A Different Kind of “Bar”-O-Meter

Project Design Review

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Course: ECE 445 Senior Design

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I. Introduction

1.1 Statement of Purpose

Most of the time, people find themselves torn between several options, especially when trying to decide on the places to have a fun night. Knowing the number of people at the bars and the atmosphere there would certainly be helpful. Thus, we aim to develop a system that can indirectly estimate those information by installing weight sensors underneath the floors and making those data readily available online. We are excited to see how this system would benefit bars and their customers and call it "A Different Kind of 'Bar'-O-Meter."

1.2 Objectives

While we aim for our system to enhance the communication between businesses and their customers, we have outlined certain specific objectives to be accomplished over the course of the semester.

Project Goals:

- Develop weight sensors with less than 10% error and cost less than $50/sensor
- Realize data transmission from sensors to PC
- Establish online portal (social website) to display information to public
- Power entire system with minimum cost (around $400/system)

Intended Functions:

- Convert wall power to 5V DC voltage @ 500 mA needed for sensing pads
- Estimate weight on the tile using pressure sensors
- Send analogue signal from sensors to data transmitter through wire
- Convert analogue to digital signal and aggregate data for processing
- Parse/analyze data on computer and provide live update online

Benefits to Customer:

- Affordable cost for bars/clubs to install and setup
- Long-term investment in marketing effort for bar owners
- Easily accessible live information online on bars to customers

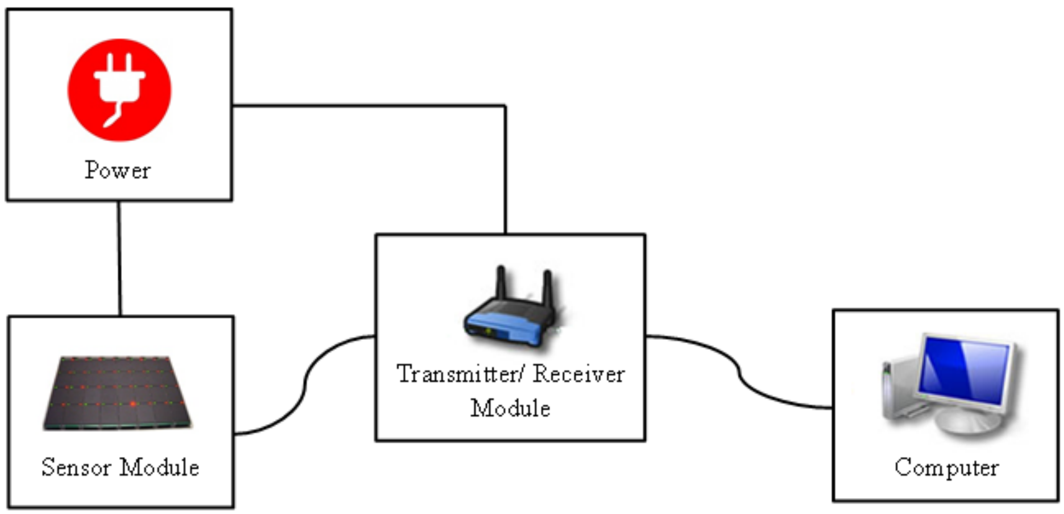
Product Features:

- Sensing pads powered by wall power to lower cost
- Data transmitter/receiver powered by wall power to avoid sudden power outage
- Present estimate for number of people online in the form of an interactive map
- Interpret bar atmosphere based on data collected and display online

II. Design

2.1 Block Diagram

Our system consists of mainly four modules: Power Supply, Sensor Module, Transmitter/Receiver Module, and Computer/PC. The functionality of each module and the relationship between the modules are presented below.



2.2 Block Descriptions

a. Power Module

The Power module intends to supply electricity to both the Sensor Module and the Transmitter/Receiver module using wall power. Since computers usually already have their own power supply, we have excluded the consideration of powering computers. For both the Sensor Module and the Transmitter/Receiver Module, we plan to use 120V AC wall power directly. Specifically, we have designed an AC to DC convert to lower the voltage from the wall power to 5V and generate sufficient direct current at 500mA for the sensor pads and transmitter/receiver module.

b. Sensor Module

The Sensor Module measures the instantaneous pressure on a sensing pad. A pressure-sensing pad has an area of $0.25m^2$. A "Bar-O-Meter" system contains a set of sensing pads, which can cover the entire to-be-measured area. Each pad performs the measurement synchronously, but independently, with relatively small time interval (~10ms). The pressure level of a pad reflects the active level of people on top of it. After calibration, a read of zero pressure means the area is empty, a pressure in the range of a normal person's weight means someone is standing on the area. Also, a stable pressure tells a low activity, and an unstable pressure shows that the area measured is active. While each individual sensing pad in the system corresponds to a specific area on the map, sending data directly from each pad is costly. Therefore, the pressure data are collected via wires from all pressure sensing pads and stored in each of the respective microcontrollers. The data collection step is essential to prepare for the data transmission step.

c. Transmitter/Receiver Module

The Transmitter/Receiver Module aggregates all the information from all microcontrollers without loss of information, then transmits it via Bluetooth transmitter. This block is needed to communicate between the pressure sensing pads and the display terminal. Each entry for the data transmitted will consist of the number that determines the location of the pad and the pressure associated to it. After receiving data, it is then ready for the Computer to process and display.

