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Bioelectrical Body Fat Analyzer

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***Abstract**: For our project, we are using the microcontroller provided to make a device that would measure body fat percentage of human body. The basic principle behind the project is known as bioelectrical impedance analysis. This technique uses a small alternating current(AC) flowing between two electrodes attached to skin surface to determine impedance. By determining the opposition to the electric current through body tissues, we can easily estimate the water content of the human body and use it to estimate fat-free body mass. The V-I response characteristics of these tissues can provide a good estimation of percentage body fat.*

***Keywords:** opto-isolator,BIA, TBW, FFM, FM and BMI.*

I. Introduction

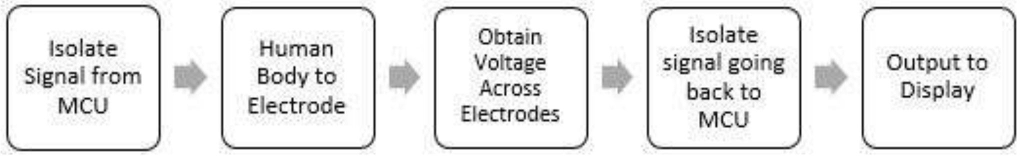
It has always been easy to record human's weight loss. However, it is more tedious to measure human's body fat percentage. Certain methods include skin callipers and hydrostatic underwater weighing which are difficult. One can also roughly estimate their body fat percentage by looking in the mirror. However bioelectrical impedance analysis provides a quick and simple method to estimate one's fat content. The inspiration of this project is to promote personal health and to track daily workout progress.

Obesity poses a high risk factor by welcoming diseaseslike coronary artery disease, hypertension, type II diabetes,pulmonary disease, osteoarthritis etc. Bioelectrical-Impedance Analyzer (BIA) gives opportunity to makedifferentiated diagnosis and forms the basis for treatment.This is possible by precise measurement of Fat mass (FM),Fat Free Mass (FFM) and Total Body Water (TBW).

The major component of the human body is water. Thefat and protein component are relatively small, withreminder being primarily bone and minerals. The FFM is thechief structural and functional component of human body.

FFM – water =72%; protein =21% & bone minerals=7%.FM consists of 20% water, 80% adipose (fat) tissue and in obese persons this adipose is the largest component.[1]

II. Logical Structure



2.1 Hardware and Software Tradeoffs:

For this project, the amount of hardware complexity was required in order to achieve basic functionality of the model, and could not be translated into software. One piece that could have simplified hardware complexity that would be the use a 555 timer IC or other oscillator to generate the input signal to the subject rather than the microcontroller.This oscillator could be switchedoff of the same power source as the rest of the biological side of the circuit, it can eliminate the need for the input signal isolation. However, this increases the difficulty of adjusting frequency. For this reason, we opted to use the microcontroller to generate signal rather than doing it with other hardware. While this increased hardware complexity, we felt that the ease of signal control gained by the MCU was worth the trade-off.

The major hardware as well as software trade-off was in taking user's input. Currently, the setup of our project takes user's input from a computer UART terminal. The more hardware based alternative would be to take user's input from a keypad. While a keypad improves device portability, it is also a less reliable input method and would restrict the software to a state machine based design.

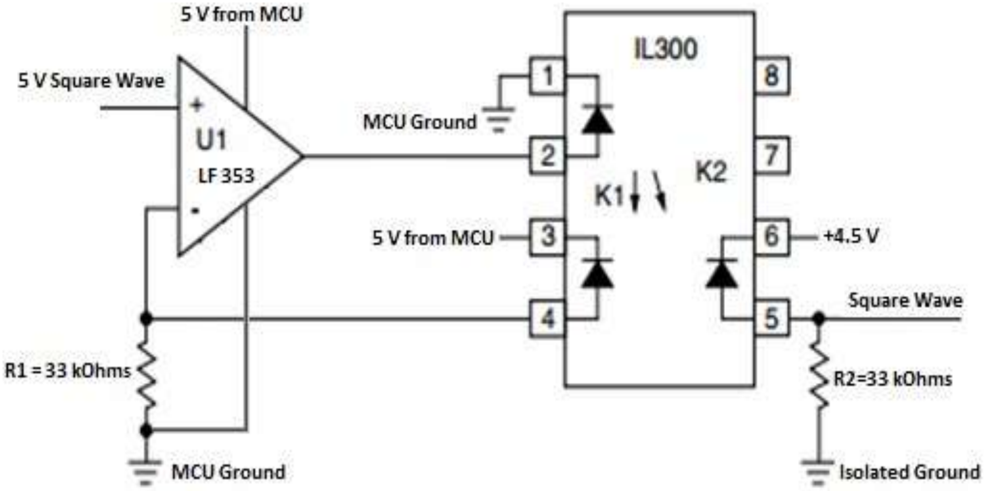
In further part we will be studying the hardware and software of our project.

