Table of Contents

1.0 BACKGROUND ............................................................................................................... 4

2.0 PROBLEM DEFINITION .................................................................................................. 4
  2.1 Problem/Need ........................................................................................................... 4
  2.2 Client Needs ............................................................................................................ 4
  2.3 Constraints ............................................................................................................. 5
  2.4 Specifications ......................................................................................................... 5
  2.5 Objective and Deliverables ...................................................................................... 6

3.0 CONCEPTS DEVELOPMENT .......................................................................................... 6
  3.1 Microcontroller Selection .......................................................................................... 6
  3.2 Wireless Transmitter/Receiver Concepts Considered .............................................. 7
  3.3 Wireless Transmitter/Receiver Concepts Selection ............................................... 7
  3.4 LCD Concepts Selection ......................................................................................... 7
  3.5 7-Segment Display Concepts Selection ................................................................... 7
  3.6 User Interface Concepts Considered ....................................................................... 8
  3.7 User Interface Concepts Selected ........................................................................... 8
  3.8 Power Conversion Concepts Selection .................................................................... 8
  3.9 Current Time Clock Concepts Considered ............................................................... 9
  3.10 Current Time Clock Concepts Selection ................................................................. 11
  3.11 Housing Enclosure Boxes Concepts Selection ....................................................... 11

4.0 PRODUCT DESCRIPTION ................................................................................................. 11
  4.1 System Components and Design Plan ...................................................................... 11
  4.2 Electrical Components ............................................................................................ 12
    4.2.1 Microcontroller .................................................................................................. 12
    4.2.2 Wireless Transmitter/Receiver ......................................................................... 13
    4.2.3 Liquid Crystal Display (LCD) .......................................................................... 13
    4.2.4 7-Segment Display .......................................................................................... 14
    4.2.5 User Interface (Keypad) .................................................................................. 14
    4.2.6 LED for Warning Lights .................................................................................. 15
    4.2.7 Power Conversion ............................................................................................ 16
    4.2.8 Current Time Clock .......................................................................................... 17
  4.3 Mechanical Components .......................................................................................... 18
    4.3.1 Housing Enclosure Boxes ............................................................................... 18
  4.4 Functionality of the Speaker Timing System .............................................................. 18
    4.4.1 System Functionality Flow Chart ..................................................................... 18
    4.4.2 Programming the System ............................................................................... 20

5.0 PRODUCT EVALUATION ................................................................................................. 21
  5.1 Microcontroller Testing ............................................................................................ 22
  5.2 Wireless Transmitter/Receiver Testing .................................................................... 22
  5.3 LCD Testing ............................................................................................................ 22
5.4 Keypad Testing ......................................................................................................................... 23
5.5 7-Segment Display Testing ........................................................................................................ 23
5.6 LED (Warning Lights) Testing ................................................................................................ 26
5.7 Testing Entire System .............................................................................................................. 27

6.0 ECONOMIC ANALYSIS ........................................................................................................... 28
6.1 Budget ...................................................................................................................................... 28
6.2 Per-Unit Costs .......................................................................................................................... 30

7.0 CONCLUSIONS ...................................................................................................................... 32

8.0 APPENDICES .......................................................................................................................... 33
   Appendix A – Operating Instruction Manual
   Appendix B – Wiring Diagrams and Schematics
   Appendix C – Test Code
   Appendix D – Source Code
   Appendix E – Drawing Package
   Appendix F – Bill of Materials
   Appendix G – Pictures of System Being Built
   Appendix H – System Evaluation
List of Figures & Tables

Figure 1: A Typical Voltage Regulator Circuit ................................................................. 9
Figure 2: Pictures of the Components for a Radio-Controlled Clock .......................... 10
Figure 3: Commercially Made Radio-Controlled Clock ........................................... 10
Figure 4: System Design Block Diagram ................................................................... 12
Figure 5: Rabbit 2000 Microprocessor ..................................................................... 13
Figure 6: Prototype Board with Microprocessor and Wireless Module Installed .......... 13
Figure 7: Wireless RF Module .................................................................................. 13
Figure 8: LCD ....................................................................................................... 14
Figure 9: Front Side of Display ............................................................................... 14
Figure 10: Keypad, Encoder IC, Oscillator ......................................................... 15
Figure 11: Keypad, Encoder IC, and Oscillator Wired Together & Attached to the Prototype Board .................................................................................................. 15
Figure 12: LED's for the Indicator/Warning Lights .................................................. 16
Figure 13: Power Adapter and Plug-In to Station ..................................................... 16
Figure 14: Radio-Controlled Clock ........................................................................ 17
Figure 15: Battery Compartment on the Back of the Master Station ..................... 17
Figure 16: System Functionality Flow Chart .......................................................... 19
Figure 17: LCD Displays Test Message .................................................................. 22
Figure 18: LCD Being Tested with Keypad .............................................................. 23
Figure 19: Testing Keypad with Oscilloscope ......................................................... 23
Figure 20: Testing Single Digit Display .................................................................... 24
Figure 21: Testing All Displays ............................................................................... 24
Figure 22: Display Driver, Inverter, & Voltage Regulator Wired Together ................ 25
Figure 23: Front Side of Display (with Mosfets) ....................................................... 25
Figure 24: Back Side of Display ............................................................................. 25
Figure 25: Testing Display with Microcontroller .................................................... 26
Figure 26: LED's Being Tested with Microcontroller ............................................... 26
Figure 27: Components Being Tested Before Assembly ......................................... 27
Figure 28: Components Being Tested After Assembly ......................................... 27
Figure 29: Speaker Timing System (Both Units) ...................................................... 28

Table 1: Budget ........................................................................................................ 29
Table 2: Cost Associated with the Master Station ..................................................... 30
Table 3: Costs Associated with the Slave Station ..................................................... 31
Table 4: Total Unit Costs ......................................................................................... 32
1.0 BACKGROUND

The Western Protective Relay Conference (WPRC) is an educational forum for the presentation and discussion of broad and detailed technical aspects of protective relaying and related subjects. It is hosted by the WSU Center for Distance and Professional Education and is held annually in Spokane, Washington in the month of October. About 450 people from around the world attend the conference. The WPRC allows participants to demonstrate and apply advanced technologies that prevent electrical power failures. Speakers are invited to present papers selected by a group of protective relaying experts.

