Auto-Tuner with LCD Display

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1. Introduction

1.a Problem

Stringed instruments like guitars are a very important cultural tool. Found in almost every country in the world, music from stringed instruments has united groups and communities for thousands of years. This level of connection is only possible if the instrument's sound is good, and the first step is to ensure the instrument is in tune. Tuning a guitar properly can be a bit of a challenge, either by someone with a good enough ear to determine whether a string is at the correct pitch or by using a tuner that displays the string's current pitch. Using either method, the person tuning the guitar must tune each peg and repluck the strings until each string is at the correct pitch. This process can be extremely time-consuming, tedious, and often inaccurate as pegs are turned too far. Additionally, this process is almost impossible for individuals with limited hand strength or missing extremities. To make these important cultural items as accessible as possible, it is necessary to have a device that allows easy tuning for all individuals, regardless of their circumstances, and that is more efficient than traditional tuning methods.

1.b Solution

Our proposed solution to this problem is a motorized guitar tuner. This tuner would remove all inaccuracy and physical exertion from the tuning process, allowing for a perfectly tuned guitar with a fraction of the effort. The tuner has 3 main pieces: 1)a sensor which captures the vibrations produced by a string being plucked, 2)a microcontroller which interprets the sensor's values, converts them to a pitch value, and sends adjustment values to the peg turners, and 3) peg turners which adjust the position of the pegs to bring the string into tune. All of these components would be held in a plastic case, which would be clipped onto the guitar headstock. Once all pegs are connected to their designated turners, the device will no longer need to be removed until tuning is complete. This allows all strings to be tuned simultaneously, reducing strain and potential damage to the instrument.

The top of the tuner will include two main features: 1)an LCD display to convey information about the string and what adjustments need to be made, and 2)a series of buttons that allow adjustments to the tuning procedures in case a different standard is desired for each string. This tuner, powered by an internal battery, would allow for quick, efficient tuning of a guitar as easily as possible.

1.c Goals and Benefits

- Allow the user to see in real time what note is being played
- Tune each string to within ± 5 cents
- Tune the whole guitar in under 60 seconds to maintain efficiency
- Detect frequency within 50 ms of pluck
- Limit our applied torque to reduce chance of string snapping

1.d High-Level Requirements

- Limit our applied torque to reduce chance of string snapping
- Detect frequency within 50 ms of pluck
- Tune the whole guitar in under 60 seconds to maintain efficiency
- Tune each string to within ± 12 cents

1.e Visual Aid:

