A Tube Tester for High Power Transmitting Tubes

Make sure that "hamfest special" or tube that has been sitting on your shelf for years doesn't ruin your amplifier.

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Most ham radio operators who use a vacuum tube power amplifier either have spare tubes sitting on their shelves or have contemplated buying one (new or used) at a hamfest. That used tube (and even a new one that has been sitting for a long while) constitutes a real risk to your amplifier the first time it is installed and turned on. Shorted or gassy tubes can create huge loads on the amplifier power supply and any other components that are in the conduction path and literally destroy transformers, diode chains and capacitors. That hamfest "deal" can cost your hundreds of dollars and many hours of grief.

Even new tubes that have been sitting patiently on the shelf for years, ready to jump into action when the primary tube finally fails in the middle of a DX contest, can easily cause the same problems due to minute outgassing that can occur over time.

A bargain tube loses its luster if it blows up your amplifier.

High power tubes have traditionally been hard to test without a method of applying actual filament and plate voltages — just what you want to avoid in your amplifier if the tube is indeed bad. This was our challenge, too. We had accumulated many tubes over the years that were sitting as backups including pulled tubes from magnetic resonance scanners for years while 3-500Z, 3CX-800 and 3CX-1500 (8877) tubes were in common service. Subsequently, we built or modified amplifiers that used the 3-500Z and 3CX-1500 (8877) tubes.

Both authors have experienced tube arcing at startup due to the very problems described above. In several cases we needed to replace substantial power supply components due to these catastrophic tube conductions.

A nice article appeared in *Electric Radio* by Tom Marcellino in 2009 describing a homemade high power tube tester.[1] The intent of his article was to evaluate the output quality of his specific tubes of interest and grade their performance. We were not interested in the tube types chosen for his tester and we didn't need to test for output, but rather to insure we would not injure our amplifier when a "new" tube was first introduced. If the tube doesn't hurt the amplifier, it is then easy to use the amplifier as the best test of actual tube quality and output.

Marcellino's article did stimulate our thoughts as to how we could achieve our intended goal. We discussed what we needed to accomplish and then began to pull parts from our combined "junk boxes."

This project is probably not one that every amateur will or can embrace. However, we believe this tester has resulted in an extremely useful device that would make a wonderful project for a club or group of like minded amateurs. Combining resources can also make this a fun and useful project and one that can be achieved with existing parts.

Design Goals

Our amplifiers were using only 3-500Z, 3CX-1500 (8877) and 811A/572B tubes. The 811A/572B tubes can be tested in good quality tube testers (for shorts and conduction). The 3-500Z and 3CX-1500s are not testable by the average ham with available equipment (short of the "plug it into your amplifier" trick). So, we decided to focus on these tube types. This tester was therefore designed and built to deal only with our specific tube needs.

As our amplifiers use tubes common in

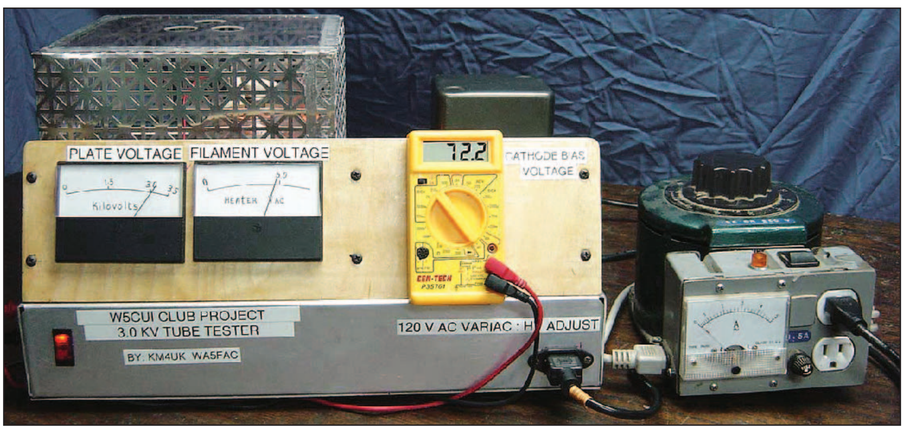

Figure 1 — The completed high power tube tester in use. The Variac to the right is used to incrementally increase the plate voltage and view the line current in the event there is a short or too high a current draw for a particular setting. The switch on the left below the meters separately turns on the filament voltage and fan.

