Accurate Calibration Of The Hickok 539B And Hickok 539C Tube Tester

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The Usual Safety Disclaimer

It is a sad commentary on our legal system to have to say this, and a bit of an insult to most people's intelligence to point out the obvious, but ... there are potentially fatal voltages and currents present in this set. If you plan on doing any kind of work on it you should know how to work around potentially lethal voltages. If you don't, get someone who does to help you or get someone else to do the work.

Introduction/Background

Most of the data in this writing is based on experience with one 539B, my personal set, which I have owned for about 20 years and on which I tested many thousands of tubes until the meter failed. In the process of repairing this set, I wound up almost completely reverse engineering it to the point of computer (SPICE based) simulations of all the important circuits.

Like just about every other 539B/C owner I thought I had one of the best testers around (which I still think is true) and, since it seemed to agree fairly well with tubes tested on other testers, that it was quite accurate (maybe, but probably not as much as I thought previously. Read on to see why I say that!)

Warning, Production Run And Other Changes

My set carries a serial number of 152-0470 and was obviously manufactured very early in the production run (the 470th set produced?). The transformer is dated "OCT. 1955". (Alan Douglas in his book on test instruments lists this model as produced from 1956 to 1962, and the Padgett site lists it as starting in 1957, but even the operating manual is dated 1955, so the 539B has been around a little longer than some people think.)

Hickok clearly made some important and poorly or undocumented changes during the production run. My other set is a "junker" set which I got at the ARCI meeting in the summer of 2012. It is missing the meters, the roll chart, some of the precision resistors etc. It's serial number is 152-10361 and the transformer is dated "SEPT 1956". The exclusion chain SELECTOR switches on the older set ("OCT 1955") have multiple decks as shown on the 539B schematic. On the newer set ("SEPT 1956") , SELECTOR switches are as shown on the 539C schematic. The color coding of the wiring is the same (identical) on both sets. However the wiring color scheme is entirely different on the (excellent) pictures of a "DEC 1960" set on a site called "Jimmies junkyard". Some of the sub-assemblies appear to be different, also. Most likely your set is going to be slightly different from mine, so some of the information here may be incorrect for your set! **Be warned!**

Additional Warnings

Hickok seems to have spent little effort (money!) on keeping their documentation correct or making it available outside the company. In addition, as you will soon see, there are several cases where the Hickok engineers made design or procedure errors.

The Schematic Diagrams And The Documentation, In General

Schematic diagrams for both the 539B and 539C are readily available for free on the internet. These all seem to be reprints of the “official” Hickok documentation. It has been noted that the 539B schematic contains errors in the bias meter circuitry. This was corrected (but only partly) in the 539C schematic. In fact, both schematics contain literally dozens of errors, especially in the circuitry around the SHORTS switch.

Some examples:

1. Deck 6 rear of the SHORTS switch is easy to examine with the set out of the case. Compare it to either schematic - not the same! (Sort of a mirror image).
2. Deck 6 front of the SHORTS switch is shown with nothing connected to it on both schematics but it definitely has plenty of wires connected when you look at the actual set.
3. Some decks on the SHORTS switch are shown in the T.T. (Tube test) position and some are shown in position 1.
4. Both schematics show the SHORTS switch with 12 positions. There are actually only 11 positions!
5. The gas test circuit, even on the “OCT 1955” set, is as shown on the 539C schematic (different from the 539B schematic).
6. The SHUNT potentiometer (R23) is **not** actually wired as shown on the Hickok schematic.

There are others, but this should give the “flavor” of the problem. The bottom line is that you can’t (and shouldn’t) completely trust the schematics.

Calibration, Modification And Related Topics

First, What Do You Mean By "Calibration"?

The Hickok 539B/C tube tester has only two adjustments for "calibration", R8 and R15. R8 adjusts the zero for the transconductance sensing circuit (one adjustment that affects ALL 6 transconductance ranges simultaneously, but not equally) and R18 which adjusts the over all zero for the entire transconductance circuit when measuring transconductance (and, again, one adjustment that affects the zeroes of/for all 6 ranges to varying degrees). And worse yet, these adjustment **interact** with each other, which means, among other things, that they must be set in the right way and in the right order, or the accuracy could be made **worse**. There are **no** adjustments that allow for correcting the gain of **any** of the ranges. With one important exception and several lesser, one can **check** the calibration for the 6 ranges without too much trouble, but correcting any error that might be present involves changing the values of some of the circuit components, and in some cases, slight modification of the circuits.

Although not even included in the traditional calibration procedure, there is also an adjustment on the MAIN METER which adjusts its sensitivity over a limited range.

Statement Of Good Intentions

If you are going to pay someone to "calibrate" your set for you, you should be aware that the usual procedure (as popularized by Daniel Schoo) contains several errors, including the use of the "calibration" tube at the end. On the other hand, doing this yourself requires some degree of skill and exposure to potentially hazardous voltages.

The following (lengthy) procedure will allow you to make your set almost as accurate as it can be, at least, as best as I am able to determine it. In the spirit of scientific inquiry I include explanations of the working of the various circuits so you and/or others can confirm (or question) my current understanding of the design of this set.

Solid State Replacements For The Rectifiers In This Set

In this model of Hickok tester, solid state (SS) replacements have several advantages. First, **appropriate** SS replacements can reduce the heat load in this unventilated set by almost 25 watts. Second, they will not change their characteristics significantly over time, unlike vacuum tube rectifiers and the calibration will be more stable, so you don't have to re-calibrate very often. Third, they will tend to make the power supply voltages slightly higher, which has almost **no** effect on the actual measurements, but will make the power supplies "stiffer", meaning that their voltages will change less under the additional load of actually testing the tube.

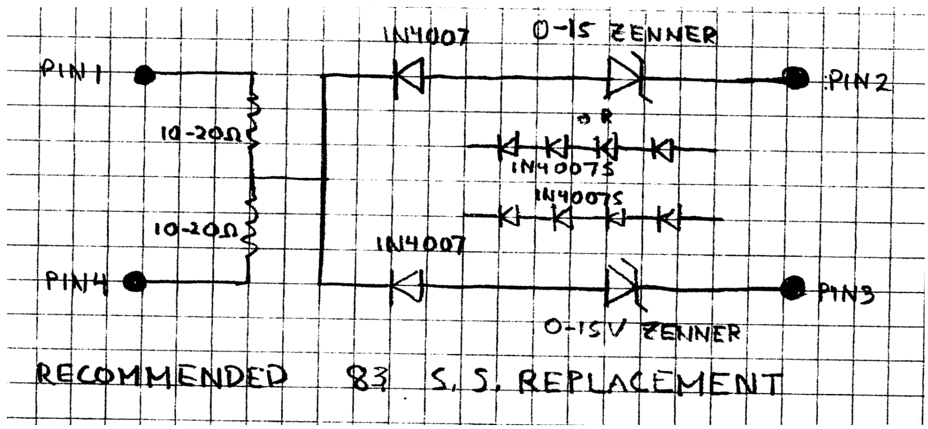

Figure 1: Type 83 Solid State Replacement

For the type 83 mercury vapor rectifier tube, the theoretical best replacement would use two 12 to 15 volt zener diodes. However, this is extremely non-critical and I recommend simply 2 to 4 1N4007 (or equivalent) diodes in series as in as in Figure 1 *Type 83 Solid State Replacement*. For the 5Y3 replacement, two diodes and two resistors of about 400 to 500 ohms will work. 450 ohms at 5 to 10 watts each is a good compromise. See Figure 2 *5Y3 Solid State Replacement*.

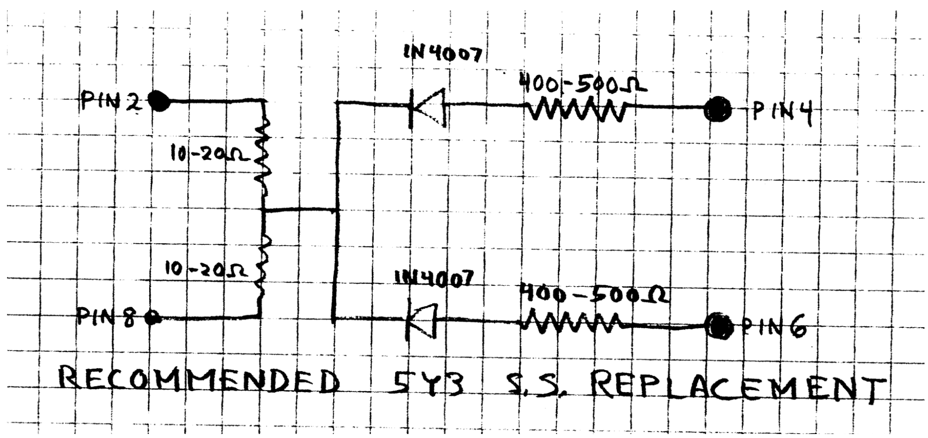

Figure 2: 5Y3 Solid State Replacement

This modification has a possibly significant unintended consequence. When testing tubes which do not put much of a load on the tester power supplies, such as low power tubes designed for battery use, the line adjust control may not be able to bring the primary voltage down to the desired 100.0 volts AC. This is easily dealt with by adding an appropriately sized resistor in series with the main transformer primary winding. A 18 ohm 2 watt resistor, for example, did the job in my set. See Figure 3 *Line Adjust Circuit*.

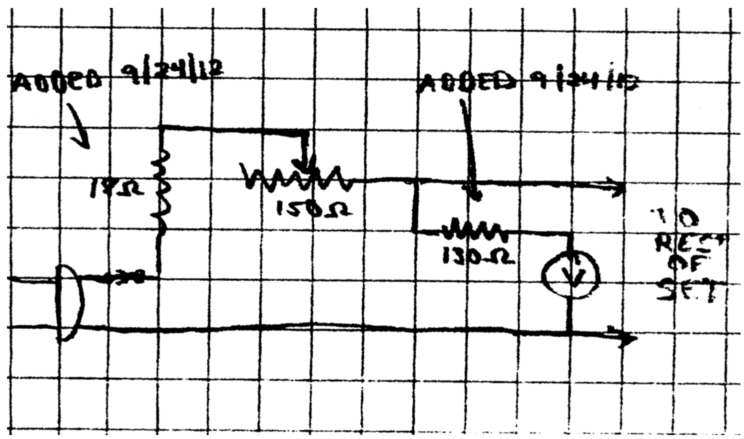

Figure 3: Line Adjust Circuit

General Comments Section

1. The voltage, resistance and current values given are all based on correct values as measured with modern, high input resistance meters (not 1K ohms/volt as in the calibration procedure that is usually seen on the internet). In general, shunt resistors are neither necessary nor desired.
2. In general, before checking (or correcting) the calibration for any of the functions of this tester, the LINE ADJUST control should be set so as to have 100.0 VAC at the primary winding of the main power transformer (i.e. LINE ADJUST METER at the red line). This is probably **the** single most important setting of them all when you are **actually** testing a tube. If you can, it would be a good idea to monitor this voltage with an **accurate** external AC voltmeter during the calibration procedure so you can compensate for slight power line voltage changes as you work (which are bound to occur). If you have or could get temporary access to a constant voltage transformer such as a SOLA transformer, it could make the over-all calibration procedure easier.
3. The Hickok method of checking the LINE ADJUST meter is also incorrect. What matters is that it correctly measure 100.0 VAC. It doesn't really matter if it reads the 120 volt AC line voltage correctly or not. On my set, the meter measured 120 volts fairly accurately, but measured too high when the actual voltage at the primary of the transformer was 100.0 volts. However, what is really the most important is that you calibrate at the exact same conditions that you will be using when actually testing tubes, whatever the actual value may be.
4. The MAIN METER is probably the most difficult component to replace if disaster strikes (actually it is not, but a) that's another story and b) it's

still a lot of work unless you can steal a good one from another tester), so it makes sense to protect it from catastrophic component failure or, more likely, mistakes made by the person working on the set or operating it. See the Know Your Meter section for some recommendations.

5. The "corrected calibration" values given here are all based on using solid state replacements for the 5Y3 and 83 tubes originally used in this set.

A Timely Warning

There are at least two articles on the internet which recommend a modification to the transconductance circuit of adding a trimming variable resistor between R39 and R40. **Do not do this**. This modification can be used to improve the accuracy of any one range, but will degrade the accuracy on other ranges.

Mechanical Meter Zero

This pertains to all three meters on the set, but primarily to the MAIN METER. Before powering up the set, the physical zeroes of the meters should be checked and adjusted. This is done by turning the slotted screw head located at the center bottom of the meter. Note that the meter zero will, in general, be highly position dependent, especially for the MAIN METER. Change the physical orientation of the tester (and hence of the meters), and you will usually have to change this adjustment also. Just setting the tester on an angled surface will often be enough to require re-adjustment of one or more of the meters.

To calibrate the tester (and especially to make any changes to the set) you have to have access to the back of the set and it is/will be difficult to keep the MAIN METER physically zeroed. A way around this difficulty is to measure the voltage separately at the main meter terminal posts with a separate voltmeter using test clips/leads.

Line Adjust Meter

Comments

This is critical to accuracy. Based on experiments with a known good 6L6GB test tube, a 2% error in this setting can cause a 6% — or more — error in the transconductance reading.

Why is this?

The usual, simplified definition of transconductance is the ratio of the change in plate current (delta Ip) of a tube divided by the grid to cathode (or filament) voltage (delta Vcg) which produced it at some specific set of tube operating conditions (quiescent plate voltage, suppressor grid voltage, screen grid voltage, control grid bias voltage, etc.). So, in essence, you have to measure or at least have some way of knowing, two quantities, delta Vcg and delta Ip.

In most Tube Tester designs, including the Hickok 539B/C, the delta Vcg is held "constant" at some design value and the delta Ip is then measured by some method. In most transconductance testers, including the Hickok 539B/C, a small AC voltage (delta Vcg) obtained from a separate winding of the main transformer is added to the DC bias voltage on the control grid to make the transconductance measurement.

This has some potential accuracy consequences. Unless some method to compensate for variations in the primary 60 Hz. line voltage is included, the actual Vcg from this secondary transformer winding may vary by as much as 10% or more due to normal power line voltage variations at the primary winding of the transformer.

The Line Adjust control used in the 539B/C compensates for this effect. *(In some other testers, a similar adjustment also covers the possibility of filament voltage drops when testing tubes which draw large amounts of current or voltage (i.e. power), namely in testers that don't have a separate transformer to supply filament voltage to the tube under test. The 539B/C does have a separate transformer.)*

So the point is that even if you can calibrate your tester to measure the delta Ip to a very high accuracy, if you don't also have an accurate delta Vgc, the over all accuracy of the tube under test transconductance measurement may still be poor. Accurately calibrating the control grid signal voltage is every bit as important as properly calibrating the "transconductance measuring" circuit itself.

Procedure

Connect a known accurate AC voltmeter across the primary winding of the MAIN POWER TRANSFORMER (see Figure 3 *Line Adjust Circuit*). Adjust the LINE ADJUST rheostat so the external voltmeter reads exactly 100.0 VAC. The 539B meter should also read exactly 100.0 V (the red line). Make sure that this meter is in its usual orientation (facing up) and has had its mechanical zero properly set.

If the panel meter reads too high, you can put a small resistor in series with the meter to make it read correctly at 100.0 VAC (130 ohm happened to work in my set). If it reads too low, you might be able to correct this by taking the meter apart, (if there is an internal series resistor, for example) but this option is not recommended.

The best options are to just use the setting that you already have, if it is close to correct (and use this setting consistently for the calibration and when actually using it to check tubes), or to carefully mark the actual position of the needle on the face of the meter with 100.0 volts on the MAIN TRANSFORMER primary winding, and use this as your new "red line". *(Disregard/ignore the "old" red line.)*

In reality, if the actual AC LINE ADJUST voltage is off by 1 or 2 volts, this will probably not significantly affect the readings by itself. The critical thing is that the voltage be **exactly** the same whenever tubes are actually being tested as it was for the calibration, even if it is off by several volts, as long as it is the same each time you use the set. This is because the AC grid signal for the transconductance measurements comes from a separate winding on the MAIN POWER TRANSFORMER and is unregulated. This voltage is critical to the accuracy of the transconductance measurement and is directly affected by the voltage on the transformer primary as measured by and adjusted according to this meter.

"Standard" Configuration Of The Knobs And Switches

For each step, the positions of most of the knobs and switches don't matter, but not always. Sometimes, if a switch is left in the wrong position from the previous step, it could make a difference. So, I will define a STANDARD CONFIGURATION as follows:

Table 1: Standard Configuration

NORMAL/SELF BIAS TOGGLE SWITCH	normal
VR VOLTS & MILS POTENTIOMETER	CCW
VR VOLTS & MILS/BIAS VOLTS TOGGLE SWITCH	bias volts (down)
BIAS RANGE SWITCH	10 V
BIAS VOLTS POTENTIOMETER	CCW
METER SWITCH	normal
SELECTOR SWITCHES	all 0 or off
SHORT TEST SWITCH	other tubes test (down)
SHORTS SWITCH	tube test
CATH. ACT. TOGGLE SWITCH	normal (right)
SHUNT POTENTIOMETER	0
FILAMENT	6.3 V
PLATE VOLTS SWITCH	normal
POWER TOGGLE SWITCH	on (up)
LINE ADJUST POTENTIOMETER	POWER METER at red line (TEST)
FUNCTION SWITCH	C

After each step, return all controls to "STANDARD CONFIGURATION" before starting the next.

If "P4 locked" has been pressed, press "P4 non lock" to release it before continuing.

In general, it is best to do the following sections in the order given, as some depend on previous adjustments having been correctly and accurately made. For safety reasons, you should turn off the power before making the changes specified in each section.

Filament Voltage

1. Be sure the LINE ADJUST METER reads 100.0VAC (red line). Set the FILAMENT SELECTOR switches to “H” and “S”. Connect AC voltmeter leads to pins 2 and 7 of the octal socket. Make sure that the CATHODE ACTIVITY switch is set to “normal”. Measure the AC voltage at each position of the FILAMENT switch from 0.6V to 117V. They should agree with the setting of the FILAMENT switch. I have no “specification” values for this but filament voltages are usually specified at +/- 10 % so +/-10 % is probably acceptable and if they are within about +/- 5% or so, that is probably as good as can be expected. These measurements seem to vary, and there is no easy way to correct this.
2. Set the CATHODE ACTIVITY switch to “test”. Re-measure the filament voltage values. They should be reduced by around 10%. Again, there isn’t much that can be done about this. As a guess, a drop of more than 15% might be a cause for concern, i.e. something that needs to be checked into.

Voltage Regulator Tubes (Function Switch H), Voltmeter

1. Set PLATE SELECTOR switch to “3” and CATHODE SELECTOR switch to “8”. Set FUNCTION switch to “H”. Connect negative lead of DC voltmeter to pin 8 of the octal socket and the positive lead to pin 3. Set the BIAS VOLTS/VR VOLT& MILLS toggle switch to "VR VOLTS & MILLS position. Push P4. Use V.R.VOLTS & MILS control to adjust for reading of 200 V on the DC meter. Verify that the MAIN METER also reads 200VDC. You should be able to get the full 200 volts, but if it doesn’t quite make it, then check at 150V instead. If the meters don’t agree, change the value of R23 (470 Kohm) to make the MAIN METER read correctly.

Measuring The Sensitivity Of Your Main Meter

If you are only interested in checking the calibration, this section can be omitted. There are a confusing number of modifications that can be made for slight improvements in the accuracy of the main transconductance circuit, and many of them will depend on the actual sensitivity of your MAIN METER. Although not really a part of the calibration procedure, now would be a good time to measure the actual electrical characteristics of your MAIN METER.

Without changing the set up from the above section, and using a separate millivolt meter, measure the actual voltage present at the MAIN METER terminals when the voltage regulator adjustment gives a Full Scale reading on the MAIN METER. If you can’t get Full Scale, then make a measurement at 1/2 of Full Scale and multiply by 2. (You may find that your meter is less sensitive than the Hickok specifications, i.e. that it takes more than 172.5 mv. to get Full scale deflection

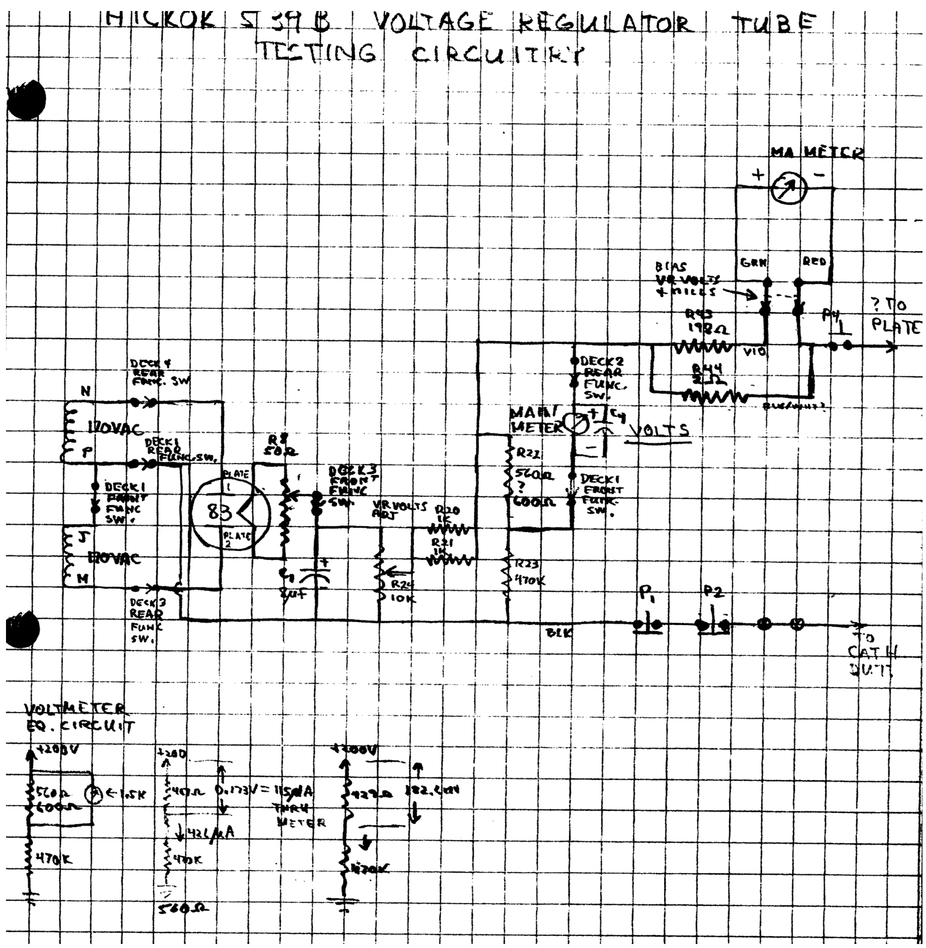

Figure 4: Voltage Regulator Tube Testing Circuit

of the MAIN METER, as there is a tendency for the permanent magnet in the meter to slowly lose it's strength over time.)

