



Hands On Tubes



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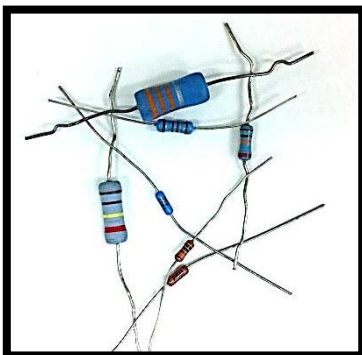
This lab is intended to give you a basic **idea** of how Vacuum Tubes work in audio circuits. This requires a rudimentary understanding of electronics theory so we'll start with that. If you are comfortable with that information feel free to skim the introduction.

a few minutes of **Basic Electronics**

Electricity is, quite simply, electrons moving. So the question is; where do they move and why? An electron is a negatively charged particle. The most basic tenant of electronics is that like-charged particles repel and oppositely-charged particles attract. If, for example, you set two magnets on a table with the same poles facing each other, they will move apart; if you face the opposite poles, they will move together. Electrons (you should remember from basic physics that electrons have a negative charge) are attracted by positive (opposite) charges and repelled by negative (like) charges. Electrons will ALWAYS flow from a more negative charge to a more positive charge. We call that movement (or flow) of electrons, **Current** flow. We use the letter "**I**" for current and measure it in Amperes or Amps using the letter "**A**".

Though the terms "electron flow" and "current flow" represent the same thing they are traditionally thought of as going in opposite directions. They are the same in every other way.

We need a force to get the electrons moving. That force is called **Voltage** and is measured in Volts. We use the letter "**V**" for both voltage and Volts. The larger the voltage "pushing" the electrons, the faster the electrons will move. That means *more voltage = more current, less voltage = less current*.



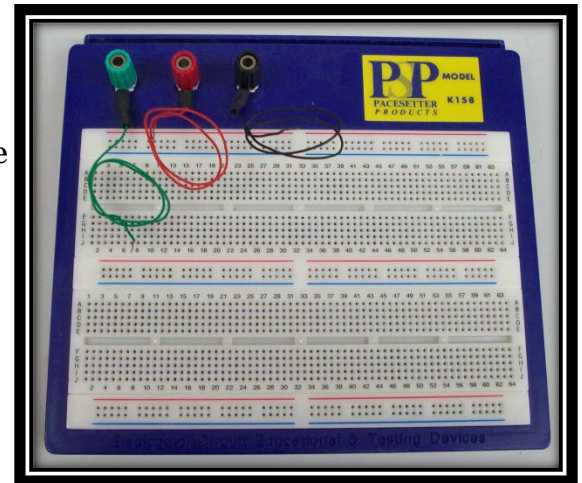
When we move electrons through something the difficulty with which they move is called **Resistance** and we represent it with the letter "**R**". There are components that have very specific amounts of resistance. They are called resistors! Resistance is measured in Ohms and we use the symbol Omega " Ω ". The schematic symbol for a resistor is shown below. A resistor would have defined amount of resistance in ohms (or Kohms, Mohms). This value is most often represented on the actual component (shown to the left) as colored bands. The last page of the lab gives the code for these.



We will be using breadboards (photo to right) to create our experiments. These are just simple ways of connecting things.

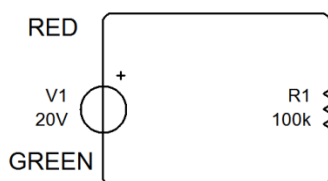
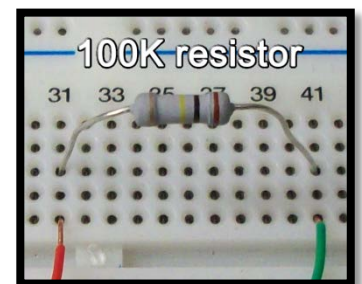
The breadboard is made up of rows and columns of holes. These holes will accept component leads or wires. If you place the breadboard as shown in the photo the columns of 5 holes have all 5 holes connected together. The rows with **red** or **blue** lines running along with them have all 25 of the holes that run with the **red** or **blue** line connected together.

At the top of the breadboard are a **Green**, **Black**, and **Red** post. These are called 5-way binding posts and we will use them to connect a Voltage source to the breadboard. The wires running from them will connect to holes on the breadboard.

