CHIPPER

Capacitive Bed Occupancy Sensing for an Intelligent Alarm Clock

A Senior Project Presented to

The Faculty of the Electrical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment of the Requirements for the Degree

Bachelors of Science Electrical Engineering

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ABSTRACT

What if your alarm clock knew when you got out—and stayed out—of bed? Current alarm clocks happily let you go back to bed after turning them off. In this project, I build an alarm which only stops ringing when you get out bed, and starts ringing again if you lie back in bed.

This project uses capacitance to detect bed occupancy. A person on or near the bed creates a tiny, picofarads level increase in capacitance, as seen by a sensor placed under the mattress. A microprocessor interprets this signal, and also drives an audio alarm. Shielding of the sensor and automatic calibration of the sensor ensures the system works for any room and bed.

COMPANY INFORMATION

While building Chipper for my senior project, my team and I applied and were accepted into the Hot House, a summer accelerator that helps Cal Poly startups turn into real companies. During this project, I worked with Jacob Stewart and Dylan Brodsky on customer development, setting up and running our Alpha testing program, and promoting the product including our introduction video. I also worked with Fred Wilby, who is in the process of building a Bluetooth phone application to control alarm times and settings on Chipper. I will be working with them this summer to turn Chipper into a commercial product. All engineering and project management in this senior project report is my own.

For more information about Chipper, please visit

WakeUpChipper.com

CHAPTER 1: INTRODUCTION

1.1: MOTIVATION

Your alarm blasts. You wake up, but then hit snooze every few minutes until you waste your entire morning. You finally get out of bed, but with only 10 minutes to get out the door. You've tried novelty alarms, you've tried setting your alarm on the other side of the room, but you always just fall back asleep. Waking up is hard.

But what if your alarm clock knew when you got out—and stayed out—of bed? For my senior project, I build an intelligent alarm clock that senses bed occupancy. It knows when the user is in bed and only turns off when the user leaves bed. If the user returns to bed within a certain timeframe, the alarm will start again.

With this alarm clock, people will have total control over when they wake up, so that they have more time in the morning and can ultimately lead a healthier, more productive, and less stressful life.

1.2: CUSTOMER SEGMENTS AND NEEDS

Our target customer is anyone who has trouble waking up in the morning. Typical sleep patterns change over different ages, so this product will be most useful for those age 15 to 24. They include high school students (or parents of high school students) that need to get to 8 am class, college students with irregular class schedule, and young professionals in the 9 to 5.

To better understand customer needs, my business team and I set up a booth at the University Union on campus at Cal Poly. We showed people on the street our early prototype, and learned about how they currently wake up and problems they faced.

After talking to a few hundred customers, we discovered that more than a third of the people we talked had behavior such as setting multiple alarms or setting an alarm on the other side of the room. It took this group at least 20 minutes to get out of bed in the morning, they were always in a rush in the morning, and were suffering the consequences of being late or absent to morning class. With more time in the morning, they would have time to eat breakfast, prepare for the day, do hair and do exercise.

Some of the responses we received from our online survey surprised us. Here are a few unedited testimonials:

> *"Alarms on my cell phone, alarms on my alarm clock, sometimes calls from family and friends if I ask them to."*
>
> *"I currently have about 6 alarms set for an hour and a half from when I absolutely HAVE to get out of bed if I want to get to class on time. It takes me a VERY long time to get out of bed in the morning."*
>
> *"I subconsciously silenced it by unlocking my phone in a half sleep and then fell back asleep."*
>
> *"I keep pressing snooze and eventually it's an hour later"*
>
> *"I usually go back to bed after I turn off the alarms. I often sleep through morning lectures"*
>
> *"Multiple times, I have been woken up by my alarm clock, thought to myself "five more minutes" and turned my alarm off rather than hitting snooze, leading to me missing all my classes that day."*

After identifying the customer's demographic and pain points, we asked about what marketing requirements we needed. Table 1 shows the main marketing requirements.

TABLE 1 MARKETING REQUIREMENTS

Marketing Requirement	Justification
Makes sure you get out and stay out of bed	This is the core feature of the product. Customers want an alarm that is guaranteed to get them out of bed.
Same functionality as a normal alarm clock	Customers are used to the features of a regular alarm clock
Easy to Install and Calibrate	The user must be able to install and set up the device on their own in minimal time and effort.
Reliable detection	Incorrect detection would mean that the device does not turn off… or worse, lets the customer sleep past their alarm. A consistent response that does not deteriorate over time is critical.
Price Point	Customers already have alarm clocks and many use their phone. Most alarm clocks sell for less than $100, so we will have to focus on making the price low for commercial production.

1.3: ALTERNATIVE SOLUTIONS AND PRIOR ART

Our biggest competition is the status quo. Most people set multiple alarms on their phone, or own a bedside alarm. But nothing stops them from turning off their alarm while they are still asleep, or going back to bed after hitting the alarm set on the other side of the room.

Bed occupancy sensing already exists, such as the Telehealth [1] bed alarm, including ones that are placed under the mattress. However, these devices use pressure or mechanical changes in the sensor to detect bed occupancy. They are bulky and expensive.

The idea for an intelligent, bed occupancy sensing alarm clock has been thought of many times before, but due to the choice of sensor technology and the execution, they never became a commercial reality. US Patent 5,764,153 [2], filed in 1996 and since lapsed, details:

> *"A new Pressure Controlled Alarm Clock System for providing an alarm clock alarm which can not be turned off unless a user is removed from a bed, and where the alarm restarts if the user returns to the bed in a predetermined amount of time."*

Engineering student Cooper Bills built a pressure-based alarm clock in 2010 while studying Masters in Engineering at Cornell [3]. These alarms lacked a reliable, low cost method to sense the entire mattress. But by measuring capacitance instead of pressure or mechanical movement, Chipper will be the first viable intelligent alarm clock.

CHAPTER 2: BACKGROUND

2.1: INTRODUCTION TO CAPACITANCE

Instead of measuring force, pressure, or mechanical movement, we will measure capacitance. This will allow us to build a sensor that is cheaper to build, thinner, and sensitive to a larger area above the mattress.

Capacitance is the ability of an object to hold an electric charge between two objects. If an object has more capacitance, it will hold more charge at a given voltage:

$$C = q/V$$

where C is the capacitance of the object, q is the charge, and V is the voltage.

One way to store charge is with a set of parallel conductive plates. As shown in Figure 1, positive charge equal to +q on one plate and a negative charge equal to –q on the other plate creates a voltage V and a capacitance. An electric field E runs from the positive charges on the top plate to the negative charges on the bottom plate.

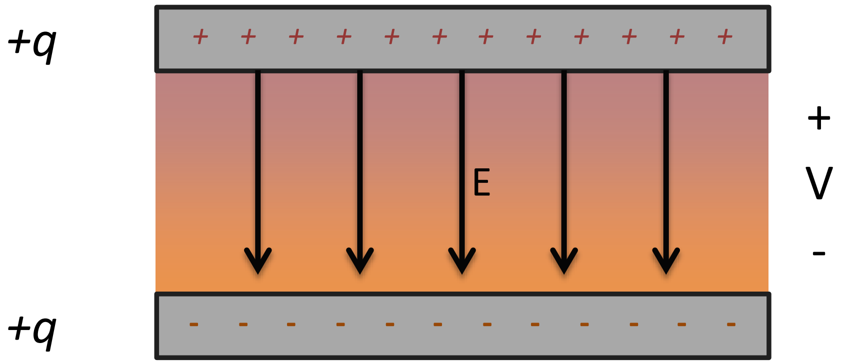

Figure 1 Capacitance between Two Plates

The capacitance of a parallel plate is determined by the geometry of the plates and the material in between the plates [4]:

$$C = \varepsilon * \frac{A}{D}$$

where C is capacitance, ε is the permittivity of the dialectic material between the plates, A is the area of the plate, and d is the distance. Increasing the size of the plates or decreasing the distance between the plates increases the capacitance. For this report, we assume that ε is equal to that of air. Different materials with a higher relative permittivity will increase capacitance, and the nonlinear effects of fringe electric fields around the edge of the two plates will decrease capacitance, so this estimate should give us an order of magnitude estimate of expected capacitance.

2.2: CAPACITIVE BED OCCUPANCY SENSING

If we build a sensor made out of a single conductive plate, we can measure the proximity of a nearby object. Figure 2 shows how other objects, such as a person, can act as the second plate.

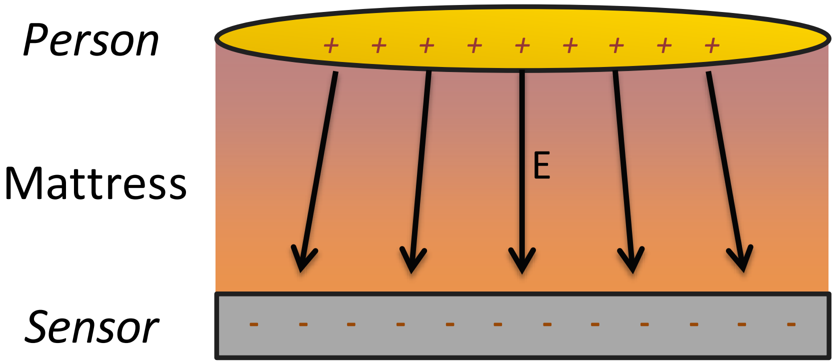

Figure 2 Capacitance between Person and Sensor

When the person leaves the bed, the sensor no longer has a second plate and the overall capacitance decreases. Due to the distances involved, the change in capacitance is very small, usually on the range of 1 picofarad (pF) or less, but by using sensitive electronics and signal filtering we can determine if the bed is occupied.

CHAPTER 3: PRODUCT DESIGN ENGINEERING REQUIREMENTS

3.1: DEFINING REQUIREMENTS AND SPECIFICATIONS

After collecting customer feedback from Section 1.2 and Table 1, I developed engineering specifications to fill my customer's needs. My customers want a system that ensures they wake up and stay out of bed. They do not want the setup process to be difficult and they expect to easily set alarm times from their phone. From my feedback, I discovered that their two main concerns are the reliability of the system and its final price. Table 2 shows the marketing requirements and the resulting engineering specifications.

TABLE 2 ENGINEERING REQUIREMENTS AND SPECIFICATIONS

Market Reqmt.	Engineering Specifications	Justification
1, 2	**Alarm Output:** Sounds an alarm of at least 70 dB at 1 meter.	This alarm volume makes sure the user wakes up.
1, 2	**Clock Functionality:** Device stores alarm times and finds the current time, and rings at times selected by user. The time period when the device may ring starts at the set alarm time and ends 1 hour later. During this time, the alarm will sound whenever it detects bed occupancy.	Allows for the user to set the alarm time and wake up when they desire. After 1 hour, the user will be fully awake and may interact on the bed.
3, 5	**Cost:** For a run of 1000 units, total cost of electronics less than $30/unit, and total cost of parts less than $50/unit.	This allows for a reasonable retail price around $99 dollars.
3	**Sensor Design:** Sensor strip takes up no more than 3 sq. ft. of space and is no more than 1/8” thick.	These dimensions ensure easy installation and minimal effect on the comfort of the bed.
3, 4	**Capacitance Sensor:** Sensor reads with a precision of at least 0.05 pF. Sensor can adapt to a parasitic environmental load of up to 80 pF.	Allows for detection of the user over the bed. The environment increases measured capacitance, so this range removes clipping and instability.
4	**Detection:** Automatically calibrates itself for slow-moving changes in measured capacitance (<.01 pF/second).	Temperature, noise, and nearby motion cause slow drift in measured capacitance.
4	**Sensitivity and Range:** Detects occupancy when under either foam or metal spring mattresses up to 10” thick. The antenna senses the area of a twin sized bed.	This ensures the sensor will work with any twin sized bed.
4	**Directionality & Shielding:** A shield or other method reduces the capacitive effect caused by objects near or touching below the sensor by at least 90%.	This makes the sensor only sensitive to the area above it, increasing sensitivity and allowing placement on any surface.