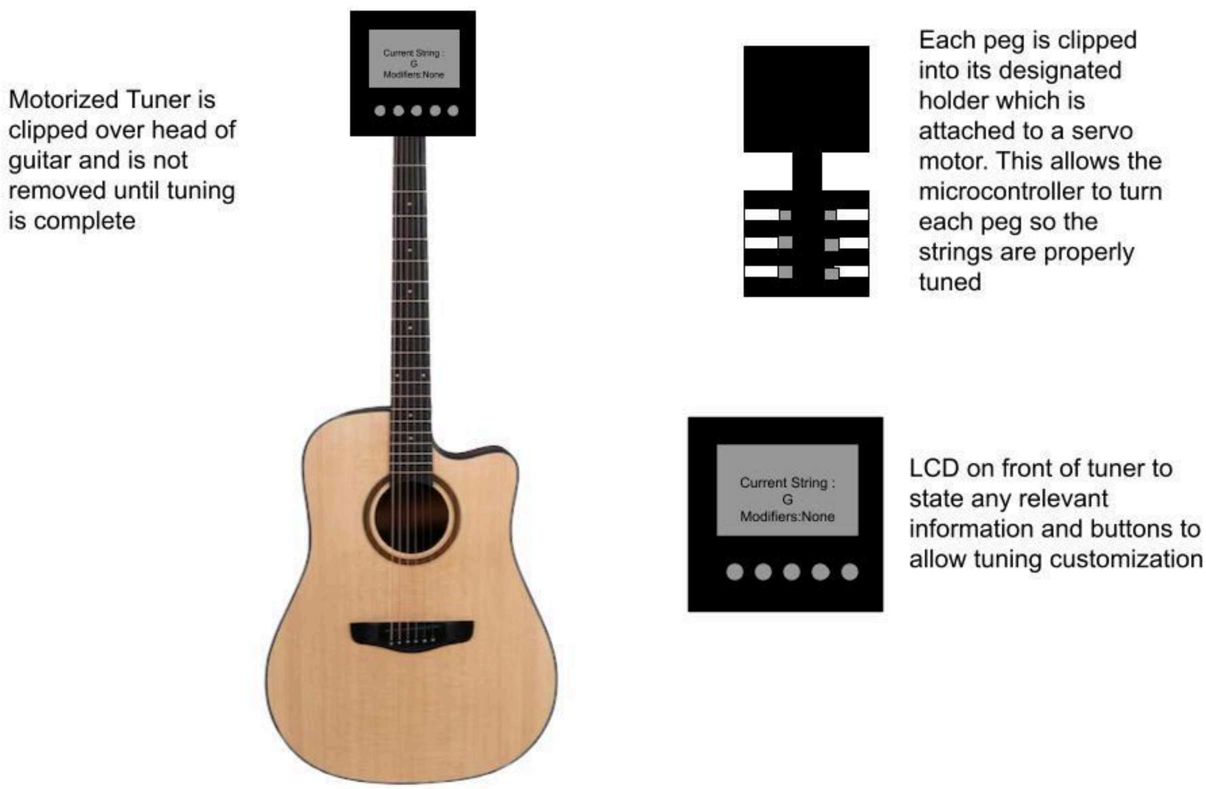

Figure 1: Visual aid of the Auto-Tuner with LCD Display

2 Design

2.a Physical Design

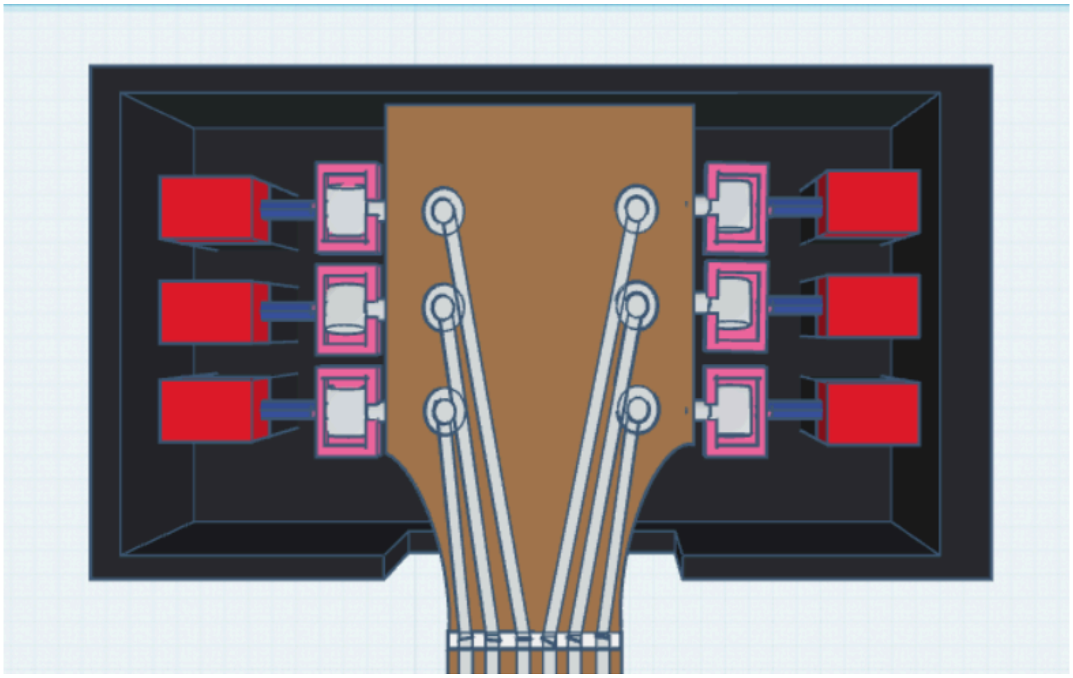

Figure 2: Top down view of tuner base connected to a guitar. Base includes the electrical and circuitry components which are connected to the sensors located around the guitar, the lcd display, and the motors used to turn the pegs.

Figure 3: Lid of tuner which contains the LCD screen and buttons. The screen is mounted on a ball swivel to allow the screen to be turned so it can be seen while the guitar is being tuned.

