Wearable Bioimpedance Device

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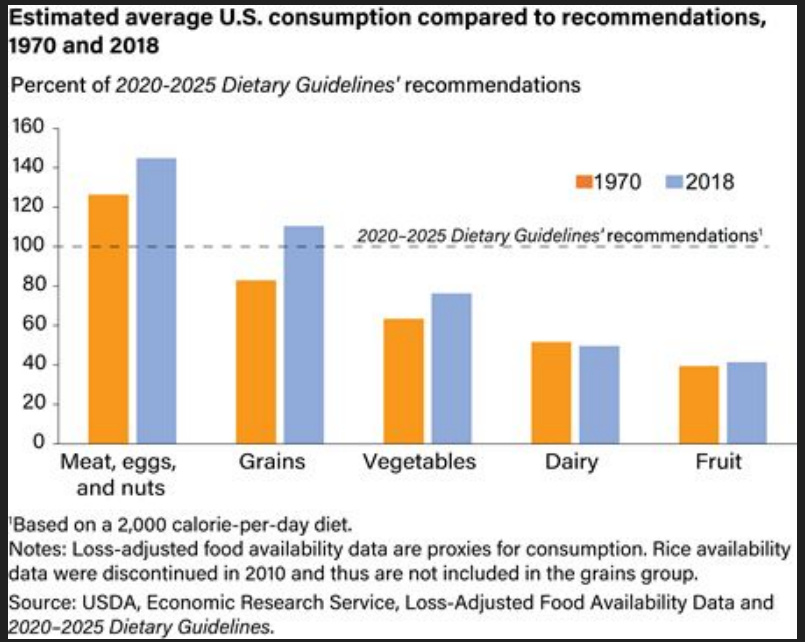
Food Consumption in the US

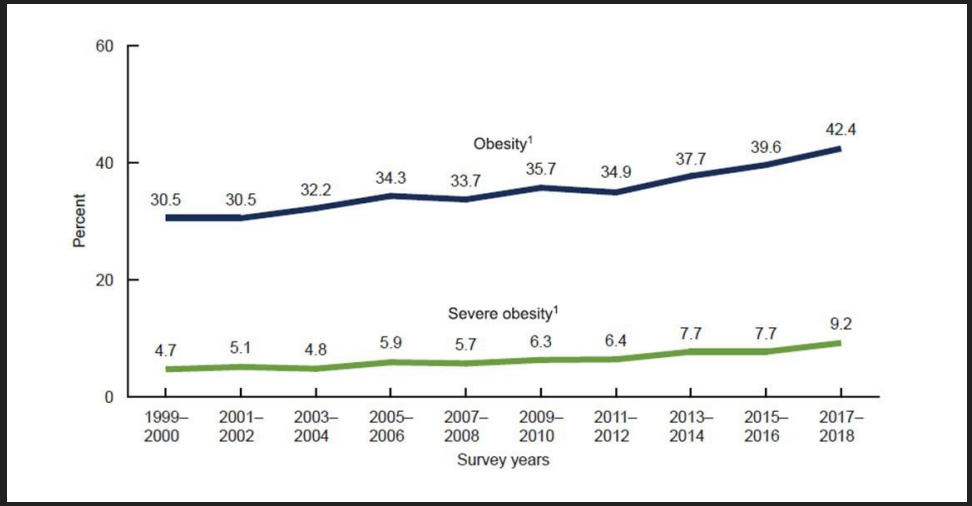
- Americans are consuming food at rates higher than recommended dietary standards.
- From the 1970's until now, this has steadily increased, showing no signs of slowing down.
- An increasingly interconnected market sponsors the rise of various new cuisines, which indulges Americans to consume more food.



[1] USDA ERS - Food Availability and Consumption

Problem: Obesity Epidemic

- Obesity and severe obesity of adults in the US has continued to grow over 20 years.
- Consequences of obesity include heart disease, cancer, stroke, and type II diabetes
- Obesity is widely known as a cause for premature death.



[2] Adult Obesity Facts | Overweight & Obesity | CDC [3] Overweight & Obesity Statistics - NIDDK (nih.gov)

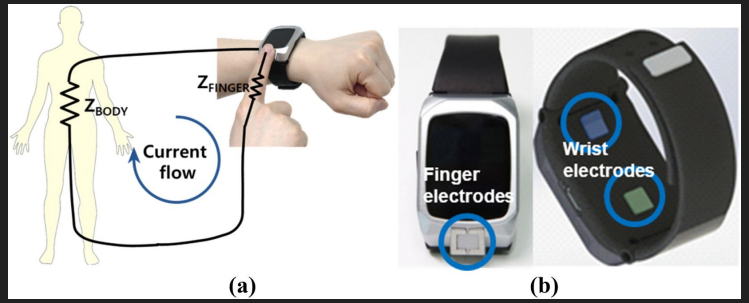
What can you do about it?

