E-Music Performance System

Final Report

Project #6

Hans Banerjee and William Karcher

TA: Kevin Bassett

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Abstract

An electronic flipfolder has been designed with the needs of large marching bands in mind. The e-reader device can store thousands of pages of sheet music on an SD card, and displays it on a 7” TFT display. Page turning in-performance is accomplished through pushbuttons, saving time over flipping pages. Music can also be selected via an on-screen menu navigable by the buttons. The device also has an LED metronome for usage in practice. The portable device is powered by 4 AA batteries and a 9 V battery, and has a battery life of over 5 hours. Protection from the elements is provided by a plastic case. The reader device was successfully demonstrated in a football game setting. Hardware has been designed for wireless communication with a central controller and a PC, in hope of being able to send cues to musicians and transmit music files. Failure to correctly interpret the wireless signal once received prevented this goal from being realized, which we intend to remedy in the future.

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1.0 Introduction

The printing costs of flipfolders for a large marching band get out of control, and managing a large repertoire of sheet music can be difficult for a performer in a marching band setting. An e-reader suited for the marching band would solve both of these problems; no printing and the ability to easily and quickly manage a large amount of music. Also, it can be hard to hear a conductor's commands during a loud sporting event. Commands to turn to a specific page, or to play louder or softer can often be difficult to audibly convey, and would be easier to interpret if they were visual. These functions can be implemented into the device, making it more than just an e-reader and more of a complete e-music-performance system.

The major goal of the project is to make a cheap, durable e-reader device that can be easily purchased in mass quantities for marching bands. A top level block diagram for the reader unit is shown below in Figure 1. This device was fabricated by using a TFT display to display the music to the performer, and using a MicroSD memory card to store the electronic sheet music files. Wireless communications was achieved through the use of Xbee RF devices. The reader's Xbee communicates wirlessly with a transmitting Xbee, which is connected to a computer. The computer sends signals to the reader, such as a signal to turn to a particular piece of music. Finally, the reader device is enclosed in a case for protection, which is outfitted with pushbuttons for in-performance page turning and music selection, and an LED to implement a simple metronome for practice purposes. The reader is powered by 4 AA batteries and a 9 Volt battery so in the event that the batteries run out, replacements are easy to find.

