Breathing Pattern & PCO_2 Analysis for Diagnosing Asthma

BENG 186B WI23

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Problem

- Present studies estimate that underdiagnosis of asthma may be as high as 73%
- There is no gold standard for the diagnosis of asthma
- Therefore it is useful to evaluate a broad range of symptoms to make a maximally informed diagnosis

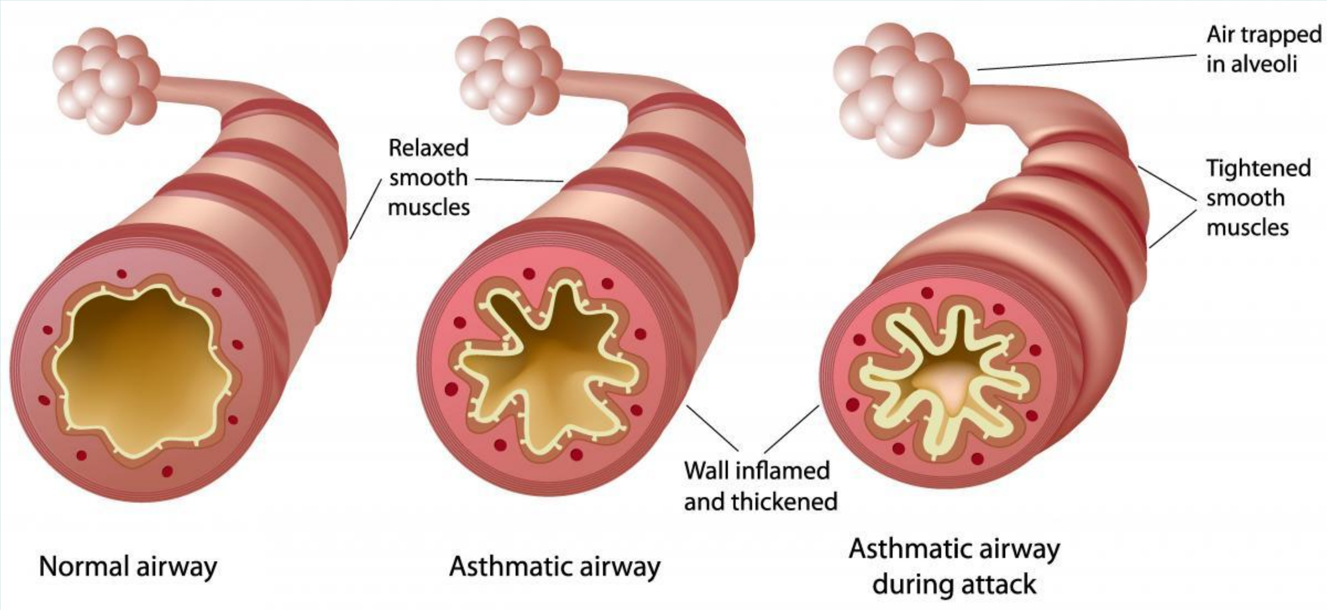
Our Aim: Design a dual-verification complimentary system for broad characterizations of asthma symptoms

Approach I

Measuring Arterial PCO_2 to Assess Hyperventilation

Dysfunctional Breathing in Asthma Patients

Mechanism: Hyperventilation as a response to increased airway resistance



- Hyperventilation leads to an **abnormal loss of blood CO_2 levels**
- To prevent further loss of CO_2, "extra mucus is secreted to clog airways which **narrow and constrict**"

Why PCO_2?

- **"a marker of sufficient alveolar ventilation within the lungs"**
- Under normal physiologic conditions, air exchange is primarily controlled by the partial pressure of arterial carbon dioxide ($PaCO_2$)

$$P_aCO_2 = K \times \frac{\dot{V}CO_2}{\dot{V}_A}$$

Figure 1. Calculation for arterial carbon dioxide tension (PaCO2) is determined from the rate of carbon dioxide production (VCO2) and minute alveolar ventilation (VA).

