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Electronic Amplification and Music

An Interactive Qualifying Project Report

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By

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Abstract

Technology has an intimate relationship with music throughout human history. Modern use of electronic amplification, especially in the case of the electric guitar, has expanded the vocabulary with which performers may produce their music. Jimi Hendrix realized this potential in his instrument, and influenced entire genres of music in doing so. A statistical analysis, using a signal analyzer and MATLAB, of both solid-state and tube amplifiers allowed a discussion on how the signal is modified to produce entirely new sounds. Finally, recommendations are made for continuation of this project.

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Chapter 1 - Introduction

Character is the backbone of our human culture. Music is the flowering of character.
-Confucius, approximately 500BC

Music is much more than just entertainment; it is deeply integrated into civilization. Over the course of human history music has taken countless roles; ritual, religion, culture, communication, mathematics and even science have all influenced, and been influenced by music. Many people have spent their lives pursuing musical "perfection," always expanding and evolving the definition of the very word. Even those who are unaware of their deep-rooted ties with music are profoundly and instinctually impacted by the concepts of rhythm, melody and consonance.

As music has progressed through time, so have the methods of creating, performing and describing it. Certain tools and conventions have arisen, the results of centuries of experimentation. Modern Western Music now consists of well-defined rules founded in scientifically grounded theory. The development of a concrete musical language played a huge role in advancing the field of music from its primitive beginnings to the rich and diverse state it exists in today. Technology has consistently aided and shaped the growth of music, giving people tools to both better perform and better describe their inner musicality.

Many individuals throughout history have advanced the understanding of music significantly. Pythagoras examined the relationships between mathematic and music. Beethoven expanded the vocabulary of classical music to bring it more expressive and explorative heights. Yet, even these great people relied on technology to enable their musical achievements. The grand piano was vital to Beethoven and his contemporaries for composition and creativity, putting a wide range of sounds literally at their fingertips. A century later, with the advent of electronics, technology again opened whole new realms for musical growth.

By converting an acoustic sound wave from air pressure to an electric pulse, possibilities never before dreamed of became reality. Performances could be documented and altered later. Signals could be shaped and redesigned to achieve entirely new sounds.

And with the new wave of technology came those who would redefine the very meaning of music. Robert Moog developed the synthesizer and removed essentially all physical constraints from the production of sounds. New genres such as jazz and rock and roll were pioneered by groundbreaking musicians like Louis Armstrong and Elvis Presley. Another such musical giant was Jimi Hendrix. His innovative use of his guitar and amplifier forever changed the instrument, rock and roll, and the face of modern music as a whole.

This paper will briefly discuss the origins of modern music, from its prehistoric roots. The focus will rest primarily on the use of technology to strengthen the natural human ability to make and enjoy music. Specifically, the modern use of electric amplifiers will be used to demonstrate this concept. Due to his prominence in the ascent of the instrument, Jimi Hendrix is used to frame the discussion.

Chapter 2 - Goal Statement

The aim of this project is to document and comment on the growth of the importance of electronic amplification in modern music, and the acoustic effects that accompany it, as well as the role of Jimi Hendrix in defining this growth. To present a statistical analysis of two different amplifiers to support this discussion, MATLAB scripts will be developed with which to examine these effects.

Chapter 3 - Background Research

3.1 - Music History

Modern music is the product of thousands of years of tradition and redefinition. It has existed in every culture, and is an inextricable part of human expression. Music has grown through history, alongside civilization, surpassing all other human endeavors, beyond all other arts.

3.1.1 - Prehistoric Music

It is believed that music, in its most basic form, predates speech. Through investigating bone records of early humans it is evident that the mechanisms for vocal chanting existed long before the mouth and tongue achieved sufficient sophistication to form spoken words. Similar to birdsong or other animal vocalization, human ancestors communicated in this manner.

Drums and flutes, which began appearing before the last Ice Age, were likely used in rituals and ceremonies. Excavations in Siberia have unearthed mastodon bones at least thirty-five thousand years old, carved into early flutes and drums. It is important to note that the materials which are best suited for instrument construction, such as wood, reed, and animal skins, are all perishable, making it very unlikely that the earliest uses of these materials would survive to the present.

Reed instruments began appearing some eight thousand years BC, showing further development in the construction of instruments. With the discovery of metalworking, new instruments were formed, such as bronze horns and brass cymbals. The famed Tomb of Tutankhamen was home to two silver trumpets, dating them to 1320 BC.

Music has served countless purposes in the past, as it does today. In Africa, historical events and family genealogies were maintained by *griots*, well-respected and revered musicians who dedicated their lives to such histories. Festivals, rituals, births, funerals, marriages and victories were all celebrated with music and dancing.

3.1.2 - The Dawn of Music Theory

The Chinese discovered around 3000 BC a relation between certain tones, which today would be called the circle of fifths. From this they constructed the pentatonic scales, each a series of five tones at fifth intervals. This scale is still used in music of the "highest moral, ethical or spiritual ideals"[1]. For the first time humans were applying a structure to describe their music

3.1.3 - Music in Ancient Greece

Perhaps more than any other ancient culture, the Greek civilization treasured music as an art form. Pythagoras studied the relationship between mathematics and music in great detail. He is credited with the generation of the concept of *musica universalis* or the idea that the universe and the motion of all its parts are governed by simple mathematical rules, giving rise to a form of cosmic harmony, or music. Pythagoras' findings were lost for centuries, but rediscovered in medieval times to provide the foundation of modern western music.

Music was used in theatre, celebration, and story telling. Religious ceremonies dedicated songs to the gods of Olympus. Dramas were complemented with choruses and musical accompaniments. It was an aim of Greek society to achieve moral clarity through aesthetic beauty, and music was an inextricable part of this doctrine.

Although the Greeks had a form of written music notation, it was used infrequently, most music instead being passed from player to player. For this reason, the true music of Greece is largely lost to antiquity.

Unfortunately, when the Romans conquered the Greeks, they retained hardly any of the musical tradition. The Romans borrowed music from the many cultures they absorbed, including the Greeks, Celts, and many others. However, music was not as highly regarded in their society as in Greece. Romans instead emphasized "the word, the law and the sword"[2]. The result was a marked decrease in the prominence of music throughout society, which persisted for a number of centuries.

3.1.4 - Religion and Music

Centuries after the fall of Ancient Greece, music once again rose to prominence, but this time not as a cultural phenomenon, instead as a religious one. The expanding Christian religion introduced *plainsong*, a form of chanting, to their worship.

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[1] Menhuhin, Yehudi and Curtis W. Davis, The Music of Man Methuen, Inc, New York, 1979. pp. 30
[2] Menuhin, pp. 43

Music also began shifting from solo performance to integrate many voices and harmonization. At the same time, musical notation was advanced to the early forms of the modern staff and note system. For the first time a common language was available to describe musical themes, a development that eventually led to the rise of the golden age of Classical music.

3.1.5 - Music from the Renaissance to Industrial Age

From the beginning of the Renaissance, around 1400 AD, and over the next four centuries spanning the Baroque, Classical and Romantic periods, music was progressed to a full art form. Composers such as Mozart and Beethoven wove complex symphonies with enormous orchestras. Strict adherence to concrete rules about harmony and meter were revered, as such music was thought to be pure, even divine. These rules were taught in formal institutions for the first time.

Much of the music from this period is dominated by the development of keyed instruments, specifically the harpsichord and later the piano. These instruments allowed great range and repeatability, enabling a composer to refine and examine a composition more closely than ever before. Improvisation was used infrequently; scores tended to be followed to the note.

As society moved into the Modern age, the rigid structure of classical music began giving way to more personal and adaptive forms. Romantic composers like Wagner began bending the rules of music, using ever-more exotic harmonization and chord progressions. This would lead to an explosion of experimentation in the twentieth century.

3.1.6 - The Twentieth Century

Technological advancements, namely Edison's phonograph recorder and Marconi's radio transmitter, introduced a separation between music and its performance. These developments lead to music's break into mainstream society and large-scale consumption. With an increased audience, performers began breaking new grounds. Jazz music emphasized the soloist, especially in improvisation. Popular music became a consumable good for the first time, driving with it entire industries, which in turn lead to further innovations. Elvis Presley, the Beatles, and the Rolling Stones, among many others, introduced and set on its course Rock and Roll.

New musical genres demanded new tools. Distribution methods evolved with increasing complexity and frequency, from vinyl album to eight-track to audiocassette to compact disc to digital format. The Internet removed not only the artist and performance from the music, but the physical medium as well, as music became a stream of data.

Instrumentation evolved as well. Electronic and synthetic music began as a novelty but quickly pushed the boundaries of what was considered music. The development of the electronic synthesizer removed essentially all physical restraints from sound manipulation and production. Toward the end of the century, computer simulations and artificial intelligence attempted to recreate and approximate music, without the aid of human performers.

3.1.7 - Music Now, and Beyond

Music has never before existed in so many shapes and forms. Enormous resources are spent on its production, and the sky is the limit. New tools and applications are created at an ever-increasing rate. New methods of collaboration, analysis and distribution are pushing music from a product sold by large corporations to an individual or community effort, shared with the global audience.

3.2 - Hearing

3.2.1 - Physiology

The human ear is comprised of three different parts, the outer, middle-ear, and inner-ear, or cochlea, all shown in Figure 3-1. Each plays a role in creating the sense of hearing.

The outer ear acts primarily as a funnel for incoming sound waves, as well as serving a protective role, preventing damage to the delicate inner workings of the ear. The eardrum is part of the outer ear. Its vibrations transfer the incoming sound waves to the middle ear.

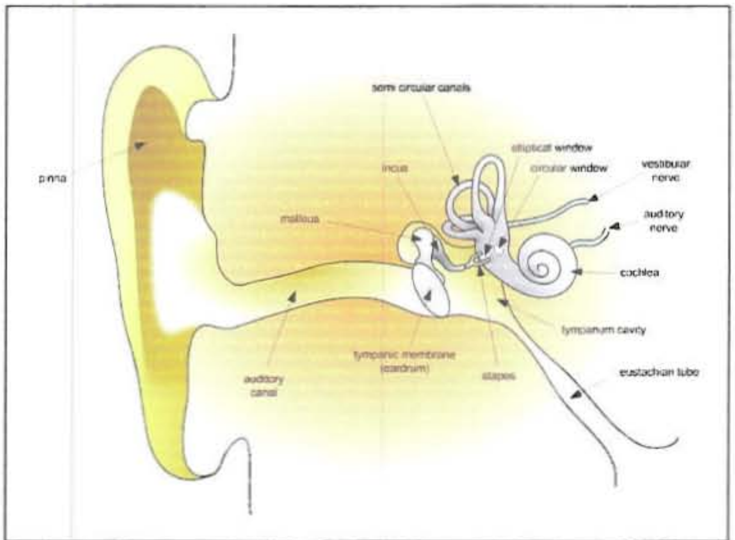

Figure 3-1: The Human Ear[3]

The middle ear connects the eardrum with the cochlea through a trio of tiny and delicate bones, the malleus, incus, and stapes. The vibration of the eardrum causes these bones to excite the cochlea.

The cochlea transmits the incoming sound information, in the form of physical vibrations, to the brain as a series of electrical impulses. Inside the cochlea is a transmission fluid, perilymph, which in turn causes a collection of small hair cells, or cilia, to deflect. This deflection stimulates the nerve endings of the auditory nerve, carrying the signal to the brain.[4]

3.2.2 - Audible Range

The average human can hear frequencies ranging from 20 to 20,000 Hz, depending on factors like age and health. Frequencies in the sub-sonic range, those below 20 Hz, are felt rather than heard, provided a vibration with sufficient amplitude. Typically, high frequency perception deteriorates with age, although hearing loss is also attributed to

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[3] Image has been released into the public domain by its author, Dan Pickard. Acquired from http://en.wikipedia.org/wiki/Image:HumanEar.jpg, April 2007.
[4] Leeds, Joshua, The Power of Sound Rochester, VT: Healing Arts Press, 2001. pp 28-30.

exposure to high intensity sound or long-term exposure to high levels of noise. This project will only focus on frequencies within the range of human hearing.

3.2.3 - Sensitivity

Sound intensity is measured in decibels (dB), and is logarithmic in nature. An increase of 10 decibels corresponds to ten times the sound energy. Most people can detect volume differences of 3dB, and some ears are sensitive down to 1dB. The ear can withstand sound pressure levels up to 1 kPa, yet can perceive sounds eight order of magnitudes less intense. Such small pressures displace the eardrum on the order of 0.01 nm, "less than one-tenth the diameter of a hydrogen molecule."[5]

3.3 - Signals

3.3.1 - Frequency Response

Frequency response is the measure of a system's effect upon a signal of a given frequency. Electronic systems will alter signals passing through them; the impact of this alteration varies with the signal's frequency. It is typically desirable to obtain a flat response curve throughout the audible range. Such a response results in the output signal to accurately reflect the input signal. To achieve this, the output of a system must match exactly the input, both in amplitude and phase. This is generally impossible; all electronic systems will have some impact upon a signal. It is possible to obtain an approximately flat response curve, however.

In the case of acoustic signals, systems are designed to maintain a flat response over the audible range, within a certain tolerance. This tolerance will vary, but because most people can hear a change of +/-3dB, tolerances are usually lower than 3dB.

3.3.2 - Equalization

Equalizers allow the frequency response of a system to be manipulated. This is done by boosting or cutting the response within a given frequency band. 3-band equalization divides the audible range into three areas: bass, middle, and treble. Though actual ranges vary, generally speaking bass covers from 20-200 Hz, mid-range from 200-2000 Hz, and

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[5] Beranek, Leo L. <u>Acoustics</u> New York: McGraw-Hill Book Company, Inc, 1954. pp. 389

treble from 2-20 kHz. It is possible to divide the frequency spectrum into any number of frequency bands for equalization, though it is rare to use more than 31.

3.4 - Jimi Hendrix

Jimi Hendrix was an innovative and ground-breaking musician, especially in the use of electronic amplification. His influence on the music world is still felt today, and his performances are frequently used as inspiration for musicians to push the limits of the guitar and amplifier.

3.4.1 - Biography

Johnny Allen Hendrix, who grew up to be known as Jimi Hendrix, was born on November 27th, 1942 to Lucille and Al Hendrix in Seattle, Washington. Al was in the military, stationed in Alabama when his son was born. Jimi had a difficult childhood, being passed between several guardians, including Lucille's sister and mother and a woman named Mrs. Champ[6].

At the age of eight Hendrix was already engrossed in music, strumming the straws off of brooms mimicking guitar playing. His first instrument was "an old ukulele with one string found by Al when he was cleaning out somebody's garage," on which Hendrix, now 15, managed to work out 'Peter Gunn' and 'Love is Strange'[7]. Shortly thereafter he bought his first guitar second hand from one of Al's friends for five dollars.

Figure 3-2: Jimi Hendrix

In high school, Hendrix joined his first band, The Rocking Kings. He was playing on his first electric guitar, a

[6] Shapiro, Harry and Caesar Glebbeek. Jimi Hendrix: Electric Gypsy New York: St. Martin's Griffin. 1990.
[7] Shapiro

Supro Ozark. The band did reasonably well, playing a regular gig at Seattle's Birdland, and winning local and state prizes. Shortly after this in 1961, Hendrix enlisted in the 101st Airborne Division of the Army, and was discharged the following year after breaking his ankle during a parachute jump.

Over the next four years Hendrix played with a number of acts, including Little Richard, King Curtis, and the Isley Brothers. He eventually formed his own band, Jimmy James and The Blue Flames in 1966. But it was not until he traveled to London in September of that year that his career really took off. Within two weeks of being in London, the newly dubbed "Jimi" Hendrix had played with a number of big names, most notably Eric Clapton's The Cream, and had formed a new band, the Jimi Hendrix Experience.

Before his untimely death on September 18th, 1970, Hendrix released five albums, including *Electric Ladyland* which reached the Number 1 spot on the US charts. A large number of posthumous releases have followed, and his music is still considered groundbreaking and innovative nearly four decades later.

3.4.2 - Equipment Overview

Jimi Hendrix experimented with many different guitars, amplifiers, and effects throughout his career. He did, however, have equipment that he preferred over others. The most common setup for live performance is shown in Figure 3-3, and was comprised of his Fender Stratocaster, running to Vox wah-wah pedal, to Octavia, to Arbiter Fuzz Face, to Uni-Vibe, then finally to the Marshall Amplifier stack.

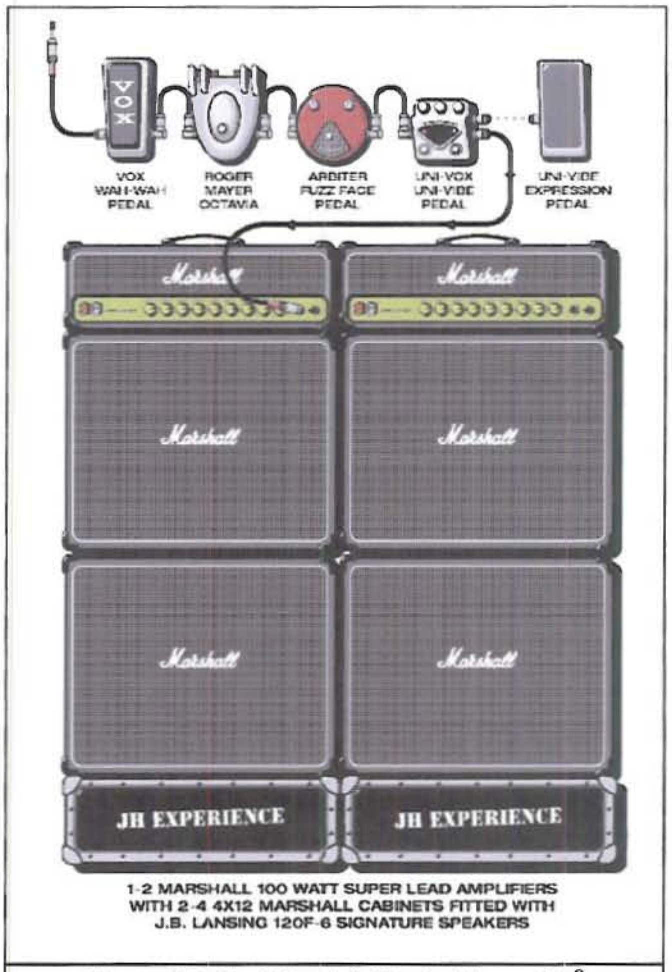

Figure 3-3: Jimi Hendrix Typical Stage Rig[8]

Hendrix also experimented with unconventional effects. He often used a Leslie Speaker, a rotating treble horn typically used by Hammond organ players to obtain a wavering sound.

