**Multi-Disciplinary Senior Design Conference**
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## Project Number: P11201

# NTID NOTIFICATION SYSTEM

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## ABSTRACT

A missed alert for a deaf or hard of hearing person may have lethal consequences. Even if outcomes are not fatal, missing vital information negatively affects quality of life for deaf and hard of hearing people, as it restricts their independence and self-reliance. Most homes and hotel alert systems are audible thus neither convenient nor practical for deaf or hard of hearing persons.

The first phase of this portable alert notification system is Morpheus. Given its Bluetooth® interface, it has the potential for increased functionality through smartphone applications. The customer plans to share Morpheus' design with Google with a proposal to design and implement applications specific to it. Possible applications that could be designed include not just an alarm clock function, but also important incoming alerts. Additionally, the application can be used to indicate calls or e-mails from important people in an office environment.

Morpheus is novel as it is an assistive device that uses Bluetooth to capitalize on the convenience that smartphones and PDAs offer. In addition, due to its small size, it is easily portable and can be easily set up in a number of settings, such as the home, office, or a hotel room. Finally, through the use of Bluetooth technology, it is easy to add new uses through designing new applications with little or no hardware changes.

## NOMENCLATURE

ADA – Americans with Disabilities Act
Morpheus - Name of prototype
Bedshaker - A device that is used with alarm clocks for deaf users. It slides under either the user's pillow/mattress.
NTID - National Technical Institute for the Deaf
PCB - Printed Circuit Board
LED - Light Emitting Diodes
BJT- Bipolar Junction Transistor
WPF – Wireless Programming Field

## INTRODUCTION

Figure 1. CAD Assembly of Morpheus

Businesses are required by the Americans with Disabilities Act (ADA) to provide reasonable accommodations to customers and employees. While the act has made strides in protecting the civil rights of disabled Americans, ongoing problems still exist. In hotels, management personnel are either ignorant of provisions such as providing strobed door knockers or alarm clocks for deaf or hard of hearing customers, or choose to ignore requirements and only implement these when legal action is applied.

Products exist on the market that include non-audible functions but are cumbersome for travel or may require permanent installation. One benchmark product, the Sonic Boom™ alarm clock, requires three large components and is better suited for home usage rather than travel. Additional assistive technologies include use of installed strobe lights to indicate incoming phone calls in deaf/hard of hearing homes. Some of these systems require permanent installation and can be inconvenient for both user and employers required by the ADA to provide them. A lightweight, inexpensive and portable alert device is needed. Our prototype, Morpheus, fills that need.

It is estimated that there are as many as 20 to 36 million Americans with hearing losses ranging from mild to profound. Over the course of 75 years, half of adults will eventually lose their hearing through natural aging, excessive noise levels, and other causes. In addition two to four babies out of every thousand born are afflicted with some degree of hearing loss.[2] While getting specific statistics is speculative, there is potentially over 20 million prospective consumers for our device. In addition, the device could potentially be useful to hearing consumers as well, such as those who have a hard time waking up to a conventional sound alarm.

## PROCESS

### i. Driver Electronics

For the driver electronics, the first goal was to develop the controls that would lead to the PCB design. The controls for this project required two separate systems, one for the bed shaker and the other for the LED array. Both of these systems contained a BJT that's base was controlled by a microprocessor. The BJT operated in two different modes of operation: Cutoff and Active. In the cutoff mode, the microprocessor sends a "low" or 0 volt signal to the base of the BJT. While in active mode, the microprocessor sends a "high" or 5 volt signal to the base of the BJT.

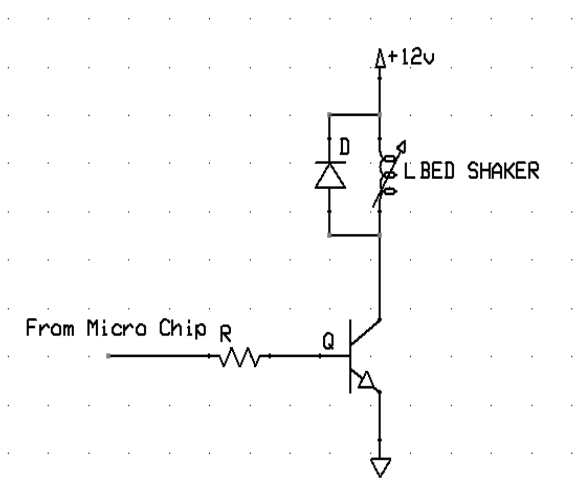



Figure 2 Schematic of Bed Shaker System

Shown above in Figure 2 is the schematic for the bedshaker system. A diode was placed across the bed shaker to prevent any reverse emf on the BJT, which could damage the device. Also, the resistor value was calculated such that the base current was less than 25 mA (the maximum current draw from the microprocessor). To theoretically calculate this value equation (1) was used.