[1]Notes appear on page 45.

amateur service, this tester will cover the needs of a large percentage of hams. Your needs may be different, but slight modifications to the filament supply design and the installation of appropriate tube sockets can allow you to do the same tests with just about any tube. We had a real advantage with the two tubes we needed to test, in that both use 5 V filaments.

The kinds of problems we needed to test for (and therefore might encounter as tube failures) would include open elements (which will not generally cause a catastrophic event) and shorted or gassy tubes (which can create an interesting and exciting display if the test is not controlled). Once again, since we did not plan to test output or transconductance, we could design and build a much simpler tester.

We wanted separate filament and plate voltage control. This allows one to energize the filament circuit with no voltage on the plate. This provides for filament warm up, which is required by some external anode tubes, or to allow long term filament heating, which is useful in some minimally gassy tubes to activate the internal getter to remove gas.

We provided not only separate turn-on of the plate supply but also incremental plate voltage increase. In shorted or gassy tubes this would allow us to be able to watch the current draw in the plate circuit and interrupt the process if abnormal current was being initially drawn. This was to be accomplished by controlling the plate voltage with an external Variac (see Figure 1). However, we still needed to build in some means to handle a dead short that might develop during tests. This can be caused by sagging tube elements during heating or by gas conduction that could develop in an avalanche fashion as plate voltage was increased. We addressed this issue with appropriate fusing of the various supply voltages and inrush power resistors in the plate supply line.

We wanted a tester that would be as safe as possible to use. The voltages employed in our linear amplifiers and in this tester can easily kill. Therefore, we wanted visual and physical safety methods to be employed that would protect us during these tests.

Our final goal was to build this tester out of existing "junk box" parts. We are both long-time amateurs so we had a good supply of "junk." However, some of our parts will be seen by the engineers in our midst as less than optimal. Please don't write us and tell us how we can use better parts. We are very happy with our result and it works great. Make those changes to your own tester and share them with your friends. As this is a "junk box" project, you may find that your existing parts may differ from ours but work just as well with some modifications to the circuit suggestions we have provided.

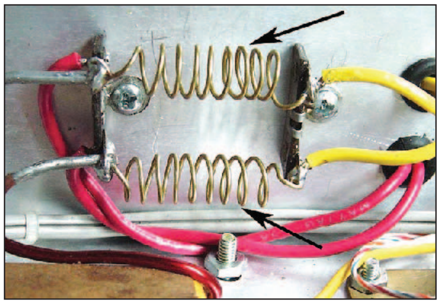

Figure 3 — Brass wire, size #18 AWG used in the filament leads to the 8877 (black arrows) to add additional resistance and bring the voltage down to 5 V ac.

Circuit Development

The tube tester circuitry logically divides into portions for the filament and the plate.

Filament Circuit

As previously stated, both of the tubes we wanted to test (3-500Z and 3CX-1500) use a 5 V filament supply. A spare filament transformer from a Drake L4B linear amplifier was available. It was capable of over 30 A at 5 V, intended to supply two 3-500Z tubes in the Drake amplifier. This transformer was a conservative choice. Being good stewards of our amplifier tubes and knowing that these tubes should never be run at higher than rated filament voltage, you will see some added resistance in the filament circuit primary (see Figure 2) that limits voltage to no more than 5 V ac on the 3-500Z. (You may need to modify the actual values for your area line voltage.)

