Gas Stove Safety Device

By

Derek Cernek

Jared Trupp

Joey Sun

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TA: Bonhyun Ku

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Abstract

The device in question is a safety device for gas stoves that requires no complex installation. It focuses on alerting the user instead of automated shut-off and relies on two separate units for its intended functionality. The device can sense flammable gases and the distance the user is from the stove. We built the gas stove safety device with some communication and materials issues, but in general, the process went very smoothly.

Contents

1. Introduction

Each year, 172,900 homes burn down due to cooking-related fires, the leading cause being unattended stoves. Additionally, many gas leaks in a home occur due to stoves boiling over and putting out the flames, causing gas to start leaking from the now-unlit stove. Based on studies performed by the NFPA (National Fire Prevention Association), about 39% of the fires per year are attributable to human negligence (unattended or unintentionally turned on/not turned off) of the stove itself. 36% of the fires are attributable to the negligence of materials around the stove, and only a minute percentage of fires are various forms of failures [1].

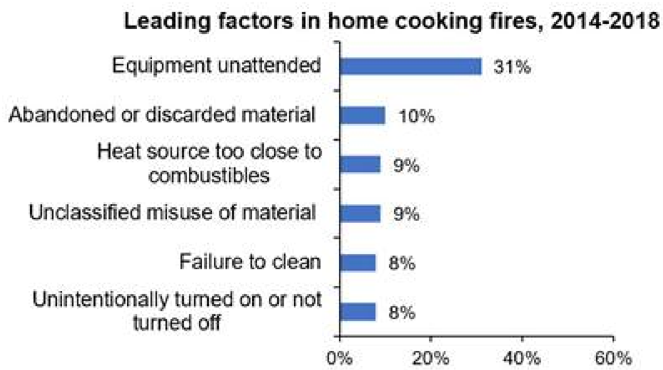


Figure 1: Chart of leading factors of home cooking fires. Two factors exist that can be solved through a clever device: Unattended equipment and unintentionally turned on.

We cannot depart from gas stoves any time soon, and so we created a safety device that alerts people to potential fire risks, known and referred to as the gas stove safety device. We define these fire risks in our high-level requirements as:

1. The device must be able to detect when the stove is on, issuing an intermittent warning.
2. The device must sense when the user has walked 5 to 15 meters away, sending a more urgent alert of some form.
3. The device must detect when a dangerous amount of flammable gas is in the air, defined as 5,000ppm methane, 2,100ppm propane, or 1,600ppm butane, triggering an immediate alert.

The high-level requirements did not change meaningfully -- the only change that happened was the assignment of numbers directly to the gas sensing requirement.

We made a few changes to the block diagram (Figure 2) during development. For one, we discovered that if we were to use a voltage booster to step the 3.3V output supported by the personal alarm's power supply up to 5V, we would potentially be risking the battery's health, as the LiPo battery best supports 3.3V, and maximum outputting only 3.7V. We also discovered that the ATmega328-PU chip does not output enough current to power the alarm and the distance sensor, so we had to wire both directly into the power supply. Other changes such as the Bluetooth modules, the controllers, and the knob sensor were adjustments made due to on-hand supply changes and shortages.

Overall, the project was a resounding success. Chapter 2 introduces the design decisions, theoretical calculations, and alternative approaches. Chapter 3 showcases the testing procedures, verification steps, and potential issues. Chapter 4 states the cost of production, for both labor and materials. Chapter 5 showcases accomplishments, points for improvement, and ethical considerations.

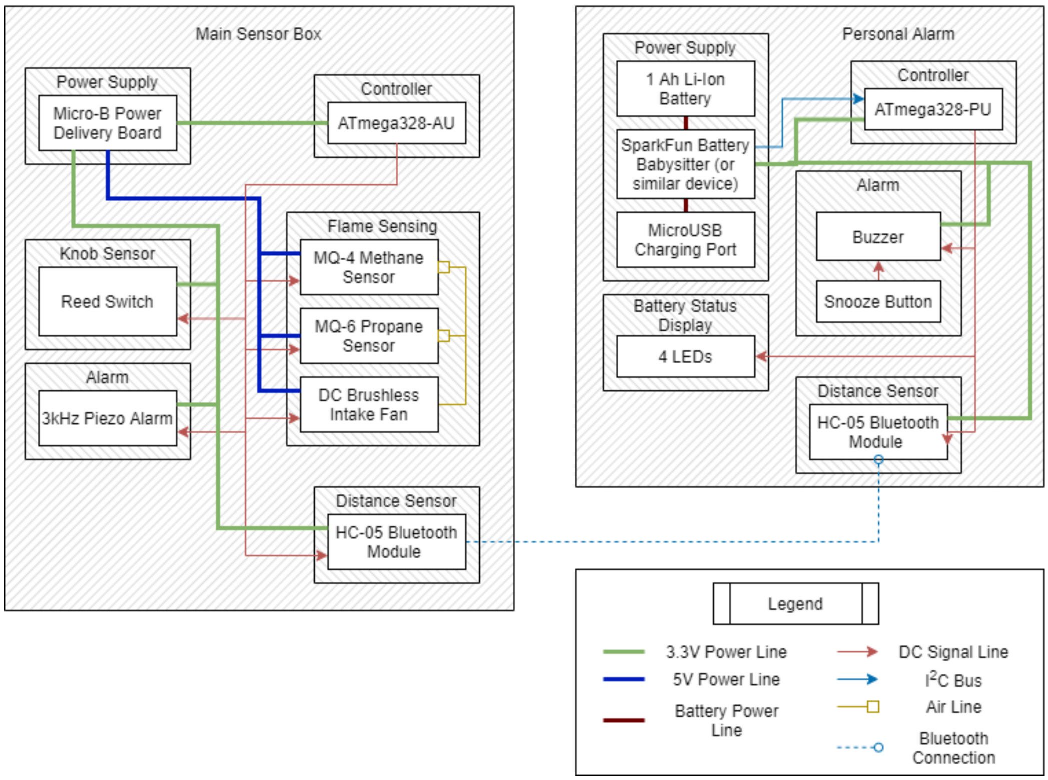


Figure 2: Block diagram of the current Gas Stove Safety Device.