2.b Block Diagram

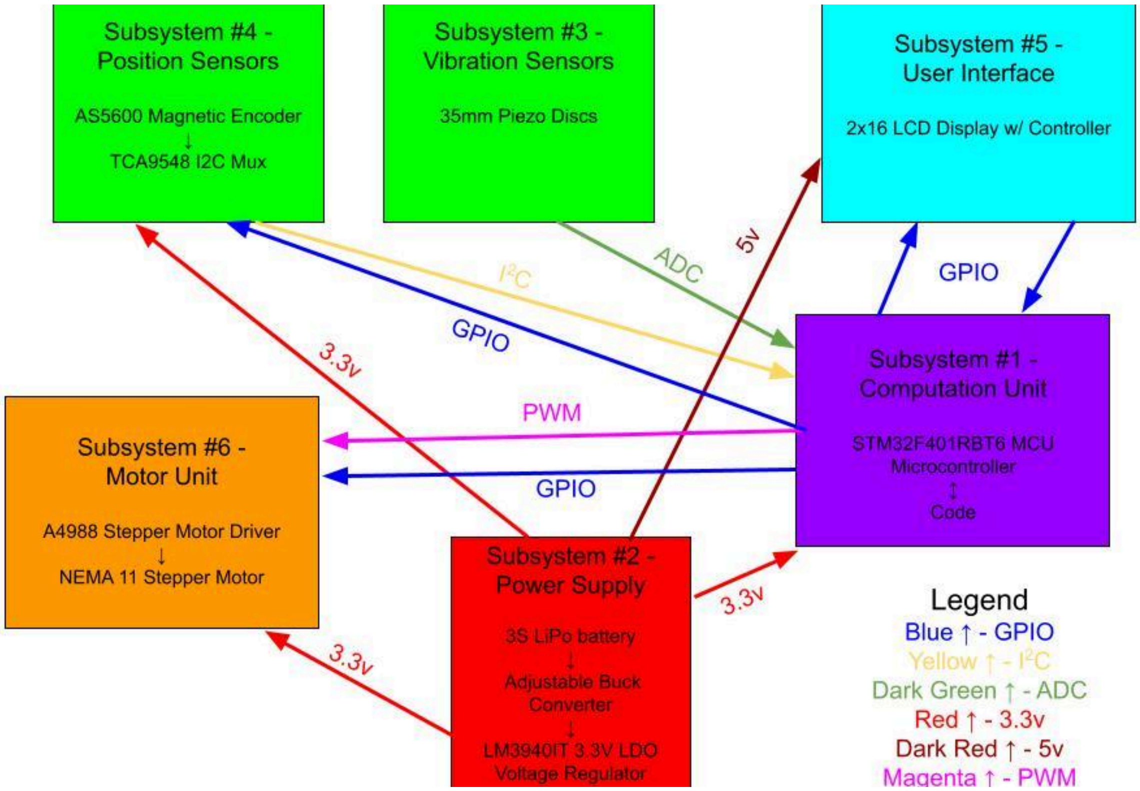

Figure 2: Block Diagram

We have 6 subsystems: Positions Sensors, Vibrations Sensors, User Interface, Power Unit, Motor Unit, and Computation Unit. Starting with our power unit, this will go through both a 5V buck converter and a 3.3V Linear Voltage Regulator to power all of our components. This includes the motors, MCU, magnetic encoders, and User Interface. Our Motor unit is made up of 2 components: The Nema 11 motor and the A4988 stepper driver. This, along with our planned 3D printed coupler, will attach to the pegs of the guitar and physically turn the tuning key. Our positions and vibrations sensors will simply take in input from the guitar, such as the frequency being played and the position of the tuning peg. This will allow us to adjust the pegs so the right frequency is being played, as well as save the angle of the tuning peg to save certain tuning profiles. Our User Interface will allow us to signal our Computation Unit on what we would like to do, such as save tuning profiles, tune the guitar to a certain tuning profile, and make a new tuning profile. Lastly, Our Computation Unit will be the “brain” of our project, taking in all of our inputs and using the code we download to the MCU to perform certain instructions, such as determining which way to turn the pegs and telling us what note is currently being played.