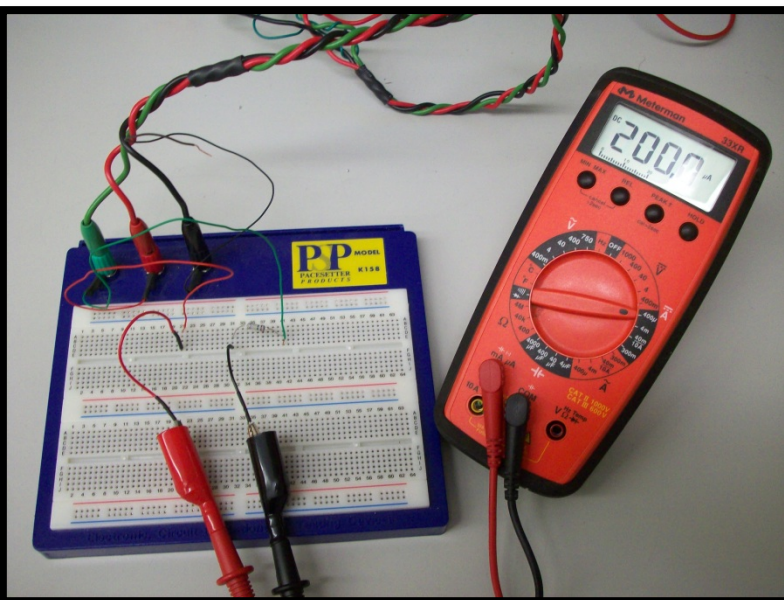


Experiment 1: We will start by doing a simple experiment with a resistor and some voltage.

1-2. Take your 100K Ω resistor (gray with brown-black-yellow-gold bands) and push one end into the middle hole of column #31 and the other end in the middle hole of column #41. It does not matter which end goes to which column.



1-2. Now push the **red** wire coming from the 5-way binding post into another hole in column #31 and the **green** wire into another hole on column #41. You have just made a circuit. Schematics are used as a way to draw a circuit. The Schematic for the circuit you just built is shown to the left.



1-3. We want to be able to measure the amount of current flowing in this circuit so we are going to add a Digital Multimeter set to measure current. Take the **red** and **black** jumper wires and clip one end of those into the leads on your Meterman Digital Multimeter (*red to red and black to black*).

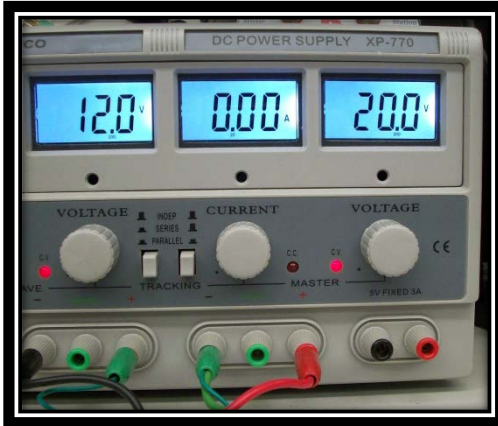
1-4. Take the red wire out of Column #31 and move it to Column #21.

1-5. Push one end of the red jumper wire (*other end connected to red lead of meter*) into another hole in column #21.

1-6. Push one end of the black jumper wire (*other end connected to black lead of meter*) into another hole in column #31.



1-7. Make sure that the **red** lead of the meter is connected to the “mA uA” jack (shown to left) and that the **black** lead is connected to the “COM” jack. Then set the meter to 400μ setting for **A** , as shown to the right.



1-8. Turn on your power supply and adjust the right side Voltage control so that the meter above it shows ~20.0V.

1-9. Your current meter should show a reading very close to 200μA. (if not, ask for help) This is because of a fundamental of electronics called Ohms Law. Ohms law says that $V=IR$, or Voltage = Current * Resistance.

In this case we have $20V = 200\mu A * 100K\Omega$

or

$20V = 0.0002A * 100,000\Omega$

1-10. Adjust the voltage control on the power supply slowly down and notice what happens to the reading on the meter. As voltage decreases, so does current. It should always follow ohms law.



