# eGuitar

Brandon Berk, William Remington, and Eric Sorokowsky

Dept. of Electrical Engineering and Computer Science, University of Central Florida, Orlando, Florida, 32816-2450

***Abstract* – Learning to the play the guitar can be a satisfying and rewarding experience. Due to the analog nature of the guitar, there are significant learning obstacles faced by both beginner and expert players. These obstacles range from finger placement and maintaining tempo to writing advanced tablature. The eGuitar aims to be an all-encompassing guitar assistant that can benefit both new and experienced guitarists by introducing some digital enhancements to the typical guitar experience. These enhancements will not require a separate guitar to be purchased, or any modifications be made to a user's existing guitar. All research and design was focused on the system's portability, which resulted in an intuitive LED fret board, user-friendly digital signal processing, and an embedded user interface (UI).**

***Index Terms* – Digital Signal Processing, Graphical User Interfaces, Light Emitting Diodes, Microcontrollers.**

## I. Introduction

As technology advances, most analog components in life are becoming complemented by a digital counterpart. These digital enhancements can improve performance, simplify processes, and improve quality of life. For learning an instrument, most digital enhancements cost a large amount of money and sacrifice the original analog feel of the instrument. Specifically for guitars, there is still a lack of an efficient learning experience for beginners or an intuitive assistant for advanced guitarists. Beginning players often face a steep learning curve where finger placement, tempo, and strumming are difficult concepts to integrate. Most beginners will spend hours just getting the basics together before any songs can be played. For expert guitarists, playing the guitar and reading tablature is easy. When they want to advance their skills, usually they will start to make their own songs. It is in this step that some guitarists do not want to take the time to hand-write their own tablature, since it can be a tedious process.

The eGuitar aims to be an overall enhancement to the typical guitar experience. This system will help both beginners and experts by targeting their specific needs as players. For those just starting out learning the guitar, the eGuitar has an LED fret board that shows exactly where players should place their fingers to play specific notes and chords. The notes that appear can be a pre-selected lesson or any song that the user wants to play. Combine the LED fret board with an intuitive user interface and you have a guitar assistant that will help lower the learning curve that beginning players face. For expert players, the eGuitar's hexaphonic pickup and digital signal processing capabilities allow them to easily create tablature and tune their guitar.

While the eGuitar aims to help guitarists of all skill levels, portability and affordability of the system is key. eGuitar can be implemented with any guitar without modification or damage to the user's own instrument. No extra guitars or amplifiers are needed to use the eGuitar system. It is as simple as sliding the LED fret boards into place and plugging in the control board to a PC. eGuitar will bridge the gap between the analog guitar and the vast array of digital enhancements available today.

## II. System Components

The eGuitar system is comprised of an LED fret board, an on-guitar control unit, hexaphonic pickup, and a Windows application. This section will give a brief description of the individual components that make up the subsystems of eGuitar.

### *A. LED Fret Board*

The core idea for the eGuitar system was to have an LED matrix that shows beginning players where to place their fingers on the guitar. The primary goal was to be able to place the LEDs directly underneath the strings of the guitar. This meant that the LEDs paired with a mounting solution needed to be less than the height of a guitar fret. The typical height is around 1 mm, so a 1 layer PCB was designed with 0805-sized resistors and 0603-sized LEDs. The initial prototype of the eGuitar will support 5 frets and open-string playing, so a total of 6 LED PCBs will be attached to the guitar. The LEDs themselves will be controlled by the on-guitar control system, which will be connected by a ribbon cable.

### *B. Microcontroller*

The microcontroller for this project is a custom designed board using the ATmega32u4 chip. This board will have an integrated charging circuit, SD card support, 40-bit IO expander, and an embedded UI. With all of these individual components, the microcontroller needed a large number of IO ports as well as a good amount of memory for program storage. The primary use of the microcontroller will be to control the LED fret board matrix, however an untethered mode will also be supported. The LEDs will be controlled using $I^2C$, and will communicate with the host PC serially via the USB port. As an added convenience, the ATmega32u4 has an on-chip USB Device Module.

