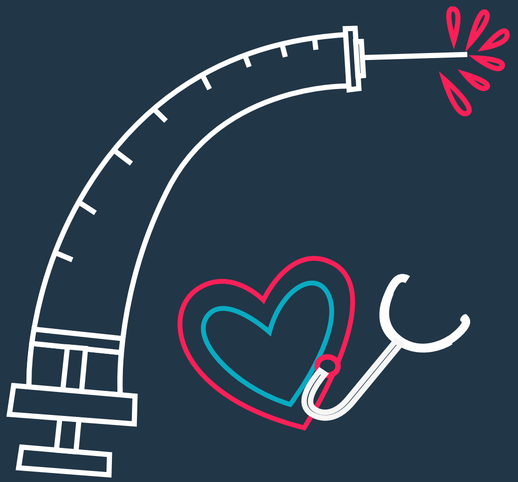
Coupled PPG-ECG Blood Pressure Monitoring Device for Hypertension Detection



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Introduction

Around 48% of all individuals in the US suffer from high blood pressure – called hypertension. Hypertension can lead to stroke, heart failure, kidney problems, among various other diseases.

Currently, the arm cuff device (sphygmomanometer) that measures blood pressure has numerous drawbacks: periodic inflation, inability to capture rapid changes, arm soreness, and inability to keep it on all the time as a monitoring device

We want to design a biomedical wristband that can accurately and continuously measure blood pressure for at-risk inpatients of hypertension-related ailments.

Our design incorporates three parts – a PPG sensor, an ECG sensor, and an XOR gate leading to a microcontroller with display.

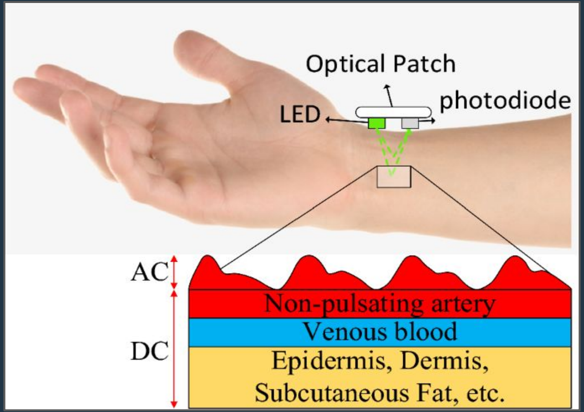
Background & Motivation

- About 46% of the adults with hypertension are not aware that they suffer from it
- Over 12.8% of all annual deaths are due to hypertension
- About 45% of adults with uncontrolled hypertension have abnormal blood pressure
- By 2025, approximately 1.56 billion adults will have hypertension

Coupled Technology Overview

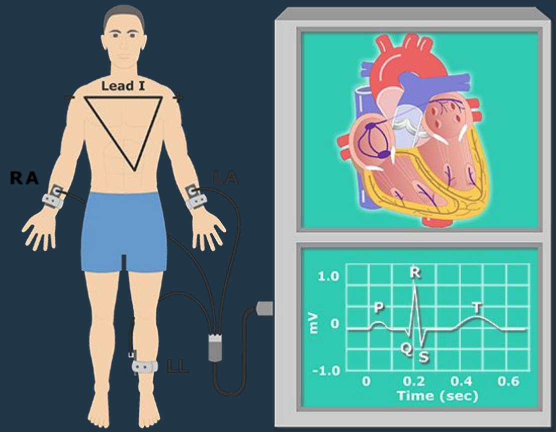
Photoplethysmography (PPG)

- Non-invasive
- Uses reflected light rays to detect blood volume change in vessels
- Gives systolic and diastolic peaks
  - Systolic peak corresponds to maximum peripheral blood volume during contraction



Electrocardiogram (ECG)

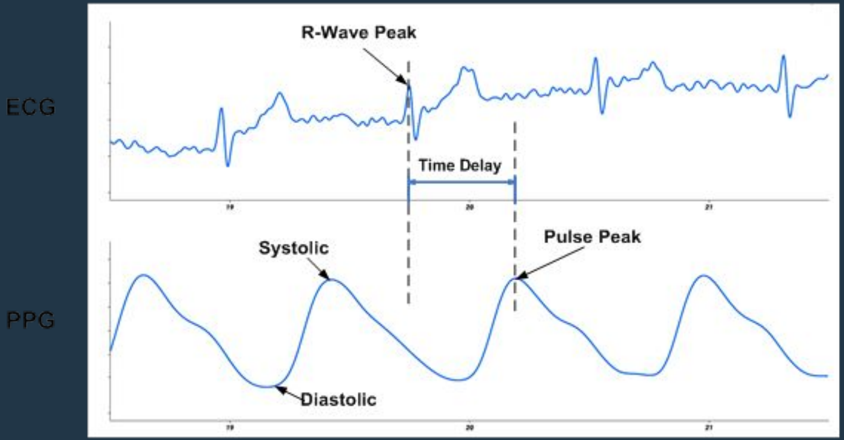
- Non-invasive
- Uses electrodes & leads to monitor heart activity
- Composed of PQRST waves representing a heartbeat's various phases
  - Focus: R-wave peak (ventricular depolarization)

