ABSTRACT

Title of Thesis:	ACTIVE INSTRUMENT CABLES WITH BUFFER AMPLIFICATION
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"When connecting electronic instruments to power amplifiers with traditional passive instrument cables signal attenuations can occur due to several factors such as signal reflections and cable capacitance. This thesis examines the possibility of better preserving electronic instrument signals by using buffer amplification built into instrument cables. Active instrument cables were developed that are powered by an internal AA battery in a form factor similar to traditional passive cables. The goal was to achieve a design that was small and had substantial battery life such that the product would be marketable to musicians."

ACTIVE INSTRUMENT CABLES WITH BUFFER AMPLIFICATION

by

Timothy A. Babich

Thesis submitted to the Faculty of the Graduate School of the
University of Maryland, College Park in partial fulfillment
Of the requirements for the degree of
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Advisory Committee:

    Professor Patrick O'Shea
    Professor Bruce Jacob
    Professor Romel Gomez

Dedication

This thesis is dedicated to the memory of Alex Brown in honor of his contributions to the field of engineering, his passion for music, and his inspiration to others.

Acknowledgements

I would like to thank my advisor Dr. Patrick O'Shea for his many words of wisdom and encouragement in addition to his contributions as my advisor for this thesis.

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CHAPTER 1: INTRODUCTION

Introduction

The art of guitar design and electromagnetic induction blended for the first

time in the late 1920's to conceive the world's first electric guitar. This innovation

captivated listeners and has continued to develop into one of modern culture's

most popular instruments. Part of the electric guitar's appeal can be attributed to

the immense range of sounds that it is capable of producing. With an electric

guitar, the musician becomes capable of tailoring his or her sound for a specific

musical environment by shaping and changing the electronic guitar's signal. The

ability to control the sound and tone of the instrument is an essential need for

musicians, yet it is one that is often difficult to achieve.

Under sponsorship of MIPS (Maryland Industrial Partnerships) and Coil

LLC we launched a research and development project to reconcile this issue in

modern guitar electronics. This thesis will examine the conclusions of the

research project.

In the several decades since the advent of electrical guitars a variety of

signal processing equipment has been developed to provide musicians with

additional control of guitar tone. However, to enable a musician to fully engineer

the sound of his or her guitar it is critical to first preserve the original guitar signal;

a key concept that is often overlooked in the shadow of high-tech equipment.

Therefore the research became focused on signal integrity. Rather than examine

new methods for tone shaping the project worked towards ensuring that the tone

pallet of a guitarists was not limited by unintentional signal attenuation.

Most modern electrical guitars suffer from signal loss in the early stages of sound production primarily due to reflection caused by poor impedance matching. This is because the internal electronics of a guitar tend to have an output impedance that is higher than the load of the instrument cable used to connect the guitar to an audio amplifier. This issue is particularly damaging to the high frequencies that are credited with making bright or warm tones.

In the past, impedance matching issues have been addressed by adding buffer amplifiers to the guitars. The obvious concern with such a practice is that it requires a power source in an otherwise passive electrical guitar. Furthermore, adding such a feature to existing guitars can be troublesome and expensive. Despite the added tone benefits of buffer amplifiers their popularity has declined and they are now relatively uncommon.

A less invasive and simpler solution was proposed as part of our research venture. The concept was to create active guitar cables with buffer amplifiers and create an alternative to building active electronics into guitars. By doing so, musicians interested in signal preservation would neither require expensive new electronics to be installed into their guitar nor purchase a new guitar. In addition, the benefits of the buffer amplifier could be applied to any number of electrical instruments by merely using the active cable in place of a traditional passive cable. The goal was to make the active cables low cost and as user friendly as a traditional cable.

After creating the first prototypes based on the designs of common guitar

buffer amplifiers, we found that prior attempts to make active cables had been done in the past. However, these efforts were unsuccessful in the market due to overly large form factors and external power needs. Therefore the direct task of the research became making active cables with a non-intrusive form factor powered by common household batteries.

At this point in the project, the goal has been reached. New patents will be pursued in the near future while Coil LLC approaches audio component manufacturers to mass produce and commercialize the designs.

CHAPTER 2: BACKGROUND INFORMATION

Electric Guitar History

The first electric guitar is widely believed to have been invented in the late 1920's. The precise date and person credited with the invention is a subject of debate. However, we do know that the popularity of electrical guitars was first driven by their ability to be amplified and therefore compete with other instruments.

At the time jazz orchestras were a favorite evening pastime. Jazz guitar players could not easily be heard against the overwhelming sound of a full brass section. Guitarists struggled to be heard in the mix and were rarely granted the honor of taking a solo. 1920's microphone technology was limited and far from ideal for guitars. Electric guitars quickly became a more practical solution. (13)

For the first time in history jazz guitarists were able to become more than a rhythm instrument. The ability to take solos and drive lead melodies instantly fueled the appeal of guitar playing. Direct guitar amplification did not simply make guitars louder; it created a new style of instrument and offered musicians a new type of energetic and aggressive sound. This new characteristic grew mutually with the spirit of Rock and Roll that began to surface in the 1950's. At this time, guitars quickly became more popular and have been a staple of popular music ever since. (13)

Most electric guitars generate sound with electromagnetic induction; the

vibration of metal strings is converted into an electric potential. Magnetic coils called pickups are placed under the guitar strings and the motion of the strings is imitated by the changing flux in the magnetic field. The effects of this process are manifested in the form of a voltage signal. (13)

The signal is then sent to a power amplifier because it is not strong enough to drive a loudspeaker. Once amplified and connected to a loudspeaker, the speaker cone vibrates physically moves air molecules at frequencies dictated by the received electrical signal; thereby creating the guitar sound that is ultimately heard. Other types of pickups exist such as optical and piezoelectric, however they are less common and beyond the scope of this paper.

The sound produced by an electric guitar is the product of several mechanisms but it is primarily influenced by the pickups. Conversely, acoustic guitars are much more dependent on vibrations of the wooden guitar body as well as the air within it. That is not to say that building materials and body shapes do not affect an electric guitar's tone. The vibration of the strings and pickups on an electric guitar are subject to all of the guitar's physical attributes. Engineering the electronics to compliment the wood and hardware is a fascinating art. Nonetheless, pickups are the epicenter of electric guitar tone; manipulating the signal created by the pickups is key element for controlling electric guitar tone.

Modern guitar innovation focuses on tone control through electrical manipulations and new technology and designs are constantly being introduced to the market. However, the design of the physical guitar has more or less

remained consistent since 1954 when Fender and Gibson released their Stratocaster and Les Paul models respectively. To this day the overwhelming majority of electric guitar bodies are based strongly on those two designs or even copied directly. (13)

As body designs became relatively standardized electrical manipulations of guitar tone became popular in order to create unique instruments. By the late 1960's it became common practice to add additional signal processing to guitar setups in the form of a stomp-box. Stomp-boxes, also known as effects pedals, are generally small metal boxes with a foot switch that enables the user to apply or bypass the tone shaping circuit it contains.

Some of the earliest and still prominent stomp-boxes were built with single stage amplifiers designed to amplify the guitar signal until it reached the supply voltage and cause clipping. In other words, the signal is amplified too much and consequently part of it is cut off. This form of distortion shapes the signal into a semblance of a square wave with odd harmonics dominating the sound. Other common stomp-box effects include phase shifting, frequency filters, and delays.

Digital effects became popular beginning in the 1980's and have continued to become more common. The primary attraction to digital effects is the ability to model the sounds of multiple analog stomp-boxes as well as various guitars and guitar amplifiers. Purely digital guitars are still uncommon, but easily available to consumers nonetheless.

While digital effects continue to improve many musicians maintain the belief that digital effects are inferior to analog electronics. Older technologies are

often perceived as having additional tonal qualities that digital modeling has yet to capture. For example, tube amplifiers are still favored by some in place of modern solid state amplifiers. Replicating older effects has become a rising trend with consumers paying high prices for archaic circuit designs and otherwise obsolete circuit components such as germanium transistors.

The attributes of the sounds created by analog electronics are often difficult to articulate or objectify. Adjectives such as warm, bright, and colorful are words commonly used to depict these characteristics. They are caused by circuit imperfections non-linear amplification and frequency responses that favor higher order harmonics.

