Biomedical Engineering

Novel Respiration Sensor for Real-Time Monitoring of At-Risk Individuals

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Context

What is respiration rate? Respiration rate is the number of breaths you take in a minute. The average adult has a respiration rate between 12-18 breaths per minute [1].
Why is respiration rate important? Bradypnea, or abnormally slow breathing, can indicate medical conditions such as heart problems, electrolyte imbalances, and even exposure to toxins such as carbon monoxide [2]. Tachypnea, or abnormally quick breathing, can be a symptom of COPD, pneumonia, sepsis, and allergic reactions [3].
What will our product provide? Our goal is to create a continuous respiration monitor which will monitor both rate of respiration and volume of respiration.

Problem Statement

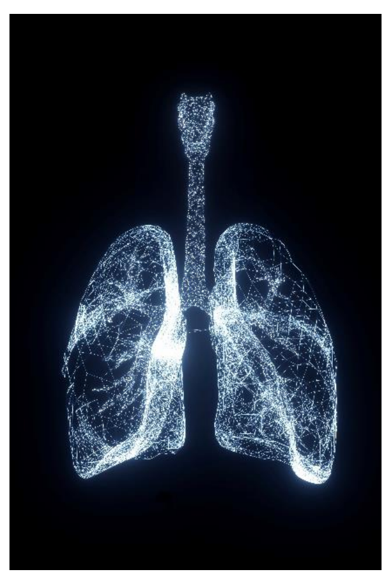
Sentinel has tasked our team with designing and prototyping a respiratory device that would aid health care workers, patients, and private individuals who are or may be at risk for respiratory diseases. The sensor must be:

1. **Cost-Effective**
2. **Comfortable for the User**
3. **Safe**
4. **Accurate**

Design Process

Determining the best way to measure respiration
We explored several methods of measuring respiratory volume and rate, including:

1. Capacitive sensing
2. Stress-strain feedback
3. Optical sensing
4. Bioimpedance



Bioimpedance was ultimately chosen due to:

- The portability potential of the required hardware
- High expected accuracy across a variety of subject positions
- Low-cost hardware and assembly
- Non-invasive nature
- Lack of cumbersome straps

Solution

Bioimpedance is a phenomenon in which the impedance of bodily tissue changes due to physiological processes, like blood flow and more importantly, respiration [4]. Using bioimpedance as method of tracking the respiratory activity of a subject requires that a small current is injected into the tissue of the subject's thorax via an electrode. A second electrode is required to measure the voltage drop across skin. The voltage drop can be used to calculate tissue resistance, which changes predictably with respect to breathing.

The device was designed to include five main blocks:

1. **A microcontroller (Raspberry Pi 3)**
2. **An impedance analyzer (AD5933)**
3. **A Howland constant current source**
4. **An instrumentation amplifier**
5. **Skin electrodes**