Marketing Requirements

1. Makes sure you get out and stay out of bed
2. Same functionality as a normal alarm clock.
3. Easy to install and calibrate.
4. Reliable detection
5. Price Point

3.2: LEVEL ZERO BLOCK DIAGRAM

As shown in Figure 3, Chipper works using a sensor strip placed under the mattress, halfway down the length of the bed. An electronics box contains the alarm and hangs off the side of the bed and, using Bluetooth, a mobile phone controls the alarm times and settings. A wall adapter powers the electronics box with standard USB power.

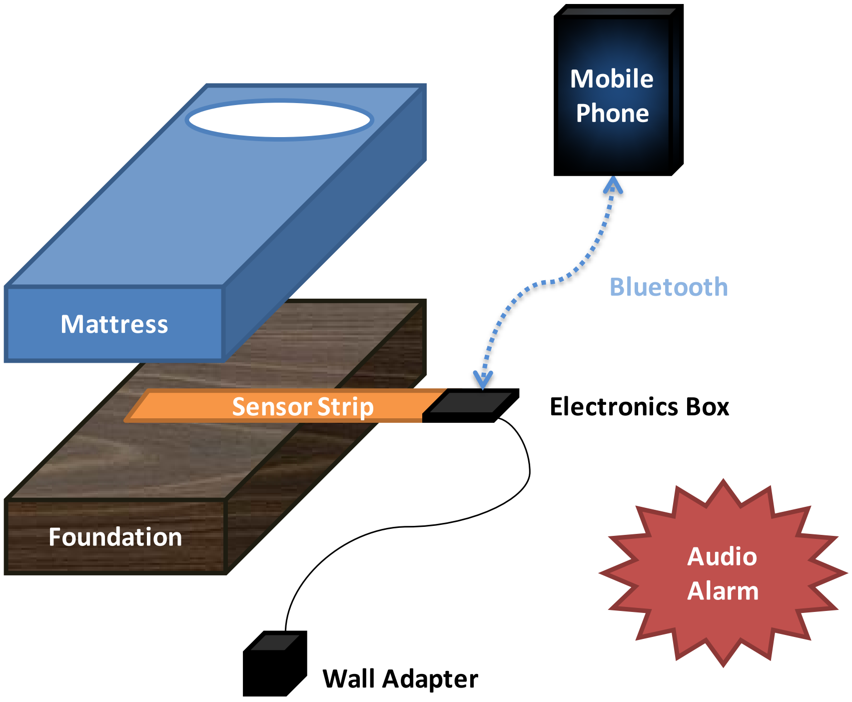

Figure 3 Level Zero Block Diagram

Table 3 breaks down in inputs, outputs, and functions of each block.

TABLE 3 LEVEL ZERO FUNCTIONALITY

Module	Inputs	Outputs	Functionality
Sensor Strip	Objects above the sensor.	Capacitance.	Senses an increase in capacitance when objects, such as the customer, go onto mattress.
Electronics Box	Capacitance from Sensor Strip; Power from Wall Adapter; Bluetooth from Mobile Phone.	Bluetooth to Mobile Phone; Audio Alarm.	Processes CapSense signal to detect bed occupancy. Stores alarm times, current time, and settings. Drives audio alarm at appropriate time. Sends and receives user interface data from Bluetooth.
Mobile Phone	User Inputs; Data from Electronics Box.	User Display; Data to Electronics Box.	Collects current time, alarm times, and settings, and transmits to alarm. Displays set alarms, sync status, and settings to user.
Wall Adapter	Mains Power.	USB power (5v, 3W).	Delivers power to the electronics box.

CHAPTER 4: LEVEL 1 FUNCTIONAL DECOMPOSITION

3.2: LEVEL ONE BLOCK DIAGRAM

Figure 4 shows the basic modules that make up the device. A Programmable System on Chip (PSoC) holds most of the electronics, including the Bluetooth Low Energy (BLE) module, the Capacitance Sensor (CapSense), and the microprocessor (MCU). The CapSense module reads the capacitance signal from the sensor strip and converts it into a digital count value. The BLE module communicates with the phone to set times and settings and display data to the user. The MCU processes the capacitance signal, runs the alarm and clock logic, and sounds the alarm at the appropriate times.

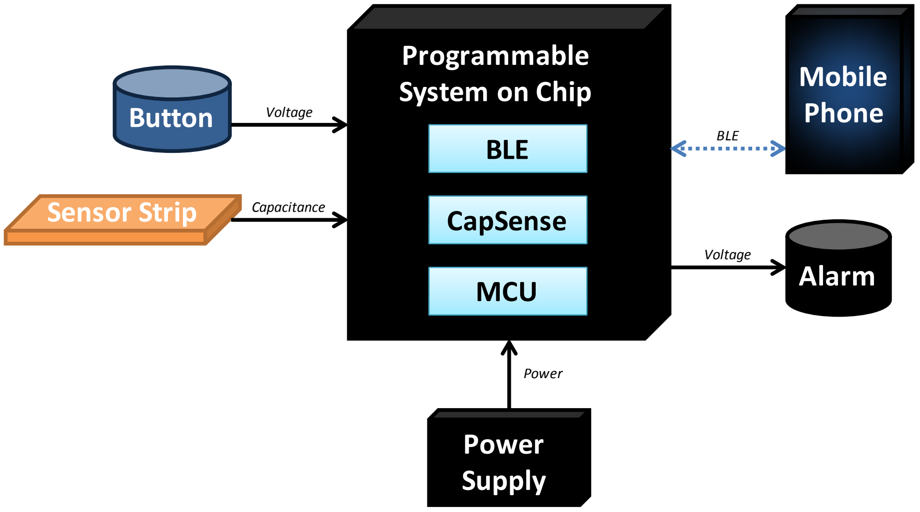

Figure 4 Level One Block Diagram

Table 4 breaks down functionality by module.

TABLE 4 LEVEL ONE FUNCTIONALITY

Module	Inputs	Outputs	Functionality
Sensor Strip	Environmental Capacitance.	Capacitance (10 to 80 pF).	Collects environmental capacitance of objects above sensor.
CapSense Module	Capacitance.	Digital Value.	Loads charge onto Strip Sensor and converts charge time into a digital value proportional to measured capacitance.
Microprocessor (MCU) Module	Data from CapSense; Data from Bluetooth.	PWM Voltage to Audio Transducer; Data to Bluetooth.	Processes CapSense signal to detect bed occupancy. Stores alarm times, current time, and settings. Drives audio alarm at appropriate time. Sends and receives user interface data from Bluetooth.
BLE (Bluetooth Low Energy) Module	Data from MCU; Data from Mobile Phone.	Data from MCU; Data from Mobile Phone.	Transmits and receives data between microprocessor and user mobile phone.
Mobile Phone	User Inputs via Screen.	Data to BLE Module.	Collects current time, alarm times, and settings, and transmits to alarm. Displays set alarms, sync status, and settings to user.
Audio Transducer	PWM Voltage from PSoC.	Audio Alarm (>70dB @ 1m).	Converts voltage signal from MCU into an amplified audio output.
Power Distribution	5V USB power.	Power to each module.	Takes in electrical power and distributes to system.

CHAPTER 5: TECHNICAL CHOICES AND DESIGN APPROACH ALTERNATIVES CONSIDERED

5.1: CONSTRUCTION OF THE SENSOR

SENSOR CONSTRUCTION VERSION 1: LARGE PADS

As I will discuss in Section 6.1, the capacitive sensor is made up of a conductive sense layer and shield layer, with insulation in between. The first iterations of the capacitive sensor were large pads made from layers of aluminum foil separated by cotton twill fabric, as shown in Figure 5. Safety pins, adhesive, and masking tape held the sensor together. The surface area of the sense pad was about 2 sq. ft.

Figure 5 Prototype Bed Sensor Pads. Calipers Provided for Scale.

To calculate the expected change in capacitance from bed occupancy, we use the equation introduced in section 2.1 [4] [5]:

$$C = \varepsilon * \frac{A}{D}$$

where C is Capacitance, ε is the permittivity, A is the area of the sensor in m^2, and D is the distance between the sensor and the user in m. With ε = 8.854x10-12 F/m (the permittivity of air), A = .185 m^2 (2 sq. ft.), D = .20 m (8 inches), we get C = 8 pF.

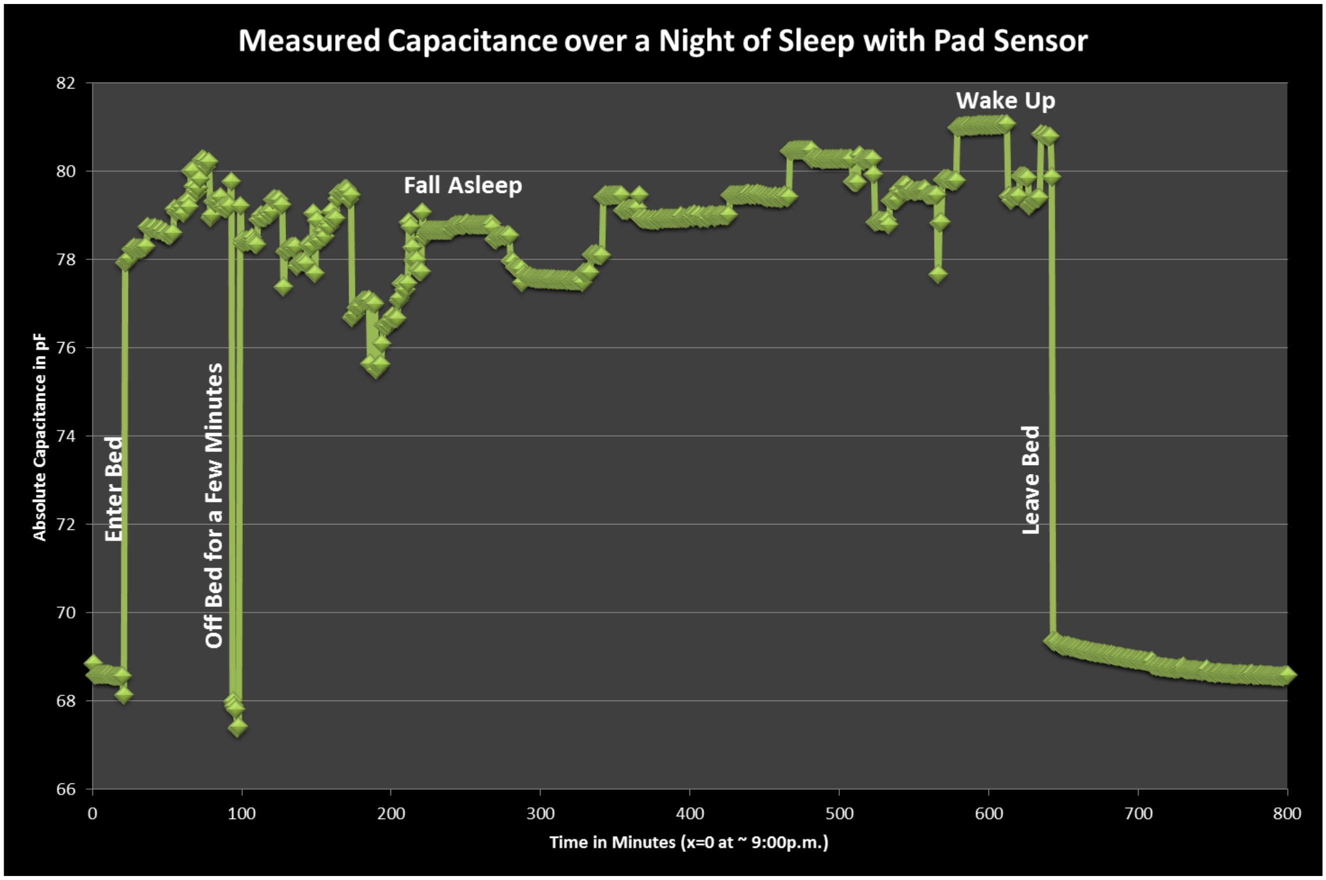

Figure 6 Pad Sensor Data

Figure 6 shows data received from the prototype fabric sensor, taken over a night as I slept. Sharp increases in capacitance indicate entering the bed, and sharp decreases indicate leaving the bed. Events where I entered or left the bed are marked. At T= 200 minutes, you can also see that I stopped reading and watching YouTube videos, and actually fell asleep. By looking at change in the signal over time to interpret motion, this sensor has the possibility to track sleep cycles. As expected, the shift in capacitance was around ~10 pF.

