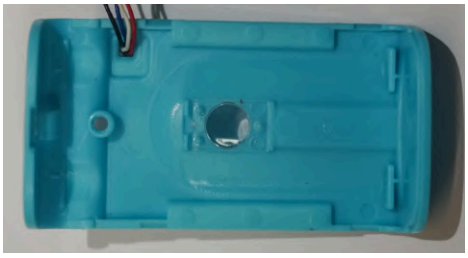
The torsion spring holds the top compartment in place and remains flexible when users open the oximeter to place their fingers for a test.

Bottom Compartment

5. Casing

Users place their finger on the exterior of this piece when testing their oxygen level. The casing is also the connector between the top and bottom compartment.



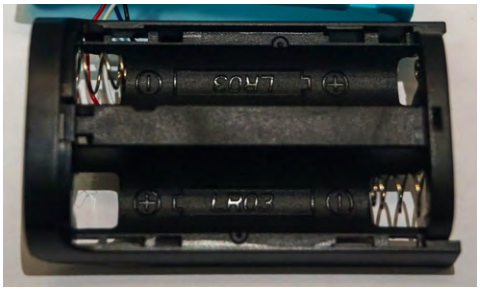


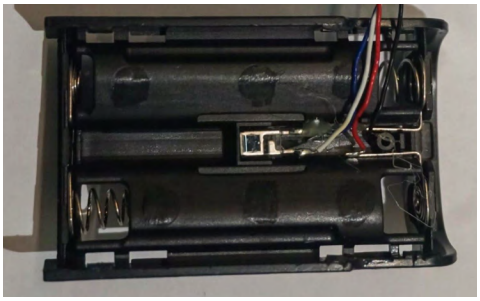
6. Plastic Window

The window gives the sensor an opening to detect the amount of light absorbed during an oxygen level test.

7. Battery Holder

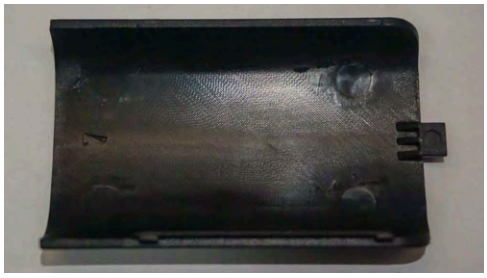
On one side, this piece holds two AAA batteries which power this device. On the other side, it contains the light sensor and wires connected to the motherboard.



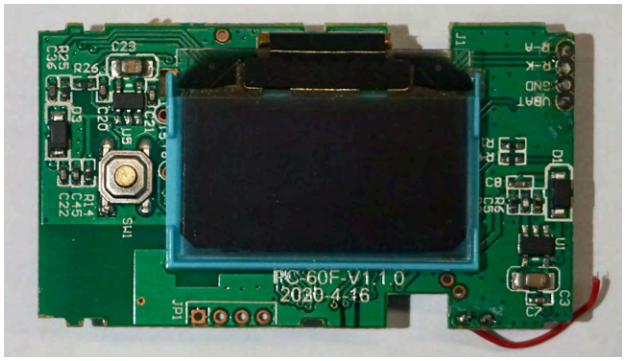


8. Battery Compartment Lid

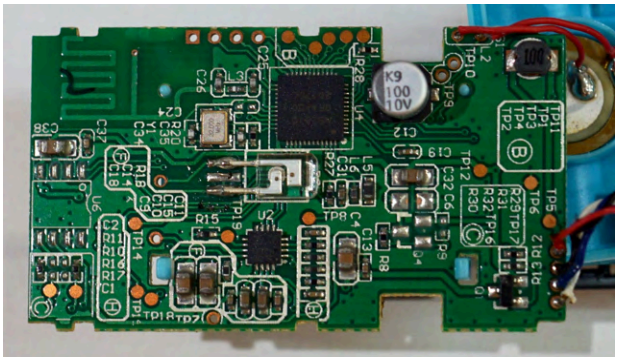
The lid protects the batteries and prevent them from falling out.



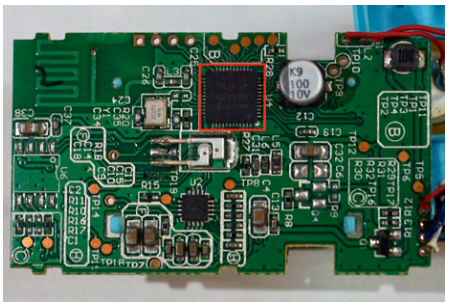
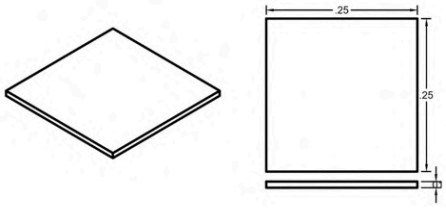
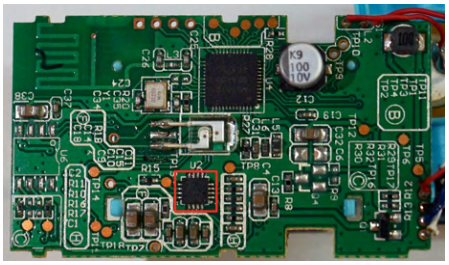
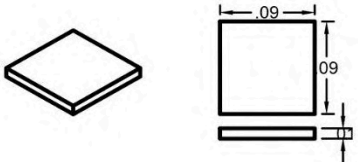
Electronic Components