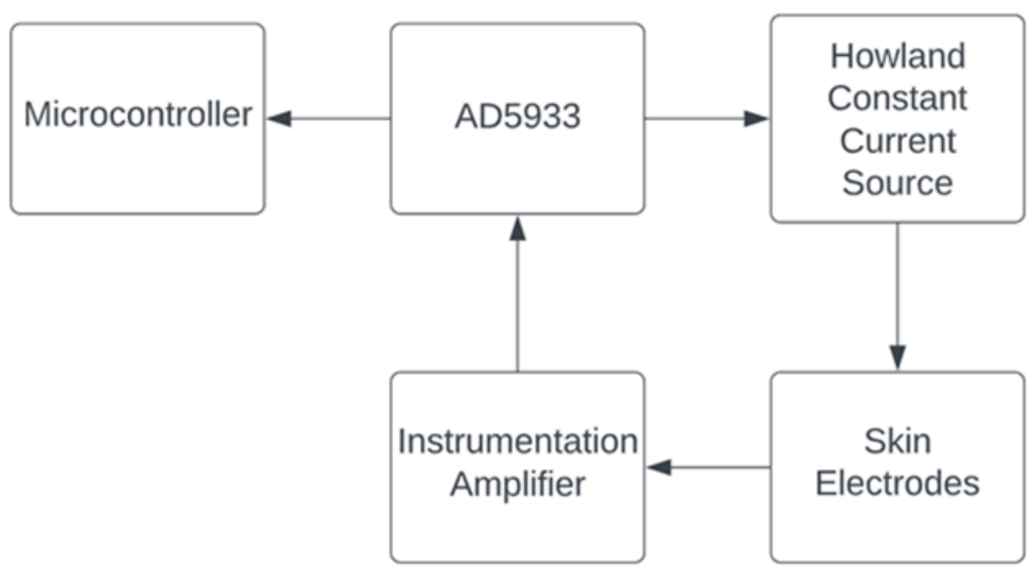
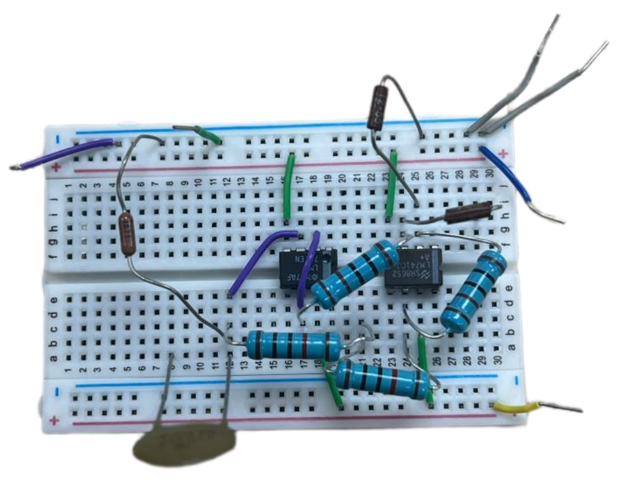


Figure 1: The block diagram for the designed sensor is shown. Source: Author

The circuit was designed in blocks, with each occupying its own breadboard. The current generator (top left) and the electrical model of the body (top right) were built on separate bread boards.

The AD5933 evaluation board (bottom right) is a stand-alone unit. The evaluation board in the AD5933 lends additional functionality to the unit to assist in programming.



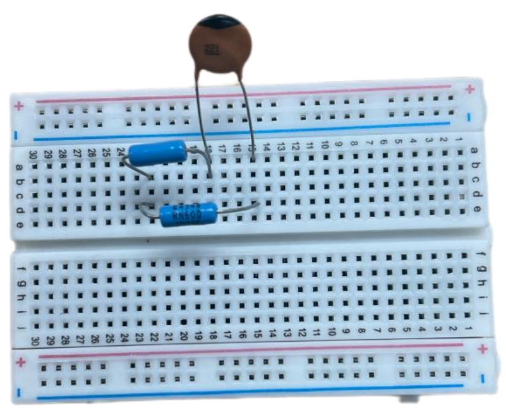
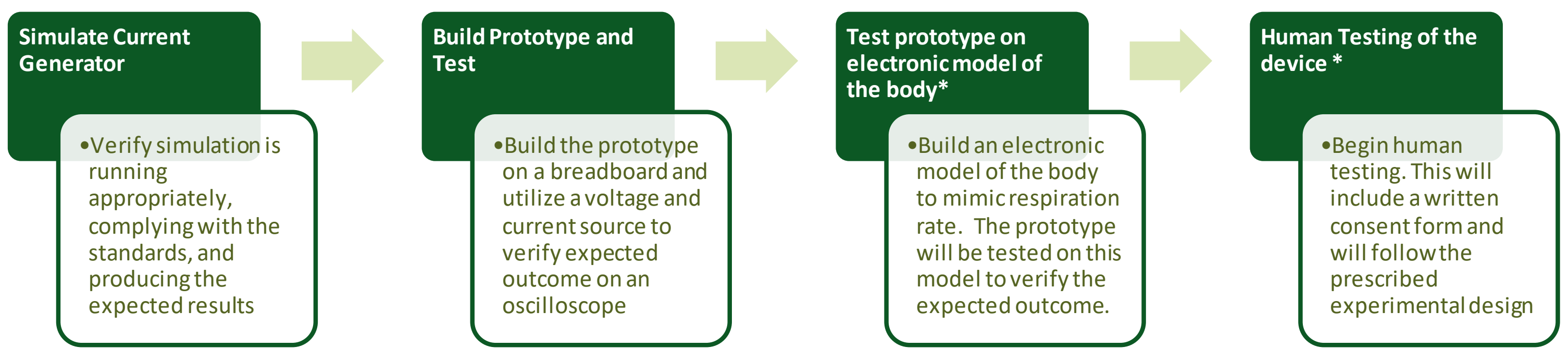