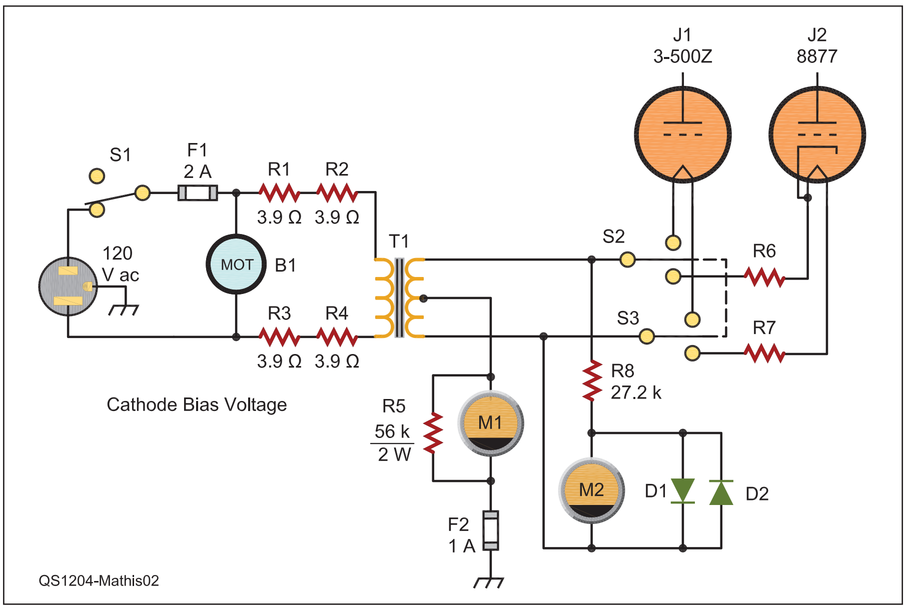

Figure 2 — Filament circuit schematic and parts list

B1 — Blower fan adequate to tubes under test.
D1, D2 — Silicon 1 A diodes, 1N4007 or equivalent.
F1 — 2 A, fast blow fuse.
F2 — 1 A, fast blow fuse.
J1 — Air system tube socket for test sample, 3-500Z, in this case.
J2 — Air system tube socket for test sample, 8877, in this case.
M1 — Panel meter to allow reading cathode current (see text).
M2 — Panel meter 5.5 V ac full scale made from surplus VU meter (see Figure 5 and text).
R1-R4 — 3.8 Ω, 4 W wirewound resistors.
R5 — 56 kΩ, 2 W resistor.
R6, R7 — Filamemt dropping resistors as needed (see text). Made from #18 AWG brass wire, 8" typical.
R8 — 27.2 kΩ, ½ W resistor.
S1 — SPST toggle switch, 250 V, 1 A.
S2 — DPDT toggle switch, 25 V, 15 A.
T1 — Filament transformer, 120 V primary, 5 V CT secondary at 15 A.

Hamspeak

Getter — Reactive material left inside vacuum tube to remove residual gas following evacuation. In many tubes the material is released following sealing by use of RF induction heating, in a process known as *flashing* the getter.

Transconductance — Parameter used to characterize vacuum tubes. The transconductance, abbreviated g_m, is the ratio of the change in current flow in the plate circuit to voltage change in the grid circuit. It is a measure of how the tube will operate in amplifier service.

Variac — Trade name of a kind of variable autotransformer that can provide voltage between 0 and typically 150 V ac from a nominal 120 V line.