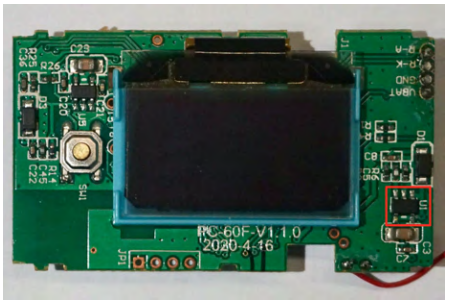
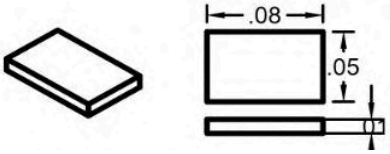
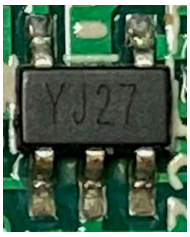
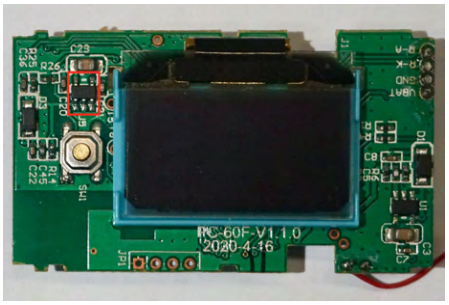
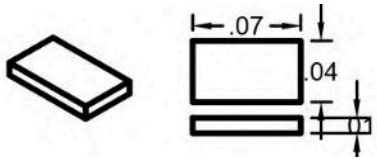
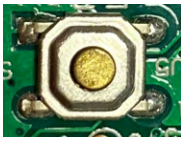
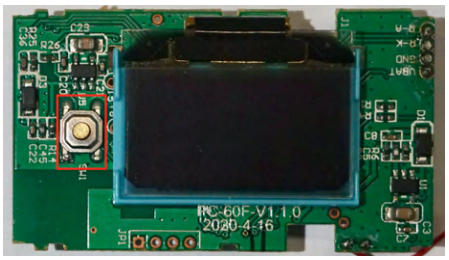
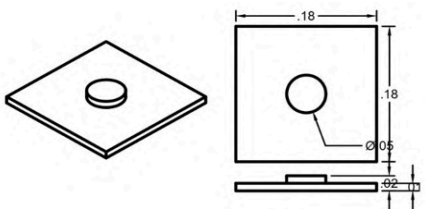


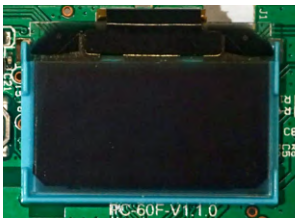
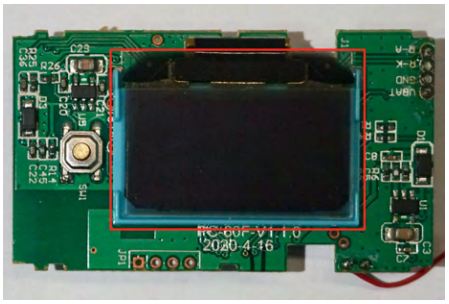
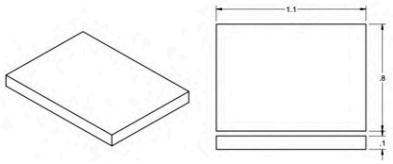
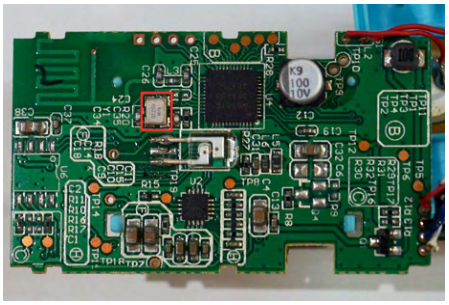
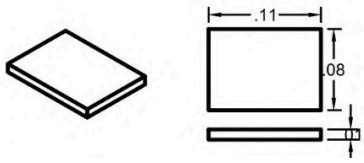
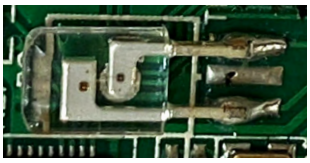
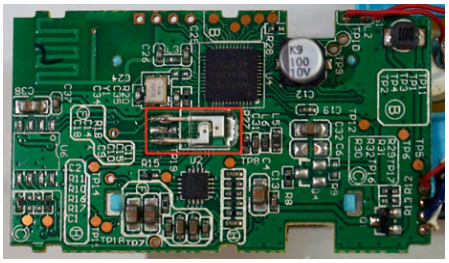
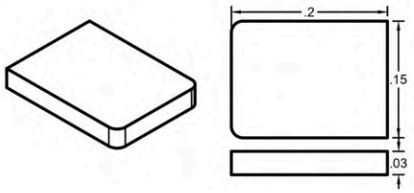
Front