Several pieces of equipment were made famous by Hendrix's impressive use. He of course bolstered the fame of the Fender Stratocaster. He also brought notoriety to Marshall's 100 Watt Super Lead Amplifiers by touring with several of the stacks in 1969 and 1970. He also used Marshall Speaker stacks containing four 12-inch Celestion speakers, which he often had replaced with JBL 120F-6 Signature speakers.

Jimi was intimately involved with his equipment selection, often mixing and matching amplifiers and stacks. Typically, he preferred more power, eventually settling with the decision that the "minimum acceptable power at the time was 100 Watts,"

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[8] Image obtained from http://guitargeek.com/rigs/img/h/hendrix_jimi_1968.gif

recalls Buck Munger,[9] the representative from Sunn Amplifier who persuaded Hendrix to sign with his company for five years, in a deal that only lasted 14 months.

3.4.3 - Guitars

Although Hendrix is mostly identified with his use of Fender Stratocasters, he did not play his first until 1964. Before this, he played on a few other models, including an Epiphone Wiltshire, a Fender Duo-Sonic, Gibson Flying-V, and a Fender Jazzmaster that he played while in Little Richard's band. Virtually every guitar he ever played was right-handed; left-handed guitars were hard to come by, and he originally taught himself to play on a reversed right-handed Supro Ozark. This resulted in a unique configuration with the Volume and Tone knobs on the top of the guitar face and the string order reversed. Figure 3-4 depicts Hendrix with both the right-handed Fender Stratocaster and a Marshall Amplifier stack.

Figure 3-4: Hendrix Playing a Fender Stratocaster and Marshall Amplifiers[10]

The Fender Stratocaster was first made by Fred Tavares in 1954. All Stratocasters feature three alnico single-coil pickups. Earlier in his career Hendrix favored the rosewood neck Stratocaster, but after 1968 he switched to maple-neck, using a blond model from November 1968 to the end of his career.[11]

[9] "The Gear of Jimi Hendrix." Guitar Player Sept. 1995. Backstage Lounge. April 2007. <http://www.backstage-lounge.com/story.asp?sectioncode=66&storycode=5695>

[10] Image source Pearcy, David

[11] Shapiro pp. 673

3.4.4 - Amplifiers

Hendrix used a great number of amplifiers, but the one he used most frequently was the Marshall 1959 100 Watt Super Lead Plexiglas (1959SLP). His other rigs included Fender Twin Reverb and Dual Showman amps, as well as Sunn 100-F amps for a short time, but the vast majority of performances from 1968 on featured Marshall equipment. From this head he would run Marshall Speaker cabinets. Anywhere from one to three of these stacks would be used at one time, ranging from eight to 24 twelve-inch loudspeakers. He would often link several stacks inputs together, driving the whole chain straight from his guitar. Above all liked power behind his performance; Mitch Mitchell, the drummer for the Jimi Hendrix Experience said, "...We knew what we wanted, which was big clout, you know, big amplifiers and make it as dramatic as possible..."[12]

Figure 3-5: Marshall 1959SLP Amplifier

The control panel layouts shown in Figure 3-6 are for the 1993 Reissue of the 1959SLP. The reissue includes the addition of an effects loop that was not present in the original models. This loop may be entirely bypassed to obtain circuitry identical to the original release of the amplifier.

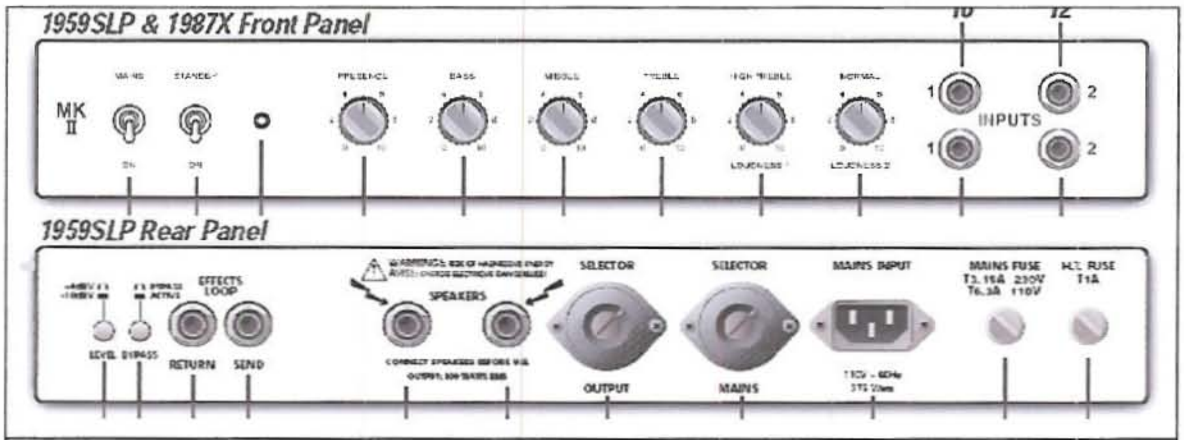

Figure 3-6: Marshall 1959SLP Front and Rear Panels

[12] Shapiro pp. 683

3.4.5 - Settings

Hendrix frequently played with, "all tone and volume controls turned full up to 10, adjusting the levels directly from the guitar."[13] This was in sharp contrast from what most other musicians were doing at that time. On Hendrix's first trip to London, he stepped onstage to jam with the guitarist from The Trinity, Vic Briggs, plugged into his experimental Marshall amplifier, and cranked the knobs to maximum. Briggs protested that he had "never had the controls up past five," to which Hendrix replied, "Don't worry, man, I turned it down on the guitar."[14] Hendrix played a week later with Cream, the biggest band in Britain, a set that rocketed him to fame.

It is very difficult, however, to determine the exact equalization settings that Hendrix preferred when things weren't maxed out, like in most performances of "Little Wing". Photographic evidence with enough detail to determine knob settings is rare; Figure 3-7 is one of only a few images that were recently used in 2005 to verify the authenticity of an amplifier that had surfaced in England as the first Marshall Hendrix ever owned.[15] All photographs and existing music by Jimi Hendrix are owned and licensed by Experience Hendrix, LLC, the company created by Al Hendrix, Jimi's father, in 1995 for the sole purpose of preserving the Hendrix legacy. The company takes its role very seriously, and does not freely distribute existing material.

Figure 3-7: Hendrix Adjusts his Amplifier Settings

For this reason, assumptions will be made in the experiments run in this project. Marshall offers suggestions within its User Manuals for equalizer settings to obtain

[13] Murray. Charles Shaar. Crosstown Traffic: Jimi Hendrix and the Post-War Rock 'N' Roll Revolution New York: St. Martin's Press. 1989. pp. 214.
[14] Cross. Charles R. "The Legend of Jimi Hendrix" Rolling Stone. RS 980. Aug 11. 2005. Rolling Stone. April 2007. <http://www.rollingstone.com/news/coverstory/legend_of_jimi_hendrix>
[15] Copyright Val Wilmer. All Rights Reserved. See "The Hendrix Amp" Rich Dickinson's Driving Force February. 2005. <http://www.richdickinsonsdf.co.uk/hendrix_amp.htm> April. 2007.

desired sounds.[16] Taking first-hand accounts from a specific performance and matching them with the corresponding suggested setting should give an approximate equalization to work with.

3.4.6 - Hendrix's Impact on Music

Hendrix was above all a pioneer in differentiating the electric guitar from its acoustic counterpart. Prior to his exploration of the instrument, it was essentially used only as an amplified version of a regular acoustic guitar. The use of effects was largely gimmicky, that is until Hendrix brought it to maturity. He expanded the vocabulary and breadth of the electric guitar to become something entirely distinct from acoustic. He explored the use of feedback as a part of the instrument and could utilize it in ways no other performer at the time could. Eric Barrett once said:

> If I tried to test his equipment, all I got was feedback. Jimi could control it all with his fingers, and I still don't understand to this day how he did it. It was all part of his genius.[17]

Hendrix learned to control the feedback that resulted from the guitar being excited by the sound out of the amplifiers. If not used correctly, feedback generates useless, undesirable sounds, but Hendrix was, "…able to position his body and his guitar relative to the amplifier's speaker cabinets so that the resulting feedback would modulate to the precise tone he wanted."[18] Doing so allowed him to create sounds no one else could. Add this to his superb technical skill at the guitar and it is no wonder Jimi Hendrix is still considered one of the greatest guitar players in history.

By expanding the role of the amplifier in the performance of a guitar player, Jimi Hendrix forever changed the instrument. His musical virtuoso led him to influence musicians in a wide range of genres, everything from blues to heavy metal to funk to jazz. As was said of him during his 1992 induction into the Rock and Roll Hall of Fame, "More than any other musician, Jimi Hendrix realized the fullest range of sound that could be obtained from an amplified instrument."[19]

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[16] MG15 Series - Owners Manual, Bletchley, England: Marshall Amplification plc.
[17] Shapiro pp. 692
[18] Murray, pp. 214.
[19] "The Jimi Hendrix Experience" The Rock and Roll Hall of Fame and Museum: Inductees April 2007. <http://www.rockhall.com/inductee/the-jimi-hendrix-experience/>

3.5 - Amplifiers

The success of the electric guitar goes hand in hand with the development and evolution of audio amplification. While early electric guitars were essentially only played through amplifiers to increase their volume, musicians like Jimi Hendrix soon discovered that the amplifier could play a large role in the sonic qualities of the instrument.

Audio amplifiers come in two varieties: vacuum tube or valve amplifiers and solid-state transistor based amplifiers. This demarcation has led to much discussion about solid-state amplifiers' ability to produce the same tone quality as vintage tube amps. This experiment will look at the effects of both types on acoustic signals, and try to make assumptions about the equipment used by Jimi Hendrix.

3.5.1 - Marshall MG15DFX Amplifier

Figure 3-8: Marshall MG15DFx

The Marshall MG15DFX is a 15-Watt solid-state amplifier with both Clean and Overdriven channels, Bass, Contour, and Treble equalizer controls, and four built in Digital FX: Reverb, Delay, Chorus, and Flange. It also features Frequency Dependant Dampening (FDD), which is a proprietary circuit designed to mimic a valve amplifier's interaction with a loudspeaker. The amplifier's power output is 15W RMS into 8Ω with input impedance from the guitar of 1MΩ. The output of this assembly is one 8-inch speaker. It also has an Emulated Line Out and

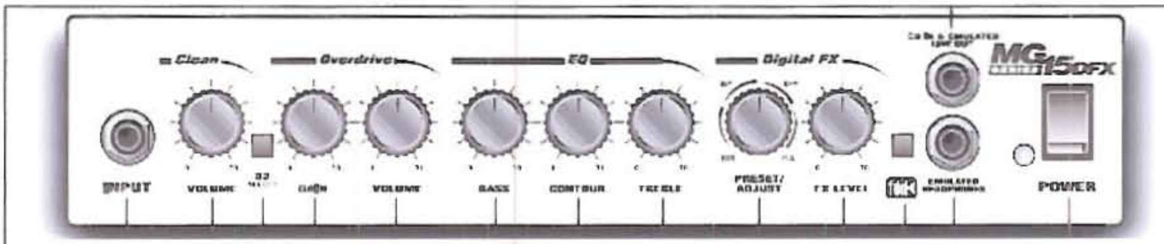

Figure 3-9: Marshall MG15DFX Control Panel

Emulated Headphone jack. This unit is tested because it is Marshall made, and features the FDD, the manufacturer's attempt to reconcile solid-state with tube amps.

3.5.2 - Fender Blues Deville Amplifier

The Fender Blues Deville, shown in Figure 3-10, is an authentically designed vintage tube amplifier. Released in 1993 as part of the Tweed series, the amp outputs 60 Watts to four 10-inch Alnico speakers. It features a number of controls, including Presence, Reverb, Middle, Bass, and Treble. In addition, the amplifier runs in either Drive or Vintage mode, and also has Bright, Drive and Standby switches.

Figure 3-10: Fender Blues DeVille

The amplifier also features 2 inputs, the second having 6dB lower sensitivity than the first. It has both a Preamp and Power Amp out, allowing for amplifier chaining. This amplifier has been subsequently reissued by Fender. This amplifier is used because its increased power output (60 Watts) and vacuum tubes are somewhat similar to those in Hendrix's Marshall 1959SLP.

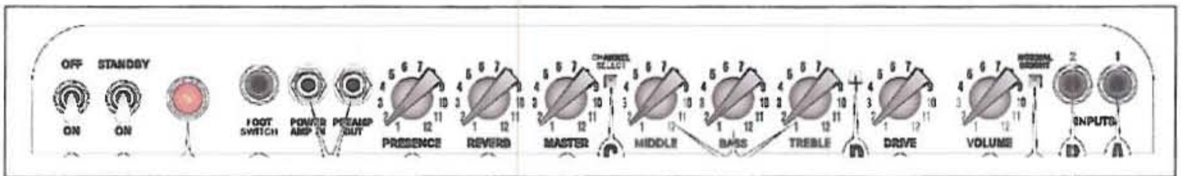

Figure 3-11: Fender Blues DeVille Top Control Panel

3.6 - Other Experimental Equipment

3.6.1 - HP 35665A 2-Channel Dynamic Signal Analyzer

The HP 35665 is a signal analyzer with a frequency range of 102.4 kHz, or 51.2 kHz in Two Channel Mode. It includes a simple function generator which will be used in this experiment. The analyzer has a sample rate of 102.4 kHz, and outputs data to a 3.5" floppy disk.

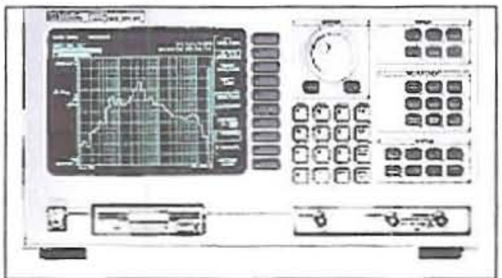

Figure 3-12: HP 35665A Signal Analyzer

Chapter 4 - Test Protocol

This document describes the experimental procedure step by step.

4.1 - Setup

Before data can be collected, the Signal Analyzer and amplifiers must be prepared. The scripts used for data analysis are provided in Appendix A.

4.1.1 - Equipment

The following is a list of equipment used in this experiment.

4.1.1.1 - Amplifiers

- Marshall MG15DFX Solid State Amplifier
- Fender Blues Deville Tube Amplifier

4.1.1.2 - Data Acquisition

- HP 35665A dual-channel signal analyzer

4.1.1.3 - Cables

- 3' BNC
- 2 x 6' Audio phono plug to ¼" mono phone plug

4.1.1.4 - Adaptors

- 2 x Phono to BNC adapter

4.1.1.5 - Software

- MATLAB R2006a
- Microsoft Excel
- Sdftoml.exe[20]

[20] Translates .dat file to .mat. Obtained on Stanford University's Electrical Engineering website. http://www.stanford.edu/class/ee122/Handouts/handouts.html. April 2007.

4.1.2 - Configure

The signal analyzer will act as both the function generator and the data collection in this experiment. First, test the Analyzer to ensure it is operating correctly before continuing the experiment. Controls on the Analyzer will be denoted in **boldface**.[21]

1. Turn on the Signal Analyzer.
2. After the display warms up, run a system reset with **Preset > Do Preset** followed by a Self Test with **System Utility > Self Test > Test Log > Clear Test Log > Return > Long Conf Test > Test Log > Preset > Do Preset**. The machine should be running with all factory default settings.
3. Insert a floppy disk in the disk drive of the Signal Analyzer.
4. Set the Analyzer to 2-channel mode: **Inst Mode > 2-Channel**.
5. Set the display mode: **Disp Format > Front/Back**
6. Connect a BNC T-connector to the *Source* jack on the Analyzer. Run a BNC to 1/4" cable from the T to the input of the Marshall MG15DFX Amplifier (shown in green in Figure 4-1) and a BNC cable to the *Channel 1* jack on the Analyzer face. Open the rear panel of the amplifier and disconnect the leads to the speaker (blue). Attach a pair of alligator clips to each lead, and connect to the *Channel 2* jack on the Analyzer with a BNC cable (red). Once connected, plug the amplifier in. Turn all knobs to their lowest setting.
7. Prepare the Fender amplifier by

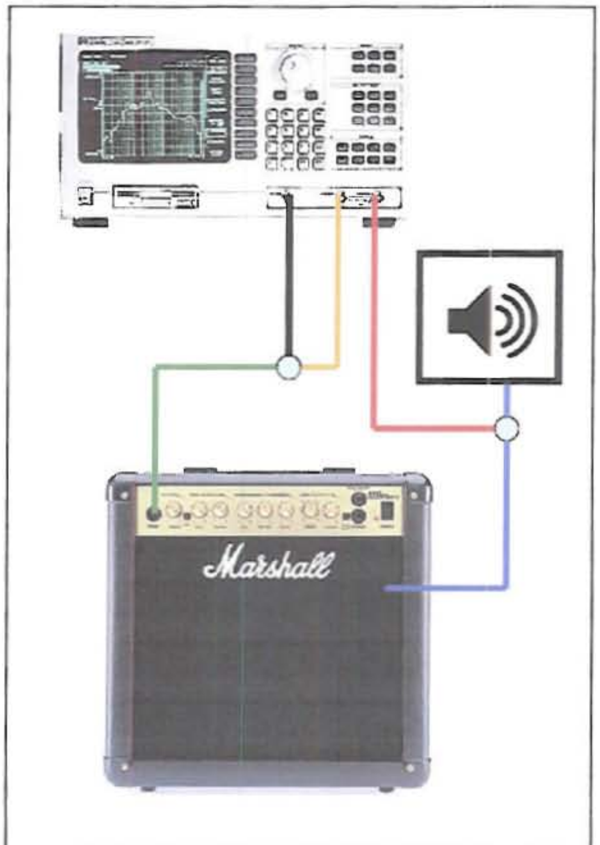

Figure 4-1: Schematic of Experimental Setup

[21] Parts of this procedure involving the basic operation of the HP 35665A Signal Analyzer were derived from the Laboratory Manual for ME 621 title "Experiments in Dynamic Signal Analysis – Revision 7" by R. Bernstein, M. Carlson, and R. L. Norton – WPI.

removing the rear panel cover and disconnecting the Internal Speaker Jack. *DO NOT TURN THE AMPLIFIER ON WHILE THE SPEAKERS ARE UNPLUGGED. DOING SO WILL DAMAGE THE AMPLIFIER.* A 1/4" phono to BNC cable will be used to connect the internal speaker jack to *Channel 2* when using this amplifier. Also, when testing the Fender, connect the *Source* cable to *Input 2*, which cuts the signal by 6dB. The Fender amp is very powerful; this cutting and very low volume settings are necessary to keep the output voltage levels acceptable.