= healthy body weight

TRACK IT!!!

Bioelectrical impedance analysis (BIA)

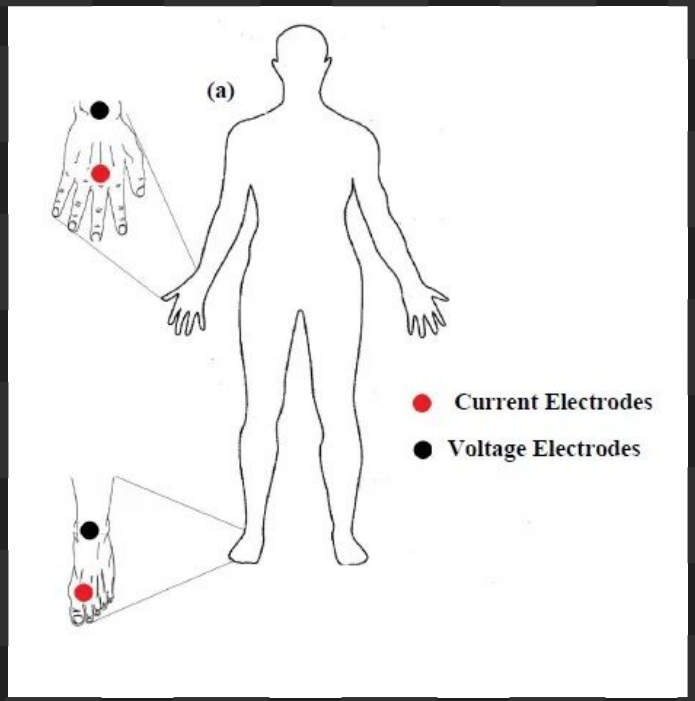
- Bioelectrical impedance analysis (BIA) is a method which determines a subject's fat-free mass (FFM) and total body water (TBW).
- Since the 1990's, BIA has become an easily accessible household method
  - ease of use
  - portability
  - Harmless procedure



(a) Directional loop of current of device and body
(b) Device electrode placement

[4] Bioelectrical impedance analysis—part I: review of principles and methods - ScienceDirect
[5]https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.nature.com%2Farticles%2Fs41598-020-79667-3&psig=AOvVaw1fvWqNWcwWXLj-koRlvls-&ust=1678721986202000&source=images&cd=vfe&ved=0CA8QjRxqFwoTCNiGr-_c1v0CFQAAAAAdAAAAABAX

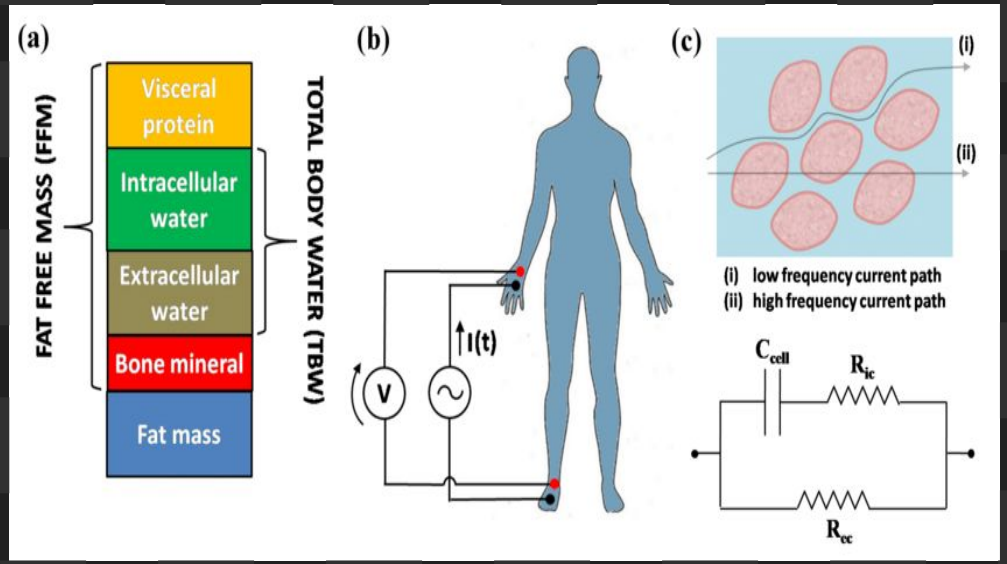
Methods: How does bioimpedance analysis work?