$$\beta_0 \approx \frac{I_C}{I_B} \tag{1}$$

From this equation the base current was calculated to ensure the BJT operated correctly. This was possible because collector current and the beta gain coefficient were both known (400 mA and 100 respectively). It was determined that an absolute minimum of 4 mA must be flowing through the BJT for the bed shaker to function correctly. Finally, since the microchip provided 5 volts, the 1,250 ohms resistor used in the final design would yield the minimum required current through the base terminal. However, to ensure that the system would work and account for component tolerances a final resistor value of 470 ohms was selected (which allowed for the base current to be approximately 10 mA). This overhead allowed for the system to work if the bed shaker drew more current or if the beta gain coefficient was low for the individual BJT.

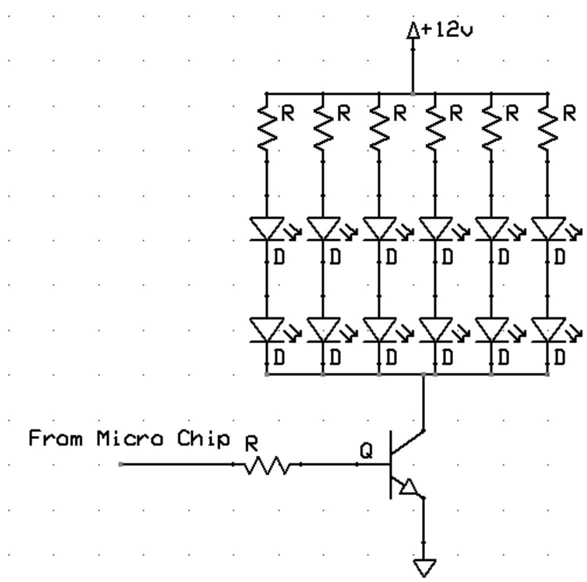



Figure 3 Schematic of flashing LED system

The schematic pictured in Figure 3 documents the LED array system. As was the case with the bedshaker, a resistor was picked to ensure that the LEDs were able to draw enough current to turn on. Through simulations in cadence and hardware it was found that the LED array drew 380 mA. This value was roughly the same as the bed shaker (400 mA) and because of this the same 470 ohm resistor was used on the base node.

However, unlike the bed shaker case, two important decisions were decided on pertaining to the LED array. The first was to put two LEDs in series and have six total sets of two LEDs in parallel. The reason behind this was the voltage drop over each LED, which with these "super bright" white LEDs was roughly 3.8 volts. By putting two of these in series the total voltage drop was now roughly 7.6 volts, which allowed for the current limiting resistor to be much smaller. Having a smaller resistor for the current limiter was very useful because it reduced the amount of power being dissipated via of heat. The equation for power is shown in equation (2).

$$P = IV = \frac{I^2}{R} \qquad (2)$$

From this equation it is clear that lowering the resistance lowers the power. Since resistors convert nearly all of their power into heat energy and LEDs convert most of their power into light this design dissipates vastly less heat than twelve LEDs in parallel. In fact rough calculations showed that the heat dissipated went from 768 uW to 384 uW, approximately half as much.

The last consideration made for this schematic was use a 100 ohm resistor to limit the current flowing through each LED pair. Since each LED has a voltage drop of 3.8 volts, it was found that the current was limited to 44 mA with a 100 resistor. This is an acceptable value of current for the flashing “super bright” LEDs being used for this project.

The rest of the circuit contained a five volt regulator to power the Bluetooth Transceiver board, a fuse for current protection, and a power switch. Once this schematic was completed, both the systems shown in Figure 1 and Figure 2 were built on a prototyping board and checked to see if they operated correctly, which it did.

With this done the next step was to design a custom PCB board. In lay out portion of this board .012 inch traces were used to make sure that the trace could handle the amount of current flow that the system required. Also, larger ground planes for the BJT, diode, and regulator where used to create a better connection to ground.