TABLE I
ATMEGA32U4 SPECIFICATIONS

| | |
|---|---|
| Operating Voltage | 2.7 to 5.5 V |
| Clock Speed | 16 MHz |
| I/O Ports | 26 |
| Flash Memory | 32 kB |
| EEPROM | 1 kB |
| Communications | USB 2.0 |

### *C. User Interface*

The eGuitar system relies on intuitive user interfaces on both the embedded and PC applications to create a user friendly experience. For the embedded side, users will select the beats per minute for their song and play/pause during untethered mode. For the PC application, a tab uploader and visualizer lets users easily port any song over to their guitar to start learning how to play it. The active digital signal processing shows users what notes they are playing and even allows them to tune their guitar. Users can also select different modes on the application which include tablature playback and a guitar tuner.

### *D. Lithium Ion Battery*

The battery used for the untethered mode is a 3.7V, 1200mAH Lithium Ion Polymer Rechargeable Battery. A built in charging circuit is included on the eGuitar control board to safely charge the battery when the USB cable is plugged in. The required voltages for the control board range from 3.3V to 5V, so the Lithium Ion battery will be used in conjunction with a variety of voltage regulators.

### *E. Battery Charging Circuit*

The battery charging circuit is comprised of 3 individual ICs developed by Texas Instruments. The first is the BQ24210 Li-Ion Battery Charger. This chip does exactly what the name implies, charges the battery when a power source is present. A connected LED lets the user know when charging is taking place. The second IC used is the BQ27510 Fuel Gauge. This chip gets battery data and sends it to a microcontroller via $I^2C$. The final IC is the TPS63002 Buck/Boost Regulator. This chip is being used to boost the 3.7V of the Li-Ion battery to 5V.

### *F. I/O Expander*

The eGuitar system will support 36 individual LEDs on the fretboard, but the microprocessor chosen does not have enough I/O ports to control each LED. Using the ATmega 32u4's $I^2C$ functionality, a 40 bit I/O expander will be used for LED control. The expander is essentially five 8-bit multiplexers that all have their own individual addresses.

### *G. Hexaphonic Pickup*

A standard guitar pickup has six individual magnetic coils that all output to one data line. This makes it very easy to play all of the sounds coming from the guitar. However, a normal pickup cannot differentiate between which strings were used to play a specific note. The eGuitar system implements a hexaphonic pickup to fix this issue. A hexaphonic or polyphonic pickup is still six individual magnetic coils, but each coil has its own output. This allows the eGuitar to detect which specific string is played at any given moment. With this functionality in place, tuning and accurate feedback is possible.

### *H. Sound Cards*

To output each individual line from the hexaphonic pickup, CM108AH sound cards will be used. Six in total will be connected to a USB hub that then connects to the host PC. These sound cards are single chip USB audio solutions that can convert the audio output from the pickup to USB.

## III. SYSTEM OVERVIEW

The eGuitar system has a number of hardware components that are attached to a guitar, but in order for those components to work effectively, a large amount of software is required. The follow sections will give a brief overview of both the hardware and software block diagrams for the eGuitar system.

### *A. Hardware Overview*

The hardware in the eGuitar includes a DSP subsystem, control system, and LED matrix. On the left of Figure 2 below shows the hexaphonic pickup and 6 sound cards integrating together to form the DSP subsystem. The DSP is controlled by the host PC, which also controls the microcontroller. In the center of Figure 1, the ATmega32u4 controls the embedded hardware, OLED, and the LED matrix. Powering all of these systems is the 3.7V Li-Ion battery shown on the top of Figure 1.