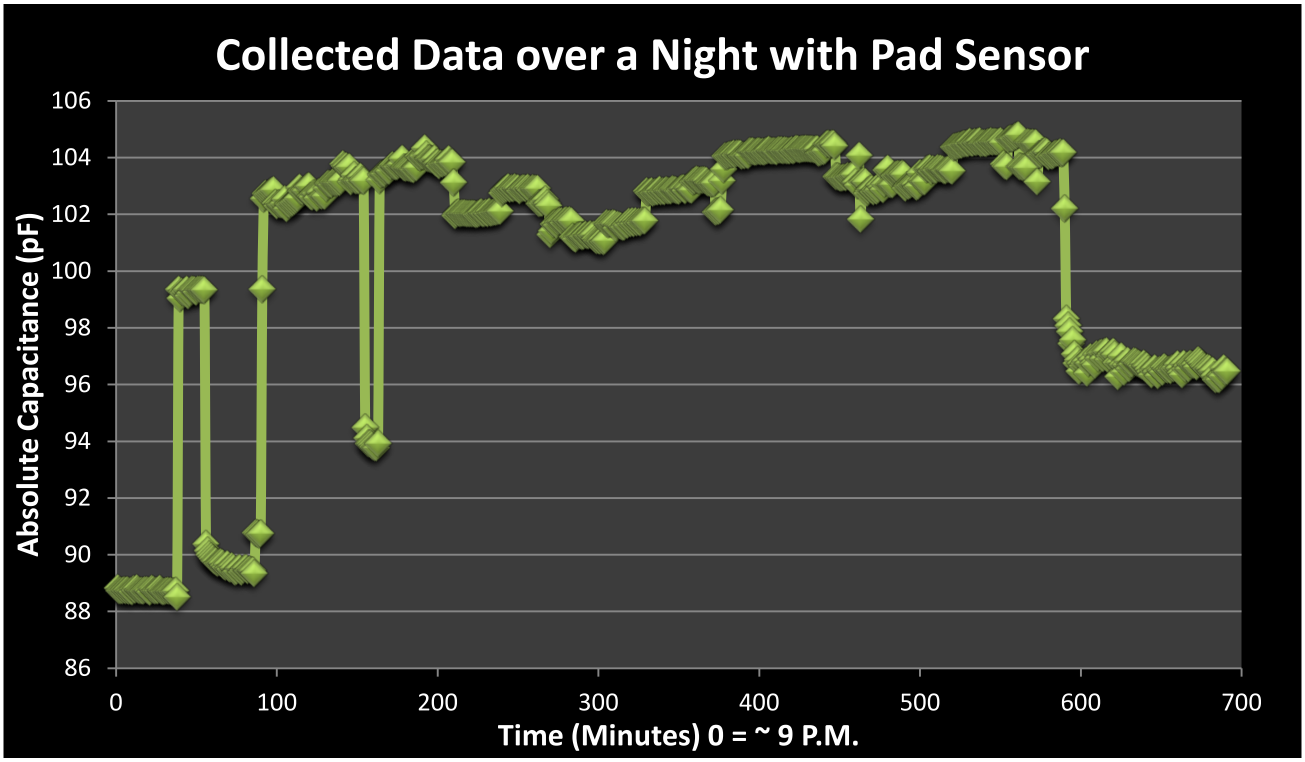

Figure 7 Pad Sensor Data with Distortion

However, while the sensor responded with a strong signal to changes in bed occupancy, there were many issues with this sensor design. The sensor responded to mechanical force, not just proximity. There was "memory" in the signal, and after being pressed down it did not return to its initial state. As you can see in Figure 7, the signal starts at 88pF, rises to 104 pF, and returns only to 96 pF. The sensor mechanically settled, causing the two plates to be closer together and creating a distortion of about 8pf, the same magnitude as the proximity signal. This makes calibration and long term reliability very difficult.

Also, the size and shape of the sensor was not economically practical. A large, wide sensor means more material, more complicated assembly, and more shipping and packaging.

Sensor Construction Version 2: Long Strips

The solution to these issues was to use webbing, the woven plastic used for straps and handles. The thick, tough material resists mechanical movement, and acts as a sturdy anchor for the conductive layers. It is incompressible and long lasting, and uses less material. These strips cost less than a dollar per linear foot.

Figure 8 Strap Sensor Under a Mattress

Figure 8 shows the strap sensor under a mattress. The sense and shield layers lay on either side of a layer of webbing. The sense plate is about 2 inches long and two feet wide, leading to an area of about 0.03 m^2 and a capacitance of 2.7 pF.

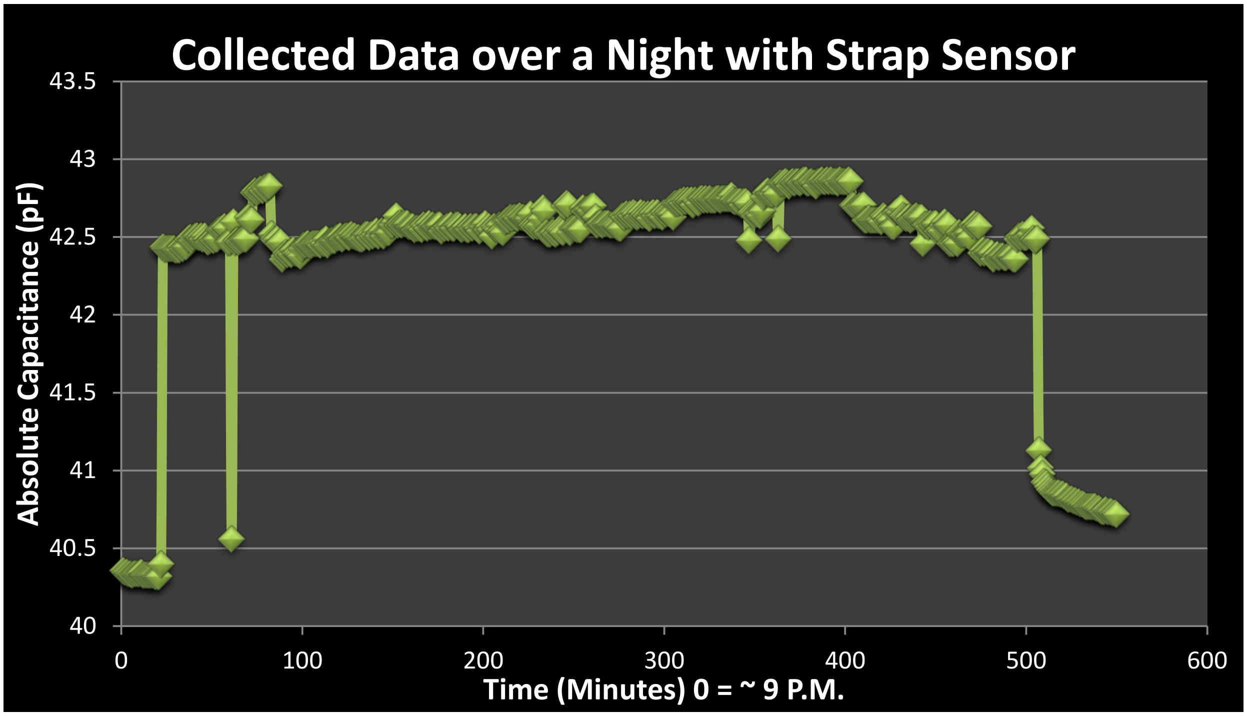

Figure 9 Strip Sensor Data

Figure 9 shows a night’s worth of data from the sensor. This sensor responds to bed occupancy with 2 pF instead of 8 pF. However, the smaller sensor also reduces environmental noise, leading to a much better signal to noise ratio. While the signal did drift and baselines did change due to settling and motion, these sources of distortion were much smaller than with the pad, and were caused mostly by the bed settling with the sensor, not the two plates of the sensor moving relative to each other.

5.2: CAPACITIVE SENSING

SENSOR CIRCUITRY VERSION 1: RC RESONATOR WITH PIC MICROCONTROLLER

The first version of the capacitive sensor used a high performance CMOS timer LMC555 [6]. Like other 555 timers, it resonates according to a RC (resistor and capacitor) value determined by external components. In Figure 10, the 39 k ohm resistor R1 sets the R value, and the 10 pF capacitor C1 in parallel with the sensor, connected to the pad at node P$1 determine the C value. The circuit is configured in 50% duty cycle mode and only needs one resistor to set the timing. R2 acts as a pull up resistor so that the output can interface with further stages of the circuit.

The circuit oscillated at a frequency f equal to:

$$f = \frac{1}{1.4 * R * C}$$

with parasitic capacitance around 20 to 25 pF, the circuit oscillated at around 800 kHz.

A tiny change in capacitance on the sensor created a tiny change in the C value and a few kHz in deviation in the output signal. A PIC microcontroller measured this change in frequency by first mixing the oscillator signal with a signal of fixed frequency using an XOR gate or D Flip Flop. This subtracts the signal frequency down to a slower, easier to measure frequency. A timer module inside the PIC measured the resulting frequency.