**Bluetooth Module with Microcontroller**

The Toothpick 2.1 Bluetooth Transceiver combines the PIC18LF6722 microcontroller and the LinkMatik (Bluetooth 2.0) radio device. The transceiver comes preloaded with Toothpick Services firmware, including a FlexiPanel user interface server, and a wireless field programming (WFP) tool which allows the software to be electronically uploaded to the microcontroller. This device was chosen because of several key features. The module utilizes a FCC/ CE certified 2.4GHz Class 2.0 Bluetooth radio. The device is very small in size with the dimensions L x W x H measuring 51mm x 22mm x 10mm, and requires a regulated voltage of only 5 volts. These features made it an ideal solution for meeting the project requirements.

**Installing the Application**

The FlexiPanel server application installed on this module allows Windows PC devices to display the stored user interface. FlexiPanel Bluetooth Protocol was used to transmit the user interface to the PC. The client software does not require modification, since the user interface specifications are stored on the Bluetooth module, and transmitted to the client each time it connects. The user interface was built and compiled using FlexiPanel Designer software.

**Running the Application**

To activate Morpheus, the user sets an alarm through an application installed on their smartphone or PDA and sets Morpheus’ internal alarm via the Bluetooth connection. When Morpheus connects via Bluetooth, an indicator LED turns blue. When the alarm is set, the LED turns green. When the alarm activates, Morpheus flashes the LED lights installed on the sides and activates the bedshaker, which is placed either under the user’s pillow or mattress.

To run the client application, the user requires a Windows PC, with a built in Bluetooth radio or external dongle. To install and run the application in a Windows PC, the following steps must be followed:

1. Download Windows Remote Client FlexiPanelWin30.exe from: http://flexipanel.com/WirelessSoftware.htm.
2. Connect the PC to the device via Bluetooth. If prompted by the PC, enter the password: four zeroes (0000)
3. Open the Windows Remote Client.
4. Update the current time of the device, as well as adjust and enter the alarm time.

**ii. Software**

One major challenge was finding a Bluetooth RF transceiver. Toothpick® designed and built by FlexiPanel Ltd was specifically selected given its documentation and files that could be built upon, shortening the learning curve for this project. There were three main components needed to accomplish the software portion of the project. These include a Bluetooth module combined with a microcontroller, a Bluetooth development board, a Bluetooth enabled interface, and software development tools. After ample research into current relevant Bluetooth products and solutions available on the market, the following were chosen:

**Bluetooth Development Board**

The Bluetooth development board was used during development as a reliable, tested environment for programming via the MPLAB In-circuit debugger.

**Microchip Inc. MPLAB IDE**

This development interface is a free, integrated toolset used for the development of embedded applications for Microchip’s PIC microcontrollers. MPLAB IDE is run as a 32-bit application on Microsoft Windows.

**FlexiPanel Designer**

This graphical user interface design tool is free software offered by FlexiPanel Ltd. to aid in the design of interfaces with their products. It is a generic program allowing one device (the FlexiPanel Server) to create a user interface on another device (the FlexiPanel Client). It provides a wireless control and monitoring facility for the device, eliminating the need for any other user interface components.

These components allow us to design and develop an application that can be used on a PC which will communicate with a Bluetooth device. There was also help guides and examples available to help guide the team through the development process.

**Interface Design**

One graphical user interface was developed. This interface allows the user to control the alarm time, the current time, and snoozing and canceling of the alarm sequence.

**Functional Requirements**

The goal was to develop an application which would allow a user to set an alarm time, as well as cancel or snooze an alarm sequence. The application required both input from the user, and a feedback which takes the user's input and sends a signal to the Bluetooth module. The interface is stored in an architecture such that the code for the interface is on the module and is downloaded to the PC when the user connects.

**Non-functional requirements**

The interface needed to be simple to accommodate a broad range of users. It also needed to have a flexible real-time clock so that the user could adjust it to the appropriate time zone. The goal was to produce a product that would be easy to use for all users.

**Pre-defined Toothpick services**

Within the protected memory of the PIC microcontroller, several Toothpick services are pre-installed. These help with programming the transceiver. The functions explained below were used in generating the backend code:

**Digital Output**

The microcontroller allows for all analog pins to be reconfigured as single bit digital input/ output pins. Several outputs were used to allow the microcontroller to trigger the indicator LEDs, White LED relay and bed shaker. The built-in functions provided with the Toothpick services made utilizing the pins of the microcontroller simple, and required only several lines of code.