Lecture speakers overrunning their allotted presentation time is a common issue at conferences. This report presents the speaker timing system that has been designed and built to help the moderator have more control over the presentation and help the guest speaker from exceeding their allotted time for their presentation. By using the speaker timing system, the conference will stay on schedule and run more smoothly. Thus, audience members will be more satisfied.

2.0 PROBLEM DEFINITION

2.1 Problem/Need

A problem has developed with speakers exceeding allotted time. Since the audience consists primarily of professional engineers and consultants, presentations that go overtime can cause attendees to be late to other presentations, missing valuable information. In addition, presentations that go over-time will cause the conference to get off schedule and cut into the presentation times of later speakers. The conference is in need of a timing system that indicates to a moderator and speaker how much time is left in a presentation.

Our team has had the opportunity to design and build a two-unit speaker timing system; each unit consists of a master station and a slave station. The master station, or moderator station, is programmed to regulate the time of the presentation. The slave station, or remote station, displays the remaining time of the presentation for the speaker to see. Using the system will decrease the likelihood of a speaker overrunning his/her allotted time and help the conference stay on schedule. A speaker timing system is necessary because adhering to the time schedule will improve the efficiency of the conference. Overall, this project will help the WPRC run more smoothly.

2.2 Client Needs

The needs of the client that initiated this project are divided into three categories. Below is a list of the client’s needs:

- Functionality
Two identical units, each consisting of a master station controlled by the moderator and a remote station in front of the speaker
- Session length and warning times programmable at master station
- Time indicator/warning lights on both stations
- System suited for dual conference sessions
- Stand alone units
- Usable at alternate conference locations

Communication
- Wireless communication between the master and slave stations
- Communication range to up to 50 feet between the master and slave stations
- Synchronized time-of-day clocks on both master stations to display the time-of-day to the moderator. The clocks are synchronized to the standard WWVB signal

Physical
- Economical System
- Long Product Life
- Durable and Rugged
- Compact, Lightweight, and Portable Size
- Powered by 120 volts AC

2.3 Constraints

The constraints for the speaker timing system are listed below:

- Budget - Sponsor would like to build each station for $300.
- Time - Deadline of completion is October 13, 2006.
- Station Size - Master Station is approximately 12x8 inches; remote station is approximately 6x8 inches.

2.4 Specifications

The specifications for the speaker timing system are listed below:

- Product life >= 20 years
- Durability – can withstand 4 ft drop
- Unit price <= $600
- Wireless Communication range >= 50 ft
- Master clock synchronized to GPS or WWVB
- Remote station base area <= 48 in^2
- Master station base area <= 96 in^2
- Master/slave weight <= 5 lb
- Acceptable power supply - standard 120 VAC power outlet
- Time counter accuracy >= 1ms
• Time to program \(\leq 1\) minute

2.5 Objective and Deliverables

The objective of this project was to provide the WSU Center for Distance and Professional Education with a speaker timing system by October 13, 2006. We performed research that confirmed the feasibility of the speaker timing system. The speaker timing system has been designed, built, and tested to meet the specifications listed in section 2.4, with the exception of the durability specification, “able to withstand a four foot drop”. We were not able to perform the calculations and design the housing in order to allow a station to withstand a four foot drop.

In addition to providing the speaker timing system, we have provided technical documentation and an operating instruction manual. The following is a list of items that we delivered to the WSU Center for Distance and Professional Education:

• Two speaker timing system units. Each unit consists of a master station and a slave station.

• Technical documentation that includes specifications, wiring diagrams, schematics, pictures, and source code.

• Operating Instruction Manual with detailed instructions on using and programming the speaker timing system.

3.0 CONCEPTS DEVELOPMENT

The speaker timing system design includes electrical and mechanical aspects. The electrical aspects include the microcontroller, time-of-day clock, LED lights, LCD display, 7-segment display, wireless transmitter/receiver, power conversion, and user interface. The mechanical aspects include the housing unit to encase the electrical components.

3.1 Microcontroller Selection

We have selected the Rabbit 2000 microcontroller to control the master and slave stations. The microcontroller comes with a development kit which includes a prototype board. The advantage of using the Rabbit 2000 microcontroller and development kit is:

• It will perform all the necessary functions to control the speaker timing system.

• It is known and used at the University of Idaho so we will be able to obtain assistance from professors and graduate students.
• The development software for the processor is already installed on the computers in the Engineering lab at U of I.

• The prototype board can be used as the main board for each station.

• The cost is reasonable ($169).

3.2 Wireless Transmitter/Receiver Concepts Considered

The master and slave stations will communicate via a wireless serial link. The wireless options that have been considered are transparent. This means that, to the master and slave, they will appear as a wire. Using this kind of wireless allows us to utilize the serial libraries of the Rabbit microcontroller to communicate with the slave station. This will help keep development time down.

Three different options have been considered for use for wireless transmission. All three of the options are OEM components that can be soldered on to the board. The first option, the Sena unit, uses Bluetooth technology for wireless communication. This is a 2.4GHz technology which has potential for interference with WI-FI networks in the hotel. The second option is the XBee ZigBee RF module from MaxStream. This is a low cost low power serial-to-wireless module that operates in the 2.4GHz range. The XBee also has the WI-FI interference issues. Its main advantage is cost, as it comes in at $19 a module whereas the Sena comes in at $55. The third option is also from Maxstream and is the XCite RF module. The XCite module operates in the 900 MHz range and has less chance for interference. However, the cost is about twice that of the XBee module at $40 a module. All of these units will require zero-configuration by the end user.

3.3 Wireless Transmitter/Receiver Concepts Selection

At the conference, the communication between the master and slave stations must have very little-to-no interference. Since the XCite module operates at 900 MHz, it has less chance for interference; therefore, we have selected the XCite RF module for the wireless solution.

