Guitar with Modular Pickups

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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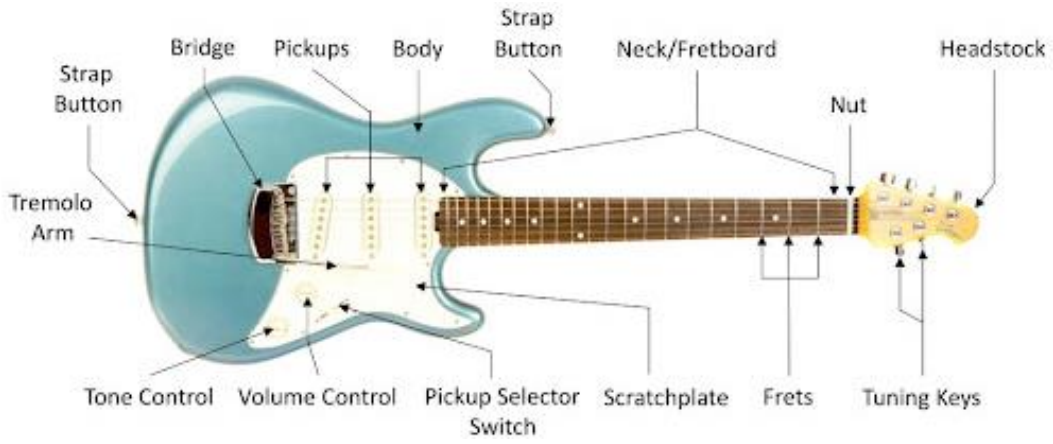
ABSTRACT

This is a one-person senior design project for the Mechanical Engineering Technology class of 2022. I chose to do this project because, being a guitar player for 17 years, I have spent too much time and money trying to get different sounds out of my guitars. After seeing but not being able to afford the few options in the market, I decided to design and construct my own. This document reviews the calculations for the bracket, the design of the bracket and connector , the construction of the guitar, and the eventual outcome of the project.

PROBLEM STATEMENT



(Figure 1: Diagram of a typical electric guitar including the location of the pickups.)

There is a serious lack of guitars with modular pickups in the general and custom guitar market. The pickup, shown in Figure 1, is a component located under the strings where you would strum. The pickup grabs the sound from the strings using magnets under each string and sends it, as an electrical signal, to an amplifier so you can hear the sound louder and add potential effects. All electric guitars have pickups but there are many types and variations of those types. At the moment, one single guitar cannot use or implement all types unless you replace them by soldering a new one in. There are very few if any solutions at the moment that offer an affordable price, ease of use, and the ability to use “off the shelf” pickups.

RESEARCH

BACKGROUND OF THE PROBLEM

When I first got an electric guitar, it was all about the look. The electric guitar comes in numerous shapes and sizes as that is what you immediately notice about the guitar. A visual preference of guitars is an immediate factor in the purchase of guitars. The pickup(s) on the guitar on the other hand may or may not be an immediate factor for many beginner and intermediate guitarists. Mostly experienced guitarists, who have progressed past learning the guitar, are looking to change tone and look into other guitar and pickup choices. There are many kinds of pickups from single coil to humbucker as shown in figure 1 (1). Each pickup produces a different tone. Even two pickups of the same type can have a different tone.

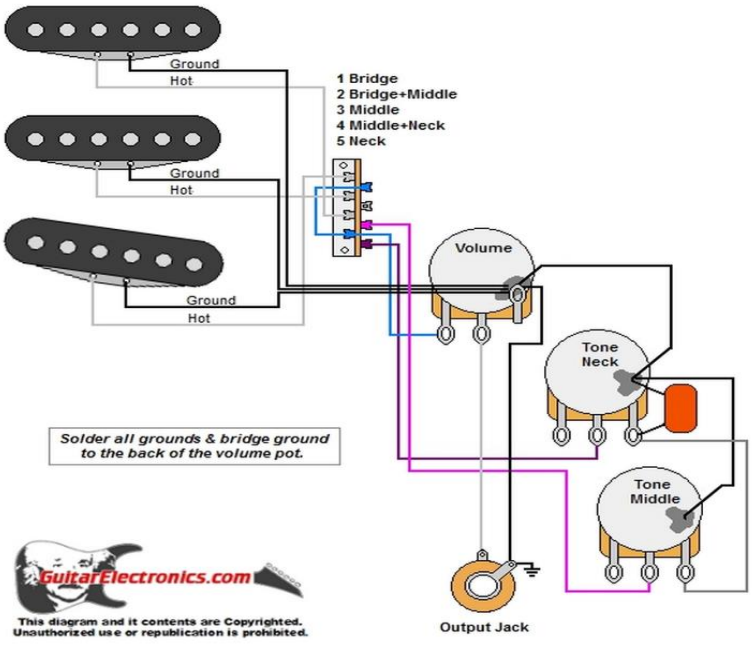
(Figure 2: A single coil pickup (left) and a humbucker pickup (right).)

An electric guitar will generally only have one type of pickup. If you would like to try another pickup, you have two main options. These options are to buy a pickup from a music store or online and un-solder the old pickup(s) and replace them or buy a new guitar that has the pickups you like (2). Both of these options have their own cons. If you do not have a soldering iron or do not know how to use one you might have to pay for someone to solder them for you. A separate issue is having to cut and restring your guitar if you want to put new pickups in your guitar. If you do not have a lot of money, you might not be able to buy a new guitar if you want to try new pickups (2).

One solution is to have a purpose-built electric guitar with the ability to swap out pickups with different cartridge slots for pickup variation. The pickups and their wiring would be separate from the guitar's body (3). These cartridges would most likely be expensive and also proprietary to said guitar (4). This method would avoid having to restring your guitar only if the cartridge is inserted from the back of the guitar's body. If inserted from the front of the guitar, then the strings are still in the way. This only solves part of the problem.

Another solution is to have a guitar with a pickup swapping station(s) for any type of pickup. This way you could use all or many of "off-the-shelf" pickups straight on to the guitar with a quick connector. Types of connectors could be pin connectors, clips, toolless wire connectors, keyed connectors, or locked connectors (5). To avoid having to restring the guitar, there would have to be a notch cut out of the body to allow for the pickup to slide under the strings in a clean and smooth manner without catching on anything.

APPLICABLE STANDARDS



(Figure 3: Shows the wiring diagram for a 3-pickup guitar.)