Vacuum Tubes



Vacuum tubes are active components. This means that they can amplify (*make small signals larger*). Vacuum tubes are called Transconductance devices. This means that they use a small voltage to control a large current. We will be working with a Triode in this experiment. A Triode has three elements inside the component. They are the cathode, control grid, and anode (or plate). *There are also two connections for the heater that heats the cathode.* For the tube to function the **Cathode** has to be most **negative** and the **Anode** has to be most **positive**. From what you read earlier you should realize that electrons will then flow from **Cathode** to **Anode**. As long as the cathode is heated by the heater this will happen.

The Control Grid is placed physically in between the Cathode and Anode. By varying the voltage of the Control Grid we can increase or decrease that electron flow. If we give the Control Grid a negative voltage (which the electrons don't like) electron/current flow will be reduced. The more negative that voltage the more reduction in current flow that will occur. A positive voltage on the Control Grid (happy electrons!) will increase electron/current flow. Again, the more positive that voltage the more of an increase there will be in current flow.

We can now take a varying voltage on the Control Grid (like Audio) and use it to create a changing current through the tube that is analogous to the audio. In most cases we want another varying voltage, however, $V=IR$ says that if we vary current through a resistor we will get a varying voltage drop. So we place a resistor between the Anode and the positive voltage. We will then have a varying output voltage that is a larger version of the one we put on the Control Grid. In other words we made an amplifier.

The circuit you will build also has a resistor going from the Cathode to the most negative point in the circuit (Ground). This helps place the audio signal halfway between the two extremes for the tube of Cutoff (*the least amount of current flowing*) and Saturation (*the maximum amount of current flowing*).

If you want to know more about how tubes work, there is a power point presentation CD available, just ask!

Vacuum Tube Amplifier

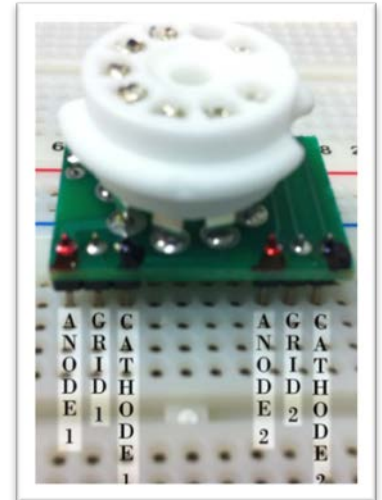
Materials needed: 1-12AX7A dual triode vacuum tube, 1-0.047 μ F capacitor, 1-100K Ω resistor, 1-3K Ω resistor, signal source and amplified speaker.

2-1. In order to add our Vacuum tube to the circuit we already built we need to move the **Green** wire from column #41. Remove and then push it into the farthest left hole of the Row with the **Blue** line running below it. This row sits above the columns we have been using.

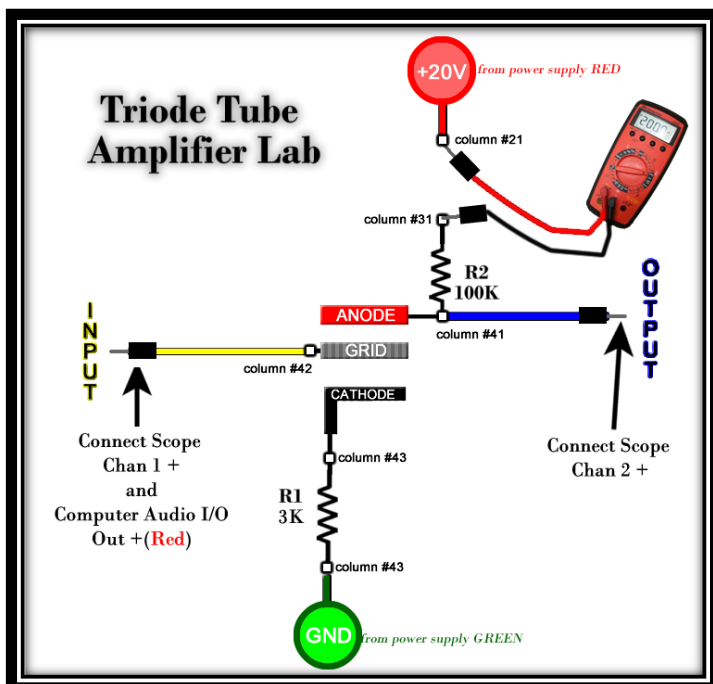
2-2. Push the **Black** wire from the 5-way binding post into leftmost hole in the row with the **Red** line running above it. This row sits above the columns we have been using. This will provide voltage for the tube heater.