4.2 - Data Collection

This section describes the collection of time domain, frequency response, and power spectrum date from both the Marshall and Fender amplifiers.

4.2.1 - Solid State Marshall Amplifier

8. Generate a sine wave at a test frequency of 440 Hz and amplitude of 1 V: **Source > Source ON > Fixed Sine > 440 > Hz > Level > 1 > Vrms.**[22]
9. Change data trigger: **Trigger > Channel 1**.
10. Set the plot scale: **Scale > Y Div > .5 > Enter > Match Y Scale**.

4.2.1.1 - Time Domain

11. Change the data type: **Meas Data > Time Channel 1 > Active Trace > Time Channel 2**. Both windows (front and back) should be relatively stationary waveforms with the same y-axis limits. Channel 2 has no signal yet, so it should be a relatively flat line.
12. Turn the amp on. Make sure it is set to Clean channel. Adjust the Clean Volume knob until the peaks of the Channel 2 waveform have approximately the same amplitude as Channel 1. This should be about a volume of 1 or 2.
13. Save Window 1 (switch between windows at anytime with **Active Trace**): **Save/Recall > Save Data > Save Trace > Into File > TRAC101.DAT > Enter**. For the MATLAB scripts to behave correctly the filenames must be of the form

[22] See Appendix B for an explanation as to how this tone was selected for this test.

TRACxxx.DAT, so begin with Track 101. The Analyzer will automatically increment your filenames from this point on.

14. Switch to Window 2 and save the trace.
15. Turn the Bass Knob on the amplifier to 2. Notice how the trace changes. Save. Repeat for Bass settings of 5, 8 and 10.
16. Repeat Step 15 for the Contour and Treble Knobs. First do each knob alone, zeroing the other two. Then set all three knobs to the same level. Try a few additional equalizer combinations; Marshall provides "Suggested Settings" in the Owners Manual.

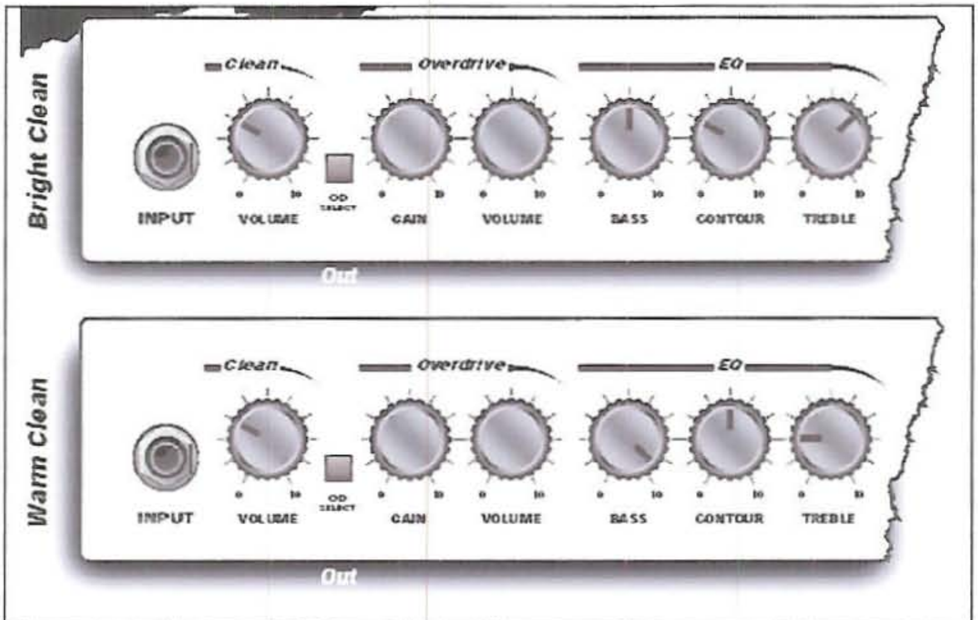

Figure 4-2: Marshall Suggested Settings

17. Repeat Steps 14 through 16 with the FDD switch on.
18. Switch the amplifier to Overdrive with the OD Select button. Set the gain to 5. Adjust the Overdrive Volume until the waveform amplitude matches that of the Channel 1 signal.
19. Perform the same equalizer adjustment pattern described in Steps 14 through 17.

4.2.1.2 - Power Spectrum

20. Change the data type: **Meas Data > Pwr Spectrum 1 > Active Trace > Pwr Spectrum 2**.
21. Zoom in on the audible range only: **Freq > Stop > 20 > kHz**. The Analyzer should now display frequencies from 0 to 25.6 kHz.

22. Turn on averaging: **Average > Num Averages > 5 > Avg On**. When averaging is active, the **Start** button must be pressed between each track recording.
23. Again record the traces for each equalizer setting in Steps 15 through 17. Do this for both the Clean and Overdrive Channels.

4.2.1.3 - Frequency Response

24. Change the data type: **Meas Data > Frequency Response >**. The second window can be set to any data type for this series of measurements; there is no Channel 1 trace to compare to.
25. Change Source to white noise: **Source > Random Noise > Start**.
26. Turn Triggering to free run: **Trigger > Free Run**.
27. Change the number of averages: **Average > Num Averages > 15 > Enter**.
28. Again record the traces for each equalizer setting in Steps 15 through 17. Do this for both the Clean and Overdrive Channels.

4.2.1.4 - Logging

29. Construct an Excel table that describes the characteristics of each Track, as shown in Table 4-1. This file will provide MATLAB with the appropriate date to generate the plots and other values in the analysis section of this procedure. The Table should be saved to the MATLAB working directory, with the filename *TestSettings.xls*. The data values are described in Table 4-2.

Table 4-1: Example Track Data Sheet

Track	OD	V	G	B	C	T	FDD	Type	Amp	NOTES	Setup
101	0	2	0	0	0	0	0	1	1	CH1	Time Domain
102	0	2	0	0	0	0	0	1	1		440 Hz
103	0	2	0	2	0	0	0	1	1		1Vrms
104	0	2	0	5	0	0	0	1	1		51.2 kHz Sample Rate
105	0	2	0	8	0	0	0	1	1		Marshall

Table 4-2: Data Sheet Explanation

Column Name	Meaning	Values
Track	Track number	Number from 101 to 999
OD	Overdrive or Clean Channel	0 = Clean 1 = Overdrive
V	Channel Volume	0 – 10 (Marshall) 1 – 12 (Fender)
G	Overdrive Gain (Drive)	0 – 10 (Marshall) 1 – 12 (Fender)

B, C, T	EQ Settings (Bass, Contour [Middle], Treble)	0 – 10 (Marshall) 1 – 12 (Fender)
FDD	Frequency Dependent Dampening	0 = Off 1 = On
Type	Trace Type	1 = Time 2 = Frequency 3 = Power
Amp	Amplifier	1 = Marshall 2 = Fender
NOTES	Notes About Track	Various
Setup	Notes About Data Set	Various

4.2.2 - Vacuum Tube Amplifier

30. Repeat all steps in Section 4.2.1 - using the Fender Blues DeVille amplifier instead. Please note that the power output on the Fender is much higher than the Marshall, and therefore the volume should be kept VERY LOW (about at 1) to achieve similar amplitude readings. Also, replace the equalizer settings of 2, 5, 8 and 10 with 3, 6, 9, and 12 respectively. The Fender does not have FDD.

4.3 - Data Analysis

This section describes the use of MATLAB to compare and analyze the data collected in Section 4.2 The script files referenced here are all available in Appendix A – MATLAB Code. For the scripts to run as written, they must be located in a folder at **C:\IQP** on the PC, with the exception of *dosrun.m*, which must be place in **C:\IQP\DAT**.

31. Once all data has been saved, move the .DAT files to a folder named **C:\IQP\DAT**. Open *dosrun.m* in the M-file Editor. Change the limits for "i" to reflect the number of .DAT files in the folder. Execute *dosrun.m*. This script converts the .DAT files to .MAT files that MATLAB can use to generate plots.
32. Open *TestSettings.xls* in Microsoft Excel.
33. Open *comparison.m*. Execute this script, and enter in the desired number of Tracks in the dialog box that appears, seen in Figure 4-3. Then enter in each Track number in the following dialog boxes.

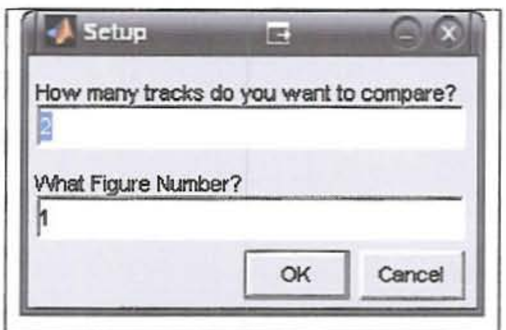

Figure 4-3: MATLAB Track Selection

34. The script will output a plot of the selected Tracks. If the Tracks selected were time domain waveforms, the script will also generate a one second tone to match the waveform. After the tone is sounded, the script will pause until a key is hit.

35. The legend of the plot, seen in Figure 4-4, will describe each Track, detailing which amplifier was used, Clean or Overdriven Channel, Volume, Gain, and the settings for each of the three Equalizer bands, Bass, Contour, and Treble, each represented by their corresponding initial and the number value of the setting on that track. An 'M' signifies a Maximum setting.

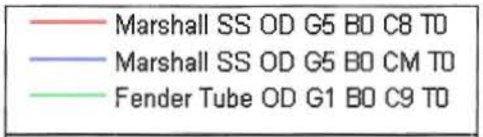

Figure 4-4: Sample Legend

Chapter 5 - Results

For the purpose of this discussion, one performance of Hendrix's in particular is considered: "Little Wing" as performed at the Winterland on October 11, 1968. This performance was selected as representative of Hendrix's style and also because of its technical complexity. Additionally, during this particular performance his "... tone, treated with only a touch of Univibe and Octavia, is crystalline, and the absence of distortion brings out many subtleties that are otherwise inaudible."[23] The statistical analysis performed on this song, used to determine what source frequency to use in Chapter 4, is found in Appendix B.

A large sample of data was obtained in Chapter 4, and numerous conclusions can be drawn through comparison of different amplifiers and different settings. Here a few representative samples will be discussed. A more complete series of plots are available in Appendix C.

---

[23] "Little Wing," Hendrix: The Jimi Hendrix Concerts. Milwaukee: Hal Leonard Corporation, 1991. pp. 96

5.1 - Frequency Response

The plot shown in Figure 5-1 details the frequency response of the Marshall MG15DFX and the Fender Blues DeVille under the white noise test performed in Section 4.2.1.3, with the equalizer set to full zeroes, over the audible range. This is the true response of the amplifier; all other settings of equalizer will impact this curve. The traces shown are the Marshall Clean (red), Marshall Overdrive (blue), Fender Clean (green) and Fender Overdrive (magenta). Notice in both cases, the overdriven channel has a boosted response that follows essentially the same curve as the clean channel on the same amplifier. Also, the flattest response for the full audible range is from the Fender Overdrive Channel, especially noticeable at frequencies above 10 kHz.

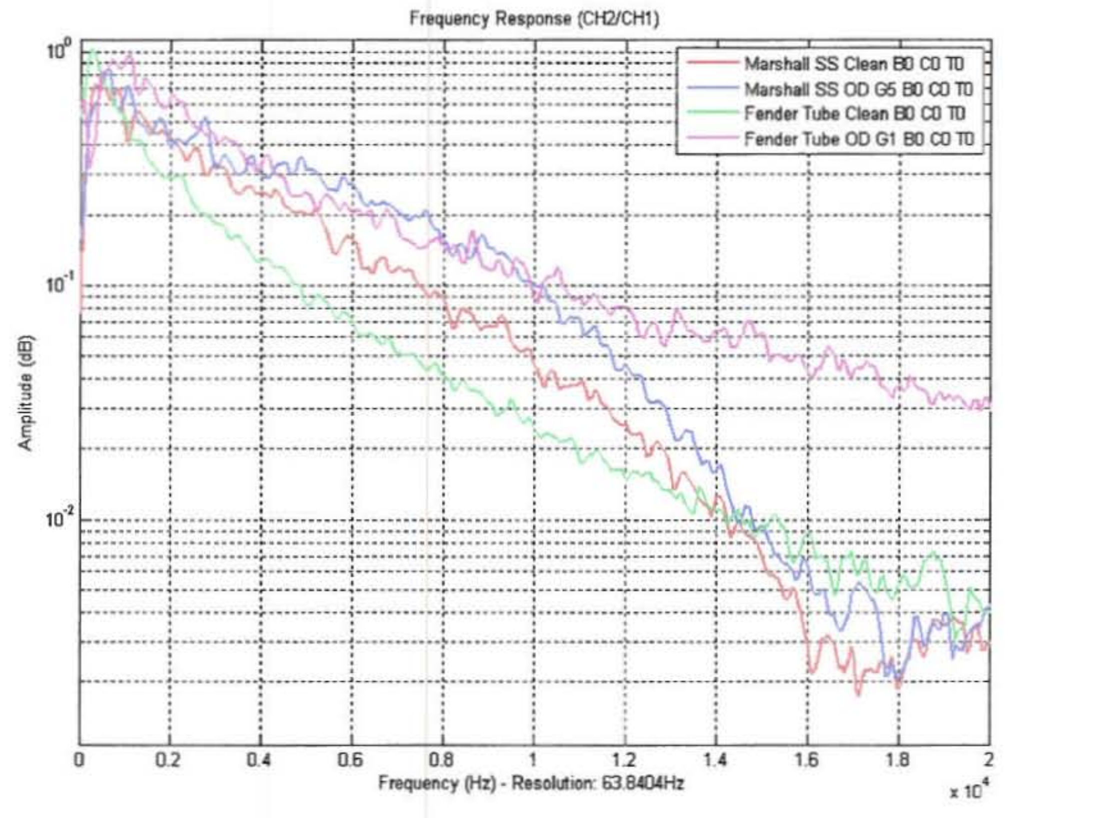

Figure 5-1: Frequency Response With No Equalizer: Clean and Overdrive, Marshall and Fender

As expected, the frequency response is impacted by changes in the equalizer settings. The Bass knob on both amplifiers affects only the low-end of the frequency range, lower than 500 Hz. Contour and Treble each have a much more pronounced impact on the majority of the audible range. Figure 5-2 compares a sample of the impact of each of the three knobs as they are increased from minimum to maximum.

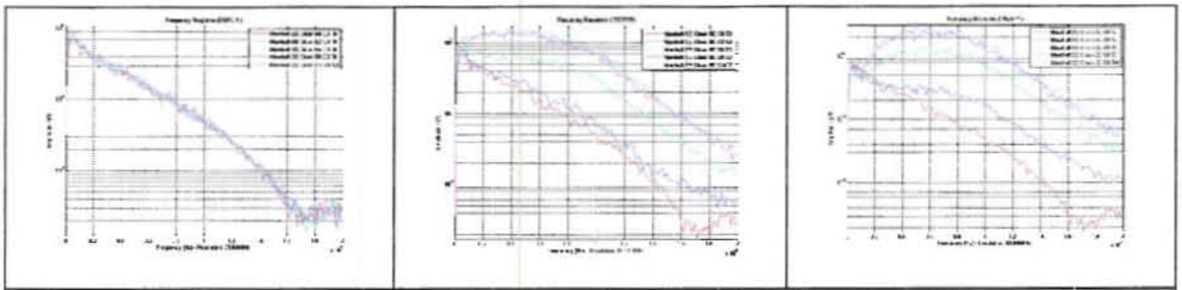

Figure 5-2: Sample Frequency Response Plots: Bass, Contour, and Treble

In an attempt to look at the response of settings that would be similar to the description of Hendrix's Winterland "Little Wing," the recommended setting for "Bright Clean" tone given from Marshall was tested. The result is displayed in Figure 5-3 between the frequency response at both minimum and maximum equalization settings, for reference.