Pathological changes in $PaCO_2$

Minute ventilation V_E is the volume of gas inhaled (or exhaled) from a person's lungs per minute. **Hyperventilation increases V_E.**

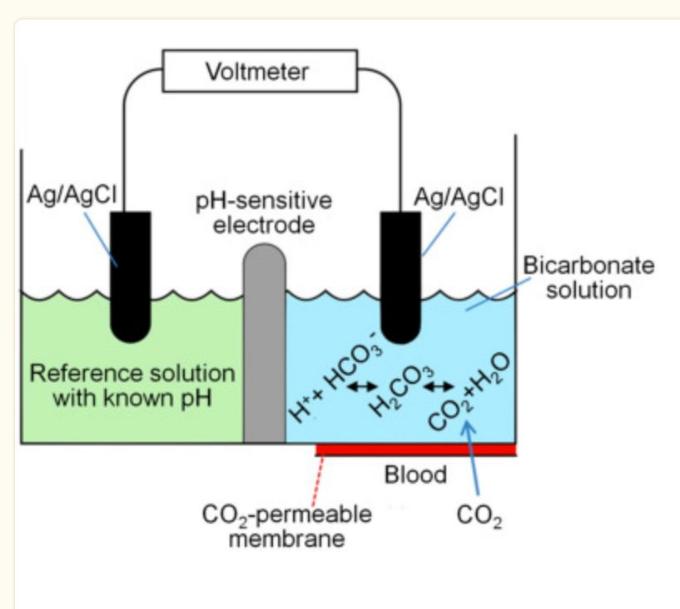
Figure 3. Arterial carbon dioxide tension (PaCO2) shifts with changes in minute ventilation. At a constant rate of CO2 production, PaCO2 falls with increasing minute ventilation (VE) and PaCO2 rises with declines in VE.

(Dead space V_D is the volume of ventilated air that does not participate in gas exchange.)

Severinghaus Electrode

Function: Measures Blood CO_2 levels

- pH meter detects net movement of CO_2
- Obtain calibration curve of PCO_2 vs pH, determine specimen's PCO_2 from this curve
- Relationship between PCO_2 and concentration of CO_2 dissolved in blood is $[CO_2] = a(PCO_2)$
- **Limitations:** invasive, CO_2 concentration is not always determinative of asthma