d. Computation and Display Module

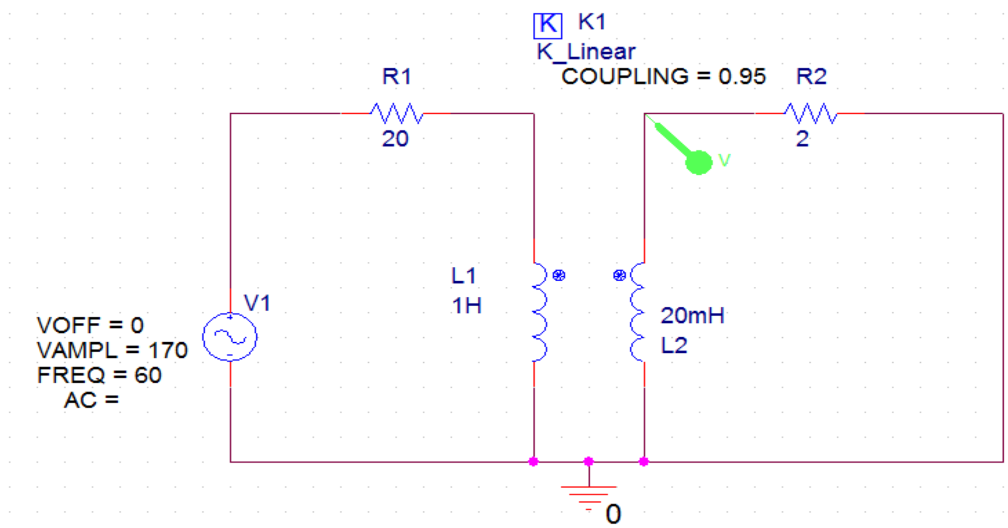
A computer analyzes the data, maps the data onto the map instantaneously, and creates an interactive map. The interactive map will be displayed on an existing social website. This block will mostly be implemented through software algorithms. A map of the bar (or any measured area) will be displayed on the terminal. The map is divided into subareas, each corresponds to pressure sensing pad placed. The level of activeness will be realized through color coding or change in patterns. The color/pattern on the map corresponds simultaneously with the intensity of the activities in the area.

2.3 Component Schematics, Simulations and Calculations

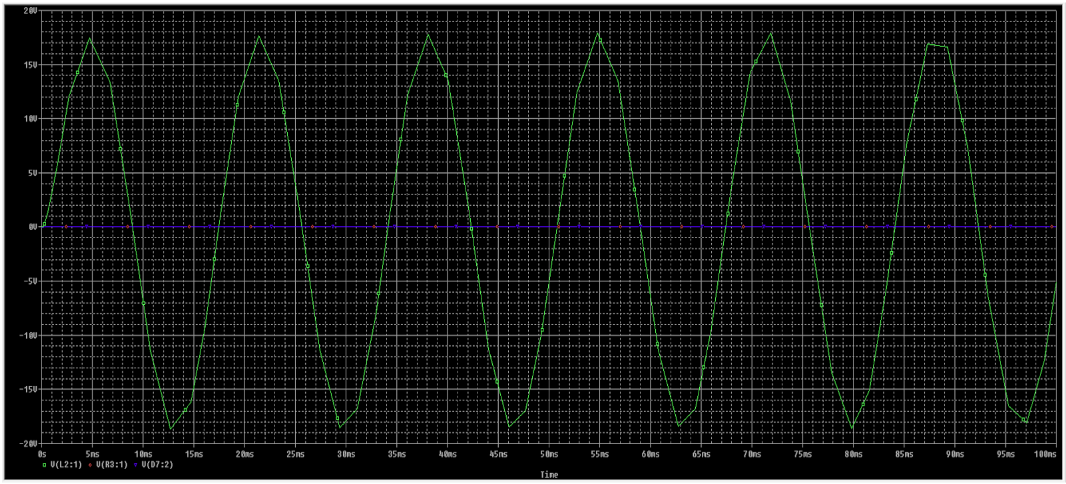
a. Power Module

The Power Module is designed to provide desired voltage level to supply electricity to the entire system. Since both the Sensor Module and the Transmitter/Receiver Module rely on 5V DC @ 500mA power supply, we plan to use a 120V AC to 5V DC converter, consisting of transformer, rectifier, and smoother.

