Testing Guitar Amplifier Vacuum Tubes with a Computer Controlled Data Acquisition System

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While replaced by solid state electronics in most applications, vacuum tubes are still used in some guitar amps. A computer controlled system for testing vacuum tubes was created. Both the hardware and software used in this system are described.

I. Background

While vacuum tubes have been almost completely replaced by solid state electronic devices, there are still a few applications where vacuum tubes are used. One of these is in guitar amplifiers. As there are few companies still producing new vacuum tubes, most of the tubes used in amplifiers are old.

The electric guitar was invented in the early twentieth century after the advent of the vacuum tube. Tube technology allowed a relatively small electrical signal from the guitar to be amplified and then converted to sound by a speaker. Electric guitars didn't become really popular until the beginnings of rock and roll. It was the electric guitar that drove rock and roll, and rock and roll made the electric guitar known to everybody.

With the advent of solid state electronics, transistors replaced tubes almost everywhere. However, there were and are many people who contend that tube amps still sound better than solid state amps. That is an interesting discussion itself, but it is not within the scope of this project.

As vacuum tubes dropped out of favor, companies stopped making them. Small niche markets, like guitar players who didn't like the sound of the new amps, weren't enough to keep vacuum tubes in widespread production. There are still companies who make new tubes, but they are generally not of the same quality as the old tubes. This has created a market for vintage tubes where buyers are willing to spend quite a bit of money to acquire just the right tube for their amp.

There are many opinions as to which tubes perform better, but there has been little quantitative study of the audio properties of these tubes. In the days before computers, studies of tubes would be done by painstakingly collecting hundreds of data points from hundreds of different tubes individually. The data generally would generally be current as a function of applied voltage. The curves created by this method would be published in a handbook and everybody would use this same data.

In order to study the various new and vintage tubes being used today, it is desirable to have the ability to test them in a more efficient manner.

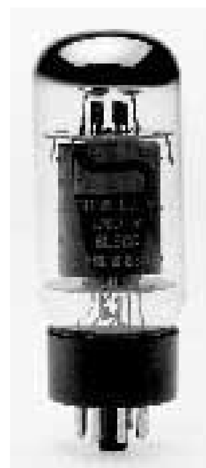


Fig. 1 Svetlana 6L6GC Power Tube

II. Introduction

In the Physics 398 class, the Physics of Electronic Musical Instruments, students explore the physics involved in electric guitars and amplifiers. The introduction of computer controlled vacuum tube testing allows the undergraduates who are taking the class to learn about and analyze the properties of various tubes.

As a part of the NSF/REU program in the summer of 2000, Noam Pikelney, working with Professor Steve Errede put together the hardware and software needed to run computer controlled tests of dual triode preamp tubes such as the 12AX7. This summer (2001) new hardware has been built to allow testing of various types of power tubes (pentodes) as well as rectifier tubes (dual diodes). The software has also been modified to work with the new hardware.

III. Vacuum tubes

All vacuum tube work according to the same basic principles. The most basic tube is the diode. There is the cathode, which is a source of electrons, and the anode or plate that attracts the electrons. The cathode is heated either directly, by running current through it, or indirectly by running a filament near it. When the cathode is hot it emits electrons. If there is a positive voltage on the plate the electrons are attracted to it. Because there are electrons moving from the cathode to the plate, there is a current. The magnitude of this current is basically a function of the voltage applied to the plate. A higher positive plate voltage will result in a higher current, until the tube reaches its saturation point. Saturation occurs when an increase in voltage does not result in an appreciable change in current. A negative voltage will cut off the current entirely, as the plate will be repelling the electrons.