* a = 0.301 mmol/liter per mmHg PCO2

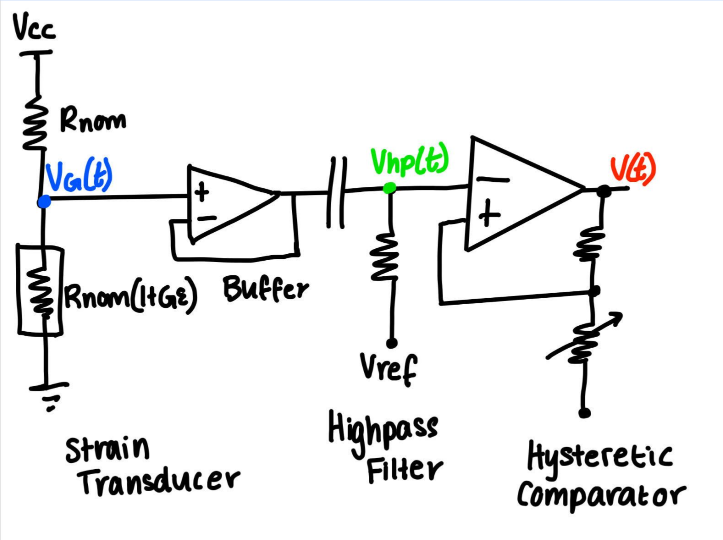
Approach II

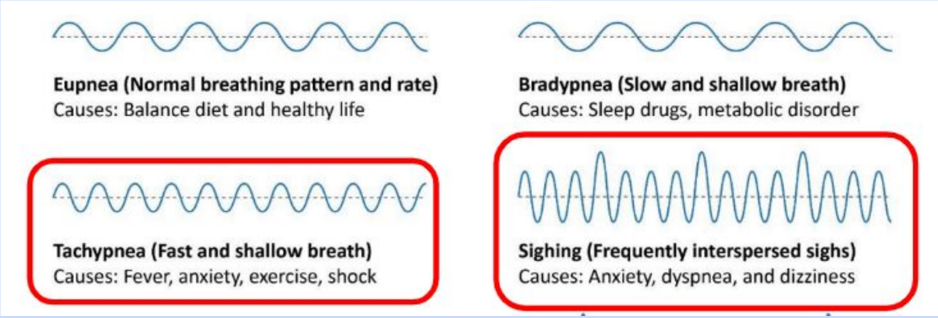
Assessing Pulse Characteristics for Hyperventilation

Problem and Proposal (2)

Problem: Detecting Breathing Pattern of Asthma Patient

Solution: Strain Gauge/Comparator System that outputs voltage of breathing pattern





V(t) can be analyzed for hyperventilation/unusual patterns

Pros: Noninvasive, easy to build

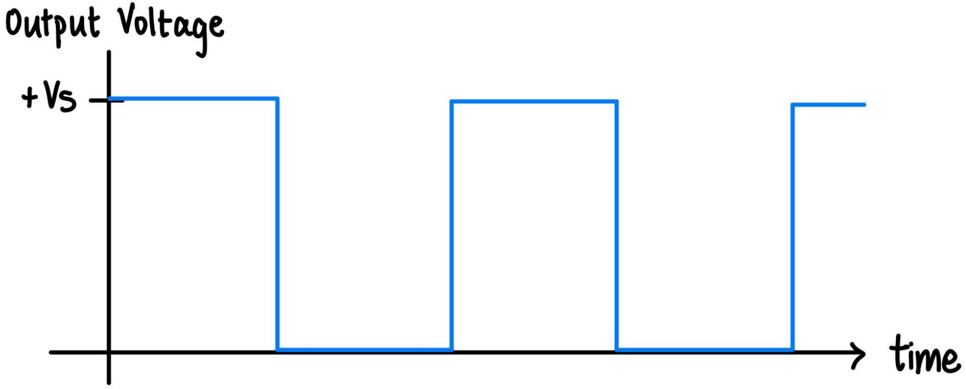
Cons: More sophisticated solutions are available

Signal Analysis (1)

- The circuit outputs **$+V_s$ when breathing out and 0 when breathing in**
- For regular breathing, we may expect the output to be a regular square wave:

Regular respiratory rate:
12-18 breaths per min

Frequency:
0.2-0.3 Hz



- For asthma patients, we need to detect: 1) hyperventilation and 2) irregular breathing patterns

Signal Analysis (2)