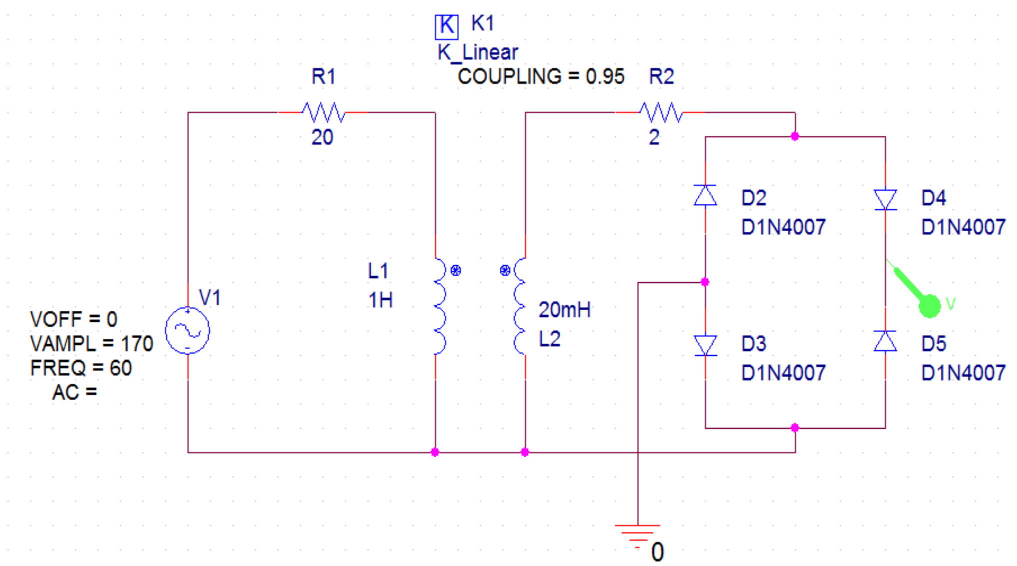
Transformer



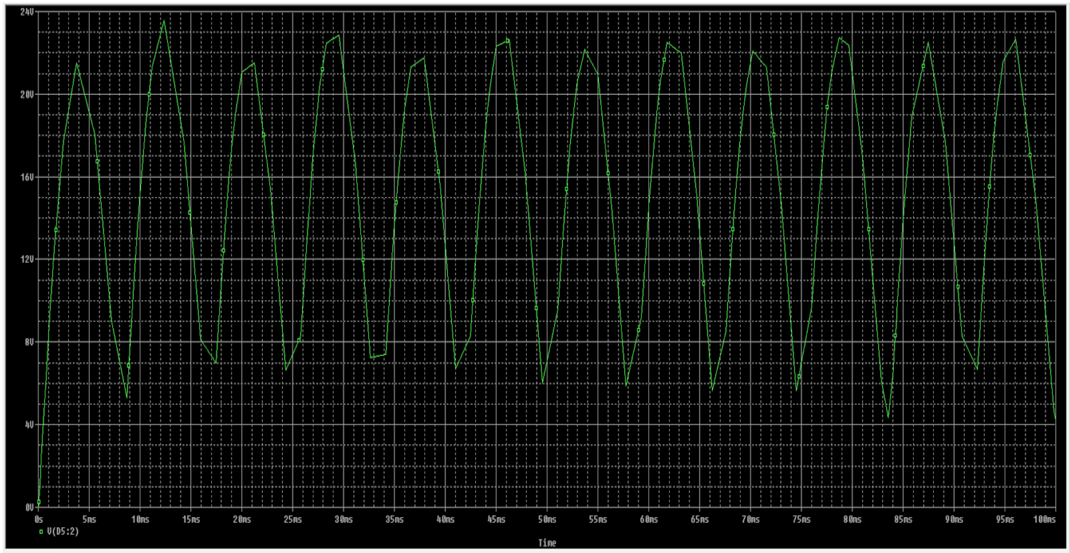
The transformer intends to lower the voltage level from the wall power ($120V_{rms}$ AC) to desired voltage level to $15V_{rms}$ AC. We intend to use 166G5-ND from Hammond Manufacturing, which also produces the 500mA current that we required. Since we required direct current instead of alternating current, we would then need to use a set of diodes to rectify this current. Below is the PSpice simulation of the circuit presented above, transforming voltage from $120V_{rms}$ AC to $15V_{rms}$ AC.



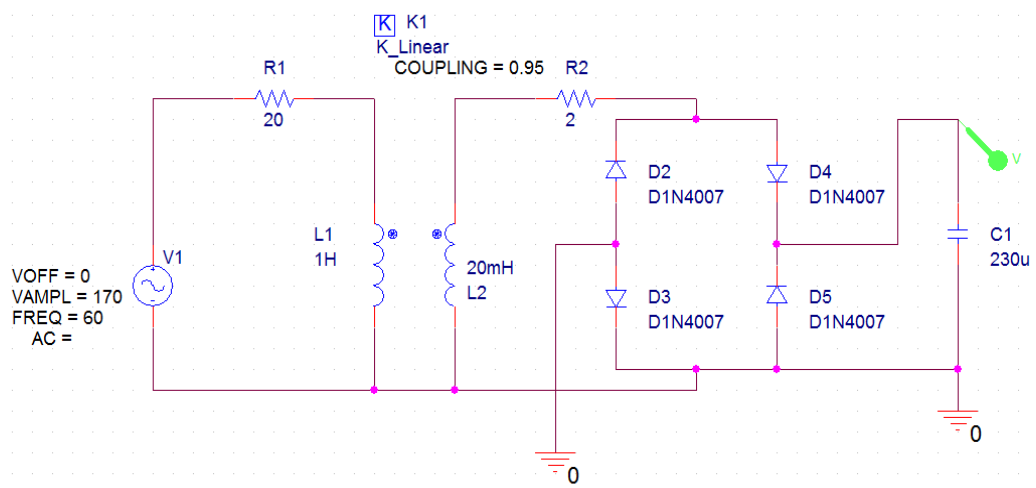
Rectifier



To rectify the alternating current, we intend to take advantage of the feature of diodes. Here, we use the bridge rectifier since it is more efficient than the half-wave circuit or the center-tapped full-wave circuit. Specifically, we use four 1N4007 diodes, from Vishay Semiconductor Diodes Division, to realize that purpose. Since the current can only go under forward-biased condition, the output current will be positive as desired.