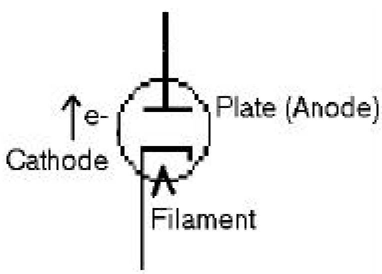


Fig. 2 Vacuum Tube Diode (Pikelney)

The triode works in the same basic way, but with an added element. There is a third electrode, called the control grid; this grid is placed between the cathode and the plate. If the voltage applied to the control grid is equal to that of the plate, the tube works like a diode. However, the voltage is usually set to some negative voltage. This repels some of the electrons making it possible to control the current flow to the plate by changing the grid voltage. In fact, it takes much less of a change in grid voltage than it does in plate voltage to change the current by the same amount. When other electronics are added, this is the property that makes tubes useful in amplifiers. The ratio of the change in plate voltage to the change in grid voltage needed to keep a constant current is known as the amplification factor. (Coxwell 53-56)

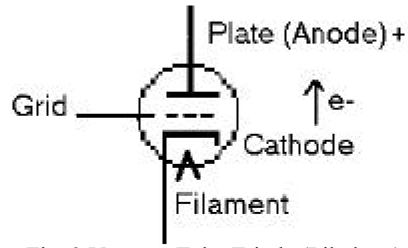


Fig. 3 Vacuum Tube Triode (Pikelney)

Tetrodes and pentodes add yet more electrodes between the cathode and the plate. They are needed to deal with problems that the triode faces in specific situations; they also generally have much greater amplification factors.

IV. Tube Testing Hardware

When creating an apparatus for the testing of dual triodes or power tubes, several things are needed: AC power to the heater filament, two DC power supplies, one to supply the negative voltage to the grid, the other to supply the positive high voltage to the plate, and a connection to the cathode to measure the current flowing out. For the power tubes, the screen grid (another electrode) is connected to the same high voltage as the plate. In the current apparatus the connection can be via a simple 1kOhm resistor, or a 10kOhm/100kOhm resistor divider. All of these connections made inside an aluminum chassis for safety, and to provide partial shielding to reduce noise. There are several different chassis used for different tube types. This is due to the fact that different tubes have different sockets and require different connections, i.e. a dual triode doesn't have a screen grid, but it does need a connection for each control grid and cathode because it is actually two triodes in one glass envelope. Finally, the computer needs to be connected via a data acquisition card that controls and monitors the power supplies and the current output.

The diode rectifier setup is different and actually simpler. Only one power supply is needed because there is no control grid, and the filament requires a different AC voltage than the dual triodes and power tubes.

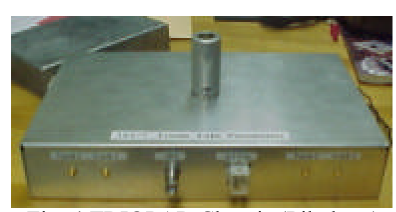


Fig. 4 TRIOPAR Chassis (Pikelney)

V. Tube Testing Software

The software used to control the tube testing was written in C using the LabWindows/CVI environment. This makes it easy to create a graphical user interface to interact with the data acquisition card. Both LabWindows and the card used, come from National Instruments.

The original program written by Noam Pikelney and Steve Errede was for the dual triode tubes, and has since gone through several revisions. The same code was adapted for use with power tubes and rectifier tubes, and the basic structure is the same. The card has two analog outputs that are used to control the two power supplies, as well as several analog inputs to monitor the power supplies and the cathode current.

The main difference between the programs for the different tubes is the maximum power dissipation on the plate. For power tubes this maximum is much greater than for the dual triode tubes.

For all of the programs the data acquisition is very similar. A certain number of samples are taken over a very short period of time, these are averaged and one data point is created. These data points are stored in an array, and when a scan is completed the data can be viewed on a graph. There are two basic plots for dual triodes and power tubes. For both of these plots cathode current is the dependent variable. In one, the grid voltage is kept constant and the plate voltage is stepped from zero to the maximum voltage for the tube, this is repeated for several constant grid voltages. The other plot is created by holding the plate voltage constant and stepping the grid voltage from its maximum negative value to as close to zero as the tube can handle (if the grid voltage gets to close to zero when the plate voltage is positive, the tube can be damaged). This is repeated for several constant plate voltages. In addition to the basic graphs described above the program also creates graphs for the conductance and resistance.