There is another calibration adjustment that the usual calibration procedures don't mention, but which can be important if you want to get the best possible theoretical accuracy from this instrument. The adjustment consists of a small metal band around part of the outside of the MAIN METER which can be moved by loosening a small screw. This adjustment slightly changes the sensitivity of the MAIN METER on the "stock" Hickok meter.

Using a pen or pencil, make a mark on the band and the outside of the meter so you can get back to the original setting. Loosen the screw and put the band at one end of its adjustment and make another Full Scale deflection voltage reading at the terminals of the MAIN METER. Put the band at the other end of the adjustment and measure the F.S. voltage. Put the band back to where it started.

Voltage Regulator Tubes (Function Switch H), mA. Meter

1. Use set up as in VOLTAGE REGULATOR TUBES, VOLTMETER section, except add a 2K, 5 WT, 1% or better resistor from pin 3 to pin 8. Set the BIAS VOLTS/VR VOLTS & MILLS toggle switch to VR VOLTS & MILLS position. Push P4 and adjust the voltage for 100VDC. The V.R. VOLTS & MILLS METER should read 50 mA. If it doesn't read 50 mA., change the value of R43 (nominal 198 ohms) so it does. *(Remember to set the voltage back to 0 and put the BIAS VOLTS/VR VOLTS & MILLS switch back to "bias volts" position when done.)*

An Important Modification Needs To Be Made Now

The following is a slight modification to the set, but is necessary to insure that the accuracy is not degraded when testing tubes which draw higher plate currents. This is not included in any of the usual calibrations procedures, and it is probable that the original Hickok engineers never even suspected that there was a problem, but if you want to be able to test higher current tubes while retaining good accuracy, you should make this (simple) modification.

Explanation: In somewhat simplified terms, the patented Hickok transconductance measuring circuit can be viewed as a sort of balanced bridge circuit with two of the legs being supplied with voltage from separate 170 VAC windings on the main transformer. To be able to maintain a good zero at both high and low plate currents, it is necessary to maintain a high degree of symmetry between the legs, and since one 170 volt winding will always have a slightly higher series resistance than the other because of the way transformers are usually constructed, it is necessary to insert some additional resistance into the lower resistance winding to make them both have the same total resistance. You actually have to do this twice, since one set of windings is used when the plate voltage switch is in the "low" position and another set is used when the plate voltage switch is “high”.

Remove the 83 tube or its SS equivalent and turn the function switch to A. This should allow you to measure the resistance of the transformer windings without anything being electrically connected to them. Measure the resistance between terminals M and J, and between terminals P and N. Unsolder the wire from the terminal pair with the lower resistance (either M or P) and insert a small series resistor with a value equal to the difference between the two measurements. Now do the same for the terminals L and J, and O and P, with a second resistor of appropriate value to make the total resistances the same, and in series with either terminal O or L, as needed. Be very careful unsoldering the wires from the terminals of the transformer, as the terminal itself may not be very secure physically. If it becomes loose and the wire from the transformer that is connected to it breaks, that could be very bad news. **Alternately and safer**: Just trace the appropriate wire from the appropriate transformer terminal to the appropriate terminal on the hi/low plate voltage switch and put the resistors in series with that end of the wire. That way, you don’t put the transformer at risk. The added resistors needed will generally be in the range of 5 to 15 ohms.

83 Power Supply Symmetry/Transconductance Zero

Connect one end of a 10 Kohm, 10 Watt, 1% resistor to one of the PLATE CURRENT posts and the other end to one of the SELF BIAS posts. (Leave the shorting links in). If you use test leads for this, be aware that the resistor may get fairly hot. You may want to monitor the MAIN METER voltage on a separate voltmeter using test leads. If you use the MAIN METER itself to adjust for zero, make sure that it is oriented in the usual position (top away from the center of the earth) and that it has been correctly mechanically zeroed prior to this. Press “P4 locked” and set the FUNCTION switch successively from ranges A to F and check for for “0” transconductance on the MAIN METER or 0 volts on the external voltmeter (if used). In practice, some ranges may be closer to zero than others. Adjust R8 for closest to zero on all the ranges. You may have to accept some degree of compromise here as there is only this one adjustment that affects all 6 ranges. *(If you are going to use Method 2 to adjust the 5Y3 power supply symmetry (see the next section), make sure that range C is as close to zero as possible.)*

If some of the ranges just won’t zero adequately, there are several possibilities. Test the 83 rectifier tube sections for significant differences in emission. (Better yet, use an **appropriate** solid state tube replacement.) Also check R37 and R42, R41 and R38, R40 and R39 for differences in value. These resistor pairs should be as closely matched as possible. R8 should normally be able to compensate for small differences in symmetry in the 83 power supply so if nothing else works, check the waveform with a scope to make sure the waveforms are reasonably symmetric.

5Y3 Power Supply Symmetry Adjustment

General: This is the source for the screen grid voltage, the control grid DC bias voltage, and is used in the leakage/ohmmeter circuit. This is a 120 Hz. full wave rectified waveform with no filtering (pulsating DC waveform). In this circuit it is important that the alternating peaks be at least reasonably symmetric. Any significant asymmetry could seriously impact the accuracy of the transconductance measurements.

If you have made or will make the zero modification (**highly recommended**, see the FURTHER POSSIBLE MODIFICATIONS AND IDEA CIRCUITS FOR THE HICKOK 539B/C section, no. 6) then this step can be omitted. If you do make this modification, you will be duplicating this calibration step right before making a measurement each time you make a transconductance measurement anyway.

Method 1) (**not** recommended, less accurate.) For this you will need an oscilloscope. It does not have to be anything fancy. It just has to be able to display 240 V (peak voltage) at 120 Hz. Connect the ground lead of the scope to terminal "G" of the MAIN POWER TRANSFORMER and the probe to the center terminal of R15. The peaks should be the same height and symmetric. If not, adjust R15 to make them as identical as possible. (Remove the scope when done.)

Method 2) Set up for testing a 6L6 tube using the roll chart values and put a known good 6L6 tube in the octal socket. The 6L6 tube should be checked to make sure that it reads the same transconductance for both the "HS" and "CX" filament settings. (See the "AN INTERESTING (AND PUZZLING) HEATER-CATHODE INTERACTION" section.) Use a jumper wire to connect the lower (bottom) end of R12 to the junction of R13 and R9. (This will short out the AC GRID VOLTAGE source. The "DC" GRID BIAS signal (from the 5Y3 supply) will now be the only signal on the control grid, and any imbalance will be "multiplied" by the tube transconductance and "measured" by the transconductance sensor circuit which we just zeroed in the last step.) Press P4 and adjust R15 to get the **least** deflection on the MAIN METER. Again, you may have to compromise to some extent. Make sure that the MAIN METER is in its usual orientation and has been properly mechanically zeroed, or use a separate meter and test leads. Remember to remove the jumper when done.

"DC" Grid (Bias) Voltage/5Y3 Power Supply

Put the positive lead of a DC voltmeter to terminal G on the MAIN POWER TRANSFORMER and the negative lead to the right end of R17 (2.25K) (as viewed from the back). Turn the BIAS RANGE switch to 40V and turn the BIAS VOLTS control fully CW (clockwise). You should measure 40 V to just slightly above. You may find it convenient to set this for about 40.5 V. As long as the BIAS VOLTMETER reads correctly it won't hurt if it is just slightly more than 40 V (not more than a volt or two, though). On the other hand, you don't want this too far off, as it is the voltage source for the leakage/ohmmeter circuitry. If not correct, adjust R18 (8.5K max). Note: When adjusting R18, you must first loosen the screw to move the tap. When you re-tighten it, be careful not to over-tighten it or you could damage it.

Change the bias range to 10 V and leave BIAS VOLTS fully CW. You should now measure 10 V to just slightly above. If not, change R17 to make it so. If you have to change the value of R17 by very much, you may want to re-check the 40 V range as you may have to re-adjust R18 slightly.

Special Discussion of this circuit: This circuit is not only designed as a resistor "ladder" or string, but also on the low range (10 V), the two potentiometers, R16 (3K) and R14 (1K), are "placed" completely in parallel. The circuit is such and the values are such that the junction of R19 and R17 is at approx. 40-41 volts (for the LEAKAGE/OHMMETER circuit) when the BIAS RANGE switch is in either position. The other two requirements are that the junction of R17 (2.25K) and R16 (the 3K potentiometer) be either 10V or 40V (depending on the BIAS RANGE switch). On my set all the fixed resistors measured OK, but only two to three of the four (above) conditions could be realized simultaneously. It finally turned out that the 3K potentiometer actually measured about 3.18K. This didn't seem to be very far off, but when a parallel fixed resistor was placed across R16 such that the total resistance became exactly 3 K, the voltages suddenly fell into line almost like magic! (and as the simulations said they should). In practice, it also happens that on the 10V range that the two potentiometers don't track perfectly and the actual voltage "droops" some on both ranges when at "maximum" setting, at least on my tester. So, if you have trouble getting this circuit to behave properly, these are some of the things to consider/check for.

Shorts Testing, Neon Light Brightness

Set the SHORTS rotary switch to "tube test" and the SHORT toggle switch to "other tubes". Put an approximately 330 Kohm (value not critical - this does not have to be a precision resistor) from one of the SELF BIAS posts to one of the PLATE CURRENT posts (leave the shorting links in place). Turn the SHORTS switch CCW (counter clockwise) to any of the the positions 1 to 4. The SHORTS neon light should glow weakly. If not adjust R45 to make it so.

Shorts Testing, Neon Light

Note: This tube tester is designed so that the user cannot inadvertently connect two test voltage sources to the same device under test (DUT) pins and thus to each other, e.g. connecting the plate voltage to cathode and thus shorting out the plate voltage power supply. (Actually, this still doesn't make it impossible, just more difficult!) The exception is the "CATHODE" and "SUPPRESSOR" SELECTOR switches. Both are at the end of the SELECTOR switches string and are allowed to both connect to the same DUT (Device Under Test) pins. This is because in normal use and for testing, the suppressor grid is usually connected electrically to the cathode. However, if they **are** shorted it should be detected on the shorts testing.

Set the SHORTS switch to "tube test" and the SHORTS TEST switch to "other tubes". Set both the "CATHODE" SELECTOR and "SUPPRESSOR" SELECTOR switches to "1" and all the other SELECTOR switches to "0" or "off". (Now both are connected to pin 1 and thus to each other, i.e. they are shorted to each other.) Rotate the SHORTS switch CCW (counterclockwise). The neon light should light on all positions except "1". Put the "CATHODE" SELECTOR and "SUPPRESSOR" SELECTOR switches on "2" and turn SHORTS switch CCW. You should get the same pattern of lighting in the neon light. Do the same for 3 to 9 on the SELECTOR switches.

If there are any failures here, you probably have a poor contact in the shorts switch somewhere. Try cleaning the contacts and/or check for physical damage.

Shorts Testing, Leakage (Ohmmeter)

Note: This is a mildly "problem" circuit. On both computer simulation and on the actual set, I could find no set of values that would allow highly accurate measurements, i.e. no way to make the meter read exactly F.S. (full scale) at 0 ohms and 25% F.S. (1 Mohm) on the MAIN METER with a 1 Mohm resistor. My advice is that if it reads close to 1 Mohm with a 1 Mohm resistor, leave it alone. The reasoning is this: If the leakage is greater than that corresponding to a 330 Kohm resistor, it will light the neon bulb on the 1 to 4 SHORTS switch settings anyway and the tube would be discarded, so accuracy around 0 ohms is unimportant. *(Actually, this turns out to be a function of the meter sensitivity. If the F.S. Main meter voltage is set to 182 mv. F.S. (Full Scale meter deflection) instead of the Hickok specification value of 172.5 mv, you can change the value of one resistor in this circuit and get a theoretical accuracy of almost 1%.)*

Put the PLATE SELECTOR switch to "3" and the CATHODE SELECTOR switch to "8". Put a 1 Megohm resistor from pin 3 to pin 8 on the octal socket. Put the SHORTS switch on "D". The main meter should read around 1 Megohm. If the reading with 1 M is too far off, you can try changing R48 (330 K).

"DC" Grid (Bias) Voltmeter

Set the BIAS VOLTS switch to 10 V. Put the negative lead of the voltmeter to the post of R16 (3 K pot.) that also is connected to R14 (the 1 K pot. immediately below it as viewed from the back). Connect the positive lead to the center post of R16. Use the BIAS VOLTS ADJUST (R16/R14) to get 10.0 V on the external meter and make sure the BIAS VOLTMETER also reads 10.0 V. Reminder: Make sure that the tester is in its usual orientation (up), and the meter properly zeroed before checking this. If they are different, change the value of R50 (9.9K) to make it read correctly.

Set the BIAS RANGE switch to 50 V and adjust R16/R14 (BIAS VOLTS

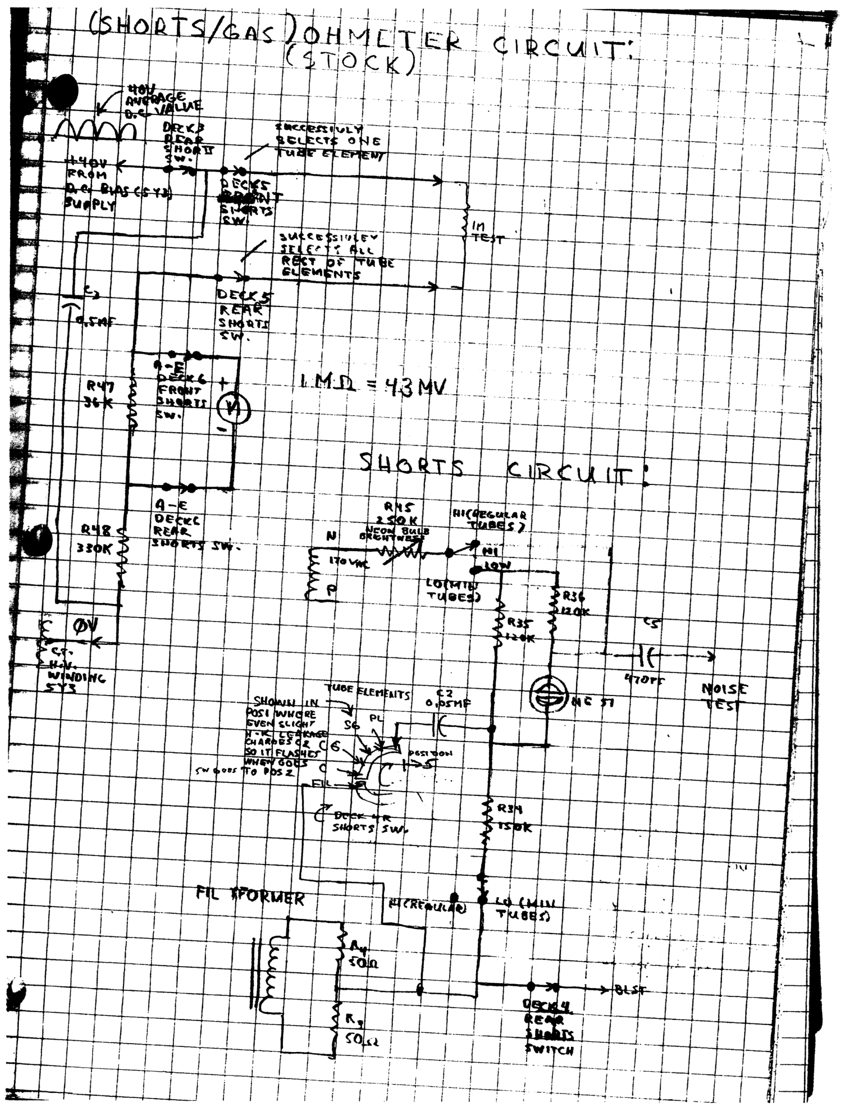

Figure 5: Ohmmeter Circuit and Shorts Circuit

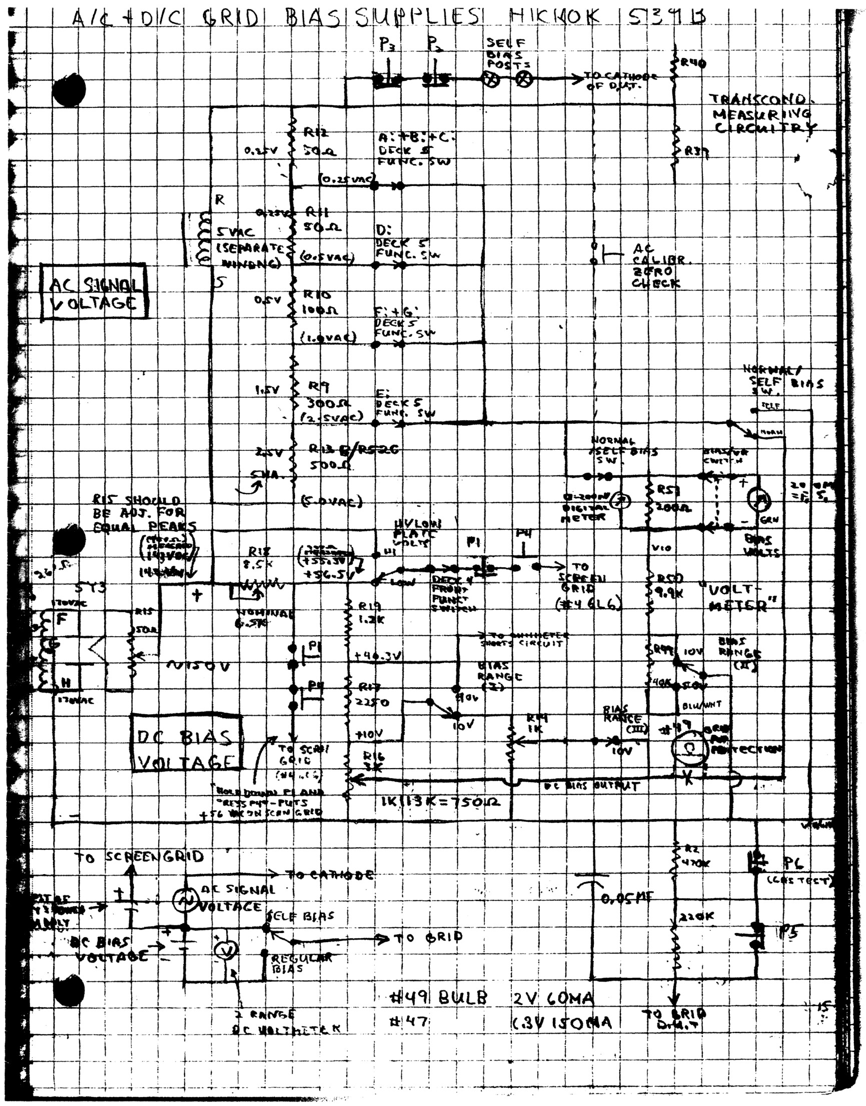

Figure 6: AC and DC Grid Bias Supplies

ADJUST) so the external voltmeter reads 40 V. Check that the BIAS VOLTS METER also reads 40 V. If not, change the value of R49 (40K) to make it agree.

Plate Voltage

1. Set the PLATE SELECTOR switch to "3" and the CATHODE SELECTOR switch to "8". Set the PLATE VOLTS switch to "high". Connect DC voltmeter between pin 8 (negative lead) and pin 3 (positive lead). Put a 270 Kohm resistor (value not critical) across the two test leads. (This will very lightly load the power supply.) Push P4. This is "spec'd" at 150 VDC +/- 5 V. (The exact value will depend on whether and what size zener is used in the 83 SS substitute. If no zener diode is used, the simulation value is about 154 volts. If a zener diode is used, subtract the voltage of the zener from this value.) If this is less than a few volts off, it is unimportant. If you properly calibrate the set to whatever voltage you actually have, the worse that could happen is that you will accurately measure the characteristics of the DUT (Device Under Test) tube, only over a slightly different range of plate voltages than were used to generate the roll chart values. It turns out that the Hickok transconductance circuit actually measures the (weighted) **average** value of the actual transconductance of the DUT over the range of plate voltages and changing the range of plate voltages slightly will usually make no detectable difference in the result/measurement.
2. Set the PLATE VOLTS switch to "low" and press P4. This is "spec'ed" at 65 VDC +/-3 V. (Simulation value is 64V if SS substitute 83 tube with diodes only).

Screen Voltage

1. Set the SCREEN SELECTOR switch to "4" and CATHODE SELECTOR switch to "8" and put the positive lead of the voltmeter to pin 4 of the octal socket and negative lead to pin 8. Put a 270 Kohm resistor (again, value not critical) across the test leads. Set PLATE VOLTS to "high". Press P4. This is "spec'd" at 130 VDC +/-5 V. I believe that this may be an error. The correct value is more like 140 V +/- 5 V, based on the simulations. In any case, it should not be higher than the corresponding plate voltage. (Reminder, make sure that the bias volts is set to zero volts.)
2. Set the PLATE VOLTS to "low". Press P4. The reading should be 56 +/-3VDC. (Simulation value is 57.0 V).
3. Alternate method: Press P1 and P4 simultaneously. The reading should be the same 56 +/-3VDC.