III. Hardware

Hardware consists of :
1.Optoisolator Circuit.
2.Human Impedance Circuit.
3.Split Supply Circuit.
4.Optoisolator With LPF.

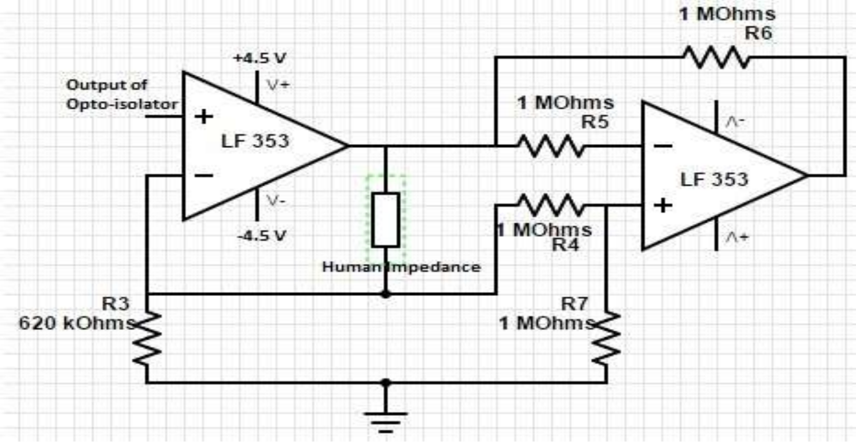
3.1 Step by step description of hardware used:

3.1.1 Isolating signal from MCU:



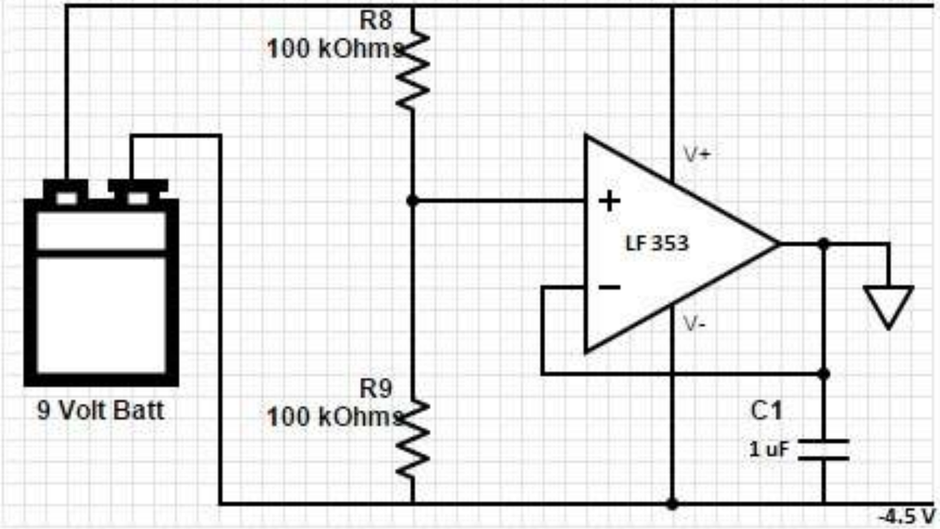
In order to isolate the user from the 110 V ground line from the Microcontroller power supply to guarantee user's safety, the circuit in above figure is used. The linear optocoupler (IL 300) is fed back into a control amplifier which determines the output of the LED in the IL 300. This controls the behaviour of the photodiodes in the optocoupler to follow the input signal. By setting the two resistors (R1 and R2) equal to each other, we obtain a unity gain so the output and input signals are equal. Since the purpose of the circuit is to isolate the input signal to the user, we must be able to use the rails from the MC unit on one side of the opto-isolator and a separate set of power rails for the other side of opto-isolator.