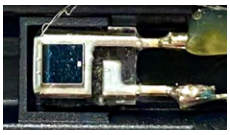
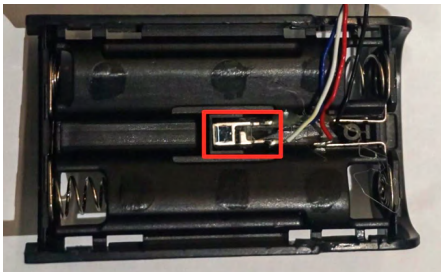
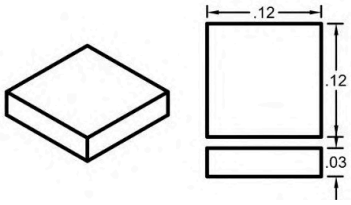
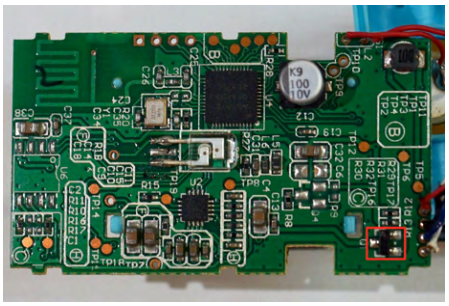
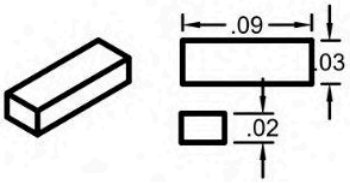
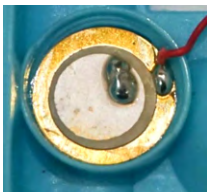
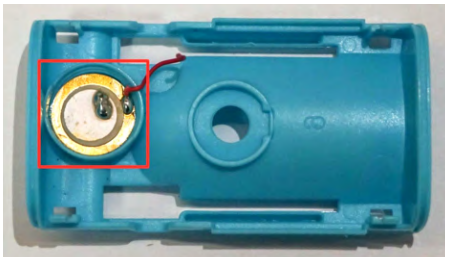
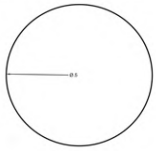


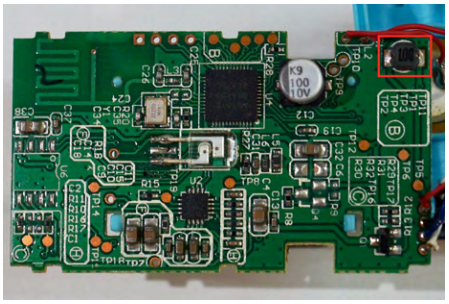
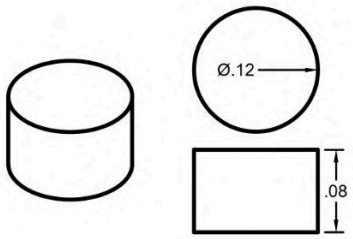
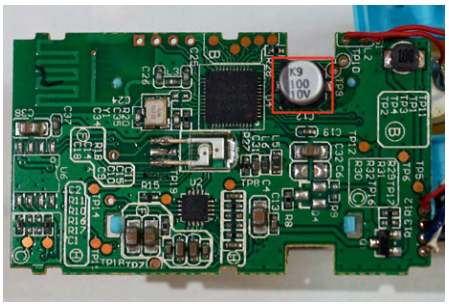
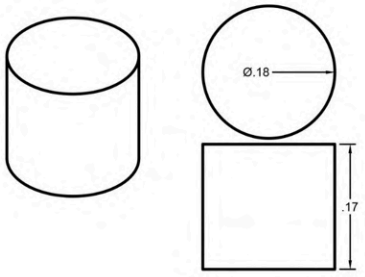
Back