Note that if the 5Y3 supply is adjusted correctly these values should already be within range too.

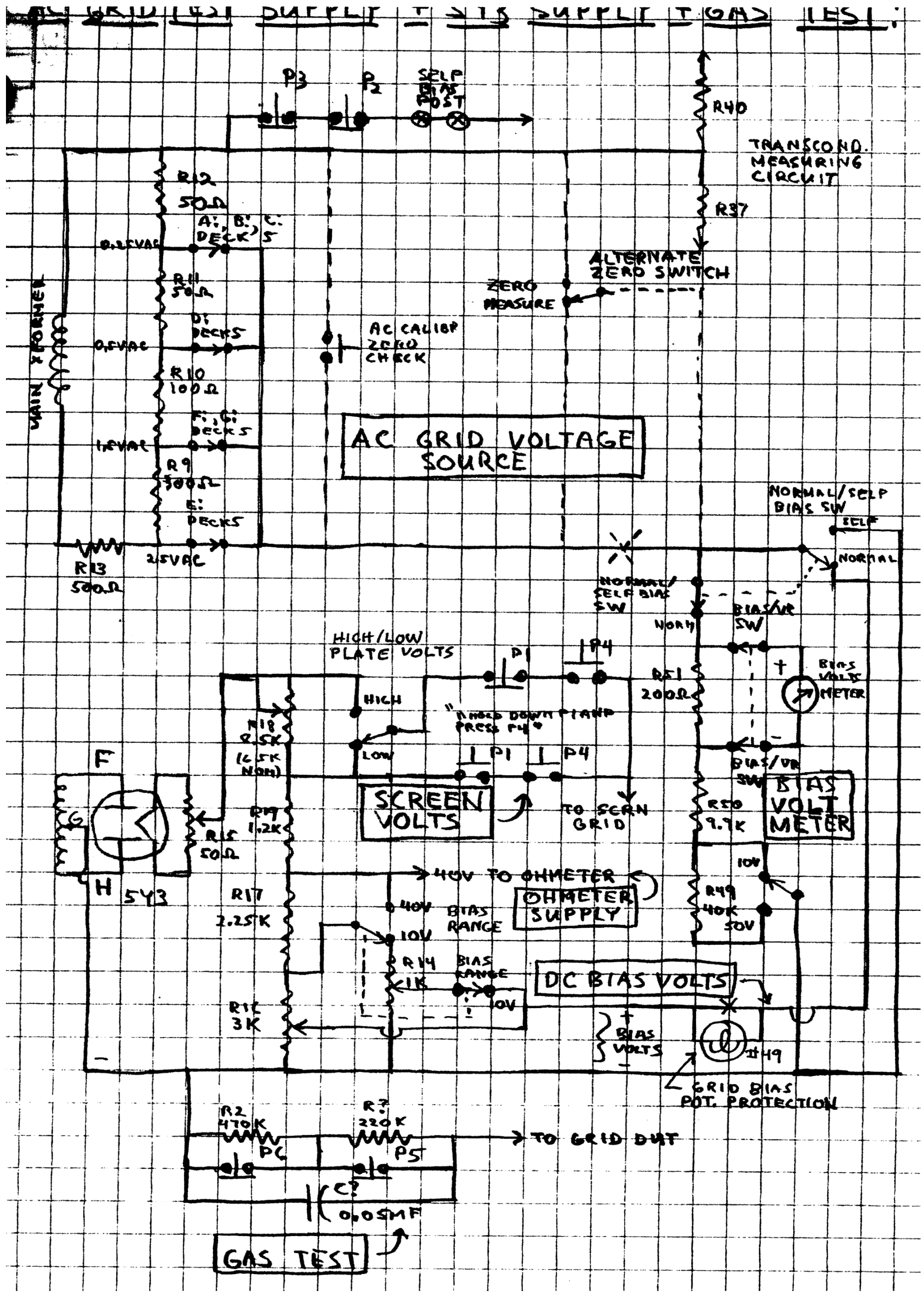

Figure 7: AC Grid Supply, Screen Supply, and Gas Test Supply

Control Grid Ac Test Voltage

See Figure 8 *AC Grid Supply, Screen Supply, and Gas Test Supply* for the grid AC signal voltage circuit.

The AC control grid voltage source is just a voltage divider resistor string that has approx 5 VAC on the input and various smaller output voltages. The first resistor (R13, 500 ohms) can be replaced, all or in part, with a variable resistor ("Trimpot") and adjusted to get exactly 2.5 volts AC across the remainder of the resistor string with exactly 100 VAC on the primary winding of the main transformer. Assuming that the values of the remaining resistors are correct, then the output voltages should be correctly calibrated as well. This method assures that the voltages are correct even if the voltage out of the 5 VAC winding isn't exactly 5 volts with the 100 volts on the primary (and it usually will be "off" a little, anyway).

Note: For this circuit, it is **very** important that the LINE ADJUST be set correctly first and monitored throughout. Use a separate accurate AC voltmeter (100.0 volts AC is the nominal value) with test leads or clips, if possible.

It is also **very** important that the meter used for the actual calibration be able to accurately measure the relatively small AC voltage (5.00 volts AC). Do whatever you have to do to get an **accurate** meter for this part of the check/alignment.

Connect one lead of an accurate low voltage AC voltmeter to the lower (bottom) end of R12 (50 ohm) and the other lead to the top end of R13 (500 ohm). You should read exactly 5.00 VAC. If not change R13 (500 ohm) to make the voltage at the junction of R13 and R9 read 2.500 VAC. Check at the junctions of:

R13 (500 ohm) and R9 (300 ohm):	2.50 VAC
R9 (300 ohm) and R10 (100 ohm):	1.00 VAC
R10 (100 ohm) and R11 (50 ohm):	0.500 VAC
R11 (50 ohm) and R12 (50 ohm):	0.250 VAC

If any of these readings are more than 1 or two percent off, replace/change the appropriate resistor to make it correct and recheck all these values. If you have to make any large changes in any of these resistors, you may have to re-check and/or change the value of R13 as well.

The underlying accuracy of the set is directly proportional to this. If you are 2% off here, then whatever you measure will usually be at least 2% (or more) off also.

Note:

1) A 200 to 300 ohm multi-turn trimmer resistor (Trimpot) in series with a 400 to 450 ohm fixed resistor in place of R13 makes this adjustment a lot easier.

2) It is **very** important that these voltages be as accurate as possible, as errors in this circuit greatly affect the overall transconductance accuracy.

Transconductance Sensor Circuits Accuracy Checking

Note: This procedure is if you use corrected AC values to check/calibrate the transconductance circuit and use the Hickok "official" values of 115 microamps and 1.5k or 172.5 mv. F.S. for the MAIN METER. However, if you use the same calibration values for the transconductance circuit (and without changing any of the "stock" Hickok resistors values), and if the meter sensitivity is adjusted to about 121 mv. full scale, the accuracy is actually better. This is situation is discussed along with possible options in the next two sections.

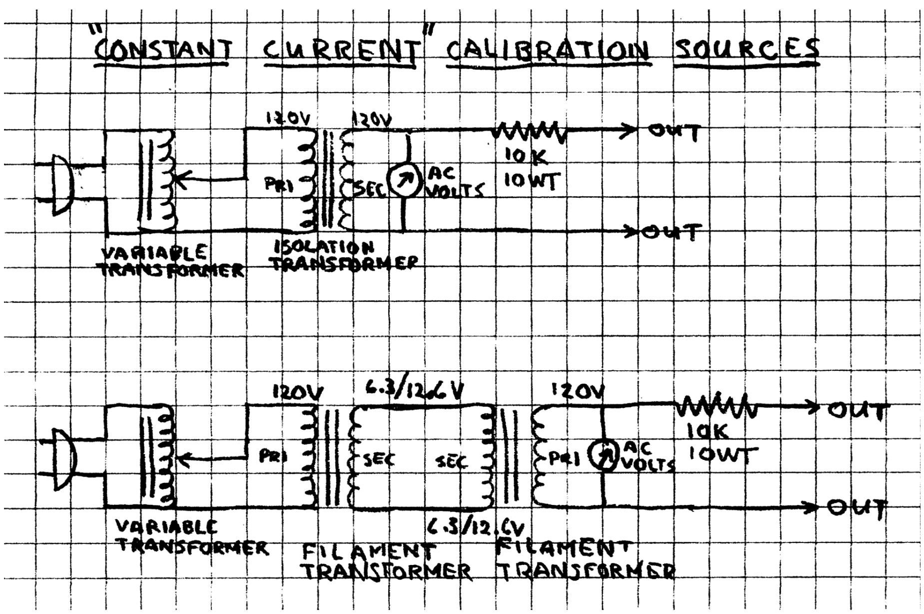

Figure 8: Constant Current Calibration Sources

Build the simple circuit as shown in Figure 9 *Constant Current Calibration Sources* using a variable transformer ("Variac") and an isolation transformer. Make sure you have already performed the TRANSCONDUCTANCE ZERO procedure. *(Transconductance range "F" needs only about 6 VAC and this is hard to set accurately with the variable transformer. If you substitute a 6.3V or 12.6V filament transformer for the isolation transformer for this range, it will make things easier but is not necessary.)* Connect one of the "outputs" of the "simple circuit" to pin 3 of the octal socket and the other to pin 8. Set the PLATE SELECTOR switch to "3" and the CATHODE SELECTOR switch to "8". Press P4 and for each of the FUNCTION ranges A-F adjust the variable transformer for the voltage specified in the tables and check the MAIN METER (or the external voltmeter connected to the MAIN METER posts) for the indicated transconductance reading or voltage. If the meter reads downscale instead of up, reverse the "output" leads of the "simple circuit".

(MOSTLY) FULL SCALE HICKOK? (Daniel Schoo) CALIBRATION VOLTAGE VALUES

A:	75 VAC	1/2 FS	86.3 mV
B:	75 VAC	FS	172.5 mV
C:	37.5 VAC	FS	172.5 mV
D:	30 VAC	FS	172.5 mV
E:	75 VAC	FS	172.5 mV
F:	6.0 VAC	FS	172.5 mV

(MOSTLY) FULL SCALE CORRECTED CALIBRATION VOLTAGE VALUES

A:	76.2 VAC	1/2 FS	86.3 mV
B:	76.2 VAC	FS	172.5 mV
C:	38.3 VAC	FS	172.5 mV
D:	30.6 VAC	FS	172.5 mV
E:	76.2 VAC	FS	172.5 mV
F:	6.32 VAC	FS	172.5 mV

(MOSTLY) 1/3 FULL SCALE HICKOK? (Daniel Schoo) CALIBRATION VOLTAGE VALUES:

A:	50 VAC	1/3 FS	57.5 mV
B:	25 VAC	1/3 FS	57.5 mV
C:	12.5 VAC	1/3 FS	57.5 mV
D:	10 VAC	1/3 FS	57.5 mV
E:	25 VAC	1/3 FS	57.5 mV
F:	6.0 VAC	FS	172.5 mV

(MOSTLY) 1/3 FULL SCALE CORRECTED CALIBRATION VOLTAGE VALUES:

A:	50.8 VAC	1/3 FS	57.5 mV
B:	25.4 VAC	1/3 FS	57.5 mV
C:	12.8 VAC	1/3 FS	57.5 mV
D:	10.2 VAC	1/3 FS	57.5 mV
E:	25.4 VAC	1/3 FS	57.5 mV
F:	6.29 VAC	FS	172.5 mV

Notes:

1. Note that the corrected values take into account the actual total resistance in the transconductance circuit and are; therefore, theoretically more accurate. They don't differ by very much, except for range F.
2. If the calibration is very far off spec., check the resistors R37 to R42 and R26 to R33.
3. In principle, it is possible to "fine tune" one or more ranges, but in reality, this is impractical as, in general, changing a resistor to correct one range changes other ranges in unpredictable ways. In other words, they interact, and badly.
4. The values of the resistors in the "bridge" and series/shunt resistor strings can be checked for accuracy and the "gain" can be checked for each range, but changing the zero using R8 is all that can be done to a "stock" tester (and it is a bad idea to try to do anything with R15 other than to adjust the 5Y3 supply as previously described.) The "gain" is essentially unchangeable. If the calibration is "off" there is not much you can do about it other than changing some of the resistors in the sensor circuitry. (And changing the zero (the "Hickok bogey tube method") cannot and will not properly compensate for a "gain" problem.)
5. Full scale meter deviations are theoretically the most accurate to calibrate with, but not possible on the "A" range since the isolation transformer can't put out the 150VAC that would be required *(See the A Quick Note On Offsets And Errors When Reading A Meter And Why This Is Important In The Hickok 539B/C section for an explanation.)* Hickok calibrated at 1/3 full scale. I suspect this was because most of the tube "set ups" would read at or near this part of the meter for a tube that was marginal and at or near the reject value. In other words, given that meters are never completely linear, you would want the set to be most accurately calibrated in the critical area of the meter which would determine whether to keep or reject the tube. Also, for range A, the 152 volts, which corresponds to F.S., would be almost as much as the plate voltage, this is in addition to the fact that a standard isolation transformer would not be able to put out this much voltage.
6. The Hickok method of calibrating the transconductance circuit is flawed for several reasons which are covered elsewhere, but in particular, the Hickok calibration values for the "constant current source" circuit (the "simple circuit" given above) do not compensate for the actual resistances in the tester circuits themselves and so they are not quite accurate. The corrected values given above do compensate for this.
7. If you have trouble finding an isolation transformer, two identical filament transformers can be used back to back as shown in Figure 9 *Constant Current Calibration Sources*. Both have to be big enough to handle the power required (which in this case, is small).
8. It turns out that if you use strictly the Hickok design values for the various resistors, that the accuracy of the set is improved if the full scale (F.S.)

meter current is adjusted for approx. 121 micro amps (F.S. voltage of about 182 mv.) using the metal band adjustment of the meter. Some actual data is presented in the next section.

How Much Can Be Gained By Modifying The Set (And Using Corrected Calibration Values And Corrected Main Meter Values?)

Note: The following data is based on computer simulations of the transconductance measuring circuits except for the actual calibration results of my set and assume the following:

1. In the first data set, all the values are exactly as specified by Hickok including all resistor values and assume that the MAIN METER full scale deflection has been set for 121 microamp. The other two sets assume 115 microamps for full scale deflection, with the same meter resistance of 1.5 Kohm. (It turns out that the exact value of C4 doesn't matter, by the way. It changes the size of the AC component but has no effect on the DC component, which is what the meter responds to.)
2. The Hickok method calibration data does not include using the calibration tube since the results of using it are variable, unpredictable, and cause it to be less accurate on most of the ranges.

These results are only for the transconductance ranges (A-F), and are the best possible (smallest) % error given the circuit configuration and the various component values:

CASES:

a. Stock set except with solid state replacement rectifiers (83 replacement does not use zener diodes), corrected calibration voltages, no calibration tube, but the MAIN METER is assumed to be 121 microamp or 182.0 mv. F.S.
b. MODIFIED SET, correct calibration, solid state replacement rectifiers (83 replacement uses four 1N4007 diodes and no dropping resistors), no calibration tube, MAIN METER assumed to be 115 microamps or 172.5 mv. F.S., and with resistor changes in the transconductance sensing circuit as follows: R33 = 350 ohms, R26 = 145 ohms, R28 = 120 ohms, R29= 260 ohms, and R37 = R42 = 459 ohms
c. My actual modified set, as in b (above)

Table 7: Accuracy comparison

	a)	b)	c)
A:	0%	-0.12%	-0.41%
B:	-0.7%	-0.29%	+0.17%
C:	+0.5%	+0.17%	+0.12%
D:	+0.1%	+0.35%	+0.64%
E:	-0.7%	-0.29%	+0.35%
F:	-1.1%	-0.01%	-0.12%

Notes:

1. Case a, the "stock" set but with F.S. meter current of 121 microamps is not quite as accurate as the others, but pretty darn good (and this is obtained without having to change any of the stock Hickok resistor values). Note that the modified transconductance measuring circuit in this set can theoretically be accurate to about +/- 0.35% (case b) and that for my set it calibrated to a theoretical +/- 0.6% (or better). The over-all accuracy of the set is unlikely to actually be this good, as there are many other potential sources of error, for example, the underlying accuracy of the meter movement itself.
2. The Hickok MAIN METER is not "mirrored". Therefore, the basic accuracy of the meter itself is probably not better than 1-2%. Although some of the Hickok sales literature claims 1% accuracy for this set, this almost certainly was not true.
3. This analysis also (indirectly) assumes the AC GRID VOLTAGE is exactly and correctly calibrated and that the 5Y3 power supply half cycles are symmetric. If either condition is not met, the actual transconductance measurement accuracy could be significantly degraded despite otherwise accurate calibration of the transconductance circuit itself. This would be true no matter how the above calibration was done.

Comment: Realistically, I would expect 1-2% (or possibly even 3%) accuracy from the modified set even after accurate calibration. This calibration will still far exceed any tester that is "calibrated to factory standards" (especially since the usual Hickok calibration method has significant flaws). It is hard to imagine why one would need to measure transconductance more accurately than this anyway and this is much more than is necessary to do accurate matching of tubes (matching tubes has to do with repeatability rather than accuracy, anyway).

Transconductance Sensor Circuit Modifications For Greater Accuracy

I only recommend this if you are **very** compulsive or if you can't adjust the MAIN METER for 182 mv. F.S. It will give better theoretical accuracy, but requires a lot of changes. *(This option is basically data set b) of the preceding section.)*

1. R26 should be changed to 145 ohms, R28 to 120 ohms, and R29 to 260 ohms. Add a 200 ohm multi-turn variable resistor ("trimpot") in series with R33. Do the Transconductance Sensor Circuits Accuracy Checking with various settings of the trimpot until you find the value that gives the best results for ranges A to E (ignore range "F" for now). The theoretical best value is total resistance of 350 ohms (original value was 230 ohms), but the actual best value will depend on multiple factors including the actual F.S. characteristics of the MAIN METER (which should be adjusted to 115 microamps or 172.5 mv. F.S. deflection for this option).
2. For the "F" range, R42 and R37 must be replaced with whatever values give the best corrected calibration. This is made easier by the fact that they don't interact with any of the other ranges, but is made harder by the fact that both resistors have to be very close to the same value or the zero will be adversely affected. Basically you have to size these empirically. *(You could start with a 10 Kohm trimpot in parallel with each "stock" resistor or a smaller value fixed resistor in series with a 50 or 100 ohm trimpot for each.)*

Emissions Ranges (Function Switch Position G) (Diodes And Rectifiers)

General Discussion

This circuit presents some problems.

First, because of the shunt arrangement, at high shunt values, inexact positioning of the shunt knob and any non-linearity in the shunt potentiometer become potential sources of significant error independent of any other considerations.

This circuit is basically one half of the transconductance circuit. One input is not used so it doesn't measure differential voltages. It is essentially a 100 ohm sensing resistor with a shunt resistance string which includes the shunt variable resistor R23 (the SHUNT control), and which is shunted by a resistor string which includes the MAIN METER.

Shunt circuits like this have the property that when the shunting resistance is high and the degree of shunting is small, most of the current goes through whatever is being shunted and only a little through the shunt and so the shunt has relatively little effect. Thus changes or inaccuracies in the shunt have little effect. The reverse is also true. When the shunt is large, (low relative shunt resistance) even small changes in the shunt values cause large changes in the total current and therefore in the final result. Thus if you are one or two divisions off in the SHUNT setting, or if the knob/dial is off by one or two marks or if the SHUNT potentiometer is non-linear, the reading may be significantly inaccurate at the higher shunt settings.

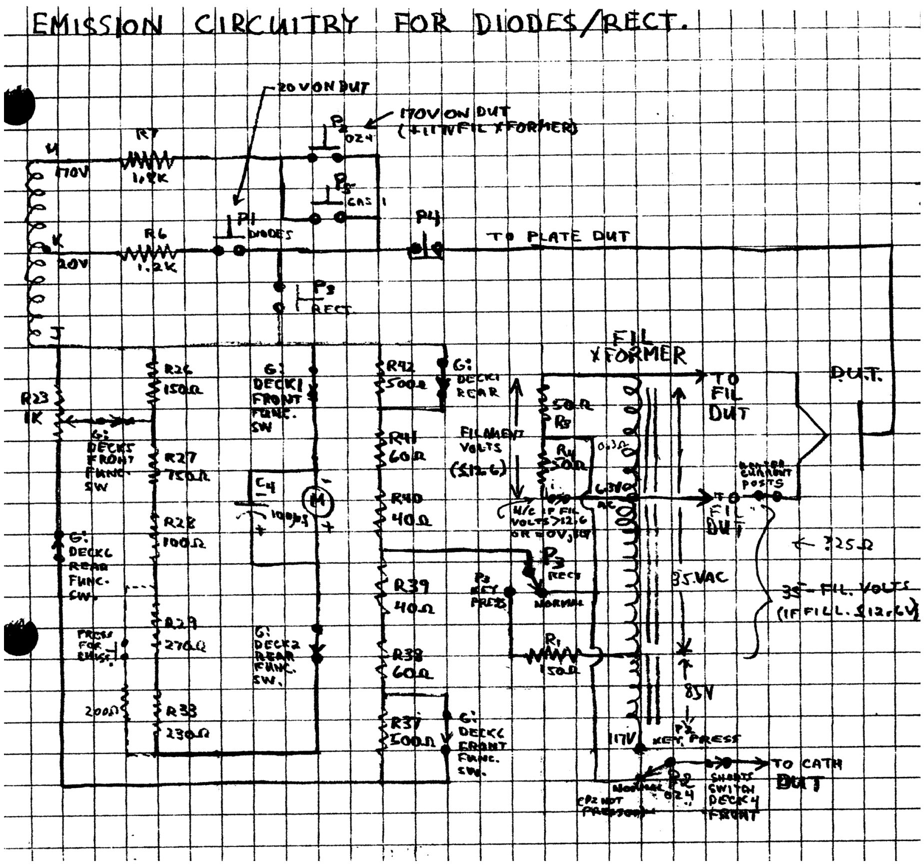

Figure 9: Emission Circuitry for Diodes and Rectifiers

Second, careful computer simulation of the actual Hickok circuits at their specified values suggest that the Hickok? (Daniel Schoo) calibration values are slightly off for the "stock" (unmodified) Hickok set. For the P1 (diodes) measurement, the Hickok? (Daniel Schoo) value is 24%, but the simulation value is 20% (Note that since this is at the low end of the shunt adjustment, that the 4% difference really doesn't make much difference.) For the P2 (gas rectifiers) measurement the Hickok value is 79% and the simulation value is 77%. For the P3 (regular rectifiers) measurement, the Hickok value is 83% and the simulation value is 81%. *(My guess is that the Hickok? (Daniel Schoo) values were taken empirically from their prototype set and that the shunt potentiometer they used in their prototype was slightly non-linear. Or, maybe they just read it wrong!)*

Third, as usual for this set, changing the resistor values to improve the transconductance accuracy affects (changes) something else, in this case, the emissions measuring circuits, so if you have modified your set, you may have considerable difficulty getting the emissions circuits to behave well.

