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| High Level Design |
| KEYtar |
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**1 Introduction:**

The KEYtar project addresses the problem of a non-musical person being able to play with other musicians in a fun environment. The project will offer a thorough exercise in the design process to create a product that is efficient, user friendly, and intuitive. With features such as key correction and the option to play the sounds of various instruments, the KEYtar will offer significant engineering challenges in digital signal processing, circuit design, and power distribution. With the necessary components available in the market, the KEYtar is also a realizable project that will provide a substantial learning experience.

# 2 Problem Description and Proposed Solution:

Playing a musical instrument such as a guitar is an activity which is very beneficial to the user for a number of reasons. It is an activity which can greatly help alleviate stress, and when people play instruments in groups, it is an excellent social activity as well. However, a large number of people do not know how to play a musical instrument, with less than 6.5% of Americans knowing how to play the guitar. These people are therefore excluded any time a group of their friends decide to have a jam session. This can create a great problem as it can cause those who are not musically-inclined to feel left out and to miss out on the fun which their friends are having.

Currently, if one decides that they want to start participating in these jam sessions, it is nearly impossible to do so without either extensive training or completely disrupting the music. Due to the wide range of keys which can be played in, it is inevitable that someone who is not trained in music and simply playing around on a guitar would often play notes that are out of key. This poses a great problem for that person who does not have training in a musical instrument but still wants to reap the benefits of jam sessions with friends without being a nuisance and disrupting the music.

In order to help those who are not musically inclined to still be able to play in jam sessions with friends, we are proposing a KEYtar. The KEYtar would be a very intuitive instrument which is shaped like a guitar and has two sets of buttons. One set of buttons would be a sort of keyboard positioned on the body of the instrument which would play individual notes. The other set of buttons would be positioned on the neck of the KEYtar and would be used for playing the chords within a certain musical key. In order to optimize the user experience, we are proposing the development of 3 major functionally modes of the KEYtar: **Standard**, **Assist**, and **Auto-Assist**.

**Standard Mode** is designed for the user who wants to use the KEYtar but already has at least a fair amount of musical experience. In this mode, the keyboard buttons would function in the same manner as a normal keyboard. The user would then be able to manually select the key he or she wants to play in, and the buttons on the neck would provide an easy and efficient way to play the chords in this key.

**Assist Mode** is the ideal mode for the user who is largely lacking in musical training. Like in Standard Mode, the user would manually select the key to play in and the neck buttons would play only the chords in this key. However, unlike Standard Mode, Assist Mode would also change the functionality of the keyboard on the body to only play notes within the set key. This allows someone without musical training to play notes on the KEYtar in any way that they like without playing out of key, leading to a much more aesthetically pleasing sound.

**Auto-Assist Mode** is designed for the user who lacks musical training but who wants to play the KEYtar in a jam session with friends. This mode functions exactly like Assist Mode except, instead of being set manually, the key in which the KEYtar plays would be determined automatically by analyzing the notes being played by the other instruments in the room. This would allow a user with virtually no concept of music to join in a jam session without having to worry about what key they are playing in.

**3 System Requirements**

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| Overall System Requirements | |
| **General** | Must be able to play music at an audible level  Must play the input from the user  Must determine the key from knob and microphone  Must be able to output sound to an external amplifier |
| **Safety** | Must not shock people  Must not splinter  Must not cause fire |
| **Power** | Must not expend more than 50 Watts  Must operate at least 30 minutes on battery power  Must charge within 1 hour  Must operate with wall plug  Must survive 300 charge cycles |
| **Cost** | Must not exceed $500 to design and produce |
| **Size** | Must be less than 4’ x 2’ x 4” in dimension |
| **Weight** | Must be less than 12 pounds |
| **User Friendliness** | Must be intuitive to operate  Buttons must be easy to press  LEDs must be bright enough to see  Must be sturdy and withstand normal usage |

**4 System Block Diagram**

*4.1 Overall System*

The major components of the overall systems are the Battery and Power Unit, Key Select, Sound Related Inputs, User Interface Display, and Audio Output systems. All of these components interface with the microcontroller for the operation of the KEYtar.

The Power and Battery Unit will supply a sufficient amount of power to the KEYtar and charge the on-board battery. The charging circuit of the unit may need to interface with the microcontroller depending on the specification of the charging circuit. Since battery voltage fluctuates, we will also need a voltage regulator to provide a stable voltage to the system.

The Key Select system will take inputs from the Mode and Key Select blocks as well as inputs from the microphone and listen button in order to determine the key in which the KEYtar should play. In Standard Mode and Assist Mode, the user sets the key select knob to specify the key. In Auto-Assist Mode, the microcontroller takes inputs from the microphone, performs a Fourier Transform, and selects the key based on the presence of tones.