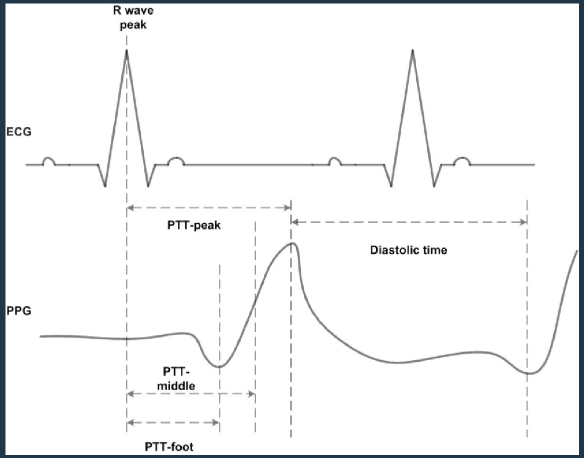


Pulse Transit Time (PTT)

- PTT is the time that it takes for a pulse to travel between two points (proximal and distal points)
- Physiological Basis:
    - R wave - when blood is pumped from the heart to periphery
    - PPG Systolic peak
  - Inverse relationship between PTT and arterial wall stiffness
    - Higher BP → stiffer walls → faster pulse wave → lower PTT
- PTT can be calculated as the difference between an ECG R wave and the PPG systolic peak

$$BP = \frac{\Delta BP}{0.7} = \frac{1}{0.7}\left(\frac{1}{2}\rho\frac{d^2}{PTT^2} + \rho g h\right)$$