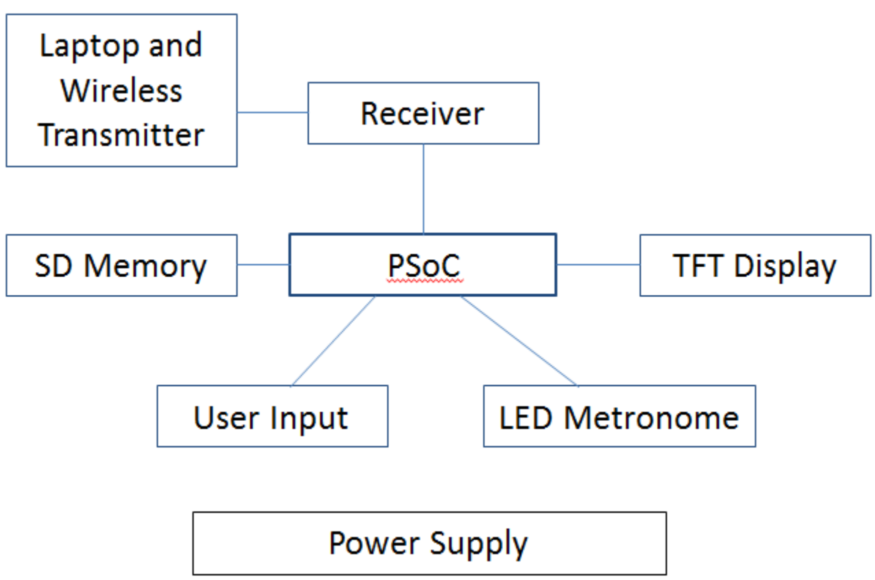

Figure 1: Reader Unit Top Level Block Diagram

2.0 Design

2.1 Reader Unit Power Supply

The power supply block supplies the PSoC, TFT display, MicroSD card, XBee, LED, and pushbuttons with a constant voltage of 3.3 V. It also supplies the TFT display backlight, an essential component to make the display readable, with 8.5 V. These interconnections are omitted in Figure 1 for neatness. The wireless transmitter receives its power from the computer and will be discussed separately. The 3.3 V supply consists of 4 1.2 V AA rechargeable batteries and a TI LM1117IDT voltage regulator. The batteries are held in a AA battery holder mounted to the back panel of the case which connects them in series and provides an on/off switch. When connected in parallel to the batteries, the voltage regulator outputs a constant voltage of 3.3±.05 V. The backlight is simply powered by direct connection to the 9 Volt battery via an on-off toggle switch. The maximum current drawn does not exceed the 1500 mA maximum rated current of the regulator, as shown below in Table 1.

3.3 V Component	**Typical Operating Current**
Display	160 mA
Receiver	50 mA
Memory	30 mA
PSoC	10 mA
User input and LEDs	20 mA
Total	310 mA

Table 1: Typical current drawn by components running on 3.3 V

Note that components such as the receiver and the user input will not be in constant use during typical operation. Thus, this is a very high estimate of current drawn. However, even under this estimate, 4 typical 1.2 V rechargeable AA batteries (Energizer NH15) providing 2500 mAh of charge [1] provide 12000 mW of power, which can run the 3.3 Volt components of the reader device for 11.7 hours, as shown below in Equation 1.

$$battery\ life = \frac{energy}{power} = \frac{4 * 1.2\ V * 2500\ mAh}{3.3\ V * 310\ mA} = 11.7\ hrs$$

Equation 1: Battery Life Calculation for AA batteries

The limiting factor on the battery life, however, is the 9 V battery. The 9 V battery only provides 600 mAh of charge, and the display backlight may use as much as 160 mA [2], thus leading to only 3.75 hours of battery life before the 9 V battery must be changed. Use of a boost converter was suggested in order for us to eliminate the 9 V battery and possibly increase battery life. However, implementing the boost converter came with many difficulties. Some were practical concerns, such as the converter being very small and hard to solder onto a PCB, and the number of passive components needed to make the converter function properly. Another was that the converter only takes voltage inputs of 2.6-4.8 V [3], meaning that it would need to be run off of the 3.3 V regulator output, leading to inefficient power conversion. A schematic of the supply system described above is shown below in Figure 2, but ultimately only the 3.3 V supply was used, and the rest of the system was replaced by the 9 V battery.

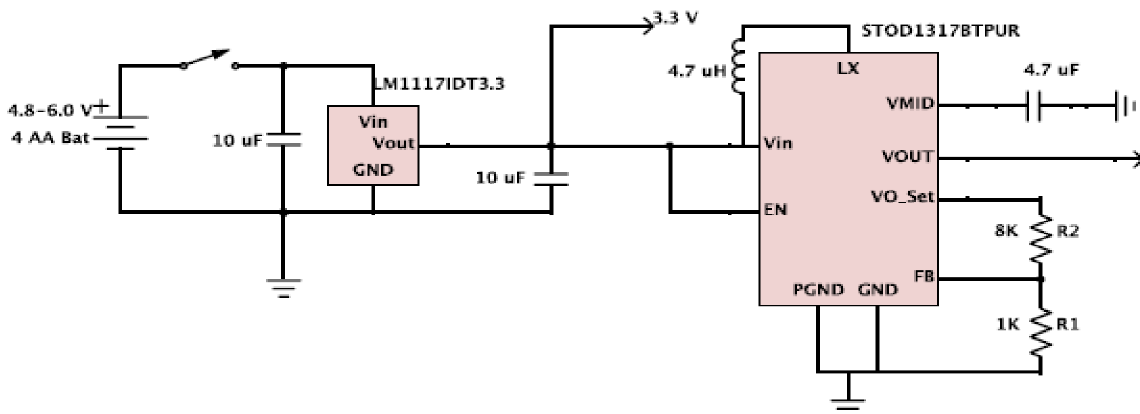

Figure 2: Initially Proposed Power Supply Schematic

2.2 PSoC Design and Software

As shown in Figure 1, the most important block in the device is the Cypress PSoC. The PSoC, a 5LP model, controls all software interfacing between the components. A pin description diagram, complete with recommended power connections, is given in the Appendix (Figure A.1) [4]. Most functions are accomplished through the 62 GPIO pins of the PSoC.

