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Eastern Kentucky University

Breaking the Myth of the Audiophile

Honors Thesis
Submitted
in Partial Fulfillment
of the
Requirements of HON 420

By:
Steven Conner Campbell
Spring 2016

Mentor
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Department of Physics

Abstract

Breaking the Myth of the Audiophile

Steven Conner Campbell

Dr. Anthony Blose

For years analog audio equipment has been deemed superior to its digital counterpart. Most musicians, casual listeners, and audiophiles agree that tube based amplifiers, PA systems, and other tube-based equipment produce better sound quality. This can also be seen in the price difference in solid-state equipment compared to valve technology. Tube amps are even more fragile than transistor based amps. At a first glance this older technology seems to be more of a hassle or trend, rather than based off a deeper understanding of physics. By exploring the innards of analog sound reproduction equipment, the science behind the difference between digital and analog audio equipment becomes much clearer. By first establishing the similarities and differences between analog and digital technologies, this project exposes why tube based audio equipment sounds better than solid-state. By building an analog effects pedal as a research tool (powered by a 12AU7 pre-amp tube) and researching older related articles, the difference in the sound quality was discovered to be explained by the amount and type of distortion caused by tubes compared to that of transistors. Tubes or valves handle voltage distortions in a way that pleases the human ear. Transistors on the other hand can produce noisy distortion that musicians and audiophiles find distasteful. The reason for this is due to the physical nature of the two different amplification processes.

Key Words: digital, analog, tube, transistor, amplifier, 12AU7, valve, triode, semiconductor.

Since the invention of the semi-conductor transistors, digital technology has revolutionized the world that we live in. From cell phones to televisions, we have developed many ways to mimic certain characteristics of nature. Digital technology replaced most of the analog equipment that we relied on in the past. Compact disks replaced vinyl records, and televisions became flatter as vacuum tubes became almost obsolete. Many other analog devices became “out of style” due to the more compact and more efficient digital replacements. This is true for almost every field that uses technology except for one - audio and music production. In recording and sound production, analog equipment is often praised for its better quality of sound. Analog equipment is superior to audiophiles. Most musicians accept this argument as well, but the actual explanation behind this reasoning can be sometimes unclear.

This project answers this ongoing dilemma by combining physics, engineering, and my love for music into a working argument that explains the reasons for analog’s supremacy over digital. I have designed and built my own analog effects pedal/preamp to grasp and explore the real differences behind the two technologies. Analog vacuum tube technology produces a clearer sound than digital transistor based technology: this is due to the fact that valves create a continuous representation of data, whereas digital amplifiers take natural data and warp it into a discontinuous expression. Digital technology breaks up the sound in a way that can often be picked up by the ear as broken or choppy. Analog amps on the other hand produce a warm and full sound quality that is due in part to keeping almost all of the original data present at the beginning of the amplification process.

Opening up this discussion the amplification process must first be understood. The goal of amplifying in electrical circuits is to design circuit that increase the amount of input voltage into a larger output voltage. This can be accomplished in various ways. Many such designs are

operational amps, tube amps, and transistor amps. The amount of voltage output divided by the amount of voltage input is defined as the voltage gain. What actually happens is the electromagnetic wave that enter the amplifier has a smaller amplitude (or height) than the desired waveform. The amplifier takes that existing data or signal and amplifies it, increasing its amplitude while conserving the rest of its form. This is seen in electronic amplifiers by the voltage gain. Increasing the voltage of the signal in turn increases the signals amplitude.

To better understand how tube amplifiers work I have created my own preamp pedal for a guitar amplifier. Originally this project was going to be to make an effects pedal but after creating the circuit it ended up being a preamp. This project build is closest to the popular Valve Caster pedal created by Matsumin. This preamp utilizes a 12AU7 power tube running at nine volts to function as a boost/overdrive preamp. The 12AU7 power tube is a double triode power tube that has functions as an amplifier for the input signal. The following is the circuit schematic for the Matsumin Valve Caster pedal that is the basis for my preamp.