3.4 LCD Concepts Selection

The LCD we have selected will be attached to the master terminal. It is 4 lines in width and 20 characters in length. The LCD will display a list of the timing parameters that the moderator can programmed. During the presentation, it will display the countdown timer. The LCD has a backlight for easy view ability in all lighting conditions.

3.5 7-Segment Display Concepts Selection
The 7-segment display is attached to the slave station to display the countdown timer. Each display is green and 2 inches tall to enable the speaker to easily see the countdown timer in most lighting conditions. Five displays are needed to make a reasonable size counter (up to 9 hours, 59 minutes, and 59 seconds).

3.6 User Interface Concepts Considered

The moderators will need to quickly learn how to use the speaker timing system and accurately program the presentation length and the warning times into the master station. Therefore, the user interface will be intuitive and user friendly. We have considered two design options for the user interface. Both options will include a Start/Send feature to begin the countdown timer and a Stop/Reset feature to stop the countdown timer and reset the system.

Option 1: Numbered Keypad
The first option is to use a numbered keypad. The numbered keypad is an easy way to enter timing information. The moderator will enter the presentation length and warning times in an hhmms format. These parameters will be displayed in the LCD window so the moderator can make sure they are correct.

Option 2: Arrow Keys
Arrow keys will be used to select timing parameters from a menu that need to be programmed. This is done by using the arrow keys to scroll and select the appropriate number of time. Using the arrow keys will take longer to program the timing parameters and will also be more difficult to learn when learning to program the master station.

3.7 User Interface Concepts Selected

The numbered keypad option will be much easier and faster for a moderator to program timing information into the master station. Although more buttons will be required to connect to the circuitry, it will be a more user-friendly product.

3.8 Power Conversion Concepts Selection

Each station will be powered by a wall transformer that plugs into a standard 120 VAC power outlet. A wall transformer will step down the voltage and rectify the AC into DC. These units deliver a rated voltage at a rated current load. The benefits of using a wall transformer are as follows:

- They offer electrical isolation from the power outlet. This greatly increases electrical safety for both the user and the hardware.
- The physical space and weight required for a power adapter is taken out of the master/slave station, which enables them to be smaller and lighter.
• The DC voltage required by the subsystems in the master/slave stations is directly delivered.

The trade-off with the wall transformer is that the majority of economical units have little-to-no voltage regulation. This means that the output voltage varies with the current load. In order to fix this problem, a simple regulator circuit needs to be implemented. The circuit that will be used is a voltage regulator IC with filter capacitors at the input and output of the IC. This circuit provides low noise, low voltage ripple, and a constant voltage level that is independent of load. Additional voltage levels can be acquired by adding additional voltage regulator ICs. Figure 1 shows a typical regulator circuit where the DC input voltage is taken from the output of a wall transformer.

![Figure 1: A Typical Voltage Regulator Circuit.](image)

3.9 Current Time Clock Concepts Considered

To allow the master station to be synchronized to the current time, a clock will be installed into the master station that will be viewable to the moderator. This will allow the moderator to begin the presentations on time. Below are the types of clocks considered:

**Option 1: Radio-Controlled Clock**

A radio-controlled clock contains a miniature radio receiver that is permanently tuned to receive a 60 KHz radio signal. The signal is broadcast from the NIST Radio Station WWVB which is located near Fort Collins, Colorado. The signal includes a time and date code. When the clock receives and decodes the signal, it will synchronize its own clock to the radio signal, thus ensuring the clock has the current time.

There are two alternatives for the radio controlled clock. The first alternative is to purchase separate components to build the clock and integrate it with the microcontroller in the master station. Pictures of the parts for the clock are shown in Figure 2:
There are three components for a radio-controlled clock: the decoder, antenna, and receiver. The advantage of having the clock integrated into the main microcontroller is the countdown timer may be more accurate. The disadvantage is that these components are prohibitively expensive. Also, the antenna would stick out of the housing unit, which would cause the system to be less durable.

The second alternative is to purchase a commercially-made radio-controlled clock and install it in each master station. Figure 3 shows a picture of a radio-controlled clock.

The advantage of the commercial-made radio-controlled clock is they are inexpensive, costing about 8 times less than alternative 1. In addition, the circuitry is already built and tested, including the display. However, there are two disadvantages. The first disadvantage is power regulation. Small clocks like the one shown in Figure 3 run on batteries so we would need to integrate the clock into the power supply of the master station or build a battery holder in the housing to hold the battery. The second disadvantage is the length of time it takes to receive the WWVB signal and synchronize the current time. Sometimes, it may take overnight for the clocks to synchronize with the WWVB signal.
Option 2: GPS
GPS clocks use the satellites orbiting the earth to synchronize the time. The advantage of GPS clocks is the time is more accurate than radio-controlled clocks. The disadvantage is they are prohibitively expensive and they do not work very well (or not at all) inside buildings. Most systems that use GPS timing inside a building have a GPS server that gets the timing signal from a satellite dish that is installed on the roof of the building. The server then sends a signal to all the GPS clocks to synchronize the time. The GPS clock for the speaker timing system is not feasible.

3.10 Current Time Clock Concepts Selection

The selection of the clock was based primarily on price. The GPS clock is not feasible for the speaker timing system because of the high cost. The commercially built radio-controlled clock is the best choice to install in the master station.

3.11 Housing Enclosure Boxes Concepts Selection

Since no one on the team is a mechanical engineer, we will consult with the ME department to determine the best means to obtain solid and sturdy enclosures to house the electrical components. The material will be of such so that the signal from the wireless transmitter/receiver will be able to pass through with no degradation in signal strength. Also, the WWVB signal will need to transmit through the material in order to update the clock. Since we need the stations to be light, durable, and portable, housing for the stations will be made from a strong plastic. We have contacted the ME shop and they have agreed to help us design and/or make enclosure boxes.