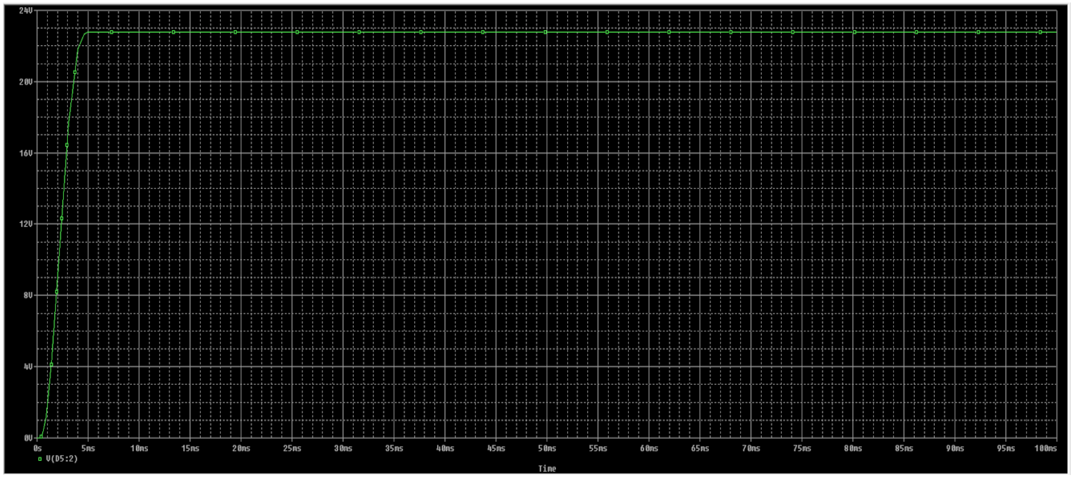
Smoothing Capacitor



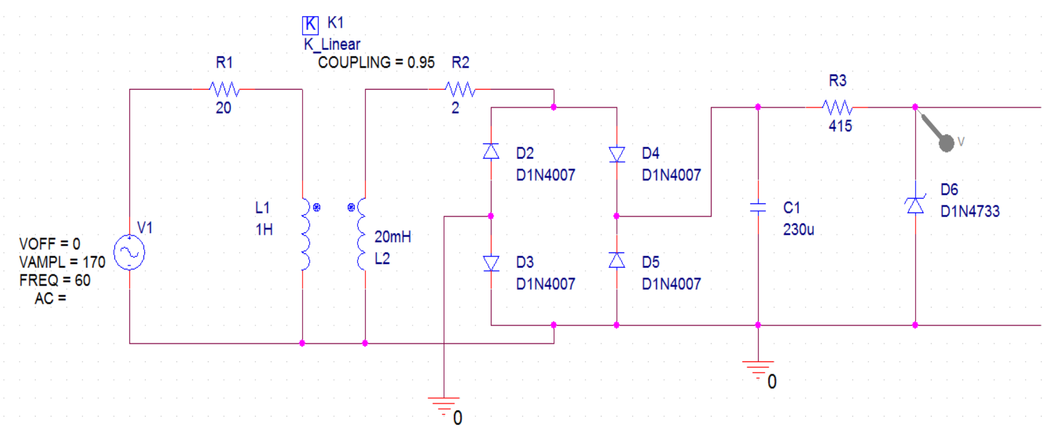
Even though we have eliminated the alternating portion of the current, we still need to maintain the current/voltage level to ensure that the system keeps running. Thus, we connect a capacitor to the circuit to smooth the current. To calculate the minimum capacitance required for the smoothing capacitor to have 1% ripple effect,

$$C = \frac{I}{2fV_{ripplet}} = \frac{35.213\text{mA}}{2 \times 60\text{Hz} \times 1.27\text{ V}} = 230\mu\text{F}.$$

In this equation, V_{ripple} is obtained from the ripple voltage allowed from the regulator, calculated in the following section. Thus, we need to obtain capacitors with 230μF.



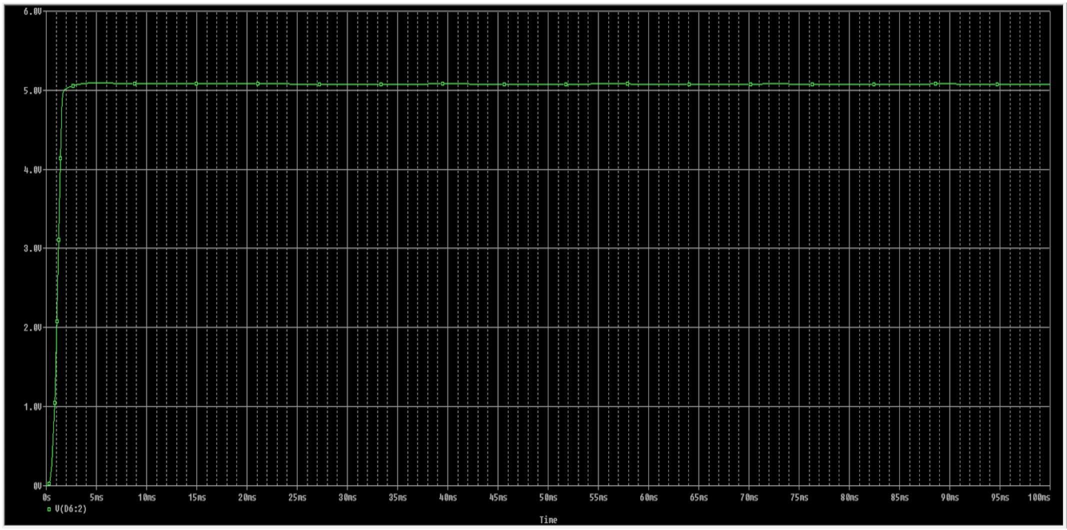
<u>Regulator</u>



Since the lowered voltage still stands at $15V_{rms}$, and the desired voltage is 5V, we employ a regulator, in this case a zener diode in series with a resistor. We use 1N4733 for the zener diode, which provides us with 5.1V zener voltage. To obtain the resistance required to achieve our goal, we calculate it as follows:

$$R_s = \frac{V_{in,peak} - V_d - V_{out}}{I_{max}} = \frac{(21-0.7\times2-5)}{35.213m} \simeq 415\Omega$$

$$V_{ripple} = max_{ripple}\frac{R_s + R_z}{R_z} = \frac{5\times1\%\times(17+415)}{17} = 1.27V$$



