A Beginning Comparison of 12AX7 Vacuum Tubes by Brand Name

Maricela Tellez
Amanda Leonard

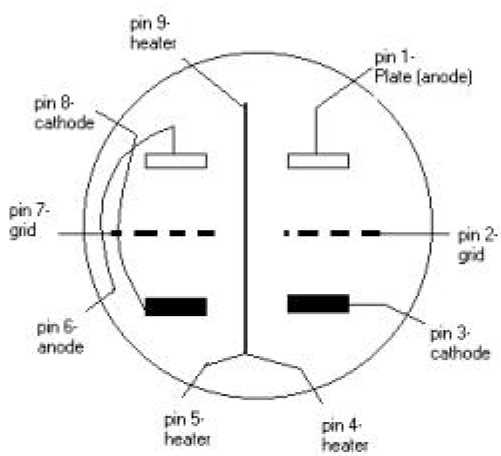
Physics 398
Fall 2000

I. Introduction

Thermionic valves, such as vacuum tubes, are traced back to Thomas Edison's time in the late 1800's. In 1883, Edison patented what he called an "electrical indicator". The "electrical indicator" was the first device to use current flowing through a space between a filament and another electrode. Edison recognized that current could flow in one direction, but he didn't put this effect to any use. Later, in 1904, the conversion of alternating current into direct current began with British scientist John Ambrose Fleming. Fleming's "oscillation valve", or better known as a diode, was based on the same current flow effect that Thomas Edison had discovered. This diode essentially consisted of an incandescent light bulb with an extra electrode inside. When the bulb's filament is heated white hot, electrons boiled off its surface and into the vacuum inside the bulb. If the extra electrode, known as a plate or anode, is made more positive than the hot filament, a direct current flows through the vacuum. Since the extra electrode is cold and the filament is hot, the current produced, as Edison observed, only flows from the filament to the electrode, not the other way. The diode essentially was used to convert alternating current to direct current in power supplies for electronic equipment.

Many other inventors tried to improve the Fleming diode, but did not succeed. The only one that succeeded was New York inventor Lee de Forest. Lee de Forest is remembered as the man who put the "grid" into the diode. Indeed! De Forest had a lamp manufacturer make copies of the Fleming diode, some having extra electrodes of various configurations, for his own exploration. From this work, his first three electrode "Audion" was patented in 1906. The "Audion" involved a type of Fleming diode with parallel plates on either side of the filament, connected together as the anode to maximize space-current capture. Wires to these two plates were brought out separately. One was connected to an antenna and the other was connected to a detector. De Forest claimed that this particular arrangement was capable of amplification. He recognized that the voltage on the other could control the current to one plate. He then reasoned that the performance of the device could be improved if the third electrode was placed between the filament and the anode. If a solid sheet were used, it would largely block the current flow to the anode, so De Forest specified a piece of wire bent in the shape of a grid iron. Upon this creation, a patent followed on January 29, 1907 of the “Audion”, or triode, as one of the first amplifying valves.

The 12AX7 is a dual triode vacuum tube with a high amplification factor (greater than 100) and low microphony. Each triode consists of three parts: the indirectly heated cathode, the grid, and the plate (anode). The tube plugs into a socket, and connections are made to each component through pins. A schematic is shown below:



The actual tubes contain cylindrical cathodes with the filament inside of it. The control grid is a coil of wire on top of the cathode, and the cathode with the grid is placed inside another cylinder, which serves as the anode.

The triode functions via the principle of thermionic emission. The cathode is made of a metal with a low work function so that when it is heated it emits electrons. The plate is set at a potential that is positive relative to that of the cathode, thus drawing the electrons towards it and allowing current to flow. When the grid is at a potential that is equal to the cathode potential, there is no effect on the plate current. If the grid is held at a potential negative relative to the cathode, it repels electrons and reduces the plate current. There is a potential at which the current stops flowing, called the cut-off potential. A variation if the grid potential between the cut-off potential and the cathode potential will induce a variation in the plate current.

It is this property of the triode tube that allows the tube to amplify a signal that enters at the grid. By coupling a load resistor in series with the tube, an AC signal entering at the grid would be voltage amplified when the signal left the plate. The 12AX7 dual triode tube is capable of amplifying the signal by approximately a factor of 100 in the ideal situation (it is typically much less).

The 12AX7 tube is often used in the preamp section of guitar amplifiers. The signal from the guitar is not strong enough to run the power tubes of the amplifier, so the 12AX7 tubes are used to step up the voltage of the signal in order to operate the power tubes. In solid-state amplifiers, the preamp section typically performs voltage amplification through transistors. It has been said that tube amplifiers have a warmer sound than solid-state amplifiers. Also, guitar amplifiers are thought to have a different sound when the tubes are replaced. This leads to the implication that not all 12AX7 tubes have the same properties even though they are theoretically built the same.

