Augmented Beer Pong

ECE 445 Final Report

Adam Seppi, Alexandra Wleklinski, Chance Coats
Group 29
TA: Vignesh Sridhar
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1. Introduction

1.1. Objective

Beer pong is a popular drinking game played by people from all over the world. Beer pong has remained relatively unchanged since its conception in the mid-20th century. The game has become trite and has seen little to no upgrades even though today's technology continues to improve.

The goal of our product is to be able to keep track of score, player shot streaks, and a champion's run counter while remaining portable, accurate, and long lasting. We have dynamic lighting embedded in the mats as well as speakers in the central hub. We hope that with the modern technology added to the game of beer pong, players will see an increase in functionality and added entertainment value. The physical product consists of two mats, one for each team's cups, which are connected to a central logic hub. We hope to complete our goal by making our product offer the ability to adapt to any table or surface, respond to game-play, and emit audio and visual stimuli based on the state of the game.

1.2 High-Level Functionality

- The system must be able to, at a bare minimum, run for 100 hours of play.
- The system must be portable. Meaning both mats and central hub should weigh less than a seven pounds (the size of a large laptop). Also the mats must be wide enough to fit 10 cups in a pyramid shape and no more than twenty-four inches wide. The opposite sides of mats should be no further than ninety-six inches apart [4].
- The system must reach a sensor accuracy threshold of 95% for cup removal detection and 80% for cup collision detection.

In Figure 1, the block diagram for our project depicts the modules that receive and transmit data, and the modules that receive power from the power supply.

In Figure 2, each component of our design is depicted with its corresponding modules inside. Section 2 is organized to allow us to touch on the design considerations and verification of each of these components.