- Core principle of BIA: Finding voltage drop across the body to deduce body composition
- Accomplished by running a small current through body and measuring the voltage drop
- This works because body fat has greater resistance than lean mass/muscle
- Muscle, fat and bone all have different electrical conductivity so we can deduce the composition based off the speed of the current.

[6] Instructables-BIA

Methods Continued



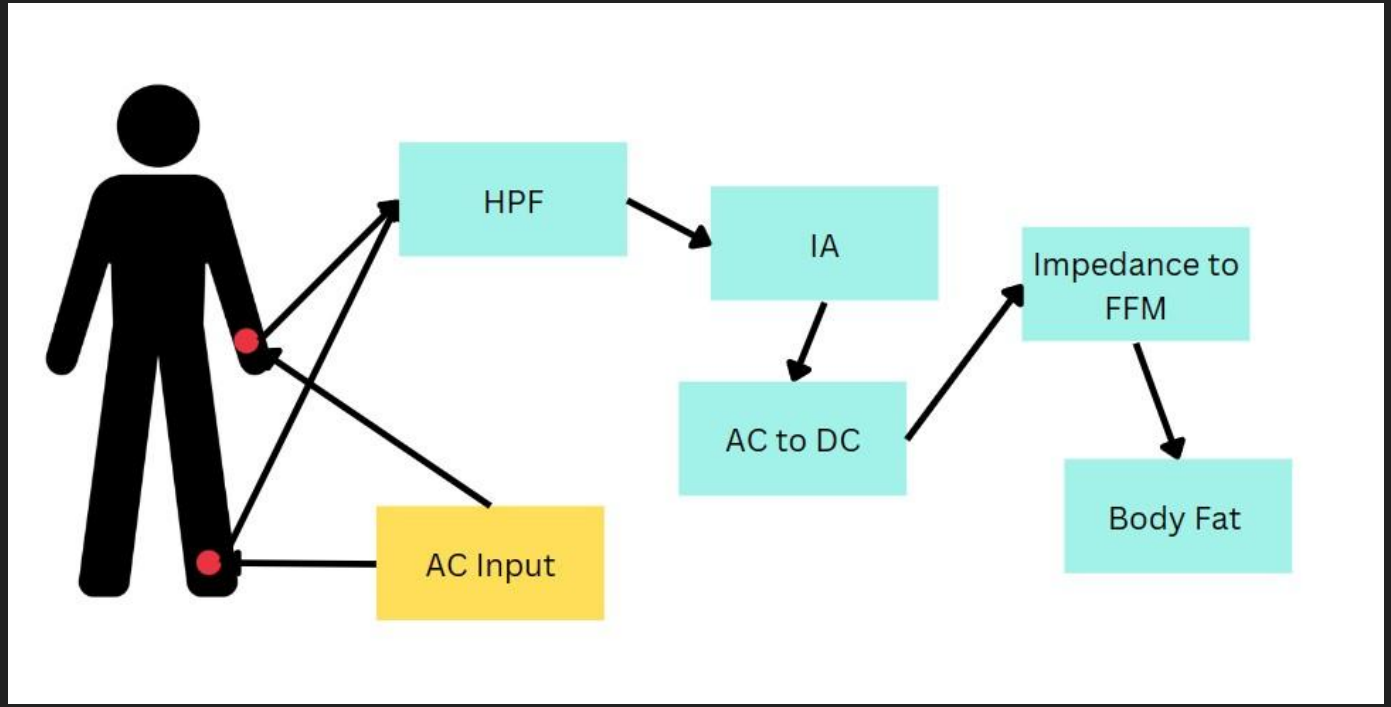
- Voltage drop is amplified using Op-Amps
- Difference between initial and final voltage is plugged into body impedance to body composition relationship equation
- Voltage drop then analyzed to find fat free body mass which is then subtracted from weight of subject to find fat mass

Fat Free Mass Equation:

$$FFM = -4.104 + \left(0.518 \times \frac{2 \cdot Height}{Resistance}\right) + (0.231 \times weight) + (0.130 \times reactance) + (4.229 \times Gender: Male = 1, Female = 0)$$