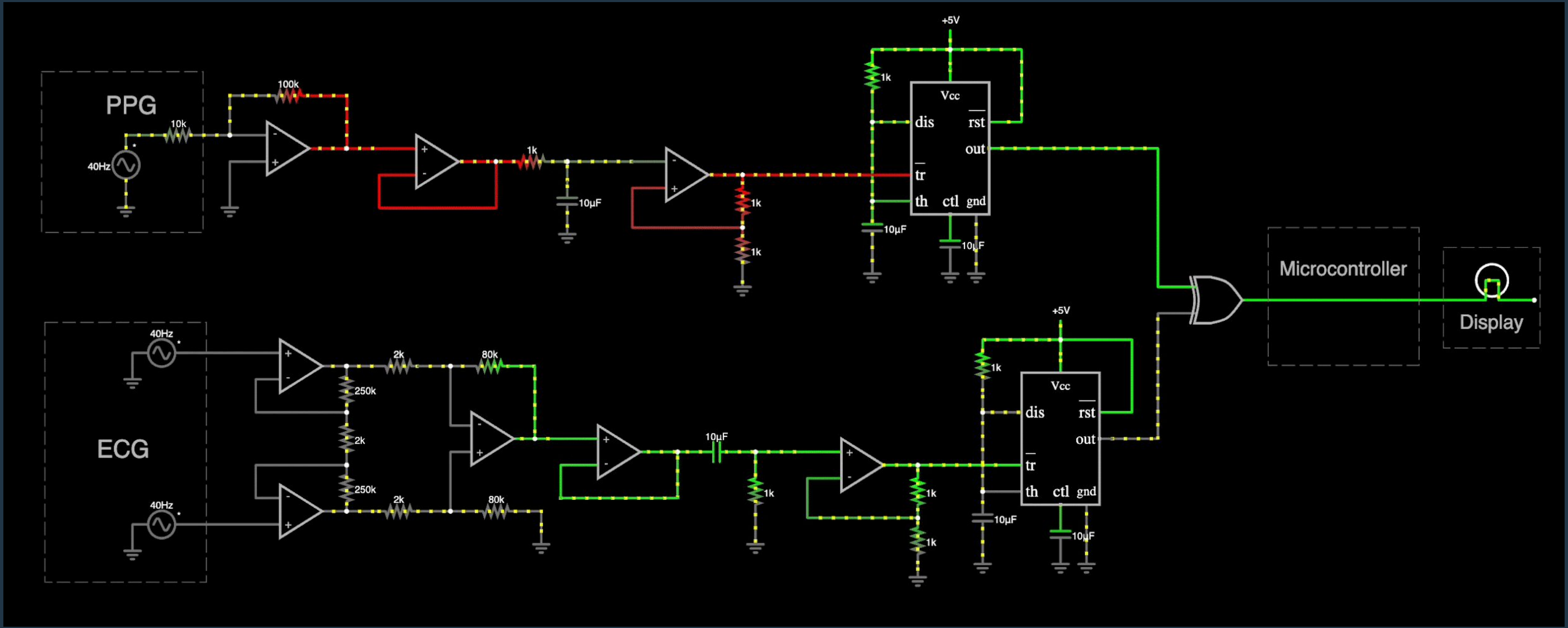


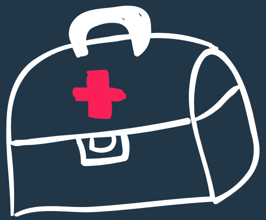


Assumptions

- Circuit resistances have 0% tolerances
- Assuming a **<u>simplified hypertensive</u>** patient case
  - Systolic blood pressure between 140-190 mmHg
  - Diastolic blood pressure above 90 mmHg
- Blood pressure at the wrist fully represents the body
- Heart rate frequency is from 1-1.67 Hz → picked cutoff frequency of Low pass filter in part 1 to 5 Hz
- Uniform wave frequency
- ECG output signal 0.5-5mV
- Threshold PTT: <80ms for hypertensive people
- Assume both 555 timers will turn off at the same time
- Max time difference between ECG and PPG peaks is 110ms.
- Difference between the RR wave peak is 600ms
- Difference between Systolic wave peaks is 350ms
- All values are taken from average hypertension patient

Circuit Schematic

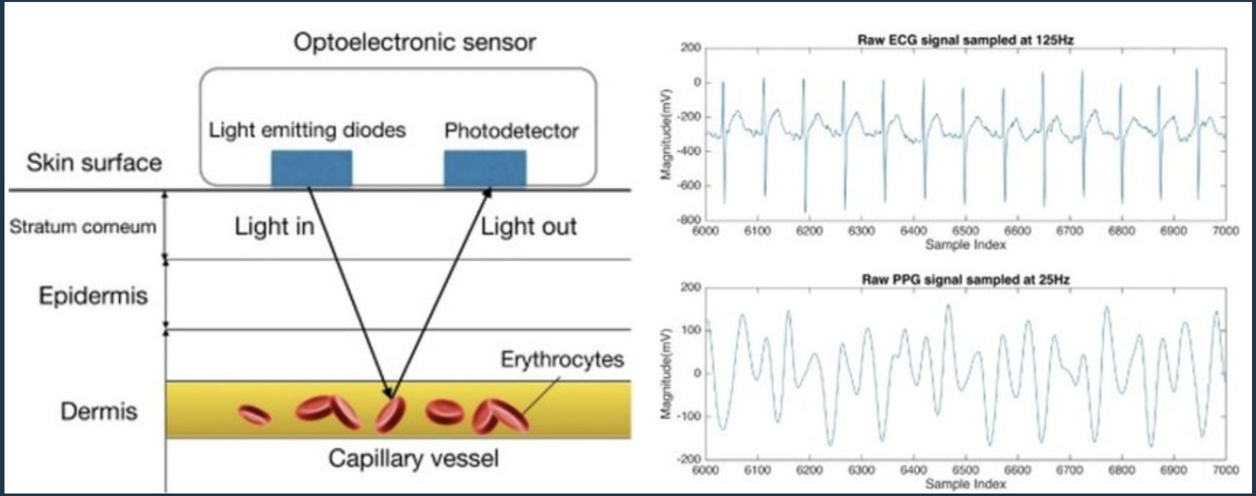




Part I Analysis

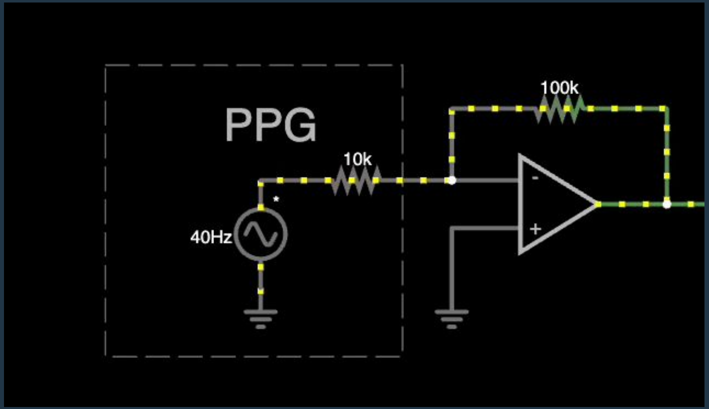
PPG sensor

- Max time difference between ECG and PPG peaks is 110ms.