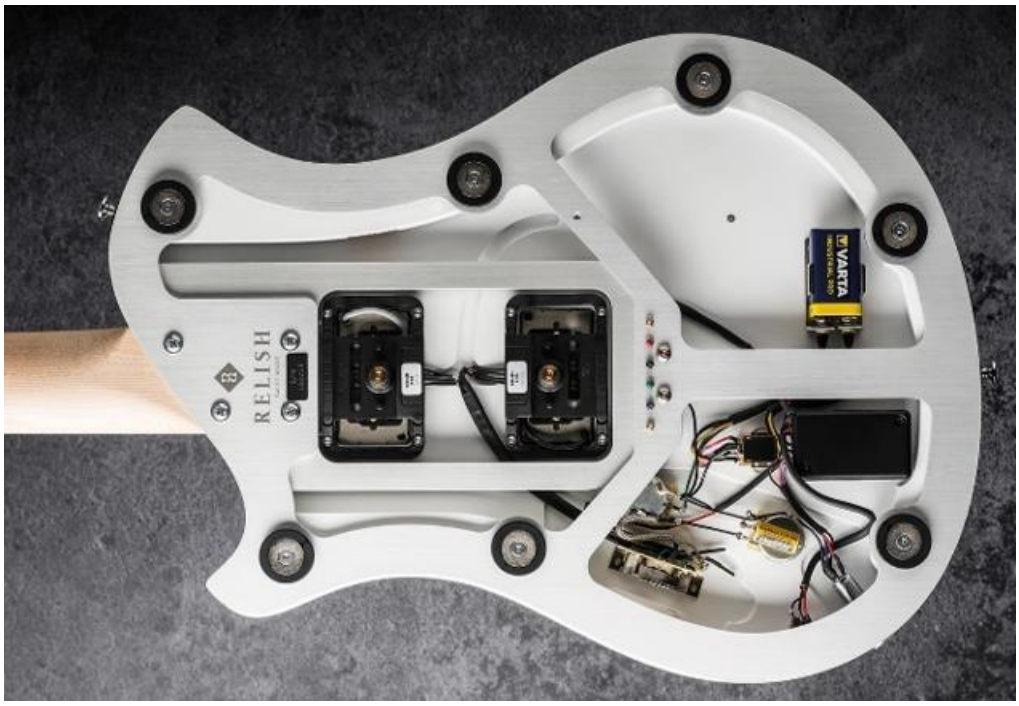
This guitar must conform to NFPA 70 Electrical Standards. Must conform to IEC and UL Standard 60947-7-4, 61058-1-1, and 61058-1-2.

Most of the time, copper wire is preferred when wiring a guitar. Aluminum is also popular. Platinum, iron, gold, and silver are also available options, but are rarely used in guitars. Silver is the most conductive, but its price is high, so it is not generally preferred. All wire in a guitar can be the same type and one way of wiring a guitar is shown in Figure 3. Solder is usually preferred for wiring because of its secure connection but any connection for low-voltage wiring is acceptable, such as pinch connectors, or lever connectors.

STATE OF THE ART

(Figure 4: Three of the available, proprietary cassettes for the Boaz design.)

The Boaz One is a modular guitar designed by Israeli American luthier Boaz Elkayam. This guitar has cassette or cartridge style modular pickups, shown in Figure 4, that can be swapped back and forth in fifty different combinations (6). These cartridges come pre-configured with a set of pickups, so you cannot use your own. The guitar is made of injection molded plastic, so it is quite different from a traditional guitar (6). The styling is also vastly different from a traditional shape, looking more like a useful tool than an artistic instrument.



(Figure 5: The reverse side of the Mary Relish One where the pickups are inserted.)

The Relish Mary One, shown in Figure 5, is built by Relish Guitars in Switzerland, which allows access to all the internals via the back of the guitar (7). Its entire back is a removable panel which is held by magnets. Once removed you can switch whatever you would like, including the pickups. You are also able to change the height of the pickup to get a clearer and smoother sound. This instrument is hand-made and looks more like a traditional guitar. This guitar is expensive as it is made with the finest materials (7).

(Figure 6: An available cartridge from Somnium with a preinstalled P-90 pickup)

Somnium guitars are guitars that have the ability to accept cartridges that either come with preinstalled pickups or you can install your own with screws (8). These cartridges, as shown in Figure 6, are installed from the back of the guitar, avoiding having to restring. The cartridges are expensive and the guitar itself is priced fairly high. Once purchased you would only have to purchase the pickups you would like from any retailer or purchase from their preinstalled pickup cartridges.

END USER

The primary end user of the modular guitar would be a late intermediate to experienced guitarist that is remarkably familiar with the instrument. They would have passed the point of learning guitar and progressed into experimentation and “tone chasing”. They would be someone who has or wants many guitars and tones but might not have a ton of room or money. This guitar would be a replacement for five or more guitars in one. Instead of having an ample collection of guitars they could have just a few or even just the one.

The secondary end user would be a salesperson. This salesperson or retailer might want to have a way for customers to try the sounds of different pickups for easy comparison. If a customer can easily try many different pickups, they are more likely to be satisfied with their purchase in a pickup specifically, or a guitar with those pickups.

SUMMARY OF RESEARCH

In summary, the ideal solution for the majority of guitarists to purchase an electric guitar with modular pickups does not exist. A near ideal solution, using this research as a basis, could be made, and improved upon for different problems. A solution would need to be able to look and function like a traditional guitar. It also needs to be simple to operate and swap pickups quickly without taking the guitar off one’s body. It would need to cost a realistic amount for the slightly above average player without compromising too much playability, craftmanship and durability.

QUALITY FUNCTION DEPLOYMENT

CUSTOMER FEATURES

I surveyed a total of thirty people. The features along with averaged responses based on a scale of 1-5 (1 being of low importance and five being of high importance) are shown in Figure 7 below.

Customer Feature	Average Response
Initial Investment Cost	3.67
Ease of Swap	3.83
Safety of Connection	3.03
Product Life	4.53
Cost of Maintenance	3.27
Build Quality	4.23
Aesthetic Appearance	3.30
Use of “off the shelf” Pickups	3.69