**LinkMatik Control**

This allows the program to access the Toothpick's Bluetooth (LinkMatik) radio directly. The LinkMatik is connected to the universal asynchronous receiver/ transmitter port of the PIC microcontroller. The services pre-installed in the module provides easy communication with the Bluetooth radio.

**Callback Functions**

When an event occurs, and the Bluetooth module needs to inform the application/ device that something has happened, it calls on one of the following provided call back functions:

- Error Status - this is called if an error occurs.
- LMTEvent - called when an event occurs on the LinkMatik module. These events are described in the documentation provided for the Toothpick.
- FXPEvent - called when a FlexiPanel event occurs, such as a button being pressed. This event handler was used to trigger the application interacting with the user, and appropriate action was taken based on the input.

**iii. Housing**

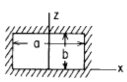
Figure 4: Prototype with Gorilla tripod

The design of the plastic housing required expertise outside the scope of the group's background. Different forms of production were considered, including 3D printing, injection molding and thermoforming. 3D printing was selected because it could be done in-house, therefore minimizing the team budget while decreasing production time. This method of manufacture also has few limitations, allowing the team to explore design aesthetics.

Minimizing the overall device size was accomplished by integrating the alert scheme into the housing, LEDS, versus including a power supply and 115 VAC power receptacles needed for a conventional table lamp to plug in. Customer feedback indicated that a device with a receptacle for a plug-in lab would be acceptable, similar to the Sonic Boom ™ alarm clock. This receptacle became the limiting factor on the size of the device, so the team proposed an integrated lighting scheme using high powered LEDs. Through communication and careful documentation, the team was able to reconcile an innovative idea with customer needs to accomplish one of the major goals of the design: minimizing size.

Given the customer needs for the product to be reliable, durable, and have a long product life, special attention was paid in designing the housing. Since Morpheus was designed to be a portable device, possibly carried in the customer's pocket, or stored in a suitcase while traveling, the design constraint of withstanding 300 lbf was placed. This was felt to be sufficient to represent a person sitting on it, or possible rough handling that the device may experience will inside a suitcase. This was modeled as a distributed load on the top surface, with all four edges modeled as fixed. The deflection at the center of the top plate, as well as the stress in this location, and the stress along the long edges of the top plate where determined by using Roark's Formulas seen in Figure X. The maximum stress, found along the center of the long edge, was calculated to be 63.09 MPa, the stress at the center equaled 30.46 MPa, and the maximum deflection equaled 5.47 mm.

8. Rectangular plate, all edges fixed




8a. Uniform over entire plate

(At center of long edge) $\sigma_{max} = \frac{-\beta_1 q b^2}{t^2}$

(At center) $\sigma = \frac{\beta_2 q b^2}{t^2}$ and $y_{max} = \frac{\alpha q b^4}{E t^3}$

| $a/b$ | 1.0 | 1.2 | 1.4 | 1.6 |
|---|---|---|---|---|
| $\beta_1$ | 0.3078 | 0.3834 | 0.4356 | 0.4680 |
| $\beta_2$ | 0.1386 | 0.1794 | 0.2094 | 0.2286 |
| $\alpha$ | 0.0138 | 0.0188 | 0.0226 | 0.0251 |

Figure 5: Roark's Formula

A simulation using SolidWorks was also utilized to prove that the design would withstand this force. The maximum deflection was found to be 39.03 MPa, the stress at the center was approximately 27 MPa, and the maximum deflection was 2.76 mm. Given these results it is seen that Roark's Formula is a more conservative approach. Given that the material is ABS plastic the material property of flexural strength was utilized as the maximum strength that material could withstand before failure. This value is 53 MPa, according to Dimension, the company that produces the plastic for the 3D printer in Brinkman Lab. With this being said it can be observed that the maximum strength calculated by Roark's Formula indicates that the housing would fail. This value was ignored and the SolidWorks value became our excepted value of stress. This was justified because the thickness of the plastic along these long edges was increased from the general thickness of the plate. There was no way to incorporate this into Roark's Formula, but SolidWorks was able to utilize this information in its stress analysis. Figure 5 shows the Von Mises stress simulation in SolidWorks.