Figure 2 (top left): The Howland constant current generator is shown. Figure 3 (top right): The electrical model of the body for testing is shown. Figure 3 (bottom): The AD5933-based evaluation board used for advanced impedance testing. The EVAL-AD5933EBZ, with feedback and calibration resistors, is shown.

Results

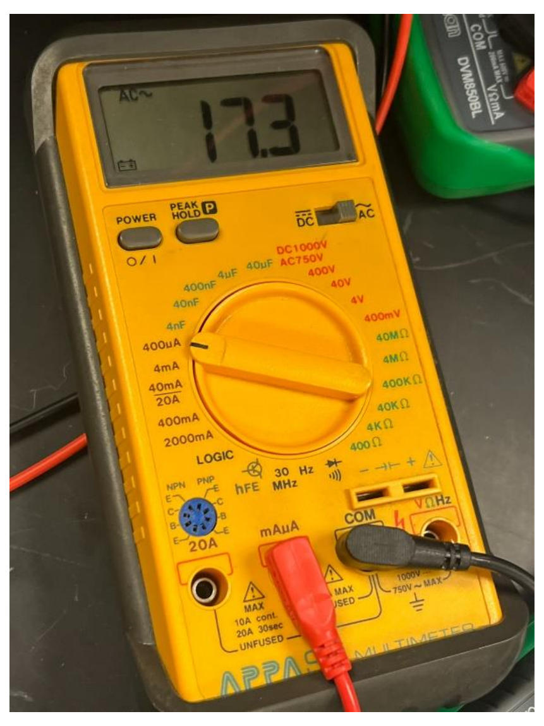
Below, our approach to testing our design is shown in a flow chart.



*Due to time constraints, these steps were not completed as a part of the Senior Design course. This portion of the results section was compiled into an Experimental Design Testing Plan and given to Sentinel.

Results (cont'd)

The Howland constant current generator was tested two ways in order to verify its safety for future use with human subjects. The circuit was first simulated using LTSPICE. Then the current generator was physically assembled, and its generated current for a variety of load resistances was verified using a digital multimeter (DMM).