4.0 PRODUCT DESCRIPTION

4.1 System Components and Design Plan

The system components for the master station include the following:
- microcontroller and prototype board
- liquid crystal display (LCD)
- keypad, keypad encoder IC, oscillator
- wireless transmitter/receiver
- three LED’s for indicator/warning lights (red, yellow, green), n-channel mosfets

The system components for the slave station include the following:
- microcontroller and prototype board
- 5-digit 7-segment display, voltage regulator, driver IC, inverter IC, n-channel mosfets
- wireless transmitter/receiver
• three LED’s for indicator/warning lights (red, yellow, green), n-channel mosfets

The system design block diagram for the system is shown below in Figure 4:

![System Design Block Diagram]

**4.2 Electrical Components**

**4.2.1 Microcontroller**

The Rabbit RCM 2000 microcontroller/prototype board is the key electrical component controlling the speaker timing system. There is a microcontroller/prototype board in both the master and slave stations. The master microcontroller interprets the input signals
from the keypad and displays them on the LCD. It controls the countdown timer and the on/off sequence of the LED’s. The microcontroller of the master station communicates to the microcontroller of the slave station through the wireless transmitter/receiver to control the 7-segment display counting down and the indicator/warning lights on/off sequence.

The prototype board is the main board of the system. All the components are attached to the prototype board in order to communicate with each other.

4.2.2 Wireless Transmitter/Receiver

The Maxstream 9XCite RF wireless module provides a low-cost, low-power method for reliable wireless communication between the master and slave station. It is smaller than a credit card and fits perfectly on the prototype board (see Figure 6). It transmits at 900 MHz which is perfect in areas where there is a multitude of electronic equipment; 900 MHz is usually well below the frequency range of modern electrical equipment such as laptops, cell phones, PDA’s, etc. thus minimizing interference. The range of the module is approximately 300 feet indoors. The module is installed in each station.

4.2.3 Liquid Crystal Display (LCD)

A 4 line, 20 character liquid crystal display (LCD) displays the menus to enable the user to program the presentation length and warning times. When the master station is powered on or rebooted, the LCD displays a menu screen to guide the user in
programming the presentation length and warning times. During the presentation, the LCD displays the countdown timer and options to pause, restart, reboot, or stop the timer. In addition, the LCD has a backlight that is always on for viewing in low light conditions. To control the contrast of the backlight, a 5-volt potentiometer is attached to the LCD (see Appendix B).

![Figure 8: LCD](image)

### 4.2.4 7-Segment Display

For the slave station to display the countdown timer, five 7-segment display digits were used. The display allows a presentation length of 9 hours and 59 minutes. Each digit is 2.3 inches high and green to enable easy viewing of the countdown timer from moderate distances and angles. When the countdown timer reaches 0.00.00, the left most digit turns into a dash and the counter counts up to 59 minutes and 59 seconds (-59.59). Figure 9 shows the front of the display.

![Figure 9: Front Side of Display](image)

To allow enough power to turn the segments on, a positive 10 V voltage regulator was used to regulate the power to the segments. A driver IC chip was needed to drive the segments. However, the driver IC chip is active high whereas the 7-segment display is active low; therefore, an inverter chip was used to invert the logic level. In addition, N-channel mosfets (60 V, 200mA) were used in the construction of the display. The mosfets act as “on-off” switches (determined by the voltage level applied) to regulate current flow to each segment at the appropriate time in order to turn the segment on and off.

### 4.2.5 User Interface (Keypad)

A 16-button, 2X8 matrix keypad is used for the interface between the operator and the microcontroller. The keypad allows the user to enter the presentation length and warning
times into the microcontroller. If a mistake is made while entering the times, the CLEAR button can be pressed to clear the entry. After each entry, the ENTER button is pressed to program that information into the microcontroller. All buttons except the arrow keys, the 2nd key, and the Help key are functional.

To interface the keypad to the microcontroller, a keypad encoder chip and a 4 MHz oscillator were used. The encoder provides enhanced keypad features such as contact debouncing and key auto-repeat in an easy-to-use package that lowers the software overhead in the microcontroller; the encoder also reduce the I/O pin requirements from eight to one. In addition, the encoder is electrically quiet; in other words, it does not radiate EMI noise from its wires leading to the keypad. This is achieved by only monitoring the keypad with unchanging signals, and scanning only once each time a key press is detected. The oscillator is needed by the encoder IC for serial communication. Figure 10 shows the keypad, encoder IC, and oscillator.

![Figure 10: Keypad, Encoder IC, Oscillator](image)

In Figure 11, the encoder IC chip and oscillator have been wired and attached to keypad. They were then attached to the prototype board and microcontroller, as shown in Figure 11.

![Figure 11: Keypad, Encoder IC, and Oscillator Wired Together & Attached to the Prototype Board](image)

4.2.6 LED for Warning Lights

The LED’s are used for the indicator/warning lights. The green light is on during the presentation, the yellow light turns on when the first warning time is reached, the yellow light blinks when the second warning time is reached, and the red light turns on when the timer reaches zero (only one light is on at a time). The red light will stay on until the user stops the timer. To drive the LED’s, n-channel mosfets (60 V, 450 mA) are used as
“on-off” switches (determined by the voltage level applied) to regulate current flow; thereby turning the LED’s on and off. Figure 12 shows the LED’s.

![LED’s for the Indicator/Warning Lights](image)

**Figure 12: LED's for the Indicator/Warning Lights**

### 4.2.7 Power Conversion

Power is crucial for the systems to work. Not only is power needed, the right type and amount of power is needed for the systems to work well. To function, each station is connected to a 120 VAC wall outlet. The power coming from the wall is AC power, whereas the system only uses DC power. Therefore, the AC power needs to be converted to DC power. After AC-to-DC conversion, the DC power must be converted down to a level that each component can safely use without overheating or burning out.

To accomplish the power conversion, a “wall-wart”, or power adapter plug, is used (it comes with the microcontroller development kit). The adapter converts the 120 VAC to 12 VDC. A 5V regulator is built in the prototype board and distributes the power to each component, as needed.

The 5-digit 7-segment display needs more power than the 5V that the prototype board supplies. Therefore, a 10V regulator was installed on the display and the power adapter was wired directly to the regulator. Each segment of the display gets the energy they need to turn on and off. Figure 13 shows the power adapter and where it plugs into the station.