<u>Power Budget</u>

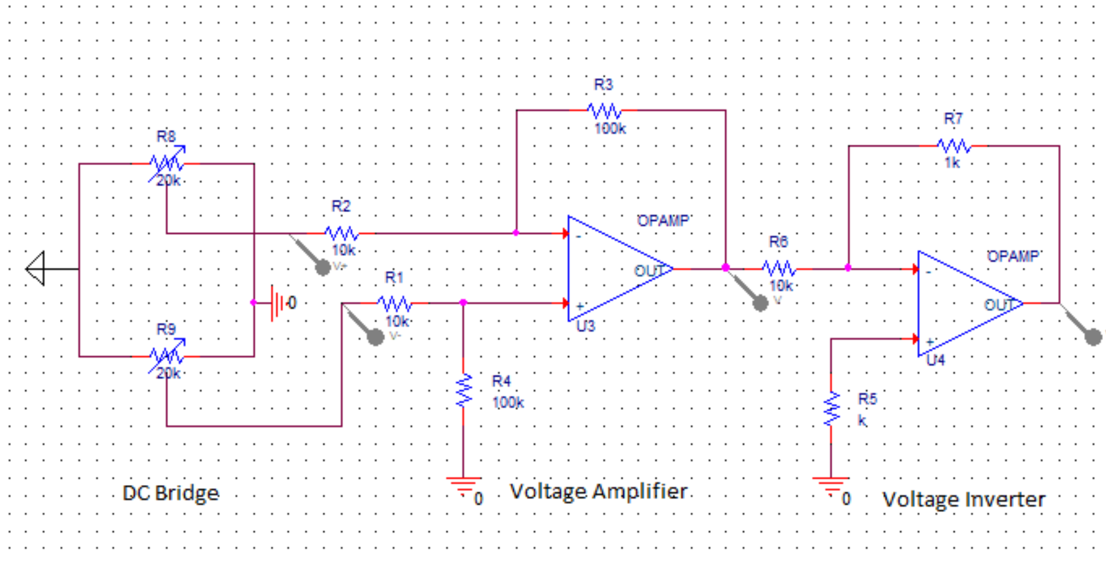
Components	Voltage (V)	Current (mA)	Power (W)	Quantity	Total Power (mW)
Pressure Sensor, NPA-600B-005D	5	10	0.05	10	500
Microcontroller, MSP430G2X11	3.3	0.22	0.726×10^{-3}	11	8
2.4-GHz Bluetooth low energy System-on-Chip, CC2540F128	3.5	19.6	68.6×10^{-3}	1	68.6

Total Power = 576.6W;

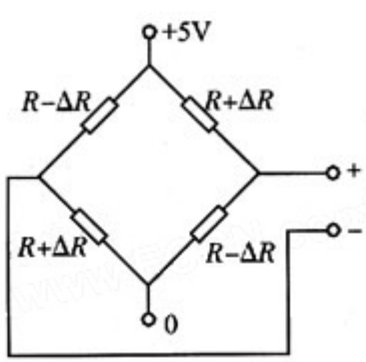
Estimated Efficiency = 60%;

Input Needed = $\frac{576.6mW}{60\%}$ = 961mW

b. Sensor Module

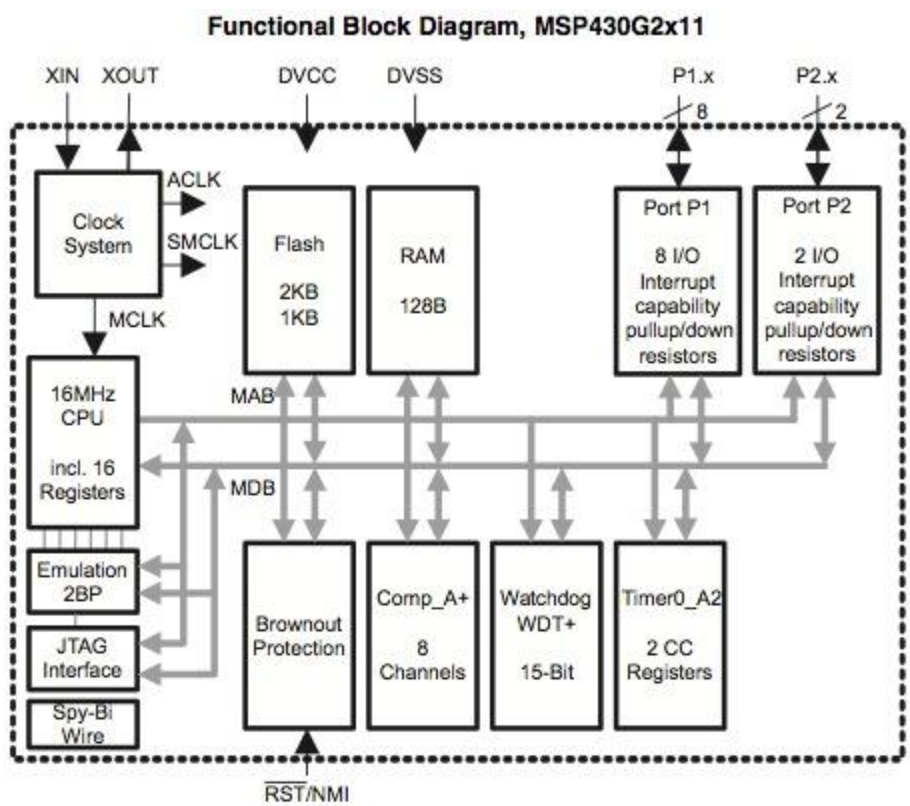


For our sensor module, we will be using this DC Bridge Circuit. As shown on the schematic, $R_8$and $R_9$are strain gauge type transducers which can measure the force applied to a fine wire, $R_1$and R_2 are two 10kΩ resistors. We will set $R_1 = R_2 = R_8 = R_9$ =10kΩ when nothing is there so that the voltage difference between U3- and U3+ should be 0V so that the output voltage should also be 0V. If we put some pressure on the gauge type transducers, the resistance of R_8 and R_9will change and we will make them change in an opposite way to make them different from each other, so there will be a voltage difference between U3- and U3+, and this voltage difference will be increased by U3 Op-Amp then reversed by U4 Op-Amp. so the output will be a positive voltage. Here are the calculations:



Assume we have the relationship between pressure and resistance R=kP(k is constant) then ΔR=kΔP so the output voltage of the bridge should be ((R+ΔR)/2R-(R-ΔR)/2R)*U = ΔR/R*U=k*ΔR/R*U. If we set R1//R4 = R2//R3 and R6//R7=R5, we will get our output voltage Uout=k*ΔP*U/R*R3/R2*R7/R6 which will be sent to our microcontroller.