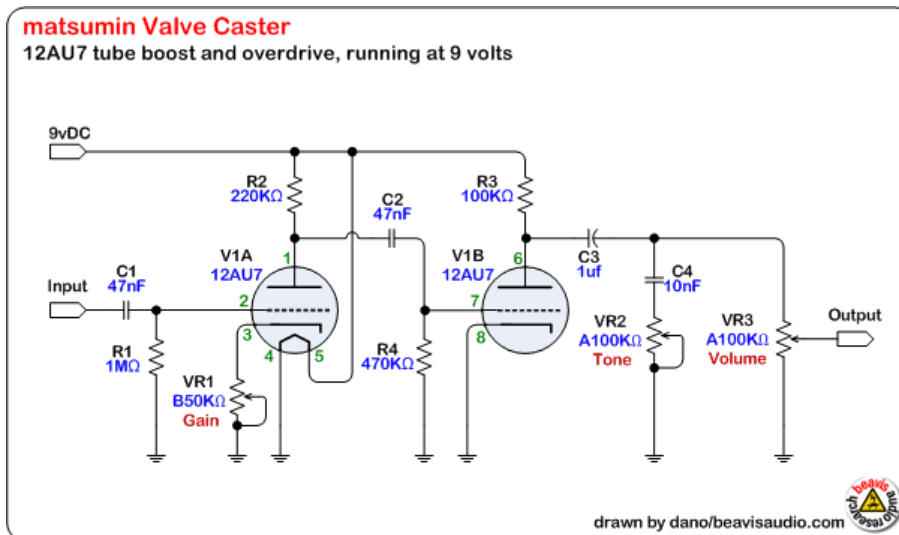


Figure 1. Circuit schematic for the Mastsumin Valve Caster pedal emulated in my design. Matsumin (2007), courtesy of miaudio.com.

This preamp takes the input signal from the guitar or bass and amplifies the signal given by the figure above. The preamp utilizes three potentiometers in various parts of the circuit to modify the amplification process which in turn yields extra control for the user over the desired sound output. The potentiometers give control over the gain, tone and volume of the pedal by adding extra resistance into the circuit in various branches. The volume potentiometer for example controls the amount of current being output to the speaker or main amp. The gain potentiometer on the other hand varies the amount of amplification and voltage change caused by the tubes by also adding resistance into the circuit. The tone potentiometer determines the “smoothness” or “brightness” of the preamp by utilizing a 10nf capacitor to smooth out the output signal. This overall combination of control over the output sound give the user a control over the loudness, brightness, and amplification of the input signal.

The design of a 12AU7 tube and how they function as amplifiers also was explored in great detail for this build. The pin layout and internals of the valve are given in the following figure.

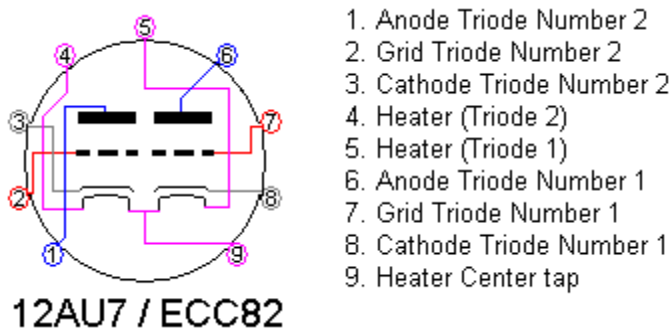


Figure 2. Pinout for the 12AU7 Tube. Courtesy of <http://diyaudioprojects.com/> and Rogers Gomez (2014).