The initial drive for inventing electric guitars was simply to achieve a volume boost. However, today what separates acoustic guitars from electric guitars is the ability to control and manipulate tone. Whether it is classic analog sound or modern digital controls that guitarists prefer they all utilize some form of signal processing.

Active Cables in Industry

Active cables have been used in industry for decades as a solution to signal distortions that occur during data transmission across cables. The term "active" implies that the cable has a silicon chip designed to act as a buffer amplifier that increases the cables performance. A non-active cable is referred to as passive and has no powered electronics in use to limit attenuation.

The most well-known of these is probably USB (universal serial bus).

USB cables were originally designed in the mid-nineties with the goal of establishing an external expansion bus that would facilitate the addition of peripherals to a common PC (personal computer). USB cables carry data as well as power such they can supply power for the internal buffer as well power to the peripheral devices being connected by the cable. (9, 10, 12)

<u>Earlier Attempts to create Active Instrument Cables</u>

Coil LLC was not the first to conjure up the idea of building instrument cables with built-in buffer amplifiers. Designs generally involved large form factors that were a nuisance to musicians; accompanied by inefficient external power sources. Consequently, such products have never become popular.

Patent #5585767, granted in 1996 to Donald Tillman, is the only intellectual property found to be relevant to active cables. The patent outlines a JFET single stage amplifier that is inserted into a guitar cable with epoxy resin. The circuit is externally powered by a 9V volt battery contained in a stomp box. (16)

The circuit referenced in the patent was investigated and found to perform extremely well. However, it was never manufactured for retail markets. The design is available to technically savvy guitar players to build for themselves at Tillman's website, www.till.com.

A European company, GWIRES, did manage to create an active cable that can be purchased. It is available in several varieties that are tailored to

various musical styles. The exact details of the circuits used were not experimented on in this project. Regardless the existence of such a product motivated of the research project because it demonstrated the marketability of the idea. (14)

The GWIRE design requires an external power source as well as an additional metal housing part way down the cable. (14)   Such features greatly detract from the product's appeal. We hope the design created in this research project will be substantially more successful as commercial product because it requires only a common AA battery to power the circuit. There are no additional visible features. Therefore it will appear the same as a passive cable; more importantly it will be as simple to use as a passive cable.

CHAPTER 3: AMPLIFIER DESIGN

<u>Pre-Amp Design Considerations</u>

Generally buffer amplifiers are implemented with simple single stage op-amp configurations. There are several varieties of op-amps designed specifically for audio amplification many of which provide excellent signal fidelity and extremely low noise. A range of op-amps were tested in different circuits as candidates for the buffer amplifier. The op-amps chosen were chosen based on popularity in guitar applications, as well as technical performance specifications such as slew rate, noise, and power efficiency.   However, after careful consideration of various designs; a single discrete JFET design was favored in place of op-amp designs with presumably higher performance. The following section will outline the various circuits considered for the preamp and criteria that precipitated the final design.

Tested Op-Amps

OPA 2107
OPA2131
TL071
TL061
NE5532
LM324

Table 3.1: Tested Op-Amps

<u>Design 1: Non-Inverting Op-amp Buffer</u>

One of the most common designs for buffer amplification utilizes a non-inverting op-amp configuration. The primary advantage of such a circuit is the extremely large input impedance provided by the virtual ground between the positive and negative terminals on the chip. This allows the buffer to easily accept signals from large range of source impedance without considerable reflection. Often non-inverting configurations can have higher distortion effects, but this is generally not within the audible range. In testing for this project such noise effects were found to be insignificant.
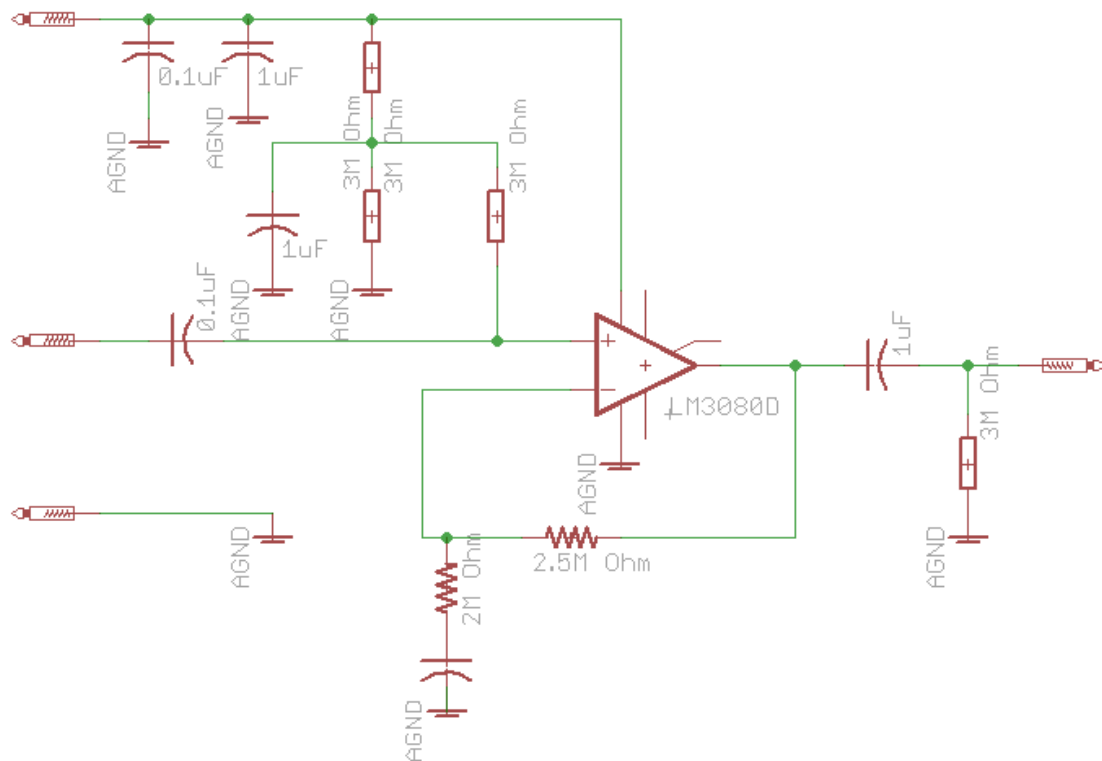
Figure 3.1: Non-Inverting Op-Amp Buffer Design
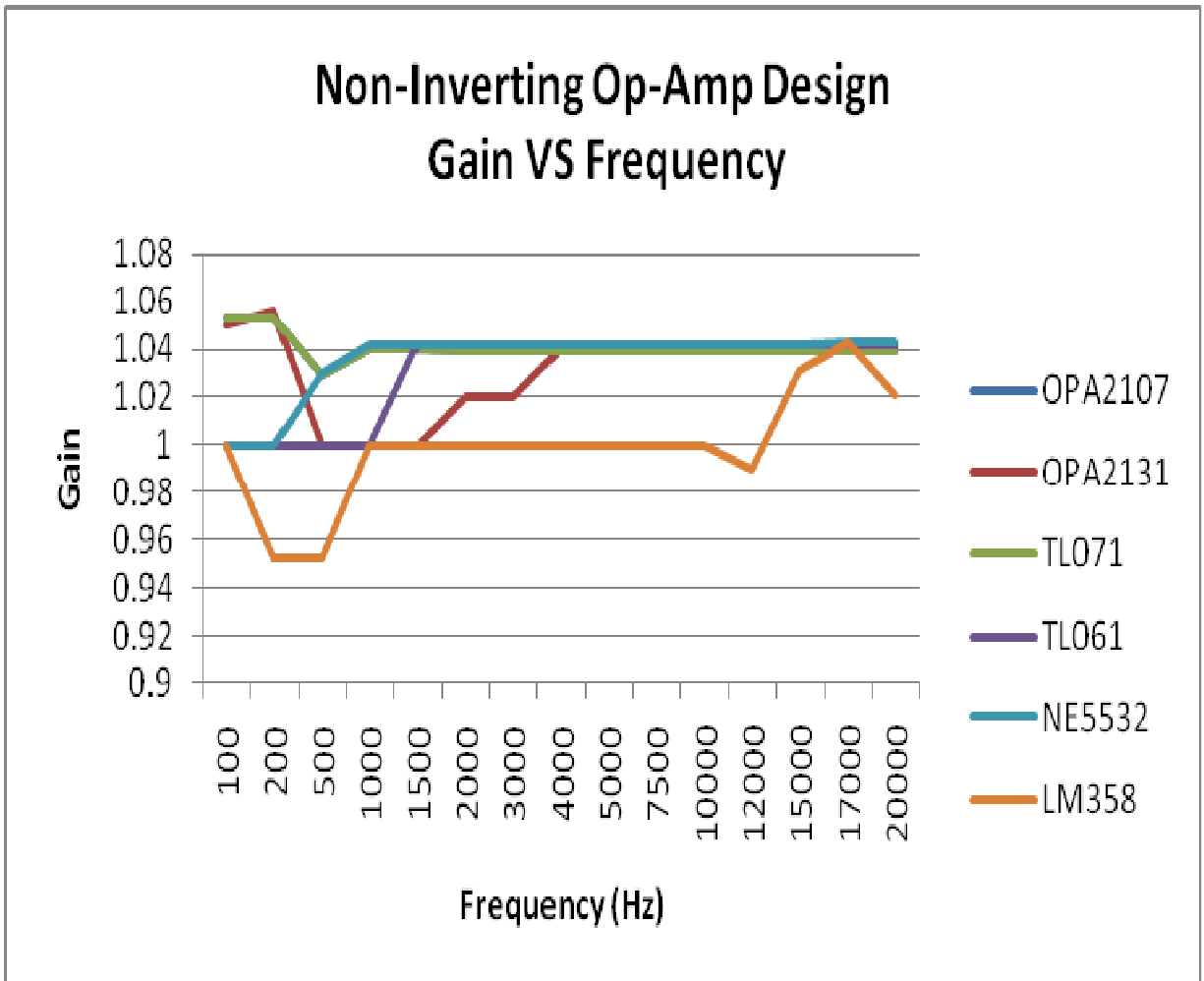
Figure3.2: Non-Inverting Op-Amp Buffer Design Bode Plot