Upon instruction to display a piece of music, the PSoC must load an image off the SD card. The SD card is connected to the PSoC software through the SEGGER Microcontroller emfile library and hardware configuration in order to read the FAT32 filesystem. The file is read, checked for the correct Windows Bitmap header for a monochrome image of 800 x 480 size, and loaded into the display memory.

The DMA system provides data from the display memory to the display hardware, configured as a long series of transactions to the hardware registers' locations in the memory map. Logic signals from the display hardware keep these DMA access synced to the correct lines and pixels. Both a character overlay (for the menu system, which consumes significantly less memory) and a full-resolution bitmap are delivered to the hardware in this way.

The display hardware configuration consists of most of the work of the display block. Two PWMs generate the horizontal and vertical sync components of the generic Data Enable signal required by the display, based off of the generated display pixel clock. These two sync components are multiplied to get the Data Enable signal, and individually alert the processor when the horizontal and vertical back porches start. The display clock also runs the shift registers which shift data from the character overlay and the full-resolution bitmap out to the display (through a mux that selects between the colors in the pallette). A frequency divider creates the signal which requests each individual byte from the DMA into the shift register for every byte in the display memory.

The menu system allows user control of the device, particularly the metronome system and the displayed music. To reduce the code footprint to ensure that the existing code works as reliably as possible, the menu execution function takes a specification of the menu as its arguments, pointing to functions in other files for the effects of the menu. The idle loop in the menu is broken by either a short interrupt that is raised upon a button press (which are debounced in hardware blocks) or a command from the central controller; when leaving the idle loop, the menu system ensures the correct action is taken, whether the action referred to one of the menu buttons or a completely separate command.

The metronome is an LED controlled by a slow PWM with a short active duration, to achieve a sharp "click" in the LED. The menu system calculates and modifies the period of the metronome's PWM through the provided Cypress API for the PWM component.

Block diagrams of the software interface between the various external components and the PSoC are shown in the Appendix (Figures A.2-A.5). The raw code files are uploaded in a separate ZIP file.

2.3 SD Memory

The music files for the device to will be stored in a MicroSD card, held in a simple Molex 47219-2001 surface mounted MicroSD Card Reader. This will allow for easy loading of music files via a computer. The MicroSD card will be 4GB, so there is sufficient space to store thousands of pages of music even in uncompressed image file formats, as shown below in Equation 2. Thus, music files will be stored on the card in simple 1-bit (black/white) bitmap file format to make display of the image easier.

$$\# \, of \, pages = \frac{4 * 2^{30} * 8}{1 * 800 * 480} = 89480 \, pages$$

Equation 2: Memory Card Capacity Calculation

The MicroSD card is interfaced with the PSoC using an SPI interface system. The PSoC simply provides a Chip Enable signal, a clock, and a serial data in signal, and the memory unit will output a single data out signal back to the PSoC. The MicroSD card will be formatted using the FAT file system. All signals to and from the PSoC will be sent via GPIO pins. Hardware connections from the PSoC to the MicroSD card in SPI mode are shown below in Figure 3 [5].

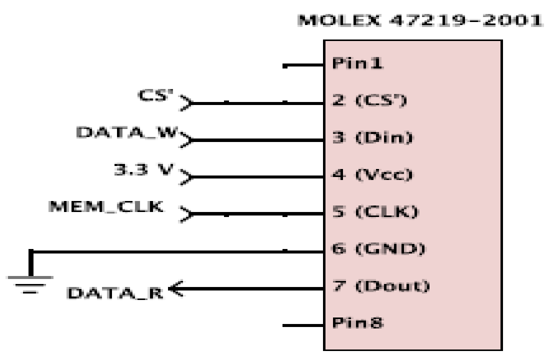

Figure 3: Schematic of PSoC to MicroSD Card Hardware Interface

2.4 Display Hardware

The display we chose is a Hantronix HDA700L-2S display. The display is a 7.0" TFT color display and has 800 x 480 pixel resolution. The size was chosen such that six to seven lines of music can be easily read by the performer, similar to a conventional flipfolder. The vertical resolution is necessary to adequately resolve the shapes and positions of musical notes (60-70 pixels per line). This display was chosen because it was the most economical display at this size and resolution, and because the display screen has an anti-glare coating to enhance sunlight readability. Monochrome displays on the market were too small or had inadequate resolution. Originally we had planned on using an E-Ink display due to its low power consumption, sunlight readability, and image stability even when powered off. However, being university students, we were unable to obtain an E-Ink display from the manufacturers at this time.