The 12AU7 tube is a double triode valve. It consists of two triodes which in turn each have a cathode, anode, and grid voltage. In a simple diode by applying a voltage to the cathode which is usually made of a mixture of calcium barium and other metals applied to nickel, the

cathode gets hot and emits a cloud of electrons that flow to the anode or plate. In the triode, on the other hand, there is an extra added element called the grid. The grid, which is a grid of wires, is placed in between the anode and the cathode. This grid allows better control over the current that flows through the triode. By applying a negative voltage to the grid, the flow of electrons can be cut off. In contrast applying a positive voltage optimizes the flow of electrons. These three active elements make up a triode. Due to sizing and spacing of the two triodes in the 12AU7 tube the voltage gain is optimized and can handle a desirable amount of power.

By varying the voltage across the grid of both triodes in tube the preamp can increase the voltage of the input signal. This in turn is “amplifying” the signal because the input voltage is lower than the output voltage. The triodes in the valve allow the initial sound waves given as electromagnetic waves to be amplified by gaining voltage which in turn makes the electromagnetic waves larger in amplitude. The definition of gain is the ratio of the amount of voltage output to the amount of voltage input for the signal. This can be controlled by the gain potentiometer which increases and decreases the amount of voltage across the grid of each triode by changing the amount of resistance in the wires connecting to the grid pins. The amplification distorts the original sound waves picked up by the pick-ups in this process but does it in a way that is much more pleasing to the ear than that done by transistor or solid-state amplifiers. To understand this difference we must first understand how transistors work.

Transistors take the main stage for digital amplifiers instead of tubes. They are much smaller than tubes and cost much less money to make. This on its own makes them seem much more advanced than tubes but the quality of sound that comes from solid-state amps often do not compare to its analog processors to many in the modern music scene. Transistors are semiconductors that can amplify a signal. They do this by the same logic as a tube.

Semiconductors at a temperature above absolute zero have electrons that exist in both valence levels and cannot freely leave the atoms of the substance. By “doping”, the process of adding impurities to the semiconductor which is usually made out of silicon, the semiconductor will either have a deficiency or surplus of valence electrons. Having fewer valence electrons creates P- type semiconductor and the opposite creates N-type semiconductors. By putting these two types of semiconductors together the P-N junction zone is created. By applying a voltage across this junction electrons will flow from the electron rich N-type to the P-type which has fewer valence electrons than in it’s pure “undoped” form. By applying a large enough voltage, the gap between the two type of semiconductors will have current flowing through it as the extra electrons move to fill the “holes” in the P region. This current will flow until the voltage is dropped or the semiconductors give out. Most transistors are usually of the NPN or PNP where there is an extra semiconductor. Most amps and preamps utilize many of these transistors to perform various functions.

Due to their small size the overall size of the circuits for solid-state amps tend to be much smaller than that of tube amps. This type of signal amplified by transistor based is a digital representation of the original sound wave. This is due to the on and off behavior of the transistor itself. The transistor has two states depending on if the voltage applied to the gap between semiconductors is great enough to entice current to flow. This is why transistors are used in almost every form of technology we use today. They are compact, and function as on and off switches as well as amps. Valves in comparison to transistors give a continuous representation of the signal. There is a required voltage to activate them but they amplify at different levels depending on the amount of voltage used. For example the 12AU7 tube used in the design of my preamp is running at nine volts. This is lower than the specifications for voltage of the tube. The

12AU7's preferred voltage is twelve volts. If the voltage on the design was increased to twelve volts the overall voltage gain would increase and the amplification of the input signal would be greater.

So now that we have established an understanding of both types of amplifiers it is time to compare each and find the similarities and differences that make tube amps more sought after. Digital technology as we know can often times be superior to analog technology. It allows devices to become smaller and more compact as well as perform to the higher standards. An example of this can be seen in the NRCCSR's 1998 *Trajectory of Audio Technologies*. Valve tubes in comparison to transistors create a fuller and warmer tone when used in musical amplifiers. Tube amps have been praised for this in the musical community for a very long time now.