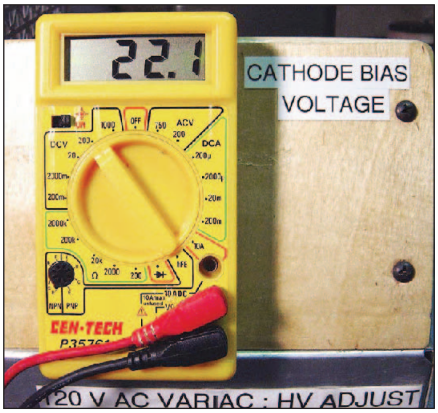

Figure 4 — Cathode bias meter. This shows a 22 V dc drop across the cathode bias resistor while testing a 3-500Z tube at over 3000 V dc plate potential. The cathode bias drop will be different for different tube types and will rise as plate voltage is increased to effectively limit plate current.

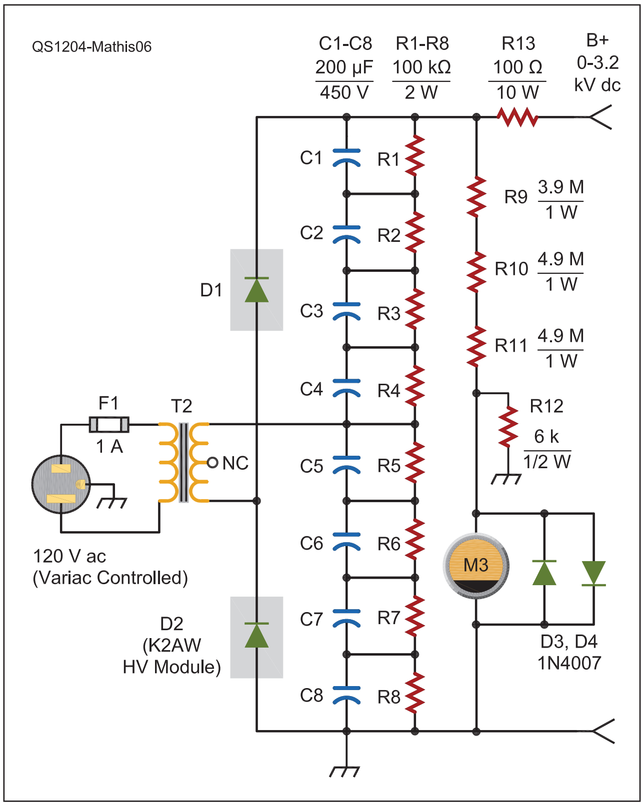

Figure 6 — Schematic diagram and parts list for plate supply circuit.

C1-C8 — 200 µF, 450 V electrolytic capacitors.
D1, D2 — High voltage rectifier diodes, see text.
D3, D4 — Silicon 1 A diodes, 1N4007 or equivalent.
F1 — 1 A, fast blow fuse.
M3 — Panel meter to measure plate voltage (see text).
R1-R8 — 100 kΩ, 2 W resistors.
R9 — 3.9 MΩ, 1 W resistor.
R10, R11 — 4.9 MΩ, 1 W resistors.
R12 — 6 kΩ, ½ W resistor.
R13 — 100 Ω, 10 W wirewound resistor.
S1 — SPST toggle switch, 250 V, 10 A.
T2 — Plate transformer, 120 V primary, 1500 V secondary at 0.5 A, or as available.

The 3-500Z is rated at 14.5 A while the 3CX-1500 uses 10.5 A. This difference will result in a different filament voltage for the 3CX-1500 unless additional resistance is added to its filament supply (beyond that found in the primary circuit). This was developed using #18 AWG brass wire. Eight inches of this wire was placed in each leg of the 3CX-1500 filament lead to limit the voltage to the desired value (see Figure 3). Obviously, this is an empiric amount of resistance but easily adjusted to your needs. The primary of this transformer is fused with a 1 A fast blow fuse.

This tester develops over 3000 V dc on the plate and therefore some form of bias is needed to insure that the idling current to each tube is limited. We selected a simple cathode bias arrangement that places a large cathode resistor in the center tap (return lead) of the filament transformer. This insures that the cathode is forced to have a positive potential (with reference to the grounded grid) as current is drawn by the plate (with increasing plate voltage). An external voltmeter (M1) was placed across the cathode bias resistor to monitor the pinch off voltage and indicate the voltage drop as the plate voltage is increased. This gives an indirect measure of cathode to plate current with increasing plate voltage.