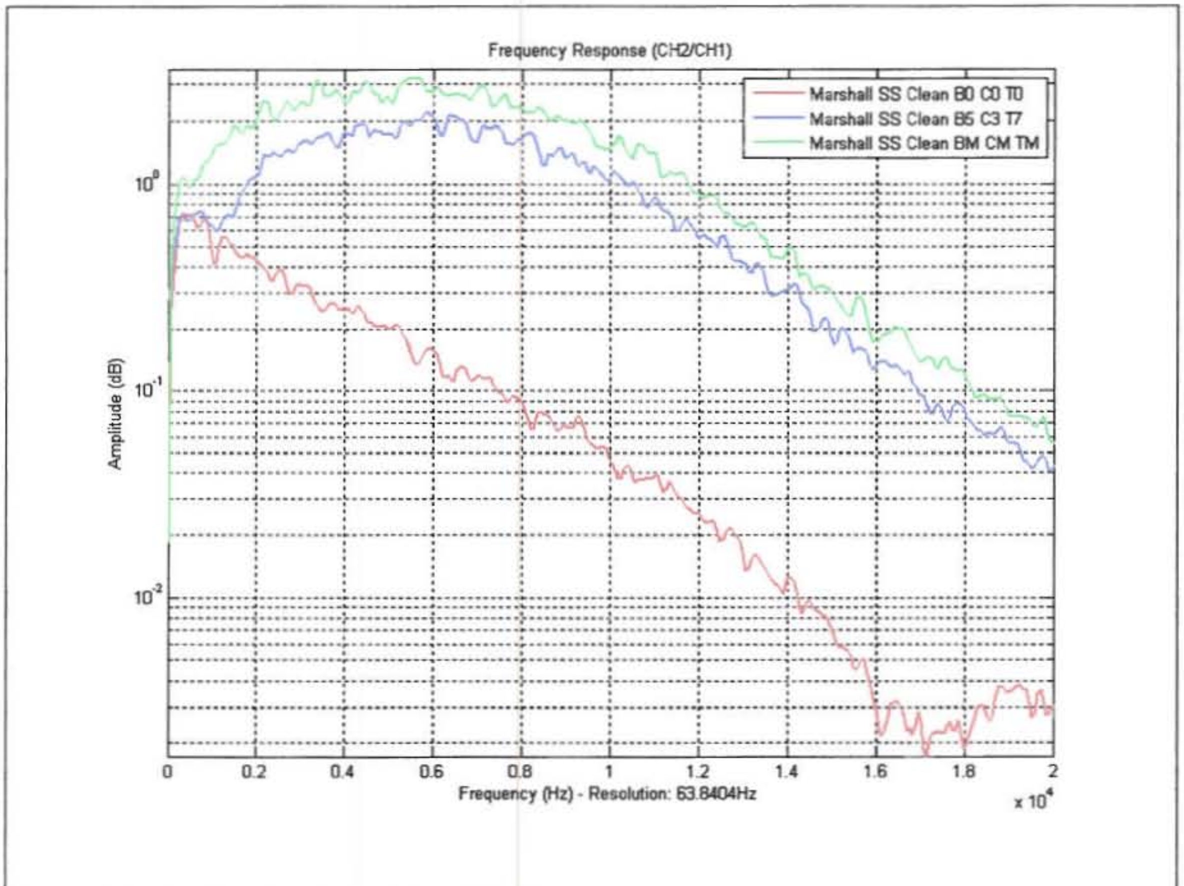

Figure 5-3: Frequency Response - "Bright Clean" Tone

It is clear that the "bright" sound comes from the elevated levels in the high frequency range, while low and midrange frequencies are somewhat subdued.

5.2 - Time Domain Effects

It is significantly more difficult to draw meaningful conclusions about the sound from plots of the time domain. It is possible, however to make a few qualitative comments. Figure 5-4 shows the "Bright Clean" suggested setting in the time domain between minimum and maximum equalization settings. The only noticeable change from the minimum equalizer setting is a slight shift in amplitude as well as a small lead in the phase. The clean signal remains entirely sinusoidal.

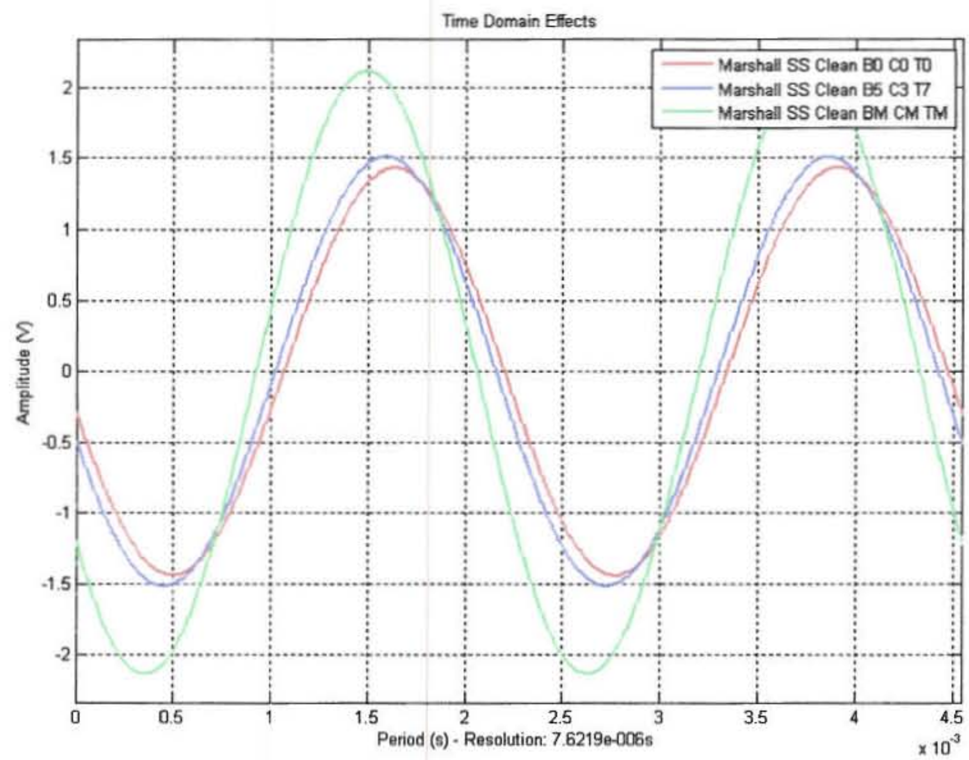

Figure 5-4: Time Domain - "Bright Clean" Tone

The Overdrive channel has a drastically different waveform. The waveforms shown in Figure 5-5 below are the source 440 Hz sinusoid in red, the Overdrive Channel of the Marshall with maximum equalizer in blue, and the Overdrive Channel of the Fender with maximum equalizer in green. It is obvious that higher frequency components have been added by the appearance of short length spikes on both the leading and trailing edges of the wave for both amplifiers. Interestingly, the leading and trailing spikes in both amplifiers occur at roughly the same time. However, the Marshall boosts the signal amplitude significantly, while the Fender cuts it to roughly half as much.

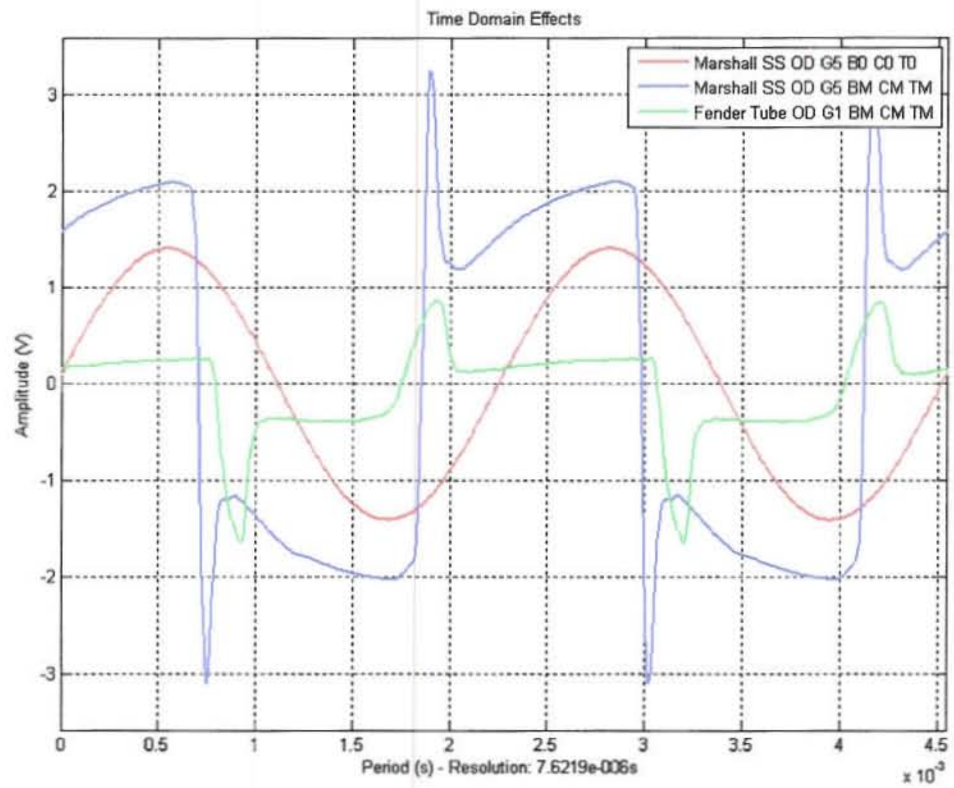

Figure 5-5: Time Domain Plot - 440 Hz Sinusoidal Source

5.3 - Power Spectra

The frequency domain offers much more accessible insight into the sound produced through each amplifier than the time domain. In this set of data, the amplifier was given an input of one pure tone sinusoid with a frequency of 440 Hz.

The Marshall, left, and Fender, right, are both shown in Figure 5-6 at minimum and maximum equalizer settings, for both channels. The Marshall amplifier produces more harmonics than the Fender in every setting combination, including both Clean and Overdrive channels. Also evident is the increase in number and amplitude of harmonics as the equalizer setting increases.

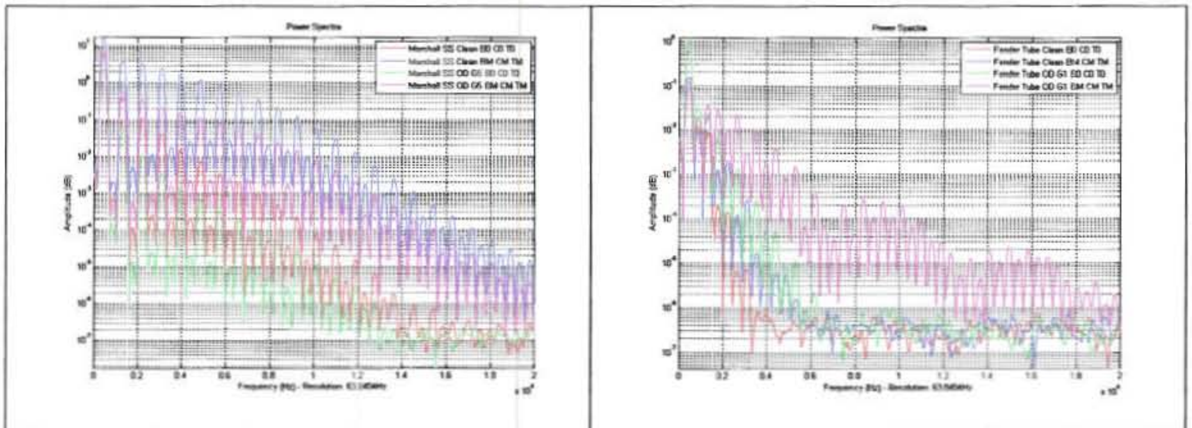

Figure 5-6: Frequency Components - Marshall v. Fender

A direct comparison of the frequency components of both the Marshall and the Fender amplifiers Overdrive channels with no equalizer settings is shown in Figure 5-7, in blue and green respectively. The power spectrum of the source signal from the Signal Analyzer is displayed in red. As expected, it has only one peak, at the signal frequency, 440 Hz. Immediately apparent are the large number of harmonics, occurring every 440 Hz. The harmonics fall off much faster in the Fender. In each case the odd harmonics are stronger than even harmonics, but that difference is much more apparent in the Marshall.

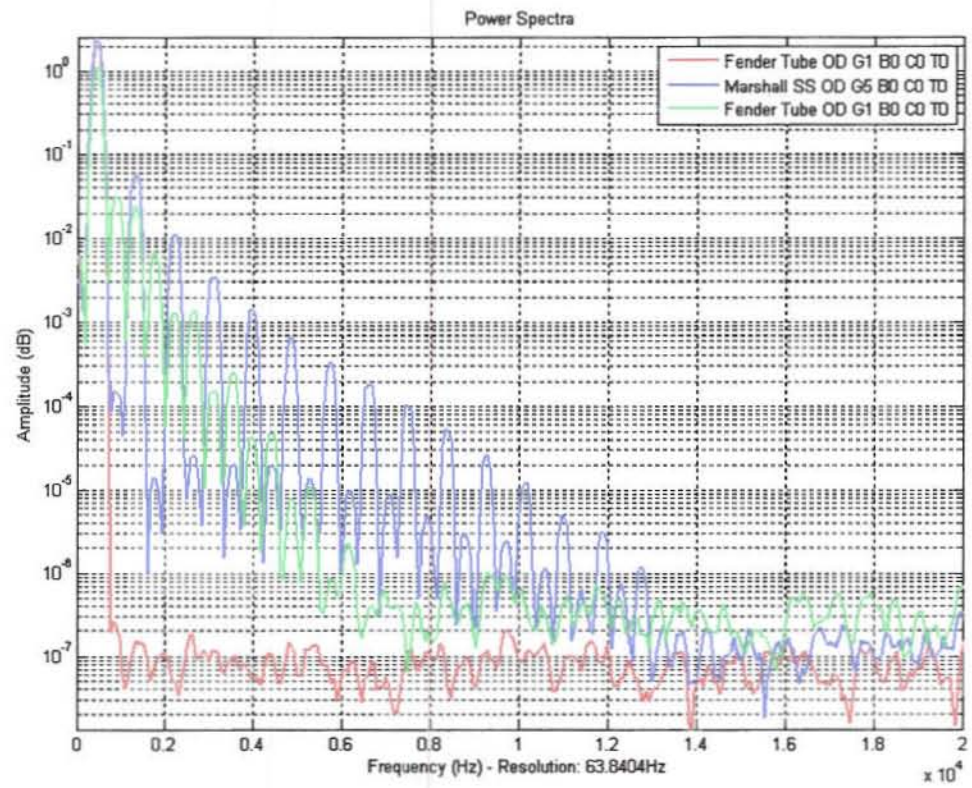

Figure 5-7: Power Spectrum – Overdrive, No Equalizer, 440 Hz Source Signal

It is this addition of harmonics that give each amplifier its own unique sound in the Overdrive channel. Increasing the Contour and Treble settings increases the amplitude of these harmonics significantly, resulting in a boosted higher-frequency tone.

Chapter 6 - Conclusions

The primary conclusion to be drawn is that changes in the amplifier settings can yield entirely different sounds. This is not a trivial statement; it implies that the amplifier has significant impact on the music produced, and must be treated with as much consideration as the guitar in defining the sound of the instrument. It is not enough to merely amplify the signal from a guitar to obtain a louder signal. Instead, amplifier choice, as well as tone setting, has a tremendous impact in the quality of the sounds it produces. Jimi Hendrix demonstrated how much more was possible through playing the amplifier as well.

Some argument was presented supporting the claim that solid-state amplifiers produce different sounds than tube amplifiers. While more investigation would be useful to rule out other factors (power settings, manufacturer methods, etc.), there is evidence that the two types of amplifiers are fundamentally different.

6.1 - Future Work

One major limitation on this project was the fact that it is the work of only one student. It would benefit greatly from a team approach. The suggested team would have included the addition of an electrical engineer for better understanding of signals and their analysis, a computer science major for development of analytical tools like the MATLAB scripts, and a music or humanities major for a more complete discussion on the nature of music. With a coordinated team with the described background, this analysis could be strengthened enourmously.

There is still an enormous amount of work that could be done with this project. It was not possible to obtain a Marshall 1959SLP, but looking at one with the methods described in Chapter 4 would certainly be interesting. In addition, it would be of value to test the amplifiers using a guitar rather than the function generator for a more realistic analysis of the interaction between the two parts of the instrument.

As was discussed above, it is difficult to obtain the exact equalizer settings used by Hendrix, but given more time it could be done. Such data would remove the need for approximations and assumptions in the measurement of different settings.

Further investigation into the other half of the electric guitar instrument, the actual guitar (see Figure 6-1), could be performed. Such tests could look into different guitar styles, pickup arrangement, and volume and tone settings. Additionally, it would be ideal to experiment with various effects pedals, particularly those used most frequently by Hendrix, like the Octavia and Arbiter Fuzz Face.

A comprehensive collection of such analyses would be a valuable resource, and would not need to be limited to only Jimi Hendrix's equipment settings. Similar techniques could be applied more extensively to the work of any musician. By creating a library of that nature, and analyzing it for correlations, it may be possible to draw conclusions about what separates a "good" musician from a "great" one.

Figure 6-1: Fender Stratocaster

Tools like this could be used as study aides for new musicians, striving to attain a sound similar to their favorite influence. While it is not probable, or necessarily desirable, for another player to recreate Hendrix's sound exactly, it would be a useful means of improving personal understanding of the instrument.

6.2 - Social Impact

As a launching point for further examination, this project provided some interesting data. The difference between solid-state and tube amplifiers has been a long debated question by musicians, sound engineers, and audiophiles. The analyses run in this project can be used to better define these differences, and help reconcile them if desired. The result from such work could potentially be a marriage of the best features of both kinds of amplifiers.