The debate between analog and digital technology is a basis for the debate between tube and solid state amplifying. To open up this discussion, Lewis's 1971 article in *Noûs* gives the mathematical differences and sets out key definitions for analog and digital data. In this article he defines analog as natural continuous data where as digital as numerical representations and discontinuous. This lays down the foundation to understand the key differences in both types of data. It brings up the idea of digital sampling which is covered in Schmidt's 2008 article *Digital Signals- Sampling and Quantization*. This article exposes the math behind how digital data is created from analog. It also raises the idea that digital data can often lose some information from being converted. When viewing a graph of an analog and digital signal comparison it is obvious to see how that information is lost from conversion of analog to digital. Digital data is much simpler looking than analog, having almost a geometric shape to its waves whereas analog data is shaped more like a continuous sine wave. In a sine wave data is constantly changing but

in the digital square wave we see that the function reaches a certain level and then drops off to a different level after a certain amount of time. This accounts for some of the “choppiness” in low quality digital audio. The following graph illustrates the ideal amplification waveform, the tube amplified waveform, and the transistor amplified waveform.

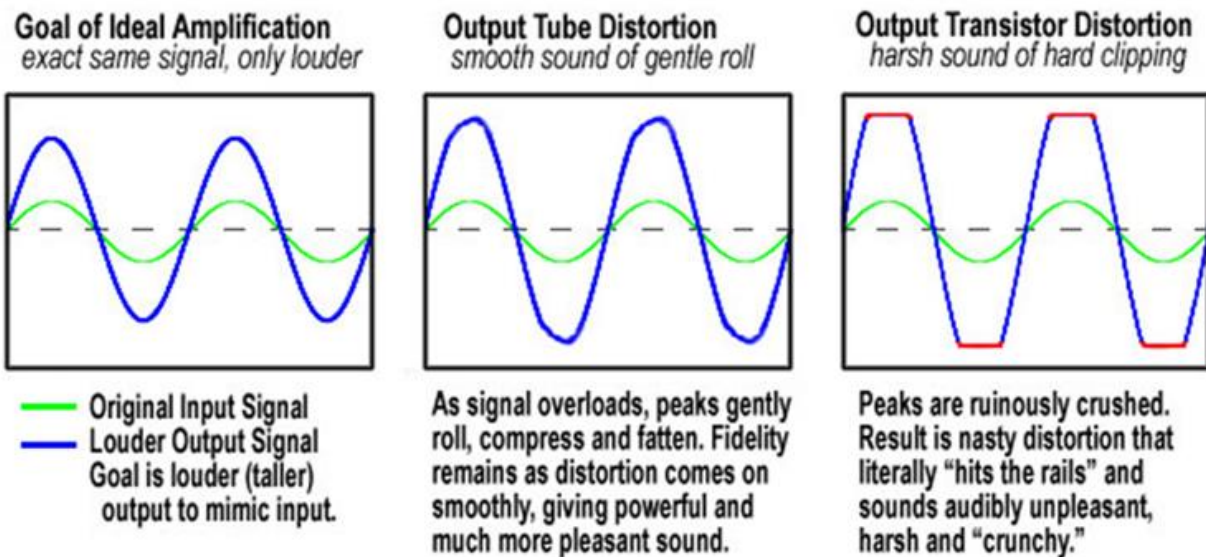


Figure 3. These waveforms give a visual representation of the differences in the amplification process by tubes and transistors in comparison to an “ideal” amplification. Courtesy of Milbert Amplifiers (2015).

The debate between the superiority of digital versus analog technology also concerns the price, reliability, and efficiency of the parts. Tubes by nature, being glass, are much easier to break. Transistors on the other hand are very more durable and do not break if dropped. Transistors are also much smaller than valves. This is much more useful in smaller applications because where bulky tubes would be required to perform various effects on a guitar amp, transistor based electronics minimize the amount of circuitry and size of the circuit. Tubes are also much more expensive than transistor because they are harder to fabricate. Cost and efficiency wise tubes are not the best choice but do to their “better” sound quality they are more sought after.