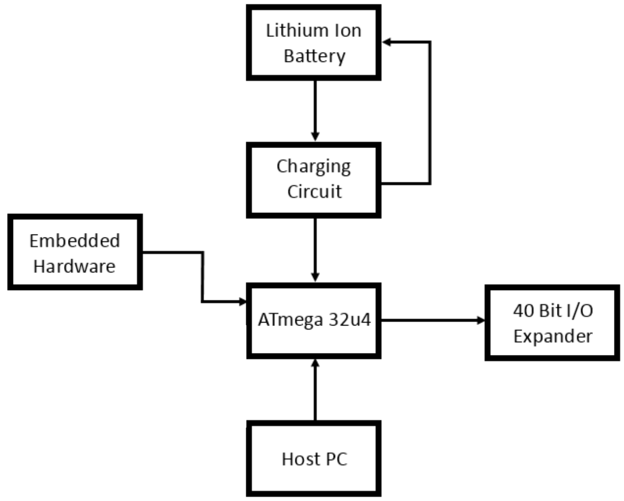


Fig. 1. eGuitar Hardware Block Diagram

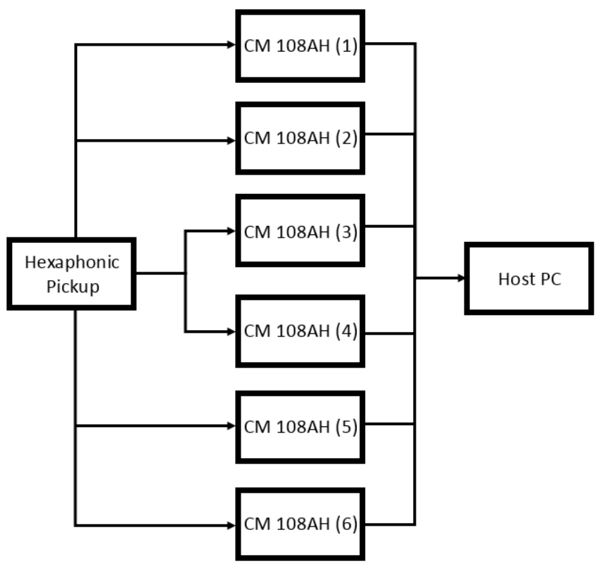


Fig. 2. Hardware Block Diagram - Pickup

### B. *Software Overview*

The software portion of eGuitar system contains a fret board visualizer, tablature functionality, and digital signal processing capabilities on the PC application. For the embedded software, LED control, user interface, and memory management are the main components. The fret board visualizer is a user interface element on the PC application responsible for simulating the guitar fretboard. If the user does not want to look down on their fret board for finger placement, the PC will mimic the proper placement. Tablature functions include importing PowerTab songs and also parsing the tablature data to send to the embedded system. The hexaphonic pickup featured in the hardware overview is used for the DSP portion of software to actively record and analyze the notes being played.

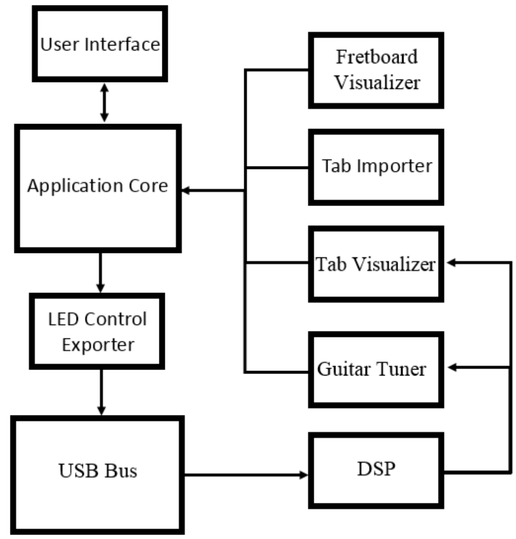


Fig. 3. eGuitar Software Block Diagram

## IV. Hardware Detail

This section focuses on the hardware components that have been designed for the eGuitar system. These components include the LED fret board, main control board, and some specific control board circuit design.

### A. *LED Fret Board*

A standard acoustic guitar neck has 19 frets and 6 strings laid along it. For beginning players, the first 3 frets are played to gain an understanding of finger positioning as well as learning the basic chords. The next step in learning the guitar expands the number of frets used to 5 with basic bare chords. In the first iteration of the eGuitar system, the first five frets as well as open notes will be supported. eGuitar implements small individual fret led boards that have the design shown in Figure 4.