Inverting Amplifier

- Used to amplify the input PPG signal while inverting it
- Inversion needed in order for the monostable 555 timer to be triggered
  - Trigger input for 555 timer: active low → input has to be below certain threshold(⅓ Vcc) to activate it

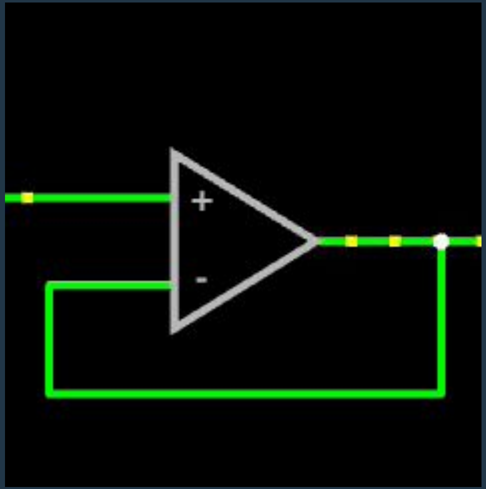


$$A = \frac{v_o}{v_s} = -\frac{R_{FB}}{R_s}$$

R_{FB} = 100kΩ
R_S = 100kΩ
Gain = -10

Buffer #1

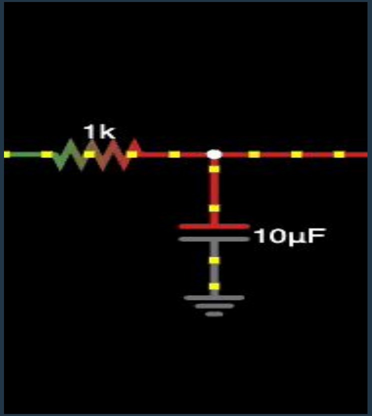
- Isolates the previous and the next stages of the circuit so that they do not affect each other.



Passive RC low pass filter

Considerations: f_c is chosen based on frequencies of PPG sensor properties. R1 and C1 are calculated from that.

- Low pass filter used since PPG waves are low frequencies ~ 1-1.67 Hz
  - PPG waves can be contaminated with high frequency electronic signals, light waves, along with making systolic peaks easier to see

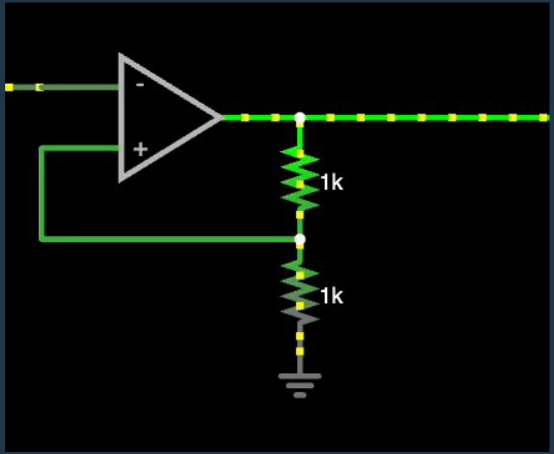


$$f_{cutoff} = \frac{1}{2\pi RC}$$

- R_1 = 3.3 kΩ
- C_1 = 10μF
- Cutoff frequency f_c= 5Hz

Comparator #1

- Compare the incoming voltage with the reference voltage.
- If Vin < Vref, Vout = V+;
- If Vin > Vref, Vout = V-, Vref = 2.5V
- V+ = 5V, V- = GND,