My suggestion is that it is best to calibrate as a "stock" Hickok set, and if you measure anywhere between or around either of the two possible shunt values, that's good enough. If you have modified your set for greater transconductance accuracy, I recommend using the corrected shunt values if you can get them to work, but really, if you are anywhere reasonably close to either set, that is probably good enough as this circuit was clearly not designed for great accuracy anyway.

Modification Of The Emissions Circuitry

The best approach is simply to leave the circuits alone and "redefine" the "diodes and rectifiers o.k." point on the meter itself, using this value as the *new* "pass/fail" line. This is the easiest and probably the best approach. This is what I would recommend. Chose the point on the meter that best calibrates all three, or, at least the DIODES and RECTIFIERS ranges, and use it for your new "diodes and rectifiers o.k." line (should be around 25% of F.S.).

Note, Sept. 2016: This section needs to be redone. I was never able to reconcile the Hickok calibration values with the simulations to get better than 5 to 10 % agreement. If it calibrates to within 5 to 10 %, I now think that the best thing to do is not to modify anything.

Otherwise, there are two basic ways to approach the above problem (and I don't recommend either one of them). One is to make the meter read correctly for these ranges. This requires some modifications. What is needed is to *add* an additional new resistor in parallel across R33 (originally 230 ohms and now 350 ohms) which will reduce the effective value of R33 to about 150 ohms. I will call this resistor R0 for reference purposes. It needs to be switched in only when the G (DIODES/RECTIFIERS) range is selected and not otherwise, specifically **not** when measuring transconductance (ranges A through F). If the switch is left in the wrong position, there will be no harm to the tester or the DUT, but the meter reading will be incorrect.

There are no *extra* FUNCTION SWITCH contacts or other method that I can find that would allow this to happen automatically. This could could be addressed one of two ways. 1) add an extra momentary switch which would have to be pressed whenever any of the emission testing switches were pressed or 2) add a toggle switch that would have to be manually put in the correct position when range G is selected and the other position for all other FUNCTION SWITCH ranges

A 2 Kohm “trimpot” should work for R0. If you choose to modify, you can then use R0 to calibrate these ranges, but be aware that this will affect all the emissions ranges simultaneously, so you will probably have to compromise somewhat to get the best results for all three ranges. These are changes that could be made, but I **don’t** recommend them.

Emission Calibration/Checking

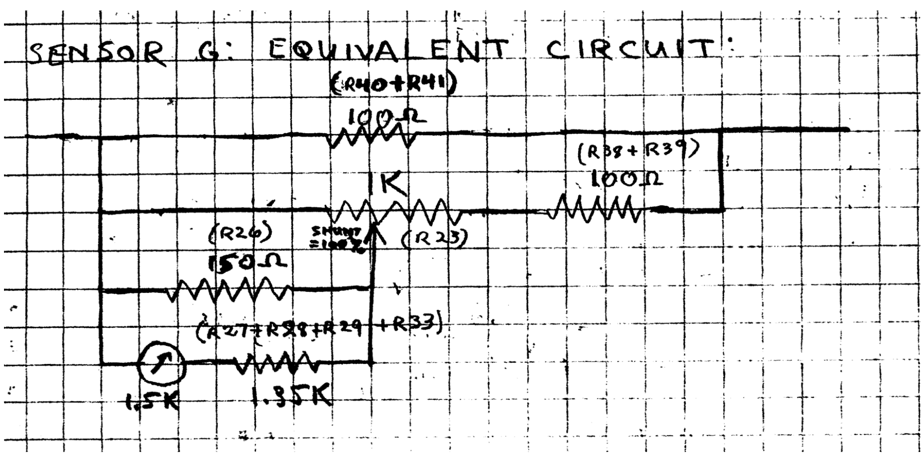

Figure 10: Main Meter Equivalent Circuit

1. **P1 (DIODES)**: Connect one end of a 1 Kohm, 10 Watt, 1% resistor to the non cathode end of a 1N4007 diode. *(The cathode is usually denoted by a band near to one end - the cathode end of the diode.)* Connect the free end of the resistor to one of the PLATE CURRENT posts and the free end (cathode end) of the diode to one of the SELF BIAS posts (leave both shorting links in place). Set the FUNCTION switch to “G”. Set the SHUNT potentiometer to “24” (Hickok) or “20” (modified set). Press P1. MAIN METER should read at or near “RECTIFIERS AND DIODES OK”. If it is too far off, change the value of R6 (1.2K). If you have chosen to modify the transconductance circuitry but not to modify the emissions circuitry, note where the meter reads and use that value as your “new”

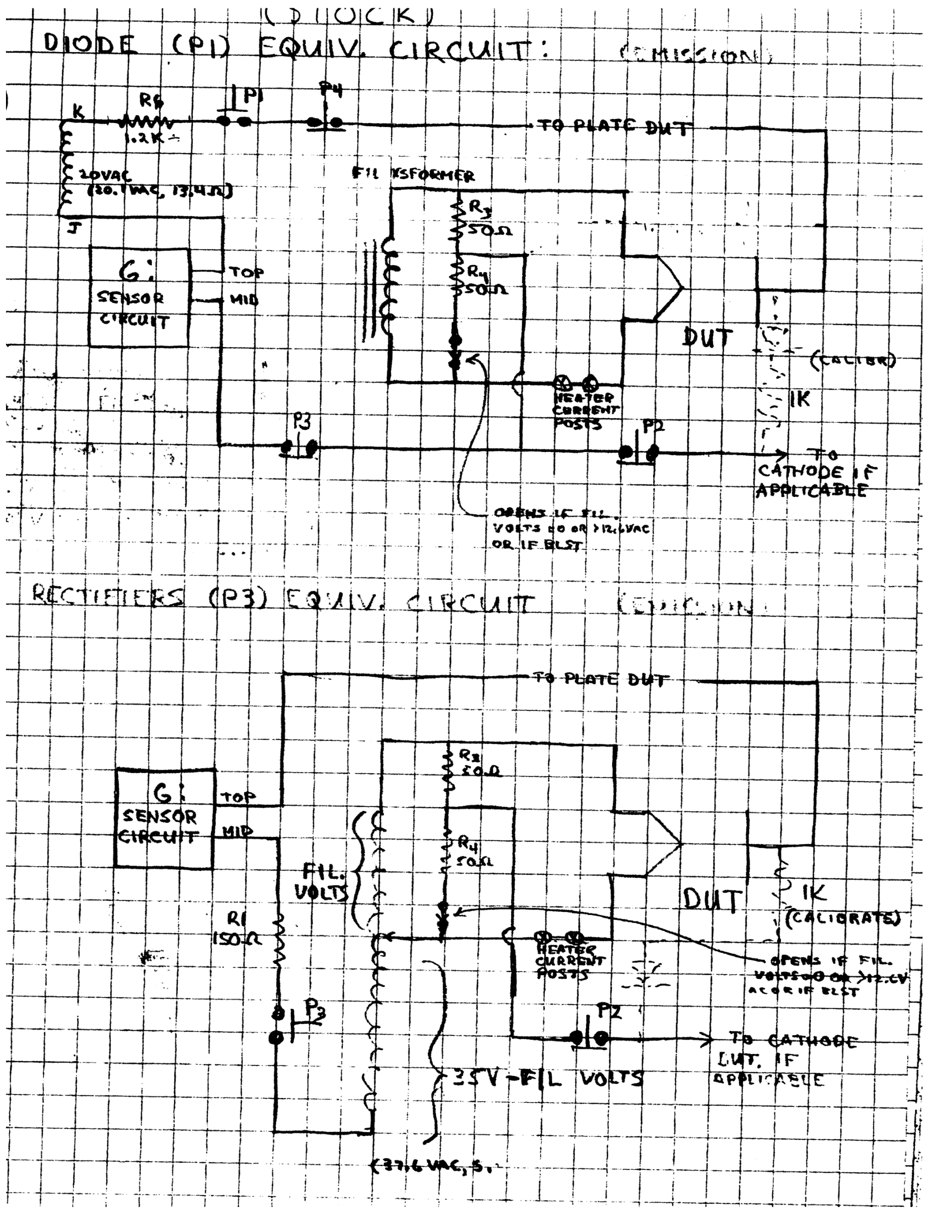

Figure 11: Diode and Rectifier Tests Equivalent Circuits

"pass/fail" line. If you have chosen to modify and to use a switch, adjust R0 for best accuracy on the P1 and P3 ranges.

2. **P3 (RECTIFIERS)**: The position of the FILAMENT switch can affect this measurement. Set the FILAMENT switch to 6.3 volts. Otherwise, use the exact same set up as above . Set SHUNT to "83" (Hickok), or "81" (modified set). Press P3. MAIN METER should read at or near "RECTIFIERS AND DIODES OK". If it is too far off, change the value of R1 (150 ohms). If you have chosen to modify the transconductance circuitry but not to modify the emissions circuitry, note where the meter reads and use that value as your "new" "pass/fail" line. If you have chosen to modify and to use a switch, adjust R0 for best accuracy on the P1 and P3 ranges.
3. **P2 (GAS RECTIFIERS - 0Z4)**: Use exact same set up as above except change the resistor to 10 Kohm, 10 Watt, 1% . Set SHUNT to "79" (Hickok), or "77" (modified set). Press P2. Be sure to check the LINE ADJUST meter and correct the adjustment if necessary. MAIN METER should read at or near "RECTIFIERS AND DIODES OK". If it is too far off, change the value of R7 (1.8K). If you have chosen to modify the transconductance circuitry but not to modify the emissions circuitry, note where the meter reads and use that value as your *new* "pass/fail" line. If you have chosen to modify and to use a switch, adjust R0 for best accuracy on the P1 and P3 ranges.

If you have to compromise, compromise in favor of the P1 and P3 ranges. The P2 range is almost solely used for 0Z4 rectifiers and these were only used in car radios, so if this range is a little off, it really doesn't matter much, since you are not likely to be testing very many 0Z4s. Note also that these ranges were never designed/intended to be greatly accurate. Consider, for example, that R6, as used in the factory "stock" set, is not a precision resistor but only a 10% carbon composition resistor!

Plate Current At The "DIODES/RECT. OK" Line For Emissions Range (Range G)

Just in case you might be interested, this is how they calculate out:

P1	4.8 ma.
P2	11.1 ma.
P3	11.4 ma.

(At F.S. Main Meter deflection, the currents are 17.8 ma., 41.1 ma., and 42.2 ma.)

(All the above are average DC values for a half wave pulsating DC waveform. To get peak values, multiply by 3.14)

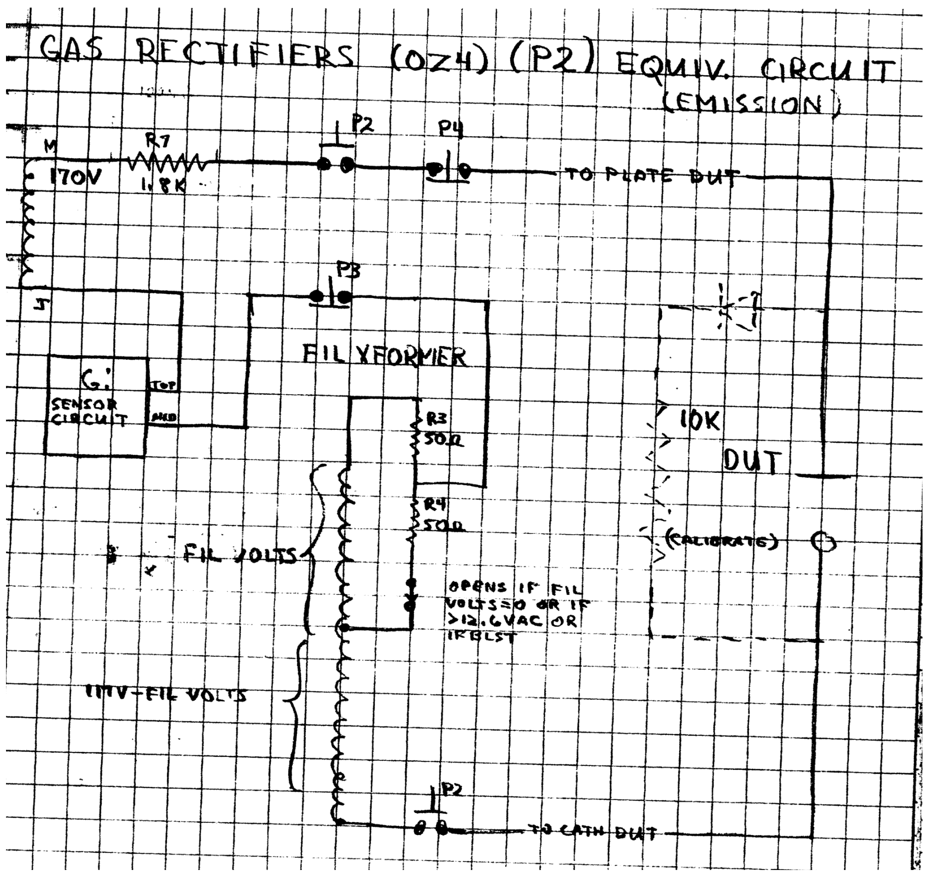

Figure 12: Gas Rectifier Test Equivalent Circuit

Gas Test

Set up the tester for testing a 6L6 tube and put in a known good, non gassy 6L6 tube. Set the BIAS VOLTMETER switch to 50 V and the FUNCTION switch to “D”. Press P5 and adjust the BIAS CONTROL to get a reading of 500 on the 3000 scale (should be about -30 V). Then press P6 and check that the reading does not change by more than one small division (ideally, it shouldn’t change at all). Connect a 10 Mohm resistor between pins 5 and 8 of the octal socket and repeat the same sequence. This time, the meter should go up by 3 or 4 small divisions. If so, you’re done. Congratulations! If not, check that the switches are operating correctly, and check (or replace) the 0.05 MF. capacitor, or possibly, the resistors R2 and R53. *(You could also change R7 (1.8K), although this would affect the P2 (gas rectifiers) emissions circuit as well, and is not recommended.)*

How it works

If a significant number of gas/ions is/are present, the control grid will intercept some of them, especially if the grid is negatively biased, tending to cause grid current to flow (how much will depend, in part, on what is connected externally to the grid), and in a direction that makes the control grid less negative or more positive. In general, this will cause the tube to conduct more plate current.

The control grid voltage, both AC signal and DC bias components, feed to the control grid through 2 resistors which are normally shorted out by P5 and P6. There is a 0.05 MF capacitor across these two resistors and so it is also usually shorted out by P5 and P6. Charge cannot accumulate on the grid as long as the resistors are shorted, since it would be immediately removed by the grid power supplies (both AC and DC). Pressing P5 allows a small amount of charge to accumulate on this capacitor if grid current is present, and pressing P6 as well puts an even larger resistance between the grid and the grid signal power supplies, allowing more charge to accumulate on the capacitor and the voltage to increase across these two resistors (if gas is present). This will increase the grid voltage and, in turn, increase the plate current. What is actually being measured is the resulting increase in plate current. In the calibration procedure, pressing P6 shifts the control grid voltage upward by about 1.3 volts, which would correspond to about 1.9 microamps of control grid current, to simulate the effect of the control grid current caused by gas in a “gassy” tube.

Notes:

1. This circuit actually only uses only one half of the “D” transconductance sensor circuit and the plate voltage is derived from only one of the 170 VAC windings of the MAIN TRANSFORMER, so it is not measuring transconductance even though it is set on what is normally a transconductance range. This circuit is essentially the same as the one used for emissions testing.
2. This circuit actually measures the effect of the grid current (caused by the presence of gas) on the plate current, and only indirectly, of the amount of

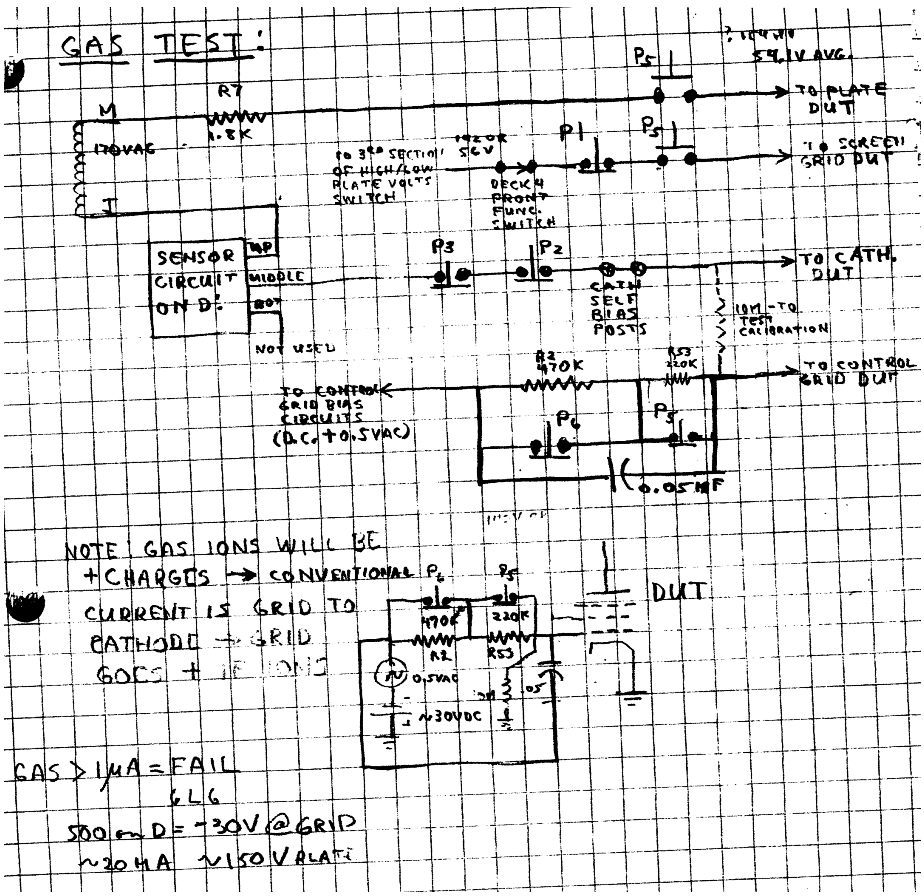

Figure 13: Gas Test

gas that may be present in the tube.

3. For most tubes, the maximum acceptable value for grid current is about 1 microamp, but for some power tubes, up to 5 microamps or even slightly more is still considered acceptable, so there is no single "magic number" for this measurement in the first place.

Comments: The presence of gas does not necessarily mean a tube is bad. First, all tubes contain contaminating gas to some extent. Second, it depends on what the gas is that is present. Third, in most applications, a small amount of gas in the tube will not significantly affect performance. Fourth, as the tube warms up, the gettering material tends to work more efficiently and, after a time, will usually remove some or most of the gas anyway.

What this gas circuit attempts to measure is actually the total grid current from any and all causes. This includes the normal grid current that flows because of direct collisions by electrons otherwise on their way to the plate as well as leakage currents and "grid poisoning" currents and currents from tube gas ionized by the usual current on its way to the plate and attracted to the grid because of it's negative charge. If the tube has already "passed" the leakage test, this measurement mostly represents the gas present and/or the effects of grid poisoning, both of which are bad, so it is still of some usefulness.

This circuit does not directly measure the grid current, but converts it to a grid voltage change using a resistor and uses the tube under test amplification to convert this to a larger and more easily measured change in plate current. Unfortunately, this "amplification" factor will be different for any given tube, depending on its operating conditions and will be different for each type of tube, also.

To get any reasonable accuracy, one would have to work out a correction factor for each tube type and each set of operating conditions. Hickok could have put an extra column in the tube chart for "acceptable grid current measurement" for the roll chart set of tube operating conditions for each tube type, but this would have required a lot of extra effort and thus have cost money for a feature that probably wouldn't have been used much, anyway.

The bottom line:

If a tube shows as grossly abnormal on this test, it probably is bad, otherwise, the reading doesn't mean much by itself.

Additional Discussion Of Circuits Used In The 539B/C, The Way They Were Designed, Some Of The Ramifications Of The Designs, And Topics Of More General Interest, Often Using The 539B/C For Specific Examples

Line Cord Recommendations

1. The line cord originally had a strain relief crimped around the cord where it would go through the wood partition with the upper compartment. This had a thin metal "ring" around the outside. If there was enough slack in the cord, the metal in the ring could possibly cause a short in the set. It has been recommended that this be replaced with a non-conducting strain relief. *(A nylon tie wrap pulled tight substituted nicely for the original strain relief in my set.)*

2. It has also been suggested that the original cord be replaced with a three wire cord and that the metal front panel be connected electrically to the "safety" (round) ground. *(I recommend this too. My set already had this done.)*

Why Is The "Shorts Miniature & Sub Miniature" Switch Present And What Does It Do?

The neon bulb SHORTS ranges use an NE-51 neon bulb. This bulb requires about 90 V to "strike" (breakdown voltage). (Once it does strike to the conductive state, it also requires a series resistor to limit the current). This circuit uses a 170 VAC winding on the MAIN TRANSFORMER so the maximum voltage it can place between tube elements is about 240 V.