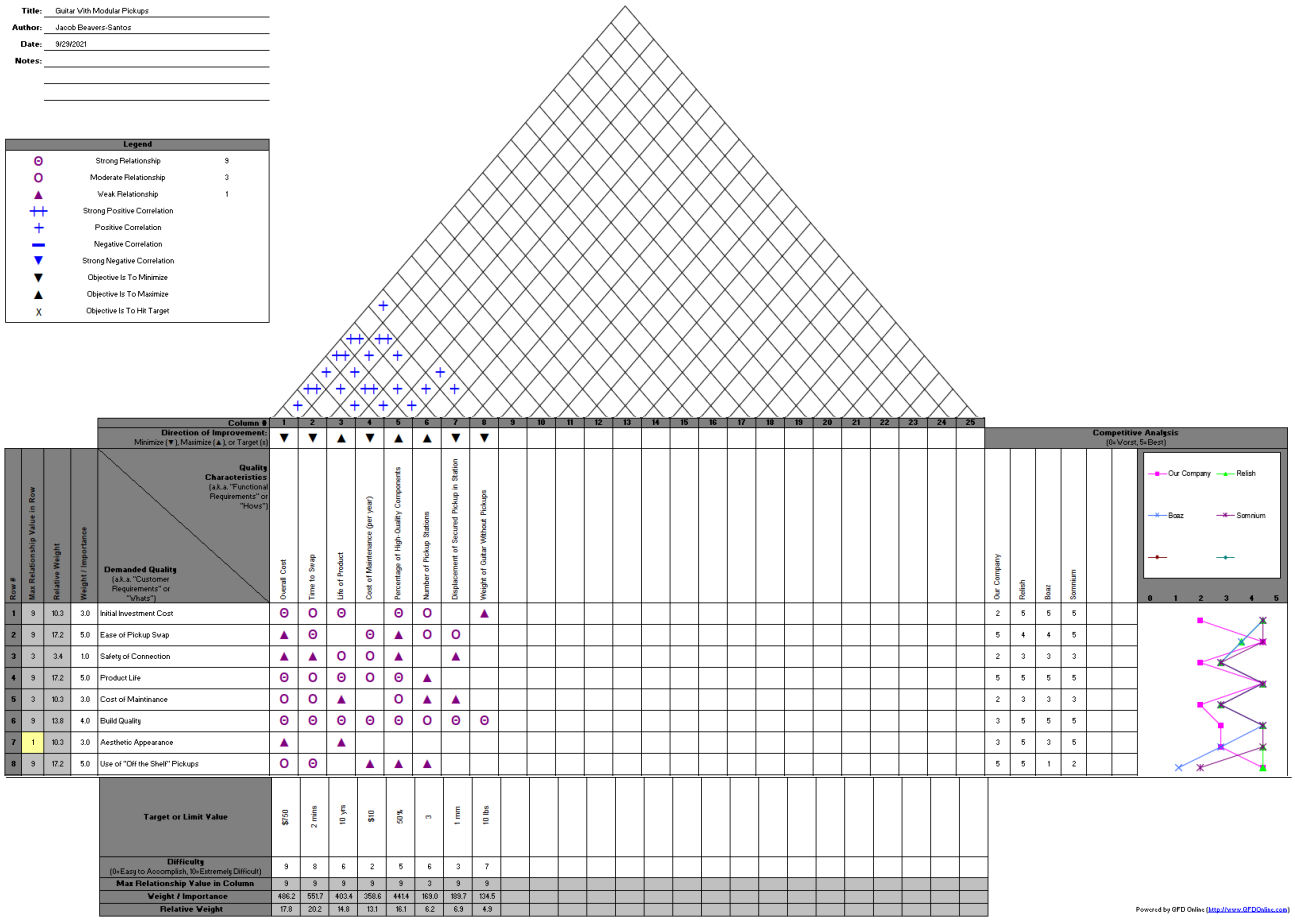
(Figure 7: Customer Features gathered from a survey of thirty people)

ENGINEERING CHARACTERISTICS

Through further thought and after reviewing my survey, I narrowed down exactly how to describe my customer features in measurable figures. This led to the following list of engineering characteristics.

1) Overall Cost ($)
2) Time to Swap (sec/min)
3) Life of Product (yrs.)
4) Cost of Maintenance per year ($)
5) Percentage of high-quality components (%)
6) Number of Pickup Stations (#)
7) Displacement of Pickup in station (mm)
8) Weight of Guitar without pickups (lbs.)

HOUSE OF QUALITY



Title: Guitar With Modular Pickups
Author: Jacob Beavers-Santos
Date: 9/29/2021
Notes:

Legend

⊙	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
X	Objective Is To Hit Target	

Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Overall Cost	2 Time to Swap	3 Life of Product	4 Cost of Maintenance (per year)	5 Percentage of High Quality Components	6 Number of Pickup Stations	7 Displacement of Secured Pickup in Station	8 Weight of Guitar Without Pickups	Our Company	Relish	Boaz	Somnium
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (±)	▼	▼	▲	▼	▲	▲	▼	▼					
1	9	10.3	3.0	Initial Investment Cost	⊙	O	⊙		⊙	O		▲	2	5	5	5	
2	9	17.2	5.0	Ease of Pickup Swap	▲	⊙		⊙	▲	O	O		5	4	4	5	
3	3	3.4	1.0	Safety of Connection	▲	▲	O	O	▲		▲		2	3	3	3	
4	9	17.2	5.0	Product Life	⊙	O	⊙	O	⊙	▲			5	5	5	5	
5	3	10.3	3.0	Cost of Maintinance	O	O	▲		O	▲	▲		2	3	3	3	
6	9	13.8	4.0	Build Quality	⊙	⊙	⊙	⊙	⊙	O	⊙	⊙	3	5	5	5	
7	1	10.3	3.0	Aesthetic Appearance	▲		▲						3	5	3	5	
8	9	17.2	5.0	Use of "Off the Shelf" Pickups	O	⊙		▲	▲	▲			5	5	1	2	
				Target or Limit Value	$750	2 mins	10 yrs	$10	50%	3	1 mm	10 lbs					
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	9	8	6	2	5	6	3	7					
				Max Relationship Value in Column	9	9	9	9	9	3	9	9					
				Weight / Importance	486.2	551.7	403.4	358.6	441.4	169.0	189.7	104.5					
				Relative Weight	17.8	20.2	14.8	13.1	16.1	6.2	6.9	4.9					

Competitive Analysis (0=Worst, 5=Best)

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PRODUCT OBJECTIVES

Initial Investment Cost (10.3)

I plan to use middle of the road materials for everything that is not a part of the pickup and its connections.

Ease of Swap (17.2)

The design of the guitar should be familiar to guitarists so that they know what they are looking at and might be able to figure out how to use it without needing to look at a manual. The method of securing the pickup should be easy to understand.

Safety of Connection (3.4)

The connection of the pickup to the guitar should be solid and not come loose or completely apart.

Product Life (17.2)

The guitar will be built with years of use in mind and will endure above normal abuse.

Cost of Maintenance (10.3)

Small things like replacing screws or greasing a small component may need to be completed as heavy use of guitars is undeniable.

Build Quality (13.8)

Medium quality parts will be used on everything not related to the pickup. Keep the quality higher than a budget guitar but the price lower than most specialty guitars.