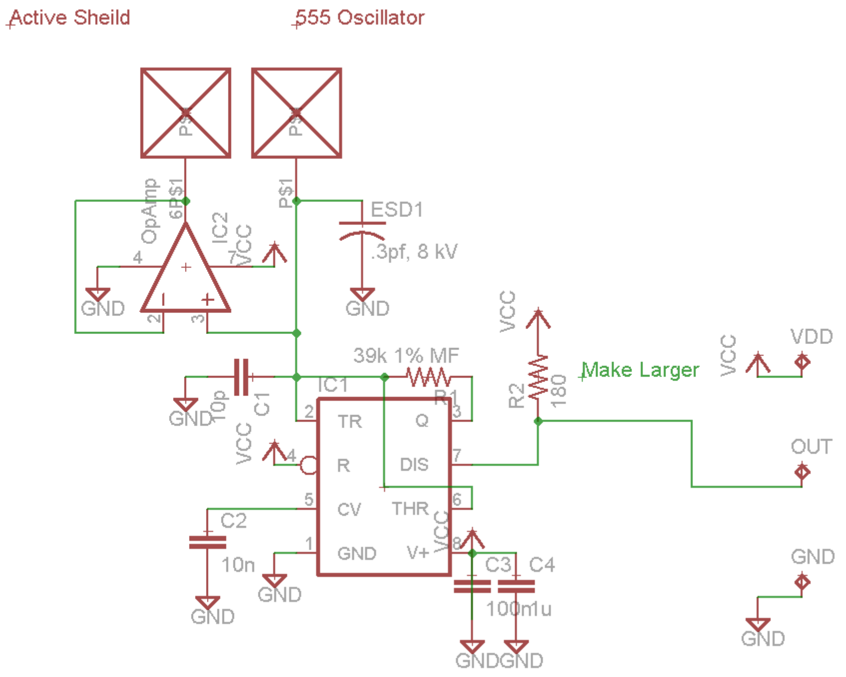

Figure 10 Oscillator Based Capacitance Sensor

I chose this method for the fast response time, high precision, and ease to implement with common integrated chips. With proper filtering and a long enough sampling time, this method could measure capacitance less than one femtofarad (1/1000th of a picofarad).

Sensor Circuitry Version 2: PSoC with Integrated CapSense

However, during my first senior project review session in February 2015, I learned about the PSoC (Programmable System on Chip) 4 BLE platform, released early 2015 by Cypress Semiconductor. Cypress integrates a microprocessor, Bluetooth transceiver, and advanced Capacitive Sensor Module, among other components, in a single chip. Even better, Cypress sells this chip on an FCC certified development board with a Bluetooth antenna, crystal oscillator, and all required external components [7, 8].

The CapSense module accurately detected bed occupancy. Because the final customer will be sensitive to the price of the product, and because the Cypress platform greatly streamlines the process of developing the project, I chose to transfer to the Cypress platform. By bringing almost every electronic component together into a $3 chip, PSoC shaved at least $10 off the cost of parts and assembly.

5.3: USER INTERFACE

USER INTERFACE VERSION 1: BUTTONS AND A SCREEN ON THE DEVICE

Finally, I had to decide how the user would receive alarm times, and how they would interact with the device.

From our customer development, we learned that most people use their mobile phones as morning alarms. They quickly set multiple alarms on a touch screen, and the idea of pushing multiple buttons to set an alarm time is archaic. Those who have a bedside alarm clock value its loudness or reliability, not its ability to display time. In a survey, less than 15% of potential customers indicated they preferred buttons and a screen over a mobile phone application. We received slightly more requests for an Android app than iOS.

I first considered adding an LCD display and button interface of a typical bedside alarm clock, but customers expect better. Also, adding a screen, multiple buttons, and custom enclosure to hold them greatly increases the cost of parts for a commercial production. Finally, the bedside interface would need to connect with a wire to the sensor module, cluttering the bedside area.

USER INTERFACE VERSION 2: WIRELESS MOBILE APP

To save cost and give the customer full control of the device, and to open the door for possible new features (sleep tracking, biometrics, ect.), I chose to leverage the mobile phones the people already own. The Cypress PSoC already adds a Bluetooth radio, and building a mobile app allows easy control of any parameter without needing to build a separate control interface.

As an electrical engineering student, I cannot develop mobile apps. However, I intend to work with a computer scientist to add a full mobile app interface after I complete this stage of the project. For now, alarm times and settings are set manually when reprogramming the device.

CHAPTER 6: PROJECT DESIGN DESCRIPTION

6.1: CAPACITIVE SENSOR DESIGN

Chapter 2 introduced the theory behind capacitive sensing. A conductor placed under the mattress senses the change in capacitance due to a nearby person when they enter the bed.

The capacitance sensor is built from two layers of conductors, separated from each other and from the environment with insulating layers, as shown in Figure 11. The top conductor, the sense layer, connects to the capacitance sensing circuitry. The electronics measure the capacitance "seen" by this layer.

The other conductor, the shield layer, directs the shape of the electric field and prevents the sense layer from detecting objects below the mattress. This layer connects to system ground, such that objects below the sensor are blocked from reaching the sense layer. The sense layer cannot "see" object below, because ground is in the way. The capacitance between the two layers was experimentally found to be about 650pF. While this greatly increases the capacitance to ground seen by the sense layer, the CapSense module, discussed in the next section, is able to compensate and calibrate, and measure the small, relative change in capacitance.

To reduce the risk of ESD reaching the PSoC and to reduce EMI noise created by the CapSense module, a 680 ohm resistor is placed in series between the sense layer and the chip, close in value to the recommended 560 ohm series resistor. [5].

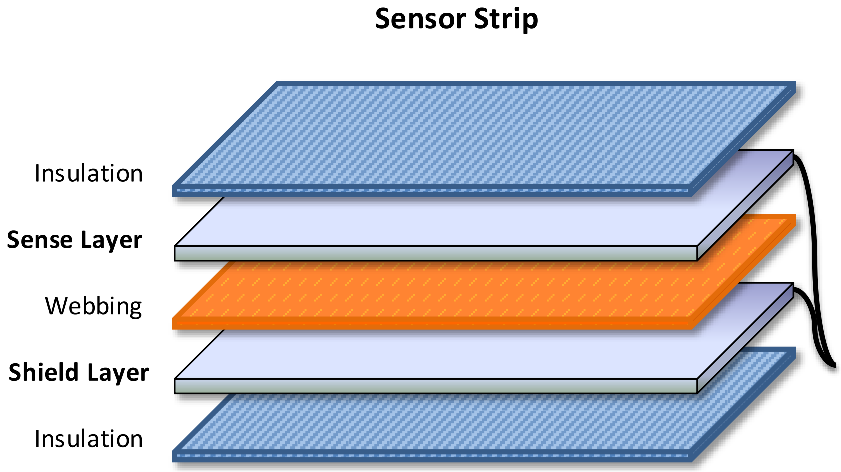

Figure 11 Capacitive Sensor Construction

6.2: CAPACITIVE SENSING WITH CYPRESS CAPSENSE

Cypress Semiconductor leads the industry in high precision on-chip capacitive sensing with their CapSense Module. Figure 12 shows how the CapSense module operates. First, a switched capacitor circuit, made up of the precharge clock and switches SW1 and SW2, convert the external capacitance Cx into an equivalent resistance [4]. The equivalent resistance related to the measured capacitance according to

$$\mathrm{Rs} = \frac{1}{Cx * Fsw}$$

Where Rs equals equivalent resistance, Cx equals measured capacitance, and Fsw equals the frequency of the precharge clock [5].

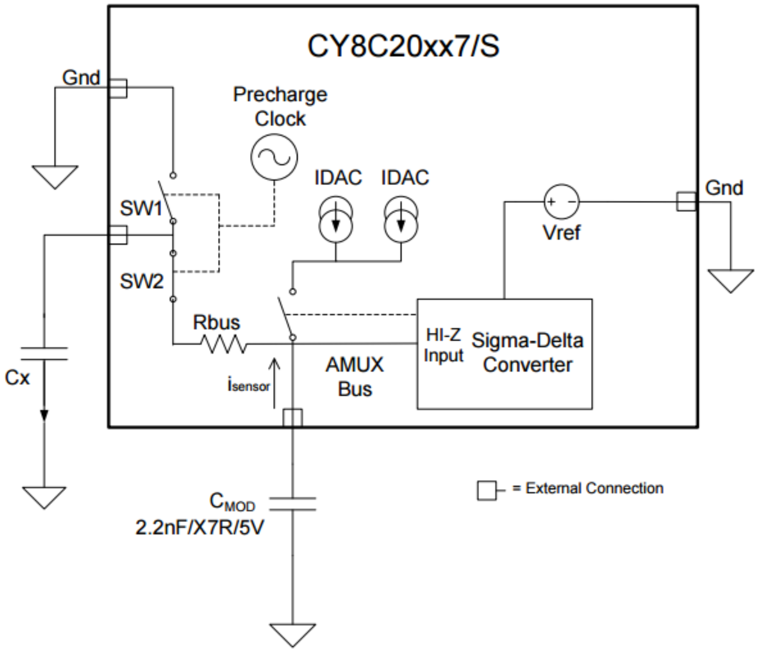

Figure 12 CapSense Block Diagram. Image Source: [4] Page 15.

The Sigma-Delta converter switches on and off the IDAC (current digital to analog converters) such that the voltage of AMUX always equals Vref. By measuring the amount of time needed for the Sigma-Delta to maintain the voltage on AMUX, the circuit senses how much current Cx sinks to ground. A larger Cx means less effective resistance and more current sunk to ground. More current sunk to ground means the Sigma Delta needs to turn on the IDAC for more clock cycles, and the CapSense module outputs a larger digital count number. The approximate raw count is given by the equation [5]:

$$count = 2^N * \frac{Vref * Fsw}{Imod} * Cx$$

Where N is the resolution of the Sigma Delta converter and Imod is the current supplied by the modulation IDAC.

To increase the sensitivity of the sensor, a second, compensation IDAC can be used to offset a fixed amount of capacitance. When enabled, the compensation IDAC is always on, and the equation for the raw count from the Sigma Delta is:

$$count = 2^N * \frac{Vref * Fsw}{Imod} * Cx - 2^N * \frac{Icomp}{Imod}$$

Where Icomp is the current supplied by the compensation IDAC. As shown in figure 13, the compensation IDAC moves up the low range of the signal that can be measured. For example, instead of measuring from 0 to 10 pF, we could measure from 5 to 10 pF with twice the precision.

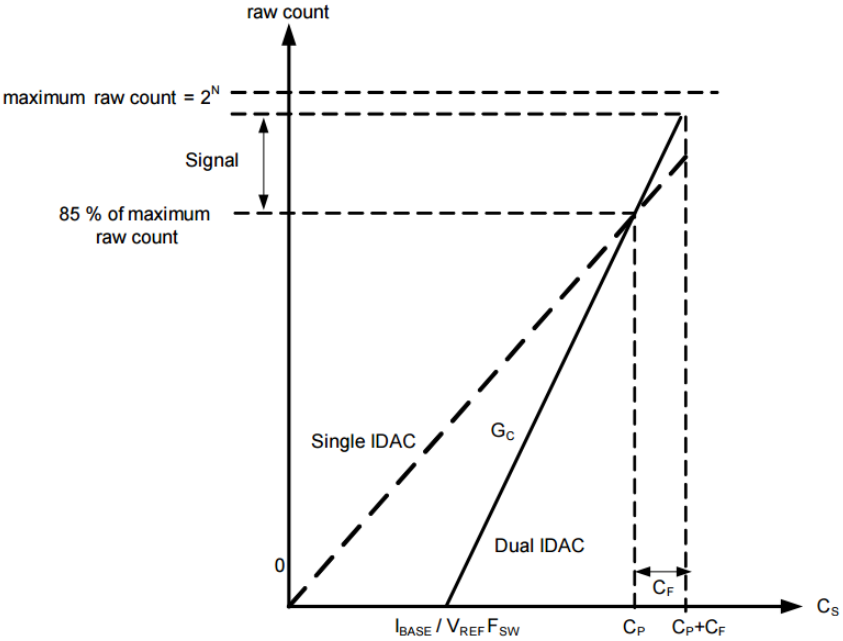

Figure 13 Change in Sensitivity due to Compensation IDAC. Source: [5] Page 46.