The miniature and sub-miniature tubes use very close spacing between the tube elements. The electrostatic forces can be quite large even at (otherwise) relatively small voltages - potentially enough to **cause** a short. Also, the resistance of the mica insulators commonly used in tubes varies with the voltage applied, and becomes lower at the high voltages that some testers use, thus it is possible for some shorts testers to produce shorts where none existed before. When the SHORTS switch is in the MINIATURE AND SUB-MINIATURE position, a 150 K resistor (R34) is placed in parallel with the tube elements during the shorts testing, which limits the voltage placed between them to around 63V. *(Actually, it does more than this, it also puts a 120 K resistor (R36) in series with the neon bulb and puts a 120 K resistor (R35) across the combination.)*

The ohmmeter (leakage) shorts testing is done with a lower voltage (pulsating DC, with an average value of 40 V) which limits the maximum voltage to about 63 V.

Comment: You may see comments on the web by "experts" criticizing the fact that many tube testers test for shorts at "unrealistically" low voltages. The 539B/C is designed so that you can test for shorts at whichever voltage (high or low) is most appropriate, a very nice feature.

Why Do You Need A Separate Gas Test? Wouldn't The Leakage Test Work For Gas Too?

The answer is, of course, "no." Here's why. Unless the gas is ionized, it can't contribute to grid or any other current flow and so is unmeasurable in the standard leakage tests. It is the current flowing from cathode to the plate and/or the screen grid that ionizes any gas that might be present and that allows it to be measured (indirectly) in the gas test.

Comments About The Special Heater-Cathode Leakage Test

This is actually covered in the OPERATING INSTRUCTIONS, but it is somewhat buried in the operators manual and it seems that it is not widely understood. There is a special feature of the SHORTS testing for detecting **very** small heater-cathode leakage (> 50 Mohm). When the SHORTS switch is in position 1, shorts between the heater and the rest of the tube elements (specifically including the cathode) are detected by the neon bulb circuit, but even moderate amounts of leakage may not be enough to light the NE 51 bulb. However, in this position a 0.05 MF. capacitor (C2) is also being charged by whatever small leakage current may be present. When the SHORTS switch is first changed from position 1 to position 2, this capacitor is discharged through the neon light (if there was enough leakage when it was in position 1 to adequately charge this capacitor in the first place) and a brief "flicker" or "flash" will be seen in the neon bulb. As far as I know, "flickers" between other positions are not significant.

Actually, the above explanation is not entirely correct . The neon light leakage circuit is symmetric with respect to the AC half cycles that power it (170 VAC) and if one half cycle charges C2, the next half cycle should discharge it by the same amount, assuming that the leakage is the same in both cases. In other words, this circuit shouldn't work since the net voltage on C2 should be zero. But it does work, and the reason is that heater-cathode leakage is usually asymmetric. If there is any (detectable) heater-cathode leakage, it is usually negligible when the filament is positive with respect to the cathode, but not when the filament is negative with respect to the cathode. *(For example, one "trick" sometimes used for hum suppression when designing sensitive vacuum tube circuits is to "float" the filaments and tie the center tap of the filament transformer winding to about +35 to +50 volts. This "trick" also suppresses the flow of AC "hum" current inside the tube from any exposed/bare portions of the filament wires to any of the other tube elements, especially to either the cathode or the grid.)*

Note that this test is hugely more sensitive than is usually necessary, or, in general, even desirable. The leakage currents that this test can detect (equivalent to >50 Mohm, according to the manual) are very many times less currents than would ever be noticeable, let alone significant, in most real life circuits/applications.

Measuring Transconductance: How Did Hickok Do It?

A word on the transconductance measuring circuitry (for those who might be interested). This is a clever circuit. It measures very small differences in voltage on top of large symmetric voltages and does it with purely passive components - no diodes or tubes or active or non-linear components - only resistors and one capacitor (well, the capacitor IS non linear in a way, but it does't matter in this circuit).

The circuit has two inputs that are fed by alternate 1/2 cycles of the DUT plate signal. The circuit inputs are symmetric and if the signal is symmetric, one half cycle charges the capacitor (C3) by the same amount that the next half cycle discharges it so the net DC voltage the meter sees is 0 volts. Any imbalance (as caused by the DUT tube as it amplifies the plus and minus AC grid voltage half cycles) will cause a net reading on the meter by charging the capacitor more on the (larger) positive half cycle of the grid voltage than the next (smaller) negative half cycle of the grid voltage discharges it. That is, the first voltage/current peak is equal to the value without the transconductance effect plus the transconductance effect (larger peak value), whereas the next half cycle plate voltage/current is the value without transconductance effect **minus** the transconductance effect (smaller peak value).

As is often the case in electronic circuits, there is more than one way of "looking" at, or analyzing, this circuit. You could also think of this as a bridge circuit with the other half being the two separate 170 volt windings, each in series with half of the 83 rectifier tube.

Note that the grid AC voltage source is critical to the over all accuracy. Any errors in the grid voltage signal is *multiplied* by the transconductance of the tube before it gets to the sensing circuitry.

True confessions: The above explanation is not completely accurate. What the sensor circuit **really** measures is **not** the difference in the peak values (amplitude), but something related to it. It really measures the differences in the **areas** under the curve for each half cycle. The voltage on C3 depends on the amount of charge on the plates of C3, which is equal to the current at each instant times the amount of time that it is at that value. It acts as an integrator. *(If C3 were not used, the physical inertia of the meter movement would perform the same function.)* One consequence of this method is, for example, that if the positive and negative half cycles in the original waveforms were asymmetric enough, there could be a significant offset in the transconductance readings even if the amplitudes of the voltage peaks were exactly the same. That is one reason why the Hickok? (Schoo) method of calibrating the 5Y3 power supply is less than optimal. What this circuit is actually measuring is the **average**

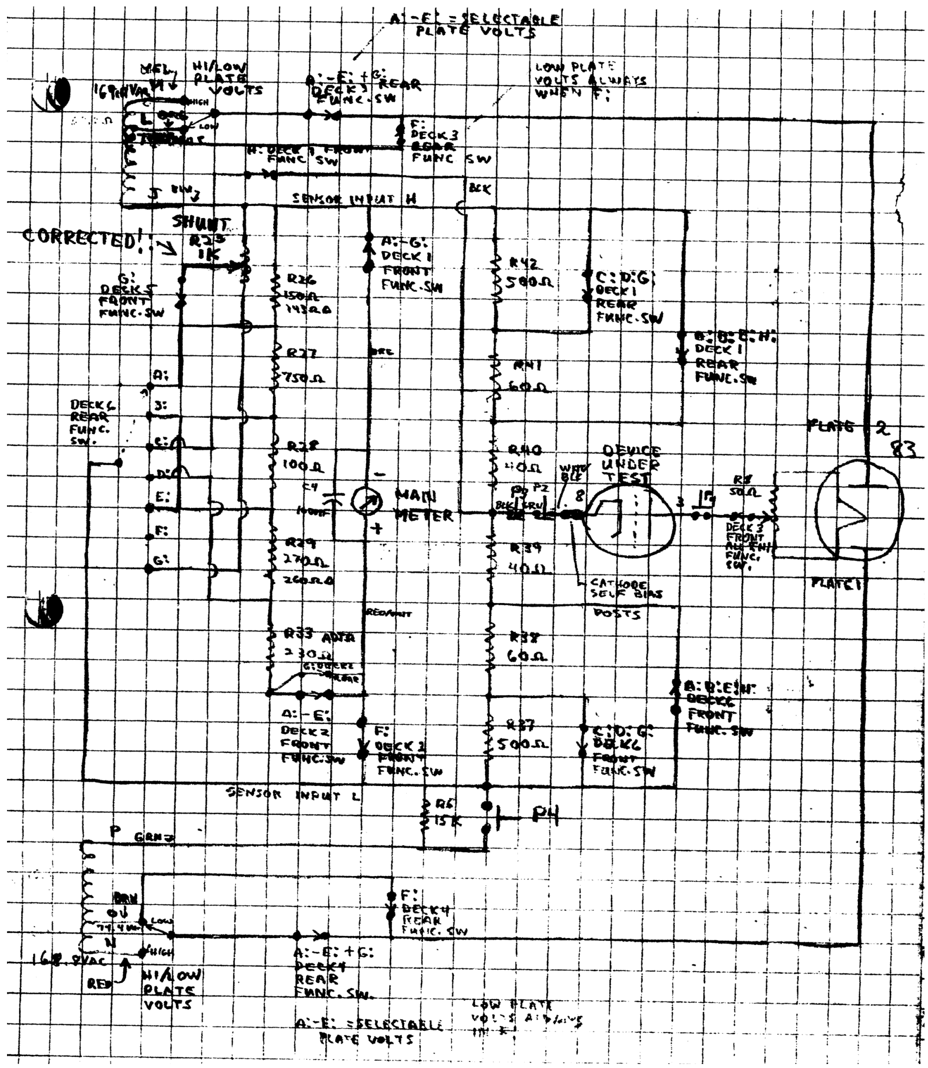

Figure 14: Transconductance Measurement Circuitry

transconductance of the tube over a wide combination of plate and grid voltages and it is a weighted average (and weighted toward the higher plate voltages).

An Important Transconductance Measurement Consideration

Frequently, when P4 is pressed, the LINE ADJUST and BIAS settings change noticeably.

Since the grid bias and screen grid supply is the same and is unregulated, if the DUT has a screen grid that pulls much current, the grid bias voltage is almost sure to increase when P4 is pressed. The Hickok *Operating Instructions For Model 539B Transconductance Tube Tester Bearing Serial Number Above 152-10000* specifically state on page 4: "Make final bias adjustments after the P4 button is pressed."

After P4 is pressed, with the plate and possibly screen grid currents flowing through the DUT, the power demanded from the transformer may increase dramatically causing the voltages it puts out to drop or "sag". If not corrected for, this can cause the transconductance readings to be substantially changed due to several factors. First the filament voltage may drop (by 10% or more). Second, the incorrect (lowered) primary voltage on the MAIN TRANSFORMER will cause the transconductance reading to be unpredictably lower (even before the cathode starts to cool off due to low filament voltage) since the AC grid voltage (which is unregulated and comes ultimately from a separate winding on the MAIN TRANSFORMER) will be lowered by about the same percentage that the filament voltage was lowered and will be significantly different (lower than) what was used to calibrate the set. This would have an unpredictable but, in general, sizable effect on the transconductance measurement just by itself. Note that this is true irregardless of whether the GRID BIAS VOLTAGE has been correctly re-adjusted or not. (An experiment with a known good 6L6GB tube gave an error of -19% if the bias voltage was kept at -3V but the LINE ADJUST was not changed. The line voltage at the transformer primary winding only "sagged" by ~9% (9 VAC) which suggests that both factors discussed above have a significant effect on the actual measurement.)

The OPERATING INSTRUCTIONS state, on page 2, section 3, referring to the "line adjustment control rheostat": "Readjust after pressing the P4 Test Button". (See the Controversial Comments Section, No. 1)

So regardless of what you may see on the internet from so-called "experts", **the line adjust and bias voltage settings should always be re-adjusted to the correct roll chart settings after pressing p4 and before actually making a transconductance measurement on the Hickok 539B/C tube tester**.

(Actually, this may reflect propagation of a mistake in Alan Douglas' classic book on tube testers and test gear. I contacted him about this and he conceded

that that it was a mistake in his book, but things like that, once they get to the internet, seem to have a life of their own and can become propagated far and wide.)

Wait for the meter needle to stabilize before taking the measurement. (See the Controversial Comments Section, No.2.)

An Explanation Of The (Flawed) Hickok Method Of Transconductance Circuit "Calibration" (Where Did They Go Wrong And Why)

Figure 15 Placeholder

Figure 15: Calibration Circuit

1. The basic calibration method used here is to use a (pseudo) constant AC current source to simulate the transconductance of the device (tube) under test (DUT). Consider the simple circuit shown in Figure 15 *Calibration Circuit*. Note that Rload includes everything in the loop except the calibration resistor (including the equivalent resistances of the power supply and the sensing circuitry and R8).

   If the value of Rcalibr is large compared to the Rload value, then small changes in Rload will cause the current Iload (current through the load) to change almost not at all. So this circuit can be a very good approximation to a constant current source. (But only if Rload is quite small compared to Rcalibr.) In this circuit (the transconductance measuring circuit), Rcalibr is 10,000 ohms and Rload is generally around 200 ohms if it uses diodes only. The exception is the "F" range where Rload is around 560 ohms if diodes only.

   It is clear from the computer simulations (see the Transconductance Circuits Accuracy Checking section) that Hickok used this method to come up with the resistor values in the "sensor" bridge and shunt resistor strings used in this set and that the calibration voltages they used to determine these resistor values were also based on the assumption that the resistances in the circuit were not significant compared to the calibration resistor. As it turns out, this was not entirely a good assumption and as a result, the sensor resistor values are all slightly "off" because the Hickok engineers didn't take into account the effect of this additional resistance (which varies, by the way, depending on which range).

2. The MAIN METER movement is specified as 115 microamp for full scale deflection and as having an internal resistance of 1.5 Kohms. Therefore, the voltage drop across the meter should be 0.1725 V or 172.5 mV at full scale deflection for each range. Computer simulation of the actual voltage at the meter corresponding to the maximum transconductance of each range

actually average about 181.7 mV, not 172.5 mV for the 6 ranges. This is another (small) source of error. It could be that the meter the Hickok engineers used in their prototype actually was a little less sensitive than the specification (121 microamp F.S. instead of 115 microamp F.S.). It is also possible that they planned on the metal band sensitivity adjustment on the MAIN METER to compensate for any differences.

3. At the end of the calibration procedure, the calibration tube is used to compensate for the above (and any other) shortcomings by changing the zero by what would otherwise be the (total) amount of error. Consider the graph of Figure 16 *Calibration Tube Plot* which illustrates this. (The curves in the graph are greatly exaggerated to make it easier to see - the actual error is relatively small). Note that the correction is made at whatever the value of the transconductance of the calibration tube that is used happens to be, and will be slightly different from one calibration tube to another, even if the transconductance of each calibration tube happened to be known perfectly and with no error. This calibration method results in a calibration line that is exact (but only for the C range) at the point of the transconductance value of the calibration tube but becomes increasingly inaccurate as you get farther away from that point in either direction and for some other calibration tube, the point where it was exactly correct would be different from the first tube unless both calibration tubes just happened to have exactly the same transconductance values. *(This means, for example, that if you had two perfectly accurate calibration tubes, one with a transconductance value of 40% of the full scale value of the transconductance range you happen to be "calibrating", and one at 80% of the full scale value, that whichever one you used to make the "correction" with, the other tube would be guaranteed not to read it's correct value.) In addition, and much worse, this changes the zero on* ***all the other ranges*** *as well, affecting their accuracy unpredictably. (This so-called calibration method causes the "calibration" to be correct at only one point on the actual calibration line of the tester and potentially incorrect* ***everywhere*** *else!)*

    a. Note also in the example above that both lines go through zero (before the calibration tube, but not after), that is, that we have assumed that the zero of the actual tester was perfect to begin with (again, before the calibration tube but not after). If this is not the case in the actual tester, the error could be even worse. The fundamental problem here is that you cannot **fix** a *gain* problem by any manipulation of the *zero*. See the Why Calibration Tubes Work Poorly section, where I attempt to explain this.

    b. True confessions: If you really think through the graphs in Figure 16 *Calibration Tube Plot*, you may note that the slopes of the "corrected" calibrations lines all have the same slope as the original uncorrected calibration line. Thus the situation I have shown would be the situation if R8 was adjusted using the calibration tube. If R15 is used to achieve this (the “Hickok” method), the situation is even worse, and almost completely unpredictable, since the slope of the resultant calibration line would be changed also (depending on whatever the transconductance of the tube happened to be) as well as the zero (and both would be different for each range).

Thus, in particular, arbitrarily changing the 5Y3 power supply symmetry adjustment based on a calibration tube in order to compensate for errors somewhere else (the Hickok method) is compounding rather than correcting the over-all error.

The bottom line here is that this “calibration tube” method just won't work right, no matter how you try to do it! There is **nothing** that can be done (ever) using a zero adjustment that can compensate at more than one point for bad gain values or vice versa! They are **independent** of each other, always, (at least for/in any linear device).

Comment: It has been noted many times that tube testers of varying makes and models give noticeably different transconductance measurements for the exact same tubes and this is seen even between testers of the exact same model and manufacturer. There are clearly a great many possible reasons for this observed effect, but at least for Hickok tube testers (and definitely for the Hickok 539B/C testers) a portion of this variability may reflect the flawed calibration tube method of calibration. As noted, the Hickok method leads to unpredictable amounts of error in all the other ranges. Thus “correctly” calibrated testers of exactly the same make and model may give noticeably differently measurements unless the “calibration” tubes used just happened to have exactly the same transconductance values on whatever range was used for the “calibrations” and even if they did agree exactly on that one range, calibrations on the other ranges could still be inaccurate to differing degrees.

Know Your Meter

1. First, protection. Theoretically, the MAIN METER itself should never “see” more than 0.1725 V (172.5 mV) across its terminals. That's not much voltage and it's easy to imagine scenarios where a lot more voltage could find it's way to the meter (with potentially catastrophic results). The 100 mF. capacitor, C4, will offer some protection, but I recommend that two silicon diodes of almost any type be additionally soldered across the meter terminals, one in each direction, for further protecting the meter. There is a significant AC component to the voltage present at the MAIN METER terminals as well as the DC component, but the combination still never exceeds 300 mV, which is not enough to forward bias a Si diode (so adding the diodes won't affect any measurements).
2. In regards to C4 — if it hasn't already been replaced, it is a good idea to do so (strongly recommended). A good replacement capacitor is cheap

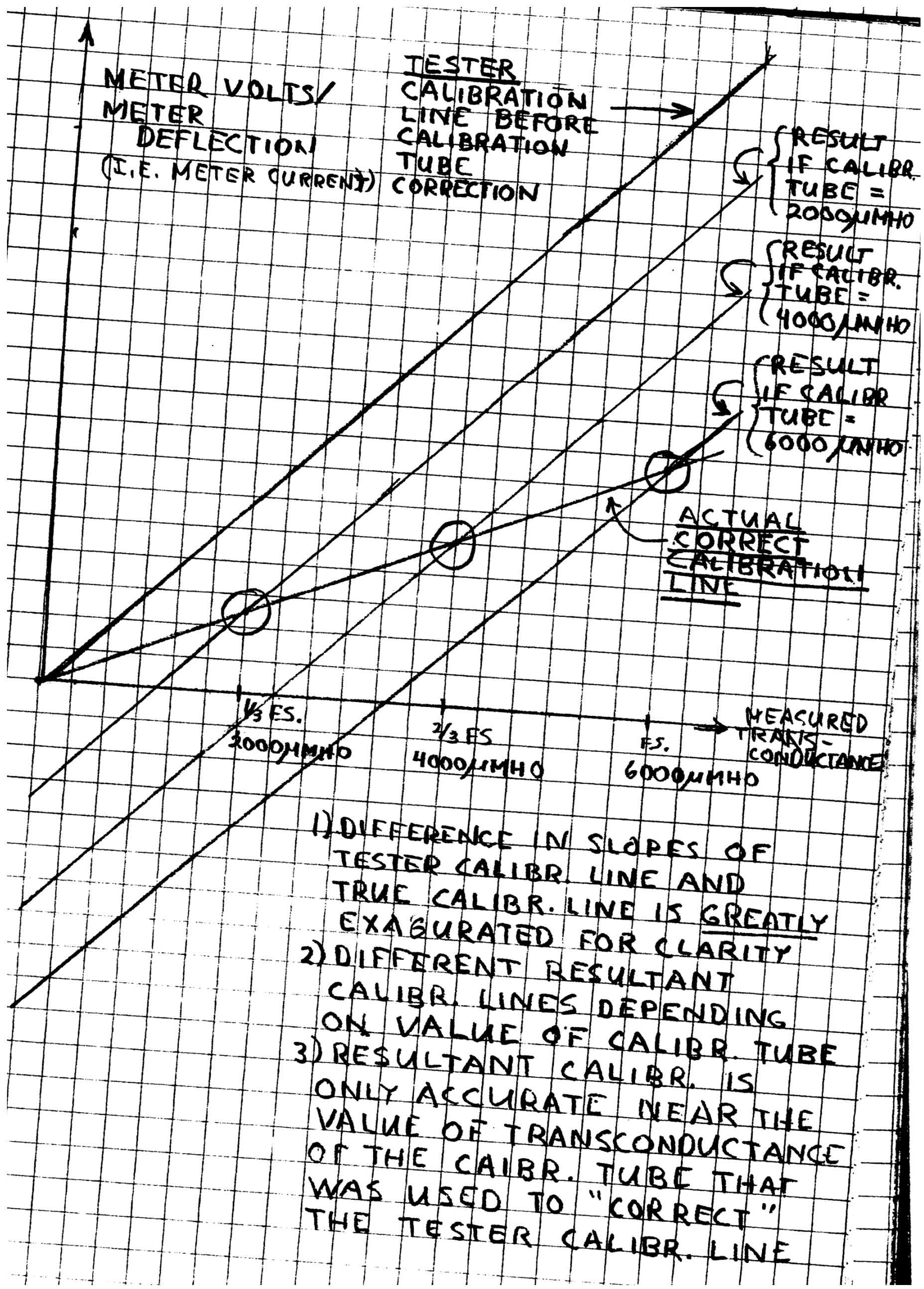

Figure 16: Calibration Tube Plot

and if the old capacitor is leaky, it could make calibration difficult and possibly unstable.

