Marshall Amplifier Emulation

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Marshall Amplifier Emulation

Just a little over a half a century ago down the street from our school (CSUMB), a well known artist by the name of Jimi Hendrix secured his right of passage into music history upon setting his Stratocaster ablaze in the final moments of The Jimi Hendrix Experience’s set during the 1967 Monterey Pop Festival. Behind the flames of the guitar a large row of Marshall amplifiers from the UK surrounding the back of the stage can be seen. By combining American guitars with British amplifiers, Hendrix and many other guitarists of his generation were able to achieve sounds and tones like no other inspiring guitarists over the next several decades including myself. Since I started playing, I have spent most of my musical career chasing those classic blues/rock tones I have come to admire so dearly. In the beginning, I often wondered why my guitar could never sound like those of my favorite records and guitarists. Quickly, I was introduced to the endless world of guitar equipment. I eventually came to the realization that it was my amplifier that was holding me back from the sound I was searching for. Growing up with modest funds, I could not afford to play through a Marshall amplifier, leaving me in search of alternative solutions.

Fortunately, living in our current technologically advanced society, it didn't take me long to discover amp modeling. Many major music companies today have successfully created digital and analog emulators. Meaning these emulation products are specifically modeled after vintage
British amplifiers like those of the 60s. These emulators are being sold and claimed to be able to reproduce the tonal and distortion characteristics of the original amplifiers for a fraction of the price, power, and size. As a result, this is creating a potential decline of high wattage amplifiers. I finally found a solution to my problem, though! But at what cost? Pricey high watt amplifiers are now becoming a thing of the past, and I still don't have have a Marshall. How accurate are these amp emulations compared to the original source?

**Brief History of the Electric Guitar and Amplifier**

Before the inception of the electric guitar in the first half of the 20th century, the guitar was solely an acoustic instrument. As the progression into this new modern Western world began, there was a recurring problem with guitar players. Musical genres were shifting away from the classical roots and moving into the large sounds of the Big Band era. These new groups were now dominated by the swing of the drums and brass instruments, and the acoustic guitar was becoming a second tier instrument, producing melodies that could not be heard by audiences, nor the other playing musicians. The guitar was slowly dying and in a desperate need of reinvention if it was going to stay relevant during the new century.

It wasn't until musicians whose music was lead by the melodies of the lap steel string guitar, started to advocate for the reinvention of their instrument that anything happened. A gentleman by the name of George Beauchamp, who began developing the first primitive electric string instrument, agreed to a partnership with Adolph Rickenbacker. By the end of 1931, the Rickenbacker International Company was created, and the electromagnetic pickup was developed and installed on an aluminum lap steel guitar designed by Henry Watson, dubbed the
“Frying Pan.” Thus it was now possible for a guitar to be heard amongst other instruments due to the electromagnetic transduction. This new development opened up a new area of musical instruments to be explored, allowing instrument makers such as Leo Fender and Les Paul to develop the modern solid body electric guitars that are still in production today (Theodoros II).

Although the electric guitar was created for the purpose of amplification, at the time the earliest known amplifiers were limited in sound, due to the fact they were intended for public address systems instead. The earliest known amplifiers had little to no tone controls. The first tone controls that were developed and integrated into the amplifiers circuits acted as high pass filters providing treble adjustment only. Considering the limited controls, poor bass output and low power wattage, the guitar amplifier still required an update if the electric guitar was now pertinent. In response, during the time period from the 1940s-60s music companies such as Vox, Fender, and Marshall created their own unique production of high output valve amplifiers driven by vacuum tube technology. The amplifiers in production now offered guitar players multiple input channels, adjustable EQ tone controls, and built-in effects units such as the spring reverb. These powerful amplifiers allowed the electric guitar to be heard by audience members at the furthest back of the venue while providing excellent sound quality (Teagle).