3.1.2 Get voltage across two electrodes:



The first step of the circuit is the current(I) source that takes in the isolated 50 kHz signal from signal generator and generates 10 uA current source at 50 kHz frequency. The resistor from the negative terminal to ground (R3) is in shuntwith the human impedance which forms a divider(voltage divider). This allows us to choose R3 so that we can get the constant current across two electrodes. The second stage of this circuit is the voltage subtractor which gives us the voltage across the electrodes (represented by the resistor labelled as human impedance). By making resistors R4=R5=R6=R7, the circuit behaves as a unity gain differential amplifier(gain=1) so the output of this amplifier is simply the voltage difference of the two electrodes.

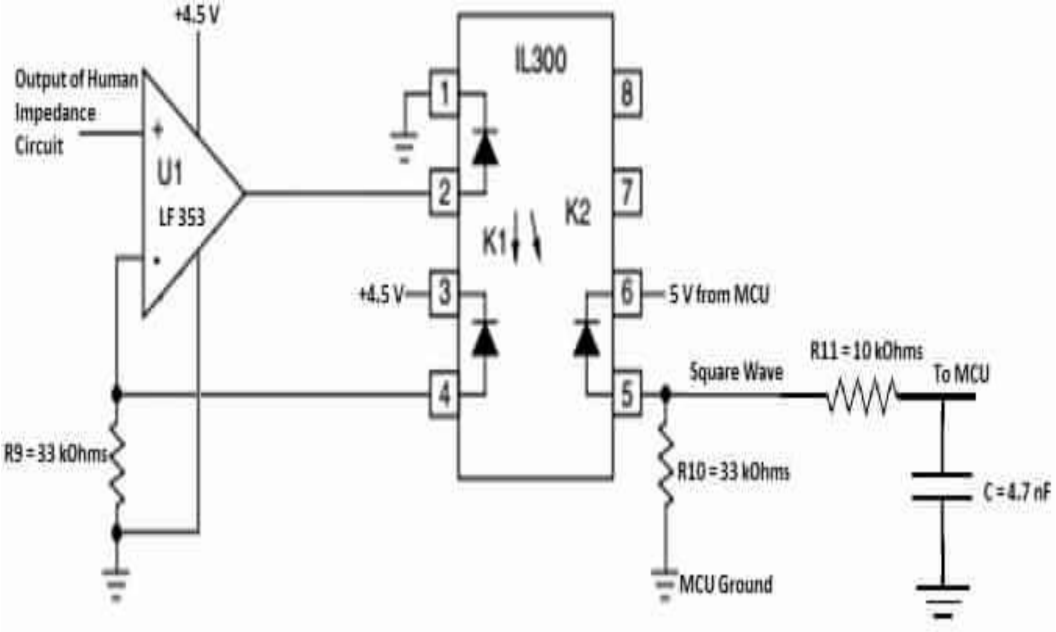
3.1.3 Split 9V battery supply:



In order to get the +4.5 V and -4.5 V rails, the circuit in above figure was used. The 9 V battery is essentially divide into the two rails through the voltage divider (the two 100 kohm resistors) with the output of the op-amp acts as virtual ground. The

1 uF capacitor removes noise in power rails. This is the way, these isolated rails can be used for the IL 300 (linear optocoupler) and the human impedance circuit.