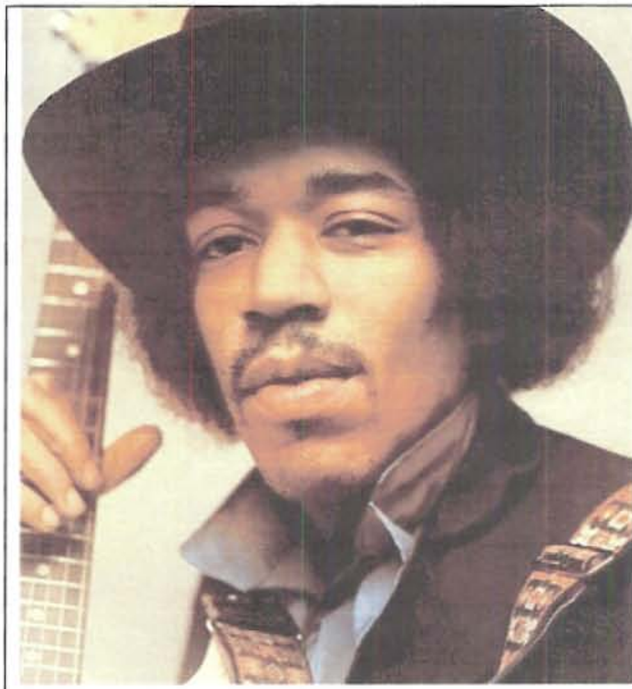

Figure 6-2: Jimi Hendrix - Innovator

Aside from that is the more important argument for the recognition of electronic amplification as an important part of the instrumentation of modern music. Following the lead of such innovators as Jimi Hendrix, the full potential of music available with modern technology may be obtained.

Beyond the technical argument, the discussion here may provide a means of commentary on the very nature of music. While technology has progressed alongside music throughout history, its advancements have led consistently to the state they are in today. The relation between technology and music is not an unguided one. Rather it follows a common trajectory over the course of human history. The trend seems to be of ever increasing ability to manipulate and generate new sounds.

The move from membrane to wind instruments, drums to flutes and the like, expanded instrumentation from rhythm alone to discrete tones, capable of melody. The development of strings, like violin, piano, and guitar, later allowed the discrete tones to be shaped and bent, allowing even more expressive use of melody. Orchestration allowed harmony and counter-point to again expand the vocabulary. And with the advent of electronics, as demonstrated in this paper through the discussion on guitar amplifiers, the musician could alter and manipulate the very sound wave they created. In addition, they could change how the signal was projected into sound through experimentation with amplification. Synthesizers and modern computing allow extremely precise control over all aspects of tone, melody, expression, orchestration, and sound, all in the virtual world.

The steady progression toward complete control over music and the components that make it has led to incredible results. But it has not changed the fact that music is intimately part of being human. The psychological and physiological foundations of what sets music apart from noise are far from fully understood. Theories are numerous, but it is quite difficult to forge an objective definition for a question as subjective as, "What is Music?" And although every individual may have distinct personal biases and tastes, the success of some musicians in exciting their audience is undeniable. There must be some common thread, a defining characteristic present in the music of history's "greats" that strikes a chord in the human psyche.

The saturation of the modern world with music of all kinds is no accident. The success of radio, iPods, and commercial music relies on the fact that people of every background enjoy and desire music. While its role may have changed dramatically over centuries, it is no less important today than ever before. Music transcends language, culture, and societal barriers. It is communication in its most pure form. It is entertainment, art, drama, and suspense all rolled together. With an objective approach, as in this project, people can continue refining the definition of music to expand it beyond even what it is now.

Perhaps Pythagorus was correct in his belief of *musica universalis*.

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Appendix A – MATLAB Code

The following code files are used to perform the analysis described in Chapter 4, and to generate the plots shown in Chapter 5 and in Appendix C. They are reference only, and may require significant changes to be used locally. Brief descriptions of every script are offered above each.

comparison.m

This script makes all necessary function calls to obtain user input, generate plots, and sound the signal if it is in time domain. It is the script that must be executed to run an analysis; all other scripts are functions referenced in this script.

```
   Initialize
clear all;
clc;

[tracks fignum f] = userdata();
j = 1;

   Retrieve Data

for i=tracks

    [name type a] = buildlegend(i);
    tolegend(j, :) = name;

    num = int2str(i);
    [x y yplay] = getdata(num, type, a, f);

    toplot(:,j) = y;
    toplay(:,j) = yplay;
    j = j+1;
end

   Plot Data

myplot(type, x, toplot, tolegend, f, fignum);

   Play the tone if time domain
if type == 1
    for k=1:j-1
        soundsc(toplay(:,k), 102400);
        if k == j-1
            disp('All tones played');
        else
            disp('Push a Key to hear the next tone.');
            pause;
        end
    end
end
```

userdata.m

This script generates dialog boxes to ask the user for input. It asks how many tracks are to be compared, what figure number the plot generated will be, and what the frequency of the Source Signal on this track was. It then asks to identify each track to be compared.

```
function [tracks fign f] = userdata()

prompt1 = {'How many tracks do you want to compare?', 'What Figure
Number?', 'What frequency is the Source Signal (if applicable)?'};
title1 = 'Setup';
def1 = {'2', '1', '440'};

answer = inputdlg(prompt1, title1, 1, def1);

numtrack = str2double(answer(1));
fign = str2double(answer(2));
f = str2double(answer(3));

for i=1:numtrack

    prompt2 = ['Track ' num2str(i) ' Data File:'];
    title2 = ['Track ' num2str(i)];
    def2 = {'101'};

    t = inputdlg(prompt2, title2, 1, def2);
    t = cell2mat(t);
    datatrack(:, i) = str2double(t);
    i = i+1;
end

tracks = datatrack;
```

getdata.m

This script reads the track data from file and builds a vector for each track. In the Time Domain, it is necessary to take only the real components of the plot, so further calculations are necessary.

```
function[x, y, yplay] = getdata(filename, type, amp, f)

outputpath = strcat('C:\IQP\DAT\TRAC', filename, '.mat');
outputpath = char(outputpath);
S = load(outputpath);
names = fieldnames(S);
load(outputpath);

x = char(names(1));
y0 = char(names(2));
x = eval(x);
y0 = eval(y0);

if type == 1                    % Time Domain
    p = 1/f;
    for i = 1:length(y0)
```

```
        if y0(i) < 0
            y(i) = -1*abs(y0(i));
        else
            y(i) = abs(y0(i));
        end
        if amp == 2
            y(i) = -y(i);
        else
        end
    end
    y = y';
    for j = 1:length(y)
        if x(j) <= p
            yplay(j) = y(j);
        end
    end
    yplay = yplay';
    while length(yplay) <= 102400
        yplay = cat(1, yplay, yplay);
    end
elseif type == 2                Frequency Response
    y = abs(y0);
    yplay = 0;

elseif type == 3                Power Spectrum
    y = y0;
    yplay = 0;
end
```

myplot.m

This function sets all parameters and generates the traces for each comparison plot.

```
function [h] = myplot(type, x, toplot, tolegend, f, fignum)

   Set Line Properties
set(0,'DefaultAxesColorOrder',[1 0 0;0 0 1;0 1 0; 1 0 1; 0 1 1],...
       'DefaultAxesLineStyleOrder','-|--|:');

   Determine Period
p = 1/f;

   Find Axes Limits and Resolution
maxx = max(x);
resx = num2str(maxx/length(toplot));

if maxx > 20000
    maxx = 20000;
end

maxy = 1.1 * max(toplot);
maxy  = max(maxy);

   Create the Figure
figure(fignum);
whitebg([1 1 1]);
```

```
    Plot Settings

     if type == 1              Time Domain

         h = plot(x,toplot);
         axis([0 2*p -maxy maxy]);
         xlabel(['Period (s) - Resolution: ' resx 's']);
         ylabel('Amplitude (V)');
         mytitle = 'Time Domain Effects';

     elseif type == 2          Frequency Response

         h = semilogy(x,toplot);
         axis([0 maxx 0 maxy]);
         xlabel(['Frequency (Hz) - Resolution: ' resx 'Hz']);
         ylabel('Amplitude (dB)');
         mytitle = 'Frequency Response (CH2/CH1)';

     elseif type == 3          Frequency Domain

         h = semilogy(x,toplot);
         axis([0 maxx 0 maxy]);
         xlabel(['Frequency (Hz) - Resolution: ' resx 'Hz']);
         ylabel('Amplitude (dB)');
         mytitle = 'Power Spectra';

     end

legend(tolegend);
set(h,'LineWidth', 2);
set(gcf, 'color', 'white');
title(mytitle);
grid on;
```

buildlegend.m

This function queries the Excel sheet *TestSettings.xls* for data related to each track and then constructs the legend for the plot. Because each legend string must be the same number of characters, decimal and two-digit settings are represented with one character only, being an 'M' for numbers larger than 9.

```
function [name ty a] = buildlegend(r)

eqs = ddeinit('excel', 'TestSettings.xls');
r = r - 99;
r = int2str(r);

   Determine Clean or Overdrive and Gain
qch = ['r' r 'c2'];
qg = ['r' r 'c4'];

ch = ddereq(eqs, qch);
g = ddereq(eqs, qg);
if g > 9
```

```
    g = 'M';
else
    g = int2str(g);
end
G = ['G' g];

if ch == 0
    ch = 'Clean';
else
    ch = ['OD ' G];
end

   Determine Amp Type
qam = ['r' r 'c10'];
amp = ddereq(eqs, qam);

if amp == 1

    qfdd = ['r' r 'c8'];
    fdd = ddereq(eqs, qfdd);

    if fdd == 1
        amp = 'Marshall FD ';
    else
        amp = 'Marshall SS ';
    end
    a = 1;
else
    amp = 'Fender Tube ';
    a = 2;
end

   Determine Equalizer Settings

qb = ['r' r 'c5'];
qc = ['r' r 'c6'];
qt = ['r' r 'c7'];

b = ddereq(eqs, qb);
c = ddereq(eqs, qc);
t = ddereq(eqs, qt);

if b > 9
    b = 'M';
else
    b = int2str(b);
end

if c > 9
    c = 'M';
else
    c = int2str(c);
end
```

```
if t > 9
    t = 'M';
else
    t = int2str(t);
end

B = [' B' b];
C = [' C' c];
T = [' T' t];

   Construct Legend Title
name = [amp ch B C T];

   Get Plot Type
qty = ['r' r 'c9'];
ty = ddereq(eqs, qty);
```

dosrun.m

This script is run outside of the *comparison.m* family, only necessary when converting .DAT files to .MAT files, as described in Chapter 4.

```
for i=101:400

    num = int2str(i);
    datname = ['TRAC' num '.dat '];
    matname = ['TRAC' num '.mat '];

    path = ' C:\IQP\DAT\';

    command = [path 'Sdftoml.exe /x ' datname matname];

    dos(command);

    print = i

end
```

Appendix B – Little Wing Solo Statistics

Table B-1 is a representation of the guitar solo, from measure 102 to the song's end, played by Jimi Hendrix in the song "Little Wing" as performed at the Winterland on October 11, 1968, as transcribed in Hendrix: The Jimi Hendrix Concerts.[24]

The data in Table B-1 indexes each note with its location (measure and beat), tone, duration, and any ornamentation present (BD = Bend Down, BU = Bend Up, HO = Hammer On, NA = No Ornament, PO = Pull Off, S = Slur, SU = Slide Up, V = Vibrato). The chord the note is played over is also listed, as well as a sum of the total duration of each tone (all octaves). This sum was used to select the source frequency in the amplifier experiment performed in Section 4.2 the A4 is the most prominent note in the solo. Four octaves of notes, ranging from C3 to B6, and the corresponding note frequencies (taken from an ideally tuned piano) are found in Table B-2.

Table B-1: "Little Wing" Solo Note Statistics

#	Measure	Beat	Note	Length	Ornament	Chord	Total Length of Tone
13	2	4	A4	0.125	BU	G	
15	3	1	A4	0.063	NA	Am7	
17	3	1	A4	0.125	NA	Am7	
19	3	2	A4	0.031	NA	Am7	
21	3	2	A4	0.031	NA	Am7	
23	3	3	A4	0.031	BD	Am7	
27	3	4	A4	0.125	BD	Am7	
31	4	2	A4	0.063	NA	Em7	
34	4	3	A4	0.063	NA	Em7	
37	4	3	A4	0.063	HO	Em7	
39	4	4	A4	0.188	SU, V, HO	Em7	
41	5	1	A4	0.188	S, V	Bm7	
42	5	2	A4	0.063	NA	Bm7	
46	5	4	A4	0.063	BD	Bm7	
65	7	3	A4	0.063	BU	Fadd9	
66	7	3	A4	0.125	NA	Fadd9	
67	7	4	A4	0.063	BU	Fadd9	
80	9	2	A4	0.063	NA	D	
82	9	2	A4	0.042	NA	D	
85	9	3	A4	0.042	BU	D	
88	9	3	A4	0.250	NA	D	1.865
4	1	4	B4	0.125	NA	Em	
5	1	4	B4	0.063	NA	Em	
7	2	1	B4	0.250	NA	G	

[24] Hendrix pp. 104

8	2	2	B4	0.125	S	G	
16	3	1	B4	0.063	BU	Am7	
18	3	2	B4	0.031	BU	Am7	
22	3	3	B4	0.031	BU	Am7	
24	3	3	B4	0.031	BU	Am7	
26	3	4	B4	0.031	BU	Am7	
32	4	2	B4	0.063	BU	Em7	
43	5	2	B4	0.188	SU, V, HO	Bm7	
45	5	4	B4	0.188	BU	Bm7	
48	6	1	B4	0.063	PO	Am	
50	6	1	B4	0.063	PO	Am	
52	6	2	B4	0.063	PO	Am	
57	6	4	B4	0.125	NA	Am	
58	7	1	B4	0.125	BU	Am	
61	7	2	B4	0.125	BU	Am	1.750
73	8	1	C4	0.125	NA	C	
77	8	2	C4	0.125	NA	C	
47	6	1	C5	0.063	BU	Am	
49	6	1	C5	0.063	NA	Am	
51	6	2	C5	0.063	NA	Am	
65	7	3	C5	0.063	BU	Fadd9	
67	7	4	C5	0.063	BU	Fadd9	
69	7	4	C5	0.125	NA	Fadd9	0.688
91	10	1	CHORD	LONG	GD	D	
70	8	1	D4	0.042	PO	C	
72	8	1	D4	0.042	PO	C	
74	8	2	D4	0.042	PO	C	
76	8	2	D4	0.042	PO	C	
78	9	1	D4	0.188	BU	D	
79	9	1	D4	0.063	NA	D	
81	9	2	D4	0.063	NA	D	
87	9	3	D4	0.042	NA	D	
89	9	4	D4	0.125	NA	D	
90	10	1	D4	0.063	NA	D	
3	1	3	D5	0.125	NA	Em	
6	1	4	D5	0.063	HO	Em	
10	2	2	D5	0.063	BD	G	
14	2	4	D5	0.125	NA	G	
25	3	3	D5	0.031	NA	Am7	
56	6	4	D5	0.063	BD	Am	1.177
29	4	1	E4	0.250	V	Em7	
35	4	3	E4	0.063	NA	Em7	
71	8	1	E4	0.042	PO	C	
75	8	2	E4	0.042	PO	C	
80	9	2	E4	0.063	NA	D	
86	9	3	E4	0.042	PO	D	
88	9	3	E4	0.250	NA	D	
1	1	1	E5	0.500	BU, V	Em	

2	1	3	E5	0.125	BU	Em	
9	2	2	E5	0.063	BU	G	
54	6	3	E5	0.250	BU, V	Am	
55	6	4	E5	0.063	BU	Am	1.750
82	9	2	F#	0.042	NA	D	
84	9	2	F#	0.042	PO	D	
85	9	3	F#	0.042	BU	D	0.125
64	7	3	Fnat	0.063	NA	Fadd9	0.063
11	2	3	G4	0.188	V	G	
12	2	3	G4	0.063	NA	G	
20	3	2	G4	0.031	NA	Am7	
28	3	4	G4	0.063	NA	Am7	
30	4	2	G4	0.063	NA	Em7	
33	4	2	G4	0.063	NA	Em7	
36	4	3	G4	0.063	NA	Em7	
38	4	4	G4	0.063	NA	Em7	
40	5	1	G4	0.063	NA	Bm7	
44	5	3	G4	0.250	BD	Bm7	
53	6	2	G4	0.125	NA	Am	
63	7	2	G4	0.063	SD	Am	
66	7	3	G4	0.125	NA	Fadd9	
68	7	4	G4	0.063	BD	Fadd9	
69	7	4	G4	0.125	NA	Fadd9	
70	8	1	G4	0.042	PO	C	
74	8	2	G4	0.042	PO	C	
83	9	2	G4	0.042	PO	D	
59	7	1	G5	0.063	NA	Am	
60	7	1	G5	0.063	NA	Am	
62	7	2	G5	0.063	NA	Am	1.719

Table B-2: Chromatic Note Frequencies (Hz)

Note	Frequency	Note	Frequency	Note	Frequency	Note	Frequency
C3	130.813	C4	261.626	C5	523.251	C6	1046.50
C#3	138.591	C#4	277.183	C#5	554.365	C#6	1108.73
D3	146.832	D4	293.665	D5	587.330	D6	1174.66
D#3	155.563	D#4	311.127	D#5	622.254	D#6	1244.51
E3	164.814	E4	329.628	E5	659.255	E6	1317.51
F3	174.614	F4	349.228	F5	698.456	F6	1396.91
F#3	184.997	F#4	369.994	F#5	739.989	F#6	1479.98
G3	195.998	G4	391.995	G5	783.991	G6	1567.98
G#3	207.652	G#4	415.305	G#5	830.609	G#6	1661.22
A3	220.000	A4	440.000	A5	880.000	A6	1760.00
A#3	233.082	A#4	466.164	A#5	932.328	A#6	1864.66
B3	246.942	B4	493.883	B5	987.767	B6	1975.53

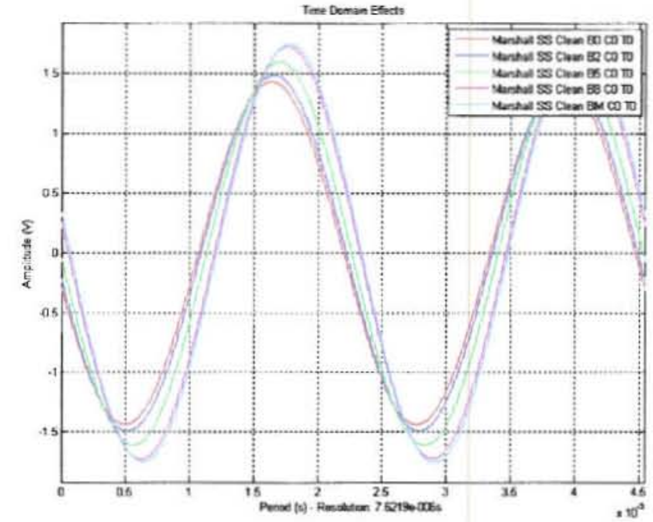
Appendix C – Data Plots

The following plots show the effects of various equalizer settings as they increase on the Time Domain, Frequency Response, and Frequency Domain of both the Marshall MG15DFX and the Fender Blues DeVille amplifiers. The data was gathered as described in Chapter 4. Both the Time and Frequency Domain plots were given a fixed sine wave source at 440 Hz. The Frequency Response was measured using white noise.