Valve Amplifiers Generally Explained

In order to understand the valve amplifier and how their components work alongside one another, one must understand the concept of an electric signal flow. The function of an amplifier is to make an electrical signal louder. The amount of electricity an amplifier utilizes determines the minimum and maximum loudness that can be obtained. Like water, electricity flows
directionally; the beginning of this path originates from guitar, travels into the amplifier, and eventually comes out of the speakers. Internally, a valve amplifier is composed of three sections: a preamp section, a power section, and loud speakers. The preamp section is composed of several smaller vacuum preamp tubes that collectively work together to convert a weak electrical signal into an output signal strong enough to be noise-tolerant and strong enough for further processing. The preamp stage is also responsible for influencing the tonal characteristics of the signal. The power section is composed of several large power vacuum tubes that further amplify the preamp signal in order to prepare the audio signal for the final stage in amplification. The final section of the amplifier signal chain is the loudspeakers. An amplifier unit usually contains one to four loudspeakers in various sizes and cabinet types. The purpose of the loudspeaker is to project the entire electrical signal so that it is audible to the human ear; without loudspeakers the electrical signal would never be able to escape the power section.

**Electrons as the Heartbeat and Vacuum Tubes as the Vessel**

Serving as the heartbeat of electrical energy, electrons are negatively charged stable subatomic particles (Mims, pg. 8-9). If an electron is attracted to a positive charge inside a vacuum, the electron will still travel a path to the source of the positive energy despite the absence of air and matter. Inside the glass envelope of a vacuum tube is a cathode with a slight positive charge, ready to release electrons when heated. Surrounding the cathode is an anode that carries a high positive charge to attract electrons. When powered inside a vacuum, electrons will continuously travel towards the anode. When a third component known as the grid is implanted between the anode and cathode, the electron flow can be further manipulated. In order to connect
the grid to the relative voltage coming from the transducer, the transducer generates a tiny electric signal that releases electrons to the plate, and the rush of electrons from the cathode to the plate mirrors the guitar signal, amplifying it many times over (Formosa).

**Introduction to High Gain Amplifiers: The Fender Bassman**

In 1952, Fender unveiled a new line of amplifiers geared toward the bass guitar dubbed the Bassman amplifier. Though they were initially intended for the purpose of amplifying the bass guitar, the Bassman became a popular model amongst other instrument users such as electric guitarists, harmonica players, and even lap steel guitarists. A popular and important amplifier in its own right, the Bassman also became the foundation for which Marshall and other music companies built their high-gain tube amplifiers. Although Fender released several Bassman model variations throughout the years such as the Bassman 5B6, and the Bassman 5D6, it was the 5F6 Bassman model that specifically served as the blueprint for Jim Marshall’s JTM45 in the early 1960s (Owens).

**A Legend Born: The Marshall JTM45**

Jim Marshall was born in London on July 29, 1923. Subsequently, Marshall took up the drums, and by the late 1930s he was teaching and playing professionally. After two decades of playing on the road, Marshall opened a music store: Jim Marshall and Son in Hanwell, London. At the time of establishment, the store sold a variety of musical instruments and attracted many young emerging British talents of the time. In an effort to meet the demands of a new generation, Jim Marshall and his associates took it upon themselves to begin the process of designing a new
amplifier that could meet the contemporary needs of these musicians after a request was made by Pete Townsend of The Who. Eventually, in 1963, the Marshall JTM45 model amplifier was unveiled and quickly began to make a name for itself. The amplifier was handmade in an all-aluminum chassis by Ken Bran and Dudley Craven. Unlike the Bassman, the earliest prototype JTM45’s produced incorporated KT66 tubes in the output stage (“JTM45 2245”). However, the KT66 tubes were eventually scrapped from the design and swapped out with 5881 tubes, a similar version tube of the 6L6, and ECC83 (12AX7) valves in the pre-amplification stage. In 1965 the company pushed their application even further and created the 100-watt Marshall amplifier, the Super 100 head, and, to the horror of roadies everywhere, the Marshall 8x12” speaker cabinet. As the 8x12” speaker were too bulky to transport, the large cabinet was replaced by two smaller stacked 4x12” cabinets giving birth to the iconic Marshall Stack (“Marshall History”).

JTM45 Preamp Valves Examined

The tonal characteristics of the JTM45 differentiates itself from the Bassman because of the formatting of the preamp. The preamp is the primary influence of the tonal characteristics of any amplifier. The JTM45 amplifier contains four channels that run through a three-valve preamp; each valve affects the sound differently. The first valve is dedicated to giving the incoming guitar signal its sound color since it is closest to the input jack. The second valve is the least critical sound-wise and uses a low gain cathode follower for tonal purposes. This position is the most demanding electrically of the three in the circuitry. The third valve has the second most
tonal influence on the signal after the first valve. This position is also dedicated to the phase
inversion that allows the amplifier to split the guitar signal into separate channels (TedB).