6.3: Signal Processing and Event Detection

Before anything, the raw signal from the CapSense module is filtered by a one pole IIR filter. The output of this recursive filter equals 15/16 the previous term and 1/16 the input term. This gives a very slow moving capacitance signal. However, the response time of the sensor is not important and taking a few seconds to determine a change in occupancy has little impact on the final quality of the product.

The detection algorithm detects bed occupancy when the capacitive signal rises, and detects the lack of occupancy when the signal falls. Due to intellectual property that I wish to protect and keep trade secret, I cannot disclose details on the detection algorithm.

6.4: USER INSTALLATION AND CALIBRATION

To set up the Chipper, the user must follow three steps:

1. Place horizontally under mattress halfway down the length, with the electronics box hanging off the side. Plug the wall adapter into a socket.
2. Lay on bed for 30 seconds. This allows sensor to settle.
3. Leave bed and press button on electronics box until you hear two short chirps. This means the bed is now calibrated.

Figure 14 Placing the Sensor Under a Mattress

In this process, the user plugs in the device and places it under the bed as demonstrated in Figure 14. Then, because the sensor is not accurate until the mattress and sensor settle, they lie on the bed. After leaving the bed, they press a button, telling the system to recalibrate and to be set to on unoccupied state.

6.5: REAL TIME CLOCK AND ALARM CLOCK LOGIC

A 32.768 kHz crystal drives the real time clock. 32768 times a second, the crystal created an interrupt which incremented a counter in software. This software counter incremented seconds, minutes, hours, AM/PM, and day of week so that the system tracks the current time. This timer also creates the square wave that drives the audio buzzer in software.

The starting value of the real-time clock was manually set in software before reprograming the device. The real time clock starts counting at an initial value equal to the current time.

The device decides when to ring by looking at stored alarm times. If the current time is greater than the alarm time but less than an hour past the alarm time, the device is activated and will ring if occupancy is detected in the bed.

The crystal provided on the PSoC module, [9], has an accuracy of 20 ppm. This causes an error of up to 10.5 minutes every year [10]. In a later version, either the mobile phone will have to update the time every few months, or we will have to use a more accurate crystal.

In Table 5, we show an example morning of Chipper in use. The alarm goes off at the set alarm time. For the next hour, it rings if it detects bed occupancy. When Chipper detects motion on the bed, it assumes the user left the bed and the alarm will turn off. After an hour, the alarm will not go off until the next alarm time.

TABLE 5 CHIPPER USE CASE

Occupancy	**Bed Occupied**	**Bed Occupied**	Motion on Bed	Bed Unoccupied	**Bed Occupied**
Alarm	Alarm Off	**Alarm On**	Alarm Off	Alarm Off	Alarm Off
Time	**6:55 am**	**7:00 am**	**7:01 am**	**7:03 am**	**10:00 pm**
Situation	Chipper waits until alarm time to begin ringing.	Chipper detects occupancy and starts ringing.	Chipper detects movement on the bed, assumes you are leaving, and turns off alarm.	Chipper detects the bed is unoccupied. Alarm turns off but will start again if you get back in bed.	After an hour, entering the bed will not turn on until the next alarm time.

6.6: ALARM FAILSAFES

Due to the experimental nature of the detection algorithm, I added two failsafe modes to guarantee that testers' alarms go off in the morning, even if the system incorrectly measures occupancy. Once the system is proven, these states will not be needed.

FAILSAFE 1: STILL DETECTS OCCUPANCY AFTER LEAVING BED, AND DOES NOT STOP RINGING.

Without this failsafe, if Chipper does not detect the user leaving the bed, it will not stop ringing. In this failsafe mode, holding down the calibration button for 2 minutes resets occupancy detection and turns off the alarm. Table 6 outlines an example where this failsafe is in use.

TABLE 6 FAILSAFE 1 SCENARIO

Occupancy	Bed Occupied	Bed Occupied	Bed Unoccupied	Bed Unoccupied
Alarm	Alarm Off	**Alarm On**	**Alarm On**	Alarm Off
Time	**6:55 am**	**7:00 am**	**7:01 am**	**7:03 am**
Situation	Chipper waits until alarm time to begin ringing.	Chipper detects occupancy and starts ringing.	Chipper still detects occupancy after you leave bed and continues ringing.	*Failsafe 1:* Hold down the button for 2 minutes to manually turn off the alarm

FAILSAFE 2: CHIPPER DOES NOT DETECT OCCUPANCY AND DOES NOT RING AT ALARM TIME.

Without this failsafe, Chipper would not ring if the user was sleeping and it did not detect occupancy. In this failsafe mode, when it detects no occupancy at alarm time, Chipper will ring no matter what for 4 minutes. The only way to turn off the alarm in this mode is to wait 4 minutes or to hold down the button for 2 minutes, as in Failsafe 1. I plan to remove this failsafe once I prove the reliability of our detection system. Table 7 shows this failsafe in action.

TABLE 7 FAILSAFE 2 SCENARIO

Occupancy	Bed Occupied	Bed Occupied	Bed Unoccupied
Alarm	Alarm Off	**Alarm On**	Alarm Off
Time	**6:55 am**	**7:00 am**	**7:04 am**
Situation	Chipper thinks bed is unoccupied but it is occupied	*Failsafe 2:* Chipper will ring for 4 minutes if the bed is unoccupied at alarm time, regardless of occupancy or motion.	After 4 minutes, Chipper returns to normal operation and only rings if bed is occupied for the remainder of the hour.

6.7: DRIVING AUDIO ALARM

A buzzer creates the audio alarm. Four pins from the PSoC created a 2.048kHz square wave that drives the buzzer directly. As shown in Figure 15, pins BUZZ_1 and BUZZ_2 each sources 4mA of current at Vdd. The N_BUZZ pins are driven at the opposite of the BUZZ pins. When Buzz is high, N_Buzz is low, and when Buzz is low, N_Buzz is high. With this configuration, the buzzer receives an 8 mA square wave with amplitude equal to 2 times Vdd.

In software, the alarm turns off for 0.3 seconds every second. This pattern makes the sound harder to ignore by the user and increased the perceived intensity of the sound.

During parts selection, I chose a buzzer rated at 85 dB [11]. However, it was measured at 10 cm. At 1 meter, the alarm has a volume of 65 dB [12], missing the alarm output specification. This volume was somewhat quiet but loud enough to wake up testers.

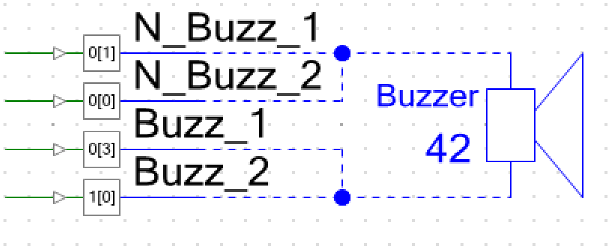

Figure 15 Audio Buzzer Schematic

6.8: POWER SUPPLY

For a power supply, I chose an off the shelf wall adapter with a standard 5V USB mini power output rated to supply up to 2.75 watts of power. Choosing a UL listed power supply and keeping the rest of the circuit low power and low voltage removes any dangers of electrical shock and simplifies safety certification for the final product.

Along with this power supply, 2 AAA batteries act as a backup power source in case the user tries to turn off Chipper by unplugging it. The two power sources were put in parallel with two schottky (low voltage drop) diodes as shown in Figure 16, such that the batteries would not drain if the device was plugged in. While the wall adapter supplied 5V and the batteries 3V, the PSoC chip accepts 1.9V to 5V with no change in performance and without any external power regulators.

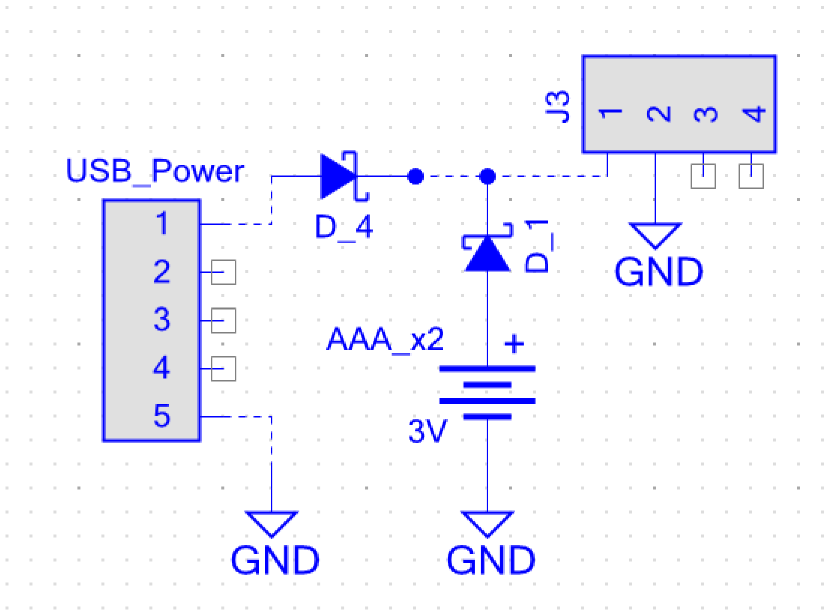

Figure 16 Power Supply Schematic

CHAPTER 7: PHYSICAL CONSTRUCTION AND INTEGRATION

7.1: IMPLEMENTATION BLOCK DIAGRAM

Figure 17 shows the system from a physical view. The system consists of a capacitive sensor strip may of layers of conductive and insulating materials, a power supply, and an enclosure which connects to the sensor and contains the electronics.

Initially, the sensor was going to be two layers of conductive fabric sewn together with a strip of webbing in the middle, to insulate the two conductive layers. However, after sewing the parts together, it was found that the motion of the sewing machine caused the fine threads of the conductive fabric to splay and short out across the webbing. Unable to find a solution to this issue, I decided to construct the sensors with masking tape and aluminum foil on the webbing. The masking tape held the foil to the webbing and insulated the foil from the environment. In a later iteration, I will find a more durable way to construct sensors.