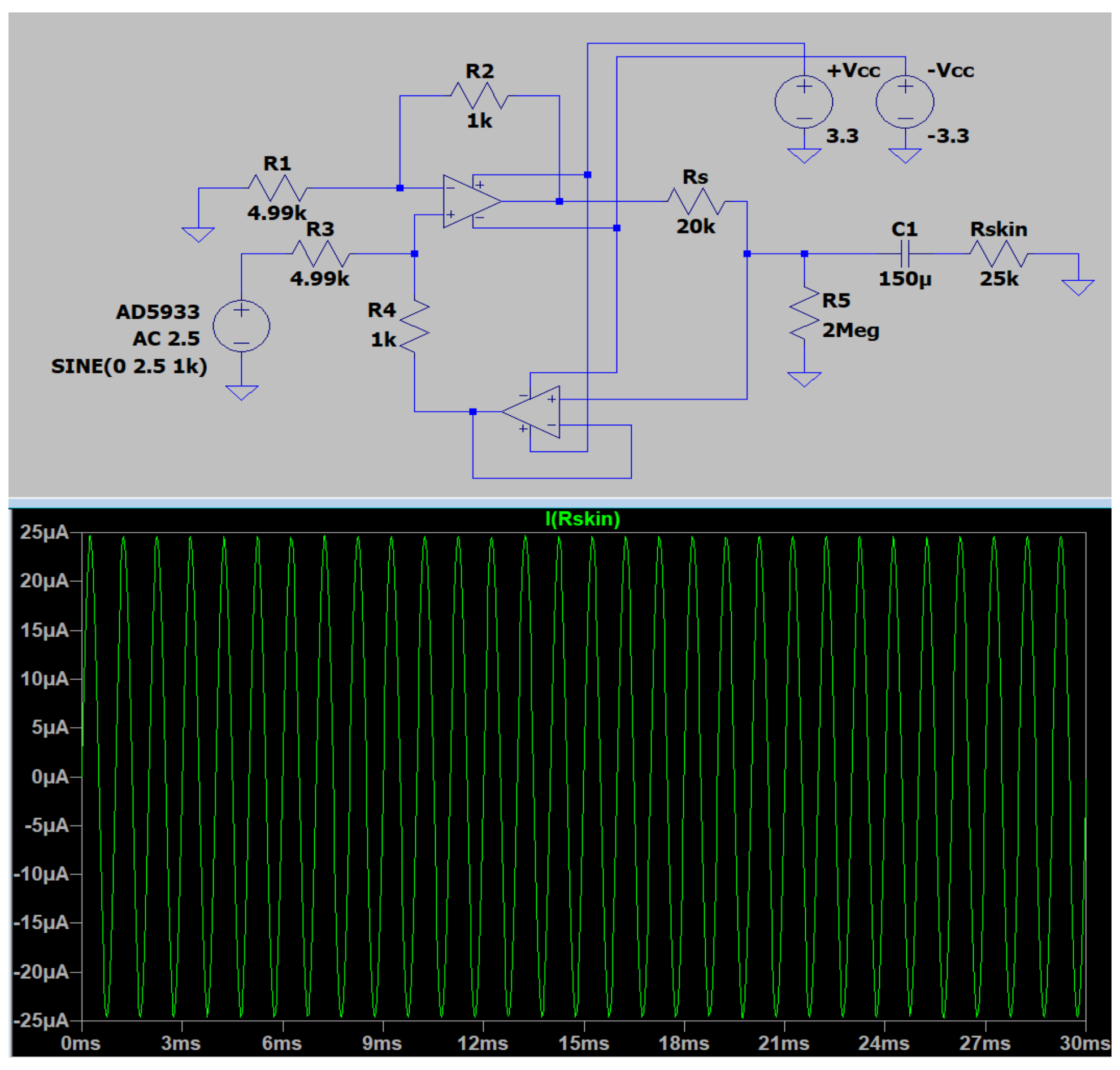


Figure 4 (above): A DMM displaying the measured AC current of the current generator, which was stable for several resistive loads (0-10 kΩ) is shown. Figure 5 (right): The simulated output of the current generator is shown. Source: Author