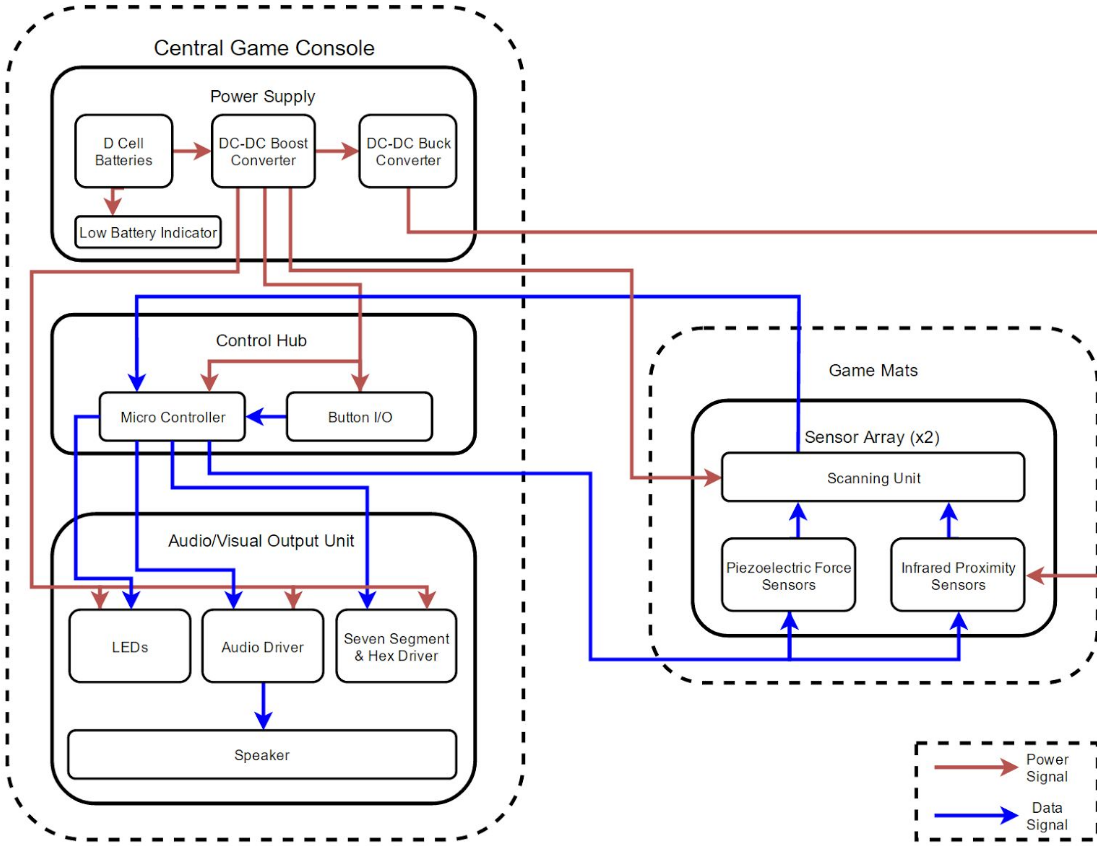

Figure 1 - System Block Diagram

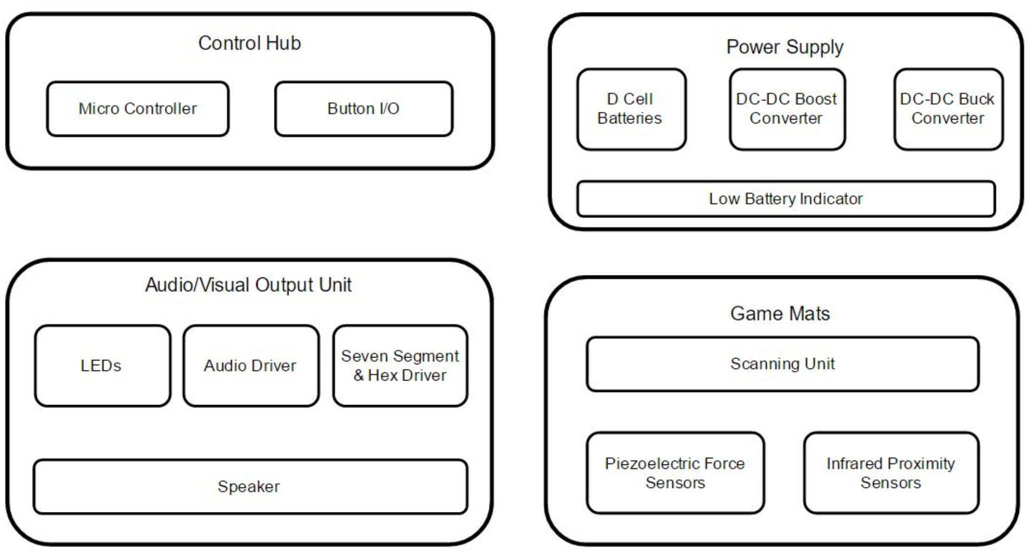

Figure 2 - Components of Product and Corresponding Modules

2. Design

2.1 Design Procedure

The game requires multiple modules to meet the objectives: a power supply, control hub, two sensing arrays, and an audio and visual unit. The power supply draws current from disposable D-cell batteries, and boosts the voltage to usable levels for the other modules. The sensor array consists of infrared sensors to detect cup removal and piezoelectric sensors to detect a hit. The control hub consists of a microcontroller to process sensor data and create output response. Lastly, the audio and visual unit will accept data from the microcontroller, output exciting noises and power LEDs based on gameplay.

2.1.1 Physical Design

Our physical design seeks to abstract individual components of the project away from the user and help the flow of gameplay. This is primarily for aesthetic reasons, making the game look like a high quality product, and safety reasons, keeping the product liquid proof to prevent harm to the product and the user. We place the control hub and audio and visual unit in a central position away from cups of liquid. The scanning unit and the sensor array are placed in a triangular mat that is waterproofed through a combination of neoprene and acrylic.

One alternative to this design would be to build the project into a constructed table. The advantage of this would be for a more solid design with less flexibility in the sensor mounts. However, we wanted to make our design portable to be used in a variety of environments. For this reason, our product is able to rest atop any reasonable length table without needing to be plugged into an outlet.

2.1.2 Power Supply

The power supply module turns stored energy within the D-cell batteries into useable voltage levels for our system. We chose to build the power supply using three main components. These sub-modules include a DC/DC boost converter, a DC/DC buck converter, and a low battery indicator. We chose to have our boost converter output at 3.3V, and chose the buck converter output voltage to be stepped down to 1.7V to power the infrared sensors.

Alternatives to our design approach include using a higher boost converter output voltage or the use of non-switched-mode DC/DC converters. Our choice of 3.3V fit within the input voltage range of many other modules, which meant we would need fewer voltage converters in our project. Additionally, we decided to use switched-mode DC/DC converters because they provided relatively high efficiency, putting the project in a better position to achieve our battery life goal.

2.1.3 Control Hub

The control hub is the decision maker of our project. All sensor data is transmitted back to the microcontroller which determines the addresses to scan through as well as whether or not it should signal audio or display a given number on the hex display. We also incorporated buttons onto our control hub to receive input for nondeterministic game events.

One alternative to our current design would be to input the sensor data from the infrared sensors and piezoelectric sensors directly into the microcontroller as analog values. We decided to use a comparator since the actual voltage level of these sensors is less important than if the sensor voltage exceeded a set threshold. For this reason, our existing comparator for the low battery indicator allowed us to save pins on the microcontroller for potential future upgrades.

2.1.4 Game Mats

Our game mats are the eyes and ears of our project. The game mats contain all the sensors which inform the control hub of the current game state. There is also a scanning unit that includes a multiplexer and decoder system to switch between sensor boards depending on which cup's data needs to be read. Scanning between sensors prevents multiple sensor boards from being activated at once. This gives the illusion that all sensor boards are being actively polled simultaneously but saves on power.

An alternative to this would be to remove the scanning unit, which alleviates the conceptual task of addressing to different cup's sensor boards, however, this approach would have lead to a staggering number of pins to the microcontroller if all multiplexing was removed. Our design reduces the number of pins needed for scanning through all twenty cups to six: one for the comparator input and five for addressing to cups. Also, since only one board is consuming power at any moment in time, we have dramatically reduced our product's power consumption.

2.1.5 Audio and Visual Unit

The audio and visual unit is responsible for housing a majority of the peripherals in the project. This unit projects fun and exciting feedback to alert the user to current state of the game. LEDs are mounted under each cup, and turn off when a cup is removed from play. A seven-segment display presents the current player number and the win streak at the end of a game. The speaker projects an explosion noise after a cup has been struck. The audio driver houses the data for the explosion noise.

Within the family of LEDs that we decided on, we chose to use the mid-power units. Alternatives to the LEDs included both low-power and high-power options. The low-power option would have given us better battery life while sacrificing brightness.

The high-power option would have given us worse battery life and better brightness. The mid-power LEDs gave us an acceptable power consumption and brightness.

2.2 Design Details and Verification

2.2.1 Power Supply

Shown below in Figure 3 is the schematic of our power supply board. The battery voltage is seen on the left side and is input to the boost converter. The buck converter on the right was of our own design and was built using discrete components. These sub-modules are covered in greater depth below.

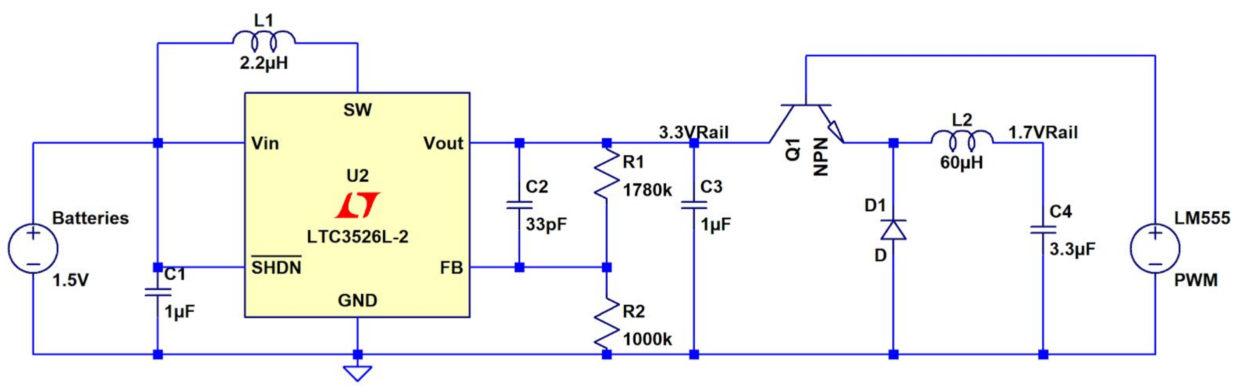

Figure 3 - Power Supply Schematic

DC-DC Boost Converter [6]