Design 2: Inverting Op-amp Buffer

For the purposes of buffer amplification the inverting configuration is generally less favorable. When buffering a signal with a range of different output impedances the amplifier requires a large input impedance. This is difficult with an inverting configuration because the input impedance is approximately equal to the value of the resistor denoted Rn. Therefore to have a large input impedance

R1 must be large. Larger resistors have a greater potential for thermal noise which is of course unacceptable in audio applications. This issue is especially critical in the feedback resistor denoted Rf. The gain of circuit is determined by the ratio of Rf to Rn, Gain = -Rf/Rn. Consequently, to maintain unity gain Rf must be as large as Rn. (15)

However, while these issues exist they are not necessarily critical. In other product designs requiring buffers inverting configurations may be used for a variety of purposes. Furthermore, in subjective listeners were unable to detect the difference in sound when comparing inverting and non-inverting configurations. However, these were voluntary opinions of various musicians; no formal subjective testing was conducted.
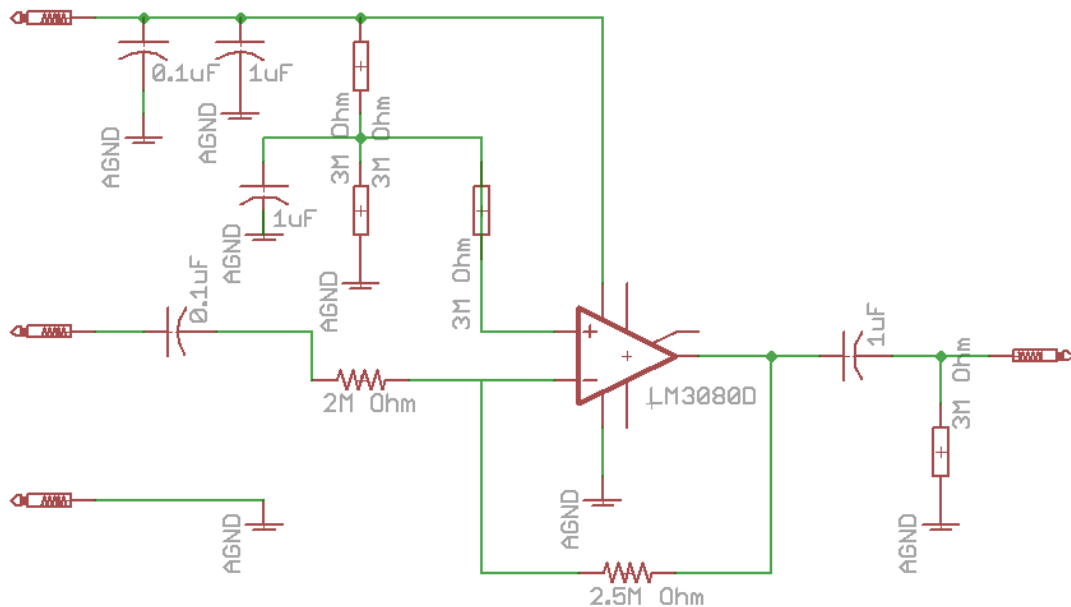
Figure 3.3: Inverting Op-Amp Buffer Design

Inverting Op-Amp Design
Gain VS Frequency

Legend:
- OPA2107
- OPA2131
- TL071
- TL061
- NE5532
- LM324

Y-axis: Gain

X-axis: Frequency (Hz)
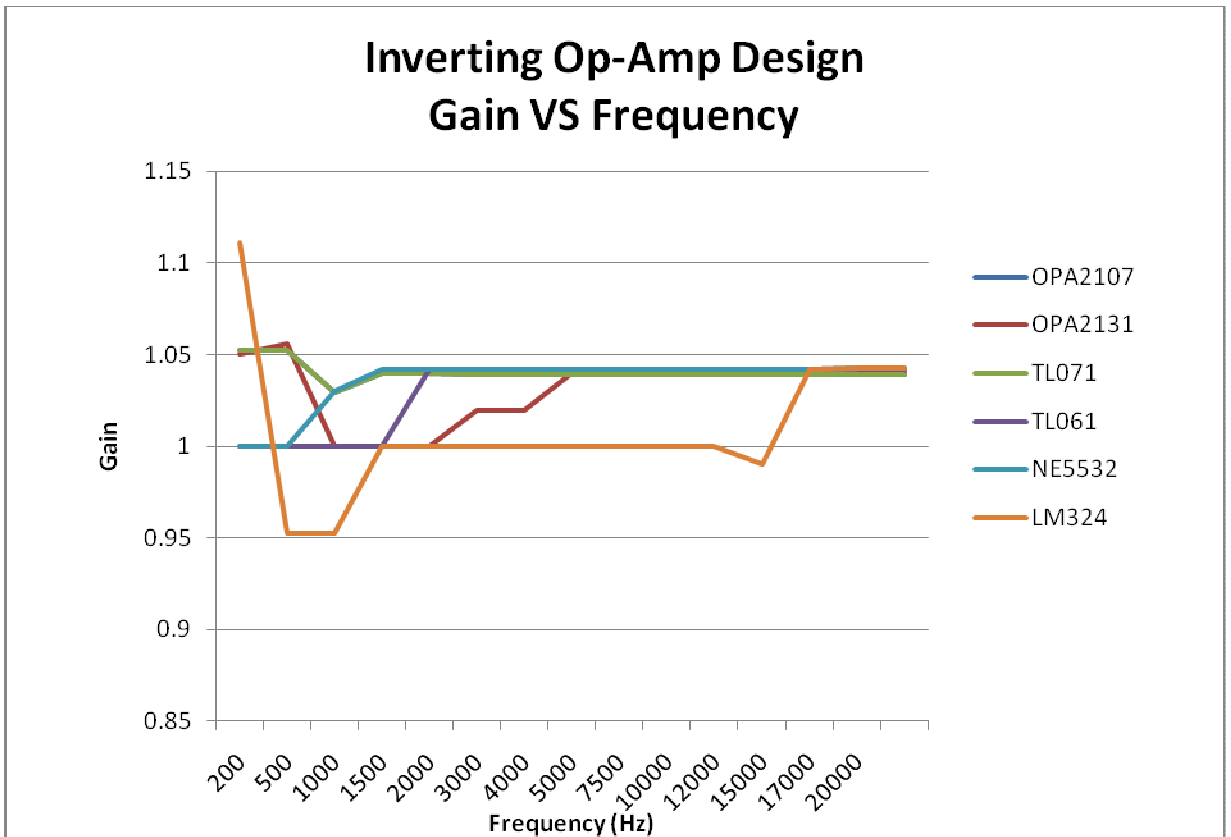
Figure 2.4: Inverting Op-Amp Buffer Design Bode Plot