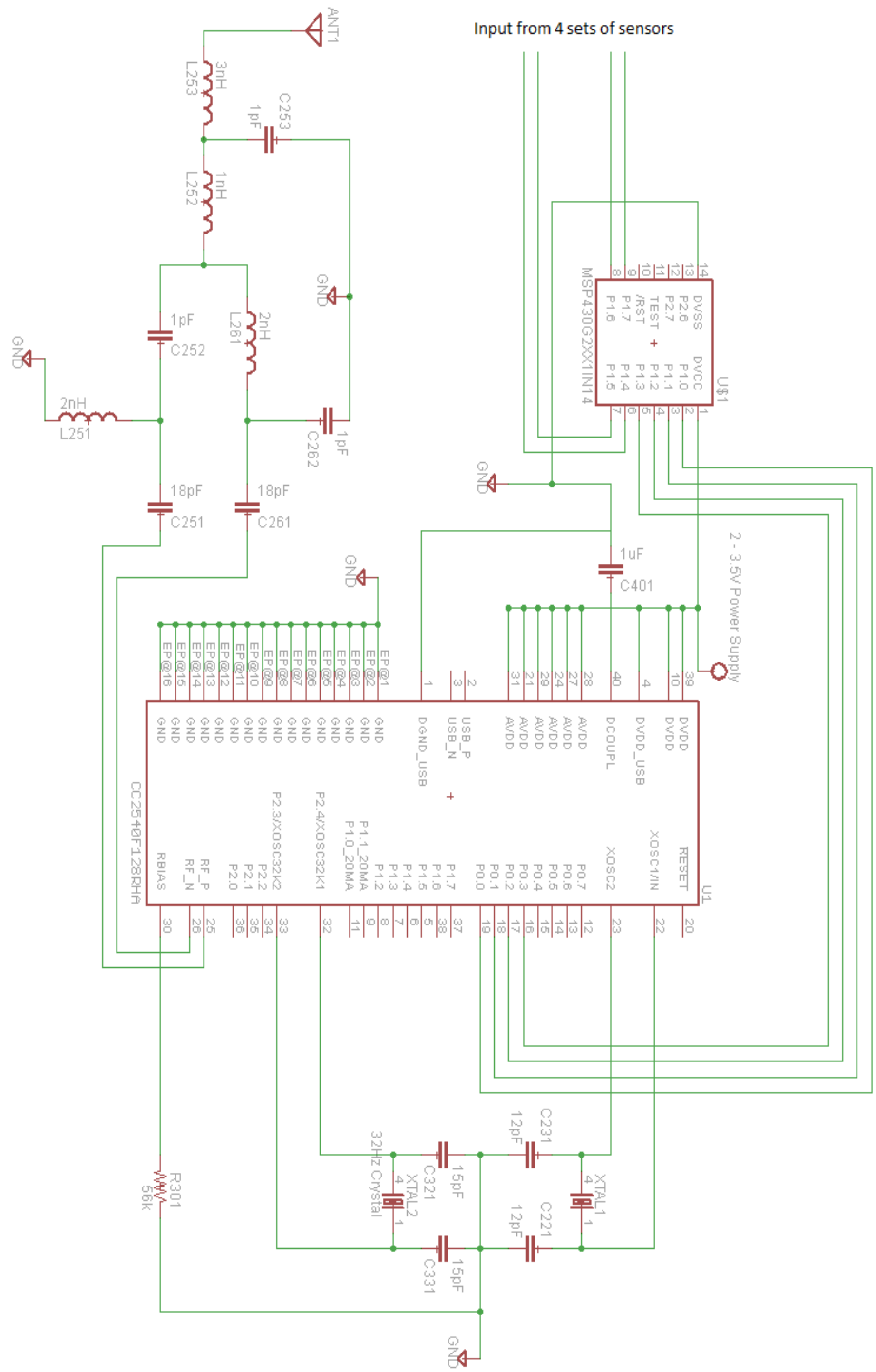
We are going to use MSP430G2X11 microcontroller to save data from each pressure sensor and then collect all the data together to a centralized microcontroller.



We will program the microcontrollers to take input from the Sensor Module, in addition to the pre-determined location (represented in number) of the sensing pad. Then, all these information will be aggregated to be stored in the centralized microcontroller, which then transmits all data to the PC via Bluetooth.

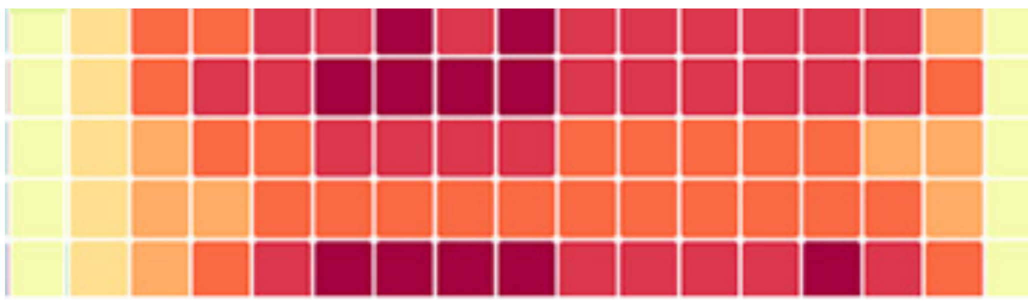
c. Transmitter/Receiver Module

We will be using CC2540F128 2.4-GHz Bluetooth® low energy System-on-Chip to transmit the data wirelessly from the microcontroller to the PC end. Since external components are required for the operation of the chip, we will be using the recommended circuit setup in the data sheet, as shown below.



d. Computation and display Module

After data is transmitted via Bluetooth and received on the PC end, we intend to use the software offered on Texas Instruments website (IAR Embedded Workbench). Then, we will utilize C/C++ to process the data gathered from all sensing pads and upload them to the website to correctly display the information on the estimated number of customers in the area and level of activity. The preliminary simulation results are shown as below, the color of each grid changes instantly with time.