Figure 4 shows a 22 V potential across the cathode bias resistor while testing a good 3-500Z at 3000 V dc. This bias limits the plate current to a minimal and safe level even at the 3000 V potential. (M1 was chosen as we did not have in our junk boxes a third VU meter of the type used in M2 or M3. This inexpensive meter was expedient and works well. All the metering could be accomplished with similar meters that are obtainable for as little as $5 at hamfests or online.)

The metering circuit for the filament supply (M2) uses a 200 µA (VU) meter movement with the full wave internal bridge left in place. A series 27.2 kΩ resistor was used to establish a 5.2 V ac full scale reading. I replaced the scale with a hand drawing but

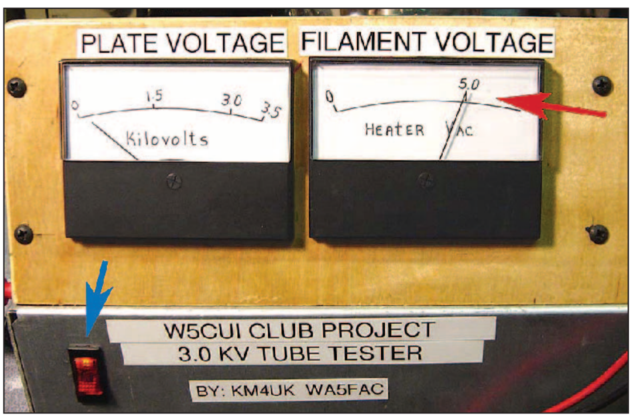

Figure 5 — The filament supply is turned on by the switch on the left bottom (blue arrow) and allows independent activation of the filament supply (red arrow) without turning on plate voltage.

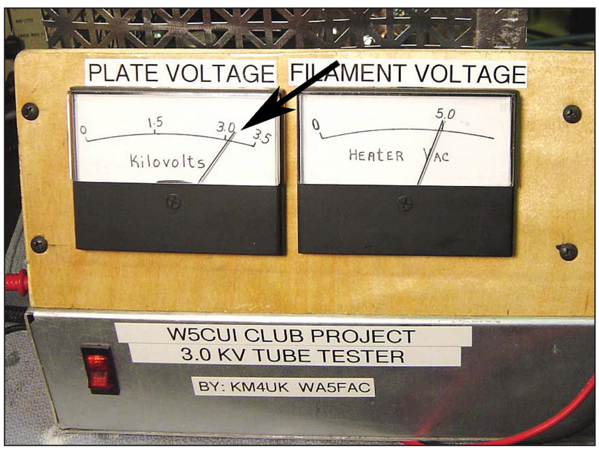

Figure 7 — The black arrow indicates full plate potential (3.2 kV). This has been incrementally activated by the Variac control and is completely separate from the filament supply.

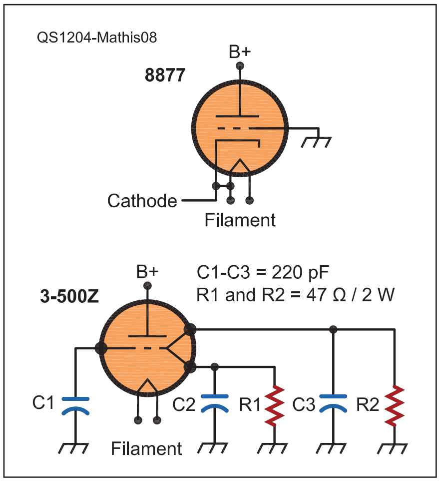

Figure 8 — Schematic diagram and parts list for tube socket connections.