Amp Emulation: Pedals as Emulators

Guitar pedals that are around today function as good makeshift amplifiers. Essentially,
the guitar pedal is designed to replicate the distorted elements of an amplifier through different
styles of clipping and influence the tonal characteristics of the the preamp tubes. Guitar
distortion/overdrive pedals have been around since the 1960s. They were built to satisfy the
growing popularity of distorted amplifier qualities amongst musicians (Case).

Each guitar pedal is crafted similarly as an amplifier on a miniature level. A high gain
amplifier and a guitar pedal produce similar styles of distortion. The biggest difference between
the two is their component make up. Each amp and pedal are built upon a foundation circuit
board that distributes and routes the incoming guitar signal. Amplifiers incorporate analog
vacuum tubes across each section in an amplifier. Instead, guitar pedals incorporate smaller
analog components such as transistors, diodes, and IC chips (Grimes). Depending on the
component configuration of the pedal, it may achieve different styles of clipping based on which
components are being used to clip each other dictating distortion characteristics such as fuzz,
tube distortion, and even digital distortion.
Pedal Diode Clipping Configurations as the Preamp

- **Standard symmetrical** - This is the most common configuration in most overdrive, distortion and fuzz pedals. This is when the clipping components are wired in a parallel series.
- **Asymmetrical** - This configuration is often used to make clipping more responsive and dynamic. It more closely resembles how a tube amp clips in its signal path. This can be achieved by either wiring a diode in a parallel series with an LED or incorporating three or more diodes in the circuit (Wampler, pg. 60).

Operational Amplifiers as the Power Section

Operational amplifiers were invented in the late 40s and have since become an important component in electronics. They provide a handy source of rich functionality in a tiny package and are essential Integrated Circuits. The operational amplifier functions as the power section in a guitar pedal as its primary purpose is as a voltage amplifier that amplifies a given signal. However, its function is not limited to just voltage amplification (Wampler, pg.18).

Virtual Studio Technology: Plugins as Emulators

Music equipment has evolved since the early 20th century. Due to the growing rise of computer technology, many analog elements have now been transferred and preserved in the digital realm. Amplifiers are no longer needed as far as recording technology is concerned. In the aspect of the spirit of live recording, amplifiers are beautiful and amazing; however, not everyone out there is blessed economically with deep pockets. Digital plugins have now become
standard in Digital Audio Workstations (DAWs) as a way to get sounds out there without the expense and even without the weight (amplifiers are heavy). Each plugin program can be uniquely coded to emulate just about anything the creator can imagine.

Although the digital realm has given us the capability of exploring the possibility of sounds, there remains a problem. Often distortion produced within an analog system is more musical than that produced within a digital one. The reason for this is analog systems do not have a frequency limit; also, analog systems are trickier to model in the digital realm due to the intricacy of analog distortion. The highest frequency a digital program can accommodate is always half of the sample rate known as the Nyquist Frequency. Any harmonic content produced within the system that exceeds the Nyquist Frequency mirrors around it. To work around the aliasing phenomenon within the digital domain, high sampling rates are incorporated as well as low-pass filters above the Nyquist Frequency in order to remove troublesome content before aliasing. High quality plugin developers take this aliasing challenge into account during the design process by implementing internal upsampling and downsampling techniques. If a given sample rate of a music project is 44.1 kHz, the plugin might, for example, upsample the audio four times to 176.4 kHz, resulting in a new Nyquist Frequency of 88.2 kHz (Izhaki, pg. 448-49).

**Introduction to the Analysis**

Now having described in detail the history, materials, and operational functions of electronics associated with the electric guitar, I experimented thoroughly with each emulator and compared and contrasted the data amongst the JTM45. Following are the results.
Emulation Analysis Procedure

The process I used to analyze the amp emulation was quite simple. I first recorded an open low E note on the sixth string of my guitar, and an E7#9 blues chord both direct Injected into Pro Tools. I re-amped both chords through each piece of equipment at a standard setting amongst the pedals, and a common setting between the plugin and amplifier. Then, I direct injected the newly recorded signals back into Pro Tools. And by exporting each individual recording as a .wav file, I imported them into Izotope Rx. Lastly, using Izotope I was able to run a waveform, and spectral analysis on each newly recorded .wav file.