III. Requirements and Verification

3.1 Requirements & Verifications Summary

a. Power Module

Requirements	**Verifications**
1. Power supply from wall plug reads 120 V_{rms} to ensure that power is sufficient	1. Connect input voltage to oscilloscope (Agilent 54642A) to ensure that wall power is 110V - 120V
2. Power Transformer (166G5-ND) converts120 V_{rms} from wall plug to 15V_{rms} @ I_{max} of 50mA on secondary side.	2. Connect output to oscilloscope (same for items below) a. Output voltage should read 15V $\pm$ 0.05V; b. Magnitude of output current should read 50mA $\pm$ 5mA
3. Rectifier (1N4007 * 4) filters out negative voltage and generates positive-only voltage.	3. Output voltage should read only positive values, with maximum value at 50mA $\pm$ 5mA.
4. Smoother (PSU23315B-ND) gives a DC profile of 15Vwith $\pm$1.27Vripple voltage.	4. Output voltage should be smoothed to 15Vwith ripple voltage of $\pm$1.27V.
5. Regulator (1N4733) provides output of 5V $\pm$ 0.05V	5. Output voltage should be smoothed to 5Vwith ripple voltage of $\pm$0.05V.

b. Sensor Module

Requirements	Verifications
6. Weight sensor module reads 0 when no object is placed on pad.	6. Output of the sensor module should be 0
7. Weight sensor module reads weight when object is placed on pad.	7. Apply a 1 kg and a 100 kg object on the plate, output should read bigger than 0 for both cases.
8. Weight sensor module output varies linearly with input applied to pad, ranging from 0-250 kg.	8. Apply static objects of 1 kg on the pad, with increment of 25 kg, and output reading should vary accordingly, with ±10% error.
8.1. Output of the DC Bridge circuit varies linearly with weight applied to pad, ranging from 0-250 kg	8.1. Apply static objects of 1 kg on the pad, with increment of 25 kg, and output voltage of the DC Bridge circuit should vary accordingly, with ±10% error.
8.2. The Voltage Amplifier works correctly	8.2. Apply different voltage to the input of the Voltage amplifier (ranging from 0-2 V, with a 0.01 increment), the output of the Voltage Amplifier circuit should vary accordingly and change linearly.
8.3. The Voltage Inverter works correctly	8.3. Apply different voltage to input of Voltage amplifier (ranging 0-5V, with 0.1 increment), output of Voltage Inverter circuit should read same value but opposite sign as input.

9. Weight sensor module reads maximum value when applied weight is larger than allowed	9. Apply large pressure (at least > 260 kg) on sensing pad and output of the module should still read 250 kg.
10. Weight sensor module responds to sudden external pressure changes.	10. Apply intermittent weight to pads with time interval of one second, then acquire data from oscilloscope using Excel Add-In. Time delay should be less than 10ms.
11. Microcontroller (MSP430G2X11) has preset value to determine the location of sensing pad	11. Program preset values (1, 2, 3, 4) into microcontroller and then directly connects output to oscilloscope to check output match
12. Microcontroller (MSP430G2X11) converts binary value to corresponding decimal values	12. Use function generator to put in a waveform to the microcontroller and determine whether the output corresponds to the binary value.
13. Microcontroller (MSP430G2X11) converts binary output from sensing pad to corresponding decimal values	13. Connect sensing pad to microcontroller and apply known weight to the pad, observe the output of microcontroller and check against original object weight / pressure.

c. Transmitter/Receiver Module

Requirements	Verifications
14. Centralized microcontroller (MSP430G2X11) stores at least 100 entries, each entry representing information from one sensing pad.	14. Program test data into the microcontroller, outlining 100 entries to represent 100 hypothetical information. Then read output from microcontroller to ensure no loss of information.
15. Centralized microcontroller (MSP430G2X11) can send data to computer via 2.4-GHz Bluetooth (CC2540F128)	15a. Check that the computer is connected to the Bluetooth. 15b. Ensure no loss of information from the microcontroller to PC via Bluetooth.

d. Computation and Display Module

Requirements	Verifications
16. Receives information and can be read by IAR Embedded Benchwork.	16. Import data into IAR Embedded Benchwork to ensure that the data is compatible with the software provided by TI.
17. C/C++ program is robust to handle information inflow: a. Correctly parses information from centralized microcontroller; b. Interprets pressure and activity from each sensing pad.	17. Run the C/C++ program against test data a. Use test data for parsing information and check that output matches the desired result b. Ensure that the correct information regarding each sensing pad can be correctly displayed as output.

18. Upload information to website and publicize data online.	18. a. Check that the computer is connected to the Internet b. Check if the data is being updated live.
19. Website can store all data without loss of information on database.	19. Check database has enough memory to hold the designed system, including all information on sensor pads and microcontrollers for the past hour.

3.2 Tolerance analysis

The most important and significant component in this project, as we all considered, is the weight sensor that we will use for measuring the weight on a sensing pad. Because it takes in the original data and its accuracy affects our final result directly.

The aforementioned calculations for the range that we chose allow for 0-250kg of weight on the sensor. Since we plan to use a mechanical spring to measure the weight applied on the sensor pads, the component could potentially wear out over a long period of time. During our design, we need to achieve durability for this portion of the system. In addition, when the object on the sensor pad is above 250kg (approximately 3-4 adults), the output of the circuit would read 250kg only. The circuit will be able to take up to 350kg of weight. To avoid breakdown of system, we would display an error message that reads “Pad #X Needs to be Repaired” on the computer portal so that the user can notice when a sensor pad is producing a constant output for a long period of time, or simply does not read any values.

IV. Ethical & Safety Issues

4.1 Ethical Issues

All of our group members will adhere to the IEEE Code of Ethics throughout the project. The items listed below are especially relevant to our Bar-o-meter project.