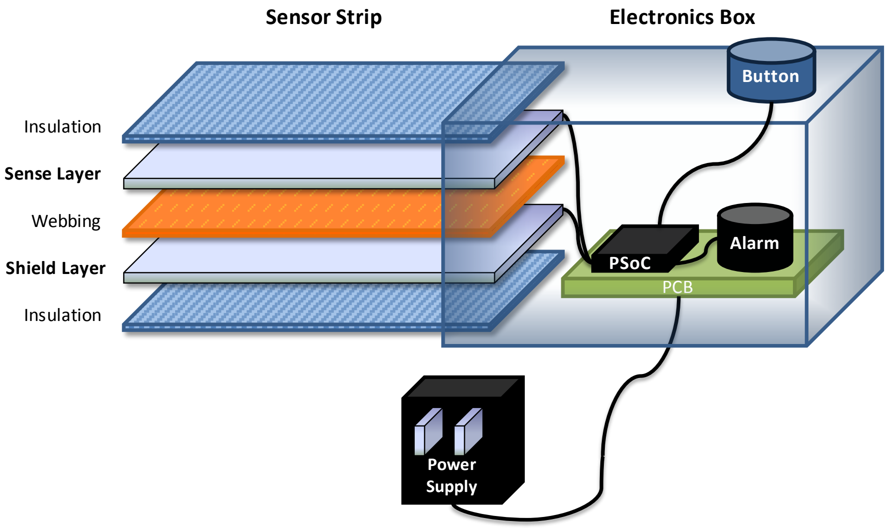

Figure 17 System Construction

7.2: PROTOTYPE PHOTOGRAPHS

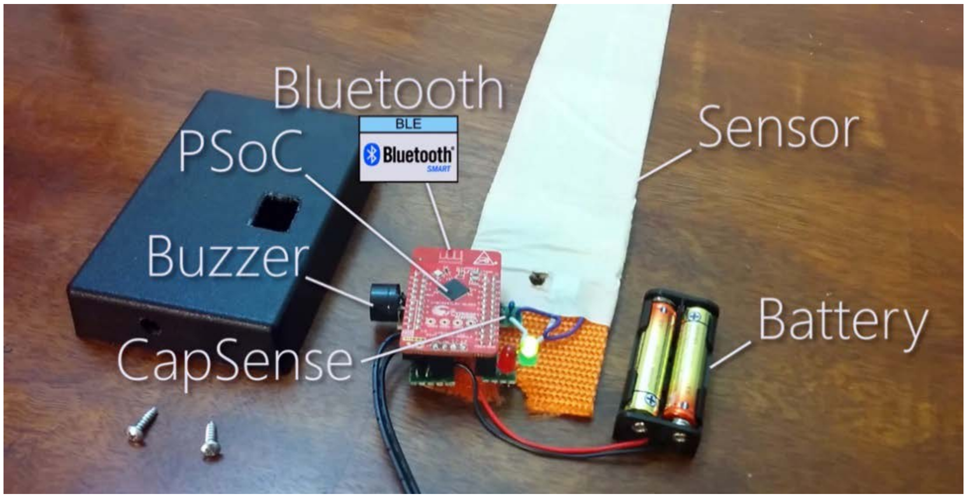

Figure 18 Photograph of Modules

For development of the prototype, I used the CY8CKIT-142 PSoC 4 BLE module [13, 7] as photographed in Figure 18. This module contains the PSoC chip, Bluetooth antenna, crystals, passive power supply components, and external capacitors needed by the CapSense module. Each GPIO (General Purpose Input Output) pin on the chip corresponds to a different location on the header connectors on the board. Instead of creating a custom PCB, the prototype combined different standalone modules that plugged into the headers on the PSoC board. The power supply, sensor, buzzer, button, and LED indicators were soldered to male header pins on small perforated soldering boards, which fit into the female headers of the module.

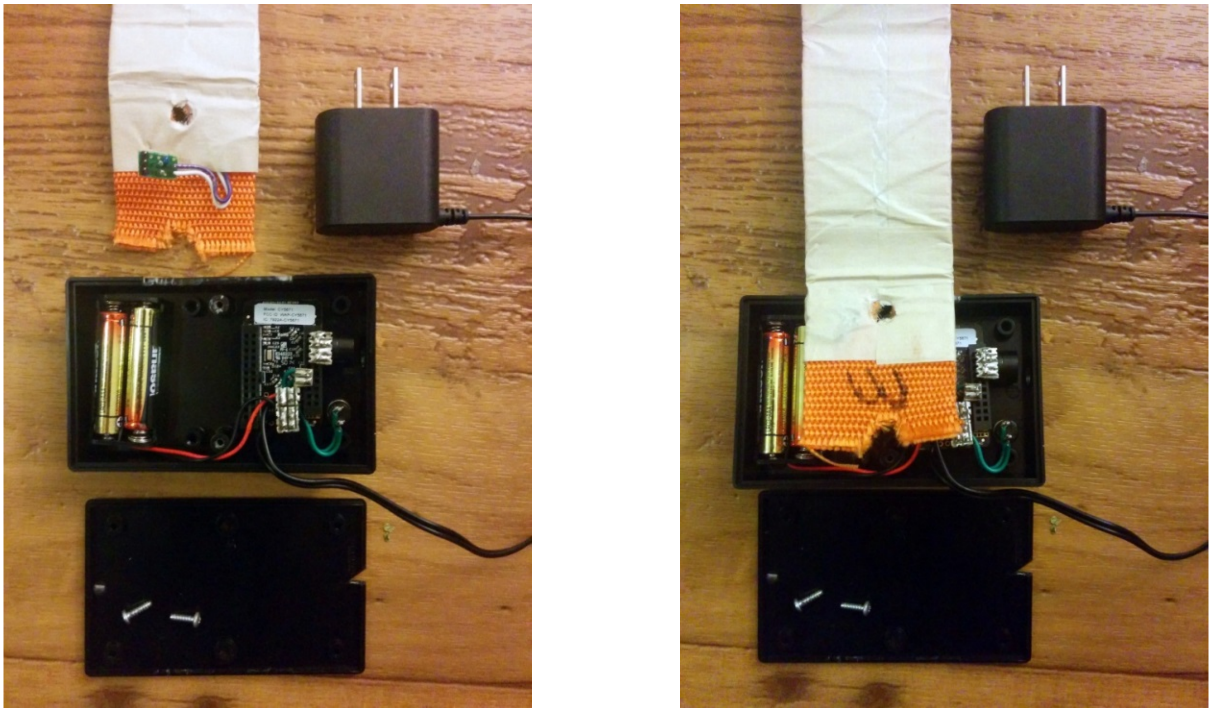

Figure 19 Internal View of Prototype

Figure 19 shows the internals of the prototype Chipper. The electronics and sensor were held together in a small plastic enclosure. The battery rests on one side and the electronics on the other, including the power supply, buzzer, and button. The sensor plugs into the PSoC board and rests above the electronics.

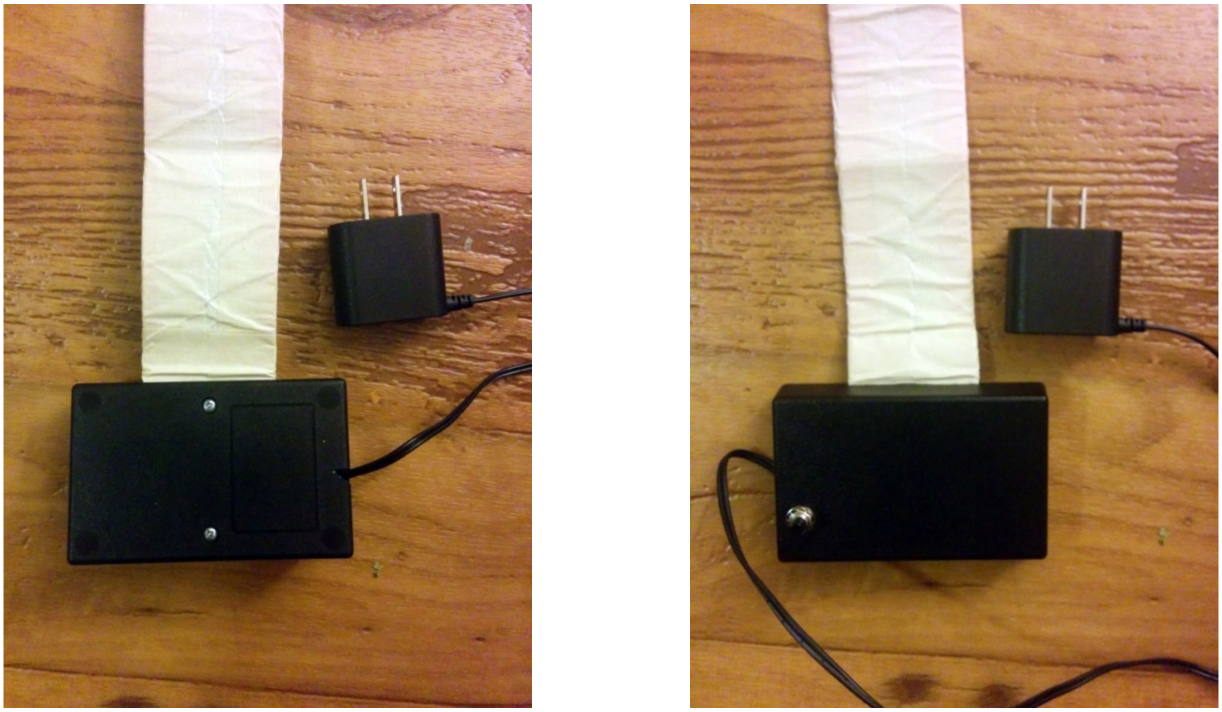

Figure 20 Exterior View of Prototype

The box is held together with two screws. One screw passes through a hole in the sensor strip. The sensor strip exits the box using a slot cut out of the box, where the two halves of the box meet.

With the box closed and the two screws installed, as shown in Figure 20, there is no space for the header pins to fall out of the connector and internal components are held together from the slight pressure. The cable for the wall socket and the button stick out of the box. Figure 21 shows the finished prototype viewed at a different angle.

Figure 21 Finished Prototype

I began working with a Chipper team member to create a prototype smartphone application, shown in Figure 22. However, I was not able to implement a Bluetooth connection before testing the prototypes. However, it turned out that our testers did not need this feature to use the Alpha prototype. To set alarm times, the current time, and device settings, I manually set values as fixed values in code before compiling and loading the program onto the PSoC. When a tester or I needed a change in alarm times or settings, I reprogrammed the device.

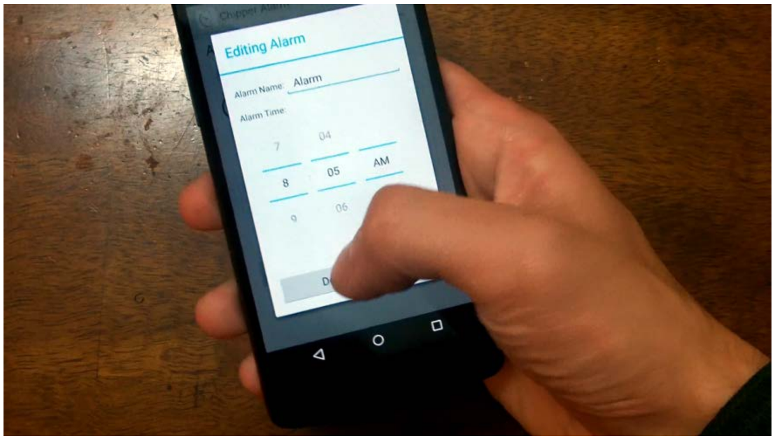

Figure 22 Prototype Phone Application

CHAPTER 8: INTEGRATED SYSTEM TESTS AND RESULTS

8.1: TEST AND REQUIREMENT VERIFICATION

During development, each engineering specification was verified by analysis, measurement, or by personal use of prototype Chipper units. Table 8 lists the results of each test. Engineering specifications not met in this iteration are in red.