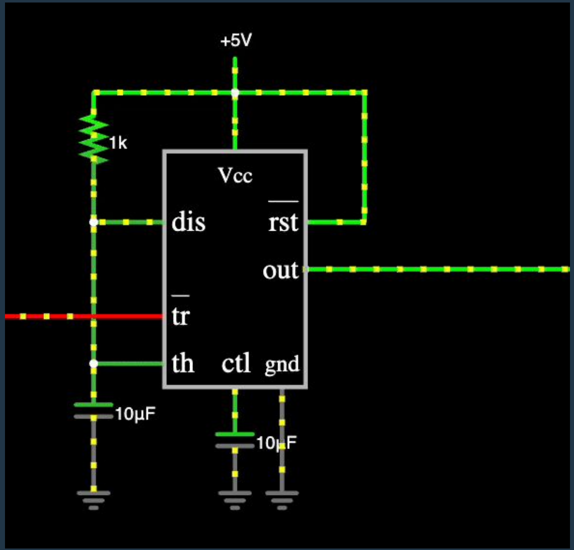


$R_{reference,\ ground} = 1k\Omega$

$R_{reference,\ out} = 1k\Omega$

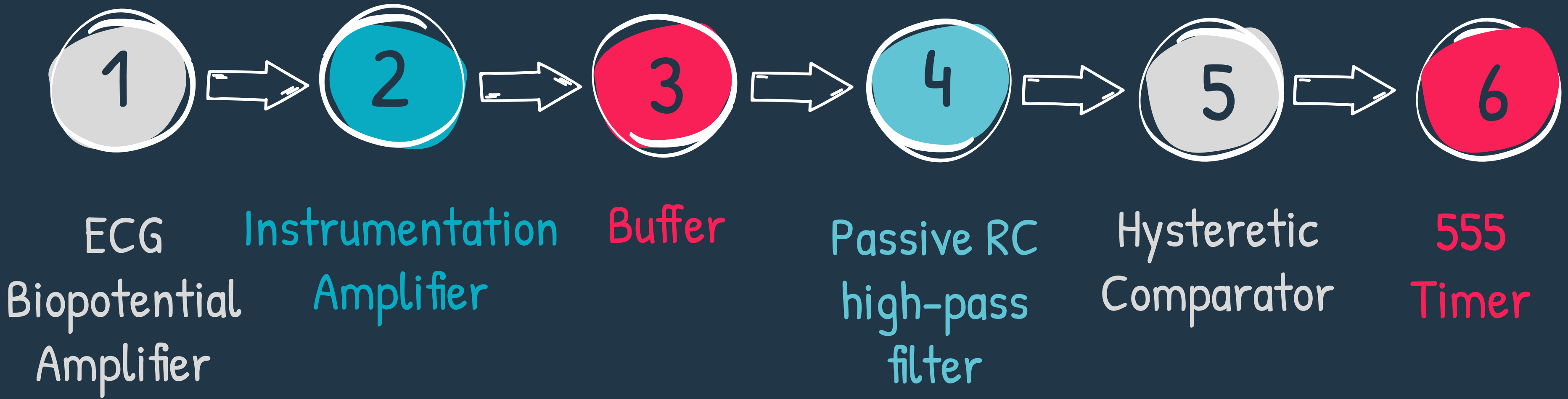
555 Monostable Timer #1 (PPG)

- Threshold: Normal PPG thresholds: 0.5-5 Hz, -4~4V
- When PPG signals from previous parts exceed the threshold, timer #1 is active, output remains high for T = RCln(3)
- Time interval we want based on PPG properties: 350ms
- One set of values that might be possible: : R = 455 kohm C = 1uF



Part II Overview: ECG Sensor

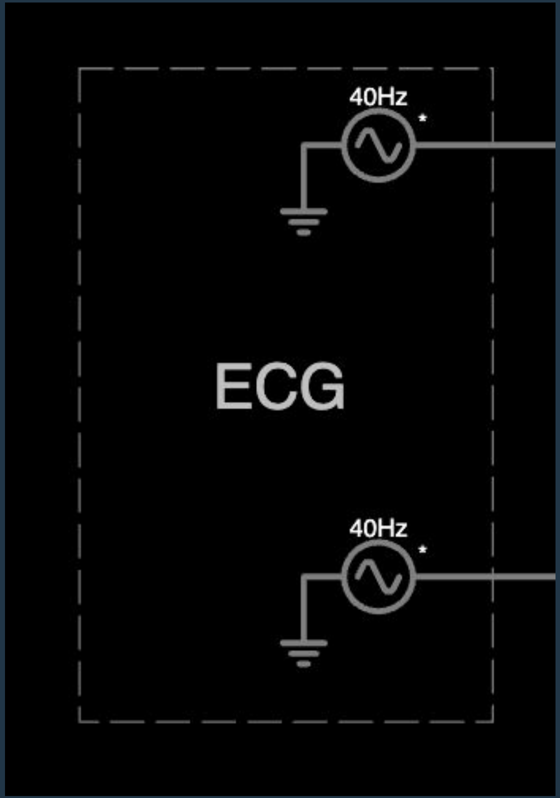
Overall Goal: Measure pulse transit time (PTT) by comparing R wave and the captured pulse wave.