3. Most of the simulations were done assuming the meter was as specified by Hickok and; therefore, that 172.5 mV corresponds to full scale (F.S.) deflection of the MAIN METER. Yours is probably (slightly) different from this; however. If you are going to monitor the MAIN METER voltage externally from the back of the set using a separate voltmeter, for example, you need to know what actual voltage causes F.S. in your meter. One way to find out this information is to measure the voltage at the MAIN METER terminals with an external voltmeter in the V.R. test mode (FUNCTION switch, range "H") and turn the voltage all the way up to 200 V (or whatever setting it takes to give F.S. deflection of the MAIN METER). Make sure the tester meter is in the same orientation as usual when using the tester and that it has been mechanically zeroed. Another method is to use the simple low voltage source circuit shown in Figure 17 *Low Voltage Source Circuit*. Knowing the actual F.S. voltage, you can calculate the important values: 1 M = 25% F.S.voltage, DIODES GOOD/BAD = 27% F.S. voltage etc.
4. Over time the magnet in the meters tend to lose strength, so don't be surprised if it takes more than 172.5 mV to get F.S. (full scale deflection). The original Hickok meter can be adjusted to some extent by moving a curved metal band (a magnetic shunt) held to the outside of the meter by a small screw. You might find this helpful.
5. Most meters that are intended to be accurate to better than 2-3% have mirrors to correct for parallax between the meter face and the needle. This meter does not. Hickok is supposed to have manufactured their own meters to high standards but the lack of a mirrored face means that the meter could be the source of the greatest error left when you get all done accurately calibrating the rest of this set. (I don't know the answer to this, but it is something to consider.) To put this another way, it doesn't do much good to calibrate the sensor circuit to +/-0.6% if the meter is only accurate to +/-2 or 3%.

Solid State Replacement Rectifiers

The 5Y3 and 83 rectifier tubes used in the set tend to last a long time and are quite reliable. On the other hand, they do age, slowly changing their characteristics/values/properties over time and will eventually fail or become unusably weak. When either of these tubes are replaced, the set must be re-calibrated. In addition, 83 tubes are getting harder to find, more expensive and contain mercury (a possible disposal problem).

The calibration and simulation values in this discussion assume solid state replacements for the 5Y3 and 83 as in Figure 2 *5Y3 Solid State Replacement* and Figure 1 *Type 83 Solid State Replacement*. If you use tubes or someone else's solid state replacement, you should still be able to obtain fairly good results,

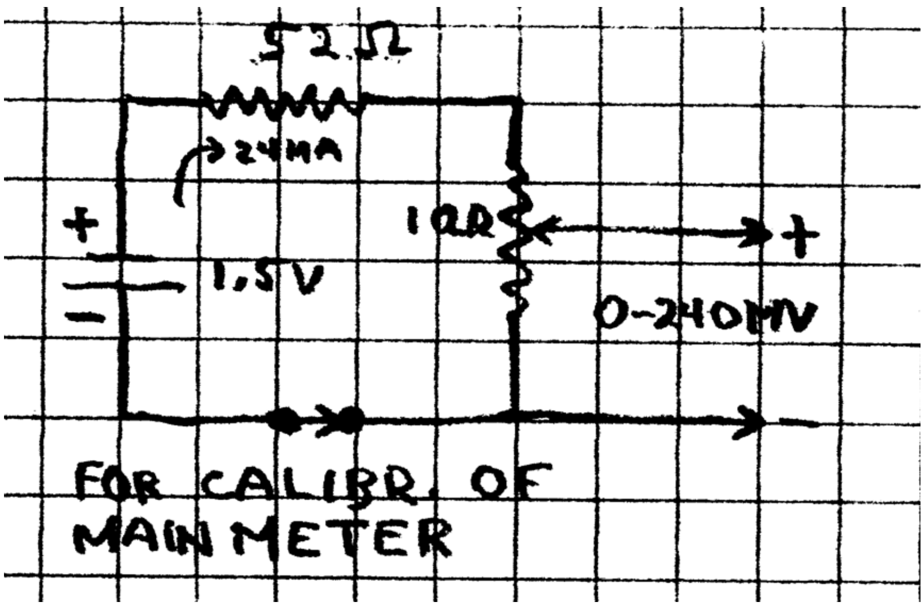

Figure 17: Low Voltage Source Circuit

just not quite as good. Making your own is easy and **much** less expensive. Without going into the details, there are several possible circuit configurations that actually make the set harder to calibrate and potentially **less** accurate. The ones given here are the simplest and the only ones that I recommend.

For the 5Y3 solid state replacement, the values of the resistors are not critical. If you look at the 5Y3 characteristic curves in a tube book, you will see they are not straight lines (as in a resistor) but, well, curves. Thus the effective resistance of the tube varies not only from tube to tube and as the tube ages, but even in the same tube depending on the total plate current. This is complicated by the fact that the 5Y3 "specs" are generally given at higher currents and voltages than are normally found in the Hickok 539B/C (or at least the currents and voltages present during calibration). The values should be be between 400 and 500 ohms. 450 ohms is a good compromise.

As for the 83, the theoretically best circuit uses about 12 to 15 volt Zener diodes (The RCA tube book says that the 83 was designed to have a "practically constant tube voltage drop (only about 15 volts)"), and one 1N4007 diode (or equivalent). It turns out that the exact value of the Zener diodes makes almost **no** difference and can be omitted entirely if desired. This will make the maximum plate voltage slightly higher, but otherwise will have no significant effect.

Note that using the above solid state replacements significantly reduces the heat build up in the confined and non ventilated spaces of the set (25 Watts, altogether), a definite benefit, but also reduces the load on the power transformers.

A possible unintended consequence of this is that you might not be able to bring the primary voltage of the MAIN POWER TRANSFORMER down to 100.0 VAC with the LINE ADJUST control when testing certain tubes, for example, those that are designed for battery operation and that don't consume much power. You can compensate for this by putting a resistor in series between the power switch and the 150 ohm POWER ADJUST rheostat. (An 18 ohm 2 W resistor worked in my set. See Figure 3 *Line Adjust Circuit*.) Even without using the SS replacement, there is a tendency to have limited range of adjustment due to the fact that when this set was designed, the average line voltage in the U.S. was 110-117 volts, but now is closer to 125 volts in many places.

Comments:

1. See the Controversial Comments Section, No. 3.
2. Some claim that the 83 SS replacement should have resistors to duplicate the load on the power transformer normally caused by the rectifier tube filament. For testers that do not have a way to adjust the AC power to the MAIN TRANSFORMER during the measurement, this may be correct, but it is not true in general, and it does not apply to the 539B/C.
3. Note that these 83 and 5Y3 SS replacements are specifically tailored to this set and should not necessarily be considered general replacements, although a 5Y3 SS replacement with 400 to 800 ohm resistors and 83 replacement with or without the 12 volt zener diodes will, in most cases, work about as well as (if not better than) anything you can purchase on the net or elsewhere.

   If you want to use the SS replacement in a set where the power draw of the filaments of the rectifiers is important, I have calculated these values and they are included, as well as the zener replacement for the 83. I also included equivalent filament resistor combinations such that the major components can all be purchased from All Electronics <www.allelectronics.com> in Van Nuys, California (or many other places, I just happened to have their catalog at hand) for about $5 per replacement SS tube.
4. There is one "source" for 83 SS replacements who says he puts a fuse in his product in case the diode fails. 1N4007 diodes are good to 1000 V and 1 Amp and are highly reliable, but if you are concerned about this, it is cheaper (20 cents, maybe) to just put two 1N4007 diodes in series. The additional voltage drop is insignificant. If one fails, the other can "take over". (I put *double* diodes in my SS replacements just to be on the safe side, but I really think this is unnecessary.)

Calibration/Bogey Tubes, Don't Waste Your Money, Make Your Own!

As you can see, accurate calibration of the 539B/C does not require a calibration tube at all, (contrary to just about everything you see on the internet). In fact,

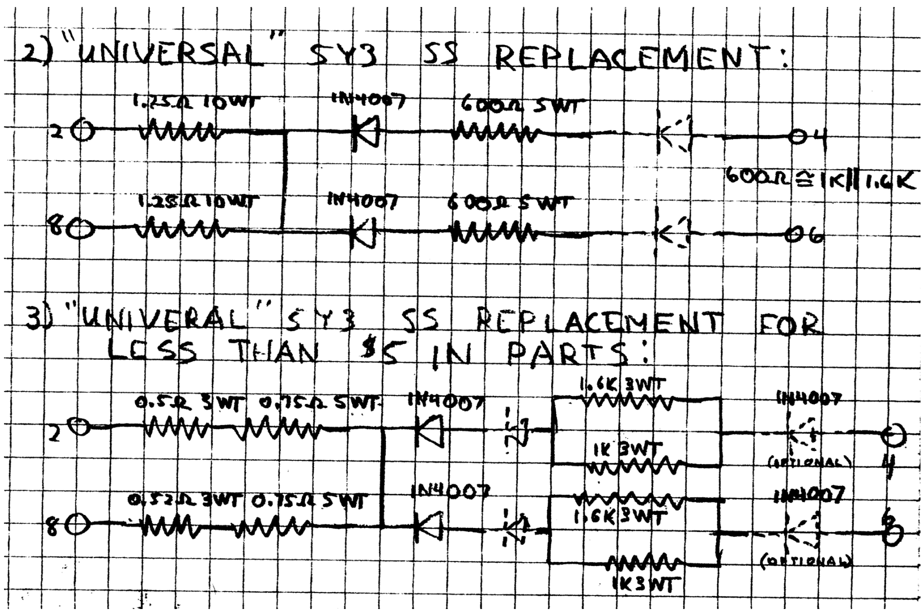

Figure 18: Solid State Rectifier Replacements for Hickok Tube Tester

using a calibration tube to calibrate this set using the Hickok? (Schoo) method actually compromises the over-all accuracy. However, having a calibration tube **can** be handy as it is a good quick way of making sure your tester is still functioning correctly (i.e. doesn't need re-calibrating and/or is not malfunctioning). Also, if you happen to be lucky enough to find a tube whose transconductance is fairly constant over a relatively wide range of operating conditions, you might even be able use it as a **rough** check of other brands or models of tube testers. A better name for this is "calibrated" tube, as "calibration" tubes are not needed for calibration and, if not used correctly, can adversely affect the accuracy of the calibration (at least, in this set, and probably in general).

Once you have calibrated/modified your set, use it to make your own calibration tube. It's highly likely yours will be more accurate than anything that can be purchased from someone else. Although the procedure contains some errors, there is a good discussion on calibration tube selection by Daniel Shoo at the end his V4.1 calibration procedure. This is available at multiple sites on the internet and his comments on this topic seem (to me, anyway) to be quite reasonable.

His comments about the original Hickok calibration tubes are interesting, but since none (at least none that can be trusted) are now available or ever will be, and since buying one from someone else is just buying their **guess** as to how it can be best done, I think that the best one can do is simply to calibrate the tube on a set that has been modified/calibrated to be as accurate as possible. *(Almost certainly, that is how Hickok made their first/original calibration tubes.)*

He also raises an intriguing observation that some tubes (6L6s) apparently introduce a spurious "hum" signal from the filaments that affects the transconductance measurements. (See the An Interesting (And Puzzling) Heater-Cathode Interaction section.)

Comment: Your "calibration" (calibrated) tube will probably not read exactly the same on some other brand or model tube tester, nor should you expect it to. This is because other manufacturers and even other models from the same manufacturer will be testing under different operating conditions (different plate and screen voltages, different control grid bias, different ac signal control grid voltage, and probably slightly different filament voltage). Any other properly calibrated Hickok 539B/C should read very close, (theoretically the same); however. Besides, any calibration tube you might purchase was most likely "calibrated" on a tester that was not as accurate your 539B/C now is, or at least can be.

Why (In My Opinion) It Makes Little Sense To Use A Calibration/Bogey Tube For Calibrating A Hickok Tube Tester

I realize I am "skating on thin ice" here in that I have basically no experience with any other Hickok testers at this point, but **if** the basic transconductance sensor circuits are the same (and it's pretty certain that they are, since Hickok had the patent on it), it can be accurately calibrated/checked, if carefully and correctly done, using the "constant current source" approach used here. *(There is good reason to think that the original Hickok engineers used this method to design and calibrate their sets in the first place.)*

The accuracy of this method depends directly on the accuracy of AC and DC meters and resistors, not (indirectly) on a tube. For less than $10 (sometimes for less than $5) one can buy a 3 1/2 digit multimeter that will be accurate to nearly 3 digit accuracy and can be used to calibrate/check any and all the ranges (6 in this case) plus the emissions and other functions. (The one possible exception is that the AC voltmeter used for checking the grid bias voltage must be at least as accurate as the overall tester accuracy desired, but this should not be a major hurdle.) Also, precision resistors are readily available and not terribly expensive these days (cheaper than calibration tubes are, for sure!)

Now consider using a "calibration" tube. At many times the cost of a meter, the "calibration" tube will be accurate to **at most** +/- 1%, probably **much** worse, and will only be accurate on the same type of tester on which it was "calibrated" because the "calibration" is only good at one set of operating conditions (screen voltage, bias etc.). Plus you would need a separate tube for each transconductance range. Furthermore, over time, the tube will "age" and lose its accuracy (depending on many things including how much and how it is used) but at an unpredictable rate and to an unpredictable degree and you have no easy way of knowing when or by how much its accuracy has changed. I might also add that it is entirely possible to get both digital meters and resistors that are accurate to 4 or more decimal places and there is no way you will ever find a tube "calibrated" to this degree of accuracy. *(Considering that tubes are inherently non-linear anyway, even if you could, it would be wasted effort!)*

See the Controversial Comments Section, no. 4.

The bottom line here is that if you are not terribly interested in accuracy, the calibration tube method is fast and relatively easy but will (except by accident) be less accurate than the "current source" method for a number of reasons and, in addition, is relatively expensive. The method given above is **directly** based on the **definition** of transconductance. The grid voltage signal is directly calibrated in a way that can be easily and accurately done with the resulting change in plate current as measured by current sensor circuits that can be directly calibrated in a similarly accurate way, and all without any need of a calibration/bogey tube and its inherent disadvantages. The bogey tube/calibration tube method is indirect and is susceptible to many possible errors along the way. Using a "calibration/bogey" tube is easier and faster, but, in general, less accurate.

If you can find a tube that is stable and has the same transconductance (or almost the same) over a fairly wide range of operating conditions, it could be useful for **roughly** checking the calibrations of other tube testers, but expecting it to be suitable for precise calibration of a quality tube tester is unrealistic unless it was calibrated on the same model tester and maybe (probably) not even then. Or, to put it another way, the "constant current source" method of calibration is much cheaper, universally applicable (should work with any tester), and potentially much more accurate than using a collection of "calibration" tubes.

In addition to all of the above considerations, the issues discussed in the section An Interesting (And Puzzling) Heater-Cathode Interaction are potentially a significant error/accuracy concern for any calibration 6L6 tube (and quite possibly other tube types, as well) which might be used on or by Hickok tube testers or any tester using their design. However, I can find no one offering calibration tubes on the internet who addresses or even seems to be aware of this potential problem. Thus a 6L6 "calibration" tube from such a source could be as much as 1000 micromho in error without them or the buyer even being aware of it. I personally happen to have one 6L6 tube that checks completely "good" but measures almost 1000 micromho differently depending on the filament connections (if not corrected for by adjusting the zero using R15 before measuring). Most of the 6L6 tubes that I have checked for this effect do have much smaller differences than this, and many show no significant differences, but some definitely do.

So, to summarize the above paragraph, if the calibration tube you buy was "calibrated" on a tester that used the Hickok circuit, but was not specifically checked for the above effect, it could be as much as 1000 micromho inaccurate/incorrect. Also if it was not calibrated on a tester using the Hickok circuit (and therefore, not checked for the above effect), but will be used to "calibrate" a Hickok type tester, the calibration based on it could still be significantly incorrect.

Comment: I very much doubt that the Hickok engineers were aware of this effect and it is quite possible that some of the **original** Hickok calibration tubes used to calibrate their testers may have been less than completely accurate to begin with because of this effect, and; therefore, at least, for use with Hickok testers, were not really suitable as a calibration tubes in the first place! This could be a significant factor in the variability seen between measurements made with different Hickok (and other) testers.

A More Detailed Explanation Of Some Of The Hickok Design And Calibration Flaws

Briefly: There are 6 transconductance ranges and to accurately calibrate all 6, it would **require** 6 separate non-interacting zero adjustments and 6 non-interacting gain adjustments. What **is** available are 2 (interacting) “zero” adjustments and **no** gain adjustments. R8 and R15 both do affect the zero of the transconductance sensing circuitry but both actually are only there to adjust the symmetry of the two power supplies (the 5Y3 and 83 power supplies). R8 can reasonably be used to “zero” the transconductance sensing circuitry on any one range, although this will affect/change the zeroes of all the other ranges to some extent as well. Trying to use R15 to “zero” the sensor circuitry will, in general, just contribute to greater over-all (transconductance measurement) error.

As long as the resistors in the “bridge” part of the sensing circuitry are well enough matched, the zeroes on the various ranges should be fairly close and separate zero adjustments for each range should (usually/hopefully) not be necessary (this assumes R8 and R15 are set accurately.) The situation with the gains is less satisfactory. The design values of the resistors in the sensor circuitry correspond to errors of around 4-7%, depending on which range (or worse, given the flaws in the Hickok calibration method.) A more detailed explanation is as follows:

To uniquely determine a line, you need two independent pieces of data. For example, two points determine a line. Or, alternately, and more to the point for this discussion, one point value and one slope value also uniquely determine a line. In calibrating **any linear** device; therefore, a **zero** value and a slope, or **gain** value, determine a unique **linear** calibration. Gain and zero values are independent. This means that you cannot change one and have any direct effect (good or bad) on the other.

In this transconductance circuit design, the **gain** for each range is set by the values of the resistors in the “bridge” circuit and the meter series/shunt string. In general, **in this circuit**, changing any of these resistors to make one range more accurate also effects some of the other ranges, making at least some of them less accurate. (The only exception is range F). They (almost) all interact, and badly. Make one range better and you make other ranges worse. This pattern became obvious from the computer simulations. However after extensive work with the simulations, I did eventually find a set of resistor values as given above, that significantly (theoretically) improve the accuracy in the transconductance sensing circuitry without requiring excessive changes. *(Note that these changes do also affect the emissions measuring circuits and may require a small change in this circuit including adding a resistor.)*

In this set, the zero setting of the transconductance ranges is significantly affected by **two** adjustments, R8 and R15 (and these two adjustments interact in the actual measurement of the transconductance of a tube, including calibration tubes). R8 directly affects the **zero** of the SENSOR circuitry by adjusting the relative sizes of the voltage peaks from the two halves of the 83 rectifier. R15 adjusts the relative (to each other) sizes of the voltage peaks of the GRID DC BIAS voltage (as well as the control grid bias voltage, because they both derive from the same power supply). This voltage is *multiplied* by the transconductance of the DUT and also affects the relative heights of the (DUT - Device Under Test) plate voltage/current waveform (which is, in turn, the input to the SENSOR circuitry). *(Note that the relative size of this effect on the measured transconductance and transconductance circuit zero will vary depending on the transconductance of the DUT and the transconductance range. This is why trying to use R15 to correct the zero of the sensing circuit* ***causes*** *bigger problems than it "fixes".)* So, the relative size of the voltage peaks of the DUT plate waveform (as seen by the sensor circuit) is directly affected by the setting of R8 but also indirectly affected by the setting of R15 because of the transconductance of the DUT. *(See the Measuring Transconductance, How Did Hickok Do It section for a slightly more correct explanation.)*

See the Controversial Comments Section, no. 5.

In summary, in this set, the zero cannot be independently calibrated for each range and it is all too easily affected/changed by multiple adjustments, and the gain, in general, effectively cannot be changed, You can't **fix** a "gain" problem by manipulating the "zero" adjustment or vice-versa (which is what the Hickok calibration tube method tries to do). The other important point is that if the resistors in the "bridge" are well enough matched, setting a good "zero" on one range should give adequate/acceptable (or at least reasonable) "zeroes" on the other ranges as well.

If you have followed this explanation to this point, congratulations and here's another point to consider: Zero is zero on all the ranges as long as the resistors in the "bridge" are **very** closely (exactly) matched. So **if** the gains were separately adjustable on each of and all of the ranges (non interactively, of course), then calibration tubes could work for checking and adjusting the gain, but you would still need one for each range to be checked/calibrated.

Another fine point in this design:

On range F, the bridge resistance consists (mostly) of just R42 and R37, which allows them to be adjusted separately for the **gain** (and **zero**, if necessary) without affecting the other ranges and the other range resistors don't affect range F (much). The point is that, since R42 and R37 don't affect the other ranges, their values are adjusted **last** and can be selected to compensate for changes in the other resistors that had to be made to make the other ranges work better. In other words, the accuracy of range F can be set as accurately as you want without changing anything on the other transconductance ranges, but not vice-versa.

Couldn't This Set Have Been Designed So Things Didn't Interact So Much?

Yes, absolutely! In fact it would have been much easier and simpler to have used separate resistors for each function and this would have made calibration/adjustment easy. *(It would have made the original design a lot easier too.)* In the modern world of inexpensive laser trimmed precision resistors this would be the way to do it. However, 55 years ago precision resistors could cost as much as several dollars each and designing with resistor strings or "ladders" used fewer of those expensive precision resistors. Engineering design is always a set of trade-offs, and at the time, this would have been considered good engineering practice.