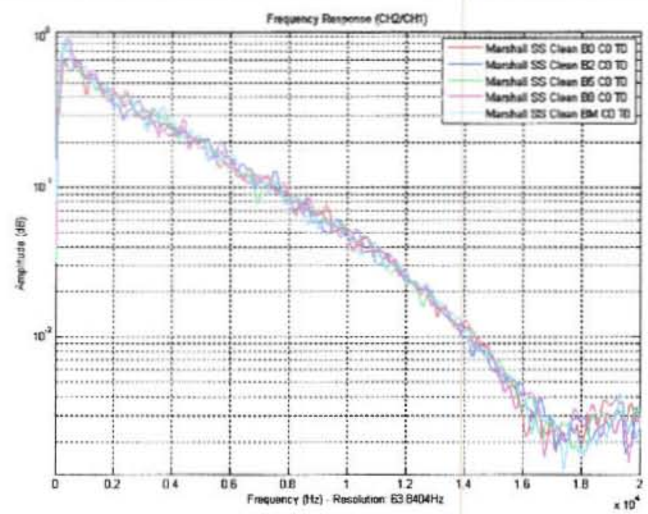
In each set of three plots, the equalizer knob being tested, Bass, Contour, Treble, or all three, was turned sequentially from 0 to 2 to 5 to 8 to 10 on the Marshall, and from 1 to 3 to 6 to 9 to 12 on the Fender amplifier, and the trace was then recorded. The resulting plots are each a collection of five traces, displaying one aspect of the amplifier's acoustics at incrementally increasing equalizer settings. Data was collected for both Clean and Overdriven Channels.

Marshall Clean Channel – Effects of Bass Knob

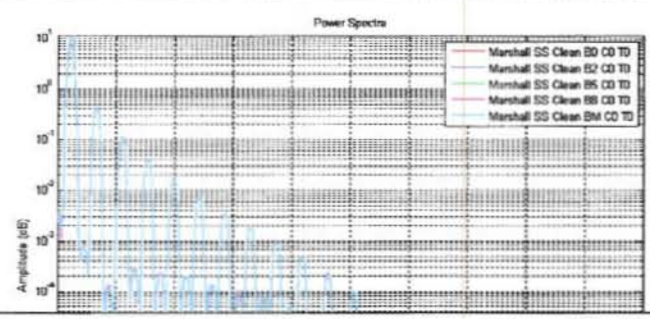
Time Domain



Frequency Response

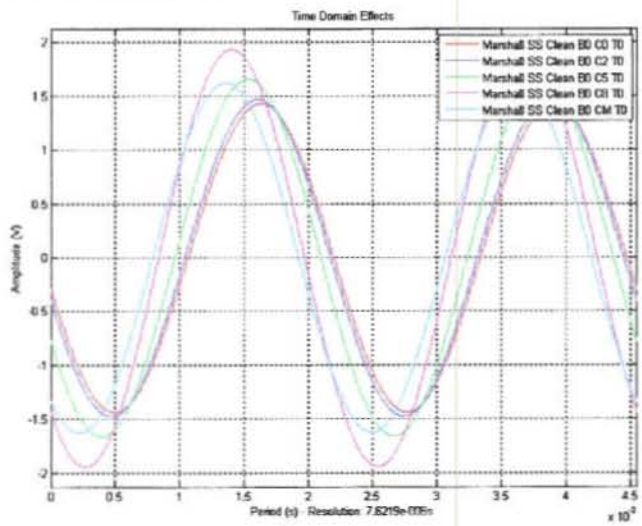


Frequency Domain

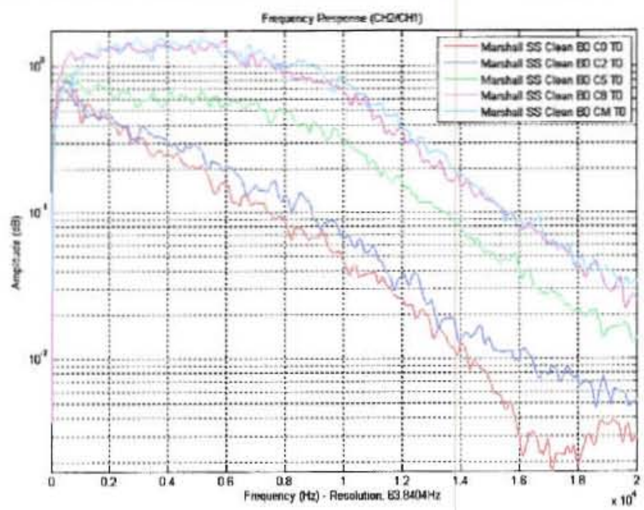


Marshall Clean Channel – Effects of Contour Knob

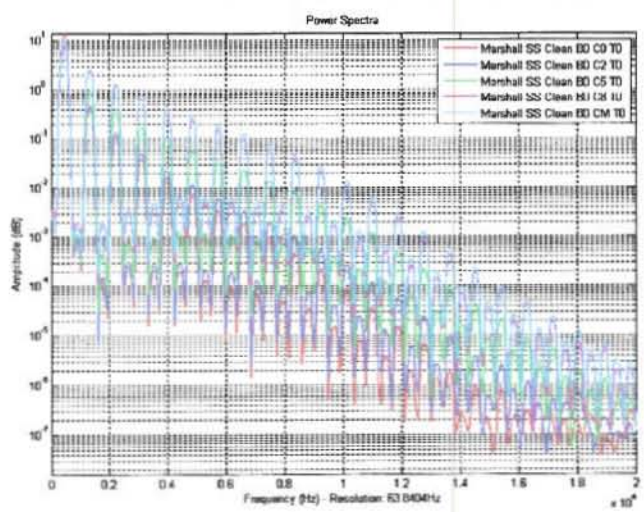
Time Domain



Frequency Response

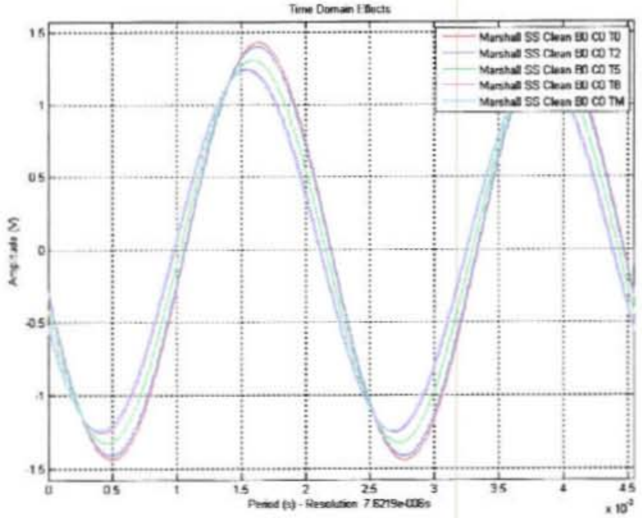


Frequency Domain

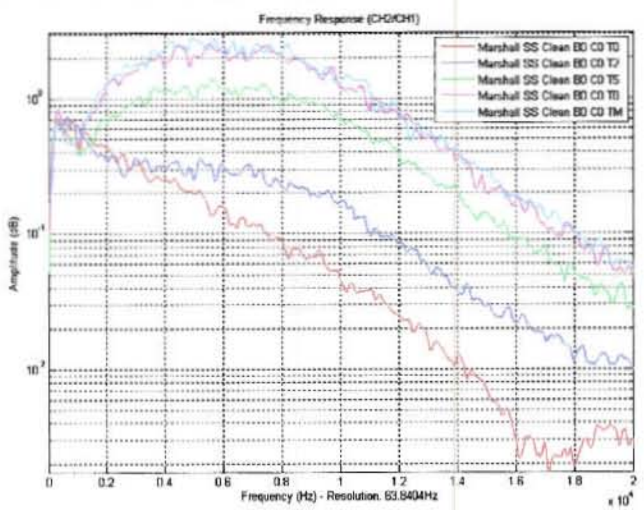


Marshall Clean Channel – Effects of Treble Knob

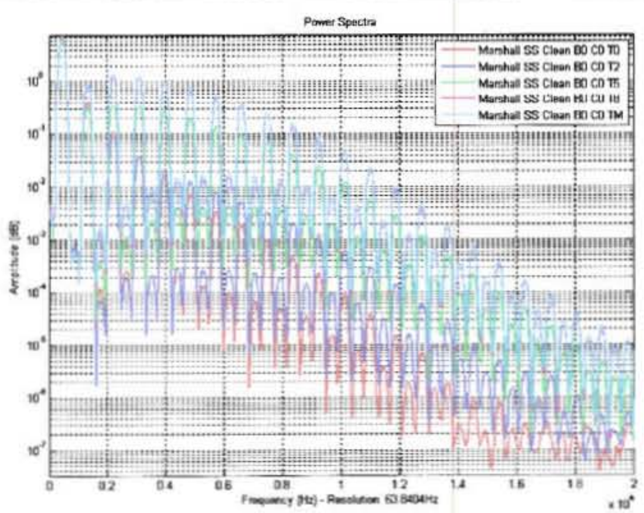
Time Domain



Frequency Response

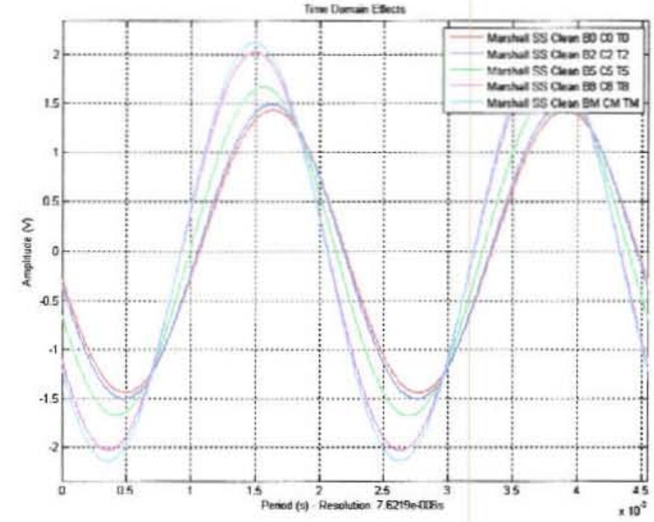


Frequency Domain

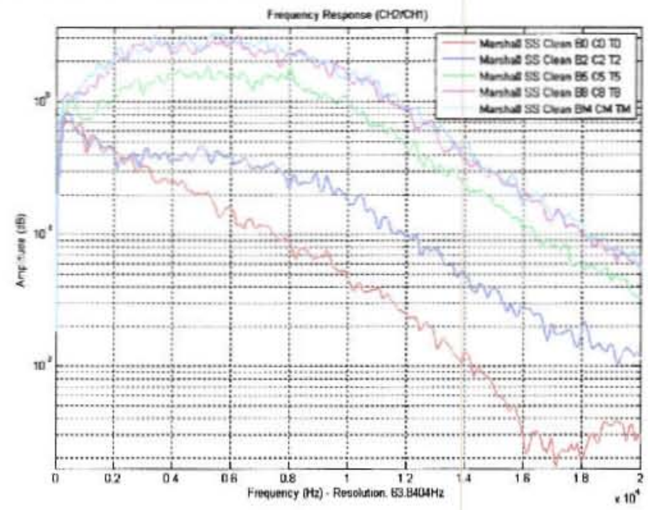


Marshall Clean Channel – Effects of Full Equalizer

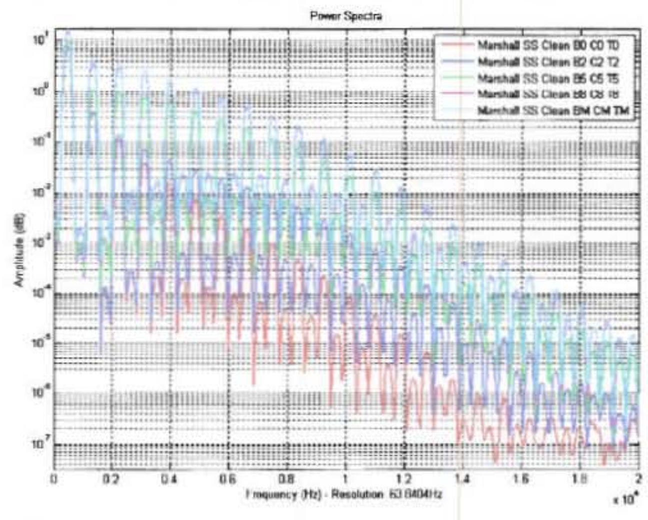
Time Domain



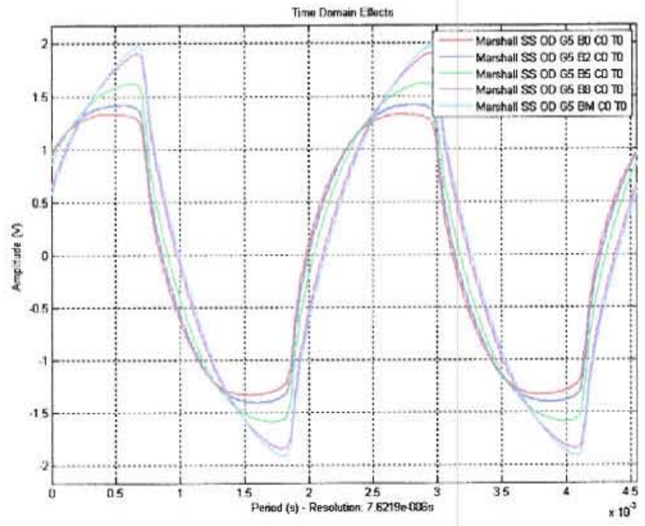
Frequency Response



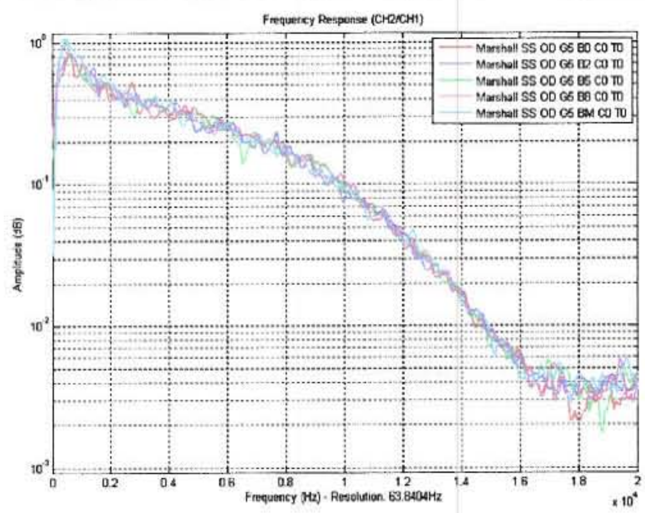
Frequency Domain



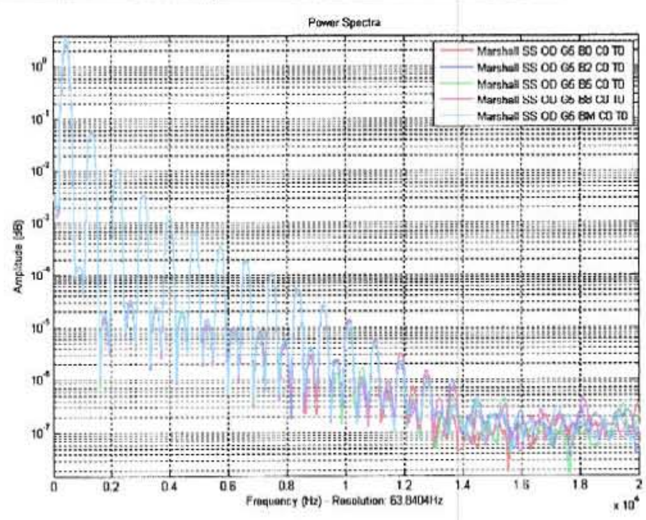
Marshall Overdrive Channel – Effects of Bass Knob