2. Design Procedure

2.1 Main Sensor

2.1.1 Physical Design/Casing

The physical design, drawn on paper, modeled in Autodesk Inventor, and 3D printed using Ultimaker Cura with a large printer is primarily an overcompensation for prototyping and testing. When the exterior design began, we had two different plans for how the prototype exterior would look (Figure 3). There are merits and drawbacks to each design. Flat is more stable, as its center of gravity is closer to the ground. Flat also allows for better prototyping, as we have adequate viewing space while working on the project. Finally, due to the low profile of Flat, it is naturally easier to waterproof as we expect liquids to come from mostly one direction. However, Tower can potentially take up less space and material than Flat. We determined that the benefits of Flat outweigh the benefits of Tower, and as such, we used Flat for our prototype design.

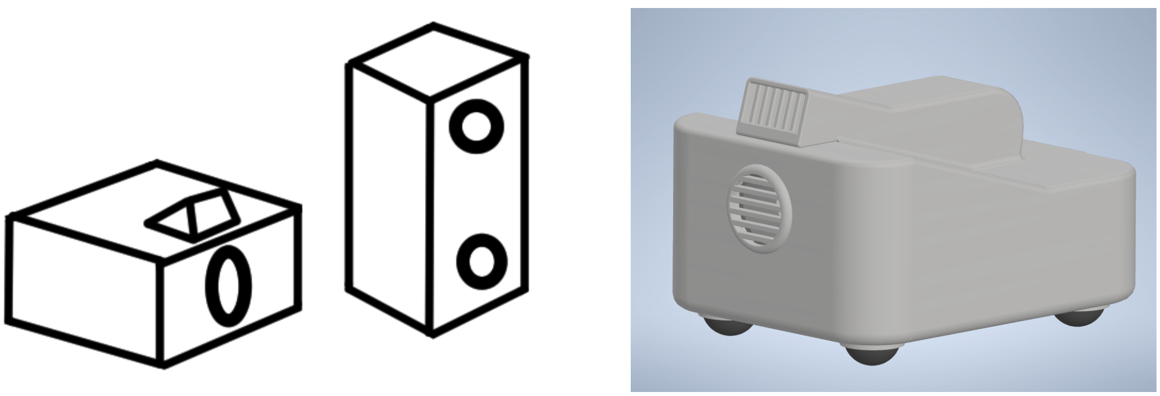


Figure 3: A sketch of both proposed exteriors and a model of the finalized exterior. We name the left sketch "Flat" and the right sketch "Tower." Both have an intake and exhaust hole for gas sensing.

2.1.2 Power Supply

The Power Supply (Figure 4) provides the circuit with 3.3V and 5V at all times. It is a critical component of the entire system because not all submodules utilize the same voltage logic. Because an AC/DC wall converter powers our system, which turns 120V AC into 5V Micro-B, our power supply focuses on converting voltage levels over converting AC to DC. We could have built our own internal AC/DC converter, allowing the user to utilize a simple wall socket instead. However, by powering the system using Micro-B, the user can instead use a cell phone charger or power bank to power this system. Doing so grants the user reduced costs on the final product, as they do not have to pay for an AC/DC converter that they already have, and allows the user freedom in portability. For our price calculation, however, we included the price of the

AC/DC converter. Molex KK connectors were used for the connection outputs to the sensors and MCU to allow for easy connect and disconnect as well as safety.

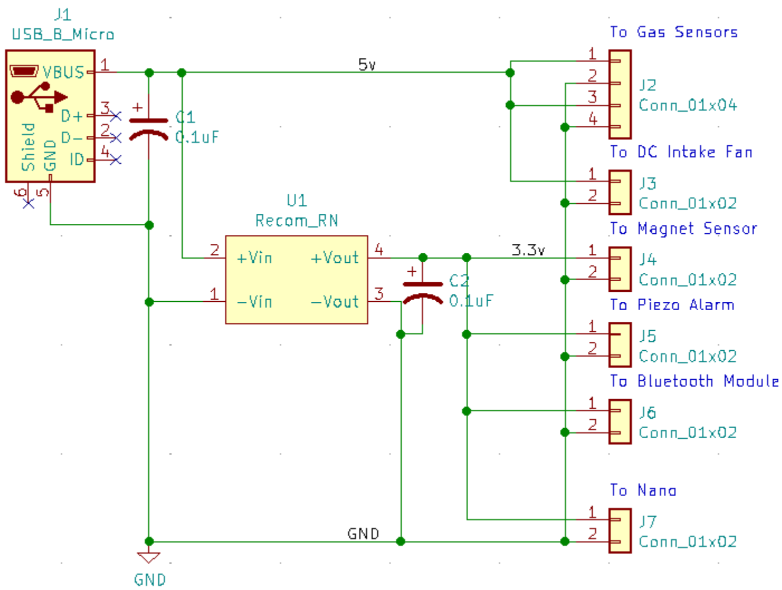


Figure 4: Power Supply and Conversion PCB Schematic

2.1.3 Controller

The controller is based on the ATmega328 architecture, with enough digital and analog pins to interface with the analog gas sensors and other sensor signals. Originally, it was designed with the ATmega328-AU in mind to keep the board footprint to a minimum, but miscommunications and alternate sizings meant the ATmega328-PU had to be used in the prototype. 5 of the digital pins were used, 3 being connections to the Bluetooth module, 1 for the output of the Hall effect sensor, and 1 driving the gate of the alarm circuit. 2 analog pins were used for the gas sensor readings. The firmware architecture was designed for two major states, the gas stove being off or on which the magnet sensor tells us. In either case, the gas sensor readings are retrieved and the alarm is sounded. If the stove is on, there is also an internal 1-minute timer where the alarm sounds briefly if the personal alarm is not connected to the Bluetooth module on the main sensor box.

The circuit schematics for this module can be found in the Schematics Appendix: Appendix D.

The circuit schematics for the following modules in the sensor suite can be found in the Schematics Appendix: Appendix D.