In order to provide a 3.3V supply rail to our project, we utilized a Linear Technologies LTC3526L-2 DC/DC boost converter which regulated the varying battery voltage (due to a loss of charge as the batteries age). It was crucial for our boost converter output to remain steady (+/- 150 mV) so a 1uF capacitor was added to the output for smoothing. The resistors R1 and R2 were chosen to achieve a ratio in accordance with equation (1) shown below and our desired output voltage. This ratio of R2 to R1 determines the output voltage through the feedback pin. Additionally, we chose large values of R1 and R2 to minimize the energy lost in the feedback network.

$$Vout = 3.3 = 1.195(1 + \frac{R2}{R1}) \qquad (1)$$

Figure 4 shows the output of our boost converter under full load as measured by an oscilloscope. We observed a DC offset of 3.32 V with a ripple of +/- 114 mV. This verification gave us high confidence that the requirements for the boost converter were achieved and that our system would have a stable supply of power therefore performing as we expected.

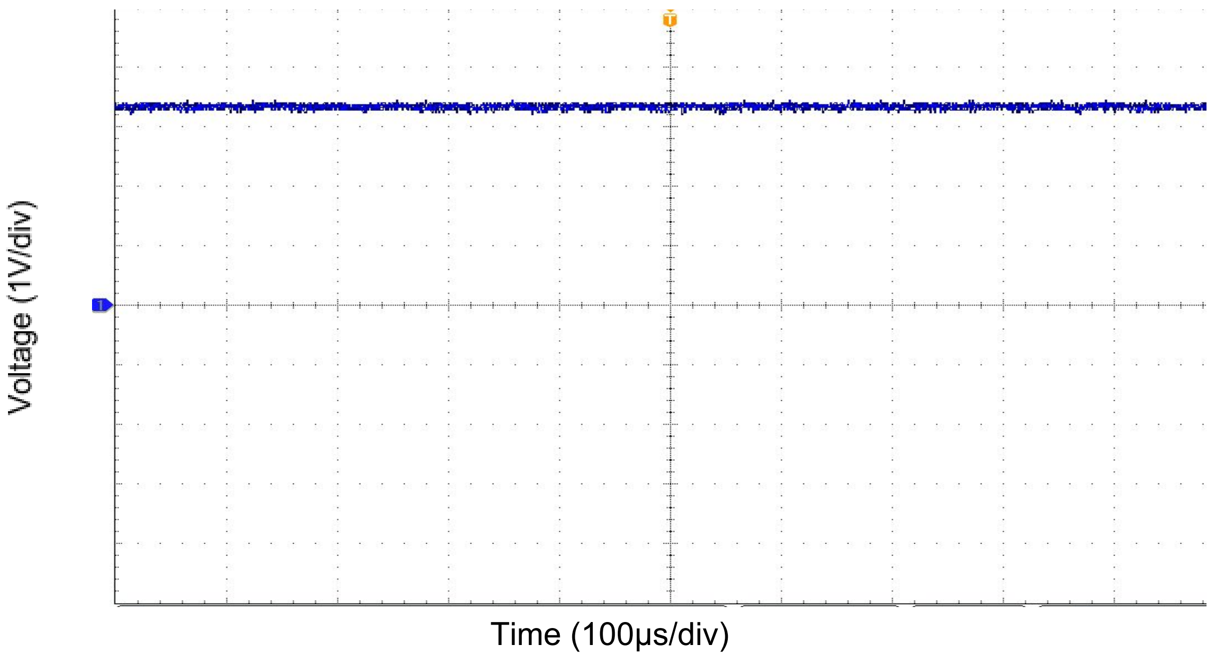

Figure 4 - Boost Converter Output

DC-DC Step Down Converter [9]

We designed and constructed a buck converter to achieve the stepped down voltage that was required by the infrared sensors.

Firstly, to achieve the correct output voltage of 1.73V from the minimum input voltage, 3.1V, we calculate the duty cycle, D:

$$D = V_{out}/V_{in} = 1.73/3.1 = 0.558 \quad (2)$$

We decided on a maximum deviation of the output voltage, ΔV, of 30mV.

Next, we settled on a switching frequency, F_{sw}, of 900kHz. This frequency was achievable using our LM555 timer chip.

Finally, we selected the maximum load current based on our earlier calculations, plus some breathing room. The max current at the load is chosen to be I_{load} = 40mA. We chose the maximum ripple current, I_{ripple}, to be 40 percent of our load, which is 16mA.

We calculated the minimum capacitances and inductances used by C4 and L2.

$$L2 = (V_{in} - V_{out})*(D/F_{sw})/I_{ripple} = 53.1\mu H \text{ minimum} \quad (3)$$

$$C4 = I_{ripple}*D/(\Delta V*F_{sw}) = 496nF \text{ minimum} \quad (4)$$

The minimum values for L2 and C4 calculated above provided good starting points for real-world values. But after observing the output voltage with these values, adjustments were made to meet our requirements listed in Appendix A. 60μH is the final value for L2 and 3.3μF is the final value for C4.

The simulated output voltage can be seen in Figure 5.