TABLE 8 SPECIFICATION TESTS AND RESULTS

Engineering Specifications	Results
Alarm Output: Sounds an alarm of at least 70 dB at 1 meter.	During parts selection, I chose a buzzer rated at 85 dB. However, it was measured at 10 cm. At 1 meter, the alarm has a volume of 65 dB, missing the alarm output specification. This volume was somewhat quiet but loud enough to wake up testers. [12]
Clock Functionality: Device stores alarm times and finds the current time, and rings at times selected by user. The time period when the device may ring starts at the set alarm time and ends 1 hour later. During this time, the alarm will sound whenever it detects bed occupancy.	Device stores up to 16 alarm times. Correctly rings at selected times and for desired time period. Test units have tracked alarm times and real time correctly for 4 weeks without issue. Bluetooth and smartphone connection to device was not completed and alarm times were set by manually reprogramming the device.
Cost: For a run of 1000 units, total cost of electronics less than $30/unit, and total cost of parts less than $50/unit.	Total cost of parts of around $20 at 1000 units. Profitable to build device when selling for $99.
Sensor Design: Sensor takes up no more than 3 sq. ft. of space and is no more than 1/8” thick.	Sensor is 1/10” thick and 2 inches wide by 3 feet long, for an area of 0.5 sq. ft.
Capacitance Sensor: Sensor reads with a precision of at least 0.05 pF. Sensor can adapt to a parasitic environmental load of up to 80 pF.	A 10 pF test load increased the count value from the CapSense by 10,000, indicating a sensitivity of 1/1000 pF. With low pass filtering, the signal varies by around 30 counts, a precision of 0.03 pF. The sensor calibrates IDAC values whenever it is set up, allowing it to adapt to parasitic loads of many 100s of pF.
Detection: Automatically calibrates itself for slow-moving changes in measured capacitance (<.01 pF/second).	System correctly detects bed occupancy more than 2 weeks in a row.
Sensitivity and Range: Detects occupancy when under either foam or metal spring mattresses up	Tested for 8” and 12” metal spring mattress on metal bed frame. The sensor works on twin sized beds and works on

to 10" thick. The sensor senses the area of a twin sized bed.	larger beds as long as user does not roll too far to the other side of the bed. The system occasionally (about once every two weeks) incorrectly detected occupancy, due to incorrect installation and inconsistency in the sensor. More reliable sensor construction and a more refined detection algorithm will remove these glitches. Thick foam mattresses still need to be rigorously tested.
Directionality & Shielding: A shield or other method reduces the capacitive effect caused by objects near or touching below the sensor by at least 90%.	Changes in the signal due to objects below sensor and due to touching metal bedframe the sensor rests on are less than the noise floor and cannot be measured.

8.2: ALPHA TESTING AND PRODUCT VALIDATION

Verification proves that that I built what I set out to build. But can Chipper actually fit customer needs and help people wake up? To prove this, my business team and I set up an Alpha testing program to distribute early prototypes.

We sold 5 prototypes to students at Cal Poly for $20, which helped cover the cost of parts. We manually programed their device with their desired alarm times and delivered it to them on campus. Beyond information from our quick start guide, we left them to install the device on their own.

No initial prototype survives contact with a real customer unscathed. Table 9 outlines some of the unexpected lessons we learned.

TABLE 9 UNEXPECTED PROBLEMS REVEALED IN ALPHA TESTING

Unexpected Problem	Future Solutions
Power Supply: A short in the power supply drained the batteries, and when the Chipper lost power from the wall, it lost track of the current time and rang at unexpected times. With another tester, the device was left unplugged and the batteries drained. This also caused unpredictable ringing.	Ensure reliability of power supply. Add an audio notification to indicate low power. Use rechargeable batteries.
Bed Railing: The high railing on the bed of one tester made it impossible to hang Chipper off the side of the bed. We had to move the location of the button and install it such that the entire electronics box was under the mattress.	Next version must be thin enough to fit entirely under the mattress and cannot be designed to hang off the side.

Removal from Bed: Two testers found out they could turn off Chipper in the morning by pulling the sensor out from under the mattress.	Add code so that Chipper knows when it has been pulled out of the mattress, such that it does not stop ringing unless it is placed back under the mattress during alarm times.

Overall, though, our feedback was very encouraging. Below are three testimonies, paraphrased from phone interviews after a few weeks using Chipper:

> *"I felt more efficient all day due to not wasting time in the morning. I got up early enough to make a good breakfast, and didn't have to rush to my classes, so I felt better all day."*

> *"It gets my ass up! With the alarm, I physically have to get out of bed to avoid the noise. The good thing about that is instead of 30 minutes, it only takes 5 to get up, and I get an extra 25 minutes per day I never had. My old system was a phone alarm, then a radio alarm, but it didn't work because I would snooze the phone alarm, and fall asleep listening to the radio. It was always a concern at night to make sure I get up the following day, especially if I have a midterm or something. Now I can go to bed without any fear of sleeping in. I will continue using it regardless of how far the company gets because I know it will wake me up."*

> *"My day to day life, I would normally wake up around 20-30 minutes before my noon class, and sometimes I would sleep past my class. The Chipper has effectively helped me wake up hours earlier than I normally would have, which has allowed me to get exercise or work done that I would normally do later or not get around to. It has helped with my health, work ethic and sanity now that I'm getting enough sleep... I always used to set extra alarms, but now I don't need it… I love having more control over my life."*

Our testers willingly paid us $20 and tolerated glitches, a lack of a user interface, and our need for feedback just to have more control waking up in the morning. We have many issues to resolve before reaching a factory-ready design, but our testers have helped us test our product, find unexpected issues, and motivate our team to bring this to market.

CHAPTER 9: CONCLUSIONS

In my senior project, I identified a solution to a widespread problem. After setting target specifications based on customer needs, I explored possible technologies and design choices. After deciding on a thin strip shape for the sensor and the PSoC platform, I built multiple prototypes. I tested these prototypes first on myself and then on 5 local students. The tests proved both that this technology can work under many different kinds of mattresses and that this solution actually helps people wake up more effectively in the morning.

I was not able to achieve everything I set out to do. Due to a mistake while selecting parts, the buzzer was more quiet than expected. Sewing conductive fabric shorted out the sensor, and I had to adapt by switching to aluminum foil and masking tape. I was overly ambitious in thinking I could pull together a mobile application and Bluetooth link by the end of the project, but luckily I was able to set alarm times manually during device programming.

The next version of the electronics box needs to be thinner and the next version of the sensor needs to be built using more durable material. The current detection algorithm occasionally misreads occupancy, and unexpected issues found during alpha testing need to be resolved. Once a more reliable sensor is designed, I can refine the detection code. Other details include accounting for Daylight Saving Time, long term crystal oscillator accuracy, ESD protection, battery backup power.

A design ready for manufacturing is a long way off. But initial testing shows, after a bit more development, that the technology will be viable. More importantly, the interest we received during customer development and the testimony we heard from testers who used our product show that Chipper is something that truly helps people and should be built.

While building Chipper for my senior project, my business and software teammates and I applied and were accepted into the Hot House, a summer accelerator that helps Cal Poly startups turn into real companies. We will turn Chipper into an actual company, find our product-market fit, and further develop our hardware and software. I plan to work at Chipper full time when I graduate next December and I hope to launch the product in a crowdfunding campaign in March 2016, while people are groggy due to Daylight Savings Time.

APPENDIX A: ABET SENIOR PROJECT ANALYSIS

Project Title: Chipper: Capacitive Bed Occupancy Sensing for an Intelligent Alarm Clock

Student's Name: David Levi **Advisor's Name:** Dr. Pilkington

1. Summary of Functional Requirements

Chipper makes sure people get out and stay out of bed in the morning. We give them control over waking up. A capacitive sensor placed under the mattress detects bed occupancy. With this information, Chipper only stops ringing when the user gets out of bed, and starts again if they get back in.

Chipper works using a sensor strip placed under the mattress, halfway down the length of the bed. An electronics box contains the alarm and hangs off the side of the bed and, using Bluetooth, a mobile phone controls the alarm times and settings. A wall adapter powers the electronics box with standard USB power.

From customer development, we learned that it was important to create a device that had the same functionality of a normal alarm clock, that was easy to install and calibrate, that had reliable detection, and that had a price point less than $100.

2. Primary Constraints

This device measures tiny changes in capacitance due to objects above the mattress. Because of this, we require a very precise and sensitive electronics and very reliable sensor that measured a large region of the mattress.

While the PSoC chip by Cypress had an easy to use CapSense (capacitance sensor), I had to write custom detection algorithm code to handle the signal created by bed occupancy. I had to experiment with different materials and shapes for the sensor, eventually settling on a thin and narrow strip, with a tough polypropylene middle layer that kept the conductive layers of the sensor from moving relative to each other.

3. ECONOMIC

PARTS LIST AND COST

The manufacturing of the device creates jobs for the people who build the electrical components and custom parts, and who assemble and ship the product. This instrument also creates work inside my startup, Chipper, where I am working with a business, a marketing, and a software team member.

Manufacturing resources for this project include skilled labor and machines needed to create custom enclosures and custom circuit boards and to assemble the final product. Natural resources required for the product include plastic for the enclosure, metal and plastic for the sensor, and silicon and other trace elements to create the electronics.

Due to customers' perception that this device was similar to a regular alarm clock, and due to our desire to help as many people as possible with this product, a low price point is critical. Table 10 shows the approximate cost of parts for the hand built prototypes used in Alpha testing, and the cost of parts in a medium sized production run of 1000 units.

TABLE 10 BILL OF MATERIALS

COST		*All units in Dollars*	
Subsystem	**Part**	**Prototype**	**Run of 1000**
Electrical	PSoC 4 BLE Chip	$10.00	$2.94
	Alarm	$0.66	$0.35
	Battery (AAA x2)	$0.76	$3.42
	Battery Holder	$1.05	$0.64
	Power Supply Connector	$2.44	$1.35
	PCB (2"x2")	$5.00	$0.79
Sensor	Webbing, 3 ft.	$0.87	$0.48
	Conductive Fabric	$3.10	$0.70
	Outer Fabric	$0.50	$0.30
System	Enclosure	$4.79	$0.50
	Interconnects	$2.00	$1.00
	Other Bits	$2.00	$1.00
	Power Supply	$4.42	$3.31
Other	Packaging	$3.00	$3.00
	Manual	$1.00	$1.00
	Total Parts Cost:	**$41.59**	**$20.78**

The parts are very inexpensive at scale, with the cost driven by the power supply, enclosure, sensor conductor, and the PSoC chip which contains almost all the required circuitry internally. However, parts are normally only 20% to 25% of the cost the final price of a product. We expect it to cost $20 in parts. Labor for manufacturing, assembly, testing, and fulfillment will cost an additional $30 to $40 per unit for a medium sized production run. Retail fees and shipping will cost another $10 per unit. If we sell at a $99 price point, we can pay off tooling and setting up for manufacturing after selling around 2000 units. After that is paid off, we can make a margin of around $30 to $40 for each unit, which we can put towards building and selling more products, operational costs, and eventually paying the team a salary.

PROJECT PLANNING

Figure 25 shows the final schedule for the project. After researching the various ways to sense capacitance and the capabilities of available microprocessors, I began designing the system. Work was divided into 5 development cycles. In each cycle, I designed, then implemented, then verified the system, and the results of one cycle impacted the final requirements of the next.