2.c Subsystem Overview

2.c.1 Computation

Computation Unit:

The control unit contains the microcontroller and our code. It serves as the system's central processing block. The microcontroller samples the vibration signal, computes the string's frequency, determines the tuning error, and generates control outputs for the LCD display and the actuation subsystem. It also interprets button inputs. This subsystem is responsible for overall system coordination and decision-making.

Control Unit Subsystem:

Requirements	Verification
Frequency detection latency <= 50 ms	Measure time between pluck and frequency display update
ADC sampling rate >= 8 kHz	Apply high-frequency test signal and measure the time between successive samples and confirm the sampling rate
Button press should be detected within 100 ms	Press button and measure delay to LCD response
LCD should refresh information at least 5Hz	Measure via debug output or oscilloscope

Table 1: Control Unit Subsystem Requirements and Verification

- Sample the analog signal
- Drive the LCD using a standard digital interface

2.c.2 Power

Power Supply:

The power supply subsystem provides power to all other subsystems in the Auto-Tuner. A Lithium-Ion battery serves as the primary energy source, and a voltage regulator converts the battery output to stable voltage rails required by the control unit, sensors, and motor actuation circuitry. Power lines are routed from this subsystem to the blocks, enabling all subsystems to operate.

Power Supply Subsystem:

Requirements	Verification
Output voltage 5.0 V +- 0.1V	Measure using multimeter
Supply >= 500 mA	Measure with current probe during stall/start
Battery life >= 1 hour continuously	Fully charge battery and operate system continuously while timing it

Table 2: Power Supply Subsystem Requirements and Verification

- Provide a regulated 5.0V +- 0.1V for digital and motor circuitry
- Supply at least 500 mA current during motor startup and display operation
- Support at least 1 hour of continuous operation on full battery

2.c.3 Vibration

<u>Vibration Subsystem:</u>

The vibration subsystem captures vibration from the guitar string and converts it into an electrical signal for digital processing. The subsystem consists of vibration sensors followed by analog signal circuitry, including filtering and amplification. The signal is routed to the microcontroller in the control unit, allowing it to identify the musical note being played.:

Requirements	Verification
Detect frequencies from 80 Hz - 1 kHz (low E and high E)	Inject known sine wave signals and verify correct detection
There should be a low-pass filter with a cutoff frequency <= kHz and provide at least 20 db attenuation at 4 kHz	Inject sine waves and measure attenuation using oscilloscope
The subsystem should achieve pitch detection accuracy within +- 1Hz	Tune each string and measure final pitch using reference tuner

Table 3: Vibration Subsystem Requirements and Verification

- Detect frequencies in the 80 Hz to 1 kHz range
- Provide signal amplitude
- Include filtering

2.c.4 Position

Position Subsystem:

This subsystem handles the measurement of the position of the tuning peg. Measuring this will allow us to save the angle of the tuning peg, in turn letting us save the string configurations into a tuning profile, which will make tuning more efficient the next time the user uses the guitar. This consists of a magnetic encoder, which will be attached to the back of our stepper motors, and a I^2C Mux, allowing us to send data one string at a time to the Control Unit.

Requirements	Verification
Achieve angular measurement accuracy within 2 degrees of actual shaft position	Use a level on a peg and check if the reading is at 0 degrees
Allow independent selection of at least 6 encoders using the I^2C multiplexer	Write firmware to cycle through TCA9548A channels 0–5 and read unique angle values from each encoder while rotating one motor at a time.
The subsystem shall measure angular position over a full 360 degree rotation	Rotate the motor shaft through a full revolution and log encoder output values. Verify 0–4095 count range and confirm step size = 360 degrees/4096 = 0.088 degrees.

Table 4: Position Subsystem Requirements and Verification

2.c.5 User Interface

User Interface Subsystem:

This subsystem will allow the user to choose what to do with this system. They can save guitar profiles, create new guitar profiles, or simply tune their guitar to standard tuning. This will be controlled by 4 buttons that are attached to our 2x16 LCD screen.

Requirements	Verification
Display tuning information including detected frequency and target note on a 2×16 character LCD.	Inject known sine wave frequencies and verify correct frequency and note are displayed on the LCD.
Allow user input through at least four push buttons to navigate menus and select tuning profiles.	Press each button and verify correct menu navigation or selection action occurs.
Operate from a 5V supply (LCD) and interface safely with the 3.3V MCU logic.	Measure voltage levels on LCD input pins when driven by MCU. Verify logic-high level is recognized and no 5V is present on MCU input pins.