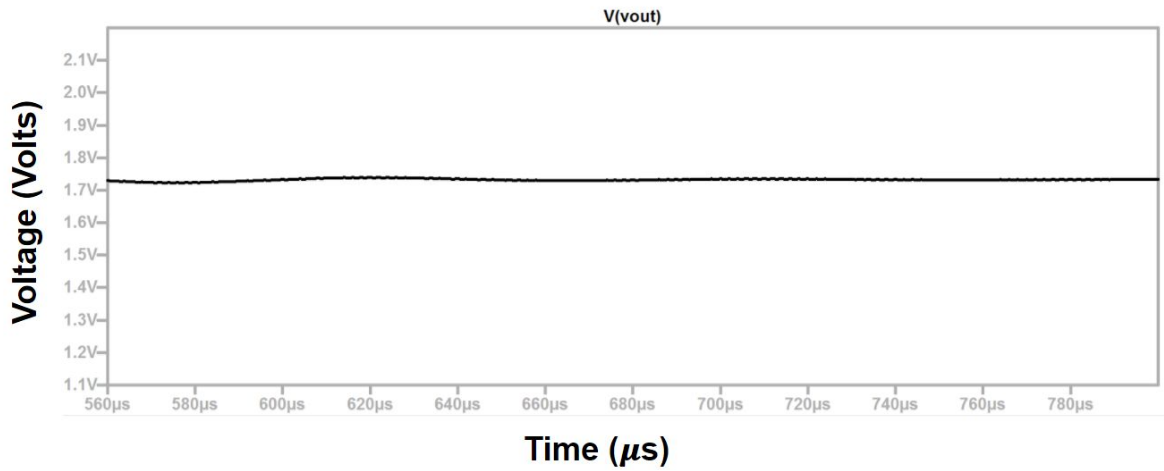

Figure 5 - Buck Converter Simulated Output

The actual buck converter output is shown in Figure 6. The output is 1.72V +/-180mV. The deviation and offset are within the allowed range, therefore meeting requirements.

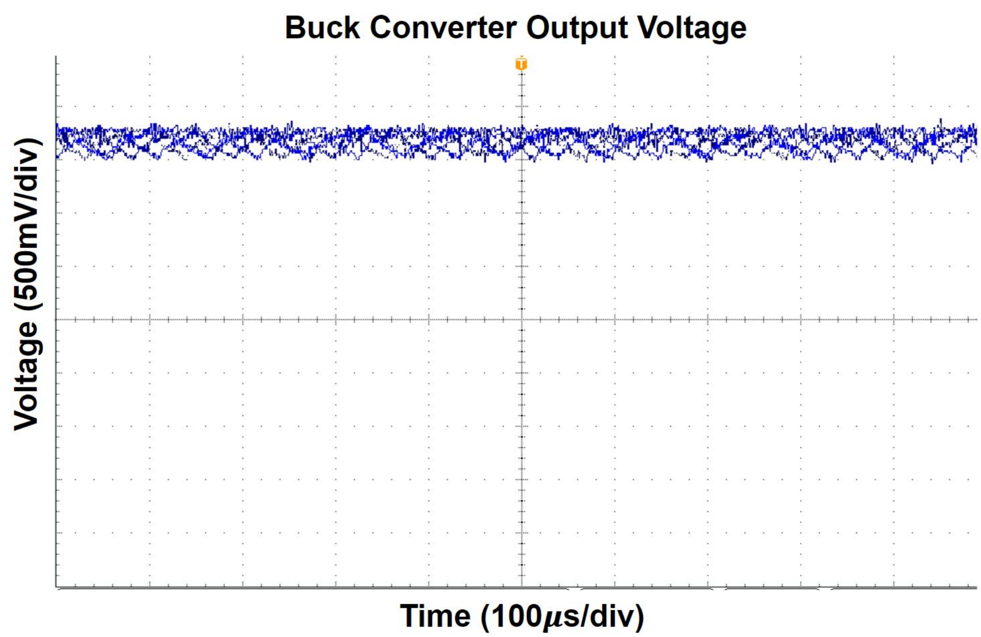

Figure 6 - Buck Converter Observed Output

Low Battery Indicator

The low battery indicator utilized the accuracy of a comparator chip to compare our battery voltage against a 0.75 V threshold. To turn on an LED once our battery voltage falls below this threshold, we used the comparator output to enable or disable a PMOS transistor. One design aspect that was difficult to grapple with was the opposite nature of the comparison. Since the indicator is using the comparator to signal when the input falls below a threshold, it is the opposite of the original intention of the comparator. For this reason, we added an inverter between the comparator output and the PMOS to achieve correct functionality.

Figure 4 shows the voltage threshold comparison we used as a reference in our comparator. Through our resistor divider, we achieved a reference of 0.753 V with a voltage ripple of +/-25 mV. The deviation and offset are within the allowed range, therefore meeting requirements.