Running rectifier tubes through this same process proved to more difficult than expected. They did not react as was initially expected, but by greatly decreasing the filament voltage the problem was overcome.

VI. Analysis

Although some data has been collected it is too early to say much about it. More scans need to be done on more tubes, and eventually it would be good to be able to correlate the electronic properties of a tube with its audio properties. Hopefully the work described here can provide the base for future projects in the Electronic Musical Instruments class.

Acknowledgments

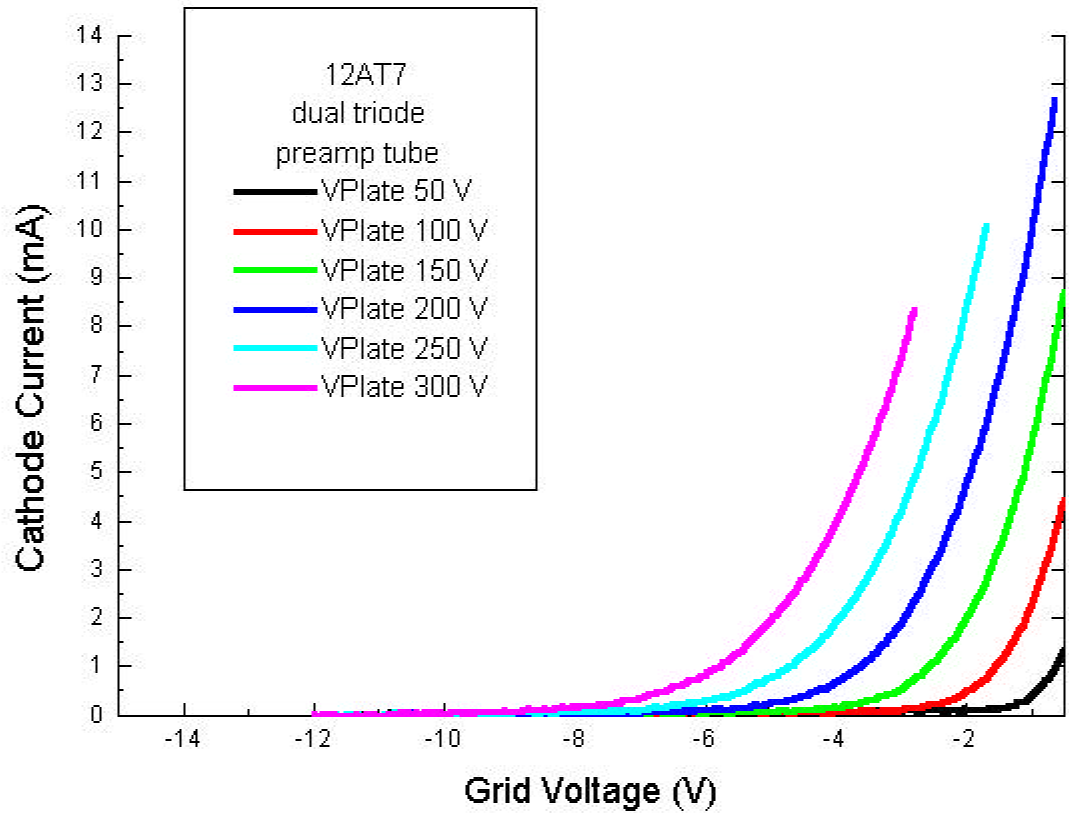
I'd like to acknowledge Steve Errede for his vision and creativity in creating the Electronic Musical Instruments class, and for allowing me to be a part of it. I'd like to thank Mats Selen for providing encouragement and assistance when Steve was not around, and Jack Boparai for his help in the lab.