Time Domain

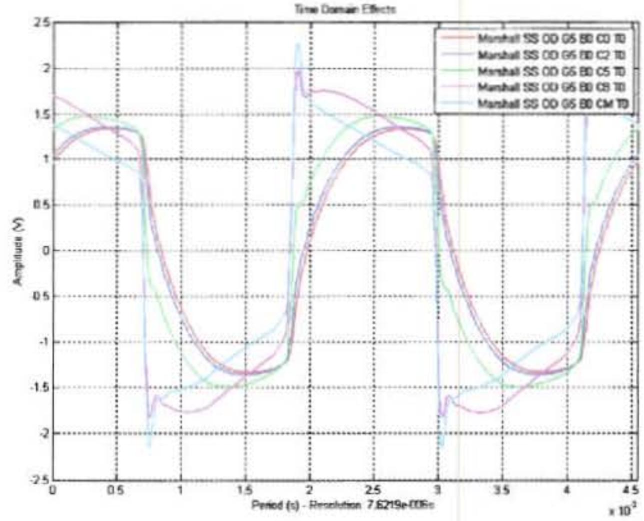


Frequency Response

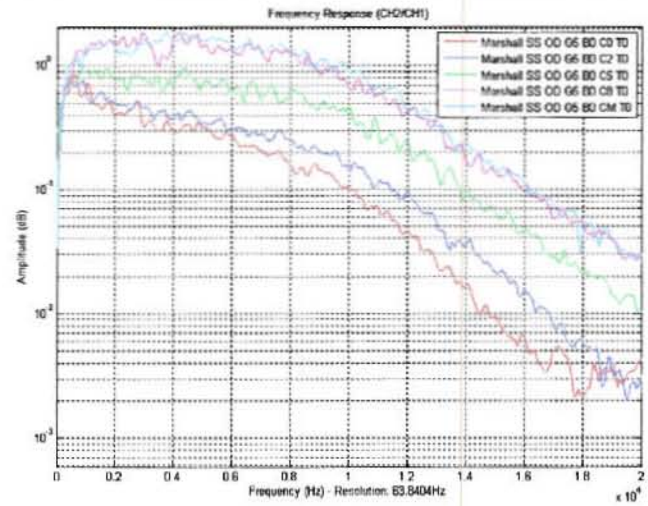


Frequency Domain

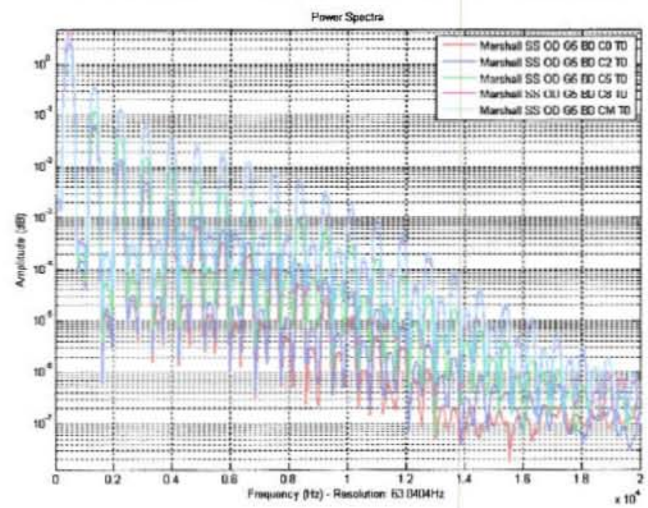
Marshall Overdrive Channel – Effects of Contour Knob



Time Domain



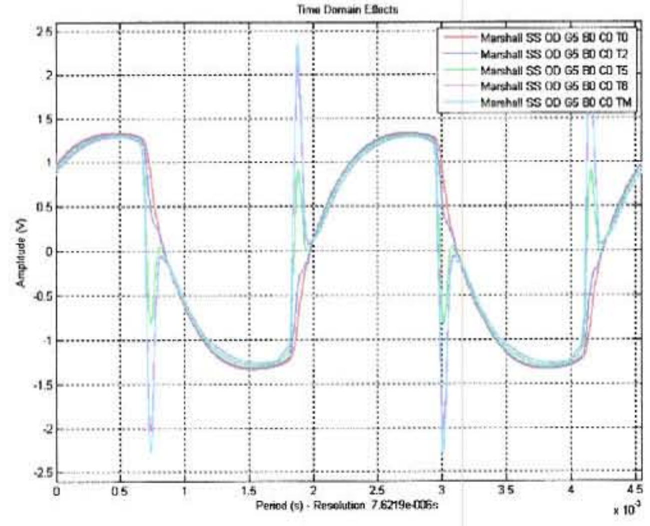
Frequency Response



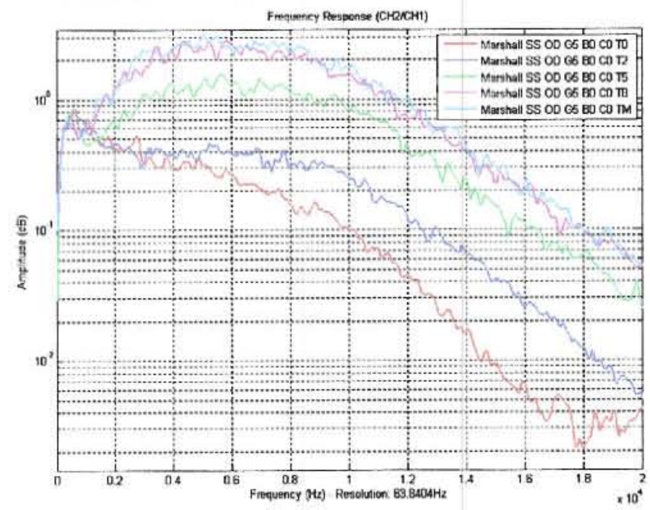
Frequency Domain

Marshall Overdrive Channel – Effects of Treble Knob

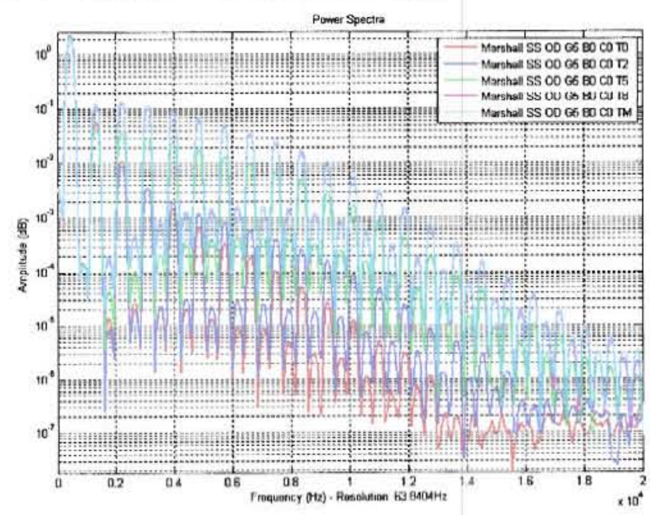
Time Domain



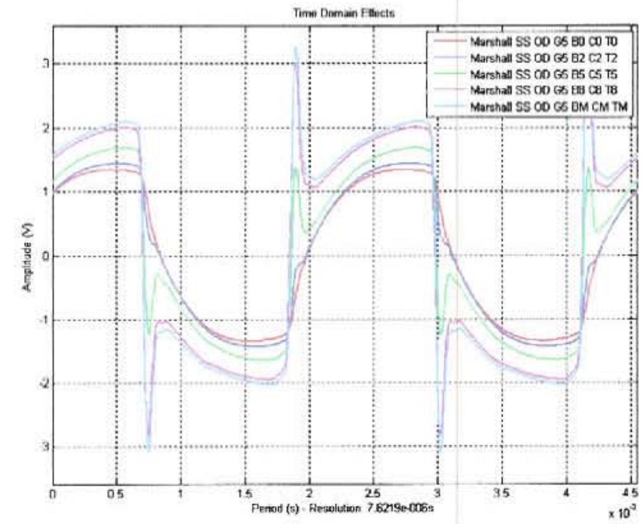
Frequency Response



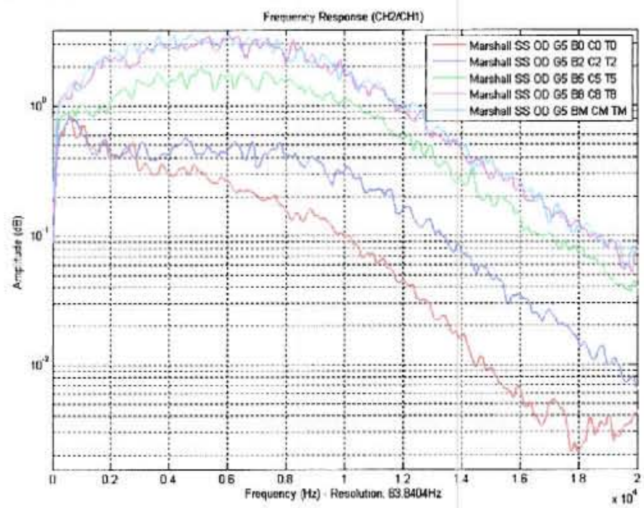
Frequency Domain



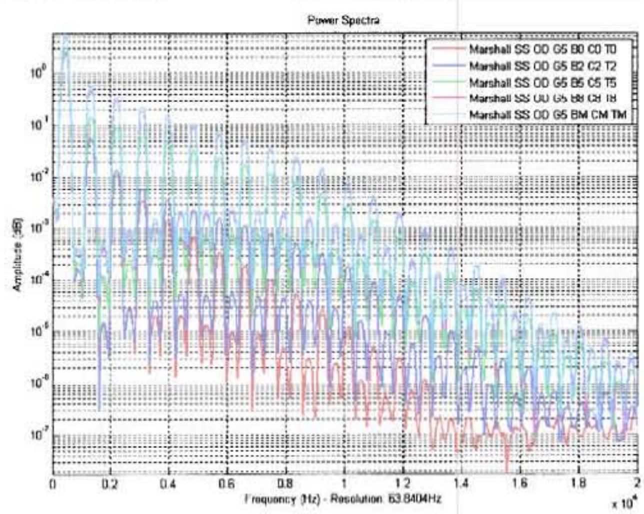
Marshall Overdrive Channel – Effects of Full Equalizer



Time Domain



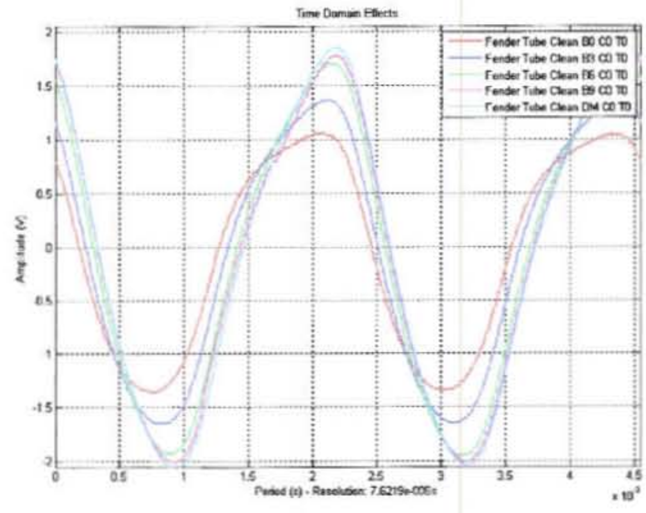
Frequency Response



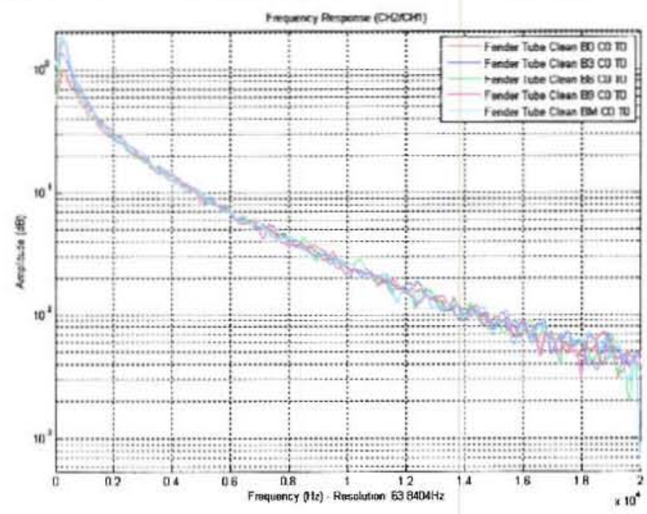
Frequency Domain

Fender Clean Channel – Effects of Bass Knob

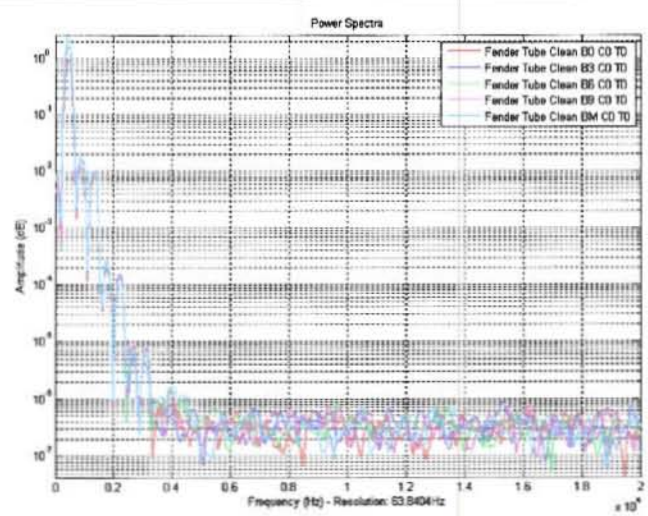
Time Domain

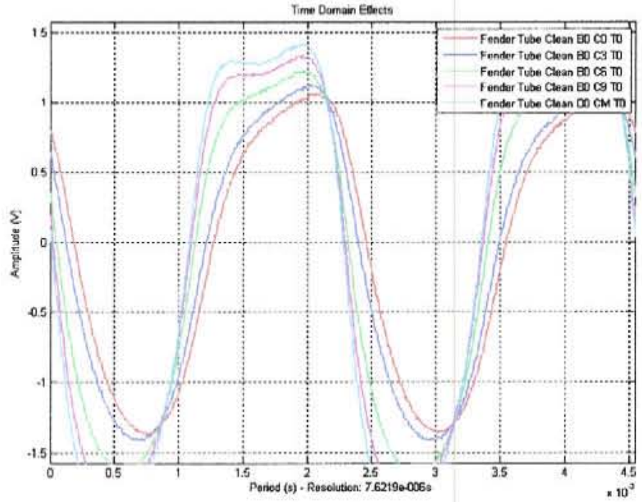
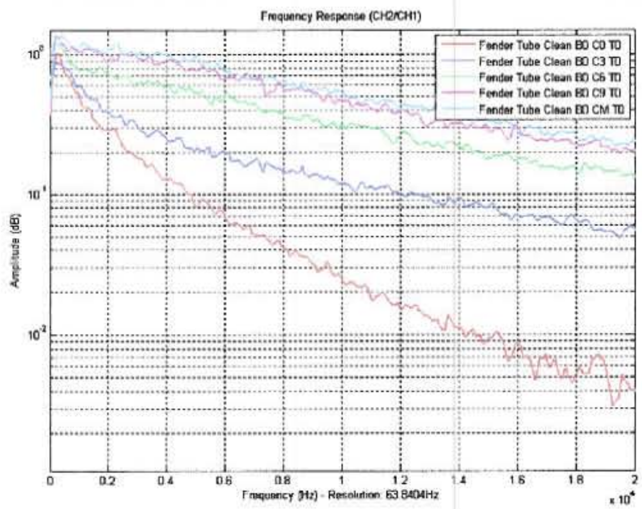
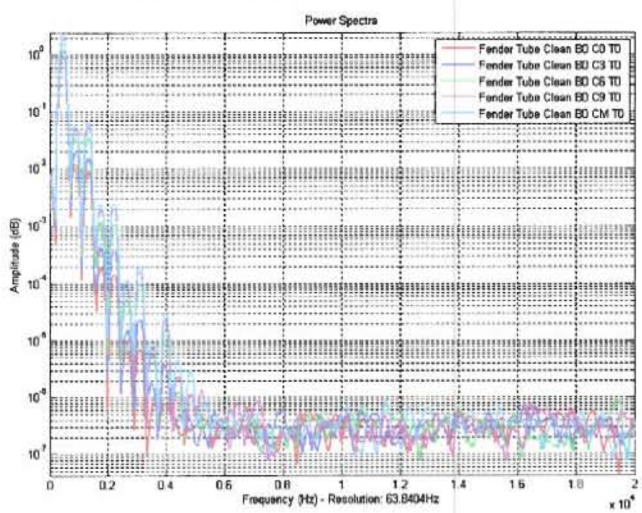


Frequency Response



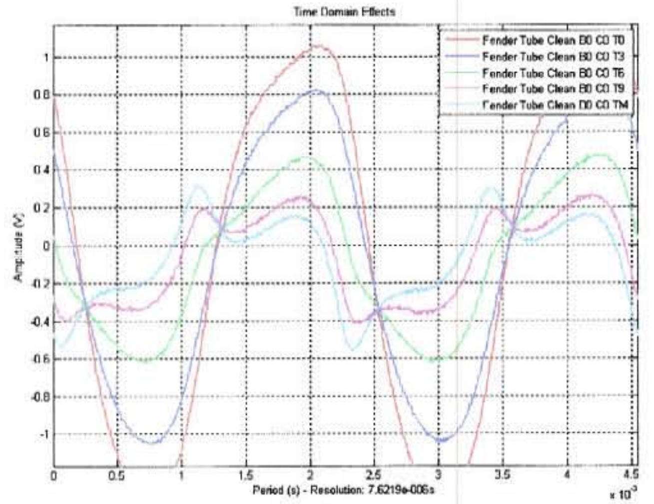
Frequency Domain



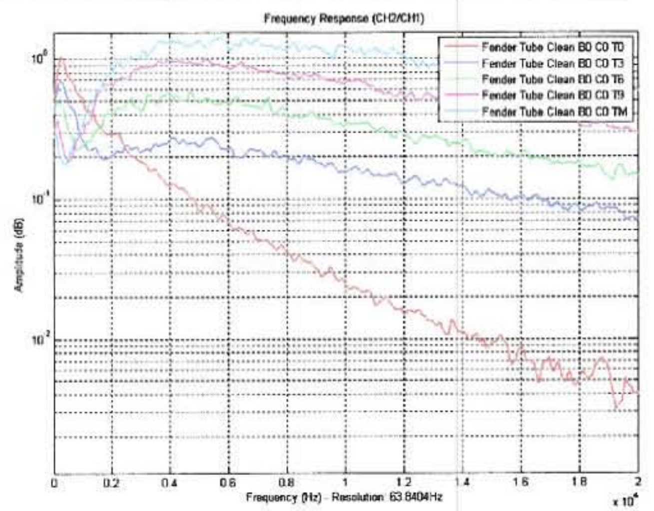
Fender Clean Channel – Effects of Contour Knob	
	**Time Domain**
	**Frequency Response**
	**Frequency Domain**