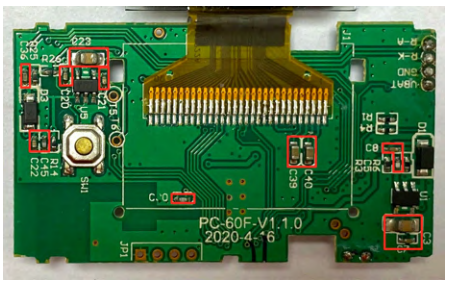
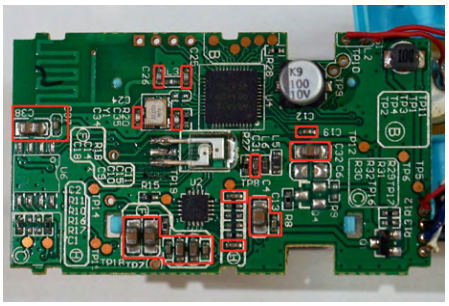
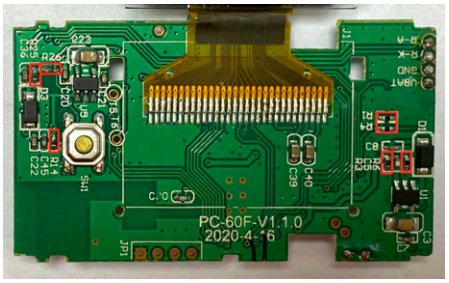
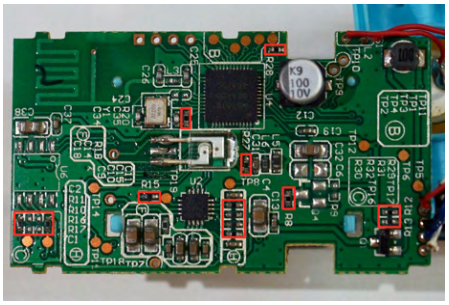
Component	Description	Location + Recreation Model
Nordic's nRF52810 Bluetooth® Low Energy System-on-Chip (SoC) 	This IC is the core microcontroller of the fingertip pulse oximeter, providing its processing power and wireless connectivity. Its powerful 64MHz, 32-bit Arm® Cortex® M4 processor allows oxygen saturation (SpO2) signal acquisition, SpO2 algorithm operation, OLED display operation, and wireless Bluetooth connectivity to smartphones. Datasheet	 *Back* 
Trusignal Microelectronics TS9514 	The TS9514 is an Integrated Analog Front-End (AFE) circuit targeting pulse oximeter applications. It connects directly to the microcontroller and the LED & sensor module (red and infrared). Its flexibility allows users to have complete control of the device's timing characteristics through precise frequency signal conversion. The TS9514's precise timing feature is especially important for pulse oximeters when measuring users' oxygen saturation and pulse rate. Datasheet	 *Back* 

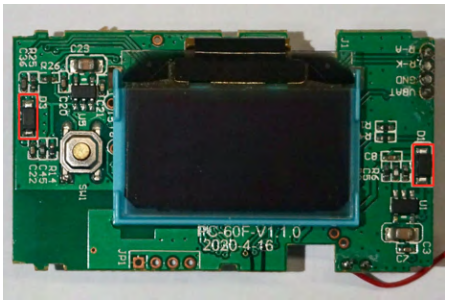
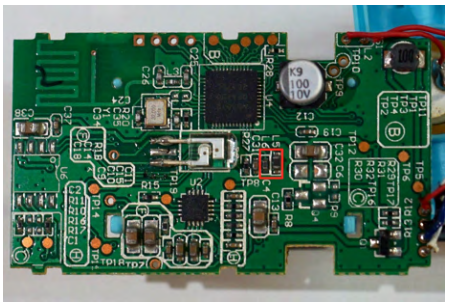
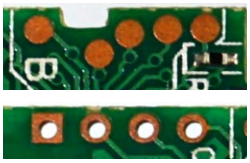
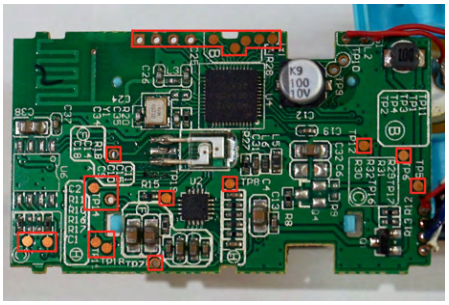
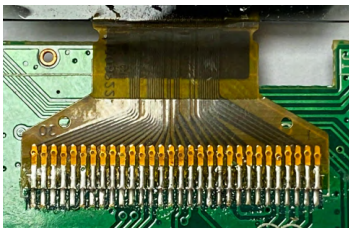
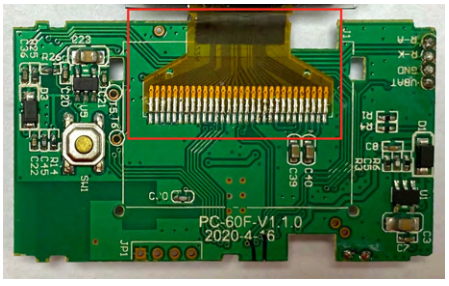
SGMICRO SGM6601 Low-Power DC-DC Boost Converter (Marking: SG4KD) 	The SGM6601 is a high-frequency boost converter designed specifically for small to medium LCD bias supplies and white LED backlight supplies. This piece could control the display or LED lights used in the oximeter. Datasheet	 *Front* 
SGMICRO SGM2032 Low Power, Low Dropout, RF Linear Regulator (Marking: YJ27) 	The SGM2032 is a low-power and low-dropout voltage RF linear regulator. It is capable of supplying 300mA output current with a typical dropout voltage of only 270mV. Other features include logic-controlled shutdown mode, output current limit, and thermal shutdown protection. This piece could act as shutdown protection in the oximeter to ensure the device is not damaged. Datasheet	 *Front* 
Button 	Directly connecting the motherboard to the exterior of the oximeter, the button allows the user to access the menu, change the mode, and view up to 12 sets of recorded data.	 *Front* 