C1-C3 — 220 pF ceramic capacitors.
R1, R2 — 47 Ω, 2 W resistors.

recommend you consider using software such as that available from Tonne Software (**www.TonneSoftware.com**) for their *Basic Meter* program, which is free to hobbyists.

Both M2 and M3 have double reversed diodes installed across their contacts. This is a trick described years ago in an article by Battishill and McCoy from *CQ* magazine that outlines several design faults found in the Heathkit SB-220 (as well as numerous other amplifiers).[2] When a tube short occurred it would commonly destroy the meters as they were part of the conduction path. The double reversed diodes protected the meters from this fault. We continue to incorporate this protection and recommend it to all amplifier builders or restorers.

The fan is wired in parallel with the filament primary (before the dropping resistors) and therefore comes on whenever the filament circuit is activated. A Dayton 4C4004A blower was available from a prior amplifier project. It provides forced air into the chassis base. As two tube sockets are installed into the chassis, each must hold a tube (one not electrically connected) or alternate methods must be used to insure that adequate forced air is injected around the tube under test.

The filament is activated separately from the plate supply (see Figure 5). This provides for both filament warm-up and separate control of the plate supply.

Plate Circuit

The plate circuit needs a high potential, similar to that experienced in the actual linear amplifier circuits, to adequately test for internal shorts and gas conduction. However, the cathode bias is set to keep cathode to plate current pinched to a minimal amount. The plate transformer needs to be capable of developing a reasonable voltage but can have a very low current rating. Our junk box transformer was rated at 1100 V ac at 0.25 A. We therefore elected a voltage doubler circuit (see Figure 6) and basically copied the arrangement from a Heath SB-220 manual. Equalizing resistors of 100 kΩ at 2 W were placed in parallel with each capacitor (200 μF, 450 V dc). The original diode chain used in the SB-220 was replaced with a single diode module (K2AW HV 6-1) in each leg of the doubler. This module is popular in amplifier circuits and advertised in *QST*. It handles 6 kV at 1 A and was in the junk box. The primary is fused with a 1 A fast blow fuse. A 100 Ω, 10 W, wire wound resistor is placed in series with the plate supply to limit current in the event of a flash over.

This circuit develops 3200 V dc (see Figure 7). It is continuously variable from zero to maximum with the Variac control. A three prong "computer style" chassis plug was installed for hookup of the Variac to the tester. This allows the Variac to be used for the plate supply, connected with a standard computer power cord, without committing it permanently to the tester. Metering on the Variac allows constant monitoring of the current drawn in this circuit with incremental increases in plate voltage. The voltage is monitored with the plate metering circuit. This again is a 200 μA (VU) meter (M3) with the internal full wave bridge removed. This meter circuit was copied from the SB-220 manual and is calibrated for 3.5 kV full scale.

Tube Sockets

Standard tube sockets specified for each type tube should be used. We set up our chassis to allow forced air to enter each socket from below. Therefore, appropriate chimneys for each tube are also needed to direct the airflow as designed.

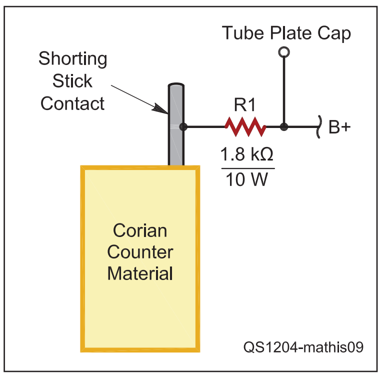

Figure 9 — Shorting tower construction diagram.

The actual electrical hookup of each socket was copied from amplifier circuits currently in use for the 3-500Z (Heath SB-220) or for a homebrew 3CX-1500 amplifier (see Figure 8).

Safety Features

As stated above, this tester develops potentially lethal voltages. Therefore, several features were developed to add as much personal safety as possible. First, a removable cage was made that sits over the tubes during testing to avoid inadvertent contact with the plate voltage leads. Secondly, plate voltage metering is provided by the meter on the front panel of the unit. This allows the operator to check for existing voltage on the capacitor bank or tube plate.