The first article to explore this debate is Hamm's (1973) article *Tubes Versus Transistors- Is There an Audible Difference?* This article addresses the audible differences between solid state digital amps and analog tube amps. In this article, Hamm discovers that the tube amps of the 1970's are superior to their digital predecessors due to their extra-subjective head room and louder sound. This is also uncovered in Fearn's (1996) more recent magazine article, *Why Vacuum Tubes?* Fearn further elaborates on Hamm's work by explaining that all preamps are overloaded but transistors and tubes handle overloads in different ways. Transistors overload in a way that creates a third harmonic distortion. Valves on the other hand produce a stronger third distortion which actually is almost inaudible. This attributes to the "warmth" that valves have over transistors. Barbour's (1999) magazine article, *The Cool Sound of Tubes*, over variations in types of tubes yields many examples of how various tubes behave and their relative noise and distortion. It gives empirical data of exactly which tubes perform to the best standards as well as arguments for the inherent physical properties of tubes that make them superior to solid state. The physical properties referred to are the same as Fearn's: tube amps have a better sounding distortion and less noise. These argument can also be seen in John Cartwright's (2012) article titled *Return of the Vacuum Tube* in which he gives many practical uses for the vacuum tube and discusses its resurgence because of its superiority in the audio field.

To prove the given arguments further, research has been dedicated to understanding tubes and transistors. When building an analog effects pedal, an understanding of tubes is crucial. To open up an understanding of tubes, Hood's (1997) book *Valve and Transistor Audio Amplifiers* over transistor and tube amps unearths the first information of what tubes and transistors really are. It explains that tubes are evacuated insulated glass cylinders with diodes on each side that allow electrons to pass through them when applied with a voltage difference. Transistors on the

other hand are semiconductors that also allow electrons to move through but in a much more complex way. Gray's (1943) book *Vacuum Tubes. In Applied Electronics* gives plenty of insight into valves and transistors at a time in which transistors were new technology. This book delves in-depth into the world of valves explaining diodes and electron physics behind tubes. It also gets into more advanced tubes technology that use triodes, tetrodes, and pentodes. This work yields crucial theory that was implemented in the construction of my effects pedal and was also explained in great detail in the previous paragraphs.

Another question also arises from this debate is concerning the precision of the human ear. Can the human ear sense the frequency differences between analog and digital data? The precision of the ear is explored in *Neuroscience* (2001) where the range for the audible spectrum for humans is given in great detail. More evidence proving that humans may be able to tell differences in digital and analog data has been described in Zyga's (2013) article *Human Hearing Beats the Fourier Uncertainty Principle*. In this article results from a test prove that some humans can discern differences in frequency up to ten times better than the limits caused by the Fourier uncertainty principle. This principle states that shorter the duration of sound the larger amount of different types of frequencies are required to represent the sound itself. Closer together frequencies on the other hand have longer durations. This principle limits the precision of the ear in terms of duration of the sound and frequency. In the tests given humans were able to hear differences much greater in frequency than what was described by the limits of the principle. This raises the question concerning how our brain encodes sound data. After all our brains interpret the analog sound data and convert it into a digital representation as neurons firing electrical impulses. This similar to the "on and off" behavior of transistors used in digital electronics.

In conclusion, the results of this project support the idea that so many audiophiles assert: tube based-analog amplification technology is superior to transistor based-digital sound reproduction. Even though analog technology is older, easier to break, and more expensive it excels where digital fails. This stark difference is due to the physical nature of a tube and diode compared to a semi-conductor transistor. Tubes overload with voltage in a way that is pleasing to the human ear. Transistors on the other hand amplify a signal similarly but, the output sound quality is noisier and choppy due to the wave being distorted in a detrimental way that sounds unnatural. After building a preamp as a research tool, the physics behind a vacuum tube and how they are arranged in a circuit for voltage amplification is much clearer. There is a lot of research that further delves into this topic listed in the reference section that gives graphs and empirical data that further supports this idea.

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