Aesthetic Appearance (10.3)

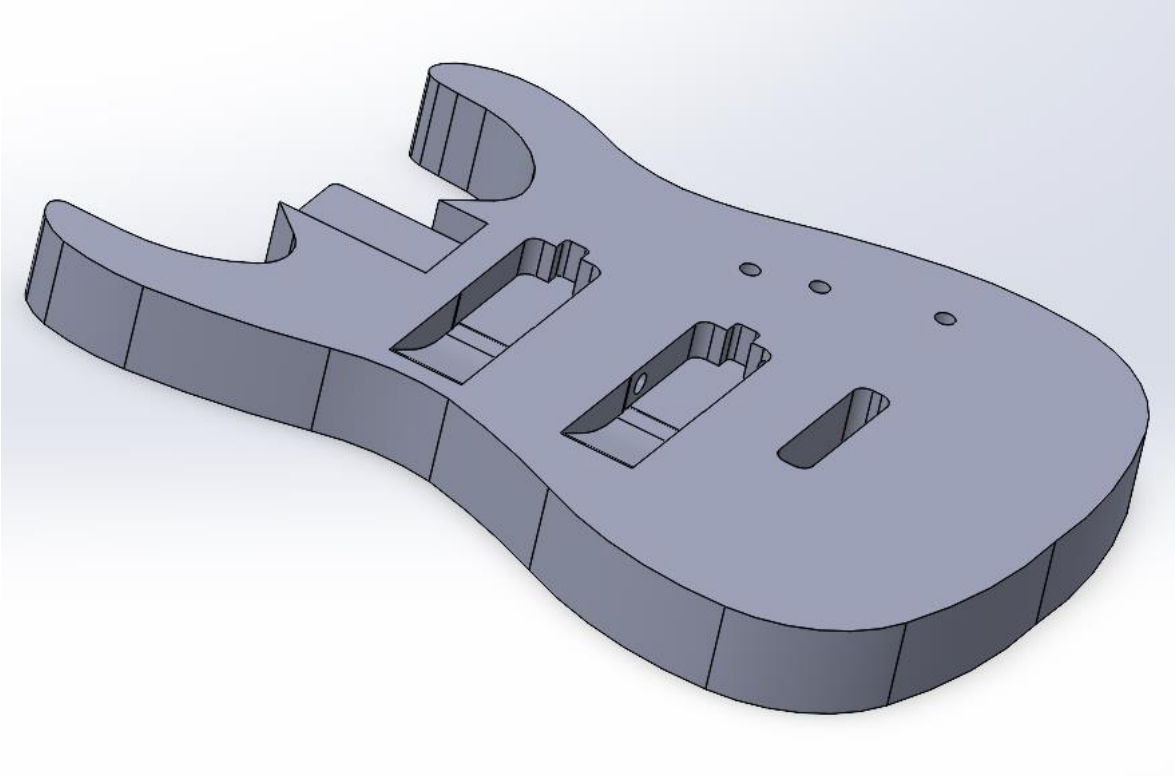
The design will retain a traditional overall design so that anyone, guitarist or not, could look at it and know it was a guitar.

Use of “off the shelf” pickups (17.2)

The pickup stations will allow any pickup type to be used.

DESIGN

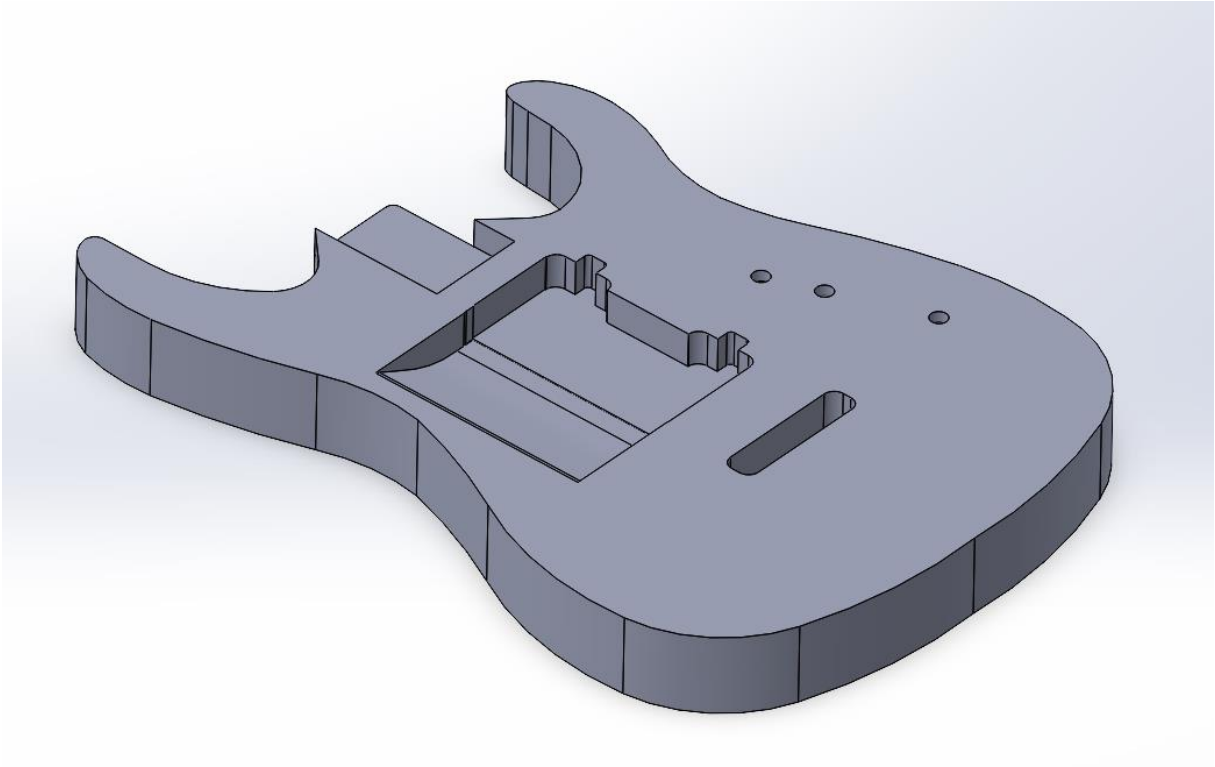
DESIGN ALTERNATIVES AND SELECTION



(Figure 8: Concept 1, with one or two slots on the front of the guitar.)

In this concept, there will be one or multiple individual pickup stations. They will each have a slot on the front of the guitar. These slots allow the guitarist to slide a pickup in and out without having to take the strings off or even take the guitar off their body. Each station will have an aligning track with a quick connector inside.

This concept could use a common body design with slight alteration to the cutouts. The drawbacks of this design are that it does not look “new” or fresh. It also might be difficult to create a mechanism to hold the pickup securely while still allowing the pickup to easily be removed in a timely fashion.