The Hantronix display has a 18 bit RGB TTL interface, but many of the RGB pins can be tied together since we only need 4 shades of gray as colors. Specifically RGB bits 5, 3, and 1 can be shorted together, and bits 4, 2, and 0 can be shorted. This turns the color display into a true 2-bit grayscale display. Although in the end we only used 1 bit grayscale, and tied those two signals together in software, the device has the ability to display 2 bit grayscale, which can sometimes help improve mage quality. Thus, the only inputs to the display unit are the two bit data output, a 30 MHz pixel clock, and a data enable signal which signifies the end of rows and frames. These inputs are sent from the PSoC via a 40 pin FFC cable and a surface mounted connector to connect the FFC to the PCB. A schematic representation of these hardware connections is shown below in Figure 4. The data input timing diagram which the PSoC implements is shown in Figure 5 [2].

The display recommends a 10 V input for the backlight. However, we discovered through empirical testing with a DC power supply that anything above 8 V provides sufficient visibility under normal lighting conditions. Thus, as stated above in section 2.1, the display backlight is simply powered by a 9 V battery.

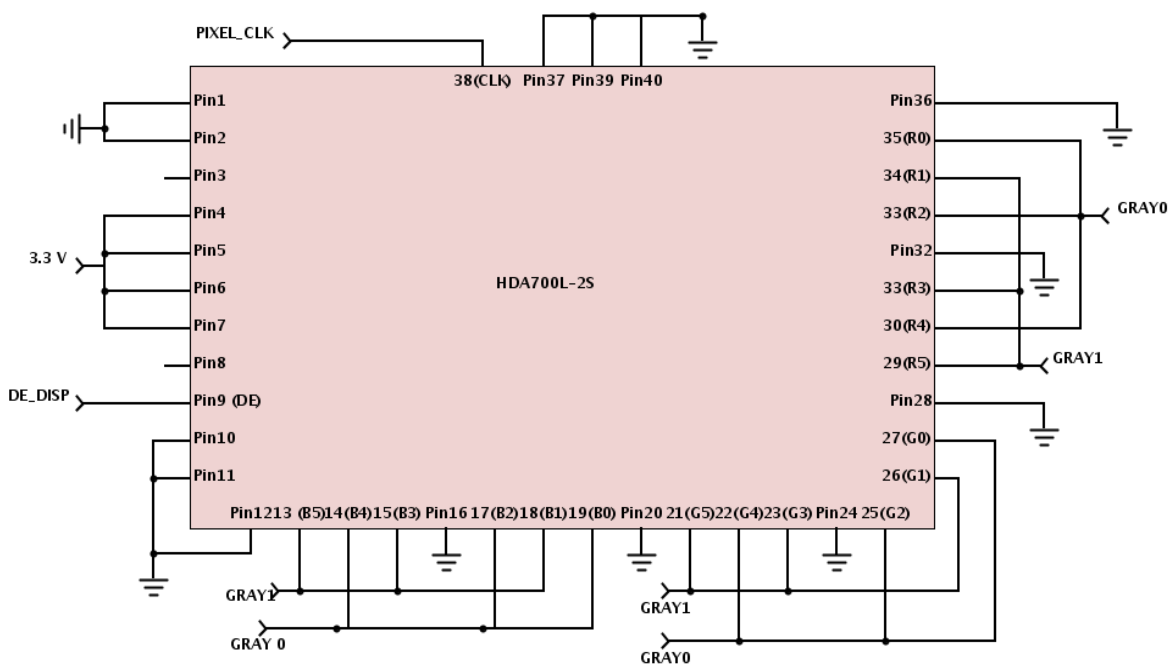

Figure 4: Display Block Schematic

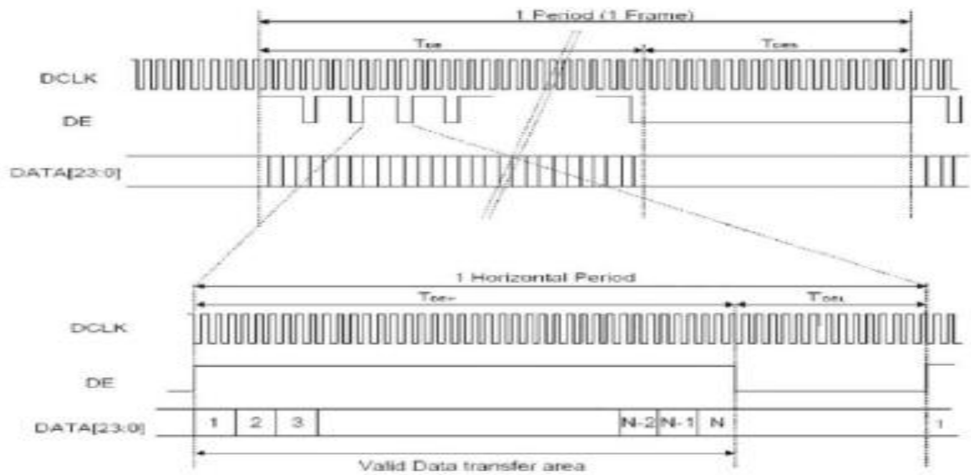

Figure 5: Display Input Timing Diagram

2.5 Receiver

The receiver unit consists of an Xbee 802.15.4 Transceiver that receives transmissions from the central transmitter. Although the receiver has a listed range of 300 feet outdoors, this is simply the transmission range of the device. Since the receiver will be operating in transparent mode, and thus not sending anything back to the transmitter, the transmission range does not matter so long as the receiver is within the transmission range of the