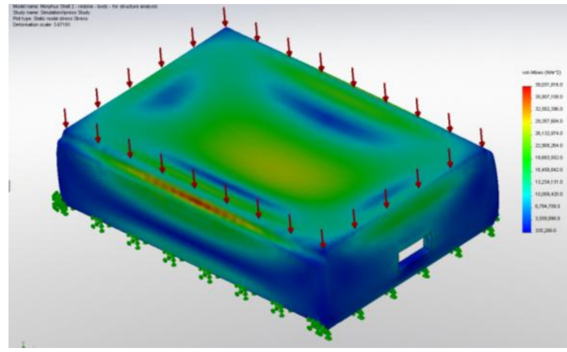


Figure 6: SolidWorks stress simulation

Preliminary thermal analysis took a conservative approach and assumed that all heat transfer occurred in one direction, out of the top of the housing (where the PCB was mounted). If calculations showed that the temperature of the surface did not exceed a comfortable temperature for handling, then it was safe to assume that enough heat was being dissipated for safe operation of electrical components and handling of the case itself. The formula used was

$$q = \frac{T2 - T1}{Rtot} \quad (3)$$

Where q is the average heat transfer, T2 and T1 are temperatures at different points in the control volume, and $R_{tot}$ is the total resistance of the thermal circuit. However, preliminary calculations were not very realistic as many assumptions were made, such as the operating temperature of the PCB. Also, developing an accurate thermal model was outside the scope of the group's expertise. Therefore testing was done to verify whether or not heat transfer issues would arise.

## RESULTS AND DISCUSSION

### i. Hardware

The first series of tests run on the custom PCB was for basic functionality of the electronics to check the ability of the circuit to trigger the LED array and bed shaker properly, along with setting the power LED and notification LED (Blue-communicating, Green-Alarm set) correctly. Then the microprocessor and user interface were connected and it was shown that the device was able to receive the alarm setting and trigger the alarm correctly when the time came.

The current that the bedshaker needed was slightly over 400 mA (~410 mA) and the LED array drew ~395 mA instead of the 380 mA that was calculated. Also, it was found that the drop across the LED pairs was roughly 7.7 volts, which is around the theoretical value. This showed that the LEDs' current were being limited to a safe operating value.

### ii. Software

The biggest issue encountered with writing the code was obtaining the correct version of the software. The most current versions of MPLAB IDE and MPLAB C18 C compiler are not compatible with the pre-defined Toothpick services. MPLAB IDE v.7.40 and MPLAB C18 C compiler v.3.10 are compatible with the Toothpick. The correct version of MPLAB IDE can be obtained from the MPLAB IDE archives on the Microchip website, whereas the correct version for MPLAB C18 C compiler would need to be requested from Microchip by email. The code was successfully written with some assistance from provided hardware and software documentation.

### iii. Housing

#### Structural Analysis

On the housing, three types of testing were performed. The first test, a drop test, was performed by dropping a block of wood that was similar in size and weight to our prototype from various heights (from 18-36 in.) with an accelerometer attached to measure magnitudes of Gs that our prototype would need to withstand without breaking. Using the wooden block instead of the actual prototype allowed us to obtain an engineering specification while preserving the prototype for additional tests.

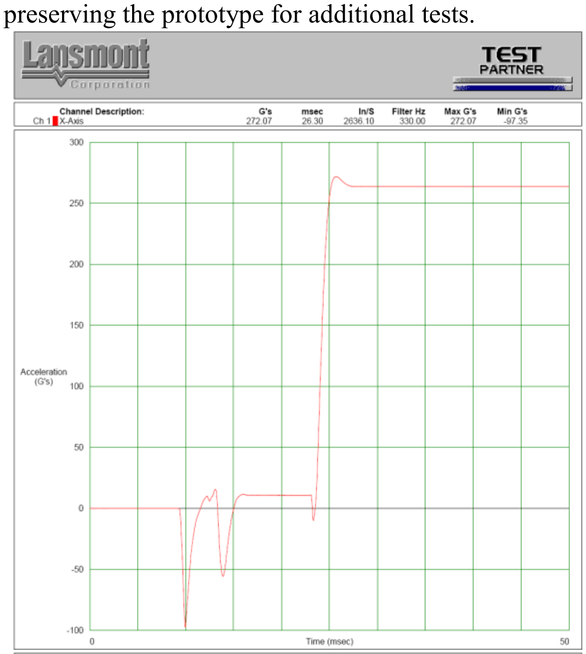


Figure 6: Drop Test Results With Block of Wood

From this preliminary testing, it was determined that our prototype should be able to withstand at least 275 Gs at 30 inches which is approximately waist height (Figure 6). In later testing using a drop table, the prototype was secured to the drop table and had an accelerometer attached to it. (Shock Test System Model 65/81TT52 Lansmont Coporation)

Results for 30 inches showed the maximum Gs experienced to be around 330 Gs in the flat orientation plane (Figure 7) This validates the housing as it did not crack at that height. The prototype was also turned on its side in two different orientations and showed failure with cracks appearing, as well as the plastic pane windows popping out. However, all of the electrical components and wiring held, so the housing still served its purpose to mount and protect the electrical components.