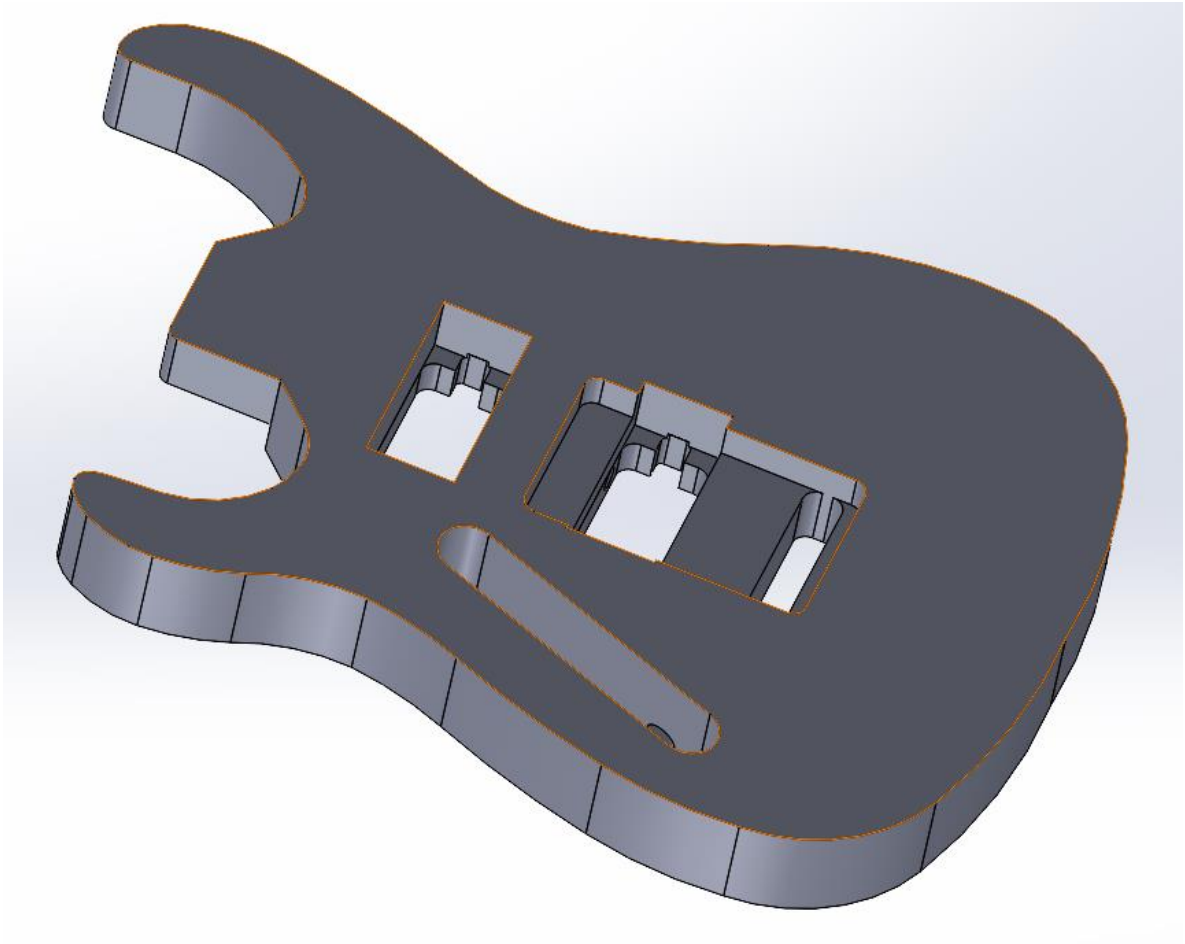


(Figure 9: Concept 2, with one large slot for pickups to slide into.)

In this concept, there will be one large slot that holds all pickups. The slot is on the front of the guitar. This slot allows the guitarist to slide a pickup in and out without having to take the strings off or even take the guitar off their body. The station will have an aligning track with a quick connector fixed inside.

This concept could use a common body design with a slight alteration to the cutouts. The cutout would be easier to do because it is only one slot. The drawbacks of this design are that it does not look “new” or fresh. It also might be difficult to create a mechanism to hold the pickup securely. Even more difficult than the first concept. This guitar would also be lighter due to removing much more wood to make the large slot. Less wood could affect strength of the body which could cause potential cracking or bending of the wood.

Concept 3:



(Figure 10: Concept 3 with Pickup slots on the back of the guitar.)

In this concept, the stations are accessed from the back of the guitar. This slot allows the guitarist to slide a pickup in and out without having to take the strings off. Along with that, the guitarist should not even have to take the guitar off his body to swap pickups. The stations will have alignment pins with a securing mechanism for each pickup.

This concept could use a common body design with a slight alteration to the rear of the guitar. The cutout would be more difficult to do as there would be a through hole for each station. This leaves the pickup with not much room to be secured to the wood. Also, the guitarist would have to take the guitar off his body to swap pickups. Might require a back plate or extra sanding to the body to round corners of the back cavity.

Final Selection:

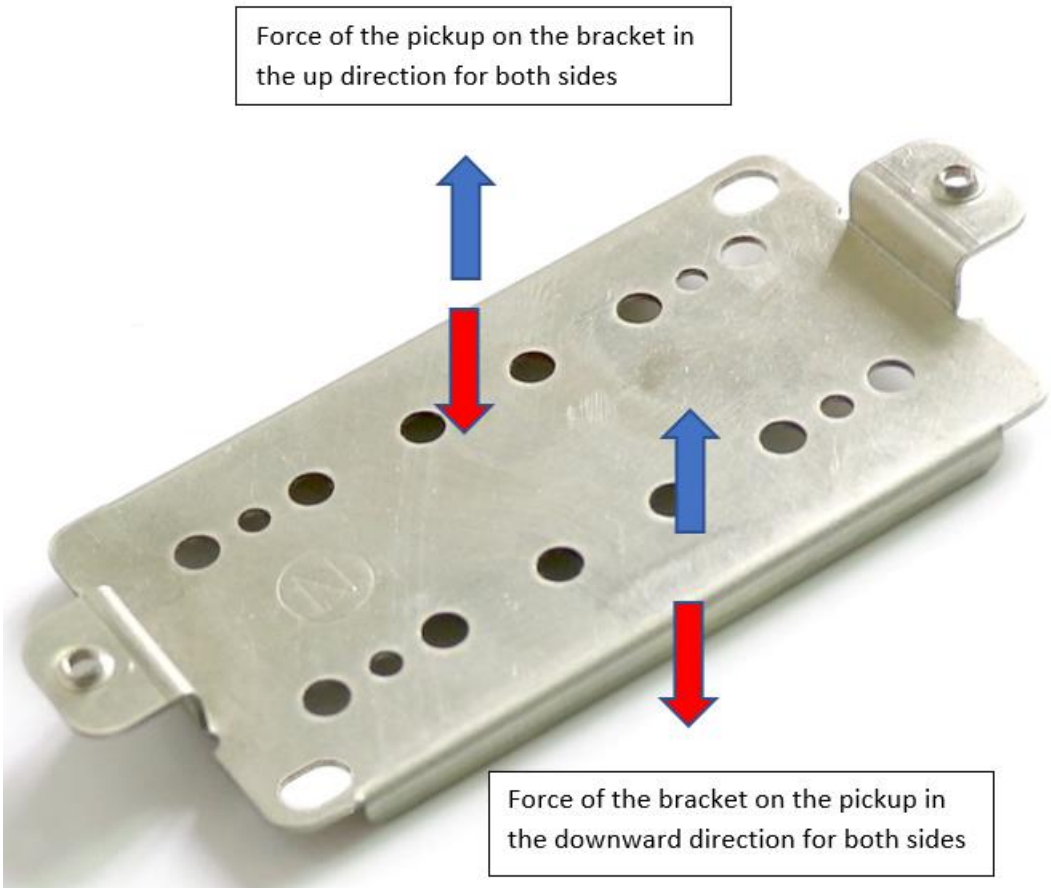
I chose to go forward with concept one, but I altered it to only have one pickup slot near the bridge of the guitar. This way I could use the space above the pickup to secure the quick connector to. Also, I would save time removing wood by hand to create the slot and could route it out. This concept retains a classic Stratocaster style body so it is familiar, but it has the slot for the pickup so that if you know what you are looking at, you will know something is different.