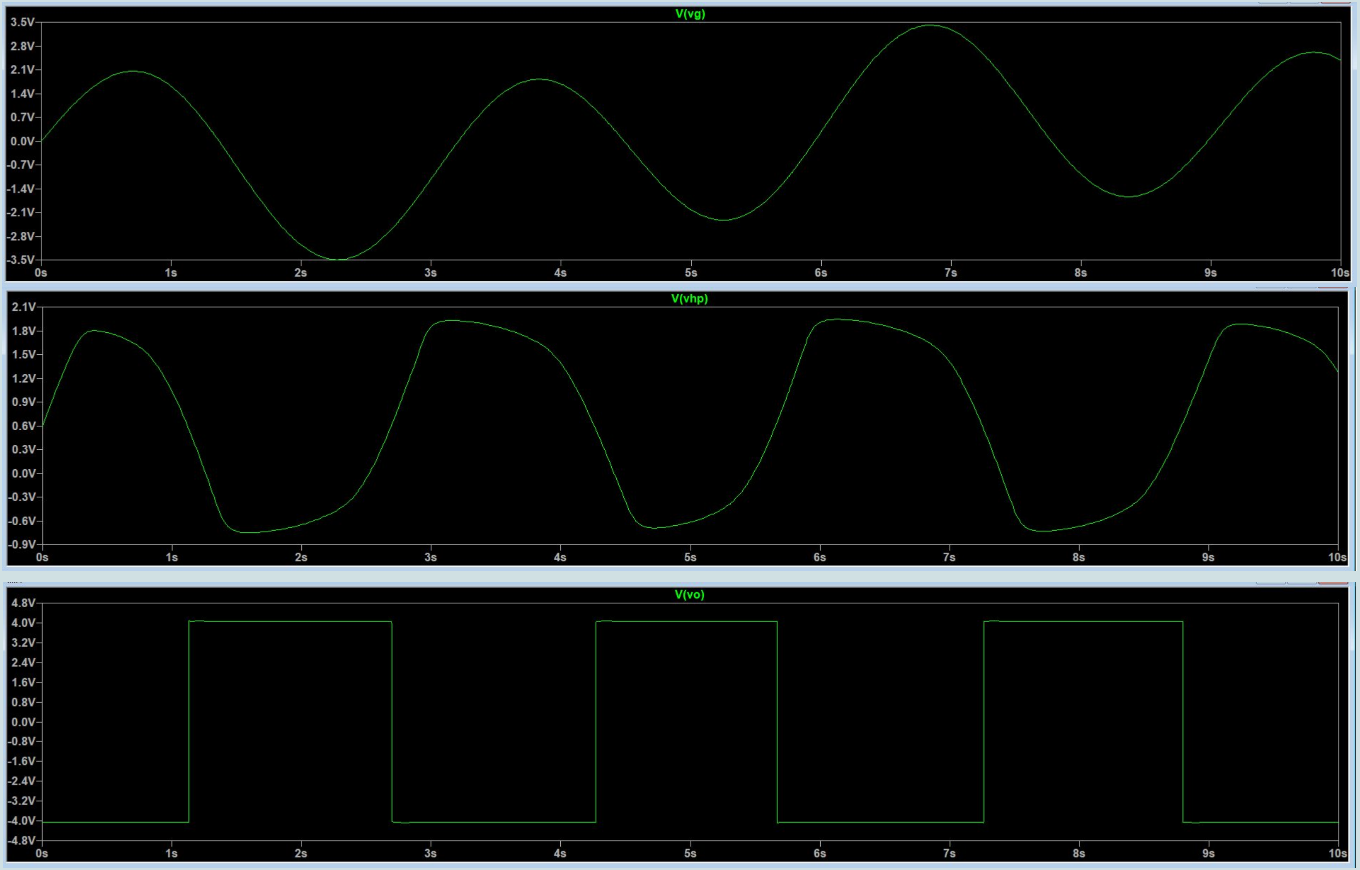
We can do more complex signal analysis by **programming a microcontroller** and have it output a voltage output sufficient to light up **an LED light**

For hyperventilation and thoracic (shallow) breathing:
Set a threshold frequency above which it identifies the subject as hyperventilating

For sighing and irregular breathing:

- We can sample the frequency over a period of time (~10 seconds); which gives us 6 samples per minute
- Take the mean and the standard deviation
- Set a standard deviation over which it classifies the subject as breathing irregularly