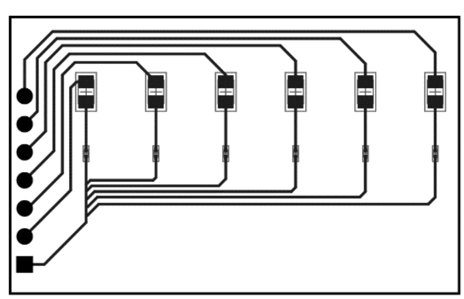

Fig. 4. Single LED Fret Board PCB

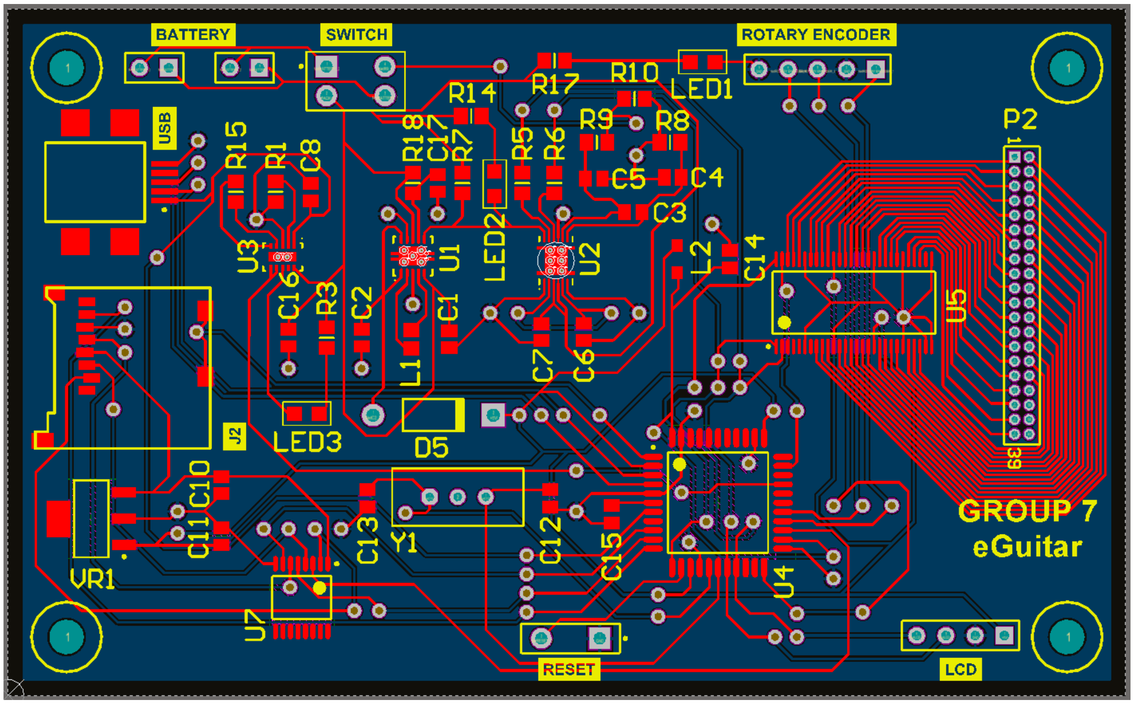


Fig. 5. Control Board PCB

The boards implement 6 LEDs connected to individual resistors and a common ground. The frets on a guitar have a height of around 0.040", so the components and the PCB need to be less than 0.040" to maintain normal functionality of the guitar. The boards are made of typical FR4 PCB material, and at 1 layer the thickness is 0.020". The resistors are 0805 sized and LEDs are 0603. All six of the LED boards connect to a 20x2 ribbon cable that lays flat behind the neck of the guitar.

## *B. Control Board*

The eGuitar offers an untethered mode where users can unplug from their PC and learn pre-selected songs of their choice anywhere. The control board of eGuitar handles all untethered tasks as well as communicate with a host PC while the system is tethered. The components that make up the control board include an ATMega 32u4 microprocessor, MicroSD card support, lithium ion battery charger, 40-bit I/O expander, and OLED screen. Figure 5 shows the PCB design. Red represents the top layer, while the blue is the bottom layer. This board will have a number of external components that need to connect to the board, so all connectors have been placed on the outer edges.

## *C. Charging Circuit*

eGuitar features an untethered mode where the user can use the system without a PC connected. In order to remain cordless, a battery must be used to power everything. Our design implements a lithium ion battery, which requires a charging circuit to properly maintain the battery's charge.