Fender Clean Channel – Effects of Treble Knob

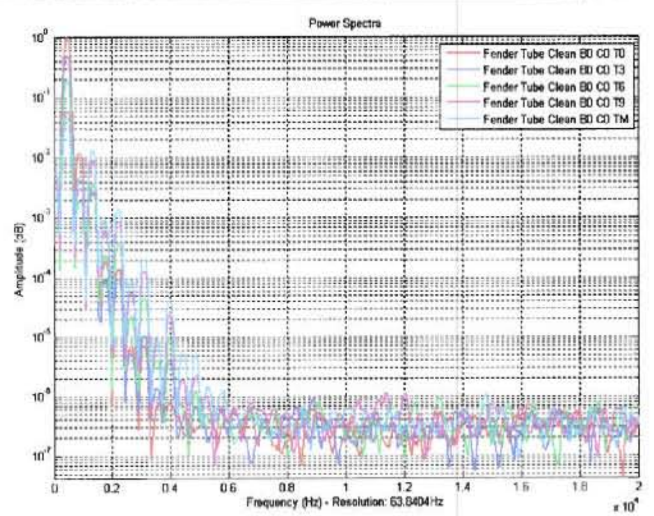
Time Domain



Frequency Response

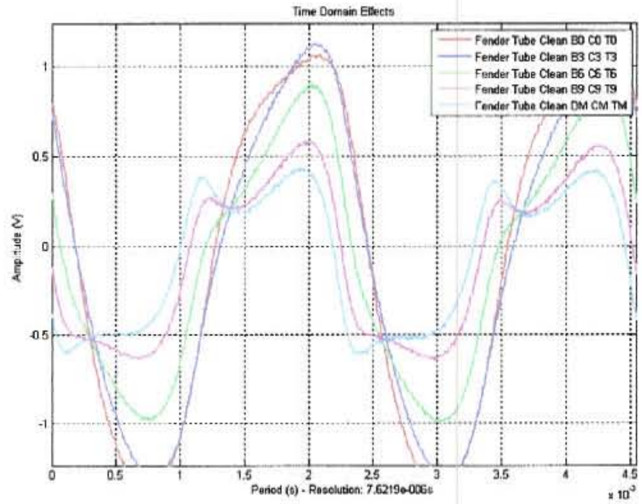


Frequency Domain

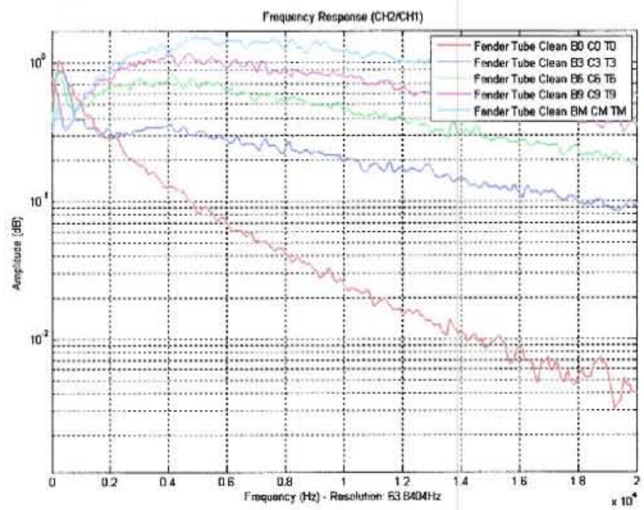


Fender Clean Channel – Effects of Full Equalizer

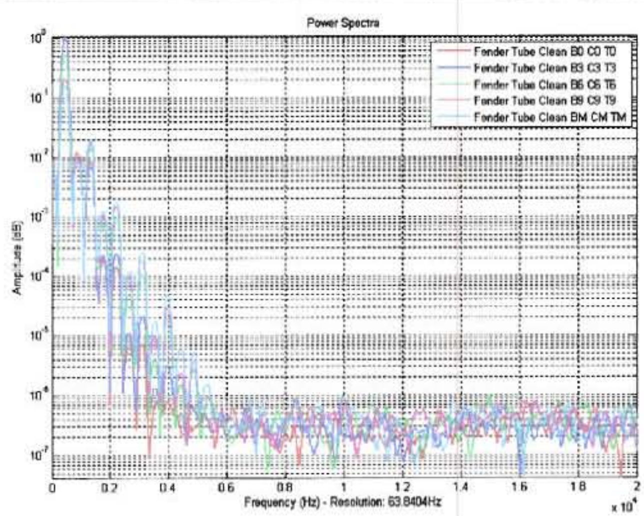
Time Domain



Frequency Response

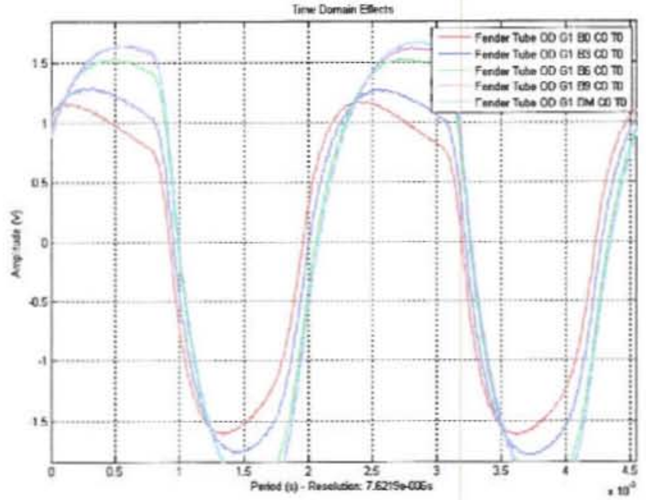


Frequency Domain

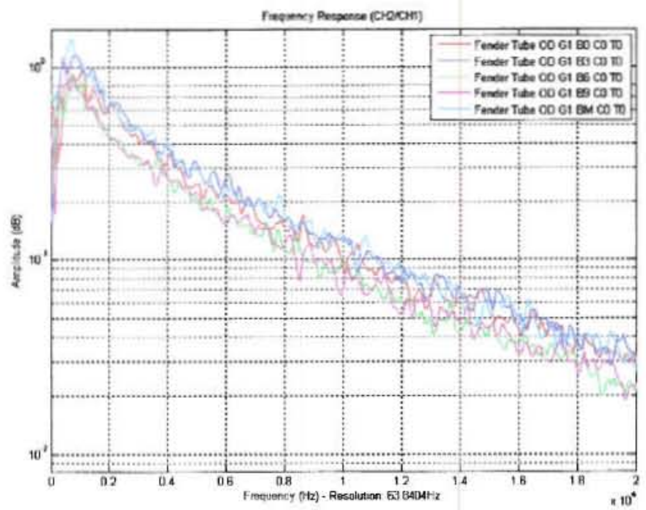


Fender Overdrive Channel – Effects of Bass Knob

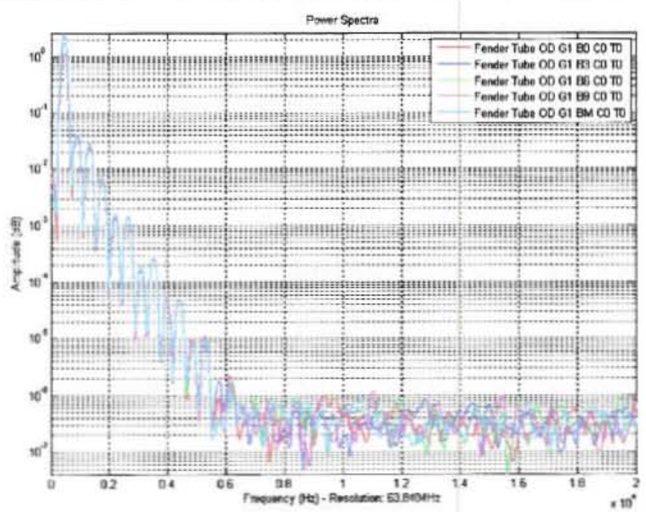
Time Domain



Frequency Response

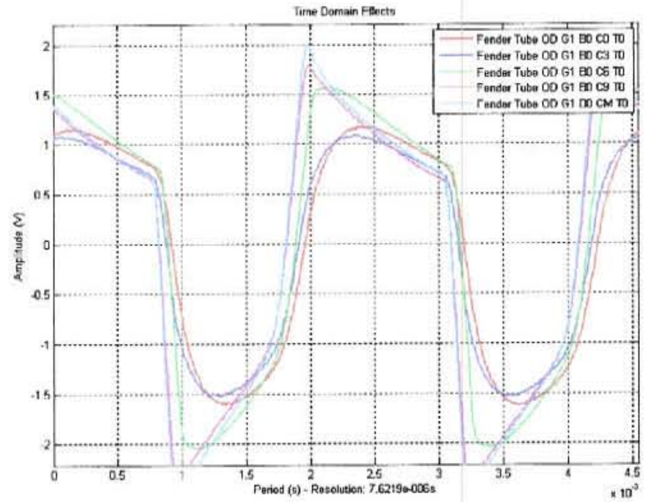


Frequency Domain

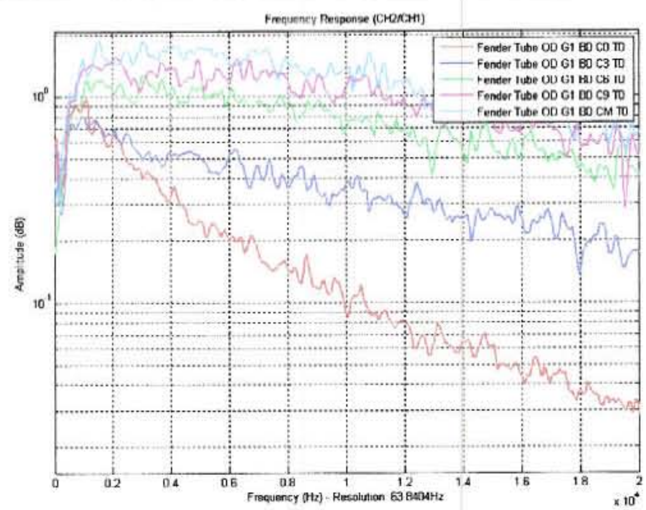


Fender Overdrive Channel – Effects of Contour Knob

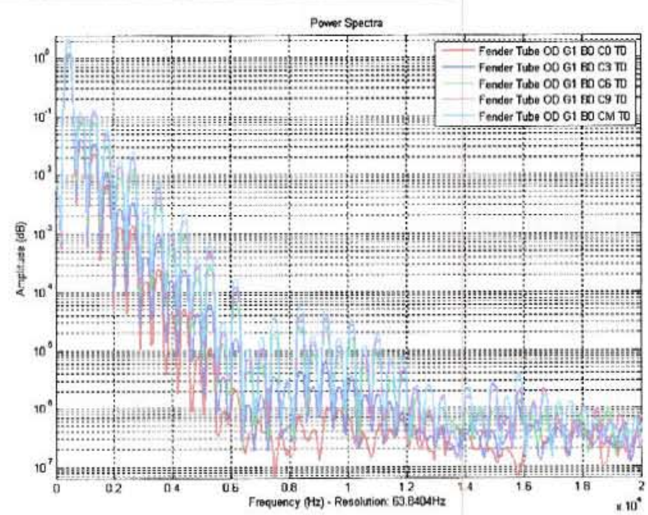
Time Domain



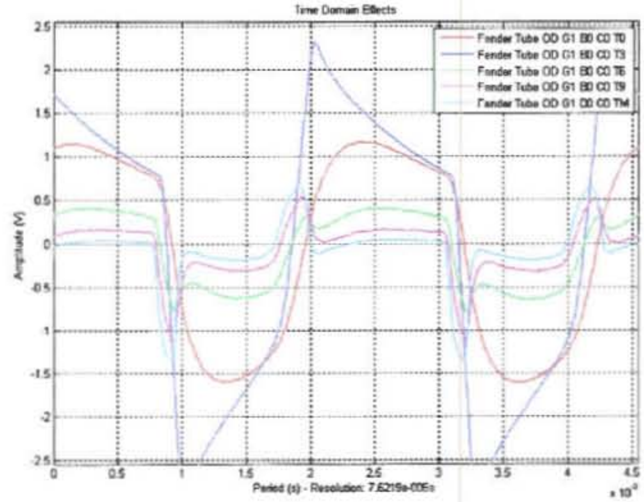
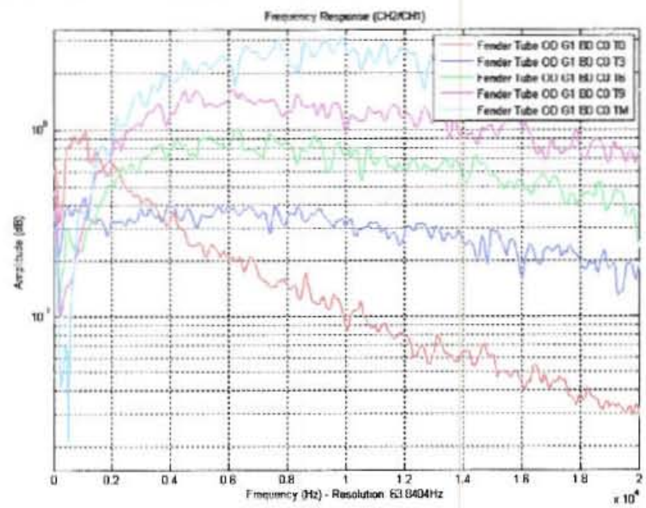
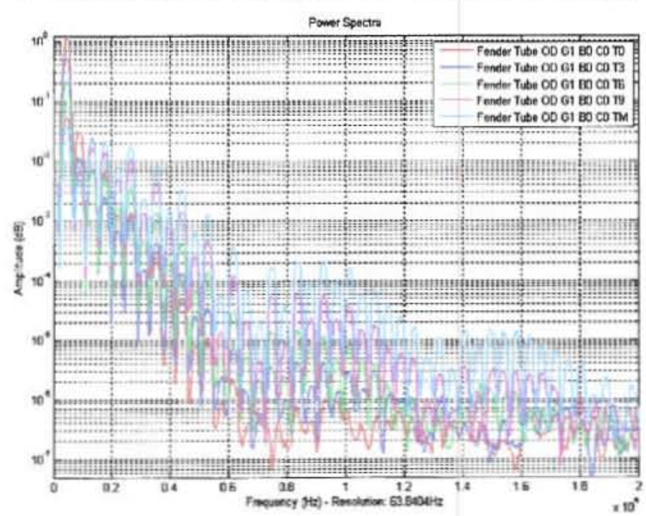
Frequency Response



Frequency Domain

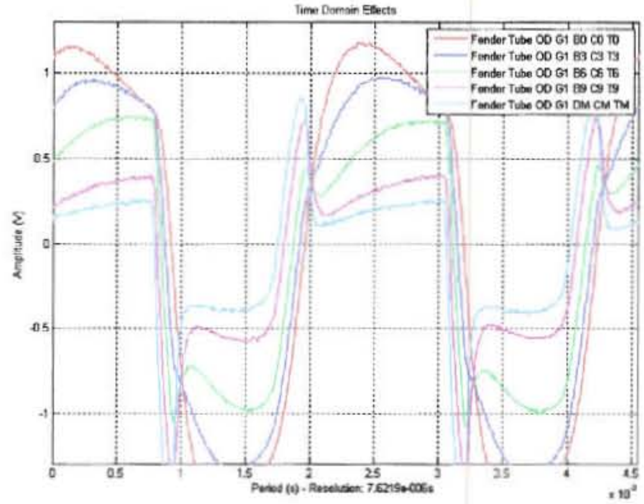


Fender Overdrive Channel – Effects of Treble Knob

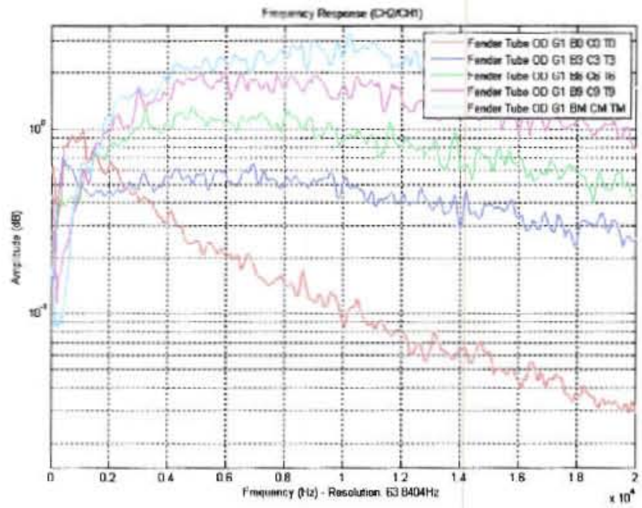
	**Time Domain**
	**Frequency Response**
	**Frequency Domain**

Fender Overdrive Channel – Effects of Full Equalizer

Time Domain



Frequency Response



Frequency Domain