Design 3: Discrete JFET

For decades single stage amplifiers made with JFETS have been a

popular design for guitar pre-amps. Musicians often describe the tone effects of

a discrete design as more pleasant then op-amps. Such designs may not be as

robust and clean as specially designed op-amps, but they do require minimal

amounts of power and are extremely simple to build. In the graph below we see

that the frequency response of the JFET design is not as flat as the op-amps.   It

is important to note that the gain variation is generally small enough to go

unnoticed until higher frequencies. This behavior is likely a large contributor to

the tones effects that musicians perceive as superior to op-amps. The frequency

response of most guitar amplifiers will begin to roll off where the gain of this

circuit increases. Therefore it will highlight higher frequencies that create a

brighter tone presence.
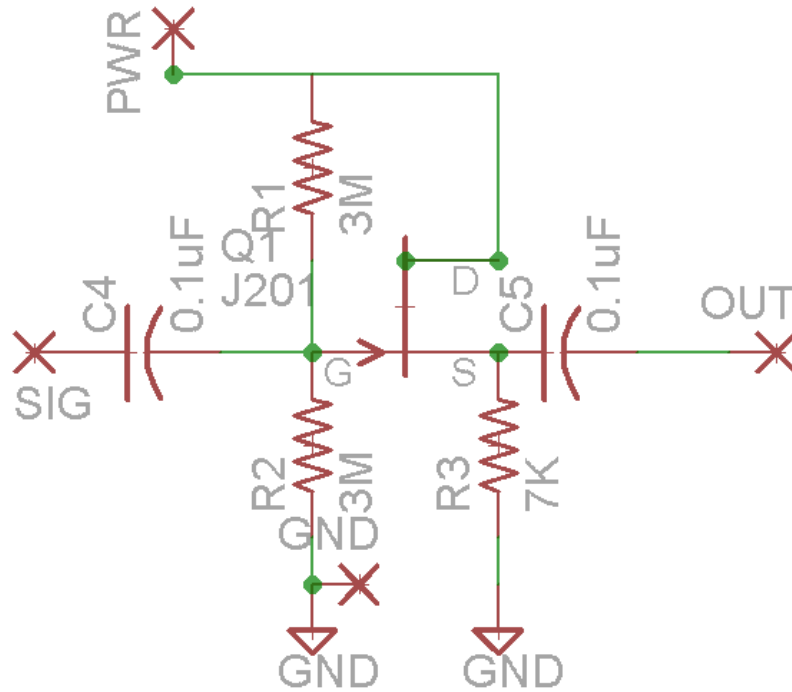
Figure 3.5: JFET Buffer Design
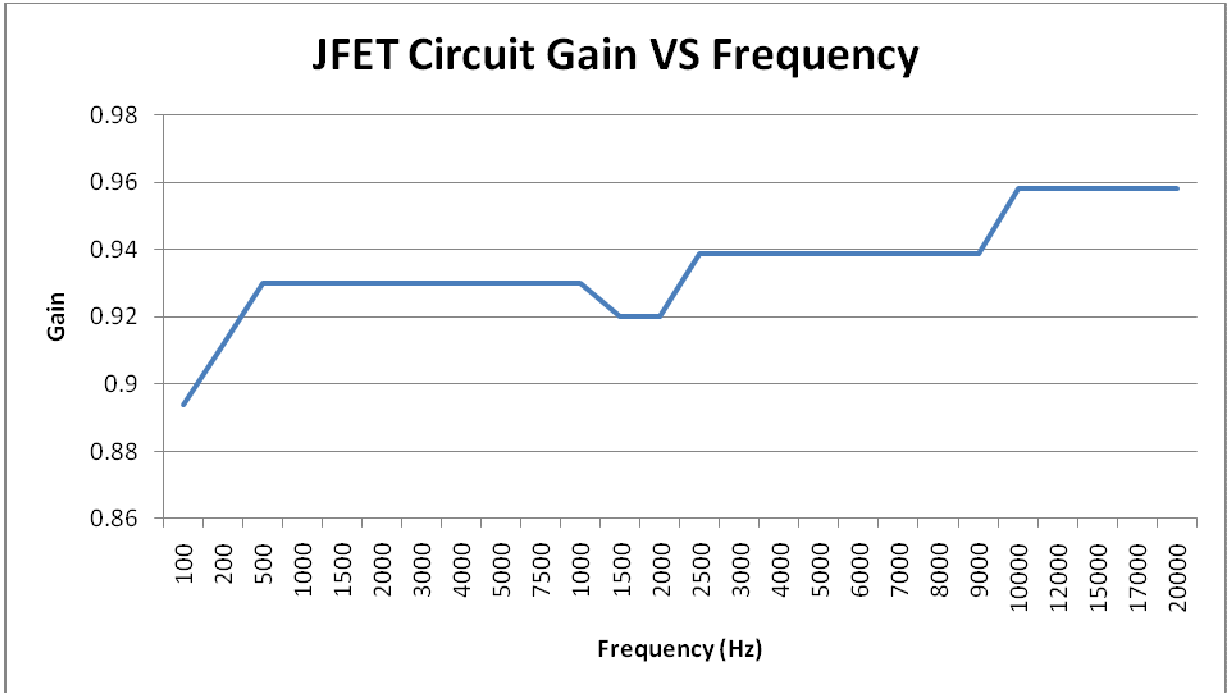
Figure 3.6: JFET Buffer Design Bode Plot

In the above graph we see the frequency response of the JFET buffer circuit. The data was collected by comparing the amplitude of the input signal to the buffer to the output signal amplitude at various frequencies. It is important to note that the gain of the JFET is slightly less than unity whereas the op-amp circuits generally had a gain slightly above unity.

For the sake of efficiency the simplest form of the JFET buffer was used. In the case of the JFET achieving unity gain requires additional components. If desired, two additional resistors could be added to the circuit in order to achieve unity gain or a gain slightly above unity.

This may be relevant for marketing purposes because the reduced signal amplitude may be perceived as degradation. Furthermore, the effects of buffering the signal could be highlighted by engineering the gain to be slightly above unity.

Power Consumption Comparison

IC	Inverting	Non-inverting
OPA 2107	3.21mA	3.22mA
OPA2131	8.17mA	8.16mA
TL071	2.44mA	2.43mA
TL061	581uA	582uA
NE5532	3.25mA	3.25mA
LM324	480uA	483uA
JFET	730uA	730uA

Table 3.2: Power Consumption Comparison

Power consumption was a driving factor in the design process because battery life is believed to be crucial for the products marketability.   The op-amps were chosen using considerations based on power consumption and audio applicability. The OPA series are designed as high-end audio chips and are commonly believed to have superior sound quality. The TL series is also considered to be an exceptional audio chip and it is an extremely popular choice in guitar applications. The NE5532 does not have the strong technical specifications of the other op-amps; however it is frequently used in audio applications and is considered to have great value in terms of cost and quality. The LM324 was selected for power efficiency.

The TL. NE, and OPA series op-amps all performed extremely well. Bode plots for these op-amps were essentially flat with a very consistent frequency response. The low power LM324 op-amp did not perform as well producing inconsistent frequency responses.

Overall, the discrete JFET circuit performed well with a relatively flat response until higher frequencies generally above 10k Hz. Above 10k Hz does not have a large impact on perceived sound. However, the subtle effect of highlighting these frequencies is generally found to be favorable if noticed. More research regarding this issue could be conducted. If it was found that this behavior is unwanted simple filters could be added to eliminate it. However, the opinions volunteered by musicians suggested that the effects were either unnoticeable or favorable we decided to not consider the issue at this stage.