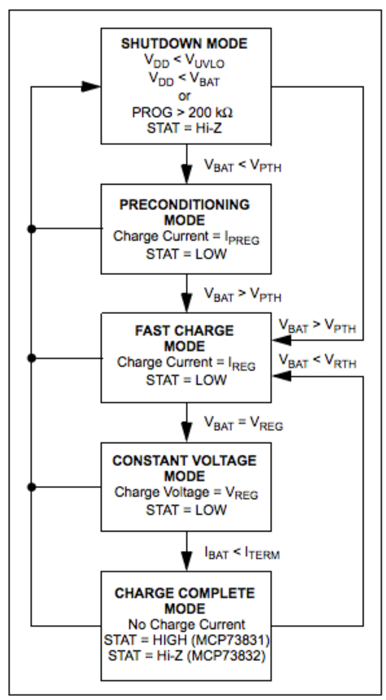


Fig. 6. Charging Flow Chart

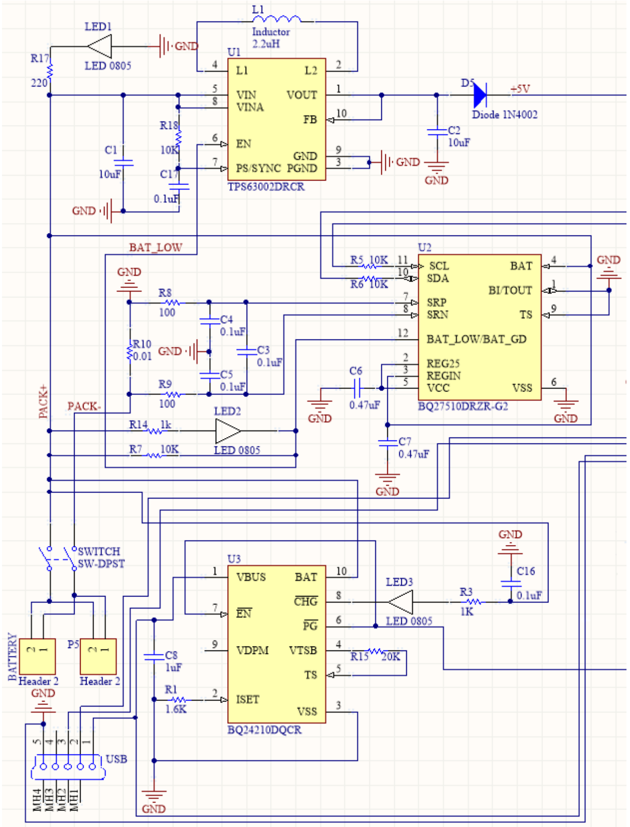


Fig. 7. Charging Circuit Schematic

As detailed in the System Components section, the charging circuit includes Texas Instruments' Fuel Gauge, Lithium Ion Battery Charger, and Buck/Boost Regulator ICs. In Figure 7 above, U1 represents the voltage regulator, U2 is the Fuel Guage, and U3 is the battery charger. Figure 6 shows the basic functionality of the charging IC. It starts with the chip turning on and beginning a preconditioning of the battery. This leads into the main charging segment where a large current is sent to the battery to reach close to 90% capacity. To top off the battery, a small voltage is sent over a longer period of time to safely maximize the battery's capacity.

### *D. Embedded Memory*

The tablature recording and playback portions of the eGuitar system will require large non-volatile memory for tablature storage. While the ATMega 32u4 does have built-in memory, it is not enough to store multiple songs tablature for playback. To overcome this the eGuitar utilizes an SD card for an easy and portable memory solution. Users of the eGuitar system will have two options in transferring tablature playback from the PC to the embedded system. The first option is to manually transfer songs to the SD card using a SD card reader and an exported tablature file. Users may not have a computer that supports an SD card, so the second option that eGuitar offers is a USB pass-through. Users are able to use the eGuitar PC application to upload tablature to the SD card that is connected to the control board.

## V. Software Detail

The following section will detail all of the software involved in the eGuitar system. The PC software consists of Windows Presentation Foundation (WPF) app as the front-end user interface for a fretboard visualizer, LED control, tablature support, and digital signal processing. The embedded on-guitar portion of the system handles tablature playback without needing to be tethered to the PC.

### *A. Fretboard Visualizer/LED Control*

The eGuitar application controls the visualization of chord structures and finger placement with two different interfaces, the 3D Fretboard Visualizer application and the direct serial LED Control of the tethered eGuitar hardware as seen in Figure 8. The Fretboard Visualizer is a 3D representation of finger placement on a guitar fretboard which supports a dynamic number of strings and frets. The eGuitar application hosts the Fretboard Visualizer executable in a sub-window that is always in view for the user's convenience, communicating the desired chord structures over a TCP socket. The eGuitar application simultaneously communicates the chord structures to the tethered eGuitar system via serial so that the embedded system may light the correct fretboard LEDs to represent the current finger placement. The combination of these two interfaces provides the user with dynamic visual system for learning songs and chords regardless of where they are looking.