![Power Adapter and Plug-In to Station](image)

**Figure 13: Power Adapter and Plug-In to Station**
4.2.8 Current Time Clock

The current time clock is a radio-controlled clock that is tuned to the 60 kHz WWVB time signal. When the signal is received, the clock will automatically synchronize itself to the correct time. Once the time is updated, the internal clock will keep the time. Unfortunately, the clock may take a long time to receive the timing signal (sometime overnight); therefore, the time can be manually set (this is usually necessary when the clock is powered on). To minimize the number of times the clock has to power on and search for the signal to synchronize the time, one AA battery is installed in the clock. Using the battery allows the clock to always be on and to continually search for the time signal. Thereby, the time is always accurate.

The clock includes a backlight for viewing the time in the dark. The light is turned on by a switch, which is installed below the clock. To turn the light on, slide the switch to the right; to turn the light off, slide the switch to the left. The clock also includes an alarm. For more information on the alarm, see Appendix A.

![Figure 14: Radio-Controlled Clock](image)

The battery will need to be replaced approximately once a year. Figure 15 shows the battery compartment. For additional information to change the battery, see Appendix A.

![Figure 15: Battery Compartment on the Back of the Master Station](image)
4.3 Mechanical Components

4.3.1 Housing Enclosure Boxes

The housing enclosure boxes are high-impact ABS molded enclosures that meet NEMA 4X specifications. The material of the boxes allows the wireless signal and timing signal to easily pass through. The body/cover has a UL94-HB flammability rating with a suggested service temperature of 0 to 80 degrees Celsius.

The boxes for the master and slave stations are all the same size (10.43 inches wide, 7.28 inches deep, and 3.74 inches high). Each box has a smooth, flat cover that is attached by M-4 stainless steel, non-magnetic screws and fastens into threaded brass inserts. A gasket (EPDM material) is inserted between the cover and box for a good seal.

4.4 Functionality of the Speaker Timing System

The master station consists of a keypad, a display window for the countdown timer (LCD), current time clock, and three Light Emitting Diodes (LED’s) for indicator/warning lights. The presentation length (hours: minutes: seconds) and two warning times are programmed by the moderator at the master station. The current time clock is a radio-controlled clock that is automatically updated by a 60 kHz WWVB radio signal. This will effectively synchronize the two master stations to the current time-of-day. The slave station consists of a 5-digit 7-segment display for the countdown timer and three LED’s (red, yellow, green) for indicator/warning lights.

When the presentation begins, the moderator presses a button to begin the countdown timer. At that time, the master station transmits the presentation length and the warning times to the slave station. Both stations begin to countdown simultaneously. The microcontroller in each station uses its own timer to control the speed of the countdown timer. When the presentation is started, the green LED turns on (LED’s are visible on both stations). When the first warning time is reached, the green LED turns off and the yellow LED turns on. When the second warning time is reached, the yellow light blinks on and off. When the countdown timer reaches zero, the yellow LED turns off and the red LED turns on. The red light stays on until the moderator stops the timer.

Once the presentation begins, the master and slave stations do not communicate with each other until the ENTER button is pressed; the ENTER button will pause the countdown timer. After the system pauses, the moderator can choose to resume, restart, reboot, or stop the countdown timer.

4.4.1 System Functionality Flow Chart

The flowchart in Figure 16 shows the functionality of the system:
Figure 16: System Functionality Flow Chart

1. Power On Initialization
   - After 2 seconds
   - Press #
     1-30 min 2-40 min 3-1 hr 4-Custom 1.5-50 min Warning

2. Time Remaining 0:30:00
   Press ENTER to Start

3. Time Remaining 0:40:00
   Press ENTER to Start

4. For Selection 1 and 3: Warning Time 1 = 5 minutes Warning Time 2 = 1 minute
   For Selection 2: Warning Time 1 = 10 minutes Warning Time 2 = 5 minutes
   Enter Warming Time
   Then Press ENTER
   CLEAR Pressed
   hours: 0-9
   minutes: 01-59

5. Enter Warming Time
   Press ENTER
   CLEAR Pressed
   minutes: 01-59

6. Enter Warming Time
   Press ENTER
   CLEAR Pressed
   minutes: 01-59

7. Enter Warming Time
   Press ENTER
   CLEAR Pressed
   minutes: 01-59

8. Time Remaining 0:00:00
   Press 1 to Resume
   Press 2 to Restart
   Press 3 to Reboot
   Press 4 to Stop

9. STopped
   0:29:29
   Press 1 to Restart
   Press 2 to Reboot
4.4.2 Programming the System

Here is an example of how the speaker timing system functions, given a presentation length of 40 minutes.

1. When the master station is powered on, it will initialize and display the **Main Menu** screen:

```
Press #,
1-30min  2-40min
3-1hr     4-Custom
1, 3: 5/1min warning
```

2. The moderator, or user, presses the #2 key and presses **ENTER**. The **Time Remaining** screen is displayed:

```
Time Remaining
0:40:00
Press ENTER to Start
```

*Warning Time 1 is ten minutes and Warning Time 2 is five minutes.*

3. Press **ENTER** and the countdown timer begins to count downward and the green light turns on.

```
Time Remaining
0:39:59
Press ENTER to Pause
Restart, Reboot, Stop
```

4. When the countdown timer reaches *Warning Time 1* (ten minutes remaining), the green light turns off and the yellow light turns on.

```
Time Remaining
0:10:00
Press ENTER to Pause
Restart, Reboot, Stop
```
5. When the countdown timer reaches *Warning Time 2* (five minutes remaining), the yellow light blinks on and off.

6. When the countdown timer reaches 0:00:00, the yellow light turns off and the red light turns on. The countdown timer will now count upwards so the speaker knows the amount of time he/her went over.

7. When the speaker ends their presentation, the moderator presses **ENTER** to pause the timer.

The moderator can then choose to *resume*, *restart*, *reboot*, or *stop* the countdown timer. When *reboot*, *restart*, or *stop* is pressed, the lights turn off and the countdown timer resets. If *resume* is pressed, the timer continues counting where it left off (the light do not change).

For more detailed instructions, see Appendix A.