Simulation: Irregular Breathing

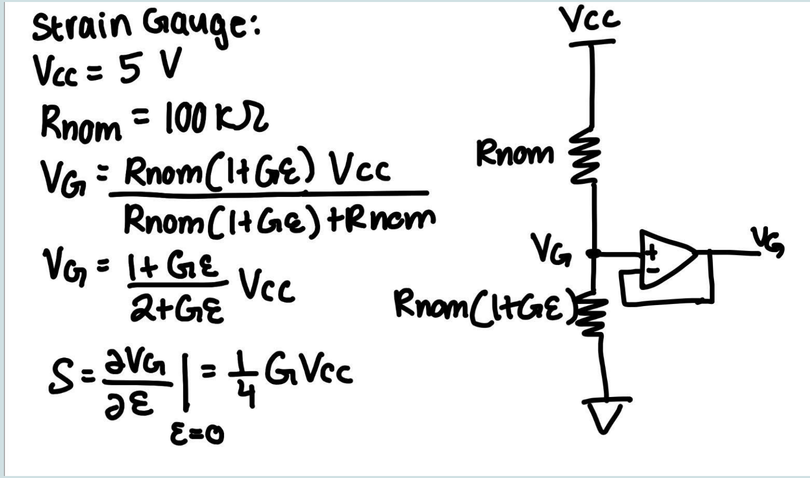


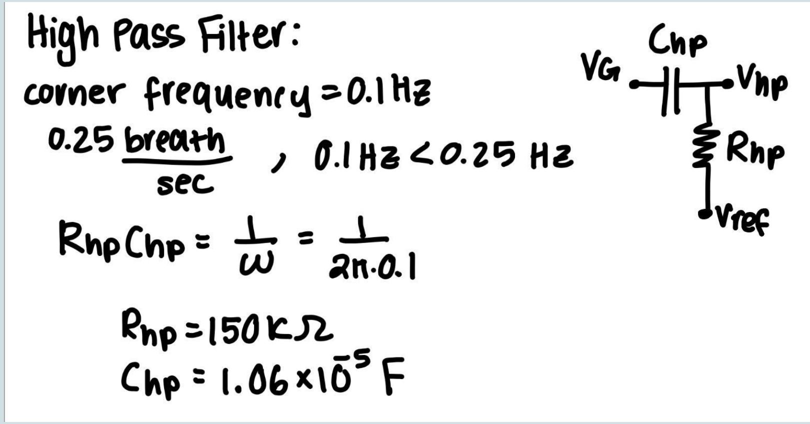
- Frequency: 0.33 Hz
- Amplitude: Vcc/2 = 2.5V
- Sighing and irregularity created by superimposing two sine waves of different frequency and amplitude

Circuit Design (1)

Strain Gauge

- More sensitive for very small displacements (changes in breathing pattern)
- Gauge factor (G) is the ratio of small relative changes in resistance and length
- Typically embedded in a voltage divider, or a differential voltage divider (Wheatstone bridge)
- Assuming nominal resistance of strain gauge and minimal effect from variance of environmental conditions

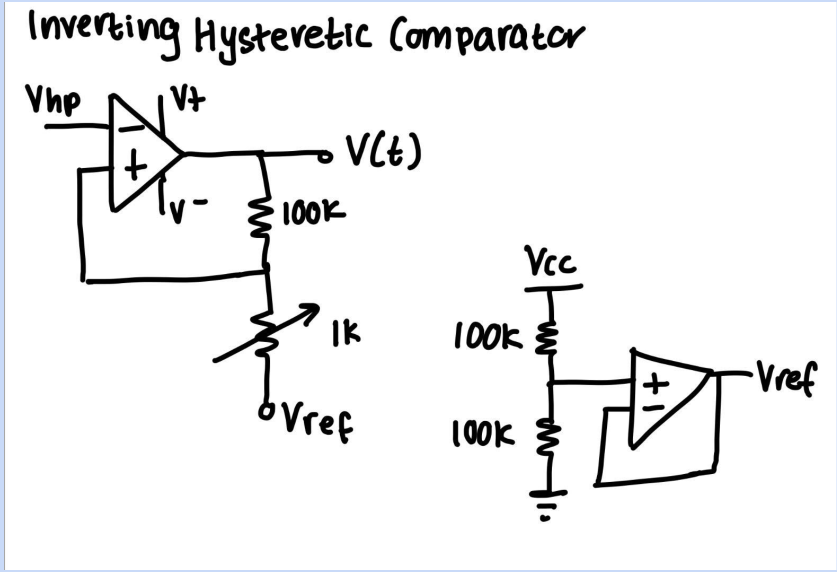




Circuit Design (2)