References

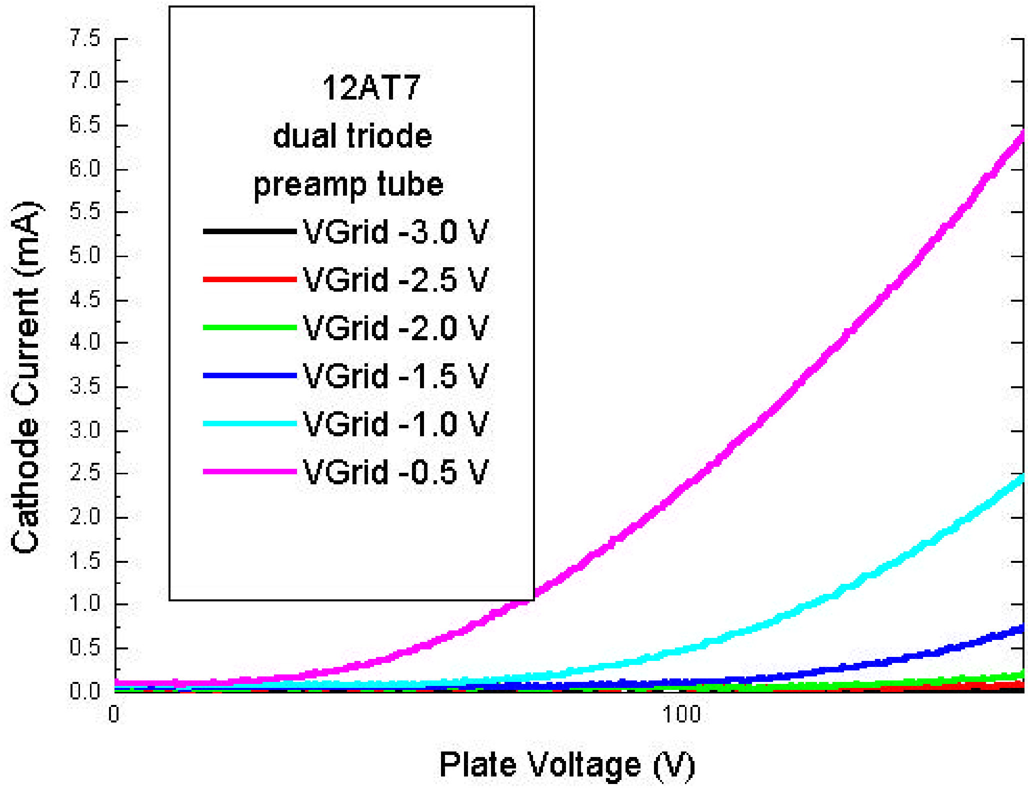
Pikelney, Noam. *Triode Vacuum Tube Laboratory Development.* UIUC REU Summer 2000.

Coxwell, Paul. "Vacuum Tube Basics". *Popular Electronics.* Oct. 1993. pp. 53-63.