central transmitter. The receiver operates at 2.4 GHz and at a data rate of 9600 baud. The receiver will be operating in transparent mode. The transmitter works with the UART serial protocol. The DMA capabilities of the PSoC allow data to be taken into the microprocessor one byte at a time. Special key bytes will signal the microprocessor to read from memory, write to memory, or display received text to the screen. The microprocessor can also be signaled to enable the metronome at a given rate.

2.6 User Input and LED Metronome

The user input system consists of 5 simple tactile switches wired to GPIO pins of the microprocessor. The buttons are wired with 10 kΩ pull-up resistors, making the pushbuttons active-low. The button inputs are debounced via a standard software library function provided by Cypress. These buttons will give the user the ability to turn to the next page of music (or the previous page), set the metronome, and navigate music management menus.

The metronome will be an LED driven from a PSoC SIO pin through a sink configuration, as shown below in Figure 6. The SIO pin can handle 30 mA of sink current, which is more than enough to illuminate an LED. A 50 Ω resistor is put in series with the LED to ensure that the current does not exceed 30 mA, as shown in Equation 2. The SIO pin will be controlled via a

PWM programmed into the PSoC through the Cypress PSoC creator software. The frequency of the metronome can be controlled through the use of the user input pushbuttons.

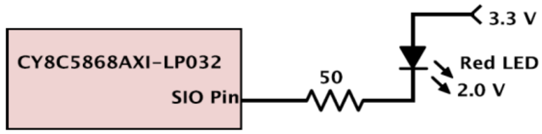

Figure 6: LED Metronome Schematic

$$I = \frac{V}{R} = \frac{3.3\,V - 2.0\,V}{50\,\Omega} = 26\,mA$$

Equation 3: LED Current Calculation

2.7 Final Assembly and Casing

All the blocks are connected together via the PSoC and a printed circuit board (PCB). The final schematic and board layout are included in the Appendix (figures A.6 and A.7).