Comparator

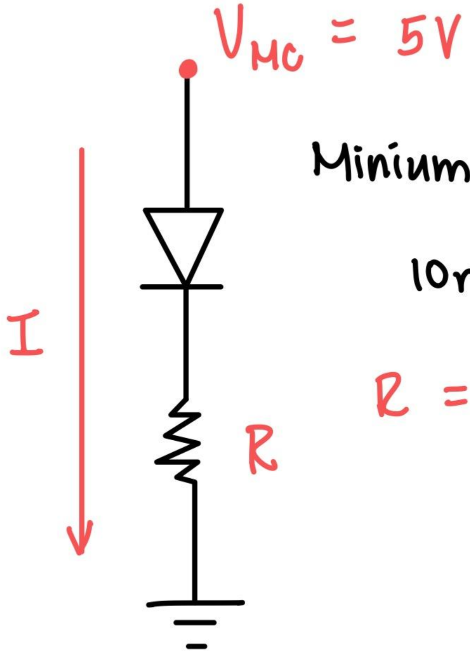
- Active circuit component
- Like Op-Amps but operate in the saturation region
- Assume all active circuit components in the design are ideal and strain outwardly on the skin = strain upon elastic band
- Design to **output positive amplitude voltage when breathing out and negative amplitude when breathing in**



Circuit Design (3)

LED Light

- The microcontroller outputs a voltage
- Sufficient current is required to light the LED