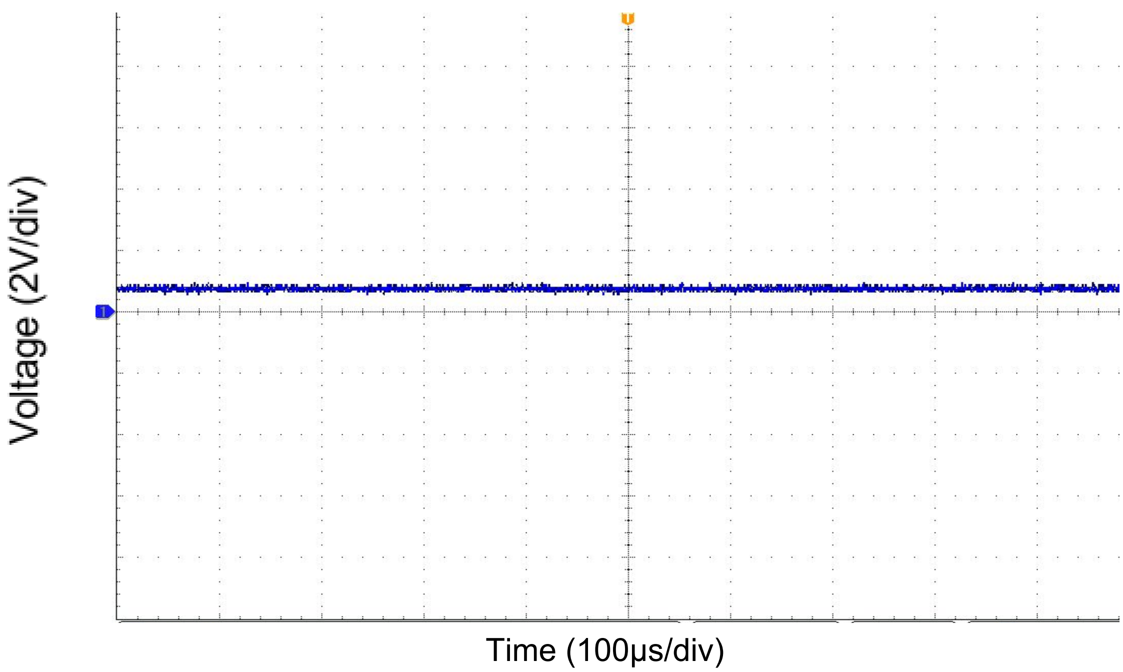

Figure 7 - Battery Indicator Reference Voltage

2.2.2 Control Hub

Microcontroller

While the microcontroller was a store-bought part of our project, the design-in procedures were crucial to the proper operation of our finished product. We needed to ensure that all of the supply and ground signals were properly powered and isolated using decoupling capacitors. Additionally, pull-up resistors needed to be added to allow the programmer to reset the microcontroller as needed. These decoupling capacitors and pull-up resistors can be seen below in Figure 8. The values shown below were chosen based upon the recommended values found in the datasheet [7]. A flowchart of the software which was programmed onto the microcontroller for our final game functionality can be found in Appendix B.

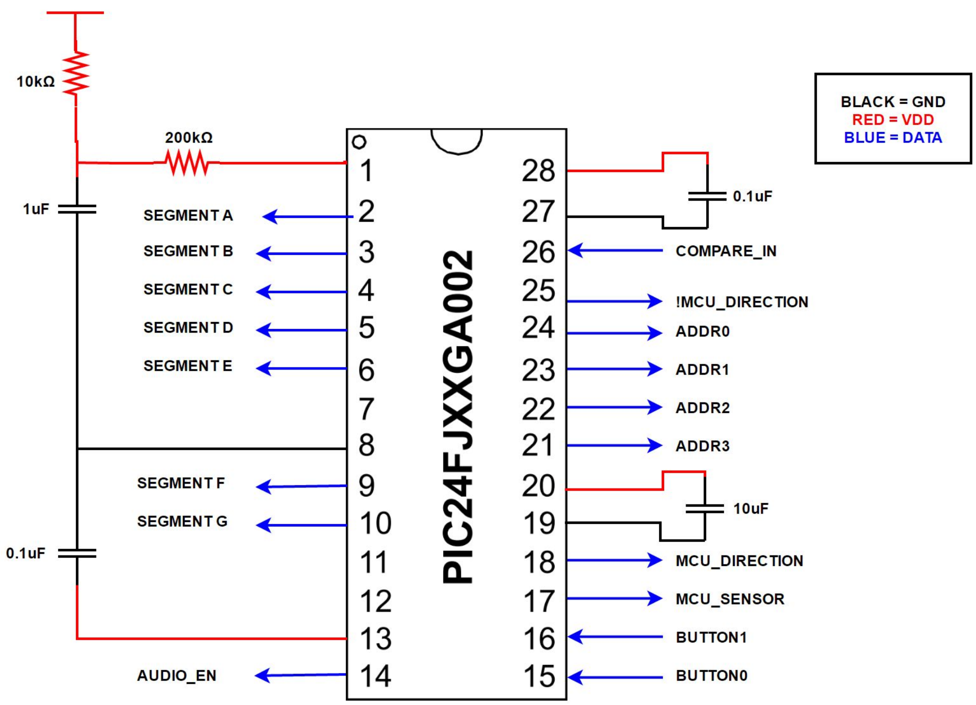

Figure 8 - Microcontroller Connections

Button Inputs

We used two Omron Electronics SW400-ND switches for our game input. These buttons signal to the microcontroller to start the game, switch to the next player, or end the current game when both buttons are pressed.

2.2.3 Game Mats

Infrared Proximity Sensor

Using infrared (IR) sensors we detect the presence of a cup in its respective slot. Paired with a comparator, the microcontroller receives a logical high if a cup is present. If a cup changes from present to removed, the sensor communicates to the microcontroller, which updates the current game's state and score. The IR emitter requires 1.7V, but we chose 3.3V for the input voltage to the receiver to increase the output voltage level of the IR sensor.

Piezoelectric Force Sensor

Piezoelectric sensors are used to detect hits from the ball into the cup. Piezoelectric disks (piezos) consume no power when detecting vibrations. Since they are passive, we did not need to have any connections from these disks to the Power Supply Module. Instead, we only routed data connections back to the microcontroller. When the sensor is placed under the cup, vibrations across the sensor generate a voltage differential when the ball strikes the cup.

A variable that we needed to take into consideration was the resonant frequency of the piezoelectric disks. Figure 9 shows voltage level outputs of three different types of sensors. We chose 2 KHz as our sensor because as the figure shows, the number of peaks at a max of 5 V is largest with 2 KHz as well as the duration of the voltage reaction. Also, by testing voltage outputs of the 2 KHz sensor, we were able to set a benchmark of 1.96V that differentiated table bumps and cup hits with high accuracy. If a ball hits a cup, the sensor will communicate to the microcontroller to play a noise.