[7] Researchgate-BIA

System Design

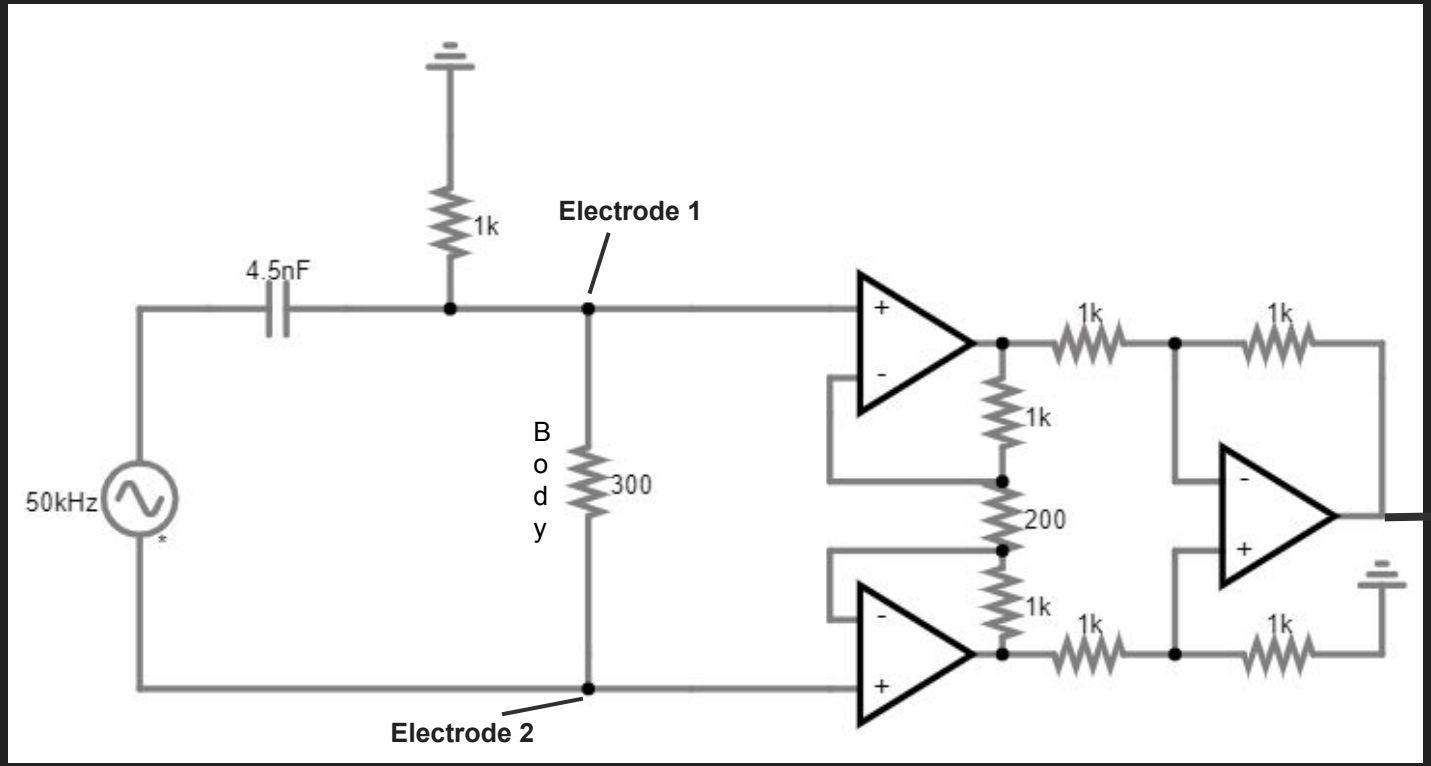


Assumptions and Parameters

- Imperative to generate a small AC current for safety - 0.1mA was chosen
- Optimal conditions depend on hydration and resting physiological conditions
  - Subject should not:
    - drink alcohol within 48 hours
    - engage in more than light physical activity within 12 hours
    - consume liquids or food within 4 hours
    - Urinate within 30 minutes
- 50kHz is primarily used for single frequency BIA [4]
- 300Ω body impedance was chosen as the minimum to account for subjects outside of the normal range of body impedances

