Guitar Tuner

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Expanded Feasibility

**Introduction**

The purpose of this document is to explore the feasibility of designing and constructing an analog to digital guitar tuner. This document will not feature a final design, constructed circuits, implementations or simulations. Many guitarists know the importance of having an in-tune instrument. However, many also require tuners if they have yet to have developed the skill of tuning by ear. This process can be made simpler by the use of a guitar tuner for tuning their guitars. This device takes the audio output from the string of the guitar, converts that signal into a digital one, and displays whether the note is sharp, flat, or in tune with the use of an LED display.

**Design**

The guitar tuner will be a device that detects the mechanical waves produced by the guitar through the air. The output result is displayed visually for the musician to see if their guitar is in tune. The guitar tuner will only tune to standard tuning of a guitar. Standard tuning from the sixth string to the first string is E, A, D, G, B, and E. The frequencies of these notes for standard tunings are shown in the table below.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| String | E () | A | D | G | B | E |
| Frequency | 82.41 Hz | 110.00 Hz | 146.83 Hz | 196.00 Hz | 246.94 Hz | 329.63 Hz |

**Table 1: Standard tuning frequency of guitars**

Table 1 shows that the smallest range of frequencies for the guitar tuner are from 82.41 Hz to 329.63 Hz. The guitar tuner needs to detect frequencies at least 5 cents lower than 82.41 Hz and at least 5 cents higher than 329.63 Hz. Cent is a logarithmic unit of measure and a ratio between two close frequencies. In the equal temperament tuning there are 100 cents between semitones, of which there are twelve. The frequency range that the guitar tuner will measure are from 75 Hz to 400 Hz 10%. The measured frequency will only be considered accurate if the guitar tuner microphone is within 12 inches of the guitar sound hole. The guitar tuner needs to be is its calibrated orientation, facing the guitar sound hole.

The detection of the mechanical waves produced by the guitar are detected by a microphone which is an input to the guitar tuner. The functional block diagram for the guitar tuner is seen below.



Sound detection will be performed by a microphone which will be powered by a DC power supply. A microphone that is feasible for the guitar tuner would be the Electret omnidirectional microphone, manufactured by CUI Inc., which has a peak to peak output of a few mV and a frequency response range of 20 Hz to 20 kHz. The frequency range of the microphone is suitable for detecting frequencies between 70 Hz and 400 Hz, which is the range of the guitar tuner for standard tuning. An output in the millivolt range is too small to process in the waveform conversion stage. An amplifier is required to increase the voltage output of the microphone from millivolts to 1 volt to 5 volts range.

Increasing the voltage beyond 5 volts may cause components in the circuit to become inoperable. The output signal of the microphone is an electrical analog signal which is proportional to the the mechanical sound waves produced by the guitar. The output signal will be in the form of a voltage proportional the the mechanical wave. The analog signal produced by a guitar when a string is plucked is not a pure tone. A pure tone, measured by an oscilloscope, would appear as a perfect sinusoid. The signal is actually a sum of multiple sine waves. The guitar has a signature pattern of sine waves whose sum makes a note on the instrument. By plucking the string near the center or over the sound hole of the guitar and measuring the sound wave, the fundamental frequency can be seen.

The amplifier circuit will contain an operational amplifier integrated circuit with capacitors and resistors. An INA326EA instrumentation amplifier is a suitable integrated circuit to amplify the circuit with a gain of approximately 1000 volts per volt. This amplifier features a 3dB cutoff of 1kHz. This is ideal is desired as the frequencies of interest will range from 70 to 400Hz. A relatively low 3dB cutoff of 1kHz will aid in the filtering of higher order harmonics. The amplifier also features a high common-mode rejection ratio over the desired frequency band. If the output range of the microphone is close to 1 millivolt, then amplifying the out signal with this gain factor will increase the voltage to at least 1 volt. The INA326EA is capable of amplifying voltage by 10 volts per volt up to 1000 volts per volt. To set the gain of the amplifier to 1000 volts per volt, capacitors and resistors must be added to the circuit. The INA326EA is an difference amplifier and has two pins dedicated to input, pins 2 and 3. This will set the gain to be 200 volts per volt. Adding a resistor in series with the capacitor will alter the gain, decreasing it to the desired gain of 100 volts per volt. Theoretically, the output of the amplifier should be in the range of 1 volts to 2 volts. The gain of the amplifier can be altered if the output voltage of the microphone is different than the expected range of approximately 1 millivolt. The IC amplifier is prefered to a discrete design in order to reduce cost. The output of the amplifier stage will be the input into the filter stage.

The filter stage will take the analog output of the amplifier stage and pass it through a multi-feedback bandpass filter. A cascaded LF347 will be used in order to generate a higher quality factor with a very flat passband from 70Hz to 400Hz. The first part of the filter stage removes any higher order harmonics as well as any low frequency noise from the amplifier stage. A digital low pass eight-order equiripple filter will be considered for the purposes of the digital stage because it allows selection of multiple passbands. The active MFBF filter will consist of two resistors, two capacitors and an operational amplifier integrated circuit. By altering the values of the capacitors and resistors, the pass and stop bands of the filter can be changed. The analog signal will be sampled by the microprocessor and an fast-Fourier transform will be performed in order to calculate the fundamental frequency of the input waveform. With the fundamental frequency calculated it is then passed to the user interface.