2-3. Now take the board with the Vacuum tube on it and push it into the breadboard. The two pins sticking out the bottom go into the **Red** and **Blue** rows and the six pins on the long side should be placed so that the one colored **Red** on the far left is in column #41. This should place it in the same column as one end of the resistor. That connects them which is what we want!

The six pins on the long side of the PC Board are the connections to the triode. There are two triodes (you will only use 1) and they are color coded: **Red=Anode**, **Silver=Grid**, and **Black=Cathode**. +20V will be supplied by the **Red** wire from the power supply and zero volts (**ground** or **GND**) will be provided by the **Green** wire (*both for the heater and the rest of the circuit*)



2-4. The schematic for this circuit appears below. You already have much of this built.

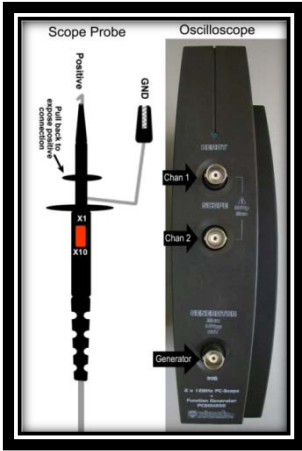


2-5. Push one end of your other resistor, a 3K Ω (brown with orange-black-red-gold bands) into column #43 so that it connects to the Black colored pin of the vacuum tube board, which is the cathode of the tube. Push the other end into column #55.

2-6. Add one of your white jumper wires from column #55 to the row with the **Blue** line running below it. You connected that row to ground from the power supply (**Green** wire) earlier so you have now connected one side of the resistor to ground and the other to the cathode.

2.7 Turn on the power supply (with it **NOT** connected to the breadboard) and set the left supply to 12V and the right supply to 0V. Then turn off the power supply and connect the power supply to the breadboard.

2-8. You now have the circuit shown on the last page built. We just need to connect input and output to something and we can see (and hear) the results.



2-9. Connect one end of your other three white jumper wires to the Blue row (Ground). Then clip the grounds from the Computer audio I/O, Oscilloscope Probe channel 1, and Oscilloscope Probe channel 2 to the other end of these wires.

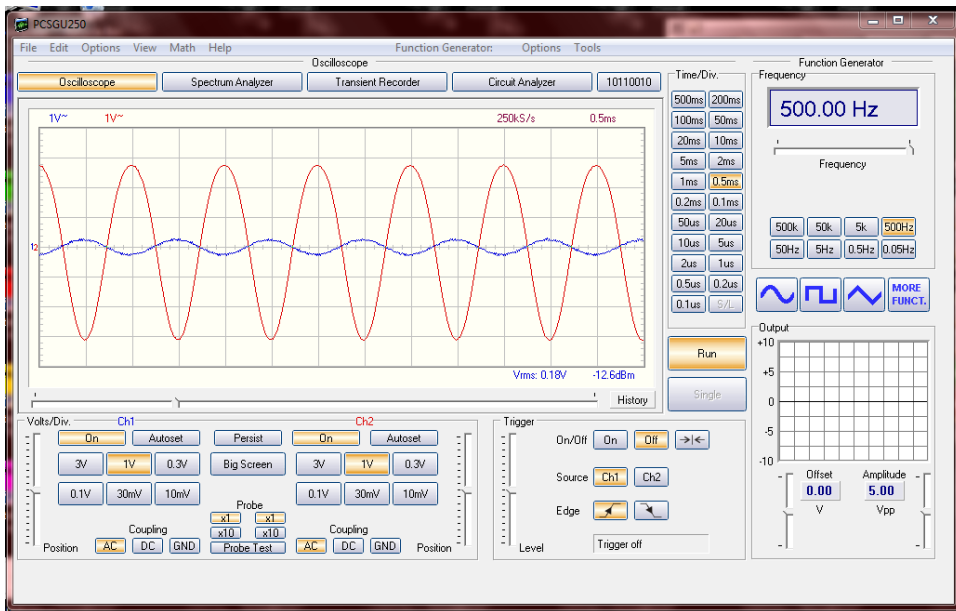
2-10. Add one end of both **Yellow** jumper wires to column #42 which will connect it to the Control Grid of the Vacuum tube. Connect the other ends to the Positive of the Computer Audio I/O (**Red** alligator clip) and the Positive of Oscilloscope Channel 1. You will need to pull back on the oscilloscope probe to expose the Positive connection (as shown to left).