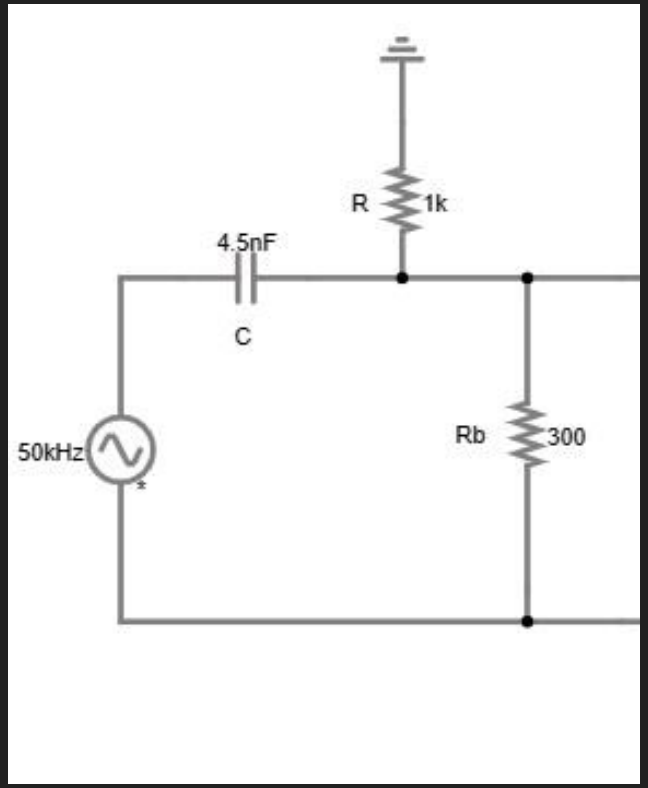
[4] Bioelectrical impedance analysis—part I: review of principles and methods - ScienceDirect

Circuit Design



[6] Conduction of Electrical Current to and through human body

Stage 1: Source, Body, High Pass Passive Filter



- Source: 50kHz and 0.035V, high frequency is safe for humans, low voltage induces low current in body
- HPF used to attenuate unwanted low-frequency noise from tissue capacitance
- Improves SNR and accuracy of impedance measurement