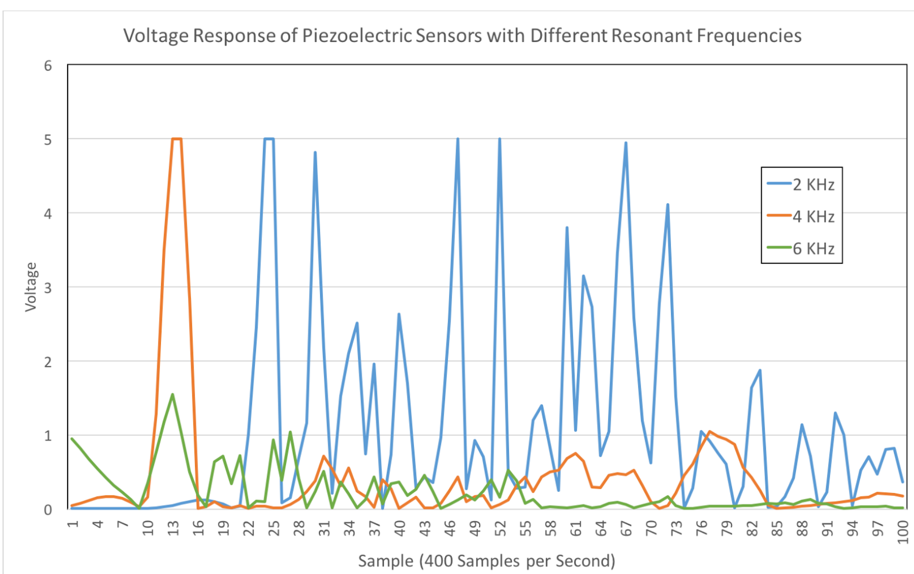

Figure 9 - Voltage Response of Piezoelectric Sensors

Scanning Unit

The scanning unit completed the task of multiplexing sensor data back to the microcontroller in an efficient manner while also reducing the number of input/output pins required in our design. The scanning unit also utilized 4-to-16 decoders to control individual sensor units which offered quick responses while saving power. A schematic of this unit can be seen below in Figure 10.

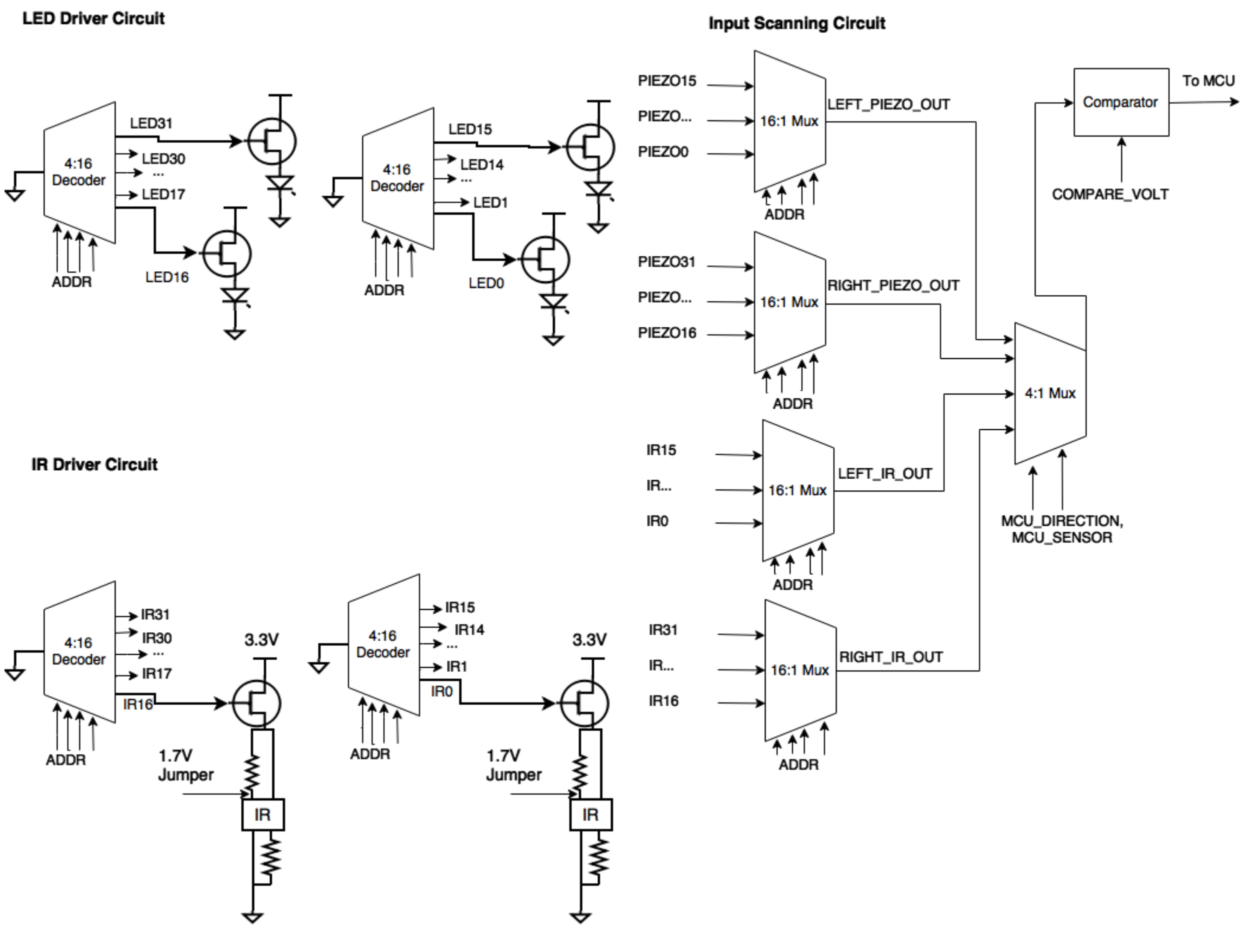

Figure 10 - Multiplexer and Decoder Design for Scanning

To determine our sensor polling frequency, we used the data presented in the previous section to determine the average duration of an impact. This data gave us a minimum polling frequency of 5KHz at which we would need to poll our sensors to avoid missing an impact. Seen below in Figure 11 is a waveform captured using an oscilloscope. The waveform shows the switching frequency of the least significant address bit. After finding the period of this waveform, we inverted the calculated value to find a frequency of 6.57KHz which is even better than our calculated minimum.