#1 to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;
This product is intended to be used in a high populated area, therefore the circuit must be packaged and protected correctly to avoid chance of electric leak or short circuit, especially when spilt by beverage or used in a damp environment.

#2 to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;
Since this product is intended for to show the activeness in a bar/club, it is possible that the bars may tamper with the "Bar-O-Meter" in order to fake the result and increase their popularity. It is important to make sure that the bars are aware of the ethical issues behind it, and agrees that they will not tamper with the product before we sell the product to them.

#7 to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;
We will always be open to criticism and suggestions, and credit to those who has contributed. We will be looking to improve our product continuously.

4.2 Safety Concerns

Electricity is invisible. It cannot be seen, heard, tasted, or smelled. So when we do electricity project. Safety should always be considered first. We will follow safety guidelines strictly to keep away from danger.

- make sure electrical service cords be in good condition
- remove from service any equipment with frayed cords or exposed wires
- avoid multiple plugs for additional connections
- never overload circuits
- never bypass any safety device on a piece of electrical equipment
- never use temporary wiring
- no food or drinks in the lab

V. Cost Analysis and Schedule

5.1 Cost Analysis:

Labor:

Name	Hourly Rate	Hours /Week	Total Weeks	Total Labor Cost*
Chen Hu	$30.00	10	15	**$11,250.00**
Tuo Liu	$30.00	10	15	**$11,250.00**
Yiming Song	$30.00	10	15	**$11,250.00**
Total				**$33,750.00**

Parts:

	Quantity	Unit Cost	Cost
Power Transformer (166G5-ND)	1	20.32	**$20.32**
Diodes, Rectifiers (PSU23315B-ND)	10	0.295	**$2.95**
Smoothing capacitor (TCX212U015J1L, 2100μF)	1	30.80	**$30.80**
Pressure Sensors (NPA-600B-005D) (5PSI, 35kPa)	10	17.67	**$176.7**
Mixed Signal Microcontroller (MSP430G2X11)	11	0.39	**$4.29**
PCB's	10	11	**$110.00**
2.4-GHz Bluetooth low energy System-on-Chip (CC2540F128)	1	5	**$5.00**
BNC Cables	2	12	**$25.00**
Software Tools	1	50	**$50.00**
Grand Total			**$425.00**

*Total Labor Cost = Hourly Rate x Hours Invested/Week x Total Weeks x 2.5

** Assuming the system contains 10 sensor pads

GRAND TOTAL = Labor + Parts = $33,750.00 + $425.00 = **$34,175**

5.2 Detailed Schedule

A Different Kind of "Bar"-O-Meter Gantt Chart

Task	Assigned Resource	2/4	2/11	2/18	2/25	3/4	3/11	3/18	3/25	4/1	4/8	4/15	4/22	4/29
Complete proposal for submission	Chen Hu	■						Spring Break						
Design preliminary weight sensor circuit	Yiming Song	■												
Design data transmission circuit	Tuo Liu	■												
Design transformer for 120V AC to 5V DC	Chen Hu		■											
Assemble weight sensor using amplifiers	Yiming Song		■											
Prepare mock design review	Chen Hu		■											
Design data transmission via Bluetooth	Tuo Liu		■											
Order parts for system	Chen Hu			■										
Refine design review	Yiming Song			■										
Assemble sensing pads for testing	Tuo Liu			■										
Refine data transmission circuit	Tuo Liu				■									
Refine weight sensor circuit	Yiming Song				■									
Refine power supply circuit	Chen Hu				■									
Develop PC-end data analyzer	Chen Hu					■								
Test all requirements data transmission module	Tuo Liu					■								
Test first four requirements for sensor module	Yiming Song					■								
Test rest requirements for sensor module	Yiming Song						■							
Test all requirements for power supply module	Chen Hu						■							
Integrate modules and prepare for mock-up	Tuo Liu						■							
Test bluetooth communication	Tuo Liu								■					
Finalize PCB and send for fabrication	Yiming Song								■					
Test PC-end data analyzer	Chen Hu								■					
Perform final cost analysis	Chen Hu									■				
Assemble circuits on PCB	Tuo Liu									■				
Fix remaining issues from testing	Yiming Song									■				
Integrated testing	Tuo Liu										■			
Perform tolerance analysis	Yiming Song										■			
Integrate all parts for completion	Chen Hu										■			
Final testing for all modules / fixing	Yiming Song											■		
Prepare for presentation	Tuo Liu											■		
Prepare for demo	Chen Hu											■		
Demo	Yiming Song												■	
Proofread/Finalize presentation	Chen Hu												■	
Proofread/Finalize paper	Tuo Liu												■	
Return all equipments	Yiming Song													■
Submit Presentation	Chen Hu													■
Submit Final Paper	Tuo Liu													■

VI. References

Power Transformer (166G5-ND): http://www.digikey.com/product-detail/en/166G5/166G5-ND/455101

Diodes, Rectifiers - Single (1N4007-E3/54GITR-ND):
http://www.digikey.com/product-detail/en/1N4007-E3%2F54/1N4007-E3%2F54GITR-ND/754813

Smoothing capacitor (PSU23315B-ND, 230μF)
http://www.digikey.com/product-detail/en/PSU23315B/PSU23315B-ND/1551648

Pressure Sensors, Transducers > NPA-600B-005D (5PSI, 35kPa)
http://www.digikey.com/product-detail/en/NPA-600B-005D/235-1320-1-ND/3757843

Mixed Signal Microcontroller (MSP430G2X11)
http://www.ti.com/lit/ds/symlink/msp430g2001.pdf

2.4-GHz Bluetooth low energy System-on-Chip (CC2540F128)
http://www.ti.com/lit/ds/swrs084e/swrs084e.pdf

IEEE Code of Ethics

http://www.ieee.org/about/corporate/governance/p7-8.html