### *B. Tablature Support*

As digital guitar tablature creation is a well-established industry, the eGuitar system merely acts to complement the existing digital learning experience as a peripheral accessory. In this spirit, the eGuitar application supports the import of ASCII tablature generated by the popular and free-to-use PowerTab software.

### *C. Tablature Visualizer*

The eGuitar system features the ability to record tablature on the fly using it's built in DSP functionality. As an extension of this functionality the eGuitar system enables the user to visualize this recording in a simple and easy to comprehend interface. This interface allows the user to specify the exact tuning of their guitar, whether it is a standard tuning set or a custom one created by that user.

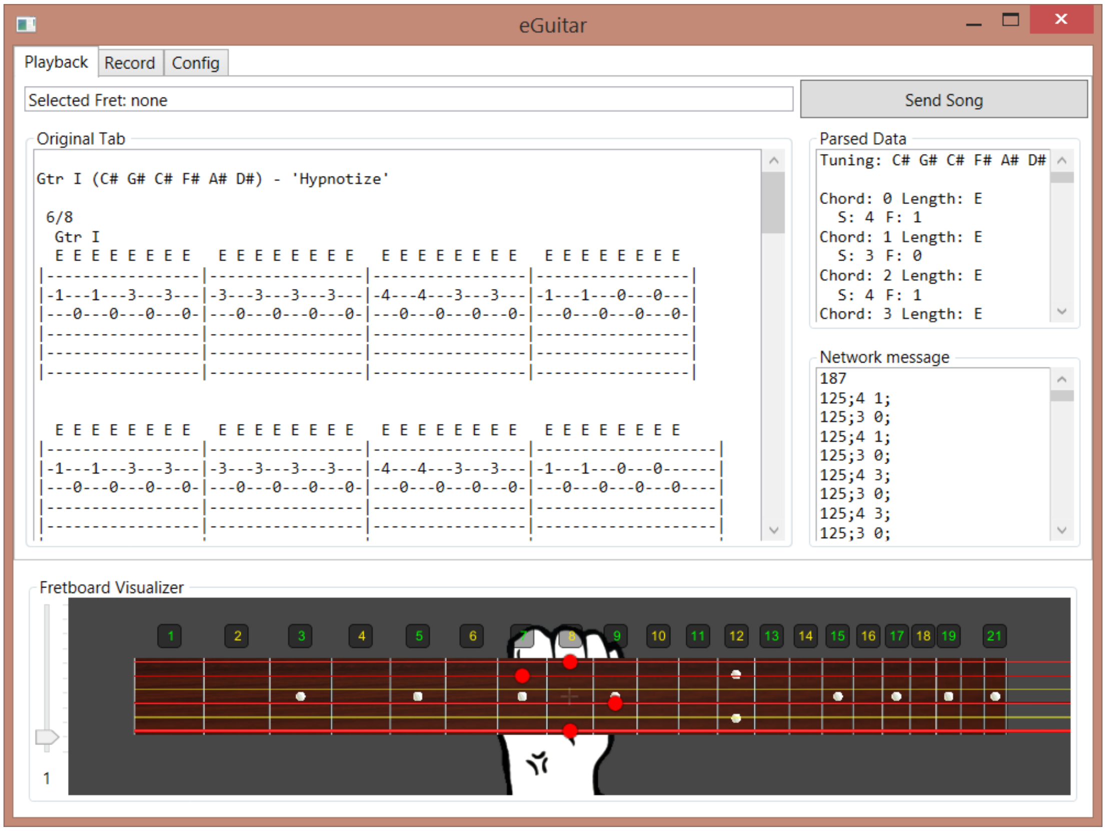


Fig. 8. Tablature Visualizer Application

The tuning specified by the user is then fed into an algorithm which calculates the exact fret that the user's finger was on when a note was played for a particular string. The results from this algorithm are then fed into an automatically scrolling timeline style interface, as seen in Figure 9, for visualization to the user.