The Sound Related Inputs include the individual notes that are being played, the chord buttons, and various other sound effects. The output pitches will be determined by the microcontroller based upon the individual buttons/keys that the user presses. The chord buttons will correspond to the chords within the specified key. The sound effects may include such features as timbre synthesis, reverberation effects, and sound distortions.

The User Interface Display consists of a seven segment display and various LEDs. The seven segment display will be controlled by the microcontroller and will display the key in which the KEYtar is currently operating. The LEDs are positioned on the KEYtar near user inputs to indicate user selections. The LEDs will also be controlled by the microcontroller.

The Audio Output system consists of an output jack, a speaker, an amplifier, and a volume control knob. The audio output is directed either through the amplifier to the on-board speaker or through the output jack. The output jack does not have volume control, but the on-board amplifier does. The user accesses the volume control through a knob.

A block diagram of the KEYtar system is shown below in Figure 1.

Microcontroller

Mode Switch

Key Select Knob

Outside Sound

Microphone

Listen Button

Chord Buttons

Note Keys

Sound Effects

LEDs

7-Segment Display

D

Batteries

Plug-In Charger

Charging Circuit

Other Components

Output Jack

Amp/Speaker

Volume Control

**Figure 1. A system block diagram for the KEYtar.**

**4.2 Subsystem and Interface Requirements**

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| Subsystem and Interface Requirements |
| ***Power and Battery Unit*** |
| **General** Must be able to power KEYtar directly from U.S. wall outlet or charged batteries |
| **Size** Batteries must fit unobtrusively inside the KEYtar |
| **Weight** Must weigh less than 2 pounds in total |
| **Power** Must output constant adequate power for the system |
| **Microcontroller** Must sense if the device is charging  **Software** Must sense the voltage of the batteries and adjust power cycle as necessary |
| **Batteries** Must be rechargeable, fully recharged in less than an hour  Must have a battery life of at least 30 minutes  Circuitry must be able to protect batteries |
| **Plug-In Charger** Must have a sufficiently long chord  Must be able to charge batteries and directly power KEYtar |
| ***Sound Related Inputs*** |
| **General** Must be able to accurately send signals to the microcontroller corresponding the sound that the user is attempting play |
| **Size** Chord buttons must be approximately 1.5 finger widths wide and  one inch tall, rising slightly above the KEYtar surface  Note keys should be the approximate width of a standard piano key  while being between 3 and 5 inches tall  Sound manipulation buttons should be slightly smaller than a dime |
| **Power** Must draw less than 200mW |
| **Microcontroller** Must accurately detect the signals from sound inputs  **Software** |
| ***Key Select*** |
| **General** Must be able to designate a key for notes and chords to be played  either through user selection or automation from outside sound |
| **Microcontroller** Must be able to execute an FFT of frequencies and use a lookup  **Software** table to determine the key |
| **Mode Switch** Must have three states (Standard, Assist, Auto-Assist)  Must be less than one inch long |
| **Key Select Knob** Must be larger than a dime and smaller than a quarter  Must be an incremental encoder rather than absolute encoder |
| **Listen Button** Must be size of a fingertip (1cm diameter circle)  Button will be pressed once, activating microphone and disabling  audio output so that microcontroller can determine key |
| **Microphone** Must pick up sound of standard noise levels  Must be surface-mounted, flush with KEYtar  Must have surface area less than 4 cm squared |
| ***User Interface Display*** |
| **General** Must accurately convey to the user the current KEYtar settings |
| **Size** LEDs: standard bulb LEDs  7 segment: standard 7 segment display (1.5” x 2.5” x .15”) |
| **Power** Must consume less than 65 mW total |
| **LEDs** Must be an LED indicating: power on or off; low battery; battery charging; battery fully charged; key identified; sound manipulation identifications |
| **7 Segment** Must output the key selected |
| **Microcontroller** Must have a lookup table for 7 segment display  **Software** Must provide high/low output for LEDs |
| ***Audio Output*** |
| **General** Must be able to output sound to speaker or output jack at a user-  controlled volume  Speaker must turn off when output jack is connected  Output jack is a quarter inch TRS  Speaker must be mounted to KEYtar |
| **Size** Speaker must be a big as possible within remaining available space  Volume control knob must be ¾” in diameter and rise above  KEYtar surface by ½”  Output jack is ¼” |
| **Weight** Speaker should weigh less than 1 lb |
| **Power** Speaker must consume less than 50 W |
| **Microcontroller** Must have digital to analog converter to output real-time audio  **Software** signal from digital data  Must be able to add separate frequency components  Must be able to update analog value that is being output at twice the maximum frequency component of the audio signal  (≥ ~40kHz) |