Part II Analysis

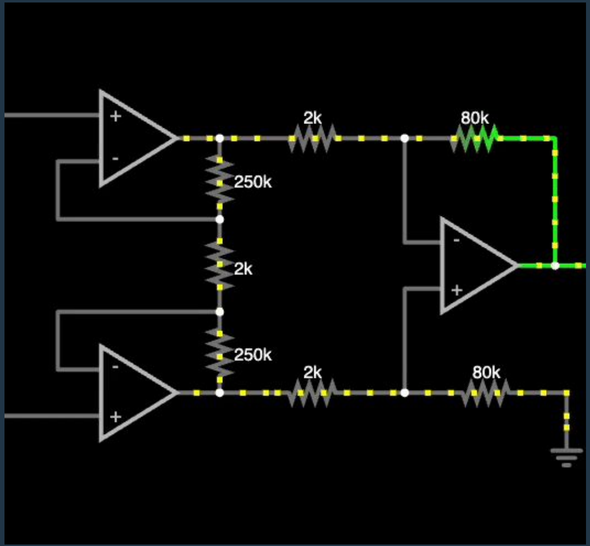
ECG sensor inputs

- Takes input voltage from biopotential amplifier and feeds a 40 Hz sinusoidal waveform into the circuit
- Simulating true ECG voltage output values
  - Top source = 2.5mV
  - Bottom source = 3mV



Instrumentation Amplifier

- Waveforms from the biopotential signal goes through the amplifier to improve signal quality to reduce noise-level.
- Voltage out of the amplifier is 10000 times the input voltage



$$Ad = \left|\left(1 + 2 * \frac{R_o}{R_a}\right) * \left(-\frac{R_4}{R_3}\right)\right| = 10{,}000$$

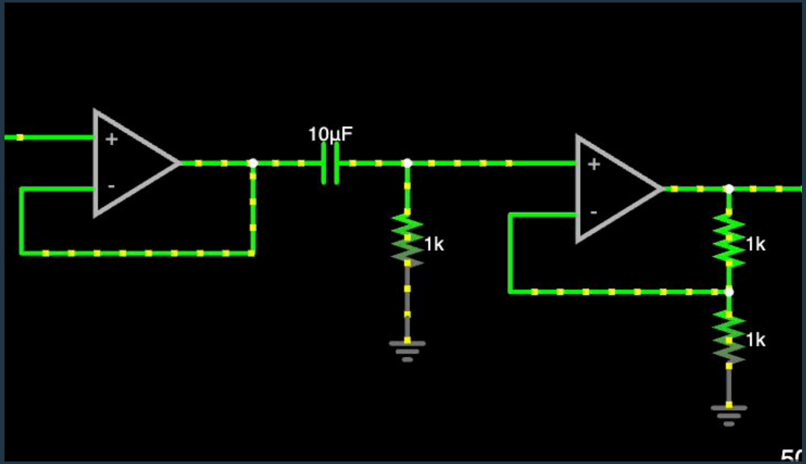
R_o = 249 kΩ

$R_a = R_3$ = 2 kΩ

R_4 = 80 kΩ

Buffer #2 and Passive RC High Pass Filter

- Passive RC high pass filter
  - Allows signals with high frequencies to pass through
- Isolates the previous and the next stages of the circuit so that they do not affect each other.



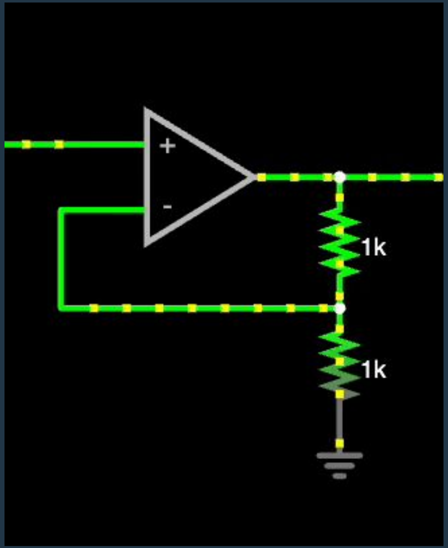
$C_1 = 10\mu F$
$R_1 = R_2 = R_3 = 1k\Omega$

Comparator #2

- Signal from the high pass filter connects to the inverting input of the comparator
- Considerations: regular ECG peak voltages: 2.5~3 mV
- Compare our input ECG R wave peak voltages with the regular ECG.
- If Vin < Vref, Vout = V+
- If Vin > Vref, Vout = V-
- Vref = 3V, V+ = 5V, V- = GND