Emulation Analysis

Since my direct injected (DI) chordal choices provided the foundation for this analysis, I was not surprised by the fact that the chords visually conveyed basic qualities spectrally as well as the most clarity; there was not much happening on the spectral level besides the regular stacking of the harmonic series. Not only was there low stimulation visually, but on the sonic level the chords were extremely dry. Nonetheless, the chords still held perfect clarity, as well as low sustain because of the lack of spectral energy a straight direct injected chord retains.

The guitar pedals provided intricate results during the entire process. I was surprised because the pedals collectively have the same purpose and the results per pedal at times shared commonalities visually in the waveform amongst each other; however, spectrally, the visual texture were not similar in some cases. The biggest differences I found were in the overall perception of the sound compared to themselves and the other emulations. The Dirty Little Secret by far reigned as the superior pedal of the three because it had the closest emulation of
them all. Under the scope of the analysis, the D.L.S. had the most spectral energy compared to the Box of Rox and the D.I.Y. clone. Nonetheless, in certain cases amongst the E7#9 recordings, the B.O.R and the D.L.S. shared very similar qualities all across the board, but upon careful listening the D.L.S. still contains a slightly darker clipping compared to the B.O.R.

The D.I.Y. clone was the black sheep of the three due to the fact that its distortion quality has an intense emphasis in the upper midrange frequencies that failed to produce chordal fullness and in no way did it sound anything like the other pedals or emulators. In one case though, the D.I.Y clone shared similar waveforms visually to the B.O.R., but that is about as equal as it gets.

One of the most interesting things I discovered while analyzing the pedals was the entire spectrograph is filled with energy, compared to the foundational chords, the plug-in, and the amplifier. In the process of trying to understand how the energy correlated to the sound, I realized that the energy is the soft white noise in the background. It seems because guitar pedals share similar components, circuits and composition they naturally generate this background noise, similar to how analog tape produces a natural hiss that can really never be completely silenced.

The results I observed from the plug-in were not surprising, to say the least. Even if I hold a natural bias against the digital realm, I didn't expect much from this emulation program. During my analysis, it was interesting to see that the plug-in waveforms shared similar shapes to the Dirty Little Secret and the foundation DI chords. Nonetheless, spectrally, the most energy was contained near the fundamental of the chords; at around the 5K mark the spectral energy started to dissipate until there was essentially nothing just like the foundational DI chords. Sonically, I think the program does a poor job in emulating the JTM45 because of the fact that
the distortion appears as dark and muddy with some emphasis around the midrange, but somehow still lacking the organic richness of physical clipping. I would never rely on this program for my tonal preferences as the pedals and JTM45 provide a better sound. However, the benefits of the plug-in are its cost efficiency and portability.

Initially, I had high expectations for this amplifier as it is the heart of this entire project, but the more I worked with it, the more I realized that this equipment is rightfully obsolete and should stay in the past with all the greats. This is just a hunch, but I theorize that, because companies are finding cheaper ways to produce products in order to save money, the integrity of the glorious products of the past were lost in the process of finding cheaper ways to produce products today. Whether or not this is true, during the process of my analysis this amplifier surprised me spectrally. The waveforms did not look like any of the others. All of the JTM45’s waveforms were unique to itself, and on the spectral level it contained a hybrid of the DI foundation chords’ harmonic series clarity and the background spectral energy of the pedals. However, in the case of the E7#9 chords, the waveform shape from (volume/gain) on 7 favored the negative db range, however, the waveform energy shape shifted in the opposite direction and began to favor the positive db range when increased (volume/gain) to 10. Sonically, the distortion was more solid and contained a darker and warmer tone compared to D.L.S. when re-amped. Similar to the pedals, the amplifier contained a cycle hum, but it is not as apparent spectrally compared to the white noise the pedals produced.