Screen L2864KMBE P2053181-05-AU09 	Operated by the core microcontroller, The screen displays the measurements of blood oxygen level and pulse rate during the test, as well as the menu and previously recorded data.	 *Front* 
SMD 32.000 MHz Oscillator 	The oscillator controls the timing of devices by giving periodic electronic signals based on its frequency. It is often known as the "pacemaker for the microprocessor" In pulse oximeters, oscillators are extremely crucial to accurately timing the cycle of each test and pulse measurements.	 *Back* 
Light (infrared and red) LED 	This LED plays a key feature in testing blood oxygen level and pulse rate. When the user places their finger on the oximeter, these LEDs shine an infrared and red light onto the user's finger. The amount of light is then detected by a sensor on the bottom compartment.	 *Front* 

Photodiode/light detector (sensor for red + infrared light) 	The sensor detects light beams that pass through the user's finger and uses this data to calculate their blood oxygen level and pulse rate. SEE FURTHER EXPLANATION BELOW	 *Bottom Compartment Battery Holder* 
SOT-23 Plastic-Encapsulate MOSFET (metal–oxide –semiconductor field-effect transistor) (Marking: S5) 	This transistor acts as a load switch for portable devices that can be used to turn on and off power supply rails. In the pulse oximeter, this transistor turns on the device when the user's finger is detected and turns off the device when it's not in use. Datasheet	 *Back* 
Capacitive touch sensor 	The capacitive touch sensor detects when the user places their finger in the device and signal the device to power on. In the pulse oximeter, this sensor connects with MOSFET Transistor to switch the device on and off when intended.	 *Top Compartment Casing #2* 

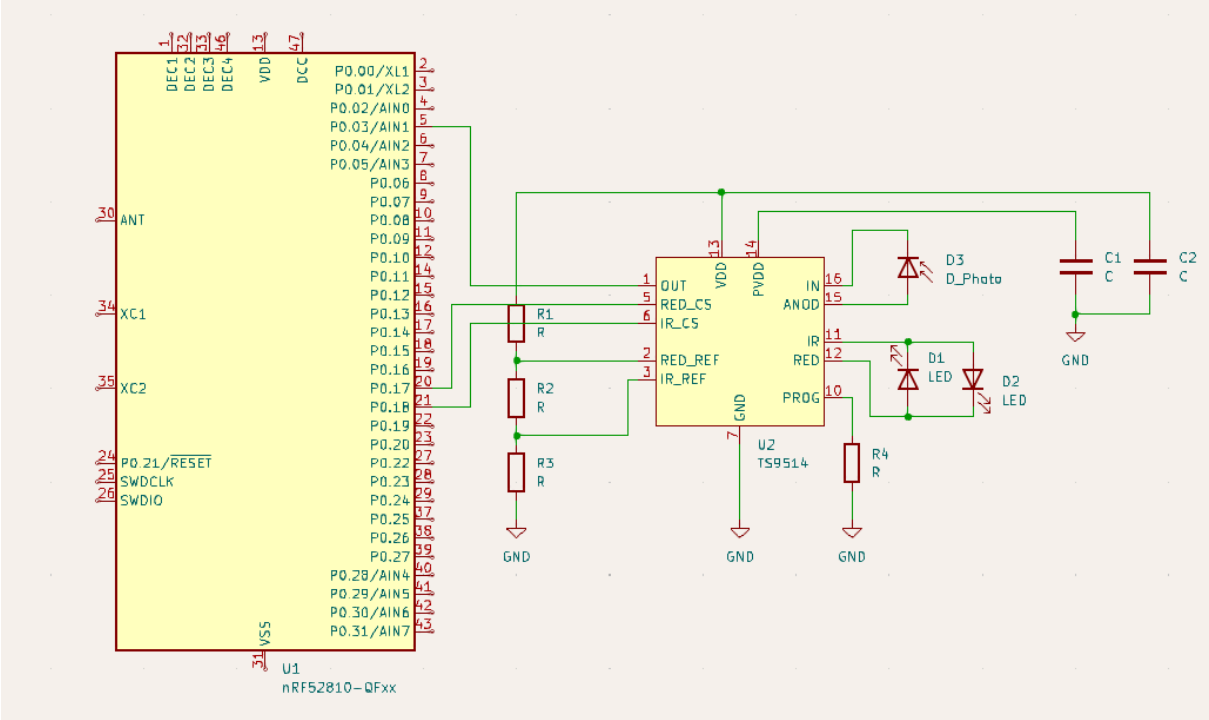
100 uH Unshielded SMD Power Inductor 	Inductors are coils of wire that can store energy in its magnetic field. This 100uH inductor connected with the batteries could be used to store energy in the oximeter's PCB. Equivalent data sheet	 *Back* 
Electrolytic Capacitor 	This polarized capacitor uses an electrolyte to achieve a larger capacitance allow reductions of voltage fluctuations in various noise filtering devices or decoupling in power supplies. Specifically, this capacitor enables the prevention of undesired electrical energy transfer between subsystems in this device.	 *Back* 