5.0 PRODUCT EVALUATION

The speaker timing system has many components that must work seamlessly together. However, before a component can work with other components, it must work with by itself, with no other component attached to it. While the speaker timing system was being built, components were individually tested. As components were being wired to other components, they were tested. When the system was finished, it was tested. Testing was ongoing while the system was built. Below is the process of how we tested the components and entire system.
5.1 Microcontroller Testing

The operating system of the microcontroller is what allows the user to enter timing parameters with the keypad and be displayed on the LCD. The operating system controls the microcontroller to turn on and off the lights of the LED’s, transmit information to the slave, and turn on and off the 7-segment display segments; it links everything together. After the separate components were wired and tested using a multimeter, power source, and/or an oscilloscope, they were attached to the microcontroller. Test code was written to determine if the microcontroller could control the component. The test code is in Appendix C.

5.2 Wireless Transmitter/Receiver Testing

The wireless communication was tested throughout the construction of the project. First, only the microcontroller and wireless module were tested. Test code (Appendix C) was written to have the master station send commands to the slave station. A PC monitor was used for the countdown timer display for each station. When the LCD and keypad were attached to the master station, the wireless was again tested to determine if commands entered by the keypad were being communicated to the slave station. When the 5-digit 7-segment display was constructed, the wireless was again tested to determine if the master station was sending the correct information to the slave station for the display to correctly function as a countdown timer. It was critical that the master and slave station seamlessly communicated with each other.

After both units (Unit A and Unit B) were built, we tested to ensure that Unit A did not talk to Unit B. We also ensured that the master station of both units could communicate with their respective slave station (and only their slave station) from up to 50 feet away.

5.3 LCD Testing

Before the keypad was wired, a computer keyboard acted as the keypad. This was used to test if key presses would be displayed on the LCD. Test code was written to perform the tests (Appendix C). Figure 17 shows a message that was sent by the keyboard on the computer and displayed on the LCD; the keypad is not attached.

Figure 17: LCD Displays Test Message
After the keypad was wired and attached to the prototype board, it was used to send signals to the LCD. Figure 18 shows the LCD displaying data entered with the keypad.

![Figure 18: LCD Being Tested with Keypad](image1)

### 5.4 Keypad Testing

The keypad, encoder chip, and oscillator were wired together, attached to the microcontroller and tested using an oscilloscope. When a key was pressed, its signal would display on the oscilloscope. In this way, we could see if the keypad was working before we wrote the test code. Figures 19 shows the keypad being tested using the oscilloscope.

![Figure 19: Testing Keypad with Oscilloscope](image2)

Next, the LCD was attached to the keypad. Test code was written to determine if key presses would be sent to the LCD (see Appendix C). Also, code was written to only enable certain buttons to work (numbers 0-9, ENTER, and CLEAR).

### 5.5 7-Segment Display Testing

The 7-segment display for the slave station was first designed and built on a breadboard. This was accomplished by wiring a single 7-segment display (digit) to the breadboard along with the voltage regulator and driver IC chip. A power source was used to supply...
power. When the power was turned on, the light on the display was very low. We discovered that the driver chip was active high; however, the 7-segment display was active low. Therefore, the full voltage wasn’t getting to the segments. To solve the problem, an inverter chip was wired to the driver IC chip. The inverter chip “inverted” the output signals from the driver IC chip so that the segments would get the amount of voltage they needed to turn on brightly. Figure 20 shows the single digit wired to the breadboard.

![Figure 20: Testing Single Digit Display](image)

After the single digit worked, the rest of the digits were wired to the breadboard. Unfortunately, the digits were very dim. It was found that the ground wires from the separate displays were not wired to the same ground, thereby causing a weak signal. Once the grounds were wired to the same ground (to the prototype board), the display lit up nicely.

Next, the microcontroller was attached to the display. Test code was written for the microcontroller to send voltage to certain segments at certain times to form numbers. The test code can be viewed in Appendix C. Figure 21 shows all ten digits wired to the breadboard and to the microcontroller. The left-most digit is turned on.

![Figure 21: Testing All Displays](image)
When testing with the breadboard was complete, the driver IC chip, inverter chip, and voltage regulator were wired and soldered together on a mounting board (see Figure 22).

![Figure 22: Display Driver, Inverter, & Voltage Regulator Wired Together](image)

The chips were tested by using a power source, oscillator, and multimeter to ensure that correct voltage levels were being outputted.

Next, the 7-segment displays and mosfets were attached to a mounting board and wired and soldered together as shown in Figure 23.

![Figure 23: Front Side of Display (with Mosfets)](image)

The board with the driver IC chip, inverter chip, and voltage regulator was then attached to the back of the mounting board of the display as shown in Figure 24.

![Figure 24: Back Side of Display](image)

The last step involved attaching the display to the microcontroller. Test code was used to determine if the microcontroller could control the display. The test program “told” the
display to turn on and off certain segments to form numbers, as shown in Figure 25. The test code is in Appendix C.

Figure 25: Testing Display with Microcontroller

5.6 LED (Warning Lights) Testing

LED’s were wired on a breadboard and attached to a power source and multimeter. Voltage was applied to each node to turn on and off the lights.

Next, the LED’s were attached to the microcontroller. Test code was written for it to turn the lights on and off, as shown in Figure 26.

Figure 26: LED’s Being Tested with Microcontroller

Lastly, the LED’s were wired and soldered on permanent mounting boards. The LED’s were again tested with the microcontroller, using the test code.
5.7 Testing Entire System

When the components were all wired together, they were tested to make sure they still functioned properly. In Figure 27, the components are being tested together before they are installed in the enclosure boxes.

![Figure 27: Components Being Tested Before Assembly](image)

In Figure 28, the components have been installed in the enclosure boxes. However, before the boxes were sealed, the components were tested again.

![Figure 28: Components Being Tested After Assembly](image)
Finally, as shown in Figure 29, the enclosure boxes are sealed and the entire system was tested.