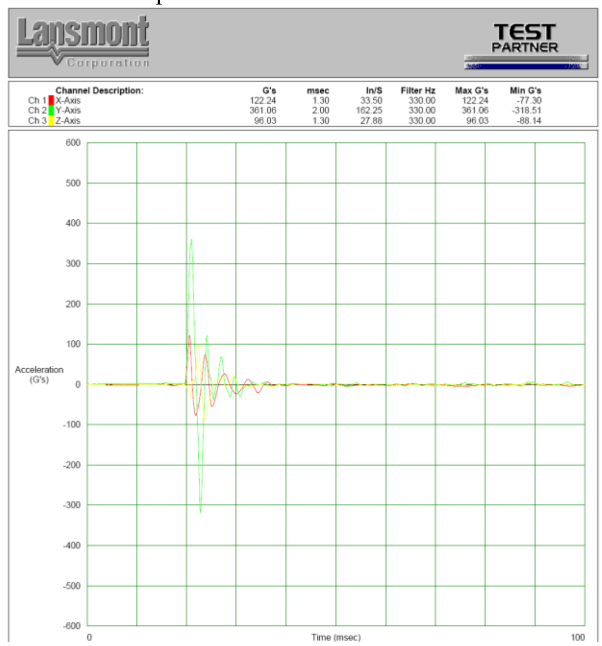


Figure 7. Shock test with actual prototype.

It should also be noted that 3D printing is very brittle, due to the process which generates prototypes by many individual layers of plastic. In addition, it is not an economic means of mass production. Other processes better suited are injection molding or thermoforming are better suited as they do not lead to brittle structures. Had the housing been manufactured by these processes, it is hypothesized the housing would have not suffered any damage such as cracks or permanent deformation. It can be observed in Figure 8 that fracturing occurred in an area of stress concentration due to an opening in the housing to accommodate the power switch. Additionally, the side planes of the housing are convex, so stress was concentrated along the center line of those planes.

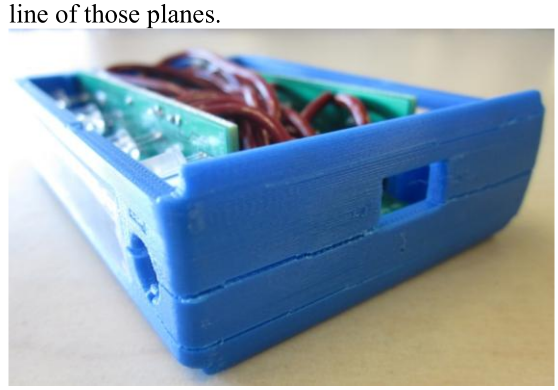


Figure 8: Fracture in housing

In addition to drop and shock tests, compression tests were performed on the prototype. A compression table was employed (Container Compression Test System, Touch Test Electronics – Model 122-15K, Lansmont Corporation) and the prototype was affixed to it. The machine then ran until it measured 341 pound-forces. The prototype was still intact with no signs of cracking or plastic deformation. Another test that was performed was a traveling profile vibration test. (Vibration Machine Test System Touch Test Electronics – MM804 Lansmont Corporation, Model 7000-10) The prototype was tested on a vibration table that simulated trucking travel. The prototype was attached to the table and experienced the selected profile for fifteen minutes. The traveling profile test was performed to ensure that electrical components and wiring would not come loose from travel.

**Thermal Analysis**

Thermocouples were attached on the final prototype on the regulator and the BJT on the PCB. These two components were known to dissipate the most heat and were measured to see how much their surface temperatures increased during operation. Additionally, a thermocouple was also attached to the surface of Morpheus to confirm that the case would not overheat.