Surface Mount (SMD) Capacitors 	Capacitors store energy by accumulating electrical charge from two electrical conductors in close proximity that insulate from each other They require less time than a battery to recharge and can release all the energy very quickly, which is beneficial to quickly activating the oximeter when needed.	 *Front (behind Screen)*  *Back*
Surface Mount (SMD) Resistors 	Resistors restrict the flow of electrical current in a circuit, causing a voltage drop. They are used to match the voltage of the battery and different circuits or between different circuits based on the components' specific needs (e.g. Battery to LED).	 *Front (behind Screen)*  *Back*

Surface Mount (SMD) Diodes 	Diodes have two terminals, anode and cathode, which controls whether currents flow through or not. Specifically, diodes only allow electricity to pass in one direction E.g. (1) Limit power flow between the button and the board to prevent current from traveling back to the button; (2) restrict current from following back to capacitive sensors	 *Front*
Surface Mount (SMD) Inductors 	Surface Mount Inductors are passive positive reactance devices used in circuits for filtering, power supplies, etc. Because of their position in the circuit, we suspect these inductors filter noise that passes through the core microcontroller.	 *Back*
Test Points 	Test points located within an electronic circuit are used to inject test signals or monitor the circuitry. It is often used to evaluate and validate designs, examine newly assembled devices, and repair a malfunctioning device. In a medical device, like the pulse oximeter, test points are important to ensure the quality and accuracy of the device meet the standards.	 *Back*
Ribbon Cables 	Ribbon cables are convenient when there is very limited space for wiring because they are flat and require little room. They are commonly used for data transmission and communication in the internal wiring of devices. In this pulse oximeter, this cable connects the screen to the core microcontroller and other components on the PCB.	 *Front (behind Screen)*

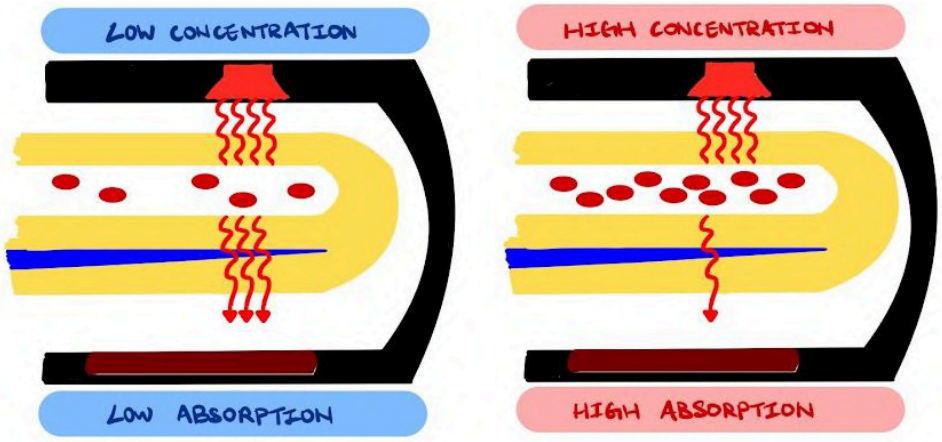
5. Findings

Circuit diagram

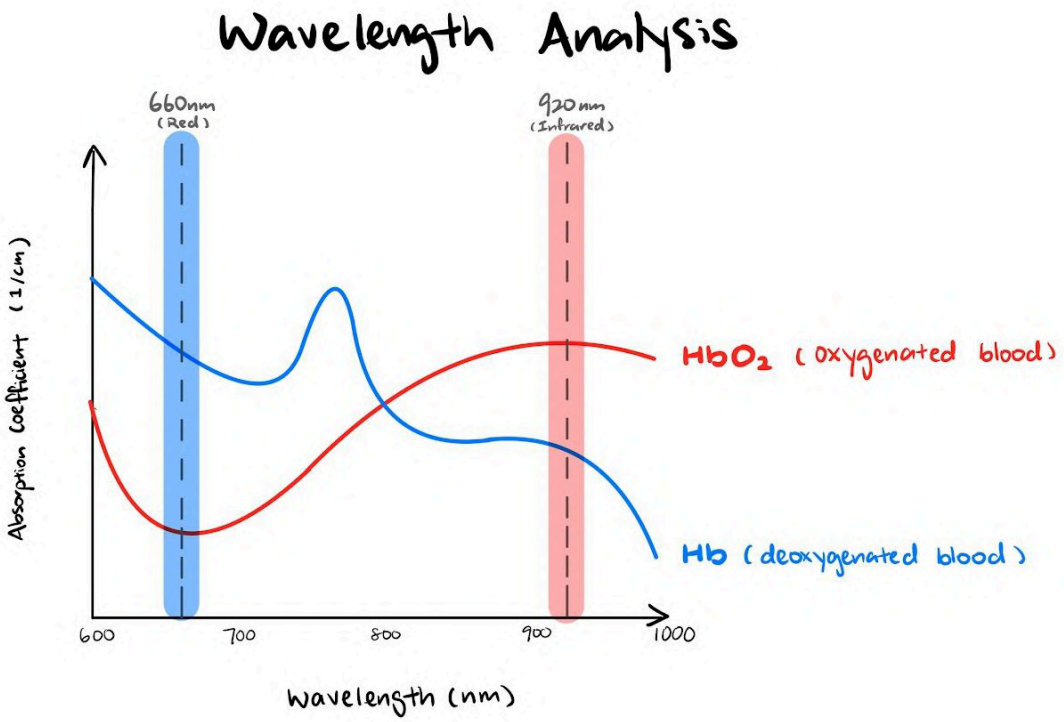


Circuit diagram of TS9514 Analog Front End, LED, and Photodiode Circuit
(We created this circuit on KiCAD to analyze how the LED, Photodiode, and Analog Front End connected at an electronic wiring level)