The difference between the inverting and non-inverting op-amp designs was found to be negligible. While the bode plots were not identical they were extremely similar and subjective listening suggested that musicians could not distinguish between the two designs. Furthermore the power consumption of the two op-amp circuits was essentially identical.

Subjective Listening

Performing subjective sound testing with human subjects was determined to be a marketing concern and beyond the scope of the engineering research. Nonetheless, it was important to check for any overwhelming trends that may have eliminated certain designs.

During a demonstration of the prototypes at a music industry tradeshow

several musicians interested in the project volunteered their opinions about the

sound quality offered by the various amplifier designs. They appeared capable of

consistently identifying between the JFET circuits compared to the op-amp

circuits. However, there did not seem to be a notable preference. When

comparing the different op-amps the OPA series appeared to be preferable while

the LM and NE op-amps were not as popular. It is important to note that all

active designs were favored over passive cables.

Amplifier Design Conclusion

Despite op-amps having better technical performance the discrete JFET

design was chosen for the active cables. The driving factors for this decision

were power efficiency and size considerations.

Most of the op-amps had considerably higher power consumption than the

JFET design. As seen in the above chart the JFET design uses much less power

than any of the op-amps. However the TL061 and LM324 actually consumed

less power than the JFET design, but the difference was at most 250uA, an

extremely small amount of current.

In light of the small difference in power consumption the smaller size and

subjective favor of the JFET design were chosen over the low-power op-amps.

The size of a surface mount JFET is a fraction of any op-amp chip which makes

board designs easier. Once again, we were challenged to make the design as

small as possible for purposes of marketing. Therefore this design was ideal for

meeting both of our critical criteria.

It is important to note the simplicity of the JFET design. Additional components could be added for issues such as noise filtering, oscillation control, and general robustness. For example, the op-amp design exhibit additional capacitors bypassing the power supply. However, in practice we found that the final output of the DC-DC converter was consistent and clean. Furthermore, the circuit has always operated well in general without any failures. Therefore, the minimum number of components was used in the interest of size.

CHAPTER 4: POWER SUPPLY DESIGN

Power Supply and Biasing

Guitar preamps and stompboxes generally operate from a 9V DC power supply. 9V DC can be handy by providing headroom for adding gain to the signal and standard battery form factors have ample lifetime. However, for the purposes of the active cables 9V DC is more voltage than needed because little or no gain is added to the guitar signal which seldom exceeds 2V peak-to-peak. Furthermore standard 9V batteries are too large to fit inside an instrument cable. In the past this issue has been addressed by storing the battery in a stomp box or using an external AC to DC adapter.

Such solutions are inconvenient for musicians and make the cables a hassle to use in comparison to passive cables. Furthermore, it makes the product appear to be another common stompbox. This issue is believed to have hindered the success of previous active cable designs by other companies. To solve the problem the active cables built in this project utilize a DC to DC converter to operate the circuit from a common AA battery. AA batteries provide approximately 1.5 volts DC, but this voltage is increased to 5 volts DC via a Maxim 856 chip.

Before settling on using AA batteries and a step up converter many other power source options were considered. This included various styles of button style batteries such as CR2032 as well high voltage remote control batteries

such as A20 style form factors. Button cell batteries are small and come in a

variety of think circular shapes. However, due to their low voltage, too many

batteries were required. It was found that there was no way to arrange them in

housing similar to the size of a standard instrument cable. Remote style

batteries such A20 and A22 were excellent for their small size. However, they did

not provide enough mAh to power the buffer circuits for more than a day.

The buffer amplifiers pull as much as 8 mA of current. To attain enough

battery life we aimed to provide at least 1,000 mAh in the power source. AA style

batteries became the practical solution. They have a narrow cylindrical build that

fits into standard 6mm audio cable housing and a lifetime up to 3,000 mAh.

Furthermore, AA batteries are among the most commonly used batteries in

consumer electronics and are therefore a convenient solution for consumers.

The issue with AA batteries is that they only provide 1.5 volts and thus a

DC to DC converter became necessary. It is important to note that AAA batteries

have as much as 2,000 mAh and are considerably small then AA batteries.

However, we felt AA were small enough such that the extra battery life was more

important than the smaller size of AAA batteries. If from a marketing standpoint

the final form factor is considered too large changing to AAA batteries would

certainly be a trivial solution.

DC -DC Conversion

Several varieties of DC to DC converters are available. The Maxim 856

was chosen for power efficiency and simplicity. Recall that one of the primary

challenges of the active cables was to create a small form factor similar to that of a standard passive cable. The Max856 chip is designed specifically to provide 5 volts DC or 3.3 volts DC depending minor circuit adjustments. Therefore this chip is able to provide a reliable 5 volt DC source without adding a large number of components to the design.

The Maxim 856 typically has conversion efficiencies above 85%.(11) Therefore a lithium based AA battery that provides approximately 3000mAh is able to last considerably longer than a 9V battery which provides approximately 1200 mAh. Based off these technical specifications a lithium based AA battery powering the MAX856 would in turn provide approximately 2550mAh for the buffer amplifier.

Current prototypes of the buffer amplifier consume approximately 0.73mA of power. Therefore the active cable will in theory last approximately 3,493 hours or 4.85 months. This parameter has not been fully tested, but a prototype of the active cable has been powered for approximately 2 months at which point the AA battery powering it still maintained a voltage of approximately 1.68 volts. Therefore it was decided that the projected battery life was realistic.

Furthermore, there is an alternative form factor design for the active cables (discussed in chapter 6) that can automatically disconnect the battery when the cable is not in use. This would considerably increase the battery life of the active cables. When the prototypes tested for battery life they were constantly powered.

Lastly, the Maxim 856 has the added perk of a built in low battery detector.

Including this feature in the prototype design was beyond the scope of this

project. Deciding whether or not to include this in the commercial product will be

a business related decision. However, the feature was tested via breadboard to

confirm the option is available.

Noise is inherent to the switching involved in DC to DC converters. At this

point we have found noise issues to be insignificant. Therefore no measures

were taken to mitigate noise with additional circuit components.
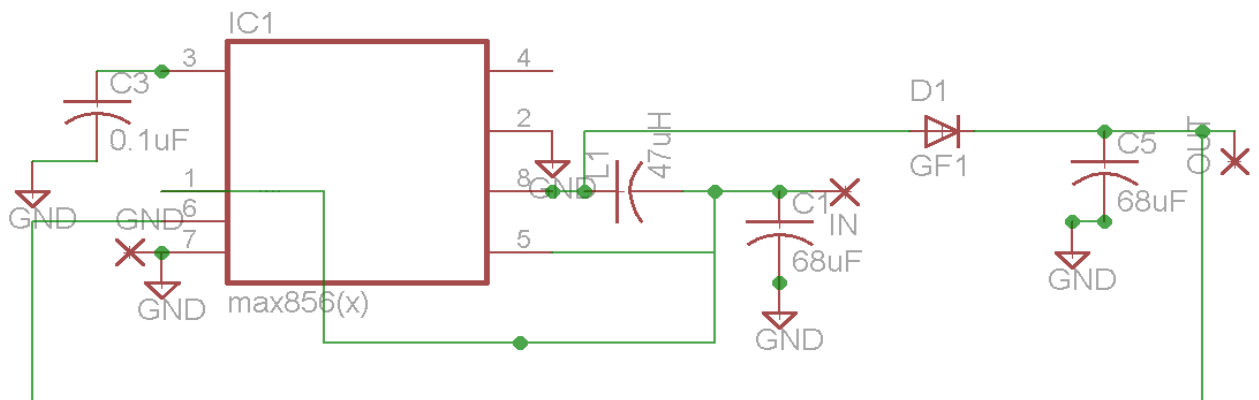
Power Source Schematic (DC-DC Converter)

Figure 4.1: Schematic DC-DC Converter

Power Supply Conclusion

Using DC to DC conversion with a AA battery was the perfect solution for this project. The dimensions of AA batteries are ideal for the necessary form factor design and when combined with the MAX 856 the power requirements and battery life requirements are met exceedingly well. The anticipated battery life of the prototypes is far beyond what is needed.