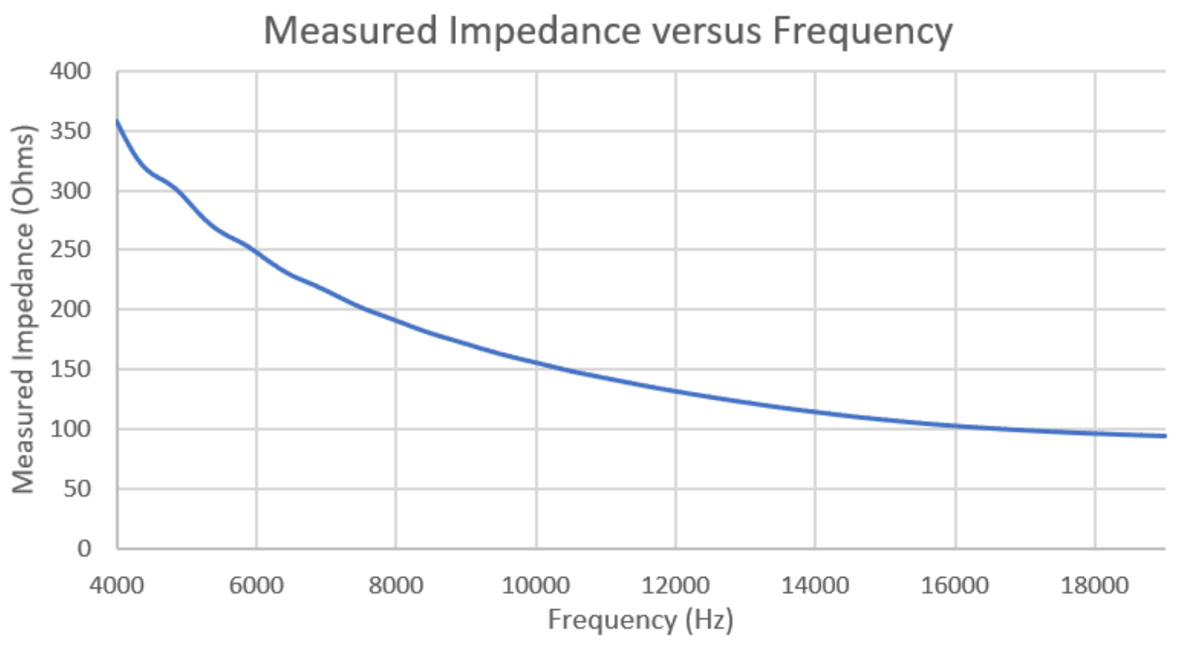


Figure 6 (above): The graph of measured impedance over a range of frequencies is shown.

The AD5933 evaluation board was used to conduct a frequency sweep, which the receiver side of the unit detected, resulting in impedance modulation. The obtained plot of impedance vs. frequency is shown on the left in Figure 6.

Discussion

The simulation of the current generator obtained in LTSPICE confirmed that the Howland constant current generator, as designed, should theoretically yield a consistent and IEC 60601-1 compliant 50 $\mu A_{P\text{-}P}$ (17.7 μA_{RMS}) current source for all load resistances. Physically assembling the Howland constant current generator and testing the current output over a variety of load resistances from 0 to 10 kΩ yielded analogous results, with a consistent current output of 48.9 $\mu A_{P\text{-}P}$ (17.3 μA_{RMS}). The safe and IEC 60601-1 compliant output supports that the generator is safe for human use as designed.

The frequency sweep conducted with the AD5933 evaluation board showed a modulating detected resistance, which indicates that the unit will be capable of detecting the impedance trends anticipated with breathing. Future exploration into the connectivity and functionality of the AD5933 unit, sans evaluation board, would allow for the incorporation of the other design blocks such as the instrumentation amplifier and microcontroller.

Consolidation of the Howland constant current generator, the AD5933, and instrumentation amplifier into a single PCB will allow for human factors tailoring of an encapsulating enclosure of an ergonomic size and shape.

Conclusions

The confirmed functionality and safety of the designed Howland constant current generator and the impedance trend sensitivity of our chosen AD5933 impedance-analyzer chip demonstrate a successful proof of concept for our proposed novel respiration sensor. If pursued further by Sentinel, next steps include assembling the device in a configuration that consists strictly of the impedance analyzer without the added functionality of the evaluation board. Such configuration will allow the device to be billed as a completely standalone, low-cost unit.

Following the complete assembly of the proposed design, testing using an electrical model of the body, namely the one featured in Figure 3 with supplied power, should be performed to further validate the design safety. Finally, human testing should be pursued to validate the device's capability of detecting real biological signals. Processing algorithms and Bluetooth connectivity may be added features of interest for Sentinel.

Ultimately, the novel sensor design succeeded in its role as a proof-of-concept exercise for a low-cost respiratory health wearable.

Acknowledgements

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References

[1]. *Vital Signs: How to Check My Vitals at Home*. (n.d.). Cleveland Clinic. https://my.clevelandclinic.org/health/articles/10881-vital-signs#:~:text=Your%20respiratory%20rate%2C%20or%20your
[2]. *Bradypnea*. (2023, March 17). Cleveland Clinic. https://my.clevelandclinic.org/health/symptoms/24832-bradypnea#possible-causes
[3]. Cleveland Clinic. (2022, September 9). *Tachypnea (Tachypneic): Symptoms & Causes*. Cleveland Clinic. https://my.clevelandclinic.org/health/symptoms/24124-tachypnea
[4] Khalil, S., Mohktar, M., & Ibrahim, F. (2014). The Theory and Fundamentals of Bioimpedance Analysis in Clinical Status Monitoring and Diagnosis of Diseases. Sensors, 14(6), 10895–10928. https://doi.org/10.3390/s140610895