The user interface will consist of a display of some sort, possibly LCD or LED. The user interface will display the fundamental frequency of the note being measured as well as the corresponding musical note. The information will be provided to the display from the microcontroller and will receive power from the power supply.

The power supply can be implemented through the use of a DC supply, mostly likely a battery. This DC supply can then be stepped down through the use of one of many commercially available linear voltage regulators. The power supply will consist of the DC battery pack in conjunction with the linear voltage regulator. The commercially available linear voltage regulators are well documented and feature thorough datasheets. A linear regulator introduces lower noise into the circuit when compared to a switch mode power supply. The switch mode power supply operates on the principle of opening and closing of switches to reduce voltage. This has the possibility to introduce additional noise into the circuit.

**Execution**

Two components that are not available in the ECE department that will need to be ordered. The Electrec microphone can be ordered from the company adafruit for a cost of $0.96 plus shipping. This microphone is also available from the vendors Digi-key and Mouser Electronics for less than one dollar. The other part required would be the microprocessor, ATmega88A, which is available from Microchip, and also owned by the lab group. The MCP6001 is available from Digikey. The parts will only take 3-5 business days to acquire and are reasonably priced. Therefore, if they do not meet the needed specifications, the loss of funds are not substantial. The only substantial cost will be ordering the PCB upon completion of our final design schematic. Cost for this will be researched as designs progress.

The PCB board will be ordered through the ECE department when they submit the request during the capstone sequence. Testing the accuracy of the guitar tuner will be simple as numerous commercial guitar tuners using sound and vibration are available to use in comparison. Each member has multiple guitar tuners to ensure this project will be accurate, with low margin of error (plus or minus 5 cents). In order to ensure the tuner are accurate, the can be compared with a tuning fork at 110.00 Hz (the note A2). The tuning fork at 110.00 Hz will produce a pure tone without any additional harmonics. An acoustic guitar will also be necessary to test the operation of the tuner and is owned by the lab group.

Git with either a Github or Gitlab front end will be used as a form of revision control. Git offers a complete history of commits with the ability to roll back to previous versions of software. In addition Git offers the ability to synchronize projects between the team members.

**Teamwork**

The group has worked on a processor design project in the past that spanned a semester and took a total of 225 person-hours to complete. In addition, the the group is also working on a discrete operational amplifier design project that has, as of halfway completion point, required 100 person-hours worth of work. The team estimates that the final project will take 220 person-hours to complete. Currently, digital signal processing is the only skill this team is lacking. This will be remedied upon completion of a digital signal processing course that concludes in May of 2018. Aside from this, all aforementioned discrete circuits and code design are feasible with the current skill sets of each team member. The team has experience building discrete amplifier circuits and converters, which is necessary for the amplifier stage. Filters, digital and analog, have been designed by each team member in the past. In addition to the electrical and computer designs of the project, each member has years of experience with musical instruments, most notably the guitar. This additional skill set will assist verifying the success of the project. As each team member have a background in music and have experience working together in their respective degrees for more than a year, this three semester project is considered feasible.

**Considerations**

To the best of the team’s knowledge, the guitar can not be used to cause harm relating to the principle functionality of the product. The design is intended to provide a convenient alternative for guitar players, vis-à-vis carrying around a tuning fork. While the device when constructed could be used as a physical conduit of violence, this is not intended and could be said of any object that can be held.

The device could be used to purposefully alter the tuning of a musicians guitar in order to maximize dissonance. This would allow for the guitar to sound terrible if the performer did not catch the tuning alteration prior to performance. Maliciously altering a person’s instrument in order to undermine their performance is quite unethical. Perhaps worse, the guitar could be tuned in order to facilitate the playing of a reggae cover of Sweet Home Alabama. The team emphasizes the product is not designed with this use case in mind.

The product is designed to work under normal room temperature conditions. The product is not meant to operate while under extreme cold or heat. In addition the product is not meant to be waterproof nor snowproof. The product, under the current scope, is meant to tune a guitar. None guitars fall outside the scope, i.e., ouds, sitars, mandolins, banjos, etc. Six string acoustic guitars are the only instrument of interest for this product.

The standards currently being investigated have been chosen in order to minimize cost. Atmega chips have been investigated due to the Team’s familiarity with the Atmega series. Coding languages such as C have been considered as well due to the team’s prior experience. Through prior experience and familiarity, the team intends to minimize development costs.

**Conclusion**

The objective of this document is to inform the reader of the aspects involved for designing a guitar tuner. A incoming mechanical wave from the guitar is amplified, then filtered to attenuate unwanted harmonics. The signal is then converted into a square wave at the fundamental frequency of the note, which is then processed by the microprocessor. The microprocessor then communicates to a user display, which shows the fundamental frequency of the note being played as well as corresponding musical note. This concludes the feasibility report.

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