The case for the reader unit is a clear polyethelene case, chosen to protect the display and other electronic components. The display is mounted on the front panel of the case, while the assembled PCB and the holders for the AA and 9 V batteries are attached to the back cover. The five pushbuttons are mounted on the left side of the unit to create easier in-performance usage for performers, who hold their instruments in their right hand. The toggle switch to turn the backlight on and off is also on the left side, while the main on-off switch is located on the back of the unit. The LED metronome is mounted on the right side of the unit. A picture of the finished unit is shown below in Figure 7.

Figure 7: Finished E-Reader Unit

2.8 Central controller

The central controller will be an 802.15.4 transceiver configured to receive commands from a fully featured laptop via a FTDI cable and a 6 pin header wired to the transceiver. The hardware connections are outlined in the schematic in Figure 8. The controller, like the receiver unit, operates at 2.4 GHz and 9600 baud. The controller can issue broadcast commands to multiple devices, so long as they are set to the same PAN ID. Using the X-CTU software provided by Digi, 1 byte ASCII characters can be transmitted via UART protocol, as well as arbitrary strings of hex values. Up to 100 bytes of data are transmitted in a single RF package. If there are more than 100 bytes of data (e.g. a bitmap file), then the software automatically breaks the data up into 100 byte packets. Commands can be transmitted simply by typing into the X-CTU terminal, and bitmaps can be transmitted by importing and transmitting text files. Furthermore, X-CTU allows the PAN ID of a device to be read and set to any value. Thus, by appropriately setting the PAN ID's of a group of receiver units and accordingly changing the transmitter ID, it is possible using this software to transmit signals to only some of the receivers, and not to others. This especially helps when trying to send multiple instruments' parts of the same piece of music.

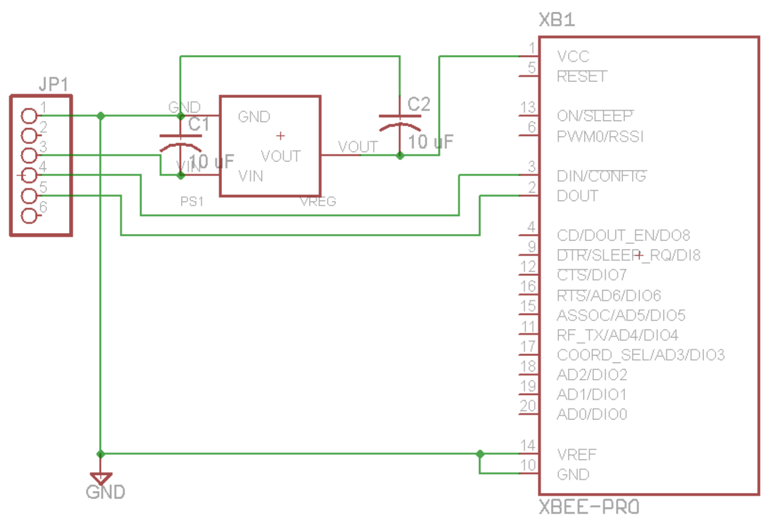

Figure 8: Central Transmitter Schematic

3.0 Requirements and Verifications.

The full list of requirements and verifications tests is shown in Table A.1 in the Appendix. A summary of the tests conducted and the results is given here.

3.1 Power Supply Testing

To satisfy the power requirements, the device was given full batteries and constantly used for a period of time. The AA batteries lasted well over five hours, as predicted by the calculations in Section 2.1. Battery life could still be improved by paying attention to the most sensitive devices; for instance, the first sign of failure was the PSoC bus clock slowing to unacceptable levels, so improving the voltage tolerance for that specific pin could help prolong battery life. The 9 V battery also lasted over 5 hours, contrary to the calculations. This makes sense, because the current drawn was based on a 10 V input, and the current through an LED network decreases exponentially when voltage input decreases. Thus, our device meets our advertised battery life specifications.

3.2 SD Memory Testing

The SD Card was successfully read and written with correct information. Since the filesystem is a standard FAT format, this was verified by reading and writing data from both the computer and the device and ensuring the results were consistent. The filesystem library was deliberately never called outside of the main path of execution, therefore interrupt safety was not a concern.