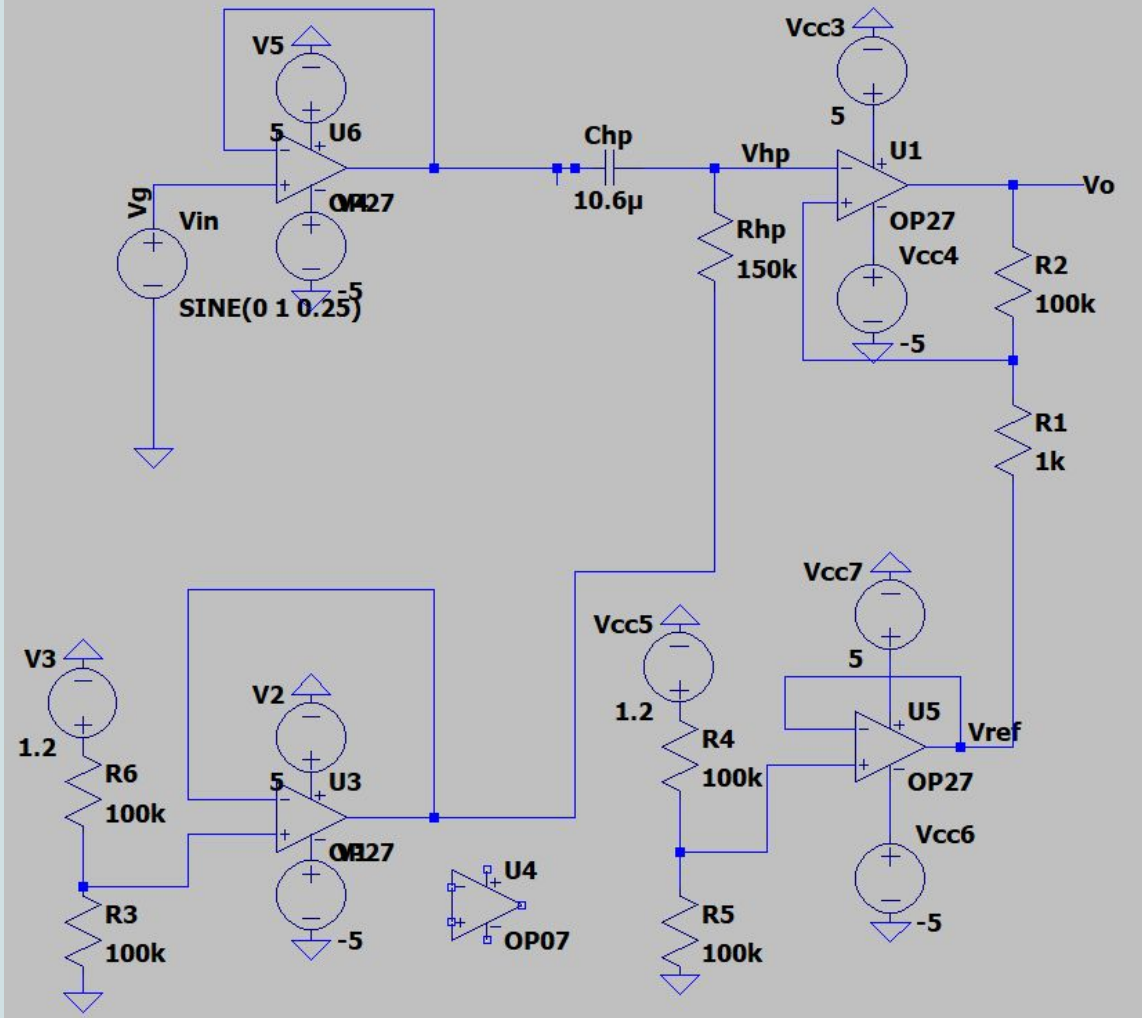
Miniumum I for LED: 10mA

$$10mA = 10 \times 10^{-3} A$$

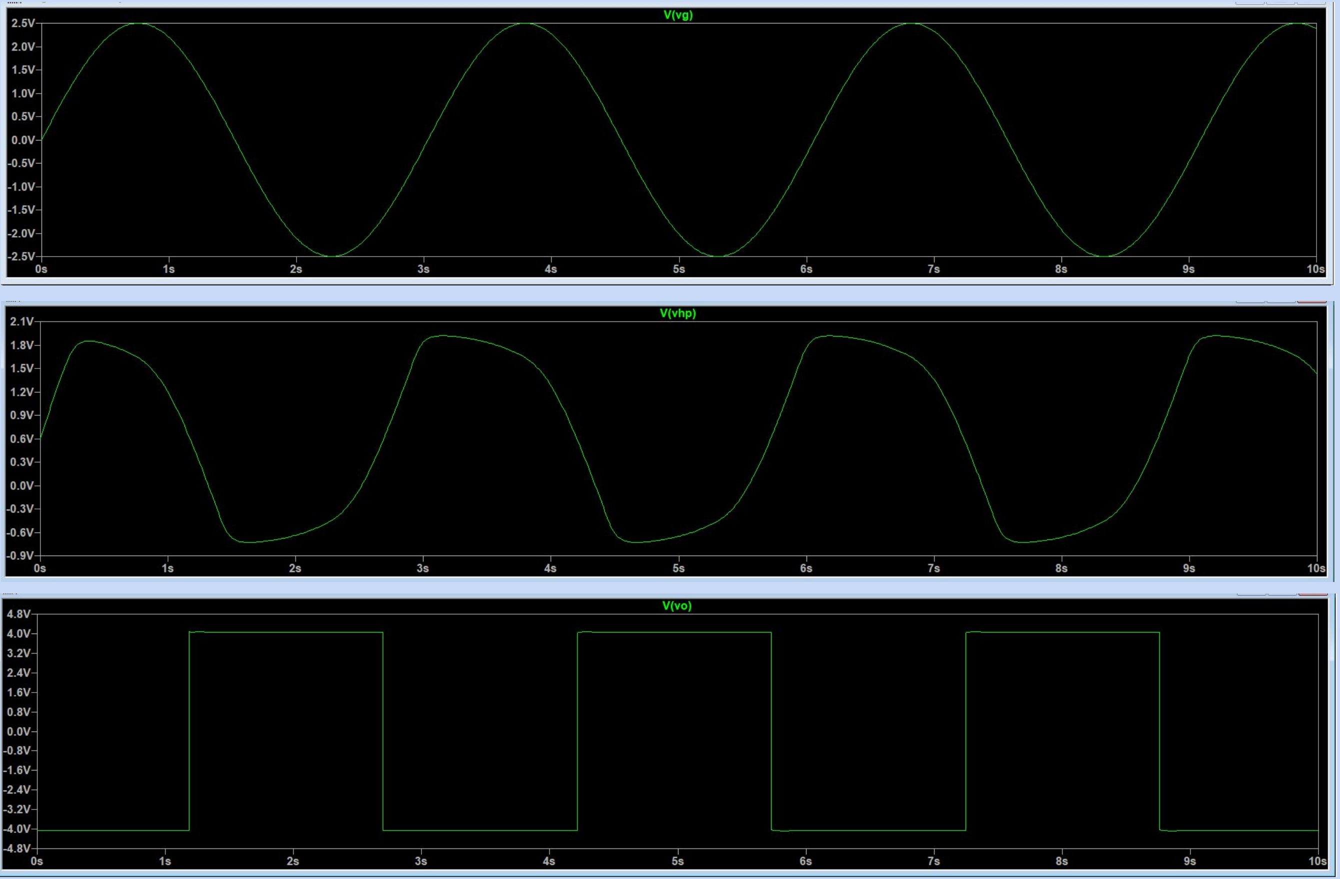
$$R = \frac{V_{mc}}{I} = \frac{5V}{10 \times 10^{-3} A} = 500\Omega$$