Metering is simply not enough, however, to insure zero potential (as meters and associated circuits can fail). Therefore, we built in a manual discharge system (shorting tower) out of a piece of Corian. This is easy to cut and drill and serves as an adequate standoff insulator. The shorting tower (see Figure 9) lets the operator short the plate to ground through a 1.8 kΩ, 10 W resistor, discharging any residual voltage on the capacitor bank without having to interact with the tube plate. Use the shorting stick, sometimes called a "chicken stick," shown in Figure 10 to make sure any remaining voltage is discharged to ground.

Using the Tester

This tester has now been in use for over a year. It allows basic testing of 3-500Z, 3-400, 4-400 and 3CX-1500 (8877) tubes. We have discovered tubes with open filaments, shorted elements and gas intrusion that created cathode to plate shorts. The shorted or gassy tubes can easily damage an amplifier and this problem is avoided with this simple tester.

The independent filament and plate controls allow both tube warm up (filament only) and slow incremental increase of plate voltage while monitoring tube operating conditions. As the plate voltage is increased, the cathode bias voltage will also slowly increase to limit cathode to plate current to a low value. Normally functioning tubes will show this slow cathode bias rise while abnormal tubes will not. The amount of cathode bias will vary with different tube types.

Shorts or gas discharge can be observed at relatively low plate voltage and the test interrupted as necessary. If gas discharge is found, then a period of filament-only activation, or plate voltage below gas discharge and conduction, can be tried to see if small amounts of gas can be eliminated.

Tubes that have only a small amount of gas will show abnormal color (usually a blue or blue-violet) and a rapid and abnormal plate current rise on the Variac meter with rela-

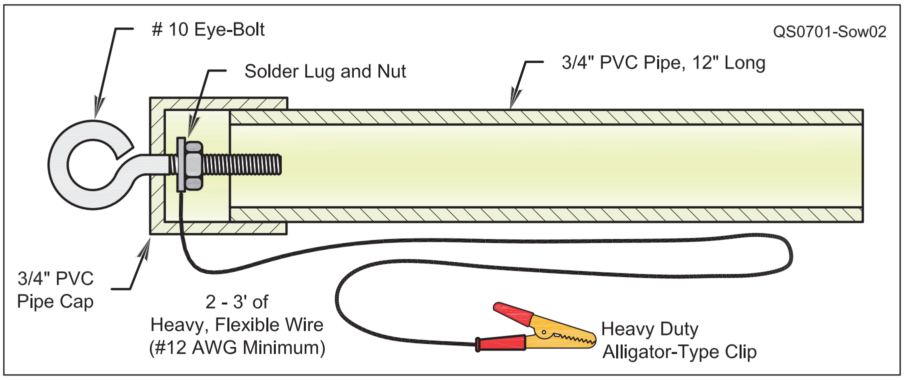

Figure 10 — This "chicken stick" can be used to verify that any remaining high voltage has been dissipated to ground. The alligator clip is attached to a ground point. While gripping the insulated shaft, touch all potential danger areas with the eyebolt.

tively small amounts of plate voltage. It is important to have these tubes not conduct at a near short circuit in your amplifier when you first turn it on.

A considerable amount has been written about tube restoration methods to eliminate very small quantities of gas.[3] It may be possible to use the tester to effect such a cure in some (but certainly not all) of these gassy tubes.

These high power tubes all have an internal device called a *getter* that is used in tube manufacturing to eliminate small amounts of residual gas left after the envelope is sealed. These getters are different from the ones used in small transmitting and receiver tubes. In the small tubes, a silver appearing deposit is seen on the inside of the glass envelope when the getter is activated (called a flash getter) by external RF energy. This material is usually made of a barium compound that interacts with the residual gas molecules to capture and eliminate them.