Figure 29: Speaker Timing System (Both Units)

Once the stations were complete and fully assembled and tested in the lab, they were tested in multiple locations. The system was:

- tested in a large auditorium that was empty,
- tested in a large auditorium that was full of people with all sorts of electronic devices,
- tested to ensure the master and slave stations could communicate from 50 feet apart,
- tested to determine how easy it was to use,
- tested to ensure that Master Station A did not talk to Slave Station B; also tested to ensure that Master Station B did not talk to Slave Station A, and
- tested at the conference center.

6.0 ECONOMIC ANALYSIS

Funding for the Speaker Timing System came from two sources: $1000 from WSU and a $750 grant awarded by the University of Idaho Electrical Engineering department. As shown in the budget, U of I purchased two of the four microcontroller development kits; an agreement was made that WSU would get the kits, but U of I would keep all the licenses for the software.

Below is an analysis of the costs of the system. The analysis includes a budget and the per-unit costs of the system. A bill of materials, that includes the vendor locations, is in Appendix F.

6.1 Budget

The total budget for the Speaker Timing System project is $1750. Table 1 shows a detailed budget from WSU and U of I. The table shows all the items that were purchased for the system and which budget the money was taken from. The remaining money available is also listed.
Table 1: Budget

<table>
<thead>
<tr>
<th>Item/Model #</th>
<th>Quantity</th>
<th>Total Cost</th>
<th>Shipping + Tax</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ordered by WSU</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCM2000 RabbitCore Development Kit</td>
<td>2</td>
<td>$338.00</td>
<td>$22.00</td>
<td>$360.00</td>
</tr>
<tr>
<td>Standard 4 X 20 Backlit LCD Module</td>
<td>2</td>
<td>$85.36</td>
<td>$17.45</td>
<td>$102.81</td>
</tr>
<tr>
<td>7-Segment LED Super Green single 2.3</td>
<td>10</td>
<td>$58.90</td>
<td>$5.85</td>
<td>$64.75</td>
</tr>
<tr>
<td>Wireless Transmitter/Receiver Module 900MHz</td>
<td>4</td>
<td>$160.00</td>
<td>$20.00</td>
<td>$180.00</td>
</tr>
<tr>
<td>Atomic Alarm Clock</td>
<td>2</td>
<td>$25.90</td>
<td>$5.95</td>
<td>$31.85</td>
</tr>
<tr>
<td>10mm Jumbo LED: Red, Yellow, Green</td>
<td>30</td>
<td>$7.00</td>
<td>$10.67</td>
<td>$17.67</td>
</tr>
<tr>
<td>N channel Mosfet (450 mA)</td>
<td>20</td>
<td>$14.80</td>
<td>$5.95</td>
<td>$20.75</td>
</tr>
<tr>
<td>16 Button Keypad</td>
<td>2</td>
<td>$26.50</td>
<td>$7.00</td>
<td>$33.50</td>
</tr>
<tr>
<td>Enclosure Boxes</td>
<td>4</td>
<td>$116.40</td>
<td>$10.00</td>
<td>$126.40</td>
</tr>
<tr>
<td>N-Channel Mosfets (200 mA)</td>
<td>110</td>
<td>$26.91</td>
<td>$5.66</td>
<td>$32.57</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$859.77</td>
<td>$110.53</td>
<td></td>
<td>$970.30</td>
</tr>
<tr>
<td><strong>U of I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCM2000 RabbitCore Development Kit</td>
<td>2</td>
<td>$338.00</td>
<td>$22.00</td>
<td>$360.00</td>
</tr>
<tr>
<td>10 V Positive Regulator Chip</td>
<td>5</td>
<td>$4.05</td>
<td>$13.30</td>
<td>$17.35</td>
</tr>
<tr>
<td>Keypad Encoder IC Chip</td>
<td>3</td>
<td>$22.50</td>
<td>$7.00</td>
<td>$29.50</td>
</tr>
<tr>
<td>7-Segment Display Driver IC Ship</td>
<td>3</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>5V Potentiometers</td>
<td>2</td>
<td>$0.50</td>
<td>$0.00</td>
<td>$0.50</td>
</tr>
<tr>
<td>Plastic Battery Holder (AA)</td>
<td>2</td>
<td>$1.98</td>
<td>$0.10</td>
<td>$2.08</td>
</tr>
<tr>
<td>Packages of Screws</td>
<td>1</td>
<td>$28.00</td>
<td>$0.00</td>
<td>$28.00</td>
</tr>
<tr>
<td>Poster</td>
<td>1</td>
<td>$71.55</td>
<td>$0.00</td>
<td>$71.55</td>
</tr>
<tr>
<td>Travel</td>
<td>1</td>
<td>$100.00</td>
<td>$0.00</td>
<td>$100.00</td>
</tr>
<tr>
<td><strong>Total from U of I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$566.58</td>
<td>$42.40</td>
<td></td>
<td>$608.98</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1,426.35</td>
<td>$152.93</td>
<td></td>
<td>$1,579.28</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Money from WSU</th>
<th>Money from U of I</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000.00</td>
<td>$750.00</td>
</tr>
<tr>
<td><strong>Remaining Money from WSU</strong></td>
<td><strong>Remaining Money from U of I</strong></td>
</tr>
<tr>
<td>$29.70</td>
<td>$141.02</td>
</tr>
</tbody>
</table>
6.2 Per-Unit Costs

The speaker timing system includes two units, each unit consisting of a master station and a slave station. Table 2 lists the costs of each component for the master station; table 3 lists the costs for each component for the slave station. Table 4 lists the total costs for each station, the total cost for each unit, and the total cost for both units (all four stations).

NOTE: Items that have no amount are those that were donated by the College of Electrical and Computer Engineering when the system was built.