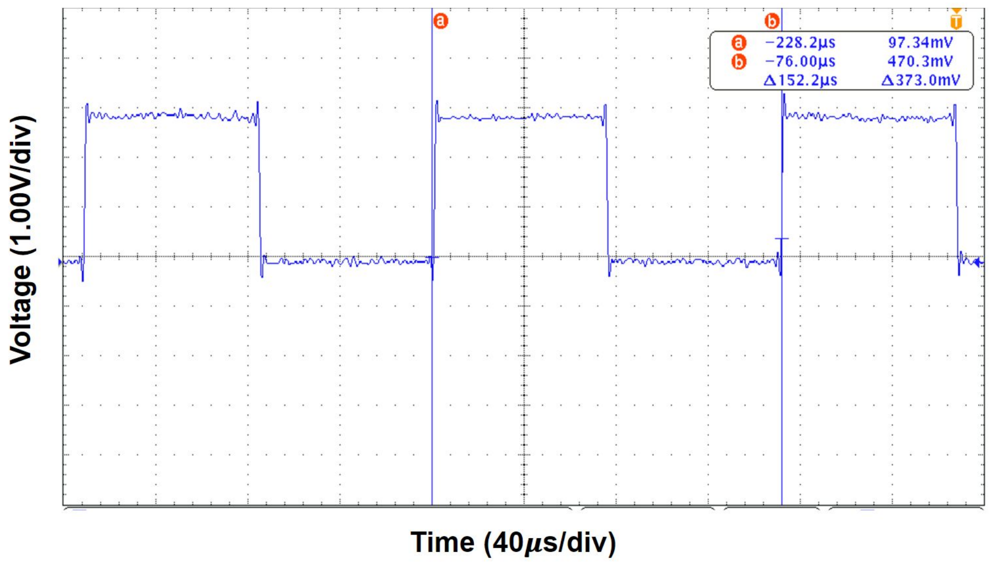

Figure 11 - Address LSB Switching Frequency

2.2.4 Audio and Visual Unit

LEDs

There are 29 LEDs installed in total. Our microcontroller constantly scans across the LEDs, hence, there is only one powered at any given time. Each LED is in series with a PMOS transistor which takes input at the gate from the output of the decoder. When the decoder pulls the gate low, the current will flow from the supply rail through the LED and to ground emitting light.

Seven-Segment Display

A seven-segment display presents the current champions' streak when a game ends. It also keeps track of which player is shooting during a game. This seven segment display is controlled by the microcontroller through the use of discrete NMOS parts to minimize current on the I/O pins.

Speaker

We chose our speaker primarily because it paired well with the audio driver. It has an 8 ohm nominal impedance and a maximum input power of 1 watt capable of reaching levels of 92 dB which exceeds our requirements.

Audio Driver

We used an ISD8120 as our audio driver. We chose this device primarily because it allows for easy audio recording, and playback of pre-recorded audio sample with a simple one pin communication protocol from the microcontroller. This device allowed our group to record the desired cup-collision sounds even after installation into the project. Once recorded, playback is initiated by pulling a level-sensitive input high for the desired playback time.

3. Costs

Name	Part #	Qty	$/unit proto.	$/unit bulk	Cost proto.	Cost bulk
LED	5050 SMD LED	33	0.05	0.01	1.65	0.33
Discrete PMOS	NX7002AKVL	33	0.11	0.016	3.63	0.528
Battery Holder	SS20508-2FF	1	1.00	1.00	1.00	1.00
Speakers	SM300208-1	1	2.66	1.20	2.66	1.20
Audio Driver	ISD1820PY	1	1.00	1.00	1.00	1.00
Seven Segment	TDSR1050	1	1.78	0.61	1.78	0.61
Hex Driver	AS1108	1	4.42	1.92	4.42	1.92
IR Sensors	OPB606A	20	1.16	0.923	23.20	18.46
Piezoelectric Sensors	7BB-41-2L0	20	1.27	1.11	25.40	22.20
Comparator	LM393PE3	1	0.45	0.094	0.45	0.094
16:1 Analog Mux	CD74HC4067	4	0.82	0.297	3.28	1.188
4:1 Analog Mux	MAX4518EEE	1	2.31	1.90	2.31	1.90
4-16 Decoder	CD74HC15M96	2	0.63	0.23	1.26	0.46
Buttons	SW400-ND	2	0.35	0.172	0.70	0.344
Microcontroller	PIC24FJ32GA002	1	2.45	1.78	2.45	1.78
Boost Converter	LTC3526LBEDC-2	1	4.53	2.48	4.53	2.48
Buck Converter	Custom	1	3.35	1.69	3.35	1.69
Assorted Discrete Parts	Multiple	1	5.00	0.50	5.00	0.50
Total Parts Cost:					88.07	57.68

Table 1 - Part Costs

$$Labor\ Cost\ =\ 3\ people\ \times\ \frac{\$40}{1\ hour}\times\frac{10\ hours}{week}\times 16\ weeks\ \times 2.5\ =\ \$48,000$$

$$Total\ R\&D\ Cost\ =\ Total\ Parts\ Cost\ (Proto)\ +\ Labor\ Cost\ =\ \$48,088.07$$

4. Conclusion

In conclusion, our final design met all high-level requirements. We are proud to see our project functioning as intended as an entertaining and enhanced version of beer pong. Our future considerations include: the addition of a second mat for complete game functionality in addition to a 3D printed case for the control hub, and fully waterproofed game mats. An accomplishment that is worth noting is our optimization of power consumption through the use of a sophisticated scanning unit. To take this product to market, special attention must also be paid to ethical dilemmas that our project encounters.

While our current physical design provides some waterproofing, we know that a device that will constantly be surrounded by water or beer-filled cups, must adhere to a water-resistivity specification in accordance with the IEEE Code of Ethics, #9: “to avoid injuring others, their property, reputation, or employment by false or malicious action” [8]. We will need to obey an IP54 rating which consists of resistance against splashing of water.