What To Do If Your Meter Goes Bad

If you find yourself in need of replacing the original meter movement, electrically, it's a bit of trouble but not too difficult. If the replacement meter movement is more sensitive than the original, it may be possible to use a combination of series and parallel resistors to achieve the same electrical characteristics as the original meter. *(If the internal resistance of the replacement meter is greater than 1.5K or if the replacement meter needs more than 115 microamps to get F.S., then the following scheme won't work.)*

If you do have a meter which meets the above criterion, here's how to determine the resistor values: Put a 2K potentiometer in series with the replacement meter (adjust it initially to give the maximum resistance so you won't "peg" the meter). Put the combination across the test voltage source of Figure 17 *Low Voltage Source Circuit*, and adjust the potentiometer of the voltage source to get 172.5 mV across the combination. Now adjust the 2K potentiometer to give full scale deflection of the replacement meter. (Re-adjust the voltage source to keep 172.5 mV output as necessary.) Use an ohmmeter to measure the resistance setting of the 2K potentiometer and put a fixed resistor of that value in series with the replacement meter. Put a much larger value potentiometer across the combination of fixed resistor and replacement meter, say 50 K. (Start this potentiometer out at 0 ohms, again to avoid "pegging" the meter.) Put a 1.5K, 1% resistor in series with this new combination and all of this across the voltage source. Adjust the voltage source to give 172.5 mV across the new combination (and re-adjust as necessary). Adjust the parallel potentiometer across the replacement meter circuit to give one half of F.S. deflection of the replacement meter. You now have the situation where half the 172.5 mV is dropped across the 1.5K resistor and half across the replacement meter with its series resistor/parallel potentiometer. Measure the value of the potentiometer and replace the potentiometer with a fixed resistor of that value. The replacement meter and series/parallel combination of resistors should now give FS deflection at 172.5 mV and have a total resistance of 1.5K, which is what you want. (The first, series resistor, makes it so that the replacement meter/resistor combination gives FS with 172.5 mV applied. The second, parallel resistor, makes it so that the combination resistance is 1.5 Kohms.) Be warned: I have not actually tested this method because my replacement meter had > 1.5K resistance, but I believe it is correct.

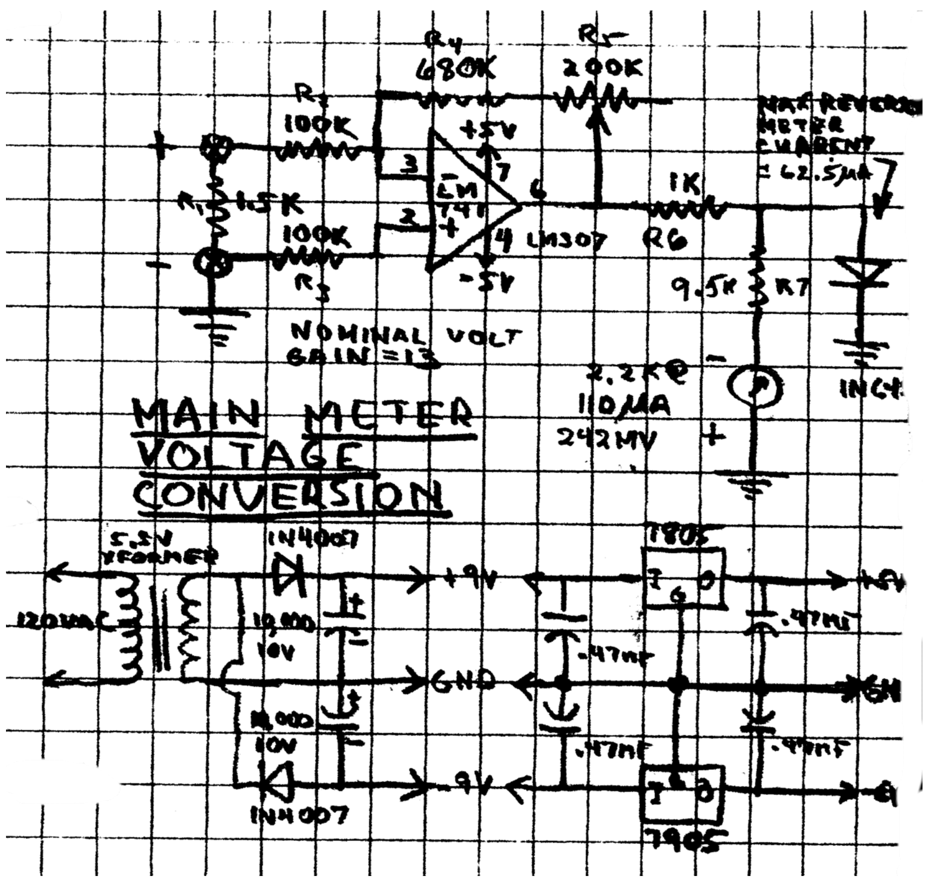

Figure 19: Main Meter Voltage Conversion

Otherwise, the following, although a bit more work, is essentially a **universal** solution. The idea is to add a simple op amp voltage amplifier circuit to convert the 172.5 mV across a 1.5K resistor to whatever voltage is required to give F.S. on the replacement meter. It is nothing more than the classic inverting op amp voltage amplifier (or you could use the non-inverting configuration instead if you wanted). Note that the power supply for the op amp has to be separate and electrically isolated by a small transformer (it can be quite small as this circuit draws practically no current). Figure 19 *Main Meter Voltage Conversion* is the schematic for the circuit I used in my set. *(This design is very much a prototype and if I were to do it again, I would do it very differently.)* If you decide to do something similar, I would recommend using a more modern op amp and higher supply voltages. (I had to change C4 from 100 MF to 330 MF to compensate for my poor design choices, but it worked and I was too lazy to go back and do it "right". The diode is to keep the meter from being "pegged" too hard downscale when the tester is first switched off.) You simply adjust the value of the op amp feedback resistor to suit your particular meter movement. You can use the voltage source circuit of Figure 17 *Low Voltage Source Circuit* to give 172.5 mV input to the circuit and adjust the feedback resistor in the op amp circuit to give FS on the replacement meter.

An Interesting (And Puzzling) Heater-Cathode Interaction

Comment: I have included this section even though modifying the set to allow "on the fly" zeroing of the 5Y3 power supply symmetry essentially eliminates this problem. It still has some interesting and possibly significant ramifications.

This section is based on an article in "Audio Express", 2007 by Daniel Schoo and has to do with "hum" from the filament affecting the transconductance measurement.

AC voltage from the filament can find its way onto the cathode due to leakage and, presumably, from capacitive coupling, and also from the magnetic field from the AC filament current. A way to "check" for this is supposed to be to take a transconductance reading and then "reverse" the filament connections and see if the reading is effected by the change. You can "reverse" the filament connections by appropriately changing the FILAMENT SELECTOR switch settings from the roll chart. See page 4 of the *Operating Instructions For Model 539B Transconductance Tube Tester*. Take each filament setting from the roll chart, and, on page 4 of the operating manual, just exchange the corresponding setting in the second column with the setting in the third column or vice-versa, and then reverse the result. Thus EV becomes FU, ER becomes BU, and HS becomes CX, etc. *(If the filament has a center tap, I don't recommend doing this unless you are sure that you are not changing the center tap connection.)*

This method seems limited in that it would be cumbersome to do for this on every tube tested. As near as I can tell from the transconductance measurement circuit design, there shouldn't be any difference, but I **can** confirm that this does seem to occur with some tubes (some 6L6 tubes, but only some of them, and this difference disappears if you adjust the 5Y3 power supply/grid bias voltage for zero transconductance reading (R15) before each measurement). The SPECIAL HEATER-CATHODE LEAKAGE TEST (above) should be **much**

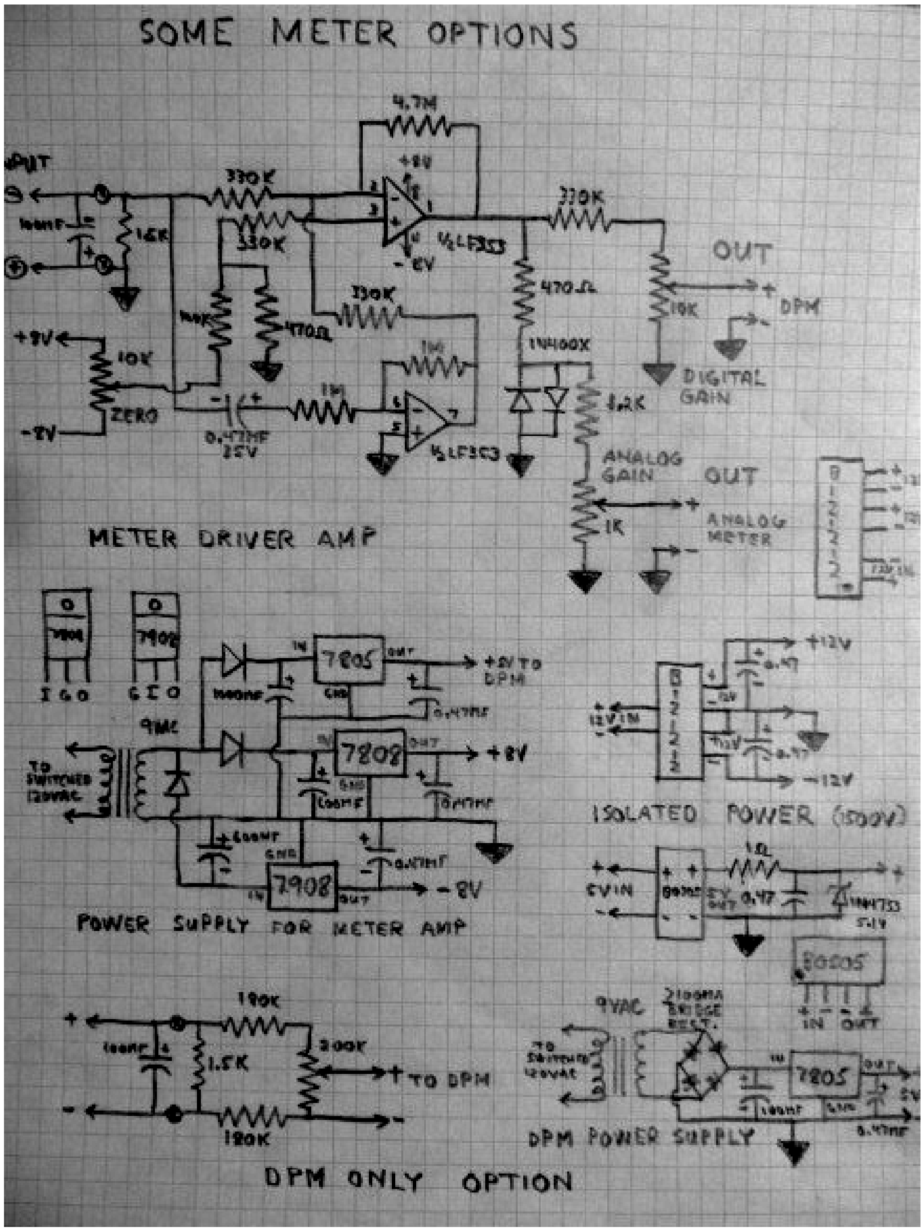

Figure 20: Replacing the MAIN METER with a 200 mV Digital Panel Meter

more sensitive for detecting heater cathode leakage, and this effect is seen in tubes with no detectable heater cathode leakage using this “special” test.

This effect does highlight two fundamental weaknesses in the Hickok method of measuring transconductance. First any spurious 60 hertz signal that can find its way by any route into either the grid signal, the grid bias signal, or onto the plate current/voltage will falsely change the transconductance measurement. Second, any asymmetry in the bias voltage peaks will have the same effect on the transconductance sensing circuit as a transconductance caused change in the plate current.

The apparent fact that the transconductance sensor circuitry sometimes reads a small signal even when there is **no** AC grid test signal on the grid of the DUT (device under test) suggests that either an AC signal is somehow getting superimposed on the grid bias signal or that something about some, but not all the 6L6 tubes is allowing some other source (other than the control grid, that is) to modulate the electron stream (for example, possibly the magnetic field from the heater current interacting with the electron stream from the cathode due somehow to the way the tube is manufactured/constructed. Another possibility is that AC modulated electrons can potentially be emitted from any portions of the heater bundle that may happen to extend beyond the cathode sleeve and thus add to the normal flow of electrons to the plate with an additional 60 cycle modulated flow of electrons.)

If so, then this would suggest that tubes that exhibit this effect might be a source of 60 cycle hum from the filament in(to) the circuit in which they were being used! In other words it seems possible that such a tube might actually **introduce** unwanted “hum” into the amplifier or whatever application in which it was being used! Even if it did happen, it is not clear whether the effect would be large enough to be of concern. *(I don’t happen to have an amplifier that uses 6L6s, so I can’t easily check this out, but if someone out there in internet-land wants a project. . .)*

Since the 5Y3 power supply also is the source of the screen grid voltage, it is possible that if the screen grid of the tube presented enough of an asymmetric load, that this could reflect back on the grid bias supply. *(This seems unlikely, but still might be possible.)*

Whatever the cause of this phenomenon, its effect on the transconductance measurement can be eliminated by adjusting the symmetry of the bias voltage (5Y3 power supply symmetry) before each transconductance reading, which is simple and fast after appropriately modifying the set, and doing so then allows the measured transconductance readings to be independent of the filament connections/phasing.

Some Thoughts About "Proportional" Transconductance Tube Testing

The definition of transconductance assumes that pure DC is applied to the plate and the various grids of the DUT with a small AC signal superimposed on the DC bias voltage of the control grid. Most Hickok tube testers, including this one, do it differently. They apply a pulsating DC waveform instead. Each "pulse" is one half of the 60 cycle sine wave and each voltage is applied simultaneously to the various tube elements. These are all of the same frequency and phase so the voltage waveform on each tube element is in the same proportion to the plate voltage waveform (i.e. all of them are at the same percentage of their peak values at all times) and to each other. The control grid AC signal that is used to determine the transconductance value and which is superimposed on the (pulsating — in this set) "DC" bias voltage is proportional, as well, as is the pulsating "DC" bias voltage itself.

One could argue that since this proportional method represents a weighted average of the tube characteristics over a range of operating conditions, it is somehow more "representative" of the usefulness/value/quality of the tube being tested.

Many tube types are normally run at higher voltages and currents than are present in this or most testers. So there is the question of how well do values obtained in this way (and at these lower operating conditions) apply to tubes run at higher power i.e. how well do measurements made in this way "scale up"?

The answer is "Probably better than one might expect." The transconductance at higher plate voltages usually increases, which would tend to make the values as measured at these lower plate voltages be too low. However, even at the lower screen grid voltages used in this and most sets, the proportional method used tends to make the transconductance measurement somewhat too high because the weighting is heavier at the higher screen grid and plate voltages. The net result is that these two effects tend to offset each other, at least to some extent.

What Does "Transconductance" Really Mean And Why Is There So Much Mis-Information About It (Including How This Applies To Calibration Tubes)?

The usual definition of transconductance is as the ratio of the change in plate current divided by the change in grid-to-cathode voltage that causes it, all other voltages on the tube being held constant.

Built into the definition of transconductance is the assumption that a tube behaves as a linear device. The assumption is that the plate current is proportional to the grid-to-cathode voltage and the proportionality constant is what we call the tubes "transconductance". If these two variables were related in a strictly linear manner, it would mean that if you were to graph them, it would be a straight line. Look in any tube manual, and just in general, at the kinds of graphs they show. Some areas are going to be fairly straight and some areas are strongly curved, but you won't see any truly straight lines. What does this mean? This behavior merely reflects the fact that even tubes that are designed to be as linear as possible never are completely linear and many, if not most, are actually quite non-linear. So the "proportionality constant" (the transconductance) is not really constant. We deal with this problem by saying "the transconductance changes depending on the operating conditions", but the fundamental situation is that we are trying to describe the operation/characteristics of an inherently non-linear device (the tube) by a linear approximation/approach (transconductance) and it doesn't always work as well as we might like. We do this because of its simplicity and because it allows us to get answers that are usually fairly close ("in the right ballpark"). In terms of the math, other approaches, although they may be slightly more accurate, are generally not worth the extra effort.

This kind of linear approximation is commonly used in electronics (and science and engineering, in general), the most famous being Ohm's law, E=IR, which gives an approximate relationship between two measurable quantities, current and voltage, in certain electrical components called resistors, the proportionality constant being what we call the components resistance. Resistance is not always a constant either, for example the resistance of the filament of a tube is very different when hot than when it is cold.

On the net, statements about the transconductance of a tube often imply that it is a fixed property of the tube if only you use the right method or device to measure it "correctly" or "accurately" enough. This is simply **not** true. (Such statements are usually associated with someone who would like to sell you an expensive tube, tube tester, or related merchandise.) In fact, the measured value of the transconductance of a tube is affected (to a greater or lesser extent) by just about everything imaginable (filament voltage, plate current, screen grid voltage, suppressor grid voltage, control grid DC (bias) voltage, inter-electrode leakage, gas, age, type of tube, manufacturer, etc.). It is anything but a fixed constant value. On the other hand, it **is** something that **can** be measured and **can** be measured to a high degree of accuracy under any given set of conditions, but what you measure (the transconductance) can change, and usually will, if any of the conditions change.

See the Controversial Comments Section, No. 6.

As a concrete example, consider an experiment measuring the transconductance of a 6L6GB tube as measured on a Hickok 539B (mine, actually, but long before the modifications and before even very accurate calibration), where the transconductance measured about 5990 Micromho in the C range and 5690 Micromho on the D range, a difference of about 5.14%. Same tester and same tube, so assuming both ranges were accurately calibrated, why were the measurements not the same and which was "right"? The answer is that, probably, both were "right" (to within the specified accuracies of each range). Also one value was measured with an AC grid voltage of 0.25 VAC (range C) and the other with 0.50 VAC (range D) grid voltage (on the Hickok 539B tester).

Slightly different test conditions would be expected to give slightly different transconductance values. See the Measurement Error section for a more detailed discussion of these results.

The engineers who design tube equipment are well aware of these considerations and usually design their equipment to be able to tolerate this variability, at least up to a point. So, in general, as long as a given tubes transconductance value lies roughly in the normal range, it should work well in most applications. That's what tube testers are designed for, to test whether a given tube is likely to perform adequately in most applications. Transconductance, for example, is not very useful or accurate for determining a tubes age (new vs. old) or "useful life left" (although this tester, the Hickok 539B/C, does have a method to try to estimate this) and it is not really appropriate to use this measurement for such purposes, in my opinion. If you see a statement such as "This tube measures 120% of a new tube.", look out! Such a statement suggests either ignorance or deceit (or both).

In some circuits, having a tube with adequate transconductance is not the only characteristic necessary for acceptable performance (e.g. a high frequency amplifier or other high frequency application — or, interestingly, sometimes, as an oscillator, especially in pentagrid convertors/mixers), so a tube that checks "good" on a tube tester may not always work in "real life" and, conversely, sometimes a tube with very low transconductance works just fine in some applications. In no way should the transconductance value of a given tube be considered the only or necessarily the definitive measurement of the value or usefulness of a particular tube.

When there is a situation where there is so much variability, it is harder to definitively prove or disprove even some fairly "off the wall" theories or opinions, and this may be part of the reason why there is so much incorrect information and so many unsupportable opinions out there on the internet. Nevertheless, these devices are well described by physical "laws" that have been known for well over a century and a half, and none of this is "magic" except for the magical glow of those good old tube filaments.

A General Discussion Of Measurement Error As It Applies Here

Whenever one makes a measurement, whether it is using a tube tester or just reading a tape measure, there will always be a limit to the accuracy involved and thus some associated error. You would not expect a 25 foot tape measure purchased from the local hardware store to measure accurately to the nearest thousandth of a inch no matter how carefully you made the measurement! The marks on the tape are nowhere close to being accurate to a thousandth of an inch and this is inherent in the measuring device (the tape, in this case), so it is simply impossible to measure to this accuracy with this measuring device. The same is true for a tube tester. Depending on the design, quality of components, calibration accuracy and many other factors, there is always an inherent limitation to the accuracy of any tube tester.

Suppose in the example given in the last section that instead of a real tube that we had a magical tube that had a truly constant transconductance value of 5840 Micromho and that we got the above measurements. Then the measured value on range C would be 2.57% low and the value as measured on range D would be 2.57% high. If both ranges were "specified" at +/- 3% accuracy, then the difference in the values measured might completely reflect measurement error inherent in the tester, and still be within the basic accuracy of the tester, since the measurements on both ranges would still be correct to within +/- 3% of the "true" value for the tube. *(Consider the kind of results that a tester "spec'ed" at +/- 15% or +/- 20% could give and still be within specifications!)* So, keep this possibility/consideration in mind when someone tries to sell you a tube with a transconductance reading given to four decimal places as measured on an Acme 2230 tube tester calibrated by the internationally recognized Joe Blow, the world expert on Acme tube testers! *(Okay, I made that last part up, but you get the idea, I hope.)*

Comment (7-21-13). The above values were obtained very early in the game on the unmodified set and were used here to illustrate the point. More recent tests with the modified and correctly calibrated set, with a grid bias that gave exactly 5000 micromho on the C: range (with a good 6L6 tube) yielded readings of a little over 4900 micromho on the D: range, and just barely under 5000 micromho on the B: range, or under 2% maximum difference. So the differences in the transconductance measurements are almost/essentially within the (very small) measurement error of the tester. *(I think this consistency also nicely reflects the vast improvement in over-all accuracy of the modified tester as compared to the stock (unmodified) tester.)*

Another point that is worth noting is that even though you may be able to read the meter on the tester to an apparent difference in transconductance value between two tubes (resolution) of 1%, or even better, that is NOT the same as the tester being accurate to that degree. So you might be able to match two tubes to 1% with such a tester but the value of the transconductance that you measure would still only be accurate to the extent of the underlying accuracy of the tester. (In addition, you would have to have 1% repeatability to match tubes to 1%, that is, that if you measure the same tube multiple times that you get the same result, whatever it is, to within 1% each time.) Thus, it would be possible to have +/- 0.5% resolution, +/- 1% repeatability and (tester badly in need of calibration!), only +/- 20 % accuracy.

Comments:

1. I estimate that my unmodified and only fairly accurately calibrated 539B was accurate to around +/-5% to +/-10%, so at least some of the 5.14% measured difference (in the above example) may have reflected a true but very small difference in the transconductance of that tube when

measured under slightly different conditions, but most, and possibly all, or at least almost all of the difference in the readings could have just reflected measurement error.

2. Repeatability on my (modified) personal set now measures about 0.7% on a good day! (see the next paragraph).

Although I have given the measured values to 3 decimal places, the last decimal place is really an estimate and is more like +/- 1 or possibly 2 digits in that 3rd decimal place (another potential source of error.). In other words, in general, I can't read the meter to a full 3 decimal places of accuracy. This "operator" error, in essence, becomes part of the over all measurement error for the device, as does, for example, the ability (or lack of it) to set the LINE ADJUST setting **exactly** the same each time by the operator (in this case, me). Setting the grid bias voltage is a similar source of potential error and contributor to the inherent measurement error of the device.