3.1.4 Isolating signal back to the MCU :



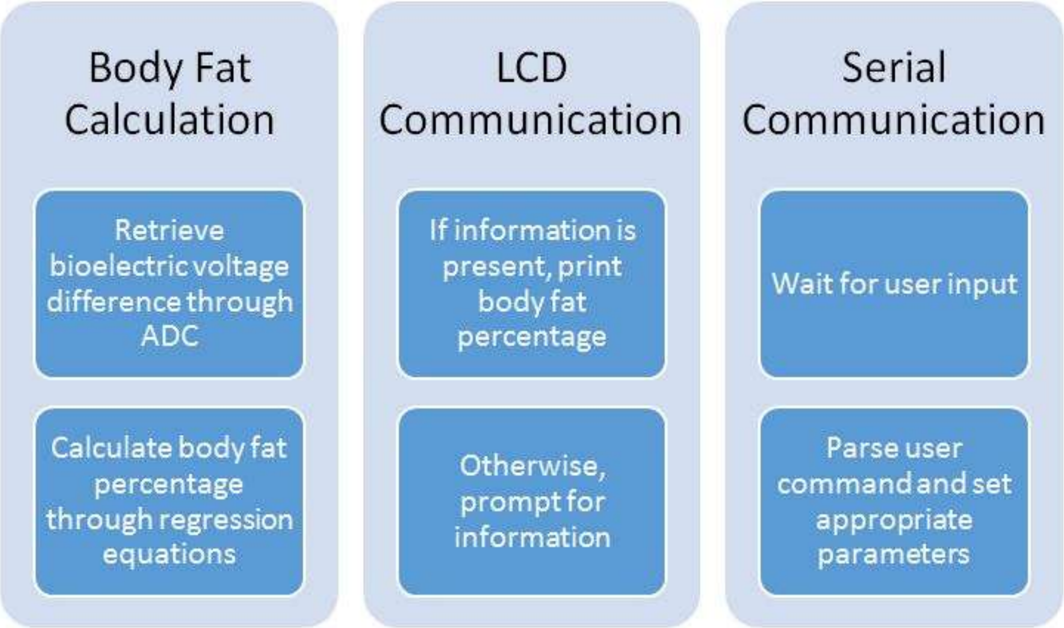
The isolating circuit is the same as the one used in previous case. So we are using power rails of the microcontroller unit to provide a stable signal for the ATMEGA1284. Resistors R9 and R10 are equal to each other to ensure unity gain since we want the output equal to the input. We need a low pass filter which was used to smooth out the signal so the microcontroller can perform calculations on the data from the signal.

IV. Software

Overview :

The overview of the project is the software component is consisted of two parts - a realtime system(RTS) for user input and bioelectrical voltage analysis, and a MATLAB script to create a regression curve correlating body impedance and user body fat.

Diagram given below shows how software works inside the system :



4.1 MATLAB Script and Data Processing:

A major part of our project is to determine body fat involved determining how the impedance information collected from the circuit related to the subject's body fat. To make the body fat equations, we need to have user's body fat, voltage, age, and weight. This data was passed to the MATLAB function mvregress, which obtains a vector of coefficients that weight the independent variables (age, weight, and voltage) that matches the collected dependent variable (body fat). Information sets for male and female test subjects were run separately, in order to create distinct equations for each gender, and for simplicity, the Analog to Digital Converterinput value was used instead of raw voltages. The advantage of this approach is that the MATLAB script uses the built-in multivariate regression function to relate several independent variables to one dependent variable, and the script can be re-run toobtain a new regression equation as the data set is expanded. The regression equations obtained were:

Males: body_fat = 0.0923 * weight + 0.1605 * age - 0.0263 * voltage
Females: body_fat = 0.1871 * weight + 0.5800 * age - 0.0920 * voltage

V. Conclusion

Results vs.Expectations :

The expectation at the start of the project was that the device would be safe, use a signal of ~10 µA and 50 kHz to determine body impedance, and predict body fat within a 10% error margin. The final circuit, while differing in certain aspects from the original design, did achieve the safety of user and signal goals, while it conditionally achieving the accuracy goal. The device operated at a safe current and did not harm any of our test subjects. Our input signal to the user is approximately 12 µA, which is close to our goal of 10 µA, and is still safe to pass through a user's body.

For our accuracy goal, we were able to achieve body fat prediction within a 10% error margin for subjects matching our test samples, but we had poor accuracy outside that fairly specific range of weights and body mass compositions. Given the small concentration of test subjects, we are pleased with the accuracy for the tested range, but there is significant room for improvement in accuracy for more body types.

Future Changes :

This project provides many opportunities for future extensions. One extension would be to improve accuracy by implementing multi-frequency bio-impedance analysis. Each different frequency provides a different weighted sum of total body water and fat free mass, so by analyzing on multiple frequencies and comparing resistance and reactance measurements from each frequency, it is possible to obtain a more accurate results, as well as other metrics like hydration, muscle mass, and bone mass. This extension might be implemented by switching the software to a state-machine based approach, and modifying timer 0 to generate different wave frequencies.

Other possible extension would be to make it portable by making it small and light in weight which could allow for health conscious users to port it with them to the gym. For example, Modifying the device to work with conductive handles rather than electrodes would increase ease of use. In addition to the other changes, a logging system and linked application could be added to track body composition and hydration changes.

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