During the process, I was displeased with the inability to plug in my guitar and turn up the amplifier head to ten with a Marshall stack, so I took it upon myself to run the Marshall JTM45 head through the speakers of my ‘65 Fender Twin Reverb. I was amazed to learn that
even all the way on ten in a live setting, this reissue amplifier head does not sustain as long as the D.L.S. when run through the Twin Reverb. Moreover, it was extremely difficult to achieve and control feedback compared to the D.L.S. It really made me wonder if this amplifier was really the cream of the crop in the mid-sixties as it appears to be on the records and video recordings. On that note, this amplifier honestly is not worth the money as it's advertised and sold today. Guitarists are likely to be better off using and making due with what they have, because at the end of the day no one can use what you have better than you, and it doesn't matter if you have the best historic or the worst modern of tools in your arsenal. Success does not come from spontaneous combustion, you must set yourself on fire… or in some cases your guitar.

The equipment used for the data collection are as followed:

- American Stratocaster-Guitar
- Reissue Marshall JTM45-Amplifier
- Catalinbread Dirty Little Secret MKIII-Pedal
- Zvex Box of Rox-Pedal
- DIY Clone-Pedal
- AmpliTube 4 JH Gold-Plugin

Settings per Pedal:


Box of Rox: Treble-5/ Middle-5/ Bass-5/ Volume-5/ Gain-10

Marshall JTM45 Settings:


Amplitube JH Gold Settings:


Programs Used:

- Pro Tools 12
- Izotope Rx 6
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<tr>
<th></th>
<th>Max RMS</th>
<th>Min RMS</th>
<th>E2</th>
<th>E3</th>
<th>B3</th>
<th>E4</th>
<th>G#4</th>
<th>B4</th>
<th>D5</th>
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<td>-78.18db</td>
<td>-24.3dB</td>
<td>-23.6dB</td>
<td>-24.6dB</td>
<td>-28.2dB</td>
<td>-26.6dB</td>
<td>-26.6dB</td>
<td>-24.5dB</td>
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<td>-54.97db</td>
<td>-8.3dB</td>
<td>-17.5dB</td>
<td>-13.9dB</td>
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<td>-53.97db</td>
<td>-17.5dB</td>
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Standard DI Chords

Low E

E7#9
Catalinbread DLS MKIII

Low E

E7#9
JH Gold

Low E (Volume/Gain 7)

Low E (Volume/Gain 10)
JTM45

Low E (Volume/Gain 7)

Low E (Volume/Gain 10)
Bibliography

“Amp-Like Effects: Stacking Overdrive & Distortion Pedals.” BearFoot FX,
www.bearfootfx.com/amp-effects/.

Case, Alex U. “First Distortion Pedal.” Recordingology Atom,
recordingology.com/2014/06/20/first-distortion-pedal/.

“Diode Clipping Circuits and Diode Clipper.” Basic Electronics Tutorials, 6 Apr. 2018,

Doyle, Michael, and Jon F. Eiche. The History of Marshall: the Illustrated Story of the Sound of

www.premierguitar.com/articles/17116-how-tube-amps-work.

electronics.howstuffworks.com/gadgets/audio-music/guitar-pedal1.htm.

Hatschek, Keith, and Joshua Monley. “Guitar Effects Pedals | The History Of Guitar Effects.”
Disc Makers Blog, 28 Mar. 2016,
blog.discmakers.com/2016/02/effects-pedals-and-the-evolution-of-music/.

Computers, Vacuum Diode.” History of Computers and Computing, Birth of the Modern
Computer, The Thinkers, George Boole,
history-computer.com/ModernComputer/Basis/diode.html.

Hunter, Dave. “5 Things About Tubes.” GuitarPlayer.com, 28 Oct. 2011,
“JTM45 2245.” *Marshall.com*,


“Phase Inverter - What It Does and How It Works.” *300guitars.com*,

www.300guitars.com/articles/article-demystifying-the-phase-inverter/.


TedB. “Re: Wanna Make Your JTM45 Sound its Best??? You'll Need a Little Bit of Cash...”

*LesPaul Forum*, 14 Dec. 2011,


gizmodo.com/how-the-electric-guitar-was-invented-1453939129.

“What Is a Rectifier?” *MESA/Boogie Support*, 21 July 2016,

mesaboogie.zendesk.com/hc/en-us/articles/223276328-What-is-a-Rectifier-.