**4.3 Future Enhancement Requirements**

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| Future Enhancement Requirements | |
| Wireless effects pedal | Must be able to add accommodation for wireless communication with an external device |
| Weighted keys (for volume) | Must be able to update the microcontroller to read how hard keys are pressed and adjust for output volume |
| Stored music files (for background music) | Must be able to accommodate a digital storage device in the KEYtar body design |
| Tutorial mode | Must have space underneath the note keys for LEDs and additional I/O ports on microcontroller  Must be able to accommodate a storage device |

**5 High-Level Design Decisions**

The high-level design description for each sub-system and interface is given below:

**5.1 Battery and Power Unit**

*5.1.1 Battery*

Since the user may not always have access to an outlet or may want to be mobile while playing, the KEYtar requires a rechargeable battery. When fully charged, the battery must have a length of life of at least 30 minutes. The battery must be at a maximum 0.5 liters in size and less than 2 pounds in weight. The battery is required to have enough voltage to run the amplifiers in the design. When the power requirement of the design can be determined more accurately, the type of battery will be determined.

*5.1.2 Power cord/rectifier*

The cord used to power the KEYtar must be at least 10 feet in length. The output must be DC. The voltage level will be determined later when a better estimate of power requirements are determined.

*5.1.3 Charging circuit*

The circuitry used to charge the battery must be compatible with the type of battery being used, which will be determined later (see Sec. 5.1.1). The circuit must keep the battery charge within a certain range. The details of the charging method are affected by the type of battery selected. One possible method includes the constant-current, constant-voltage method.

**5.2 Sound Related Inputs**

*5.2.1 Chord buttons*

The chord buttons are the interface that the user will use to play a chord on the KEYtar. The buttons will be located on the neck of the KEYtar and will be pressed with the user’s left hand. On-momentary mechanical buttons will be used to control digital voltage inputs to the micro-controller. The buttons that the user presses must be 3/4 inch wide, 1 inch tall, and 1/8 inch above the surface of the KEYtar.

*5.2.2 Note keys*

The note keys are the interface that the user will use to play specific pitches on the KEYtar. The note keys will have the appearance of standard piano keys. The note keys will be located on the edge of the body of the KEYtar. Each note key presses a button that functions similarly to the chord buttons (see Sec. 5.2.1). The mechanical buttons will be beneath the note keys, and their size requirements are not as stringent as the chord keys. The buttons simply need to be fit beneath the note keys and be activated when the note key is pressed down.

*5.2.3 Sound manipulation buttons*

The sound manipulation buttons are the interface that the user will use to change the timbre/style of sound output by the KEYtar. The location of the buttons will be on the body. The buttons will be similar to the chord buttons (see Sec. 5.2.1) except the shape of the buttons will be circular, and the size of the buttons will be smaller than a dime.

**5.3 Key Select**

*5.3.1 Mode switch*

The mode switch is the interface from which the user will select Standard Mode, Assist Mode, and Auto-Assist Mode (see Sec. 2). This is a three position slide-switch which controls a two-bit signal to the micro-controller indicating the mode of the KEYtar. The switch must be less than one inch long and less than ¼ inch wide.

*5.3.2 Key select knob*

The user will turn the key select knob to set the key of the KEYtar for Standard and Assist Mode (see Sec. 2). The knob is a mechanical incremental encoder. The signal sent to the micro-controller is a quadrature square wave that will require two micro-controller digital I/O pins. The size of the knob must be between the size of a dime and quarter. The knob will have detents to help the user select states.

*5.3.3 Listen button*

The user presses the listen button to activate the automatic key select function on the KEYtar, which activates the microphone and terminates audio output until a key is determined and selected or time-out occurs. The electrical interface for the listen button is the same as the chord buttons (see Sec. 5.2.1). The button will have a sensible click and will be the size of a finger-tip. The listen button will be located on the body of the KEYtar.

*5.3.4 Microphone*

The microphone will accept sound from the environment after the listen button is pressed. The input to the microphone will be transferred to the microcontroller via an analog signal. This signal will likely require amplification before being received by the microcontroller. The microphone will be flush with the body of the KEYtar and located in an unobstructed area. The microphone must have a surface area of less than 4 cm2. The microphone must detect frequencies from 200 Hz to 3.2 kHz.