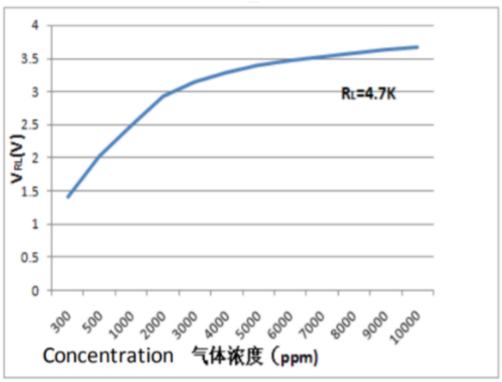
2.1.4 Flame Sensing

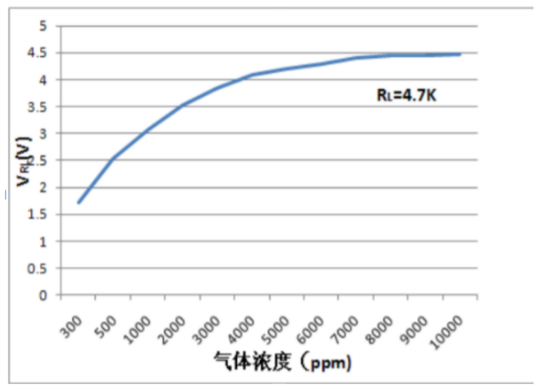
The flame sensors are a duo of flammable gas sensors, the MQ-4 and MQ-6. We find the thresholds to set our sensors under OSHA standard 1915.12(b)(3), where they state that atmospheres with gas at or above 10% of the lower explosive limit (LEL) are hazardous [8]. We can then calculate the LEL in PPM through Equation 1 using pre-measured data [9].

$$\frac{LEL}{100} * \frac{1}{10} * 10^{6} = PPM$$

Equation 1: Converting LEL to necessary PPM to detect according to OSHA standards.

The gas sensors themselves operate on a conduction change due to the presence of gas. Composed of a semiconductor material SnO_2, both sensors become more conductive as gas is introduced and lose that conductivity when the gas levels return to normal. This allows for the sensors to be long-lasting and very accurate at the expense of a warm-up time.





Figures 5&6: Methane and Propane/Butane ppm to Voltage Curves

2.1.5 Knob Sensing

The knob sensor is based on magnetic detection using a Hall effect sensor, which detects the strength of the magnetic field in the area, and a powerful magnet affixed to the knob using adhesive. The sensor is flush with the knob magnet in the off position of the knob. When the knob is off, the field lines are perpendicular to the sensor's detection, causing it to output a logical 0. When the knob is on, the sensor detects a reduced perpendicular component, causing it to output a logical 1.

An alternative is a mechanical actuator of some form. The mechanical actuator would rely on motor feedback to determine when it has moved, how far the knob has moved, and could even rotate the knob back to the off position automatically. However, the mechanical actuator would be very complex and take a long time to design for all stovetop knobs. For this reason, we chose the Hall sensor.

2.1.6 Alarm

The alarm is a CE-C75 DC piezoelectric alarm, varying in decibels proportional to the input voltage. We use a MOSFET to feed it a 3.3V DC signal, allowing it to produce about 70dB of sound at a distance of half a meter, around the sound of a normal conversation. The alarm was driven on the drain end of a BSS123 nMOS transistor, in parallel with a green LED. Both were driven at the necessary currents when the controller set the voltage at the gate of the nMOS, sounding the alarm and turning on the LED. There was also a switch between the ground of the alarm and the board ground, such that its operation could be halted physically. This was important for testing so that we could verify the alarm turning on with the flashing of the LED without the alarm constantly buzzing.

Due to the simplicity, both in wiring and in the logic of the DC piezo alarm, it is difficult to find a suitable substitute. Theoretically, one could use a buzzer that relies on a waveform, but the difficulty of generating even a viable square wave makes DC sirens the better option. Refer to Section 3.2 for further information.

2.1.7 Distance Sensing

The distance sensor utilizes an HC-05 Bluetooth module. The Bluetooth antenna on the main sensor box serves as a reference point to connect to and performs no other functions. See Section 2.2.7 for further details and alternative approaches.

2.2 Personal Alarm

The circuit schematics for each of these parts can be found in the Schematics Appendix: Appendix D.

2.2.1 Physical Design/Casing

The physical design, modeled primarily in Inventor and 3D printed using Ultimaker Cura, is designed more for ergonomics. It relies on three dimensions to stay compact. The design process was quicker, taking a small portable battery for mobile phones as the inspiration for its exterior. Smaller portable batteries are already ergonomically quite comfortable and easily carried. As such, we used similar dimensions, drastically reducing the time it took to settle on a final design.

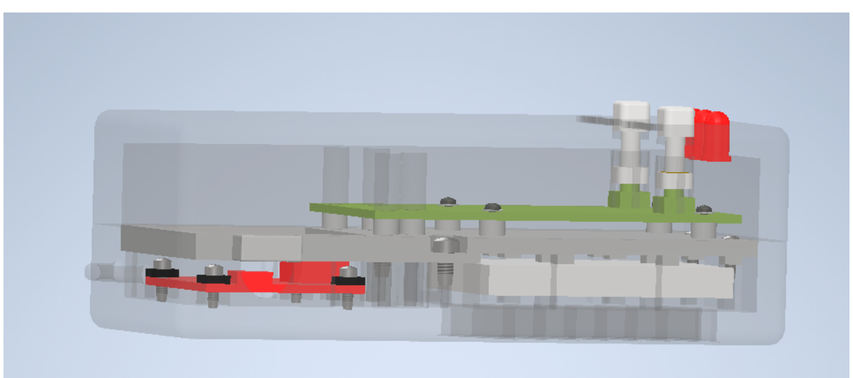


Figure 7: Physical design of the personal alarm.

2.2.2 Power Supply

The power supply is the SparkFun Battery Babysitter, manufactured by SparkFun. As the Battery Babysitter is compact, supports charge level exporting, and supplies a steady 3.3V from a LiPo battery, it was the perfect choice for our product. We could have manufactured our own, but we do not have the machinery necessary to make a power management unit as compact or as reliable as theirs. As LiPo batteries, poorly managed, are known to explode with moderate to severe risk to human life, we felt that it would be wiser to buy a proven power management unit rather than attempting to produce our own.

2.2.3 Controller

The controller chosen to control the personal alarm was the ATmega328PU. This specific microcontroller was picked because it had enough input/output pins to control or receive all of the signals. This controller is also extremely common in many DIY projects, which means there is a lot of information and resources for this controller. With these two things in mind, it made a lot of sense to use it. The through-hole package was selected because IC sockets can be used, which means the microcontroller can be taken off the board easily if it gets damaged, or to make it easier to program it. Altogether 10 of the digital pins were used and connected to different parts of the board. Some of these are unused in the current configuration but allow for more advanced features and functions with more software upgrades. In case there was a problem with the design of the circuits on the board, pin sockets were added that connect to the most important controller pins. It was designed this way to make it easier to debug, or to make quick and dirty modifications to get a prototype working. This feature was not needed in the end for the personal alarm, because the board worked as designed.