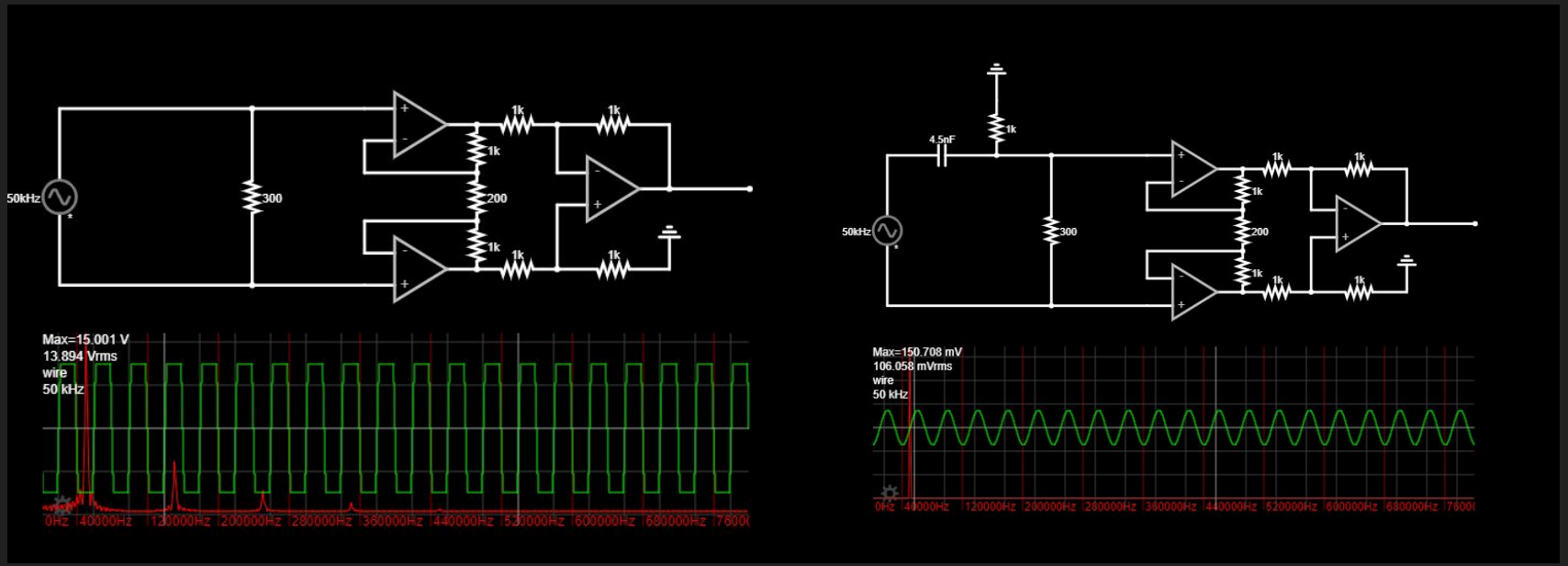
Noise Reduction with HPF

Without filter

- Integrity of the signal is affected by noise

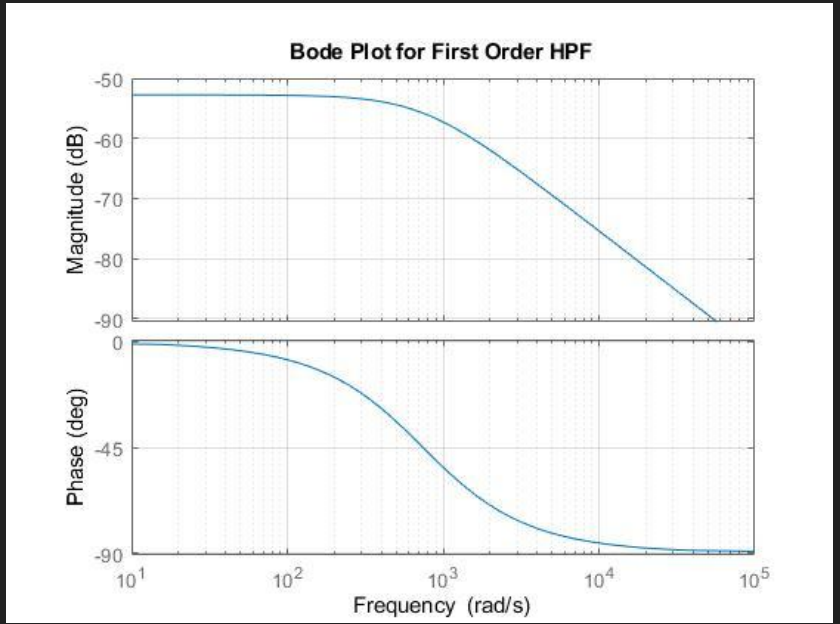
With filter

- Signal is not compromise by noise and normal oscillations are observed at 50kHz



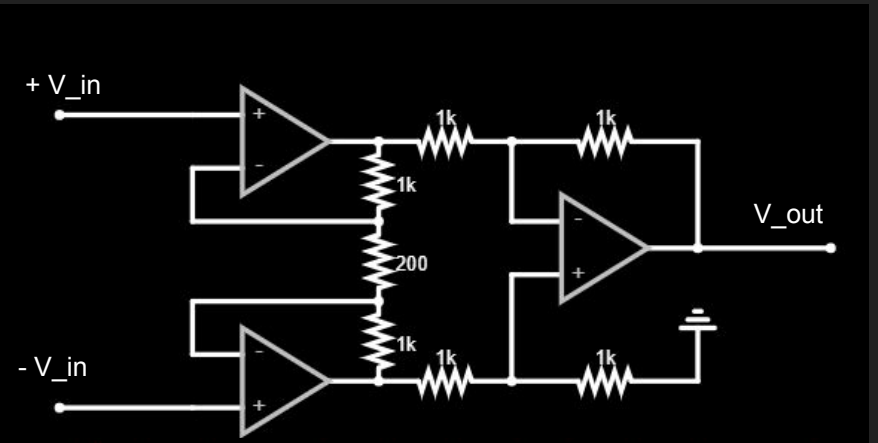
Transfer Function and Bode Plot of Stage 1:

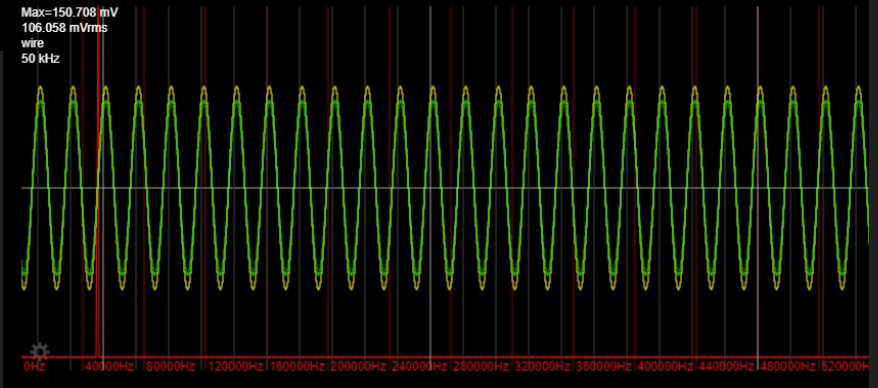
$$H(s)_1 = \frac{1}{(sR_bC + 1)(\frac{R}{R_b + R})}$$