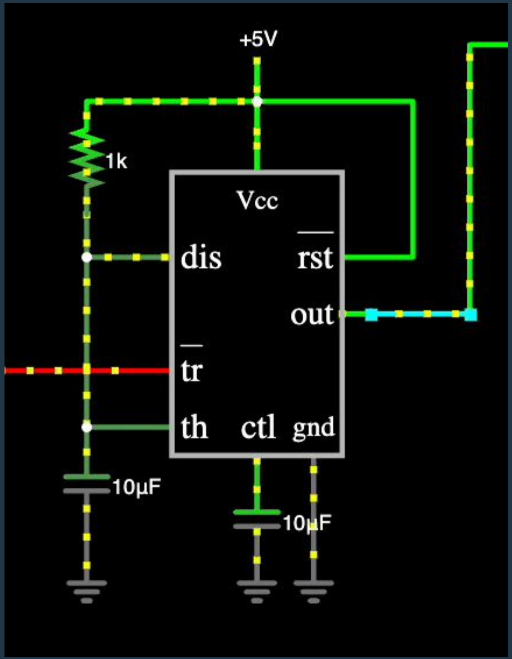
$R_{ref,GND} = 2k\Omega$

$R_{ref,out} = 3k\Omega$



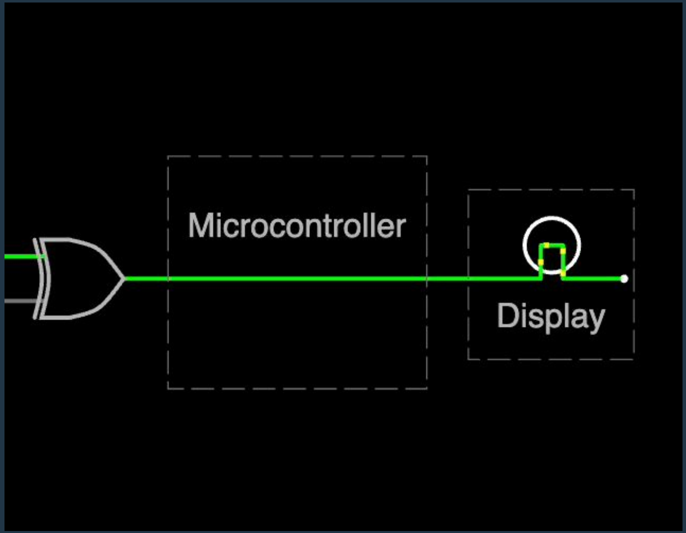
555 Monostable Timer #2 (ECG)

- Timer #2 activates when it receives a voltage signal from comparator 2.
- Once activated, output stays high for time interval $T = RC\ln(3)$
- Time interval selected based on ECG properties: T = 600ms
- One set of RC values: R = 546 kΩ, C = 1μF



Part III: XOR, Microcontroller, & Display

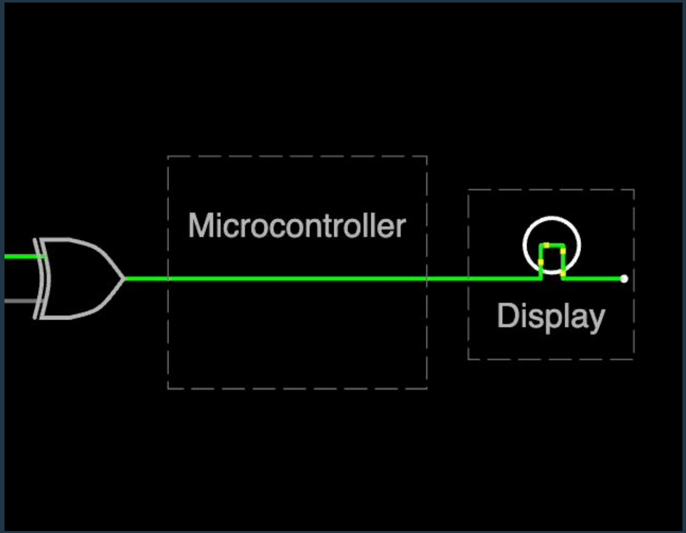
<u>Overall Goal:</u> develop measured pulse transit time and compare value to detect abnormal BP and display warning messages.