II. Our Experiment

In this experiment, we obtained the characteristic curves for four different brands of tubes (Telefunken, RCA, Groove Tube, and GE). For all brands we had used tubes, and for RCA we had new “old stock” tubes. Characteristic curves include the plate family (plate voltage vs current at constant grid voltages) and the grid family (grid voltage vs current at constant plate voltages). These curves give information on the amplification properties of the tube. By comparing the curves, it is possible to qualitatively determine the differences in the properties of the different tubes. It is also possible to determine how well the triodes in the individual tubes are matched.

The goal of this experiment was to obtain the plate and grid family of curves for various 12AX7 vacuum tubes. To do this, the TRIOPAR computer software was used. To obtain the grid family of curves, the computer software sets the plate voltage to 50V and the grid voltage is set at –5V. The grid voltage steps from –5.0V to –0.5V in 0.01V increments and takes 1000 samples of the voltage across a 1 Ohm resistor that is placed in series with the cathode. Data acquisition continues for plate voltages of 100, 150, 200, 250, and 300. The plate family of curves is obtained by setting the grid voltage at –3.0V and the plate voltage at 0V. The plate voltage is stepped from 0 to 300V in .75 increments, taking 1000 samples of the voltage across the 1 Ohm cathode resistor. Data acquisition continues for –2.5, -2.0, -1.5, -1.0, and –0.5 grid voltages.

Both the plate and grid family of curves data was completed for each vacuum tube. The equipment and procedure used for the data acquisition is as follows:

Equipment

- White/Black5/15 V DC Power Supply
- 6.3 Vac (rms) Unregulated Filament Power Supply
- 50-pin Green Connector Board
- 12A*7 Triode Tube Parameters Module
- Bertan 815 Power Supply

Procedure

- All equipment was originally shut off.
- Cables connecting the equipment together were checked to ensure that the equipment was connected correctly. Such cables were not disturbed throughout the duration of the entire data acquisition experimental phase.
- The 50-pin was plugged in to the connector board and remained intact for the data acquisition of all tubes.
    1. A Triode vacuum tube was placed in the socket and the tube shield was placed over the tube.
    2. The filament power supply was turned on. The tube was to be warmed up for 5 minutes.
    3. All programs on the computer were closed and the screen saver was shut off to ensure that no interruptions took place throughout data acquisition.

4. Labwindows/CVI was initiated by clicking on the shortcut on the desktop.
5. TrioPar2.prj was opened.
6. The 5V power supply was turned on. In doing so, the red LED above the +5 lights up.
7. The 3-pin power cable was plugged into the Bertan power supply.
8. Initiated the TRIOPAR software by clicking on Run and selecting Run Project.

Once the computer program was opened and ready, data acquisition began. The INIT DAQ button was pressed to clear all inputs and outputs. The tube type was to be specified at this time. We indicated a 12AX7 tube type by selecting option 3. The RUN GRIDFAM button was pressed to run the grid family of curves. Upon completion, the RUN PLATEFAM button was pressed to run the plate family of curves. After both grid and plate data acquisition was completed, the curve families were viewed and printed from the plots menu bar at the top of the screen. The tube data was saved for further analysis and procedural steps 1-8 were exercised for each vacuum tube.

III. Results

The grid and plate families of curves for each tube can be found at the end of this report.

The general characteristic of the grid and plate family of curves is that in the negative grid voltage region, the curves for the different plate voltages are seen to be nearly the same shape but merely displaced horizontally. For positive grid voltages, the rate of increase of current with grid voltage shows a slight decrease. This is due to two factors. One factor is that the grid is beginning to draw a fraction of the total current. The other factor is that there is a tendency for the current to saturate at large plate voltages. With this given, what can be obtained from the family curves?

Although the vacuum triode tube characteristics can be specified by a set of voltage-current curves, i.e. grid and plate family curves, an index of operation of tubes is ordinarily given in terms of tube “constants”. The constants describe the operation of a tube in the vicinity of a given set of electrode potentials. There are three constants: amplification factor, mutual conductance, and plate resistance.

Amplification factor is the relative effectiveness of the plate and grid potentials in controlling the plate current. Mathematically, the amplification factor can be computed by taking the negative quantity of the change of plate voltage divided by the change in grid voltage, all held at a constant plate current. The limit of the change in plate voltage to the change in grid voltage ratio necessary to keep the plate current constant as these changes are made extremely small is the amplification factor of the tube. The amplification factor is a dimensionless constant that measures the voltage-amplifying capabilities of a tube.

Mutual conductance of a tube is the rate of change of plate current with control-grid voltage. Mathematically, mutual conductance is the ratio of change in plate current to the change in grid voltage, held at constant plate voltage. The plate family of curves is useful to determine this quantity.

Plate resistance of a tube is the reciprocal of the rate of change of plate current with plate voltage. This quantity can be obtained through the ratio of the change in plate voltage to the change in plate current, held at constant grid voltage. The grid family of curves is useful to determine this quantity.

Since the three constants are expressed in terms of only three variables, a relation between them can be found. In this exploration, the constants were not determined. It was found that the quantity values would differ depending on where the ratio determination was done on the curves.