Our plan for waterproofing the project included spill and splash resistant game mats. The game mats are at the highest risk of exposure to conductive liquids. This poses not only an issue for the functionality of our project, but is also a major safety concern despite the relatively low voltages and currents present. As such, we decided to waterproof these game mats by using a two-layer design which sandwiches the exposed electrical components between an opaque plastic mat with locations for the cups and a closed-cell neoprene material which will not only offer water resistance, but help to isolate the sensors from the vibrations induced in the table.

5. References

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[3] Rich. R, Floor Manager of the Rock Bar Las Vegas, Julie P., Steve D., Jessie V., and Brandon D. "Infinity Glow L.E.D Beer Pong Table." *Infinity Beer Pong*. N.p., n.d. Web. 08 Feb. 2017. http://www.infinitybeerpong.com/products/customized-infinity-glow-led-beer-pong-table

[4] "Official Beer Pong Tournament Rules (WSOBP)." BPONG. N.p., n.d. Web. 24 Feb. 2017.

[5] Energizer E95. N.p.: Data.energizer.com/pdfs/e95.pdf, n.d. PDF.

[6] "LTC3526L-2 - 550mA 2MHz Synchronous Step-Up DC/DC Converters in 2mm × 2mm DFN."LTC3526L-2 - 550mA 2MHz Synchronous Step-Up DC/DC Converters in 2mm × 2mm DFN - Linear Technology. N.p., n.d. Web. 24 Feb. 2017.

[7] "PIC24FJ16GA002." Microchip Technology Inc. N.p., n.d. Web. 24 Feb. 2017.

[8] "IEEE IEEE Code of Ethics." *IEEE - IEEE Code of Ethics*. N.p., n.d. Web. 08 Feb. 2017. http://www.ieee.org/about/corporate/governance/p7-8.html

[9] Buck Converter Design Example (n.d.): n. pag. Web. http://satcom.tonnarelli.com/files/smps/SMPSBuckDesign_031809.pdf

Appendix A - Requirement and Verification Table

	Table X System Requirements and Verifications		
Module	**Requirement**	**Verification**	**Verification status (Y or N)**
D-Cell Batteries	1. Open circuit battery voltage of at least 1.5V nominally 2. Must supply 124 mA of current	1. Measure open circuit voltage with digital multimeter 2. Simulate maximum load while measuring output voltage ensuring it remains above 0.5V	**Y**
DC-DC Boost Converter	1. Accept input in the range of 0.5-2.5V while delivering a steady output of 3.3V (150mV) 2. Deliver an output current of 125 mA	1. We will sweep through the input voltage between 0.5 and 2.5V at 0.1V intervals while measuring the output voltage of our 3.3V rail. 2. With maximum load circuit, measure the output current with a multimeter	**Y**
DC-DC Step Down Converter	1. Must accept input voltages between 3.1 and 3.3V 2. Must provide adjustable output around 1.73V (+/-0.2V). 3. Must provide at least 20mA of output current.	1. Apply voltages between 3.1 and 3.3V at the input of the device at 0.05V intervals. 2. This will be tested by loading with an 85Ω resistor for the output feedback and measured to confirm 1.7V operation.	**Y**
Low Battery Indicator	1. Must turn on an LED when the battery voltage drops below 0.75V.	1. We will test this functionality by sweeping the input voltage of this module by 0.1V intervals from 0.9V to 0.8V and ensuring the output LED turns on at the proper voltage level.	**Y**
Microcontroller	1. Must have at least 18 digital I/O pins 2. Power draw must be less than 50 mW	1. Verify through specifications sheet 2. Run at 16MHz and 3.3V while measuring current drawn	**Y**
Button I/O	1. Deliver a logic high when pressed 99% of the time	1. These switches will be tested on the bench before installation into the control hub to ensure proper functionality. We will also test these buttons by using the oscilloscope to analyze the voltage response when pressed	**Y**
LEDS	1. Output greater than 20 lumens (+/-2 lumens) at 60mA	1. Apply 60mA to the LED and measure the lumens with a light meter	**Y**

	2. Possess vertical dimension less than 0.4 inches when connected to remain below bottom mat surface.	2. Measure with a digital caliper	
Seven-Segent Display	1. Each segment outputs a value greater than 10 millicandelas (minimum expected output of display) at 20mA	1. Apply 20mA current to each segment and measure the candelas with a light sensor	**Y**
Speaker	1. Must output a sound greater than 75 dB (busy restaurant or social gathering level)	1. Play audio clip from our audio driver and record the dB of the speaker in a quiet environment with decibel meter	**Y**
Audio Driver	1. Must record one 5 second clip while powered and store the recorded data in non-volatile memory. 2. Must be remotely controlled by a single level-sensitive pin.	1. A 5 second recording will be made with the device powered. After powering the device off, the device will be powered again and the recording will be played to ensure data retention. 2. After recording sound clip, the clip will be replayed by pulling a single enable high and verifying audio output.	**Y**
Infrared Proximity Sensor	1. Output a logical high when 0.25 inches from the side of a red Solo Cup 2. Output a logical low when there is no cup present in the indent	1. Measure V_{out} from sensor while the IR sensor a quarter of an inch away from the cup. (must be > 1.96V) 2. Measure V_{out} from sensor when the cup has been removed from the indent. (must be < 1.96V)	**Y**
Piezoelectric Force Sensor	1. Sensor must output voltages linearly proportional to the force of impact for use as an impact detector	1. Drop 2.7 gram ping pong ball at intervals of 5 centimeters and record voltage levels to determine force voltage relationship	**Y**
Scanning Unit	1. Must be able to turn LEDs on or off depending upon the presence of a cup 2. Must take multiple analog inputs and output a single digital output corresponding to the correct address	1. We will enable and disable LEDs while measuring current through them to ensure they are turning on and off properly 2. We will cycle through addresses with different inputs on each pin to ensure A/D conversion	**Y**

Appendix B - Software Flowchart