Coil LLC believed from a marketing stand point that a battery life of 2 months was necessary.   Testing has proven that the prototypes meet this requirement. Furthermore, even the most conservative estimates project that the battery life will far exceed the 2 months.

CHAPTER 5: BOARD LAYOUT AND DESIGN

Overview

Several board designs have been created throughout the design of the

active cables. The layouts are designed to fit in the form factor dictated by current

active cable prototypes. The most current layouts are shown below.

There are two layouts for the DC to DC converter; one has a larger

inductor circuit component and the second is more condensed and has smaller,

but more expensive inductor.   It is important to note that the amplifier design

could be made considerably smaller by using a surface mount JFET, however the

standard through-hole JFET was small enough to fit meet form factor

requirements. Lastly, there is a board layout that combines the JFET and DC to

Dc converter into a single board. This design was used in older active cable

prototypes.

DC to DC Converter: Larger Inductor Layout
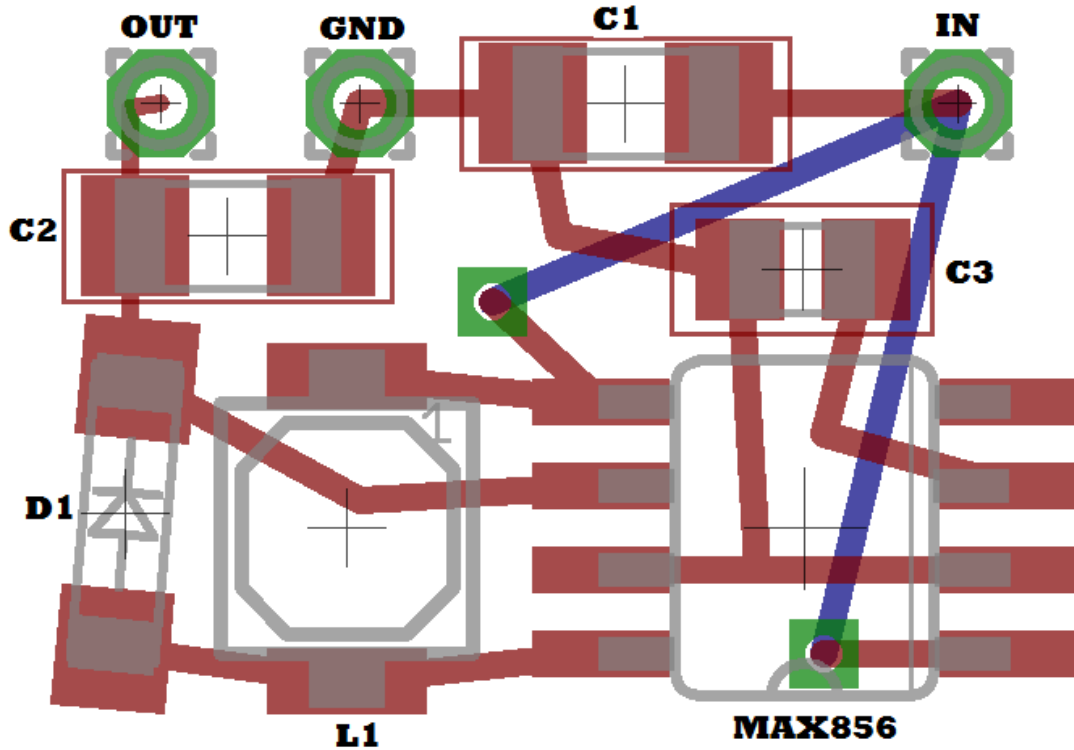
Figure 5.1: Layout DC-DC Converter –Larger Inductor

Parts List 1

Name	Type	Value	Part
IC 1	IC DC-DC converter	N/A	MAX 856
C1	Capacitor	100uF	Generic S0805
C2	Capacitor	100uF	Generic S0805
C3	Capacitor	0.01uF	Generic S0805
L1	Inductor	47uH	Kement 47uH
D1	Schottky Diode	20V 1A	B120-13-F

Table 2.3: Parts List 1

DC – DC Converter: Smaller Inductor Layout
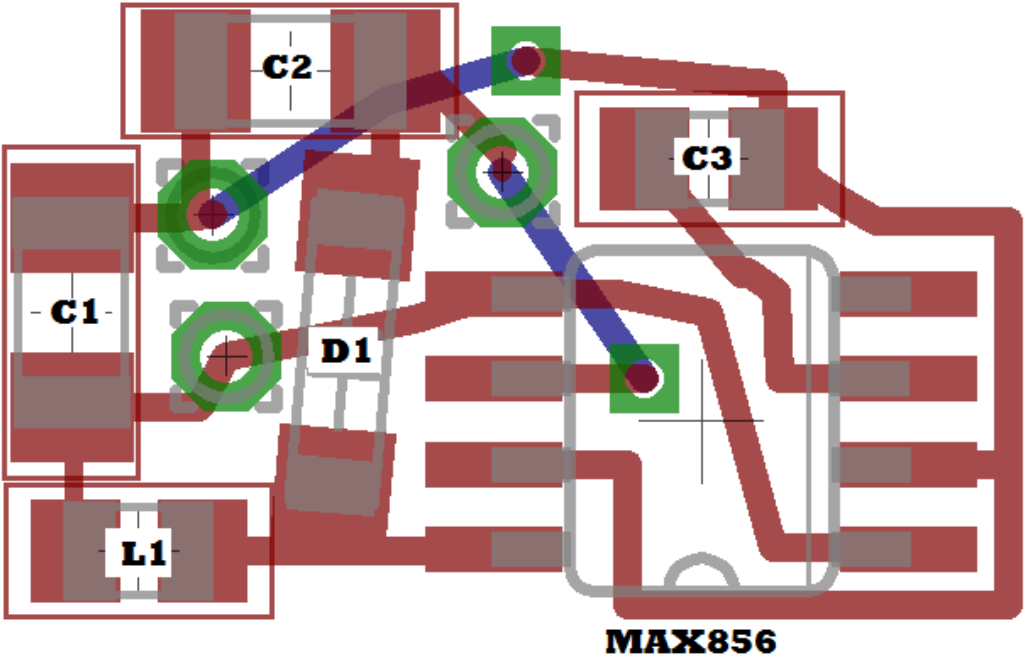
Parts List 2

Name	Type	Value	Part
IC 1	IDC-DC converter	N/A	MAX 856
C1	Capacitor	100uF	Generic S0805
C2	Capacitor	100uF	Generic S0805
C3	Capacitor	0.01uF	Generic S0805
L1	Inductor	47uH	L0806C470KPWST
D1	Schottky Diode	20V 1A	B120-13-F

Table 5.4: Parts List 2

JFET Buffer Layout
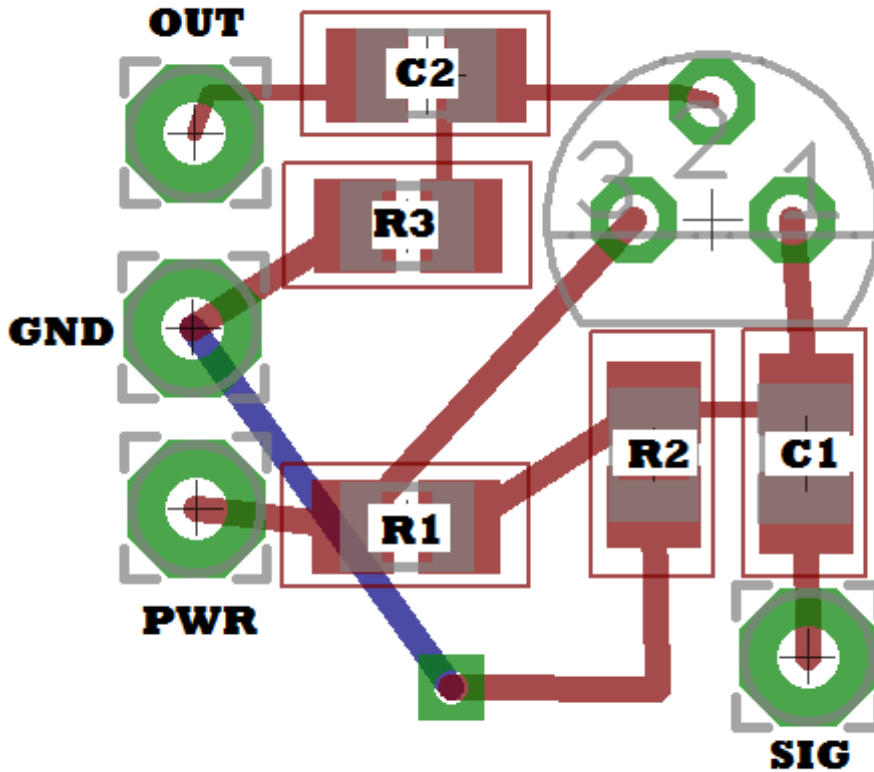
Name	Type	Value	Part
Q1	JFET	N/A	J201
R1	Resistor	3M Ohm	Generic 0805
R2	Resistor	3M Ohm	Generic 0805
C1	Capacitor	0.01uF	Generic 0805
C2	Capacitor	0.1uF	Generic 0805