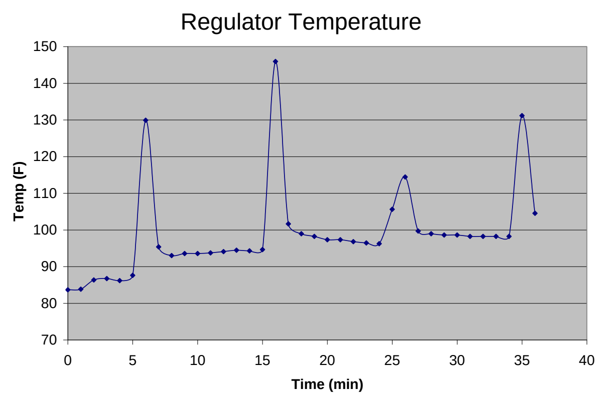



Figure 9:Regulator Temperature

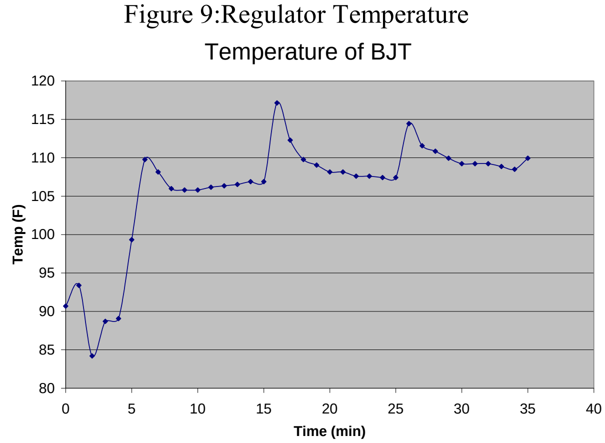



Figure 10: BJT Temperature

As shown in Figures 9 and 10, the temperatures spike only during alarm activation and drop off rapidly when Morpheus goes into snooze mode where it levels off and stays constant.

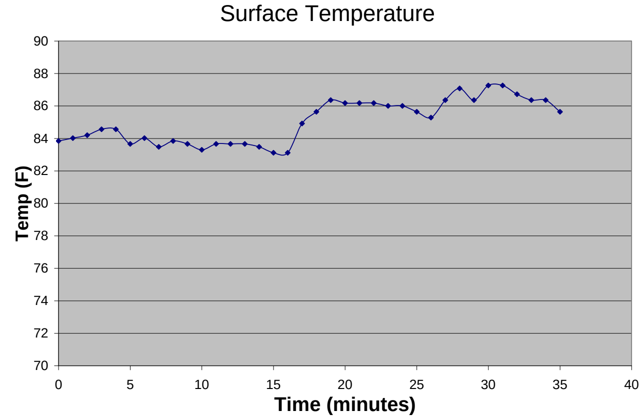



Figure 11: Surface Temperature

As shown in Figure 11, the surface temperature of Morpheus stays consistent and does not exceed 88 degrees Fahrenheit during operation.

## CONCLUSIONS AND RECOMMENDATIONS

In the present design, the power supply is outside the board and is roughly the same size as the prototype itself. This supply can be minimized two ways. First, the rating on the power supply is 12 volts and 2.5 amps; however the device never draws more than 1 amp of current. Another possible option is to design a power system to fit inside the device. This would increase the size of the device significantly so the recommendation is to keep the power supply outside the housing. Finally, the last option is to use a rechargeable battery to power the device. This was the original idea for the device, but it was found that required knowledge on the subject was lacking in the group so this option was later dropped for the present design.

Another possible issue to investigate is the interaction between the Bluetooth Transceiver board and the power switch. With our design there are times when the switch is used that the Bluetooth Transceiver will reset high causing the LEDs and bedshaker to turn on incorrectly. It was undetermined if this was a hardware or software issue due to time restraints and cost.

It is recommended to build the Bluetooth RF transceiver in house, in order to minimize the overall cost of the product, or finding one that has a lower cost. Some companies to explore include Panasonic Electronic Components, Roving Networks, Laird Technologies, Bluegiga Technologies, and FlexiPanel.

The method of 3D printing is not economically efficient for mass production. It is recommended that the housing be altered so that production methods such as injection molding or thermoforming could be utilized. These methods both have a large initial cost, the bulk originating from the cost of mold construction. After a mold is created, per unit cost of each case is inexpensive, practically equal to material costs. Further investigation is needed to select a manufacturing method, as quantity to be produced determines which method is more economic.

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