2-11. Connect one end of the Blue jumper wire to column #41 connecting it to the Anode of the Tube and the 100kΩ resistor. Connect the Positive of Oscilloscope Probe Channel 2 to the other end of this Blue jumper.

2-12. You have now built the circuit and will soon be amplifying audio!

2-13. There should be two programs open on the workstation computers; an oscilloscope program (PcLab200LT) and a signal generator program (Audio Quicktest). Make sure that they are set as shown below. They should be set for you but double check.



2-14. Turn on your power supply and again adjust the right side Voltage control so that the meter above it shows ~20.0V. Adjust the left side Voltage control so that the meter above it shows 12V.

2-15. You should now see a sine wave on the Oscilloscope screen. The Blue waveform is the signal that is going into the amplifier you just built and the red is what is coming out. The vertical axis on the display is voltage. The Blue input waveform shows about 0.25V peak (the highest point in the sine wave) while it shows about 2.75V_{PK} for the output. That is over 5 times the output, so it is indeed amplifying.

It is worth noting that this is a very simple amplifier running at very low voltage (a typical tube circuit would be closer to 200V instead of 20) so we are not talking high fidelity, just a working demonstration.



2-16. Now remove the BNC connector from the Oscilloscope interface Channel 2 by twisting the part closest to the interface to the left as shown to the left.

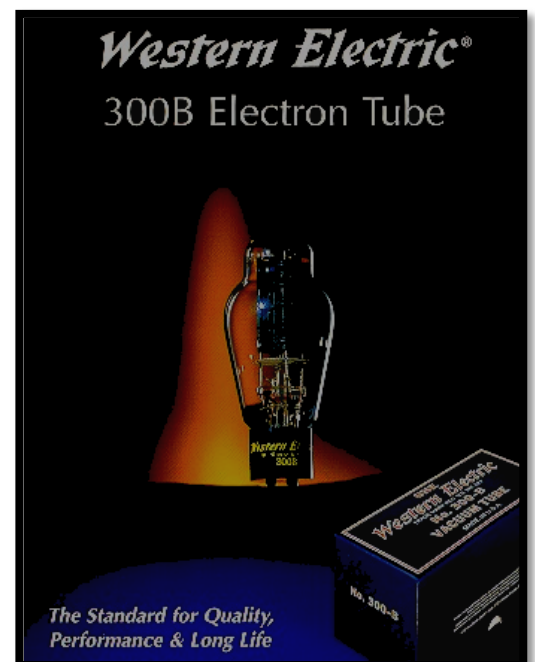
2-17. Check that the powered speaker volume is down. Reconnect the BNC to the Amplifier In of the powered speaker. Choose an instrument in Audio Quicktest, turn up the volume and listen to your amplifier. If you notice distortion it is because you are sending too much level to the amplifier. Turn down the output of the computer. You can also open Window Media Player and play some music from that Library.



How This Is Working

You have connected the Cathode of your tube through a resistor to GND (zero volts) and the Anode through a resistor to +20Volts. Since the cathode is more negative and the anode more positive electrons will flow from Cathode to Anode.

We are adding an audio waveform to the Control Grid. When this moves to the positive half of the waveform current is increased. This happens because electrons are attracted to positive (*their opposite*) Voltages. When the audio moves into the negative half current is decreased. This is because the electrons are repelled by the negative voltage.



Resistor Color Codes:

The first two, three, or four bands are the digit indicators and follow the color code below.

Black=0	Brown=1	Red=2	Orange=3	Yellow=4	Green=5	Blue=6	Violet=7	Gray=8	White=9
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The next (second to last) band is the multiplier and follows the color code below.

Black=1	Brown=10	Red=10²	Orange=10³	Yellow=10⁴	Green=10⁵	Blue=10⁶
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The last band is for tolerance. It is difficult (and often unnecessary) to make a resistor at the exact value, so they come in different tolerances. The tighter the tolerance, the more the resistor will cost. Tolerance is indicated by the color code below.

Brown=1%	Red=2%	Orange=3%	Yellow=4%	Gold=5%	Silver=10%	none=20%
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There are some easy to use Apps out there if you want an easy reference for this.