The getter used in high power tubes is a non-evaporative alloy that is made primarily of zirconium. This special alloy is used to coat a tube element and is activated by high temperature. It is not a single use material and therefore there is some potential for it to clear out minute amounts of gas that can migrate into the tube over time. It cannot heal a large leak, however.

In minimally gassy tubes recovery can often be affected. We have accomplished this, but here are some caveats. First, the getter material is not always deposited on the same element within the tube. Typically, external anode tubes such as the 3CX-1500 have the getter applied to the filament. Therefore, running the tube with filament voltage only applied may significantly activate the getter and reduce accumulated gas molecules. In some internal anode tubes (of which the 3-500Z is an example), the getter is usually applied to the plate. Running the filament in this case may do little to activate the getter and trap gas molecules. Nevertheless, we have definitely seen some tubes that initially were gassy but recover even in the internal anode category.

This tester has been very useful for testing high power tubes and preventing amplifier damage. It was a fun project for our small club. See if you can make your own, using available materials or high quality, well engineered substitutes. This is only a template for construction, but allows one to be able to test, with this or a modified tester, almost any high power tube that you or your friends may be using.

Switch to Safety!

Before you get your screwdriver out it is important to review and then follow a few basic rules. While working with high voltage equipment, safety should be in your thoughts at all times.

Always keep a mindset that lethal voltages are present in high power amplifiers. Many of us who grew up in the solid-state generation are not familiar with working around high voltages. An attitude adjustment is in order — you cannot be too cautious when working with lethal voltages!

- Never work on the unit when it is connected to a source of electricity.
- Use a "chicken stick" (see Figure 10) to make sure every contact that you intend to touch or could accidentally touch with your hands is not "alive." This is especially important around the high voltage section where electrolytic capacitors could still be charged.
- Do a second grounding check with the chicken stick to verify that there are no voltages present around the working area.
- Wear rubber-soled shoes so that your feet are not grounded.
- Never stand on wet surfaces.
- If possible use only one hand, keeping the other in your pocket.
- Never work on amplifiers if you are tired, or after cocktail hour. — *W1ZR*

Notes

[1]T. Marcellino, "A Power Pentode, Tetrode and Triode Tube Tester," *Electric Radio*, Issue 245, Oct 2009.

[2]D. Battishill, L. McCoy, W1ICP (SK), "Save-a-Buck Modifications for Heathkit Power Amplifiers," *CQ*, Sep 1992.

[3]J. Stokes. 70 *Years of Radio Tubes and Valves: A Guide for Engineers, Historians and Collectors,* Vestal Press, 1982.

Photos courtesy of the authors.

ARRL member and Amateur Extra class licensee John Mathis was licensed as WA5FAC in Pittsburg, Texas in 1960. He received a BS in Physics, MS in Radiological Physics and MD with fellowship training in Interventional Neuroradiology. He taught at The University of Maryland and Johns Hopkins Medical Institutions and now lives and practices in Roanoke, Virginia where he grows goats, chickens and antennas.

He is trustee of W5CUI, a memorial club dedicated to his original mentor who helped him get started in ham radio when he was 9 years old. This small club is dedicated to friendship and exploring the art and science of radio communications. Information about WA5FAC/W5CUI is on **QRZ.com** and John can be reached at 6270 Mount Chestnut Rd, Roanoke, VA 24018 or **jmathis@rev.net**.

ARRL member and Advanced class licensee Max Landey, KM4UK, was first licensed in 1980. He is a retired physician/radiologist. He has enjoyed audio experimentation for decades and has applied his considerable tube knowledge to this project. A founding member of the W5CUI club, he is commonly found around 7.137 MHz in the afternoons discussing technical issues of audio and Amateur Radio with ham buddies. Max can be reached at 3453 Farmington Dr, Roanoke, VA 24018-3845 or at **max33v@verizon.net**.