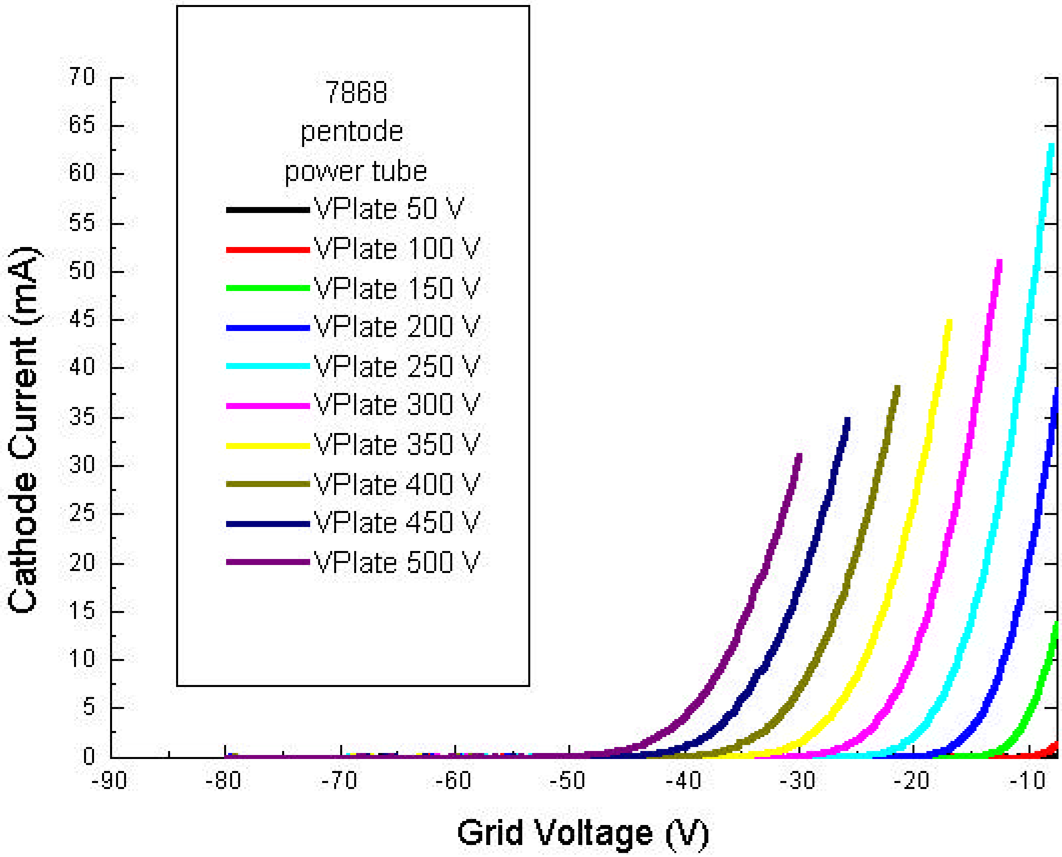
Appendix: Graphs



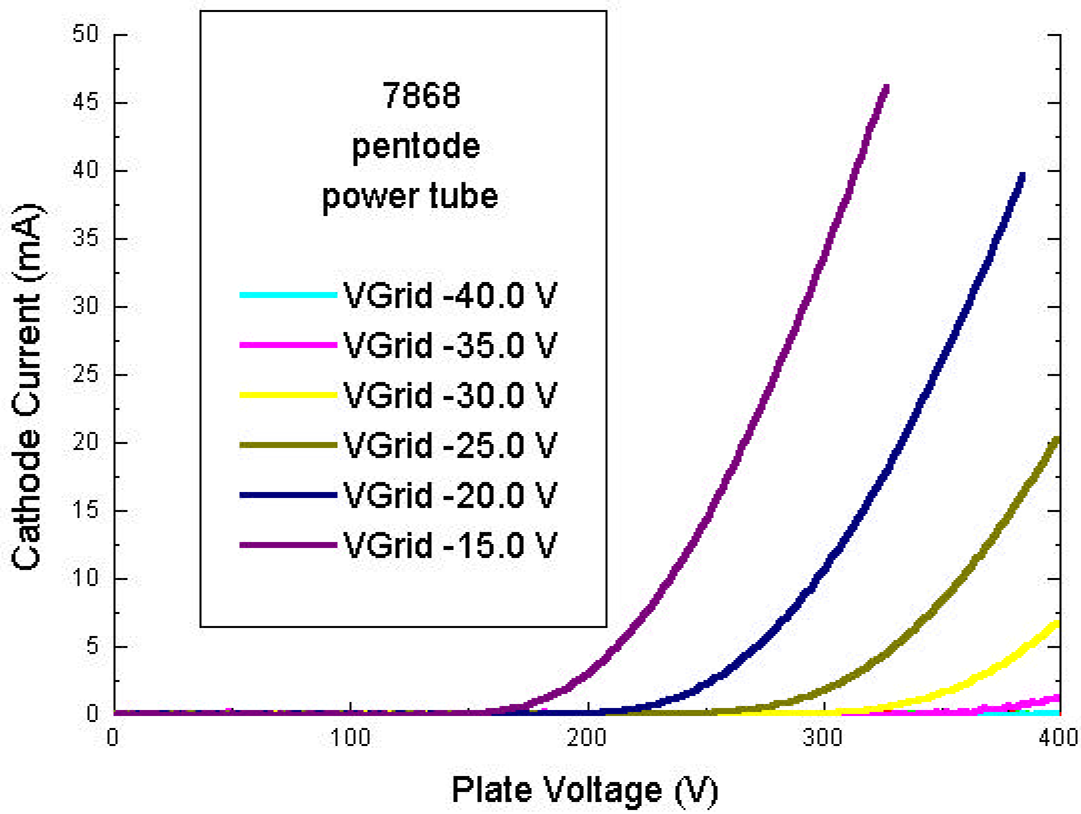
12AT7 (dual triode preamp tube) Grid Family Plot