Blood Oxygen Level and Pulse Rate

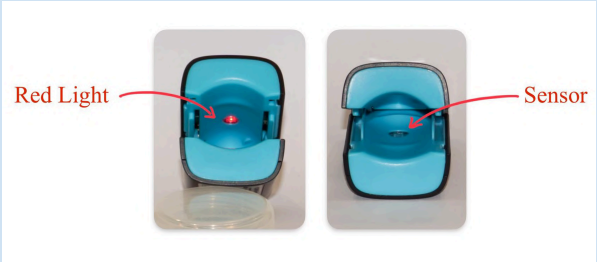


Based on the concentration of oxygen in your blood, the pulse oximeter will detect different levels of absorption.
Low absorption → Low blood oxygen level | High absorption → High blood oxygen level



During each test, the oximeter measures the wavelength of red or infrared light depending on the ratio of oxygenated and deoxygenated blood, as well as the light absorption:
Higher wavelength → Normal blood oxygen (>95%)
Lower wavelength → Abnormal blood oxygen (<90%)

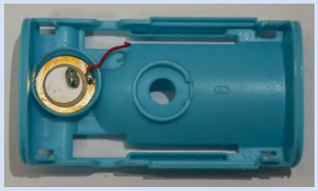
Evaluate Hypothesis

Hypothesis	Actual
The red light shined on our finger is detected by a sensor and used to determine our blood oxygen level and pulse. 	The ***red and infrared*** light controlled by the ***analog*** shines on our fingers and ***the wavelength of light absorbed*** is measured to determine our blood oxygen level and pulse. 

User Interactions: How the PC-60FW Pulse Oximeter Works?

1 **Place Finger**

Detected by
Capacitive Touch Sensor

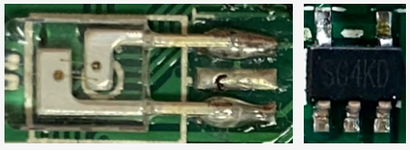


Power on
SOT-23 MOSET

Core Microcontroller
nRF52810

Communicate with *TS9514 Analog Front End*

Red and Infrared LED light up
(+ *SG4KD Boost Converter*)



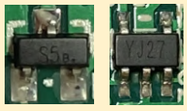
Light detected by
Photodiode

Oscillator

Data transmitted to
nRF52810

Display on *Screen*

Power off
SOF-23 MOSET / SGM2032 for protection



2 **Press Button**

Button pressed

Power on
SOT-23 MOSET

Core Microcontroller
nRF52810

3 **ViHealth APP**

Connect device

Bluetooth
nRF52810

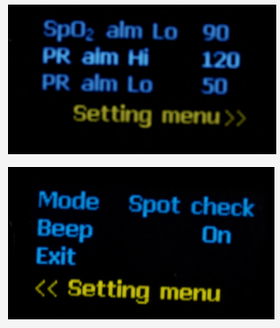
Switch to
'Continuous mode'

Data recorded

If finger detected

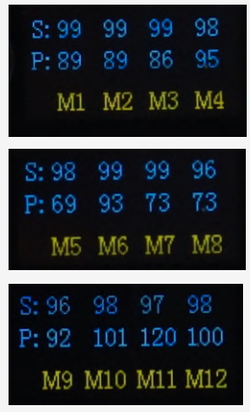
If finger NOT detected

Menu displayed

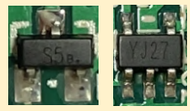


Change settings:
- Continuous mode
- Spot Check

Past 12 data sets
displayed
(scroll with button)