ENGINEERING CALCULATIONS

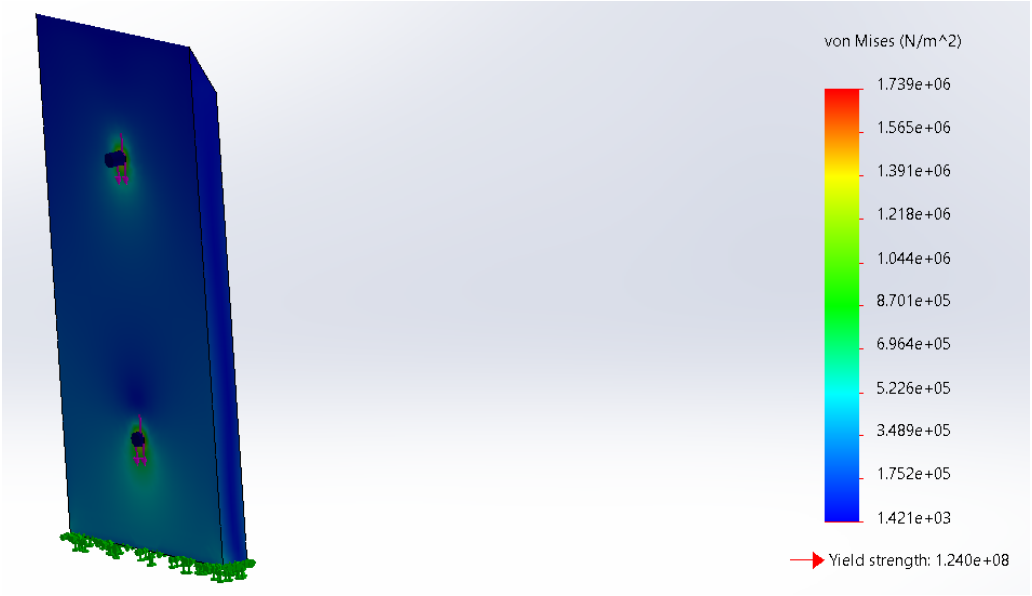
The size of the channels for the pickups to be installed are based on the largest size of pickup. Using information gathered from my own personal guitars and the pickups on the market the channels will be 3.5 inches long, 1.5 inches wide, and 1.2 inches deep. Bringing the volume to be (3.5) * (1.5) * (1.2) = 6.2 in^2

There will be no loading conditions except for the weight of the pickup on the brackets
A single pickup can weigh anywhere between 3 and 10 oz.

(Figure 11: Forces on the pickup.)



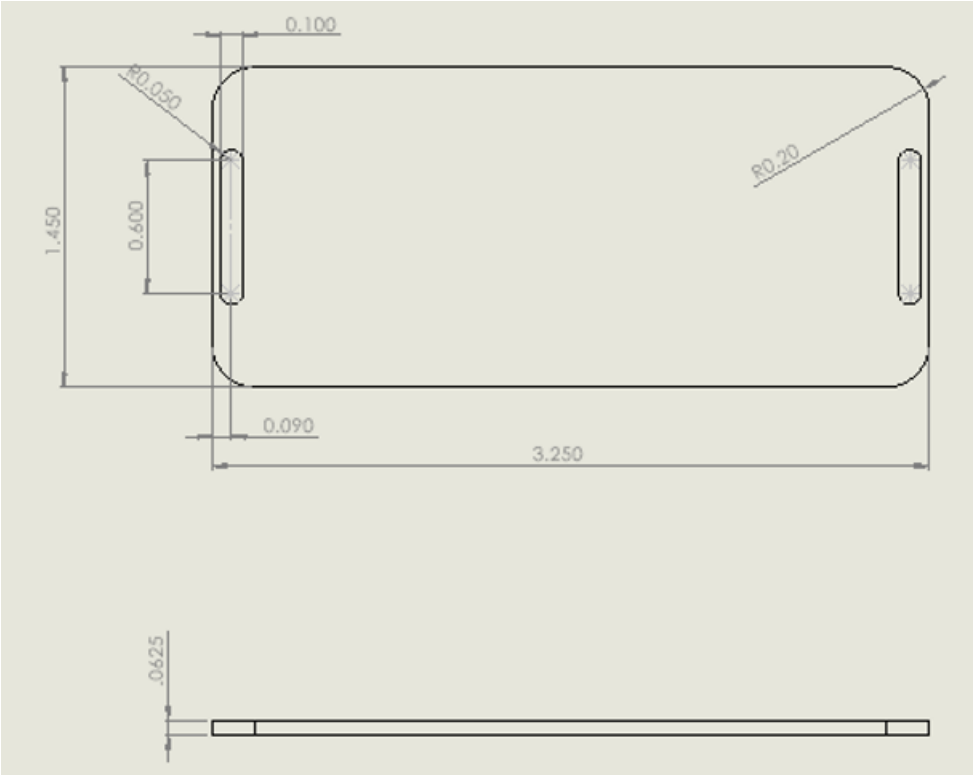
(Figure 12: Forces between the pickup and the bracket.)