3.3 Testing Conducted with Cypress Development Board

To facilitate some of the testing, we purchased a Cypress 5LP Development Kit, and fabricated a simple PCB to connect the display, SD card and Xbee to GPIO pins on Port E of the “DevBoard”. The board also powered the components with 3.3 V, eliminating the power supply as a variable, and provided some built-in buttons and LEDs for debugging and user input [6]. Schematic diagrams of the interface board and Port E are provided in the Appendix (Figures A.4, A.5, A.6).

CPU verifications were tested on the development board. Debug messages to the DevBoard’s built-in LCD character display, rather than writes to display memory, were used to verify that button inputs mapped correctly to the expected screen. Display verifications were checked by loading sample images and patterns, designed to ensure that the screen fit the expected frame of a provided image, and verifying that the expected image is displayed on the screen. The metronome was verified to be the correct speed by matching with another metronome and ensuring negligible phase shift

Using the DevBoard interface, we demonstrated our project at the Illinois Spring Football Game on April 12, 2013. Although this preliminary device was bulky, and consumed lots of power, it was certainly usable. The device legibly displayed music and changed pages on command, showing that the hardware and software for the display and memory were functioning as intended.

3.4 Communications Testing

The communication system unfortunately failed to successfully perform during the demonstration. Technically, the cause was due to a mixture of failure to properly decode data and failure to connect the device correctly. Socially, the requirement was never implemented correctly because the board was not tested with the development board; furthermore the requirements were not fine-grained enough.

Several tests were conducted to try to diagnose the problem with the communications system. The transmitting Xbee was verified to be communicating with the PC via the X-CTU software. When the transmitter and receiver were switched with each other, the PC always successfully communicated with the one it was wired to, confirming the hardware's functionality. Furthermore, X-CTU confirmed that the firmware settings were appropriate for coordinator-end device communication, as shown on the ECE 445 page [7]. However, when the PSoC was programmed to display received ASCII characters to the screen, it failed to do so. This indicates that there is a problem, either in hardware or software, in communicating the UART data to the PSoC.

4.0 Cost Analysis

The following four tables (2-5) outline our project costs. The costs are divided into reader parts (2), transmitter parts (3), "one-time purchase" development equipment (4), and labor costs (5). The reader unit's cost of $160 can easily be brought down, considering that the display and the PCB, the two most expensive components of the device, dramatically reduce in price at higher quantities. At this cost, the device seems marketable to marching bands if it is mass produced.

The grand total cost of our project (one reader and one transmitter) is:

$$\$160 + \$54 + \$95 + 2\ (\$13125) = \$\mathbf{26559}$$

Table 2: Reader Parts Cost

Reader Components	Cost
TFT Display, ribbon cable, and board connector	$60.00
MicroSD card and socket	$7.00
XB24	$19.00
PSoC 5 and programming connector	$12.00
PCB	$35.00
Case	$10.00
Batteries, holders, and voltage regulator	$8.00
Buttons, LED, resistors, capacitors	$5.00
Total	$160.00

Table 3: Transmitter Parts Cost

Part	Quantity	Cost per Unit	Total
Xbee Pro Transceiver XBP24-AWI-001	1	$32.00	$32.00
FTDI Cable	1	$20.00	$20.00
LM1117IDT-3.3 Voltage Regulator	1	$1.00	$1.00
Resistors, Capacitors, and Inductors	-	$1.00	$1.00
Total	-	-	$54.00

Table 4: Development Equipment Costs

Part	Cost
Cypress 5LP Development Kit	$50.00
Cypress MiniProg3	$45.00
Total	$95.00

Table 5: Labor Costs

Engineer	Rate	Hours	Total = Rate * Hours * 2.5x multiplier
Hans Banerjee	$35/hr	150	$13125
William Karcher	$35/hr	150	$13125

5.0 Conclusion

5.1 Accomplishments and Uncertainties

The core functionality of the e-reader was successfully implemented. The TFT display produces a stable image, and the music that is displayed on screen is legible. The page can be turned mid-performance via the pushbuttons. The menu system also successfully displays on screen, and is navigable via the pushbuttons. When a piece of music is selected, the correct file is read from the SD card, and the correct image displays on the screen. The LED metronome can be turned on and off, and its speed can be adjusted. Finally, the device is completely portable. All the components are enclosed in a secure, durable, and compact case that helps protect the device from damage. If the SD card is loaded with sheet music directly from a computer, the device can be truly used in place of a conventional flipfolder. The reader unit hardware has been successfully assembled at a price that is reasonable to our intended audience.