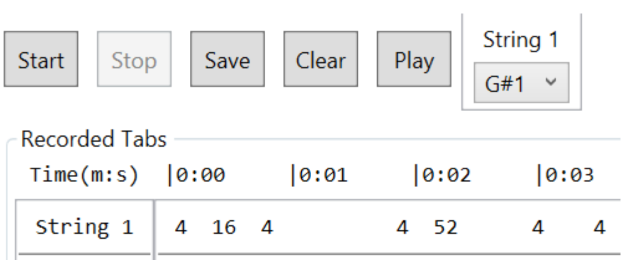


Fig. 9. Sample Tablature Timeline

*D. Guitar Tuner*

For beginning players, tuning the guitar can be a difficult task. Online guitar tuners play the correct note, but it is up to the user to match the sound. This process leads to inaccurate tuning and ultimately songs that do not sound accurate when playing the correct notes. Using the DSP subsystem, the eGuitar application provides a visual guitar tuner for convenience. As the user strums the open strings of their guitar, the application reports the frequency detected as well as the closest neighbor note. Completing this process for each string yields a well-tuned instrument, ready for playing or learning. This feature will help alleviate some of the difficulties tuning a guitar.

*E. Digital Signal Processing*

One of the core components to the eGuitar system is its robust DSP subsystem. This subsystem is responsible for processing all incoming audio data and determine the exact frequency within 0.02% as well as the MIDI note in real time. In order to achieve this accuracy the eGuitar system uses a series of filters to remove noise and a derivative of the auto-correlation algorithm.

Since the eGuitar system relies upon magnetic coils to generate electrical energy from the mechanical movement of the strings noise and interference can be generated due to the movement of neighboring strings or external magnetic fields. In order to reduce these phenomena the eGuitar system utilizes a series of radial smoothing as well as high and low pass filters. The radial smoothing algorithm performs preforms a rolling average of the audio data in order to reduce momentary spikes that can occur. The high and low pass filters are then applied to the data to ensure that we only receive data that is between 50 Hz to 1.6 kHz.

Auto-correlation is a method of determining repeated patterns in a signal or to determine a periodic signal that is obscured due to noise. In practice auto-correlation can be incredibly slow since it needs to perform a comparison for each possible frequency that needs to be detected with each data sample. The eGuitar system accomplishes this by applying a two pass approach to auto-correlation. The first pass is only preformed on every $8^{th}$ audio sample and a minimum sample of frequencies to determine the range in which the second pass should be performed. A second pass is then preformed based off of the results from the first pass. This second pass simply performs a higher resolution frequency test on all of the data samples centered on the frequency detected in the first pass. Once both passes have been performed on the dataset the result is a highly accurate frequency in Hz.

In order to convert the resultant frequency from the auto-correlation algorithm into a user readable MIDI note a simple conversion table needs to be used. These tables remain standard across all instruments and allow simple translation from frequency to notes. An example of one of these tables can be seen in Table 2 below.

TABLE 2
FREQUENCY CONVERSION

| String (Pitch) | Frequency (Hz) |
|---|---|
| 1 (E4) | 329.63 |
| 2 (B3) | 246.94 |
| 3 (G3) | 196.00 |
| 4 (D3) | 146.83 |
| 5 (A2) | 110.00 |
| 6 (E2) | 82.41 |

### F. *Embedded Software*

The embedded eGuitar software serves to present the user with tablature playback controls. With SD card support, the powering of the onboard hardware will result in the display of all tablature files found. The software supports option navigation and selection via rotary encoder turns and clicks. The selection of a tab begins untethered playback, which lights the respective LEDs in time with a song's playback. The user can toggle play/pause of the current tab, adjust the speed of playback, or return to the list of tablature on the SD card.

## VI. ENCLOSURE

The aim of the embedded portion of the eGuitar system is that all user options and functions be navigable with minimal and intuitive hardware controls. A single 3D-printed enclosure was created to contain the control board as well as all peripheral devices. These devices include the OLED screen, rotary encoder for user control, power switch, USB connector, and DSP sound cards.