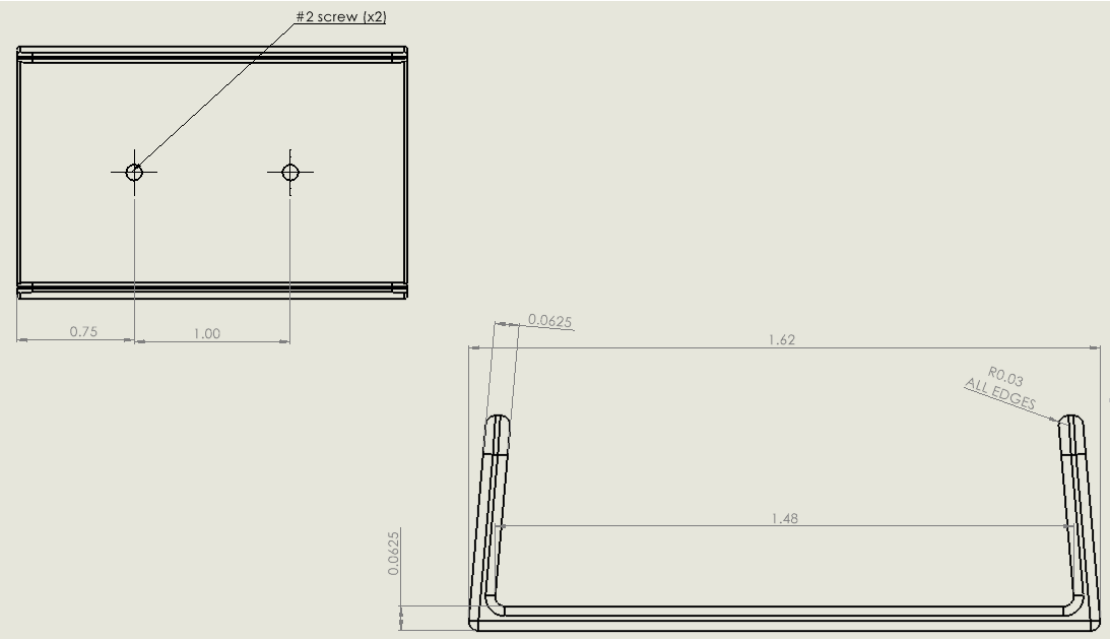
(Figure 13: FEA Analysis)

It was calculated that this design has a safety factor of 7.194

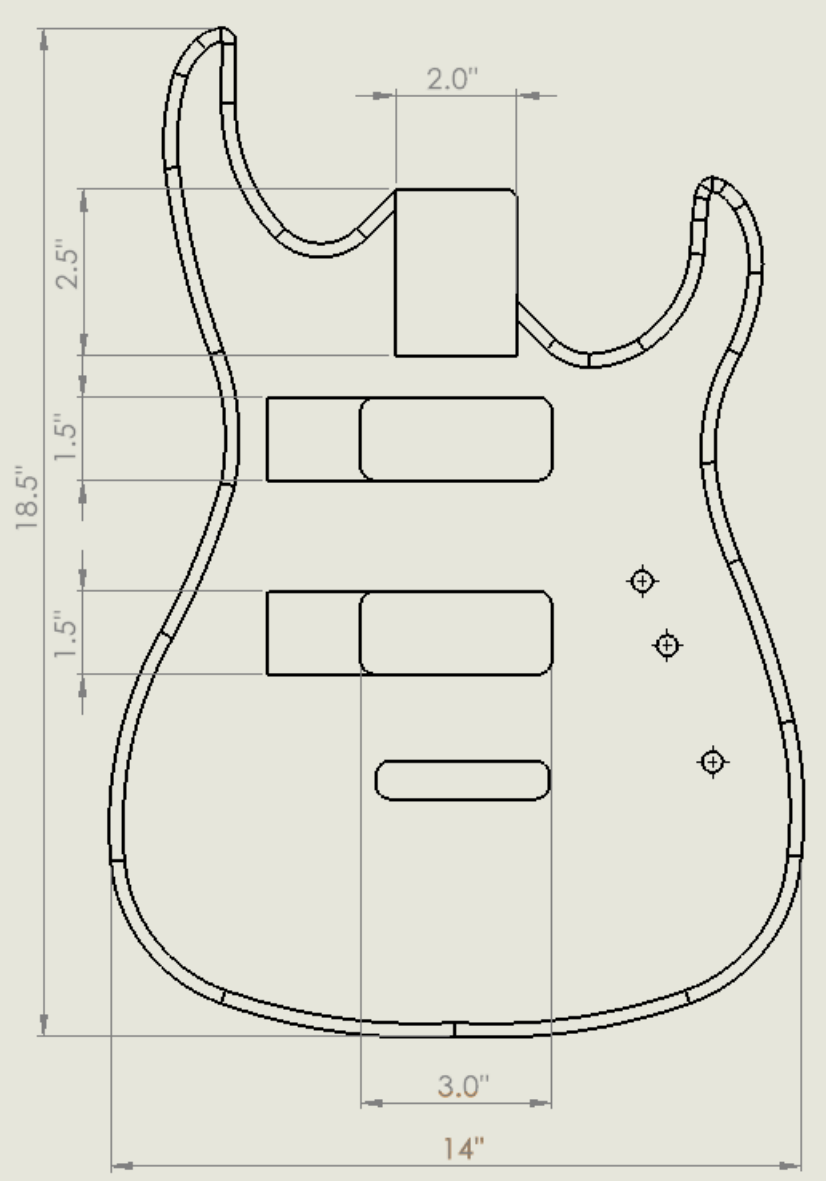
MANUFACTURING DRAWINGS



(Figure 13: Plate Drawing)



(Figure 14: U Bracket Drawing.)



(Figure 15: Guitar Body Drawing)

BUILD AND TEST

MANUFACTURING PROCESSES

A band saw was used to cut out the shape for the body of the guitar. I used a router to cut the cavities in the guitar body as shown in Figure 15. I then used a sander, dremel, and sandpaper to shape the guitar and the slot for the pickup to slide in and out of.

Three nickel-silver rectangles were cut with a bandsaw. Two were for the pickup plates shown in Figure 13, and one for the bracket shown in Figure 14, that the plates slot into. A drill and tap were used for both the plates and the bracket. I used the drill to drill two holes in all three of them. I then used the tap to thread the holes in the plates where the pickup would be screwed to. I used a bench vice to hold the bracket and bent the two ends using a hammer and mallet. I then used a tabletop grinder to smooth all edges and to make all three parts fit their intended dimensions. I used wood screws to fix the bracket to the pickup cavity. I screwed the pickups to their respective plates.

I used wire strippers to separate the hot and ground wires from the pickup and the hot and ground wires that go to the volume and output jack of the guitar. I soldered all the regular wiring together which is no different from a traditional guitar. I attached the hot and ground from the guitar to the quick connector and fastened it to the guitar with Velcro strips so it can be easily removed. I used a drill and screws to add all normal guitar parts to the body including the neck.