However, we are still uncertain as to why the wireless transmission capabilities are malfunctioning. After conducting all the tests described in Section 3, we are still not completely sure of the source of the problem. Our tests verified that the transmitter was correctly communicating with the PC. We verified that the hardware and firmware of both the transmitter and receiver are functioning and correctly set. We have diagnosed that the problem with how the microprocessor handles the UART data input from the receiver. This seems odd because Cypress has a built-in function for UART decoding, but perhaps it is not being implemented or utilized correctly in the code. We are unsure of what this coding bug is, and are working to find and correct it. Also, we have not ruled out a faulty connection or a broken pin on the PSoC as the cause.

5.2 Future Work

Many improvements can be made to make our product more marketable. First, the battery life of the device can be prolonged. This could be done by implementing the boost converter to eliminate the limiting factor of the 9 V battery. A better boost converter (one that is easier to solder, has higher input range, and requires less passive components to function) would probably be utilized instead of the one we originally purchased. Also, if a boost converter is implemented along with a variable resistor that the user can adjust, the backlight can be dimmed to conserve power. As a far reaching goal, we still seek to make the e-reader with an E-Ink display to substantially decrease power consumption, and increase sunlight readability at the same time.

Another major area of potential improvement is the device case. The case is currently heavier than originally intended, and could be made out of thinner, lighter material. Also, the glare off of the plastic case nullifies the effect of the anti-glare coating on the display. An anti-reflective coating should be applied to the clear case in order to improve visibility. Finally, the battery should be made easier to replace. Currently the batteries can only be removed by unscrewing the back cover of the case and being careful not to break any of the parts on the PCB. Battery holders that are accessible from the outside of the case are a necessity.

In the future, musical education tools such as a tuner could easily be integrated into our device. The Cypress PSoC has extensive capabilities to handle and process analog signals, and with the addition of a small speaker and microphone, the tuner could be implemented, further increasing the market value of our product.

5.3 Ethical Considerations

Our project involves no significant safety risk to the end user, as the device is merely an e-reader, and operates on a low-voltage power supply. Care must be taken to ensure the case around the device is devoid of sharp edges or other hazards that could injure a musician during a performance, but otherwise no physical harm is likely to come to the user. The larger ethical concern is embodied in Part 7 of the IEEE code of Ethics, which states we must "seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others" [8]. Thus in accordance with Part 7, we will make sure to properly honor the property of music composers by making sure that all music on our devices has been legally purchased. In general, when bands or other ensembles purchase music electronically, they have rights to distribute music files freely so long as they do not leave the band. If the ensemble director purchases a music file, he may give it out to all the performers, so long as he sends it to no one else. All of the music files used during the development and testing of the device were obtained in this way by Karcher, a member of the Marching Illini. If we warn performers about the legal consequences of redistribution of music to outsiders and placing illegally obtained music on the device, we will be able to curtail the spread of illegal music onto our devices.

6.0 References

[1] Energizer, "NH15-2300 Datasheet," [Online]. [Accessed February 2013].

[2] Hantronix, "HDA700L-2S Datasheet," [Online]. [Accessed February 2013].

[3] ST Microelectronics, "STOD1317B Datasheet," [Online]. [Accessed March 2013].

[4] Cypress, "PSoC 5LP Family Datasheet," [Online]. [Accessed February 2013].

[5] Apacer, "MicroSD Card Specifications," [Online]. [Accessed February 2013].

[6] Cypress, "PSoC 5LP Development Kit Guide," [Online]. [Accessed 12 March 2013].

[7] ECE 445 Staff, "ECE 445 Wiki: Setting up an Xbee Network for a Project," [Online]. Available: http://courses.engr.illinois.edu/ece445/wiki/?n=Topics.MaxstreamXbee. [Accessed April 2013].

[8] IEEE, "IEEE Code of Ethics," [Online]. [Accessed February 2013].