- Rb = 200Ω, C = 4.5nF, R = 1kΩ
- Slope of -20 dB/decade
- Cutoff frequency is where the magnitude response drops by 3dB, approximately 1187Hz
- Phase plot approaches -90 degrees as frequency increases above cutoff frequency

Stage 2: Practical Instrumentation Amplifier (non-inverting)

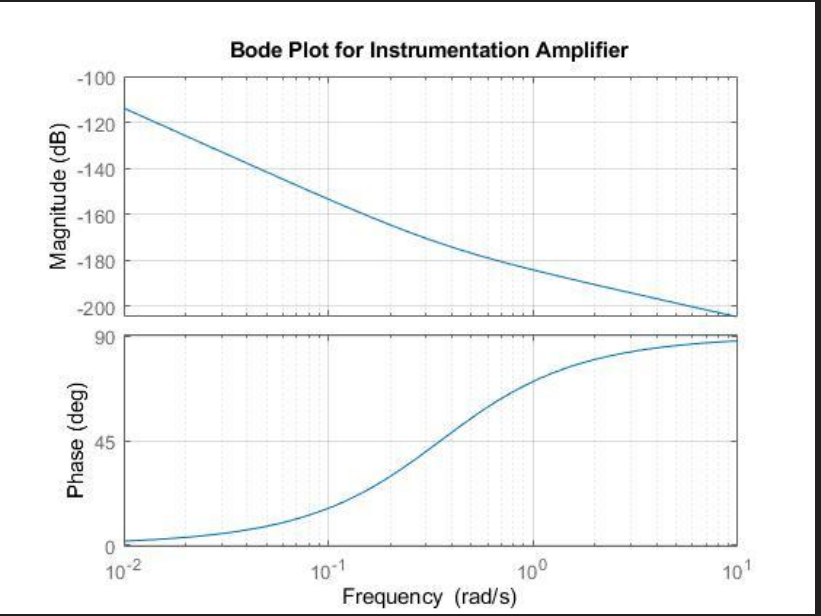




- Provides high-precision amplification of low level signal coming from the electrodes place on the skin
- Its purpose is to accurately measure the electrical impedance of biological tissue (helps determine the hydration level)
- Eliminates noise obtained from the electrodes (Common-mode rejection)

Transfer Function and Bode Plot of Stage 2:

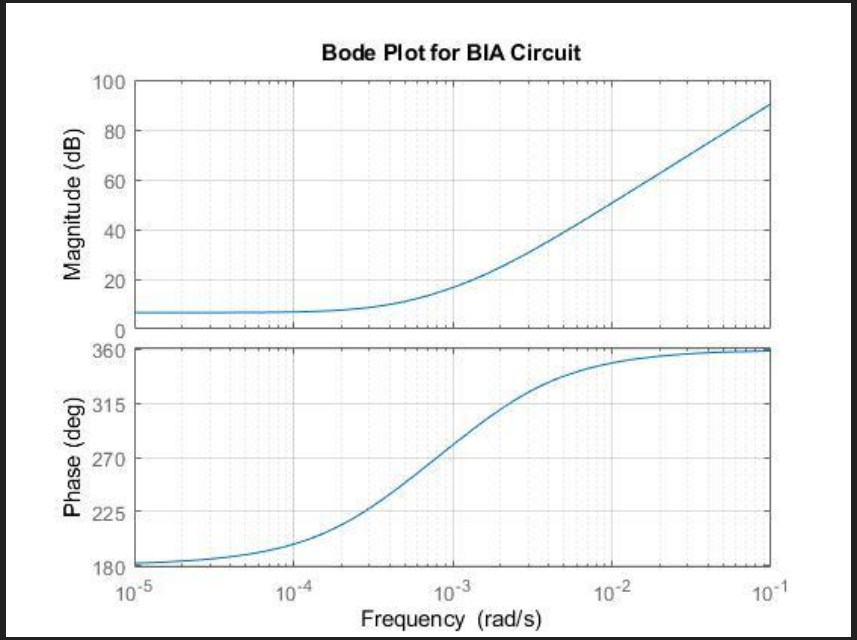
$$H(s)_2 = \frac{-\left(\frac{R_3}{R_G}\right)(1 + sR_2)}{\frac{(sR_1 + 1)}{(sR_5 + 1)(sR_6 + 1)}}$$