Table 5: User Interface Subsystem Requirements and Verification

2.c.6 Motors

<u>Motors Subsystem:</u>

This subsystem is responsible for turning the guitar pegs to tune them. It uses Nema 11 stepper motors connected to tuning-peg claws that physically rotate the guitar's tuning pegs. A4988 stepper drivers. Mechanical torque limits and a controlled rotation speed will be implemented to prevent the tuner from breaking the strings or damaging the instrument.

Requirements	Verification
Controllable rotation step of 0.9 degrees	Have a known number of steps and measure the angular change
	Count steps per revolution
Bidirectional Rotation Capability	Command CW/CCW motion
Stall detection triggers shutdown within 2 s	Physically block motor measure shutdown time.
It should provide a minimum holding torque of 0.021 N.m at the motor shaft.	Confirm motor datasheet rating exceed calculated requirement

Table 4: Motors Subsystem Requirements and Verification

- Deliver torque to rotate tuning pegs
- Enforce max torque limits to prevent snapping the string
- Support bidirectional rotation with variable speed control
- Respond to control signals
- Operate safely within the provided voltage and current limits

2.d Tolerance Analysis

One risk with the Auto-Tuner with LCD Display is that the string could snap if too much tension is given by over-rotating the pegs. Guitar strings have a finite tensile limit.

The typical string tension on a steel-stringed acoustic/electric guitar ranges from 50 to 60 N. Total string tension is 300-360 N for a 6 string guitar.

T = rF. Assuming the tuning peg radius is 5mm and using an upper bound of tension being 60 N, T = 0.005*60 = 0.3 N.m. Catastrophic failure occurs at tensions higher than normal.

The NEMA 11 stepper motor provides exactly 0.07 N.m of holding torque according to the manufacturer datasheet.

Acoustic guitars usually have gear reduction around 14:1 so the torque required at the tuning knob is reduced. This means that the Torque required at the motor is about 0.3/14 which is 0.021. This means that the NEMA 11 actually provides more than enough that is necessary for tuning. This means it could snap the guitar string by applying too much torque.

To account for these uncertainties, the control algorithm takes incremental tuning steps rather than continuous rotation. That way, it won't just go right past the tension limit the string can take.

However, this could cause a tradeoff. If the motor torque is limited, the motor could stall if the string tension is too high or if friction is present. This creates another risk. Under stall conditions, current draw increases and can overheat the motor driver, battery, or stepper motor windings.

This is why we will have software that monitors motor activity duration. If the motor stays in one position for too long or fails to change the pitch, the controller will automatically disable the motor. Current limits will also reduce the chance of overheating.

3. Cost and Schedule

3.a Cost Analysis:

Description	Manufacturer	Quantity	Extended Price (Includes Shipping)	Link
NEMA 11 Stepper Motor	Walmart	6	2*29.22 = 58.44	Link
Peg holders	Us	6	Free	N/A
35mm Piezo Discs	YQBOOM	10	10*0.99= 9.99	Link
2x16 LCD Display w/ Controller	N/A	1	Free	E-Shop Self Service
A4988 Stepper Motor Driver	eBay (gy-power)	8	8*0.99 = 7.92	Link
Adjustable Buck Converter	AITRIP	5	7.99	Link
STM32F401RBT6 MCU	N/A	1	Free	E-Shop Order
XT60 plug connectors	Padarsey	1	6.99	Link
3S LiPo battery	RCbattery	1	21.28	Link
Bottom housing	Us	1	Free	N/A
Lid	Us	1	Free	N/A
Fuse	N/A	20	Free	E-Shop Order
Fuse Holder	N/A	20	Free	E-Shop Self Service
AS5600 Magnetic Encoder	Walmart	6	6*7.50 = 45	Link
TCA9548 I2C Mux	MusRock	1	7.99	Link

3S LiPo Battery Charger	Tosiicop	1	9.59	Link
LM3940IT 3.3V LDO Voltage Regulator	N/A	1	Free	E-Shop Self Service

For the Grainger College of Engineering, the average salary is $96,766 per year. Taking into account a 40 hour work week and 52 weeks worked, the salary is about 46.52 dollars per hour.

We are expecting to spend an average of 18 hours per week on this course.