By looking at each individual graph, we were able to determine if the tube was a so-called "good tube." While every tube did generate a family of curves, indicating that the tube still functioned, not every tube produced good data. When the curves for each individual triode in the tube did not closely match each other, the triodes were no longer functioning in the same way. If this tube were to be used in an amplifier, it would distort the signal because the circuit generally relies on similar signals from each triode in the 12AX7 tube. Good tubes have very similar plate / grid curves, and therefore have very similar outputs. Examples of tubes with extremely similar sets of curves for its triodes are: Groove Tube 4, New RCA 1, Old RCA 1 & 5, and Telefunkens 5 &6. General Electric tube 4 is an example of a tube with very badly mistmatched triodes. The curves for each triode do not even have the same general appearance or slopes. Other tubes, such as General Electric 1 and New RCA 2 show enough similarity that it is still obvious that the curves are supposed to match each other, so the tube should still be considered a good one. The curves for the triodes in Telefunken 2 &3 are off enough that it is not obvious which lines should pair together, so these tubes would be considered a somewhat “bad” (or mismatched) tube.

IV. Conclusions

Because we do not have the proper data to easily obtain information such as the amplification factor (μ), it is not possible to say which tubes would have the ‘best’ performance in a guitar amplifier. It is evident from our data, however, that different brands of tubes have very different properties when it comes to signal amplification. Vacuum tubes do not have completely reproducible effects, and when one tube is replaced by another it will have different amplification properties. Out of 5 sets and 25 tubes, not a single one had identical characteristic curves. Each tube would have a slightly different effect in a guitar amplifier, and if the curves were different enough, the difference would be noticeable to the ear.

The data obtained in this experiment also leads us to the conclusion that it is important to test tubes before putting them to use. If the tube is old, it may lose some of its amplification ability in one or both triodes. It would be important to test each triode individually to make sure they give similar outputs with the same input in order to make certain that the tube is functioning properly. This will help ensure a better sound (and less unintended distortion) from the tube amplifier.

V. Suggestions for future work

The data handling for this experiment was more extensive than originally expected and prevented us from doing some of the analysis that we had hoped to do.

Although data was taken for a set of 5 tubes of the same type and varying brands, only each individual tube was analyzed. It is recommended for the future that the tube data sets be averaged for each type of tube. Averaging these values would allow for a close approximation of the performance of a particular vacuum tube type and tube types can be compared. Such a comparison would enable the determination of high performing tubes. More comparisons would have been possible in this exploration if time allowed. It was found that a lot of time was devoted to the organization of data and the discoveries of how to most effectively use Microsoft Excel. If this experiment is ever to be redone or continued, it will be very useful to become familiar with some Excel shortcuts.

Future recommendations for the most effective and efficient use of Microsoft Excel:

- Use clipboard toolbar for copying and pasting data. Simply copying first onto clipboard and then pasting in the other worksheet can easily copy all necessary data from one worksheet to another.
- Change column headings so that data sets are immediately labeled appropriately in the legend. In making the graphs, it was found that it was easier to include the name of each data set in the first cell of each data column. Doing this allowed for the name of the data set to immediately appear in the legend when creating graphs from the data sets. It saves the time of manually inputting the name of each data set by going to Source of Data from the Table menu.

- Thanks to Josh, a seventh grade student, it was learned that a graph with multiple data sets can be initially created by using only one pair of data and then simply selecting the data set column corresponding to the plate or grid voltage, copying it, and directly pasting it onto the graph. The curve immediately appears after pasting data set onto the graph. This unbelievably saves valuable time!

When we began this experiment, we had hoped to calculate the amplification factor, μ, for each tube and compare it by brand. After collecting the data, however, we realized that we had not done the proper experiment to reliably calculate this number. While we did have the graphs necessary to calculate the transconductance, g_m, and the AC resistance, r_p, which together would give μ, the values would all be dependent on the location on the graph that we chose to calculate with. Amplification factor implies a constant current, and none of our experiments were conducted at constant current. A safe experimental set-up could be devised that would allow the current to be held constant and the grid voltage scanned while the plate voltage was monitored (or vice-versa). A graph of the grid voltage vs plate voltage would give the amplification factor as the slope of the line. This would be a more quantitative way to compare the different brands of vacuum tubes, but as Professor Errede pointed out, there are safety concerns.

VI. For more information

The following are books, articles and websites we have been using this semester to guide us (they can all be obtained from Professor Errede):

Barbour, E. “The Cool Sound of Tubes.” *IEEE Spectrum*. August 1998.

Barbour, E. “How a Vacuum Tube Works.” Svetlana Electron Devices, Inc. (accessed August 17, 1999) http://www.svetlana.com/docs/tubeworks.html

Coxwell, P. “Vacuum-Tube Basics,” *Popular Electronics*. October 1993.

Errede, S. “TRIOPAR Lab Experiment”

Jones, M. *Valve Amplifiers*. 2nd ed. Newnes, Oxford. 1999.

Mitchell, P. “A History of the Grid,” in ???

O’Connor, K. *Principles of Power: A Practical Guide to Tube Power Amplifier Design.* Power Press Publishing, London, Canada. 1996.

Spangenberg, K. R. *Vacuum Tubes*. McGraw-Hill Book Co. New York, NY. 1948.