2.2.4 Alarm

The alarm is a CMT-0525 magnetic buzzer, driven using a square wave generated by code from the controller and an output pin toggled on and off rapidly. This waveform should be somewhere between 200~500Hz. Due to the usage of the controller to generate the square wave, we expected large amounts of inaccuracy in the waveform, but at the least, it produces an audible, albeit quiet, sound.

We could have instead used the same CE-C75 piezo alarm in 2.1.6 and reuse the same DC MOSFET driver. Doing so would make our jobs easier. At the same time, the CE-C75 is larger than the CMT-0525. Out of the need to save space, we instead opted to use the magnetic buzzer.

2.2.5 Battery Status Display

The battery status display is four LEDs and a push-button that toggles current flow through the LEDs on or off (Figure). This design did not change compared to the original design document, utilizing MOSFETs to drive all four LEDs when the user holds down a button. Each LED represents 25% of the charge in the battery.

An alternative design would utilize a pair of seven-segment LED displays to output the exact percentage of remaining battery life. However, this would primarily take up too much space, as seven-segment displays are much larger than 5mm LEDs. More MOSFET logic would also be introduced, taking up more space. Because of these reasons, we opted for the four-LED solution implemented in our final prototype.

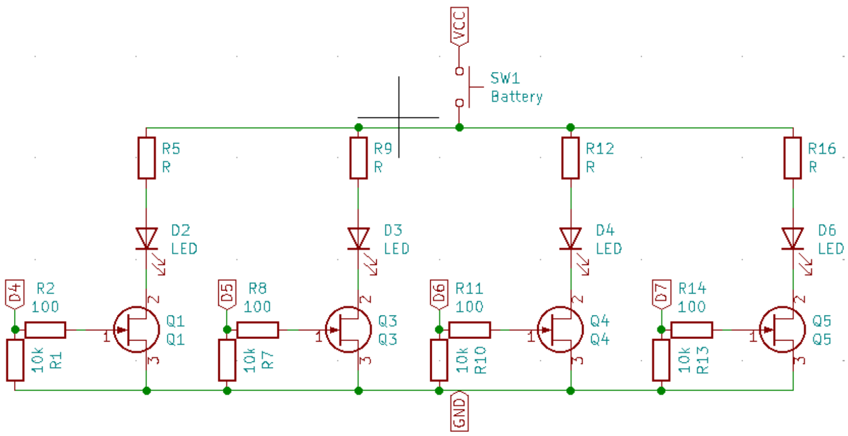


Figure 8: Battery status display schematic.

2.2.7 Distance Sensing

The distance sensor now utilizes an HC-05 Bluetooth module because when we purchased ours, the retailer sold them in a pack of two. The functionality is identical to the HC-05 and HC-06 pair if we set one of the two HC-05 chips to Receive Only.

An alternative to Bluetooth would be using a motion sensor. If we implement this solution, the personal alarm can be removed, saving the user money. However, movement sensing can be fooled by pets, which poses too much risk. For this reason, we opted to use Bluetooth over any other method.

3. Design Verification

3.1 Main Sensor

The verification of the main sensor box is split into the verification of the power supply, each main sensor, and the operation of the controller unit with the sensors. The expected current draw of all the main sensor box components was around 519mA. Verification was performed by placing a 16Ω load on both voltage rails and verifying the output voltage and current.

Table 1: Voltage and Current Analysis of Power Distribution		
	5V Line	3.3V Line
Open Load	5V 26mA (Intake into Board)	5V No Current
16 Ohm Load	5V 310mA	3.384V 208mA

Verification of the gas sensors, hall effect sensor, and alarm consisted of powering the devices according to their datasheets and analyzing them for the expected output. The alarm circuit was constructed and tested by supplying 3.3v input and connecting the gate of the MOSFET with 3.3v. Verification was met with the green LED turning on and the alarm sounding.

The gas sensors were powered and contained in an airtight vessel while a controlled level of gas was introduced. The voltage output of the sensors was verified by an increasing voltage as the level of gas increased, however, due to the methane sensor being placed on a breakout board with a potentiometer near the output it instead operated by lowering the output voltage as gas increased. Despite this, both were able to detect the appropriate gas amounts when powered.

The hall effect sensor was tested by placing a neodymium magnet near it while it was powered. Verification of this stage failed since the pins were connected incorrectly, which damaged the sensor. It was replaced by the Reed Switch which gave the same output voltage when drawing the output rail to the ground when connected to a magnet.

The Bluetooth module was initially verified by the powering of LEDs on the Bluetooth breakout when powered, the interlink being verified with both the main sensor box and personal alarm at a later time.

The controller was tested by bootloading the ATmega and flashing on test code to verify correct outputs on digital and analog pins. After this, the firmware for the sensor box was loaded and the controller was connected to the power supply board and sensor board. Initially, the firmware was designed with both gas sensors in the active high cycle for gas input. After changing the methane sensor to signal gas during low voltage conditions, the full functionality of the main sensor box was realized and fully functional.

A final test of the rigorousness of the gas detection system was performed on an actual gas stove in two parts. The first part included powering the box and causing a mock gas leak from the stove using two handheld zippo lighters near the burners. The expected response would be a flashing of the green alarm LED for 3 seconds with a second in between within 5 seconds of applying the gas. This was what we saw during the test. For the second part, the stove was turned on with a flame present. The expected response would be no alarm sounding, as well as no heating of the sensor box itself. This was what we saw during the test, verifying the main sensor box's ability to detect the flame and warn the user of a gas leak.

3.2 Personal Alarm

For many parts of the personal alarm, it either works or it doesn't. This made it easier to test and to make sure that everything works. After getting the personal alarm soldered together, the first test that was done was just testing the resistance of the solder joints between the components and pads. Doing this revealed one spot where there was an unsoldered pad, which would have prevented the alarm speaker from working. The next test was resistance checks between ground and voltage rails. This was to make sure that there were no obvious shorts on the board. After that was checked, the next step was to go into the lab and power up the board with the bench power supply. The current limit on the power supply was set to 100mA and the board was powered up. The low current limit was set to minimize damage if something failed, which once again all worked properly. Now that the board could be powered up without any problems, the next step was to test the independent circuits on the board.