Table 5.5: Parts List 3

Figure 5.4: Layout Combined DC-DC Converter and JFET

Parts List: (combined part list 2 and part list 3)
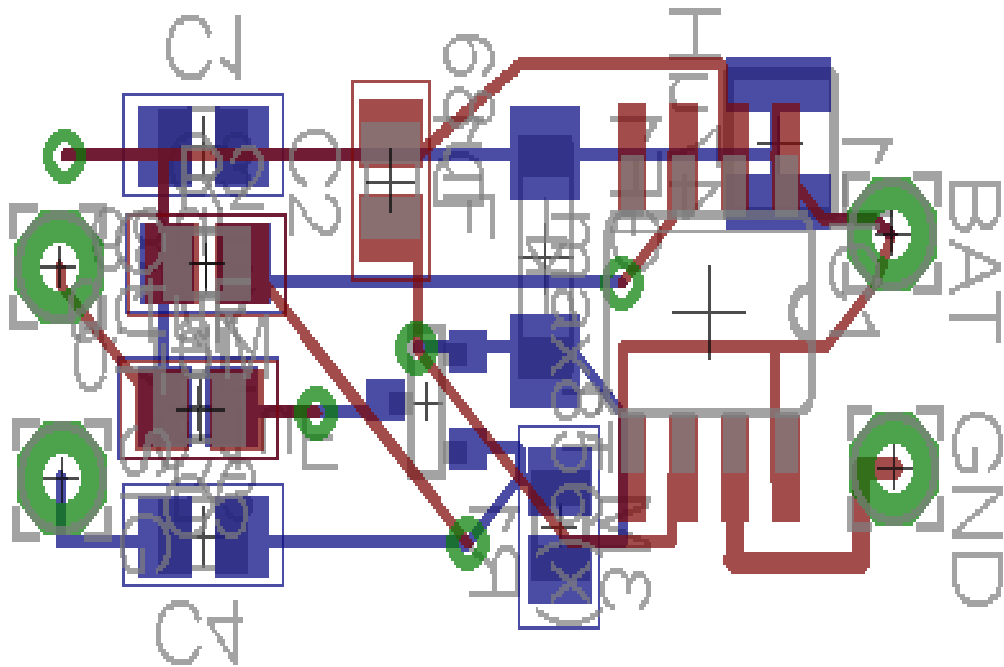
CHAPTER 6: FORM FACTOR

Overview

Recall that a small form factor was a driving requirement in this project. It is believed that to make the product marketable it must be approximately the same size as a standard passive cable. The housing of standard cables is typically cylindrical with a diameter of 15mm and length up to 70mm.   They utilize a 1/4" plug that has a signal contact at the tip with a ground contact making up the body of the plug.

Audio plug casings are easy to purchase. Many common plugs are large enough to house the circuit board for the pre-amp. However, the challenge was fitting a AA battery as well as a battery holder in the casing as well. Our current prototypes have solved this issue. But they are not developed enough for large scale manufacturing. However, the goal of this project was proof of concept through a prototype. Therefore further perfections of the cable housing are beyond the scope of this paper. At this point Coil LLC believes further development will require collaboration with an audio manufacturer to create a custom housing for the circuit board and battery that the active cables require. Pictures of current prototypes and designs for the active cable housing are shown below.

Photographs of Active Cable

Figure 6.1: Open Active Cable Housing

Figure 6.2: Closed Active Cable

Coil LLC Active Audio Plug

Description: This is a unique 6.35mm 2-pole audio plug housing that contains an AA battery holder to power cable circuitry. The cable plug, battery holder, and solder points are one solid unit. The metal casing covers the battery-holder and solder- points via screw threads under the cable plug. There are 3 solder points on the bottom of the battery holder: signal, ground, and power.

Note: all dimensions are currently estimates.

18mm

6.35mm 2-Pole Audio Plug

30mm

19mm

Screw Thread

Battery-Holder

55mm

Cable Metal Casing

Cable Metal Casing screwed to Cable Plug

65mm

Solder-Points with metal strain relief
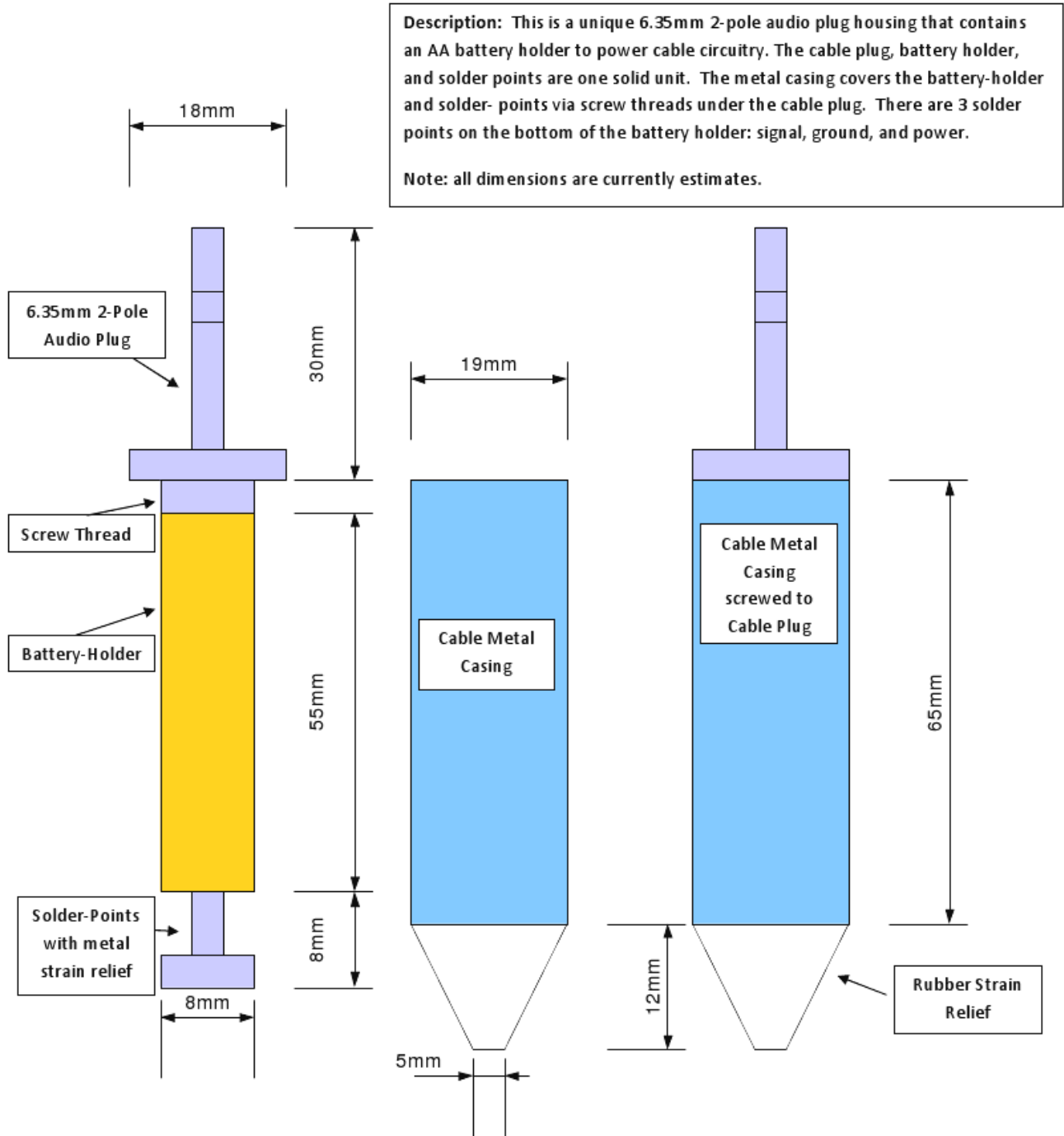
8mm