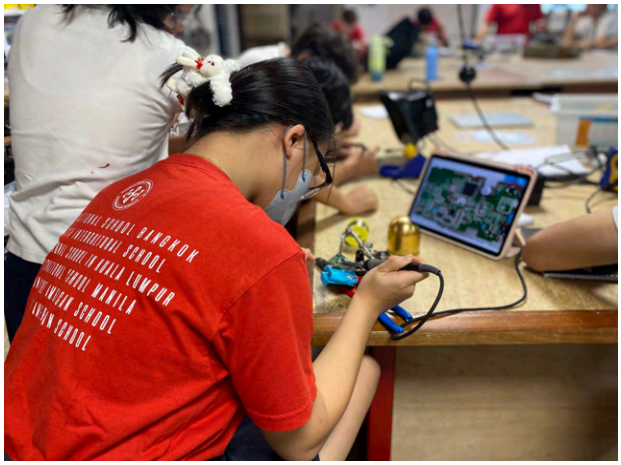


Power off
SOF-23 MOSET / SGM2032 for protection



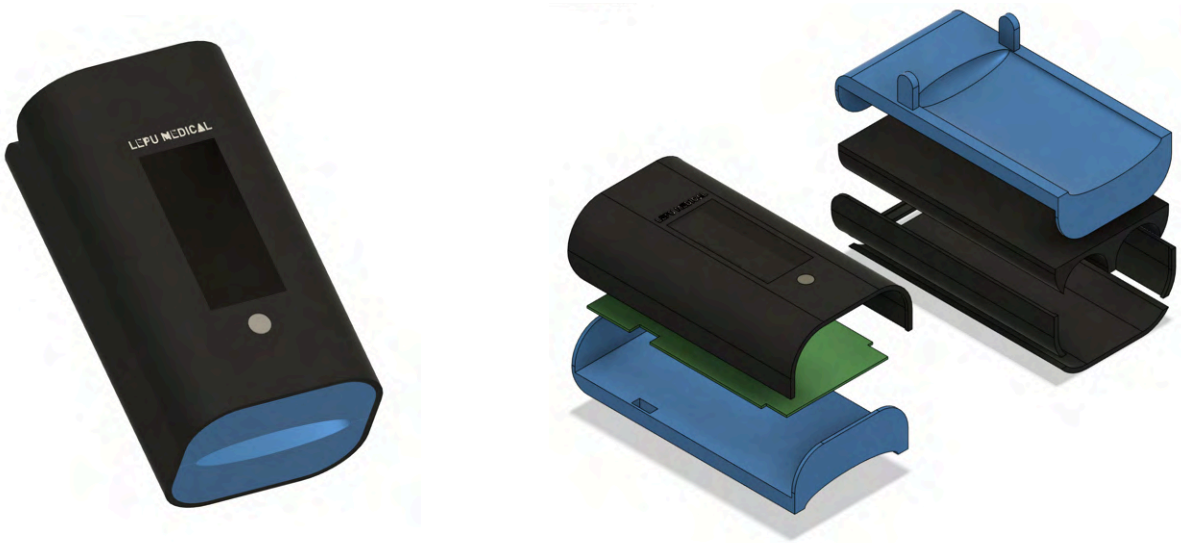
6. Re-assemble Attempt

Soldering



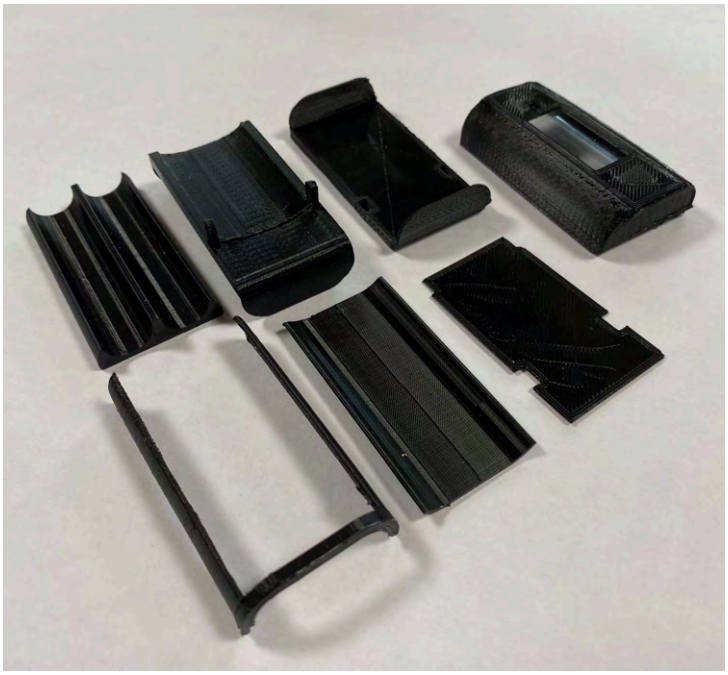

Adriana attempted to solder the wires back on the PCB because they snapped during disassembly. However, due to the small scale of this device, it was very difficult to accurately solder.

CAD Recreation



We recreated the components of the pulse oximeter on Fusion 360 to gain a better understanding of how each component connected with the others. (Left: Complete model | Right: Each component separated by parts)

3D Print



3D Print and re-assembly of our Oximeter CAD Model. Our design replicates the scale and details of the pulse oximeter, and this physical model proves our understanding of how components are integrated in this system.

7. Conclusion

During this project, we dived into biomedicine, electronics, and engineering. We've strengthened our knowledge of valuable processes we utilize in VEX, such as documentation of disassembly, CAD, and integration of complex components in a system. Most importantly, we learned the significance of technology in the medical field and how a small finger oximeter is essential to the entire population.

What we've learned:

- Conducting research with preliminary planning and hypothesis
- Application of technology and biology interdisciplinary concepts in medical devices
- How chips connect in an electronic system
- Use of multimeter to determine the connection between chips and pins
- How to use KiCAD to create schematic circuit diagrams
- How to integrate different chips in a LED and photodiode circuit
- Create a precise 3D model of the device on Fusion 360 to deepen understanding of device

Yoyo disassembling the finger oximeter

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