To test many of the circuits, it was easiest to simply just connect Vcc to the different control pins to verify that they behave as expected. For example, Vcc was applied to the MOSFET control pin on the controller socket, which then activated the corresponding circuit. Every part of the personal alarm board worked exactly as intended. With all the circuits working, the last thing to make sure it was working was the ATmega. Because we had the ATmegas ordered directly from an electronic part distributor, the controllers came with nothing loaded on them. So the first important step to use them was to burn a bootloader onto them so that we can program them with the functionally we want. This was done by using an Arduino as an ISP programmer which was used to flash the Arduino bootloader onto the controllers. Once this was done, it was a simple task of just programming the controllers, and checking if the code works. The first edition of the code almost worked completely on the first test. Only one new line of code was needed to get the code working with the basic functionally required by the design document. With the controller working as expected, the next part that needed to be tested was the Bluetooth modules and getting them to connect. This is discussed in the next section.

3.3 Bluetooth Interlink

With the default settings on the HC-05 Bluetooth modules, they do not connect automatically to each other. To get them to pair, we used an Arduino to connect to one of the modules. Using the serial terminal on a computer connected to the Arduino we were able to send commands to the Bluetooth module to set one into slave mode, and another into master mode. The master model was then set to only connect to the address specific to the slave. Once this was done, the modules then successfully started to pair with each other. Once the pairing was achieved, each part of the project functionally with the Bluetooth was checked. Once again, everything was working as expected. The last thing that we were unsure of was the module's ability to automatically reconnect. So separating the devices and bringing them back together showed that they do automatically reconnect. With that tested, everything in the project was working.

4. Costs

4.1 Parts

We had a 1kg spool of PLA filament on hand, so we avoided the cost of 3D printing during our prototyping. However, in the cost table (Appendix C), since 0.6kg of filament cannot be custom ordered, in the retail cost, we opted to put in the price for 1kg of filament instead. The bulk production cost reflects the scaled price for 0.6kg of filament.

The necessary components have a total cost of $143.67, all detailed in Appendix C. For future production, injection molding is an ideal process for making the casing, and in-house manufacturing can make the Battery Babysitter.

4.2 Labor Costs

Based on the labor rate of 3 graduate-level engineers working at $30/hour, working 10 hours per week over nine weeks, we determine our final cost for labor is $20,250, as shown in Equation 2.

$$3\,workers\ *\ \frac{\$30}{hour} * \frac{10\,hours}{week} * 9\,weeks\ *\ 2.5\ =\ \$20,250$$

Equation 2: Development costs for all members of the project.

Table 2: Cost Analysis Table (Labor)				
Partner Name	# of Hours	$ Per Hour	2.5x Multiplier	Total
Joey	90 hours	$30.00	2.5x	$6750.00
Derek	90 hours	$30.00	2.5x	$6750.00
Jared	90 hours	$30.00	2.5x	$6750.00
			TOTAL	$20,250.00

With labor costs and material costs put together, our final project costs $20,393.67 to produce.

5. Conclusion

5.1 Accomplishments

Overall, we accomplished all of our objectives. We were able to detect the on/off states of a stove. The distance sensor detected when the user steps too far away, and the flame sensor detected when the air contained a dangerous amount of flammable gas.

5.2 Ethical Considerations

5.2.1 Ignition Hazards

With safety as the top priority, we must make sure the device has few risks around a stove. Safety is the most important and applicable IEEE Ethics code that this design must follow [4].

A flame arrester will cover all electronic components to help reduce the chance that a stray spark will ignite the air. Flame arresters are fine wire meshes that cover flame sources, dissipating heat and effectively raising the ignition point of flammable gas. Flame arresters are time-proven designs, saving countless lives in coal mines ever since 1815, the year the Davy lamp was invented. With reliability and feasibility proven, this will satisfy the IEEE Ethics code of safety.

5.3 Uncertainties

Our design for the personal alarm is by no means waterproof, and this may cause issues on the user end. However, waterproofing may cause the personal alarm to heat up, causing other problems. We will require more testing and redesigns to perfect our waterproofing.

5.4 Future Work

By implementing an actuator for the stove knob, we can ensure more safety with automated shut-off. For instance, if the gas sensor reports high concentrations of flammable gases, the safety device can turn the stove off, stopping the gas flow and allowing it to dissipate.

The most sizeable improvement would be mobile app integration. By creating a mobile app, we can cut out the entire personal alarm. A mobile app saves the user $39.65 on the mass production prices, further allowing us to be more marketable than our competitors, who sell their devices at around $700 per device [3] while ours would cost slightly over $50. A mobile app would also allow us to integrate the automated shut-off, allowing the user remote control of their stoves. Further improvements such as a camera to see the food status could be broadcasted over WiFi to the user's smartphone, allowing constant monitoring of foods that take a long time to cook, such as stock and stew.

Appendix A. References

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Appendix B. Requirements and Verification Tables

<table>
<tr><th>Requirements</th><th>Verification</th><th>Status (Y/N)</th></tr>
<tr><td>2.1.2: Power Supply

1. 3.3V bus outputs 147-160mA between 3V-3.7V below 85°C
2. 5V bus outputs 630-700mA between 4.5-5.5V below 85°C</td><td>1. Power the circuit with a Micro-B port.
2. Measure all open-circuit voltages with a voltmeter, ensuring the 3.3V bus is between 3V and 3.7V, and the 5V bus is between 4.5V and 5.5V.
3. Terminate the buses with a resistive load such that the 3.3V bus is reading out its maximum rated 160mA and the 5V bus is reading 700mA.
4. Leave the device on for 30 minutes. Measure the temperature of the components using a thermometer, ensuring they do not exceed 85°C.</td><td>Y</td></tr>
<tr><td>2.1.3: Controller

1. Can read input signals from the various sensors
2. Can drive a MOSFET controlling the siren from the 3.3V bus at 5mA
3. Can drive a MOSFET controlling the intake fan from the 5V at 330mA</td><td>Read Input Signal:
1. Create two circuits where a 5V line and a 3.3V line connect into an input pin on the ATmega328 through a push-button and an output into an LED.
2. Write a script that constantly displays whether the respective pins are receiving HI or LO input. Press the pushbuttons and see if the appropriate LED turns on.