8mm

12mm

Rubber Strain Relief

5mm

Figure 6.3: Active Cable Housing Design

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Alternative Form Factor Designs

It is trivial to outfit the buffer circuit design with an on/off switch to save battery life when the cable is not in use. However, many music products are designed to have shut off automatically so that users do not have to remember to power the device on and off. To create such a feature for the active cables we attempted to design a logic circuit that would only power the cable while a signal is being received at the input. The concept was to convert the AC signal to DC and use it is as a trigger. However, the signal from typical guitar outputs was not strong enough to be useful. As such we proposed a mechanical solution.

Rather than have the active cables be sold as complete cables we recommended creating extension cords that have a male plug for the input and a female jack for the output. This would enable us to use the jack end as a switch that is only on if another instrument cable is plugged into the jack. This is a common practice for guitars that have active electronics built into them. There are varying opinions regarding whether or not such a form would more or less marketable. However, for the sake of the research it was relevant to investigate anything that increased the battery life.

Alternative Active Cable Form Factor

Figure 6.4: Other Active Cable Form Factor

CHAPTER 7: COMPARISON OF ACTIVE AND PASSIVE CABLES

The final prototype for the active cable was compared against a standard

passive cable. Figure 7.1 shows the frequency response of the standard passive

cable. The signal is shown to have an extremely limited presence of frequencies

above approximately 4,000Hz. Figure 7.2 shows the frequency response of the

active cable which shows a strong presence of frequencies up to 8,000Hz.

In each case a guitar signal was generated by strumming all six strings.

As predicted the active cable shows a stronger response for higher frequencies

that are presumably lost in the passive cable due to signal reflection and other

distortions.

The spectral analysis was done with Amadeus Pro software. It was

required that the signals from the guitars be recorded before the spectral analysis

could be performed. It is possible that there was signal loss in the recording

process.

Therefore, it is important to note that the purpose of these graphs is to

illustrate the effects of the active cable by comparing the spectral analysis results

of active cable and passive cable under the same conditions. It is possible that

the methods used to attain the spectral analysis resulted in additional signal loss.

However, the results are still meaningful because such losses would have

affected the results of each analysis equally.

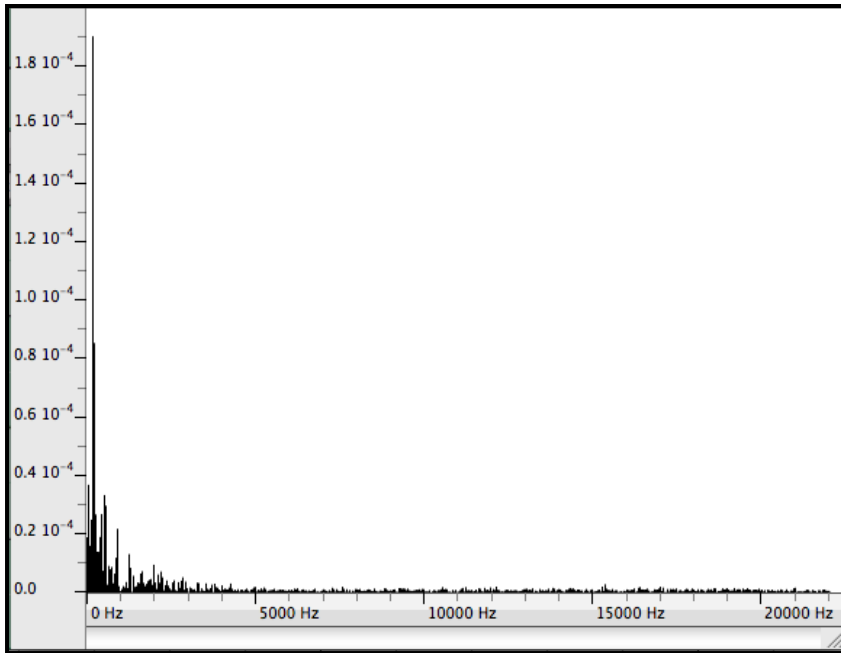Comparison of Active Cable and Passive Cable Spectral Analysis

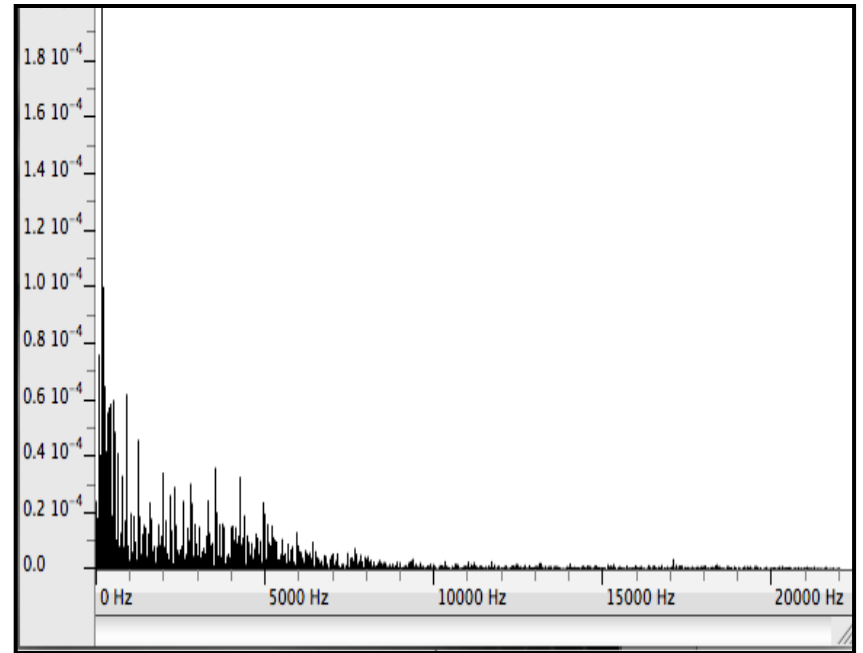Figure 7.1: Passive Guitar Cable Frequency Response

Figure 7.2: Active Cable Frequency Response

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CHAPTER 8: CONCLUSIONS

The purpose of this project was to examine the possibility of creating

active instrument cables within design parameters that would make them

marketable to musicians. These parameters included creating a form factor

similar to that of standard passive instrument cables and designing an internal

power source that provides multiple months of battery life using common battery

types. After thorough investigation we believe we have created a prototype that

meets these requirements.

This was achieved by examining several different circuit and device

designs. The goal was to achieve high performance, exceptional power

efficiency, and to create a small form factor. Our prototypes are believed to be the

most elaborate and capable active instrument cables built to date. They are

considerably smaller than previous creations, they do not require external power

sources, and they are able to last over 4 months on a single AA battery.

The novelty of this product makes marketing projections inherently difficult.

However, it is possible to compare to other instrument cables and electronics that

offer similar results. Professional instrument cables can cost over $100. The

projecting manufacturing cost of these active cables can be as low as $20.

Therefore it seems plausible that they could remain competitive with the pricing

of passive instrument cables that do not have buffer amplification.

Frequency analysis plots as well as subjective listening have showed that

the active instrument cables do in fact increase the presence of higher order frequencies in the guitar signal. This provides musicians of electronic instruments with the option of better preserving their signals and to have a warmer and brighter tone.

We have achieved proof of concept and there is now the option of bringing the concept to retail markets with the collaboration of audio manufacturers.

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