1. Labor:
   $46.52/hour * 16 weeks * 18 hours/week * 3 people = $40,193
2. Parts:
   $175.19 ($25.19 over budget)
3. Sum:
   $40,193 (labor) + $ 175.19 (parts) = $40,368.19

3.b Schedule:

Week	Task	Person
2/22 - 3/1	Design PCB	Everyone
	Finish Design Doc	Everyone
	Sign up for Design Review	Lee
	First Round Orders	N/A
3/1 - 3/8	Design Review with TA and Instructor	Everyone
	Second Round Orders	John
	Finish PCB Design	Everyone
3/8 - 3/15	Breadboard Demo with TA and Instructor	Everyone
	Third Round Orders	Nicholas
	Teamwork Evaluation I	Everyone
	Work on Control Subsystem	Lee

3/15 - 3/22	PCB Assembly	Everyone
	Work on UI for LCD	Nicholas
	Work on Sensing Subsystem	John
3/22 - 3/28	Test PCB	
	Fourth Round Orders	Lee
	Mock Demo	Everyone
	Work on the Actuation Subsystem	Nicholas
3/28 - 4/4	Individual Progress Reports	Everyone
	Test all Subsystems	Everyone
4/4 - 4/11	Test Demo	Everyone
	Team Contract Assessment	Everyone
	Test subsystem requirements	Everyone
4/11 - 4/18	Make sure subsystem requirements are all completed if not already done so.	Everyone
	Start Final Presentation	Everyone
4/18 - 4/25		
	Work on Final presentation	Everyone
	Mock Demo	Everyone
4/18 - 4/25	Final edits, bug fixes	Everyone
	Finalize final presentation	
4/25 - 5/2	Final Demo with Instructor and TA	Everyone

	Final Presentation with Instructor and TA	Everyone
5/2 - 5/6	Final Paper	Everyone
	Finish Individual Notebook	Everyone

4. Discussion of Societal Impact, Engineering Standards, Ethics, and Safety Considerations:

4.a Contribution to Public Health, Safety, and Welfare:

This project ensures that guitarists can tune their instruments to the fullest with ease. It contributes to public welfare by improving accessibility, usability, and safety in musical practice. Many beginner musicians who struggle with manual tuning will no longer have such difficulties. This will encourage learning and eliminate the risk of improper string tuning that could damage the instrument. Users will achieve tuning quickly and consistently, supporting music education and creative expression.

From an economic perspective, the device minimizes instrument maintenance costs that could result from incorrect tuning. Socially and culturally, music plays an important role in artistic expression worldwide. Improvements to music and easier access to it make it easier for people to participate.

4.b Applicable Engineering Standards

1. IEEE Standards - for electrical system safety and circuit design compliance
2. ACM/IEEE Software Engineering Standards - for coding practices, reliability and system documentation
3. IPC Standards - for PCB design, soldering quality
4. UL / IEC Safety Standards - where applicable, to ensure low-voltage electronics meet consumer product safety requirements

4.c Ethics and Professional Responsibility

For our handheld automatic guitar tuner, ethical considerations include ensuring the device operates safely and reliably without harming users or damaging the instrument. We will communicate the device's limitations as we progress on this project, including tuning accuracy and compatibility constraints across different guitars. Our implementation will include safeguards/thresholds to prevent over-tightening strings or applying excessive torque, which can cause the string to snap and potentially harm someone. Our project does not involve human or animal research, the collection of personal data, or the handling of sensitive information, so IRB and IACUC approval are not required. Overall, our design will prioritize user safety and responsible engineering practice.

4.d Safety

Although our device will operate at low voltage, several electrical and mechanical safety concerns must still be addressed. Some electrical risks can include short circuits, battery overheating, and improper wiring. These risks will be mitigated through regulated power supplies and current limiting. Some mechanical risks include string breakage or excessive motor torque, which will be controlled through software limits and gradual tuning adjustments. During the development of this device, we will follow standard lab safety practices, including proper soldering procedures and safe handling of power supplies. By implementing these precautions, we can minimize risks.

5. Citations:

[1] “Acoustical Physics of Music: Lecture Notes,” Department of Physics, University of Illinois Urbana-Champaign, 2017. Available: https://courses.physics.illinois.edu/phys406/sp2017/Lecture_Notes/P406POM_Lecture_Notes/P406POM_Lect3.pdf