Driving MOSFETs:
1. Write a script that switches an output pin between HI and LO.
2. Create two circuits where a 5V line and a 3.3V line connect through two MOSFET transistors. Place resistors so one outputs 5mA and the other 330mA in theory.
3. Connect the output pins to the gates of both MOSFETs. Use an ammeter to determine proof of functionality.</td><td>Y</td></tr>
<tr><td>2.1.4: Flame Sensing

1. MQ-4 can detect 5,000 ppm methane.
2. MQ-6 can detect 2,100 ppm propane.</td><td>1. Create a circuit and script using the microcontroller that causes an LED to flash when respective concentrations of gas are reached. Place the circuit into an airtight vacuum box, and allow the sensor adequate warmup time.</td><td>Y</td></tr>
</table>

3. MQ-6 can detect 1,600 ppm butane.	2. Fill the box with pure nitrogen at first; then add in the respective testing gas until the proper ppm has been reached. Look for LED flashing.	

2.1.5 Knob Sensing 1. The sensor must be able to output HI when the knob is in the OFF position, and output LO when the knob is turned 30 degrees away from the OFF position.	1. Set up a circuit that powers the AH1815 with 3.3V. Feed the output pin into an LED. The LED should be on. 2. Place the AH1815 flush with a magnet stuck to a stove knob with no gas, and slowly rotate the knob. Mark where the LED turns off. 3. Use a protractor to measure whether or not the knob has turned 30 degrees or less.	Y
2.1.6 Alarm 1. The alarm must be able to output at least 60dB of sound when standing 40 feet away. 2. The alarm must not exceed 90dB of sound when standing 1 foot away.	1. Build a circuit using the alarm with an adjustable voltage. Turn the circuit on and measure the number of decibels the alarm produces at 3.3V. Cover alarm with insulators until the sound reaches 60dB of sound at a distance of 40 feet. The person damping must wear ear protection. 2. Move the measuring device next to the alarm. Measure the decibels and ensure the amount is below 90dB of sound.	Y
2.1.7 Distance Sensing 1. The HC-05 Bluetooth module must automatically disconnect after at most 15 meters of distance in an open room.	1. Build a circuit using the HC-05 and power it on. 2. Using a mobile phone, connect to the HC-05 and slowly walk away until the Bluetooth connection drops. 3. Measure the distance and check to see if it is equal to or less than 15 meters.	Y
2.2.2 Power Supply 1. The power supply can output a consistent 3.0-3.7V at 80mA while on battery power.	1. Set up a circuit where the voltage and current can be measured across the 3.3V terminal. Plug charged battery into the power supply. Measure voltage. 2. Place a resistor across the 3.3V terminal to the ground that gets the current as close as possible to 80mA. Measure voltage.	Y

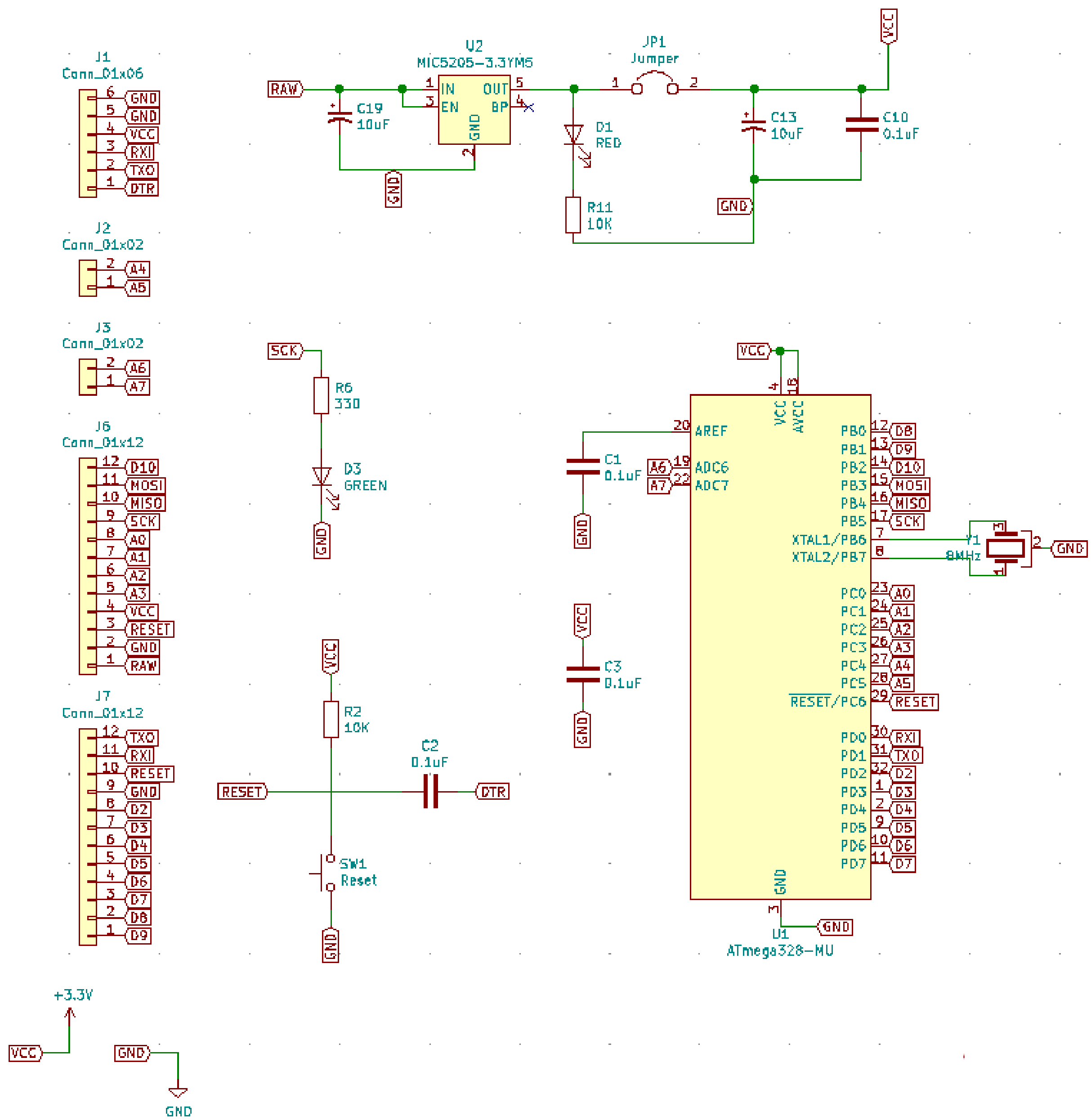
2.2.3 Controller 1. Utilizes a 1-minute timer that can be reset through 1 pin and initiated/deleted through another. 2. Must be able to process an I^2C signal that comes in the form of a percentage, convert it into a 25/50/75/100% format, and output it across four signals.	Timer: 1. Connect the output pin for the timer's alarm to an LED. Power on the controller. 2. Feed HI into the STATE pin input signal and the SNOOZE signal to simulate a pull-up signal. The LED should not be on. 3. Turn the STATE signal to LO. LED should light after 1 minute. Flick the SNOOZE signal quickly once between LO and HI. The LED light again after 1 minute. 4. Flick the SNOOZE signal again and turn the STATE signal to HI. The LED should not light up after 1 minute. Battery Display: 1. Connect the Battery Babysitter to the controller with the proper I^2C setup. Connect the battery in. Observe the signals on HI and the signals on LO. 2. Wire up the 3.3V output to a resistive load that allows for 50mA theoretical current and discharge the battery slowly, turning the resistive load off every 30 minutes for 5 minutes to let the battery cool. Keep an eye on the output signals. After a few hours, a few signals should toggle. 3. Plug a charging cord into the Battery Babysitter and watch the output signals. After a few minutes, a few signals should toggle.	Y
2.2.4 Alarm 1. The alarm must be at least 50dB in volume when placed in moderate insulation. 2. The alarm must be at most 75dB in volume when worn around the neck. 3. The button must output a signal when pressed. This triggers	Alarm Volume: 1. Connect the buzzer to a breadboard and ready a waveform generator. 2. Stand 3 feet away with a sound decibel measurement device and connect the buzzer to the waveform generator. Ensure we measure at least 50dB of sound. 3. Take the buzzer out of the pocket or jacket and move the device 1 foot away from the buzzer. Ensure the sound is below 75dB.	Y