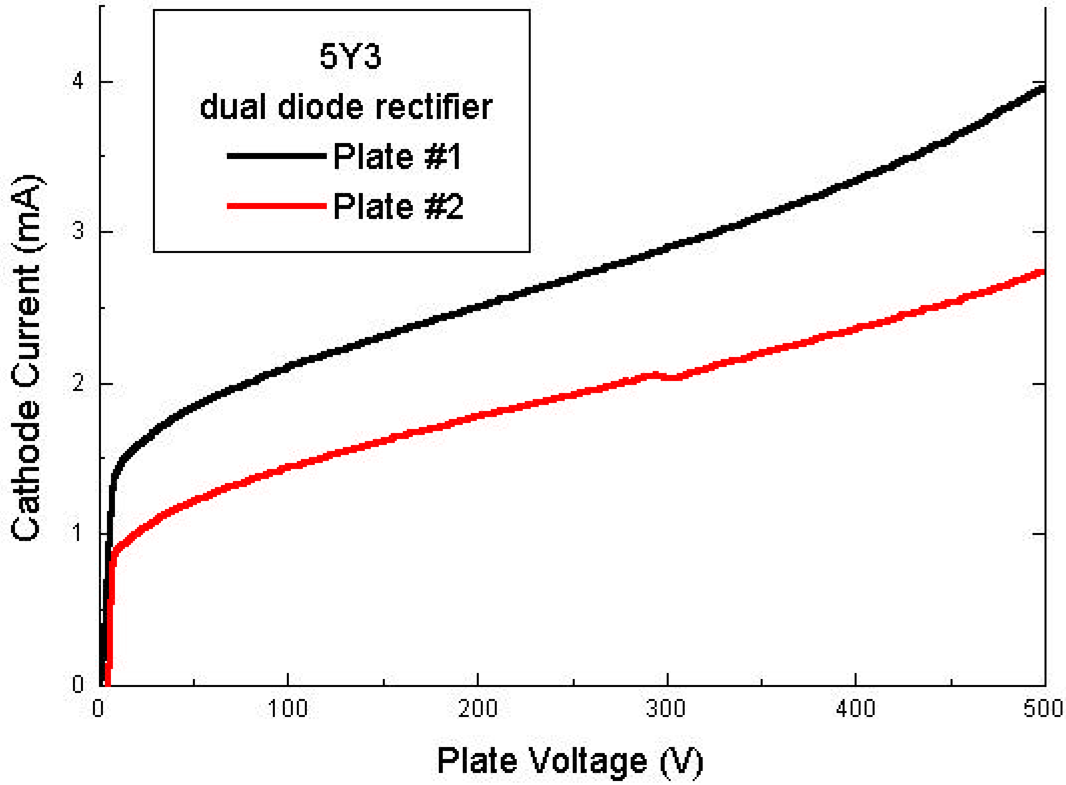
12AT7 (dual triode preamp tube) Plate Family Plot



7868 (pentode power tube) Grid Family Plot



7868 (pentode power tube) Plate Family Plot



5Y3 (dual diode rectifier tube) Plate Family Plot