Table 2: Cost Associated with the Master Station

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCM2000 RabbitCore Development Kit</td>
<td>1</td>
<td>$ 169.00</td>
<td>$ 169.00</td>
</tr>
<tr>
<td>Maxstream Xcite OEM RF Wireless Module 900 MHz</td>
<td>1</td>
<td>$ 40.00</td>
<td>$ 40.00</td>
</tr>
<tr>
<td><strong>LCD Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard LCD Module 4 X 20 character</td>
<td>1</td>
<td>$ 42.68</td>
<td>$ 42.68</td>
</tr>
<tr>
<td>5V Potentiometer</td>
<td>1</td>
<td>$ 0.25</td>
<td>$ 0.25</td>
</tr>
<tr>
<td>6.2 ohm Resistor</td>
<td>2</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>Keypad Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-Button Keypad</td>
<td>1</td>
<td>$ 13.25</td>
<td>$ 13.25</td>
</tr>
<tr>
<td>Keypad Encoder IC Chip</td>
<td>1</td>
<td>$ 7.50</td>
<td>$ 7.50</td>
</tr>
<tr>
<td>Oscillator</td>
<td>1</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>330 ohm Resistor</td>
<td>4</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>4.7 Kohm Resistor</td>
<td>4</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>LED Components</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 mm Red Long Lead</td>
<td>1</td>
<td>$ 0.20</td>
<td>$ 0.20</td>
</tr>
<tr>
<td>10 mm Green LED Long Lead</td>
<td>1</td>
<td>$ 0.25</td>
<td>$ 0.25</td>
</tr>
<tr>
<td>10 mm Yellow LED Long Lead</td>
<td>1</td>
<td>$ 0.25</td>
<td>$ 0.25</td>
</tr>
<tr>
<td>N channel Mosfet (450 mA 60V)</td>
<td>3</td>
<td>$ 0.74</td>
<td>$ 2.22</td>
</tr>
<tr>
<td>10 ohm resistor</td>
<td>1</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>130 ohm resistor</td>
<td>1</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Lacrosse Technology Compact Atomic Alarm Clock</td>
<td>1</td>
<td>$ 12.95</td>
<td>$ 12.95</td>
</tr>
<tr>
<td>Battery Holder AA</td>
<td>1</td>
<td>$ 0.99</td>
<td>$ 0.99</td>
</tr>
<tr>
<td>Box Nema4X ABS 10.43 X 7.28 X 3.74 inches</td>
<td>1</td>
<td>$ 29.10</td>
<td>$ 29.10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>$ 318.64</td>
</tr>
</tbody>
</table>
### Table 3: Costs Associated with the Slave Station

#### Slave Station

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCM2000 RabbitCore Development Kit</td>
<td>1</td>
<td>$169.00</td>
<td>$169.00</td>
</tr>
<tr>
<td>Maxstream Xcite OEM RF Wireless Module 900 MHz</td>
<td>1</td>
<td>$40.00</td>
<td>$40.00</td>
</tr>
</tbody>
</table>

#### 7-Segment Display Components

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-Segment Display Single 2.3&quot; Green</td>
<td>5</td>
<td>$5.89</td>
<td>$29.45</td>
</tr>
<tr>
<td>N-Channel Mosfets (60V 200mA T092)</td>
<td>80</td>
<td>$0.25</td>
<td>$20.00</td>
</tr>
<tr>
<td>IC Pos Volt Reg 10V 1.5A to 220A</td>
<td>1</td>
<td>$0.81</td>
<td>$0.81</td>
</tr>
<tr>
<td>7-Segment Driver IC Chip (samples)</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Inverter Chip Motorola</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>68 ohm resistor</td>
<td>35</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>390 ohm resistor</td>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>47k ohm resistor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.1 micro farad capacitor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.33 micro farad capacitor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10 micro farad capacitor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

#### LED Components

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mm Red Long Lead</td>
<td>1</td>
<td>$0.20</td>
<td>$0.20</td>
</tr>
<tr>
<td>10 mm Green LED Long Lead</td>
<td>1</td>
<td>$0.25</td>
<td>$0.25</td>
</tr>
<tr>
<td>10 mm Yellow LED Long Lead</td>
<td>1</td>
<td>$0.25</td>
<td>$0.25</td>
</tr>
<tr>
<td>N channel Mosfet (450 mA 60V)</td>
<td>3</td>
<td>$0.74</td>
<td>$2.22</td>
</tr>
<tr>
<td>10 ohm resistor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>130 ohm resistor</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box Nema4X ABS 10.43 X 7.28 X 3.74 inches</td>
<td>1</td>
<td>$29.10</td>
<td>$29.10</td>
</tr>
</tbody>
</table>

**Total** $291.28
### Table 4: Total Unit Costs

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly Screws</td>
<td>1</td>
<td>$28.00</td>
<td>$28.00</td>
</tr>
<tr>
<td>Wire, Ribbon Cable, Solder, etc.</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td><strong>Master Station =</strong></td>
<td></td>
<td></td>
<td>$325.64</td>
</tr>
<tr>
<td><strong>Slave Station =</strong></td>
<td></td>
<td></td>
<td>$298.28</td>
</tr>
<tr>
<td><strong>Per-Unit Costs =</strong></td>
<td></td>
<td></td>
<td>$623.92</td>
</tr>
<tr>
<td><strong>2 Master Stations =</strong></td>
<td></td>
<td></td>
<td>$651.28</td>
</tr>
<tr>
<td><strong>2 Slave Stations =</strong></td>
<td></td>
<td></td>
<td>$596.56</td>
</tr>
<tr>
<td><strong>Both Units (All 4 Stations) =</strong></td>
<td></td>
<td></td>
<td>$1,247.84</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td></td>
<td></td>
<td>$1,247.84</td>
</tr>
</tbody>
</table>

**7.0 CONCLUSIONS**

All but four specifications of the speaker timing system have been met; durability, unit price, remote station base area, and product life.

- We were not able to perform the calculations in order to design the housing to allow a station to withstand a four foot drop. Therefore, the durability of the system has not been tested due to the fear of breaking the system. We do not know if it will withstand a 4-foot drop.

- The price of the master station was approximately $325 and the price of the slave station was just under $300. The average station cost was just under $315. The unit cost was approximately $625.

- The master and slave stations are the same size (10.5 inches in length, 7.3 inches in width, and 3 inches in height). The base area for all stations is 76.65 in².

- There was no way we could test how long the speaker timing system would function. However, the speaker timing system was made with high quality components and built with great care. As long as the system is taken care of and not handled roughly, or dropped, we anticipate the system to function for many years. The only maintenance that should be required is changing the AA battery for the clock approximately once a year.
8.0 APPENDICES