**5.4 User Interface Display**

*5.4.1 Seven segment*

The 7-segment display will show the current key of the KEYtar to the user. The 7-segment display will show either A, b, C, d, E, F, or g (9) to correspond to the key, and the dot will indicate the sharp notation. A maximum of eight digital outputs from the microcontroller will be used to light up the 7-segment display, but five outputs in conjunction with a shift register is an alternative design. The brightness of the 7-segment display will be determined later by aesthetic taste and power considerations.

*5.4.2 LEDs*

The LEDs will indicate the following to the user: power on/off, low battery, battery charging, battery fully charged, key identified, and sound manipulation identification. The LEDs will consume as little power as possible while still remaining visibly bright. Each LED will have a digital I/O pin on the microcontroller.

**5.5 Audio Output**

*5.5.1 Amplifier*

The amplifier will drive the on-board speaker. The input to the amplifier is an analog output from the microprocessor corresponding to the desired sound output. The output of the amplifier is a scaled version of the input and will be put through a filter before going to the speaker.

*5.5.2 Speaker*

The speaker will output the sound desired by the user. The speaker will weigh less than a pound and require less than 50 Watts of power. The speaker must have a frequency response in the audible range, with less emphasis on the lower frequency ranges. The speaker should be located on the body of the KEYtar in an unobstructed area.

*5.5.3 Output jack*

The output jack will be located on the bottom side of the body of the KEYtar, flush with the surface. The output jack will take the output before the amplifier (see Sec. 5.5.1). The output jack will be ¼ inch TRS.

*5.5.4 Volume control knob*

The user will turn the volume control knob to control the volume level of the output sound from the speaker. The user will turn the knob clockwise to increase the volume level and counter-clockwise to decrease the volume level. The volume control knob will control the gain of the amplifier (see Sec. 5.5.1). The knob will be non-detented and will likely be a potentiometer.

**6 Open Questions**

*6.1 Battery type*

We are currently uncertain of our battery type. Once we determine the system power consumption, we will be able to choose a battery based on energy densities that the system will need as well as a few other factors, such as charging methods, number of charging cycles, cost, and safety. If we fail to find a battery satisfying these conditions, we will simply resort to using a wall outlet without a charging circuit.

*6.2 Charging circuit*

The charging circuit is dependent on the charging method of the battery, which in turn is dependent on the type of battery (see Sec. 6.1). Once a battery is selected, we can discuss how the charging circuit will charge the battery.

*6.3 Key note mounting details*

The manner in which the key notes will be mounted to the body of the KEYtar is still uncertain. We have yet to find keys that could be purchased that will satisfy the sub‑system requirements. We hope to find keys that will spring up to the original position after being pressed down, while maintaining the ease with which it is pressed down.

*6.4 System power consumption*

The system is too complex to estimate the power consumption without a more detailed design. Also, this estimate significantly affects other parts of the system, such as the battery type and power supply.

*6.5 Parallel or serial data*

We have more or less settled on a parallel approach for the inputs from the buttons and note keys to the microcontroller. However, we are still debating using serial communication with a shift register for the 7-segment display.

*6.6 Sound effects*

We are currently considering several possibilities for the sound effects, including timbre synthesis, sound distortion, and reverberation. This decision is not crucial to meeting basic system requirements and will be chosen on preference.

**7 Major Component Costs**

The costs for the major components of the system are delineated below. There will be other costs in the project, such as resistors, transistors, capacitors, etc. Consequently, the total cost of the project will be more than $301, but less than $500.

|  |  |
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| **Approximate Costs of Major Components** | |
| **Item** | **Price ($)** |
| DC wall jack | 25 |
| Wood | 50 |
| White keys | 22 |
| Black keys | 22 |
| DSP chip | 32 |
| Speaker | 10 |
| Circuit boards | 75 |
| Amplifier parts | 25 |
| Seven segment display | 5 |
| Batteries | 25 |
| Microphone | 10 |
| **Total Approximation** | **301** |

**8 Conclusion**

The KEYtar offers a formidable design and engineering challenge. The prospect of a battery-operated device that can output sounds of multiple pitches and timbres based upon user input selections, while monitoring that the input meets the specific requirements of being within the right key signature, involves significant hardware and program design.

These engineering challenges have been considered thoroughly and have been addressed with design requirements. With the goal of maximizing functionality and minimizing cost, the requirements have been debated and revised.

Following these specifications, the KEYtar will be an entertaining device that offers the user an intuitive understanding of music and the ease of playing a musical instrument with others. Consequently, the KEYtar has potential in the market as a useful and fun instrument.

**References**

Most price references were obtained from Digikey. We also relied heavily on Wikipedia for background information when making certain design decisions. Google searches were also utilized to teach ourselves some background information on various aspects of the high level design.