Part III Analysis

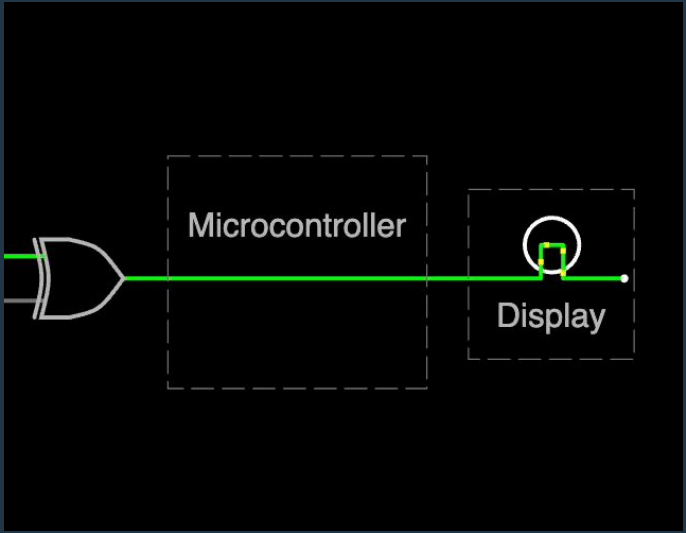
XOR Gate

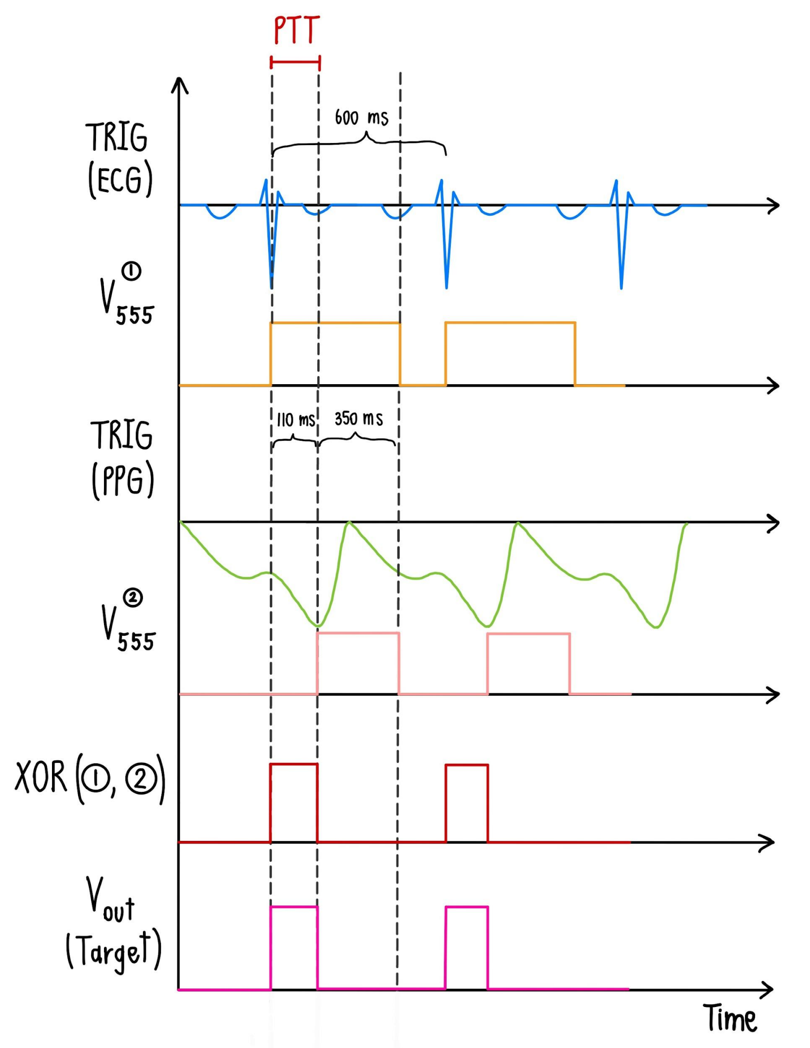
- Takes input from the two timers.
- XOR gate produces a TRUE output if the two timers are not sending out outputs concurrently
  - The TRUE message feeds into the microcontroller.



Timer 1(A)	Timer 2(B)	OUT
0	0	0
0	1	1
1	0	1
1	1	0

V_{in} of the timers vs V_{out} of the timers vs XOR gate responses





Microcontroller & Digital display

- Takes voltage output from XOR gate
  - Includes built-in code that calculates amount of time the XOR gate was activated → that time is the PTT
  - Uses equation below to convert PTT to BP
- Converts analog signal containing BP information to digital as it leads into a digital display.
- The digital display will show the BP and a warning message if microcontroller determines that the BP is higher than 140 mmHg.

$$BP = \frac{\Delta BP}{0.7} = \frac{1}{0.7}\left(\frac{1}{2}\rho \frac{d^2}{PTT^2} + \rho g h\right) = \frac{A}{PTT^2} + B$$

$$A = (0.48 \times height)^2 \times \frac{\rho}{1.4}$$

Design Limitations

- Currently inaccurate compared to traditional cuff-based blood pressure readings
- Vulnerable to physiological, environmental, and motion-induced noise
  - Due to changes in heart-wrist length, there may be fluctuations in blood pressure readings
- Necessitates regular calibrations for reliable readings
- ECG leads must be constantly worn to operate
  - Product limited to medical settings
  - Potential future consideration

Significance and potential applications

- Enables long-term tracking and data collection for inpatient blood pressure monitoring
- Widespread applicability to diagnosing blood pressure related medical conditions

Acknowledgements

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