Circuit Model

- The voltage generated by the strain gauge is modeled using a sine function (Vin)
- Input Breathing Wave: Vg
- Output Wave: Vout



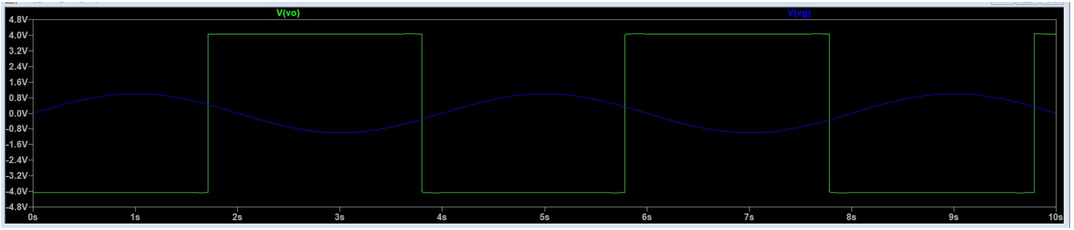
Simulation: Hyperventilation



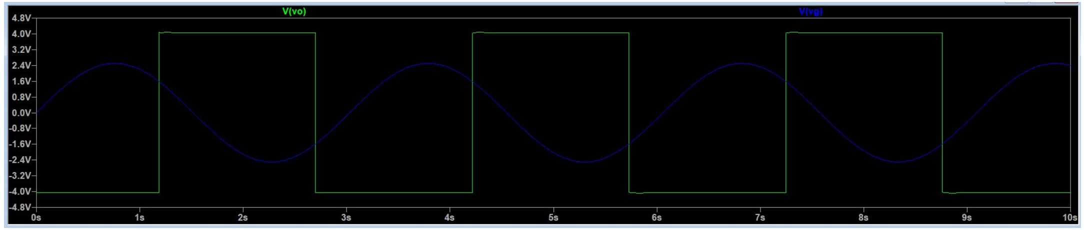
- Frequency: 0.33 Hz (20 breaths per minute)
- Amplitude: Vcc/2 = 2.5V

Preliminary Results

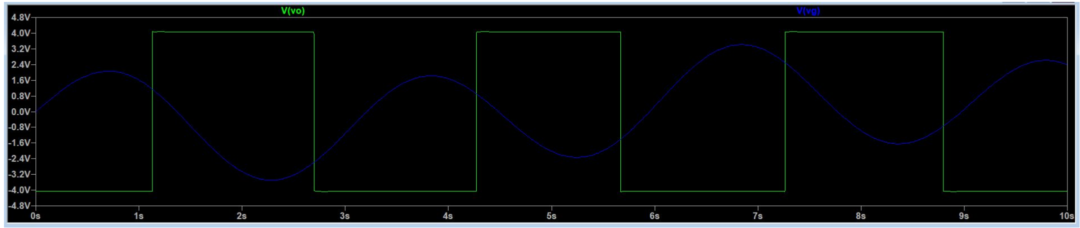
Normal Breathing



Hyperventilation



Sighing and Irregular Breathing



- Output is low when breathing in and high when breathing out
- The triggering rate and duration depends on the frequency of the input signal
- Hyperventilation can be determined by the frequency of the output wave.
- Sighing and Irregular breathing can be determined using the duration of the trigger.

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-troubleshooting our models

Citations

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