the SNOOZE function in the controller (2.2.3)	Button Signal 1. Wire up a button in a pull-up or pull-down configuration with an LED as the signal recipient. Press the button to ensure functionality.	
2.2.5 Battery Display 1. The distance sensor must be able to reconnect to the distance sensor on the sensor box.	1. Create two separate circuits with two Bluetooth chips. One is rigged to cycle power. Let both connect. 2. Walk out of the room with one, twenty meters away. They should be disconnected now. Walk back into the room to see if they automatically reconnect.	Y
1. Sensor box passes IP52 Protection 2. Personal alarm passes IP51 Protection	Sensor Box IP54: 1. Enclose the box and seal all locations with hot glue. Place a brick inside to weigh it down. 2. Using a hose, spray water at the device for 10 minutes from all angles from a distance of 1 meter away. 3. Dry device exterior and remove sealants. Examine interior for water by tactile examination. If water leaked in but only trickled to the bottom, this is not a concern. Personal Alarm IP51 1. Enclose box and seal with hot glue, a stand-in for a better sealant during production. 2. Place the box upright under a dripping source of water (a faucet will do if the surface is flat) for ten minutes. 3. Remove the box and look for signs of water entering using fingers.	Y

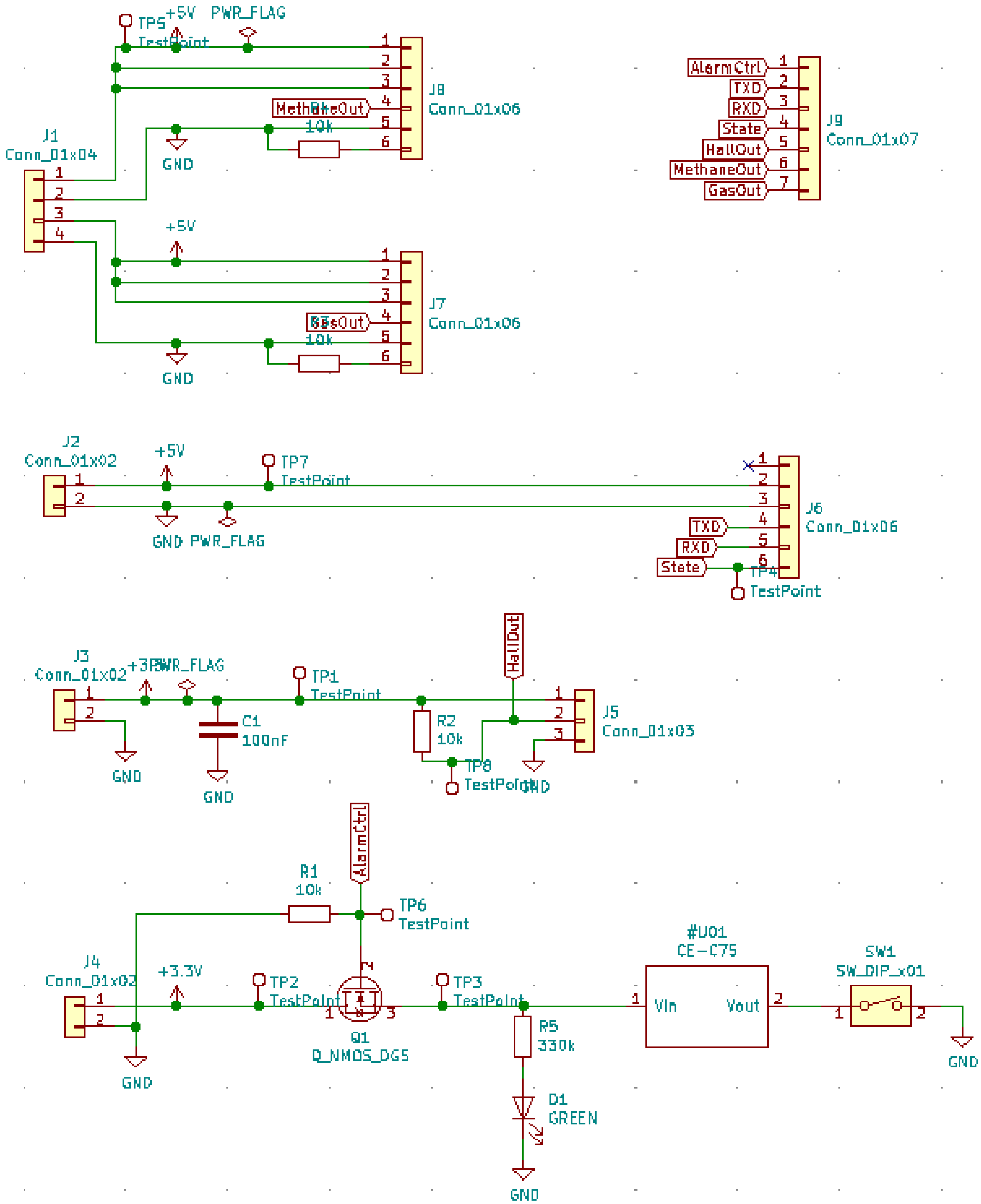
Appendix C. Parts Cost Table

Table [FILL]: Parts Costs				
Part	Qty	Manufacturer	Retail Cost ($)	Bulk Cost ($)
ATmega328-PU	1	Microchip Technology	$2.30	$1.91
ATmega328P-AU	1	Microchip Technology	$2.32	$1.92
PLA Filament (Black)	600g	Push Plastic	$29.00	$9.84
AC/DC Wall Adapter	1	SoulBay	$14.99	$14.99
MQ-4 Methane Sensor	1	Zhengzhou Winsen Electronics	$4.95	$4.46
MQ-6 Propane Sensor	1	Zhengzhou Winsen Electronics	$4.95	$4.46
HC-05 Bluetooth Transceiver	2	HiLetGo	$15.98	$15.98
AH1815 Hall Effect Sensor	1	Diodes Incorporated	$0.70	$0.24
COM-13940 Alarm	1	Challenge Electronics	$2.95	$2.66
CMT-0525 Buzzer	1	CUI Devices	$2.01	$1.14
AFB0505 5V DC Fan	1	Delta Electronics	$12.06	$7.21
LTL-4231 LED	4	Lite-On Inc	$1.56	$0.27
PCBs	4	PCBway	$20.00	$3.07
PRT-13813 1Ah Li-Ion Battery	1	Datapower	$9.95	$8.96
PRT-13777 Battery Babysitter	1	SparkFun	$19.95	$16.96
Various Small Components			$0.00	$0.00
		TOTAL COST	$143.67	$94.07

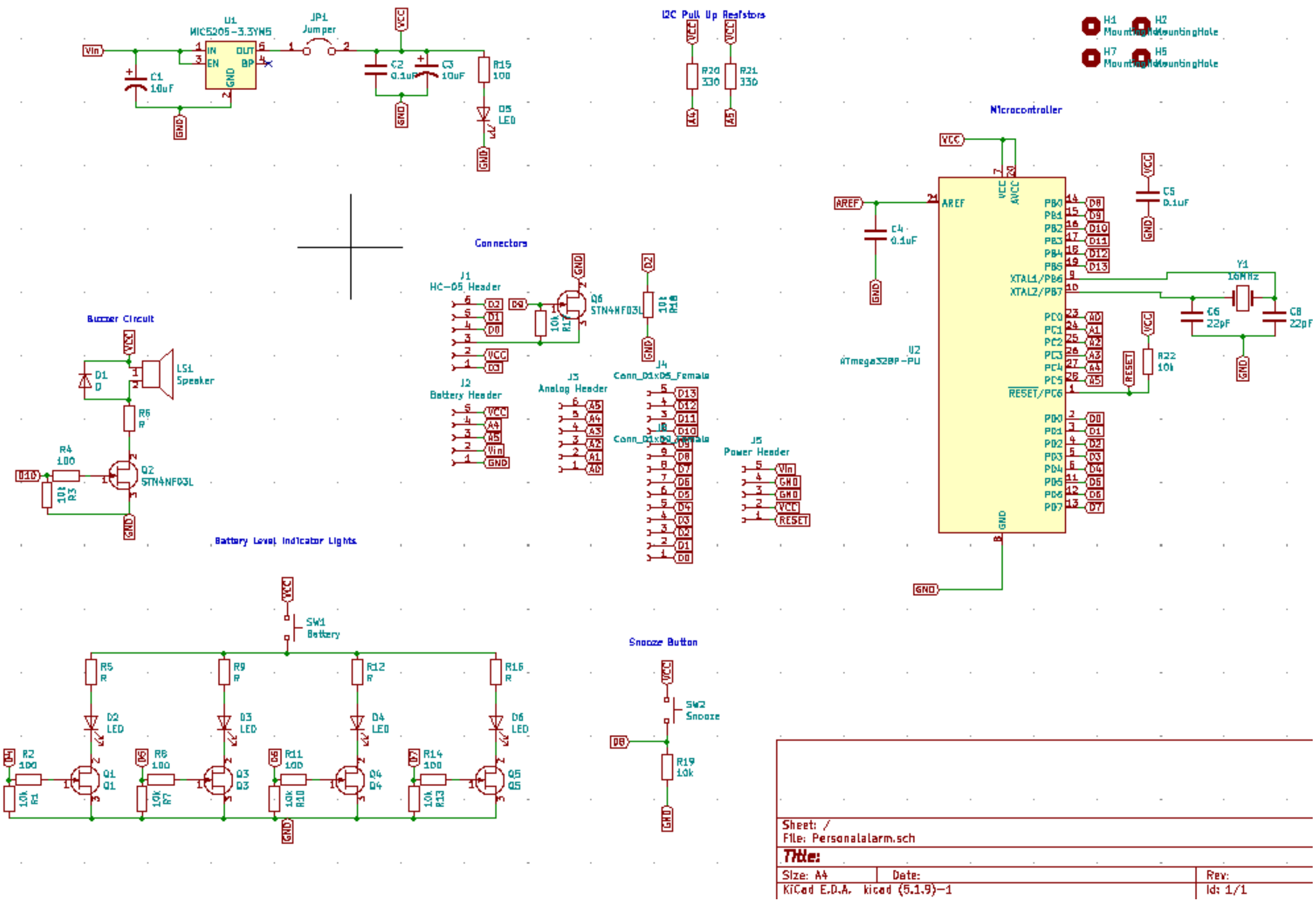
Appendix D. Schematics



Main Sensor Box Controller



Main Sensor Box Sensor Suite



Personal Alarm Circuit Schematic