TEST PROCEDURE AND RESULTS

Time to Swap (sec)	**Sound after swap (Y/N)**	**Volume Works after Swap (Y/N)**
25.1	Y	Y
21.6	Y	Y
29.2	Y	Y
19.8	Y	Y
24.5	Y	Y
AVG = 24.04	Y = 5/5, N = 0/5	Y = 5/5, N = 0/5

(Figure 16: Test Results)

The test results in Figure 16 show the vast improvement to the swap time while the sound and volume remain functional. The time to swap went from 25 minutes on average to an average of 24.04 seconds. This is 62.5 times faster than a regular electric guitar. The sound and volume both were operational in all five tests with no issues.

PROJECT MANAGEMENT

BUDGET AND BILL OF MATERIAL

ITEM	QUANTITY	COST W/TAX	Purchased
Guitar Kit w/ Unfinished Body	1	112.86	1
Extra Guitar Wire	1	12.79	0
Soldering Iron + 60/40 Solder	1	42.80	0
Sand Paper Variety Pack	1	10.70	0
Wood Carving Kit	1	31.02	0
18% Nickel Silver Sheet - 6" x 6" x 1/16" (0.0625", 1.587mm)	1	24.77	0
Humbucker Pickup	1	20.00	0
	TOTAL	254.94	1

(Figure 17: Proposed Bill of Material)

ITEM	Qty Needed	Qty Purchased	COST W/TAX	Purchased
Guitar Kit w/ Unfinished Body	1	1	112.86	112.86
Extra Guitar Wire	1	0	12.79	0.00
Soldering Iron + 60/40 Solder	1	0	42.80	0.00
Sand Paper Variety Pack	1	0	10.70	0.00
Wood Carving Kit	1	1	31.02	31.02
18% Nickel Silver Sheet - 6" x 6" x 1/16" (0.0625", 1.587mm)	1	1	24.77	24.77
Humbucker Pickup	1	1	20.00	20.00
Wire Strippers	1	1	12.88	12.88
Metal Drill Bit	1	1	5.29	5.29
Thread Tap	1	1	5.29	5.29
4 Screws	4	4	0.75	3.00
Velcro Strips	1	1	3.88	3.88
Dremel w/ attachments	1	1	42.59	42.59
3 Wire Quick Connectors	1	1	12.56	12.56
TOTAL	**17**	**14**		**274.14**
			Budget	**500.00**

(Figure 18: Final Bill of Material)

After consideration of parts I would like to use and miscellaneous extra parts and tools, I produced a budget of $500 for the guitar. The total amount spent ended up being close to the original amount and well below my $500 budget. From the original Bill of Material, I ended up getting extra guitar wire, a soldering iron, and sandpaper for free. I did have to buy more things that I had not considered which brought up the cost a little. Altogether I only used around 55% of my budget so that was great.

SCHEDULE

Dates	Milestones Completed
11/30/2021	Finalize design and find parts for purchase
12/11/2021	Christmas Break Begins
1/10/2022	Christmas Break Ends
1/15/2022	Acquire and layout all parts to make sure everything is in the right place
1/17/2021	MLKJ Day
1/21/2022	Modify body of guitar for modular stations. Manufacture and test fit parts
2/25/2022	Add all normal hardware to guitar unrelated to the modularity
3/25/2022	Complete wiring
4/8/2022	Test guitar and perfect part placement and secure pickups
4/14/2022	Tech Expo Day

(Figure 19: Proposed Schedule)

Dates	Milestones Completed
11/30/2021	Finalize design and find parts for purchase
12/11/2021	Christmas Break Begins
1/10/2022	Christmas Break Ends
1/15/2022	Acquire and layout all parts to make sure everything is in the right place
1/17/2021	MLKJ Day
1/21/2022	Modify body of guitar for modular stations
2/25/2022	Add all normal hardware to guitar unrelated to the modularity
3/25/2022	Complete wiring and manufacturing of brackets
4/8/2022	Test guitar and perfect part placement and secure pickups
4/14/2022	Tech Expo Day

(Figure 20: Final Schedule)

Overall, the final schedule kept close to the original schedule. The only miss step was that the sheet of nickel-silver came 2 months late causing a delay in fabrication of the bracket and pickup plates. Changes to the schedule are shown above and highlighted on the final schedule shown in Figure 20.

CONCLUSIONS

The guitar functions well and pickups can be swapped very quickly and easily when compared to any other traditional electric guitar for $500 or less. The goal was to make the guitar look and sound like a regular guitar while being able to switch pickups in under 30 seconds without re-stringing or removing the guitar from a player's body.

The bracket, while it keeps the pickup mostly in place it allows the pickup to move up and down a little bit more than it should. Tweaking to the angle of the sides of the bracket are needed. Also, the smoothness of the pickup removal process could be improved in several ways. It would be better if the slot were carved out a little more for the pickup to have more room to slide out. The wiring could also be more concise. It may be possible to fix the wire connections to the bottom or one side of the pickup so it would automatically slide into a connector with no need for connecting hot and ground wires individually. This would allow more room for additional pickups and allow for a cleaner construction. Another change would be to make the guitar have a fixed bridge so that more room in the back cavity could be used for the pickup system.

Overall, the guitar is an adequate solution to the current problems from guitarists. This electric guitar with modular pickups was able to allow pickup swapping in under 30 seconds. It allowed swapping without re-stringing. The swapping could occur without removing the guitar from the player's body.

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APPENDIX A

BLANK SURVEY

1. How important is each feature of a Modular Pickup system?
1 = Low Importance 5 = High Importance 0

	1	2	3	4	5
Initial Investment Cost	☐	☐	☐	☐	☐
Ease of Pickup Swap	☐	☐	☐	☐	☐
Safety of Connection	☐	☐	☐	☐	☐
Product Life	☐	☐	☐	☐	☐
Cost of Maintenance	☐	☐	☐	☐	☐
Build Quality	☐	☐	☐	☐	☐
Aesthetic Appearance	☐	☐	☐	☐	☐
Use of "off the shelf" Pickups	☐	☐	☐	☐	☐

2. What did I not include or consider in the ranking that I should have? 0

3. Which pickup locations should be included in the guitar and have the ability to be swapped? 0

- ◯ Bridge, Middle, and Neck Pickups
- ◯ Bridge and Neck Only
- ◯ Bridge Only
- ◯ It makes no difference to me.

4. How much would you be willing to spend for this guitar with the price reflecting the overall craftsmanship?
0

- $0 - $500
- $500 - $1000
- $1000 - $5000
- $5000+

5. Why should I consider your responses? (How long have you played guitar? Have you worked on your own or other's guitars? etc.) 0

APPENDIX B

FINAL BUILD

(Figure 21: The final build of the guitar with modular pickups)