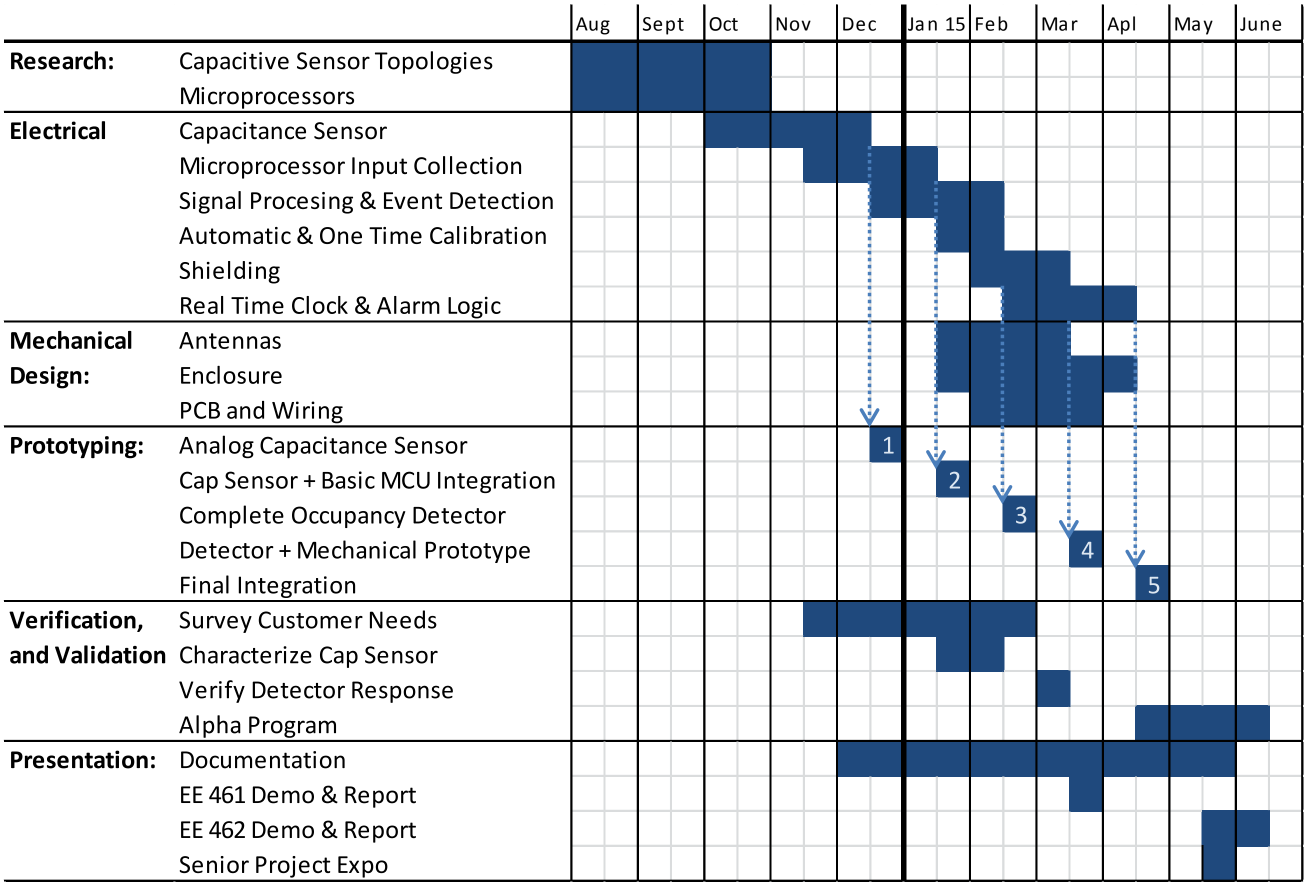

Figure 23 Project Gantt Chart

In Cycle 1, I build an analog capacitance sensor which outputs an analog frequency. Cycle 2 integrated a microprocessor capable of reading and filtering this frequency signal. Cycle 3 increased the functionality of the microprocessor, giving it calibration and the ability to detect occupancy. Cycle 4 added the sensor, shielding and basic functionality for the audio alarm. Finally, in Cycle 5, I added a real time clock and brought the system together on a development board with added custom electronics inside an enclosure. Figure 26 breaks down the completion of subsystem, by prototype number.

After creating the basic digital capacitance meter in Cycle 2, I characterized actual sensitivity, resolution, and sample time of the sensor. After creating the complete detector, I characterized the range and consistency of response in different settings. I solicited customer feedback throughout the project, and, after the first complete prototype, I validated the product with customers in an alpha program.

Prototype Number	**1**	**2**	**3**	**4**	**5**
Capacitance to Frequency	■				
Frequency Subtraction	■				
MCU reads in Frequency from Cap Sensor		■			
Basic Digital Filtering		■			
Advanced Digital Filtering			■		
Basic Event Detection			■		
Automatic Calibration Against Environmental Shifts			■		
One Time Calibration Mode			■		
Test Mode			■		
Character Display				■	
Alarm Sound Output				■	
Shielding				■	
Alarm Clock Logic				■	
Real Time Clock					■
Failsafe Logic					■
Power Supply					■
Basic Sensor		■			
Sensor with Shielding				■	
Controls and Inputs				■	
Electronics Designed				■	
Electronics Assembled Built					■
Enclosure					■

Figure 24 Subsystem Development by Prototype Cycle

While the program overall stayed on track, there were a few significant changes that I did not anticipate when first starting the program. First, until cycle 3, I was designing a custom capacitance sensor from scratch using mostly discrete electronics. I wrote my own firmware to calibrate and measure the signal. However, after discovering the capabilities of CapSense on PSoC, I realized that I could get as much functionality for a lower parts cost by switching over. After a few weeks of development, I had a capacitance sensor that was in many ways better and easier to work with than the custom one I spent months designing. However, this time working with a custom capacitance sensor gave me more insight into how capacitance works, especially under a mattress.

My team was accepted into a local accelerator program called the HotHouse which will give us the space, mentorship, and seed money to spend the summer developing our business and technology. We will crowdfund our first 500 units early next year, and will ship our product by the end of next year.

4. IF MANUFACTURED ON A COMMERCIAL BASIS:

Tens of millions of people, especially young adults, have problems with waking up and are being let down by their current alarm clock. Long term, we could sell 500k units per year.

Parts for the device cost around $20. At large scale production of 100k units with streamlined processes, manufacturing labor and other per-unit costs will reach around $20 per unit, and allow us to profitably reach a price point in the $60 to $70 range. However, while we learn the actual costs of building the device and only create devices with small and medium scale production, we are targeting a $99 purchase price.

Near term, we plan to sell 1000 units at $99 in a crowdfunding campaign, gaining $100k in revenue and about $20k in profit to put into building more devices. At our long term goal of 500k units/year and revenue of $10 per unit, we could achieve up to $5 million in profit/year.

The device is very cheap for the consumer to use after purchase. The customer will need to buy a new Chipper about every decade. Also, it may be necessary to replace the rechargeable batteries once or twice during the life of the product, a cost of about $10 spread over 10 years.

5. ENVIRONMENTAL

This instrument impacts the environment in the use of resources required for manufacture. Aluminum for the sensor, plastic for the enclosure, and the components needed for electronics, including rare trace elements, require harvesting from the natural environment.

Whenever possible, we use ROHS and lead-free parts. The device should be durable and last for at least a decade, but plastic and metal parts are recyclable. The electronics do not recycle, but the device can easily be broken down into separate materials. In this way, we reduce the environmental cost at the end of the product’s lifecycle.

6. MANUFACTURABILITY

It takes 4 steps to manufacture a Chipper. A factory needs to print and assemble the PCBs, to plastic mold inject the enclosure, to construct the sensor, and to assemble the parts into a final product.

PCB printing and assembly, along with plastic mold injection, are common manufacturing steps. Many online resources offer turnkey production for small and medium sized orders, and overseas factories can easily scale up production.

However, the construction of the sensor does not follow an obvious manufacturing process. Not many products combine conductive materials between layers of insulation in a flexible, fabric package. Also, the sensor must be built so that the layers do not move apart, as slight separation can distort the capacitive signal.

The sensor might be glued, laminated, or sewn together, and I have not finalized the materials it will be made from. If the sensor is made out of a material that can be sewn, we can look into custom sewing factories that normally make clothing and gear such as backpacks. Due to the complexity and unusual construction of the sensor, we plan to look for a domestic manufacturer that we can easily visit during design for manufacturing.

Finally, the product must be assembled, packaged, and shipped. This process should only take a few minutes per part, and we might do this in-house for a medium sized run of 1000 units. However, long term we will need to find a domestic or international factory that can do this for us.

7. SUSTAINABILITY

After initial installation and calibration, the device needs no user maintenance. When changing beds, the user will have to reinstall and recalibrate the device. Otherwise, the user can forget that they even use the device, and simply enjoy waking up in the morning.

Alarm times and other settings are controlled from a mobile app from the phone. We can add more features to the app, such as the ability to display information about last night's sleep, just by updating the app. It might be possible to upgrade the firmware of Chipper wirelessly, using the Bluetooth connection from the phone.

While the device is durable, we do not expect it to last forever. The device should be replaced about every 10 years to ensure reliability. Due to the low price point and low natural resource requirements of the device, the hardware will not be upgradable, and the consumer will need to buy a newer version of the product.

8. ETHICAL

This project follows the ethical framework set out in the IEEE Code of Ethics. At no point do I exaggerate what this product can do or hide possible harms. The project strongly supports the ethical intention “to improve the understanding of technology, its appropriate application, and potential consequence.” I have made sure to educate my customers about how capacitance works and how it senses occupancy. I do not want them to see the device as a magical and mysterious black box, and instead enlighten them as to how the technology works.

This project also follows Utilitarianism, creating the greatest good for the greatest number. Waking up earlier does create some short term pain, but being more timely makes the customer happier in the long run. It also helps the customer be more productive and timely, making people around the customer happier.

9. HEALTH AND SAFETY

This device puts electricity near the bed, which at first sounds like a bad idea. However, the amount of electricity that reaches the device is small. We use a UL-listed 3rd party wall socket that outputs standard 5v USB power to power our device. The device draws a few watts to power the buzzer, but even in a short circuit, this is not enough electricity to harm someone or start a fire. We will need to make sure that our battery backup power supply uses the necessary voltage and temperature safeguards to make sure the battery does not rupture, especially during recharging.

The sensor strip is made out of polypropylene and other tough, inert materials. This reduces the risk of the sensor becoming moldy if left in a moist environment.

The circuit measures capacitance by pushing charge on and off the conductive sensor. This action creates tiny near-field electric fields. However, with the PSoC CapSense, this charge is very small, and the frequency that the charge is loaded is pseudorandom, spreading out energy to many frequencies. We add a resistor in series to further reduce current and thus emission from the sensor. We can also decrease the speed that the sensor moves charges, or reduce the number of samples the device takes over a night. Because of these design choices, we do not anticipate our device interfering with other electronic devices or violating FCC certification. There are no known health risks to the tiny electric fields the device creates, and the device creates emissions much less than other common electronics.

10. SOCIAL AND POLITICAL

This device gives individuals, especially the young and students, an unbeatable way to wake up in the morning. This gives them more time and a more productive morning, and control over their sleep schedule. Parents will no longer have to use force or threats to wake up their teenagers. Professors and employers will be able to rely on people showing up to class and work in morning hours.

The only harm done is to the end user, in being uncomfortably forced to get out of bed. But after a few minutes awake and out of bed, they will be happy that they woke up.

My startup venture Chipper will profit from sales of the product, and use the profit to expand our business so that we can build and sell more products.

11. DEVELOPMENT

During this project, I learned how to more deeply analyze circuits using LTspice. I learned how to model complex and large function using Microsoft Excel, and also used Excel to graph and interpret raw data collected from the capacitance sensor. I learned how to write firmware for both the PIC microprocessors, and the Cypress Programmable System on Chip (PSoC) platform. I learned how to accurately measure capacitance in real time both with my custom sensor design and the PSoC CapSense module. I learned how to solicit customer feedback and how to run an alpha testing program. The References section below shows the literature search performed during this project.

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