The main design influence was where the enclosure would attach to the guitar. As seen in Figure 10 below, the enclosure for the eGuitar controls looks very similar to a first generation iPod. On the bottom of the enclosure features an Ethernet port, MicroUSB port, and an opening for a USB cable that connects to the host PC. The Ethernet port will not be used for internet capabilities, but will be used instead to connect the hexaphonic pickup to the USB sound cards. The MicroUSB port will be used to program the microcontroller as well as charge the internal battery. On the right side of the enclosure is an opening for the ribbon cable that connects to the LED fret board. This opening can be seen best in Figure 11 below. Finally, the left side of the enclosure has a power switch to turn on the whole system.

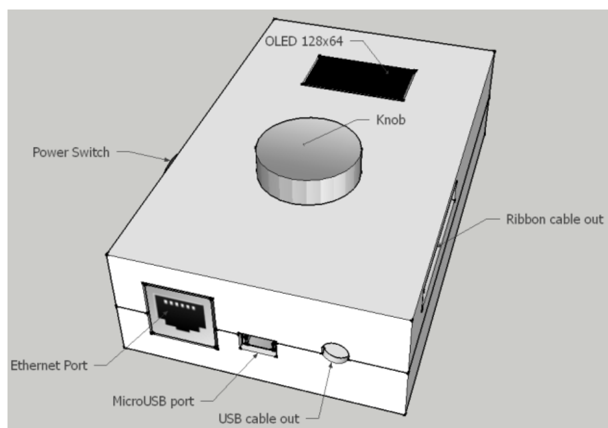


Fig. 10. eGuitar Control Enclosure

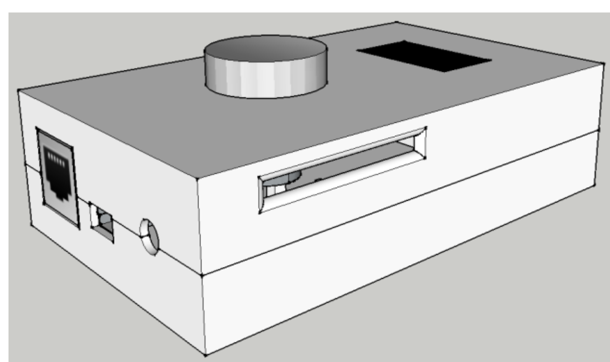

Fig. 11. Side view of enclosure

## VII. Conclusion

The eGuitar system will hopefully fulfill the goal of assisting both expert guitarists as well as beginners. The steep learning curve faced by those just starting to play the guitar can be eased by using eGuitar. With the LED fret board and user-friendly interface, utilizing the eGuitar system will make the tedium of learning fun and easy. The PC application paired with the hexaphonic pickup will help players see exactly what they are playing and how to improve on their performance. Even for expert guitarists, the digital signal processing software implemented in eGuitar will accurately create tablature of their own songs.

A major influence in the design of the eGuitar system was the form factor. There are many ways to indicate proper finger placement for playing a note or chord. During the research phase of this project, a clear form factor for the LED fret board was found. Putting the LEDs directly under the strings on a guitar adds a level of convenience to beginner players. They get visual cues that are easy to understand and do not require any additional focus.

## Acknowledgment

The authors wish to acknowledge the assistance, support, and teachings of Dr. Samuel Richie. With his help, the eGuitar became the product that the authors wished it could be. Also, the authors would like to thank the following professors for agreeing to review this project: Dr. Lobo, Dr. Li, and Dr. Guha.

## VIII. The Engineers

**Brandon Berk** is a senior at the University of Central Florida and will be graduating with his Bachelors of Science in Computer Engineering in May 2015. Following his successful Virtual Reality Kickstarter, Brandon plans to continue work with Wearality Corporation in Orlando, FL, as the Lead Product and Innovation Engineer.

**William Remington** is a senior at the University of Central Florida and will be graduating with his Bachelors of Science in Electrical Engineering in May 2015. William is currently an intern at Irvin Technologies Inc., and has accepted a full-time position with them starting in May. His primary focus will be development of automated test equipment as well as embedded hardware design.

**Eric Sorokowsky** is a senior at the University of Central Florida and will be graduating with his Bachelors of Science in Computer Engineering in May 2015. Eric is currently the Technical Lead at the Innovators Garage of Lockheed Martin. He will be continuing this position full-time starting in May. Eric’s primary task is the development of AR and VR headsets for military simulations.