- R1 = R2 = R3 = R5 = R6 = 1kΩ; RG = 200Ω
- Follows HPF response with corner frequency determined by resistors
- Gain decreases as frequency increases
- Phase shift occurs at -45 degrees at the cutoff frequency

Transfer Function and Bode Plot of BIA Circuit:

$$H(s) = \frac{R + R_b}{R(CR_b s + 1)} - \frac{R_3(sR_2 + 1)(sR_5 + 1)(sR_6 + 1)}{R_g(sR_1 + 1)}$$



Theoretical Voltage Gain

$$\frac{V_{out}}{V_{in}} = \left(\frac{R_3}{R_2}\right)\left(\frac{2R_1 + R_{gain}}{R_{gain}}\right) = 11$$

Therefore, it is expected to obtained an overall voltage output of 150 mV

From Voltage to Fat-Free Mass

- Gain = 11 = $A_v = \frac{V_o}{V_2 - V_1}$, Output voltage = 150.708 mV

- Voltage Difference = 13.636 mV, Current across resistor = 44.883 μA
- V = IR
- R = 303.8 Ω
- Real Value = 300 Ω
- Percent error = 1.27%
- Plug resistance into FFM equation
- measured mass - FMM = body fat

$$FFM = -4.104 + (0.518 \times \frac{2 \cdot Height}{Resistance}) + (0.231 \times weight) + (0.130 \times reactance) + (4.229 \times Gender: Male = 1, Female = 0)$$

Discussion

a. Simulation Analysis

- Frequency tested of 50kHz yield normal oscillation; we can assume that noise will not affect the integrity of the signal
- Theoretical value for the voltage output give 150.722mV, however the simulation showed an output slightly less

b. Benefits and Limitations

- Our circuit design contains noise minimizing effect in two areas; the frequency filter and the instrumentation amplifier. This allow the individual to wear the device while doing daily activities.
- The limitations of our design is that it is composed of two electrodes, therefore, only half of the body is measure. The other half will have to be estimated compromising the precision.

Conclusion

The overarching health issue that our wearable Bioelectrical impedance analysis (BIA) device seeks to address is obesity. Obesity can result in the emergence of serious health complications and is brought on by bad diets, physical inactivity, and hereditary predispositions.

Essentially, the device measures impedance (resistance) by sending a weak electric current through the body, and the voltage difference is then measured.

Utilizes a circuit design that has an inverting operational amplifier and an instrumentation amplifier.

Perturbations:

- Still needs to be tested on actual human body
- Age/gender
- Resting metabolic state
- Hydration level(Can skew data/results)

Conclusion (continued)

What we aim to accomplish with our device:

- Have it be affordable/accessible
- Although we want our device to primarily help those who suffer from obesity we also aim to have it be of help to every citizen regardless of health
- Using our circuit design we will also be able to manufacture things like a device for electrical muscle stimulation(for therapy and recovery)

All in all, we want our wearable bioimpedance device to be known as a common appliance/gadget that can be used by practically anyone who chooses to. It will provide users with a detailed breakdown of their body composition with the click of a button, thus giving them a sense of where their overall health is. Taking into account the accessibility and convenience of this device, we are certain it will be on the wrists of almost everyone in years to come.

References

[1] Food availability and consumption. USDA ERS - Food Availability and Consumption. (2023, January 26). Retrieved March 12, 2023, from https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-availability-and-consumption/

[2] Centers for Disease Control and Prevention. (2022, May 17). Adult obesity facts. Centers for Disease Control and Prevention. Retrieved March 12, 2023, from https://www.cdc.gov/obesity/data/adult.html

[3] U.S. Department of Health and Human Services. (2021, September). Overweight & Obesity Statistics - Niddk. National Institute of Diabetes and Digestive and Kidney Diseases. Retrieved March 12, 2023, from https://www.niddk.nih.gov/health-information/health-statistics/overweight-obesity

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[5] Jung, M. H., Namkoong, K., Lee, Y., Koh, Y. J., Eom, K., Jang, H., Jung, W., Bae, J., & Park, J. (2021). Wrist-wearable bioelectrical impedance analyzer with miniature electrodes for daily obesity management. Scientific Reports, 11(1). https://doi.org/10.1038/s41598-020-79667-3

[6]Fish RM, Geddes LA. Conduction of electrical current to and through the human body: a review. Eplasty. 2009 Oct 12;9 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763825/

[7] *Bioelectrical Impedance Analysis (BIA) Principle of Work*. https://www.researchgate.net/figure/Bioelectrical-Impedance-Analysis-BIA-principle-of-work_fig5_319317929.