Another point about errors: There are numerous possible sources of error in this set. Ideally, one would hope that for each source of high error there would be another source of low error and that they would all average out in such a way that there would be no net error. I think that this *serendipitous* effect is significant in Hickok testers, because there are several potentially significant errors in the design and calibration of these sets, but even so, Hickok testers, in general, seem to still be fairly accurate in practice. In the real world, I think that the best that one can do is correct each source of error as much as possible and remember that you simply have to live with the fact that there will always be some error left.

A Quick Note On Offsets And Errors In The Grid Bias Signal And, In General, When Reading A Meter And Why This Is Important For The Hickok 539B/C

This concept becomes relevant because of the tendency to get offsets in the transconductance measurements for some tubes (but which can be corrected by on-the-fly adjustment of R15, the bias voltage symmetry adjustment (see the An Interesting (And Puzzling) Heater-Cathode Interaction section).

Suppose, for example that you had four small divisions of positive offset on the C range. This amounts to causing the reading to always be 1000 micromho too large. If you have a 6L6 with a transconductance of 5000 micromho, this means you read it as 6000 micromho or 20% too high. (The needle of the meter is slightly less than 1/2 scale.) If you measured another tube with 14000 micromho, it would measure as 15000 micromho (full scale deflection of the meter), and this would only correspond to 7.1% error. The point to note is this: the smaller the deflection of the meter needle when you make the reading, the more the (percentage) error that is introduced into the measurement because of any offset that may be present. *(This is one reason why it is best to calibrate at full scale meter deflection whenever you can.)*

This effect can be significant because, assuming that the sensor circuit zero and gain are already adjusted accurately, any asymmetry of the peaks of the 5Y3 power supply will be "multiplied" by the transconductance of the DUT (tube being tested) before it gets to the transconductance measuring circuit and will become an offset which will add to or subtract from the actual correct reading. This offset will vary depending on the transconductance of the particular tube being tested and will be yet another source of error in the transconductance measurements.

In addition, the amount of error introduced from the 5Y3 power supply asymmetry will be affected by the bias setting for the DUT and this will introduce another (variable) offset error depending on the bias settings used for the DUT. For example, suppose that there is 5 mv of error signal when the bias is set at -1 volt. If the bias voltage were doubled to -2 volts, the error part of the bias signal would then be 10 mv., which would, in turn, be multiplied by the transconductance of the tube under test and so the offset error in the transconductance measurement (because of this effect) would be doubled also (and would add to whatever other error that might be present). The point is that the size of the offset error will also vary depending on the bias voltage being used for the measurement as well as the transconductance of the tube itself.

The above considerations tie in with the importance of modification number 6 in the Further Possible Modifications And Idea Circuits section in improving the over all accuracy of the Hickok 539B/C tester.

Some Comments About Emissions Testing

Much of the analysis (above) has been about the transconductance features of this tester. Transconductance is essentially a measure of how well the tube can **control** the flow of electrons to the plate. Another feature that can be "tested" is the **amount** or number of electrons that can flow from the current emitting electrodes (emissions testing). For tube types which don't have grids or control structures, like diodes, this is all that can be tested for, and emissions only types of tube testers usually just tie the grids to the plate during testing and only test the tube as if it were a simple diode (so really, these testers are testing just the filament and/or cathode — the electron emitting structures — of the tube).

For diodes, AC voltage is applied and the DUT is used as a half wave rectifier and the tester measures the (average) DC current. *(All three 539B/C ranges also have a current limiting resistor to protect the tester circuits and the device being tested and which also further reduce the voltage at the tube when it is actually under test.)*

For (low power) diodes, the Hickok 539B/C uses a low voltage (20 VAC). This is to protect the DUT diode. If you apply too much voltage and try to "pull" too much current from a low power diode (i.e. if the tube is operated at a current level sufficient to exhaust the space charge around the cathode to a great enough extent and/or for a long enough time), the electron emitting material on the cathode can be permanently damaged, especially if any gas is present in the tube (and there is always some gas present in any tube.) In the “cheap” emissions testers, those which merely tie the grids and plate together, with the control grid tied to the plate and thus highly positive instead of the usual negative bias, it is all too easy to cause excessive and damaging currents to flow in low power tubes! Even for regular (power) diodes, the applied voltage is fairly small (35 VAC max. in the Hickok 539B/C), except for the gas rectifier diodes (approx. 287 VAC in the 539B/C), which need high voltage or they won’t “fire” (in this respect they are rather like the NE-51 light as described in the Shorts Miniature And Sub-Miniature Switch section).

You will see comments on the net about how diodes are tested at unrealistic conditions because they don’t test the diode at the high voltages they normally work with. In general, this is yet another example of mis-information and ignorance.

Basically when a normal, good diode is reverse biased, it will draw almost no current until the voltage is so high that it arcs internally, probably destroying the diode and whatever it is connected to. In general, if there is any significant reverse current (for example, from a short or leakage), this should be detected in the SHORTS and LEAKAGE circuits and at voltages well below anything likely to be destructive. *(The exception to this is the “back emission from the plate”, which must be evaluated at high reverse voltage and is sometimes associated with internal arcing and premature decrease in emission. I don’t know of any standard tube testers that actually test for this.)*

The situation is only slightly more complicated when the tube is biased such that current flows, and the the current is the key to understanding it. If the current emitting electrode, whether it is the cathode or the filament, is able to emit enough electrons to meet the demand from the circuit in which the tube is used, the voltage dropped across the tube is generally small, usually a few tens of volts or less (rectifier tubes are designed this way, and there are good reasons for it. Whatever voltage that the tube drops across itself is that much less that is available elsewhere and also, this represents wasted power and a potential source of unwanted heat.) So, if the tube has adequate emission, it is only necessary to apply a relatively small voltage to get the rated current. If the tube has low emission, when you apply the same relatively small voltage, the current will be below what it should be and the tube will measure as “weak”. If the current is low when a higher voltage is being applied, then you also know the tube has low emission but you would know this equally well from applying the lesser voltage. The bottom line here is that you don’t need to apply high voltages to find out if a tube has low emission (except for gas diodes), so there is no good reason to design a tester that way (with very high voltages).

Note that there are always limitations, even in a tester as good as this one. Testing of rectifiers with high current capabilities may be inadequate because the amount of current available from the tester for testing purposes is much smaller than the maximum rated current of such tubes. Thus it is the current limitation that matters, not the "limited" or "low" voltage of the tester. Such a tube might easily supply adequate current to test "good" on this tester and most testers, but not be able to supply enough current to perform satisfactorily in some legitimate applications. In other words, if such a tube tests as "bad", it's bad, but even if it tests "good" on this or similar tube testers, it still might not be "good enough" (i.e. too weak) for some applications even though the application itself is within the specified ratings for a "good" tube of that type.

Or to put it another way, there is a strong tendency for most (nearly all) tube testers to incorrectly pass high current rectifiers as "good" even when they may be "weak" and for emissions-only testers to pass any high current tube as "good".

A bit of philosophy: Electrical Engineering is really just applied physics, so just as in physics, there is usually more than one "correct" way or approach. Thus in the above situation, one could also say that "the voltage drop across the tube is excessive" or that "the effective resistance of the tube is too high" (as opposed to "it simply can't pass enough current" or it's "too weak"). Sometimes, the specifications for a rectifier tube will be given as a certain maximum voltage drop at a given current. It just depends on how you choose to look at it.

Why Tube Testers Are "Better" With Multi-Grid Tubes Than Triodes And Why Tube Testers Don't Measure Mu

First, a little theory: There is a fundamental theorem in Electrical Engineering called *Thevenin's theorem* that states that any voltage or current source can be approximated by an appropriately sized ideal voltage source in series with an appropriately sized ideal resistor (or impedance, if analyzing AC circuit properties), and this includes tubes used in typical tube circuits. (The "mirror image" to Thevenin's theorem is *Norton's theorem*, which states that any voltage or current source can be represented by an ideal current source in parallel with an ideal resistor (impedance). If you know the values for the Norton's equivalent, you can easily calculate the Thevenin's equivalent or vice versa.)

It is an observation that pentode tubes, in general have plate resistances that are relatively high (as much as 1 Mohm or more), compared to the resistances (impedances) in the circuitry (external to the plate) in which they are usually used. This is as opposed to triode tubes which typically have much lower plate resistances (sometimes more like 1000 ohms or even less). So a pentode used in a typical circuit "looks like" a voltage source with a high (internal) resistance in series with (externally to the tube) a substantially lower (equivalent) resistance, rather like the "constant current" circuit that is used to calibrate the tester. So the tube "looks" more like a current source that is a function of (the transconductance value times) the grid-to-cathode voltage. That is, basically, it behaves more like a Norton's equivalent current source.

The comment is sometimes made that tube testers sometimes don't do a good job with triodes, because of their low plate resistance, and, in general, there is, at least some truth to this. Here is one way of explaining why: In the circuits that they are typically used, their lower plate resistance makes them act more like an ideal voltage source in a voltage divider circuit than as a transconductance device (which is how the tester is designed to evaluate them). In design work, and sometimes for "matching" triodes, mu is considered the more useful parameter (that is, as a Thevenin's equivalent with a voltage source that depends on the grid-to-cathode voltage, namely, the "mu" of the tube.)

"Mu" is basically a voltage gain measurement, the ratio of the plate (to cathode) voltage change to the grid-to-cathode voltage change that causes it. Commercial tube testers don't measure mu or plate resistance, at least, not directly. For triodes, mu is almost completely a function of the tube geometry and is essentially constant, as it almost is for pentodes (except at very low plate voltages), unlike transconductance and plate resistance, which may change significantly. Thus, it wouldn't make a lot of sense for a tube tester to measure Mu, since it doesn't tell much about whether the tube is good or bad unless/until it is **very** bad. Mu, transconductance, and plate resistance are simply related mathematically, but you have to know any two (both measured at the same operating conditions) to calculate the third. If you are interested in mu, a curve tracer is probably the fastest and easiest way (if just you happen to have one available).

(By the way, for pentodes and tetrodes there is another mu that most people don't even know about, mu with the subscript sg, which is the screen grid voltage gain with respect to the control grid. This can usually be ignored and becomes significant (and highly variable) at very low plate voltages.)

Another consideration is that tube testers are designed such that they essentially evaluate the tube as if it were in Class A (A1, usually) amplifier service and for tubes used in other applications (for example, pulse and digital service), parameters other than transconductance (or mu) may be more useful for evaluating the value or suitability of any particular tube or tube type (or its "useful life" or "life left").

Some Thoughts About Matching Tubes For Push-Pull Audio Output Stages Using A Tube Tester

*(How tubes **should** be matched for this kind of application - but frequently are not)*

One sees many comments and complaints about buying "matched" tubes and how they do or don't actually work as expected in (audio, usually) circuits because these circuits frequently employ significantly higher voltages than are present in most tube testers. This is yet another example of mis-information. It is the plate current and not the plate voltage that is important when matching tubes for this kind of application (at least for multi-grid tubes). Fortunately, the Hickok 539B/C tester was designed in such a way that this can be easily done. The following is an attempt to describe a reasoned method of tube matching using a tube tester and an attempt to explain why.

Generally speaking, tubes (pentodes, especially) are considered to be best (most usefully) approximated as transconductance devices. That is, that they output a current that is a function of the grid-to-cathode voltage (usually a linear relationship is assumed, again, for easier computation and because it gives answers that usually are close to the “real world”). In other words, the plate current is determined by the grid-to-cathode voltage and is assumed to be independent of the plate voltage (that is an important, but frequently overlooked assumption). Remember, this is just an approximation to the real world (tubes, for example, are non-linear, really), but it is a useful approximation, and usually gets you close to the “right” answer. In this model, the tube can be considered a “magical” device that changes its output voltage to whatever it takes to force the right amount of current (based on the grid-to-cathode voltage) through whatever is connected between it’s plate and the (B+) supply voltage source (assuming that the B+ supply voltage is sufficient).

The 539B has a set of jacks with a removable shorting link which allows easy monitoring of the plate current. Simply connect a current meter to the jacks and remove the link. (This can be yet another use for that $10 multimeter that you purchased instead of that expensive calibration tube!)

First, the tubes should be matched at the normal quiescent (meaning when no signal is present to be amplified) current of the device or application that you want to use them in, whatever that may be. So if you buy a set of matched tubes, you have to know at what current they were matched. At a minimum the tubes should be matched so that the bias voltage required to achieve the desired plate current is close to the same in both of the matched tubes (that is, they should be matched on this basis). This assumes that each channel of the amplifier in question has only one bias adjustment that simultaneously affects both push-pull output tubes of that channel. If the application device has separate adjustments, you could modify this approach. In effect this gives you matching for one point on the transfer characteristics curve (assumed to be a line). *(All you need now is the slope. Remember, one point value and one slope value is all it takes mathematically to uniquely determine a line.)*

Now, at this point the tubes may be closely enough matched for most applications, but if even closer matching is desired, further matching can be based on having transconductance values as close to the same for the matched tubes as possible at the desired plate current. This essentially gives the same slope value at that point (plate current) for each of the matched tubes. So, if the tube’s transfer characteristics really were linear, the two tubes would perform identically. In the real world, they’re not ever completely the same, but this method should give results that are about as good as it is practical to get and should compare favorably with tubes matched on the basis of their “actual” characteristic curves using a curve tracer.

This method is easier and faster than a curve tracer and cheaper (curve tracers suitable for use with tubes are rather expensive these days and there aren’t that many of them around!). It also allows more meaningful comparisons to be made.

For example, it is more useful to know that "These tubes were matched to have the same bias voltage and transconductance at a plate current of 25 ma. and those were matched at 50 ma." than "The curves for these these tubes look about the same on my curve tracer."

See the Controversial Comments Section, No.7 and No. 8 and the Some Considerations (And Opinions) About The Importance Of Plate Voltage On Tube Parameters section.

So, just knowing that tubes were matched somehow is not much use without knowing how and under what conditions. *(And by the way, a tube curve tracer is a perfectly good way to match tubes,* ***but*** *you still do have to know what what the curves mean!)* Also note that matching tubes at the tube tester's roll chart grid bias voltage values (which is what you would normally be doing when testing tubes in the usual way) is less likely to be satisfactory unless your application just happens to be close to the measurement conditions of the tester for that tube type (something that is not likely to happen very often).

An interesting consequence of this analysis is that you can match tubes quite accurately even if the tester is inaccurately or poorly calibrated. It doesn't matter whether the transconductance values you measure are accurate, only that they be repeatable and the same for both matched tubes. Another important point is that the plate voltage used is of limited importance as long as it is sufficient to obtain the desired plate current.

So, if you are contemplating purchasing matched tubes, you should ask the seller three questions:

1. Were these tubes matched for similar plate currents at the same bias voltage?

2. What plate current were they matched at and is that approximately what the intended application requires?, and possibly,

3. Were they further selected to have similar transconductance values at that selected plate current?

By the way, one should also consider to what extent the "matching" has been done. A set of "matched" tubes matched to 10% or 20% or even 40% might work perfectly well in most applications or for most tube types, but 5% or better might be required (or at least desired) for others.

Note that the transconductance is measured not at the tube tester roll chart values but at a grid bias voltage that is based on the measured plate current.

I've noted before that there is usually more than one valid approach to any problem/situation. Another way of looking at the above matching scheme is that matching the plate currents at the same (DC) bias points matches the tubes for their for DC properties and matching the transconductances at this (DC) point additionally matches them for their AC characteristics at these operating conditions.

Limitations to this method of tube matching

Matching tubes with a tube tester has many advantages, including being fast, easy, and repeatable and that tube testers with adequate capabilities to do so are still fairly plentiful and readily available, but there also are (always) limitations, too.

The fundamental assumptions underlying this method of matching is that the tubes' characteristics are approximately linear at the operating point of interest and that the operating conditions of the test roughly correspond to the actual actual conditions in the application. Most of the time and for most tubes, these conditions will be adequately met and this method will yield good results, but If either of these conditions do not hold, the method may not work satisfactorily, nor should it be expected to.

If the tube you are trying to match is non-linear at testing conditions that normally should be linear for that tube type, then it is likely to cause distortion in the actual application and should not be used anyway even if you can find another tube that is similarly matched at those conditions. Testing at two different plate currents (two point testing) should "pick up" this situation and, once you have the tester set up at one plate current, it doesn't take much extra time or effort to just change the grid bias voltage for a different plate current and check for a match at that value also. (Matching using a curve tracer will readily "pick up" this situation as well, of course.)

Most tube testers operate at lower plate and screen grid voltages than in most actual applications. This can be a significant factor, but mostly not, at least in general, and tubes matched this way seem to work quite satisfactorily most of the time and in most applications. (See the Some Considerations (And Opinions) About The Importance Of Plate Voltage On Tube Parameters section for some further discussion of this issue.)

Is A Curve Tracer Better Than A Tube Tester For Matching Tubes?

With one possible exception (see the Issues With Small Signal, High Gain Tubes section), I think the answer is "In theory, yes, but in practice, no, they're about the same" (i.e. they work about equally well, overall). A curve tracer, by its nature, tests tubes at a variety of operating conditions, potentially including the plate currents and voltages that duplicate those of the desired application, whereas a tube tester generally only tests at one set of operating conditions, and usually at lower voltages than are used in many applications. (See the Some Considerations (And Opinions) About The Importance Of Plate Voltage On Tube Parameters section.) Of course, with a tube tester, there is nothing stopping one from matching tubes based on two or more sets of plate currents, although this generally wouldn't yield much improvement over the single point method outlined above anyway unless you had a tube that just happened to be really badly non linear (in which case you wouldn't want to use it anyway). The idea here is that tubes that match at two different points on their operating curves are likely to remain reasonably matched at higher plate voltages, or other changed operating conditions, as well.

Another point is that for a high power tube like a 6L6 or other power amplifier tubes, the curve tracer may well test at the higher voltage and current levels that duplicate the actual operation of the tube, but only for a fraction of a second and the DUT (device under test) will will not be evaluated at anything like the same heat/temperature levels that it will likely experience in actual use. This is a little like taking a reading with a tube tester while the tube is still heating up. Most tube testers will probably not test close to the operating temperature the tube will experience when actually in use either. Basically, neither device will be able to test under exactly the same conditions as an actual application, but both should be able to put you "in the right ball park".

In actual practice, there are several reasons why a curve tracer can be **less** accurate than the tube tester. First, the "operator" has to be knowledgeable enough to correctly interpret and measure the curves as opposed to just reading a number from a tube tester meter. Second, most curve tracers display their results on a 5 inch CRT screen and I doubt that one could read the values to better accuracy than 3 or 4% from the screen. Third, the underlying accuracy and linearity of the amplifiers in the set and of the CRT deflection plates is at least a potential limiting factor (In my Tektronix tracers (both the 575 and 576 models), the amplifier linearity is "spec'ed" at 3%, which is not as good as the over-all accuracy of my modified Hickok 539B tube tester). Fourth, curve tracers, like tube testers, must be calibrated and their accuracy will be no better than the calibration accuracy no matter how fancy or expensive the set. *(Note that the second and third arguments are actually very weak with respect to tube* ***matching****, since accuracy is not the important factor.)*

Comment: Of course, a vendor can just include copies of the curves for his tubes and let the buyer try to figure out what they mean with respect to the buyers intended application.

So, in general, although the curve tracer may be better for matching tubes in a few special circumstances, tubes matched by the tube tester method are about equally likely to perform satisfactorily in most real world applications and, given that curve tracers are relatively rare and expensive whereas tube testers adequate to match tubes are much more common and less expensive (and that they are easier and faster to use, a lot less trouble, and don't require any special expertise), it is my opinion, that in the real world, tubes (correctly) matched by either method are about equally likely to give satisfactory results.

Issues With Small Signal, High Gain Tubes

It is claimed that tube testers, in general, do not do a good job of evaluating high gain small signal tubes such as the 12AX7. To a varying extent, but in general, this is all too true. This effect is best explained with an example: How does a Hickok 539B/C do with a 12AX7? (The answer, by the way, is "pretty good, but not perfect", but still **very much** better than most other tube testers.)

The roll chart values specify a bias of -1.3 V on range D, which uses 0.50 VAC as grid signal voltage. The peak bias voltage is; therefore, -2.04 V, and the peak grid signal voltage excursion is +/- 0.71 V. So the grid voltage varies between 0 and -1.33 V on one half cycle and between 0 and -2.75 V on the alternate half cycles.

Comment: In this analysis it is tempting to just add and subtract the AC grid signal voltage to and from the bias voltage and think the grid voltage swing is -0.80V to -1.80 V. But remember first that the AC grid signal is 0.50 V RMS which means that it actually swings +/- 0.71 V. Second, the grid bias voltage is actually a series of half waves of a 60 cycle sine wave which means it goes from 0 V to -2.04 V and back to 0 V 120 times per second. It is the **average DC value** of this waveform that is -1.3 V. *(Although it is not possible to prove or disprove it, I strongly suspect that the Hickok technician or engineer that made these roll chart set-up values probably, and mistakenly, was thinking along these lines.)*

There is a plot of the transfer characteristics for an actual 12AX7 given in Alan Douglas' book *Tube Testers and Classical Electronic Test Gear* (page 12). From it, it is clear that even -1.33 V is beyond the low end of the most linear portion for this 12AX7, and that -2.75 V is well below cut-off for this tube. (This tube would never be used as an amplifier at these operating conditions as the distortion would be excessive.) The fundamental assumption that the transconductance is linear in the region of operation of this tube is invalid (very invalid!) whenever the grid voltage is lower than -2 V because anything lower than this voltage completely cuts off the tube and no plate current flows at all. The transconductance measurement will, at best, only be close to what it would be if this tube were evaluated/tested completely in the linear portion of it's transfer characteristics curve and probably not close at all. (In terms of how the transconductance sensor circuitry works, during part of the negative excursion of the grid voltage half cycle, no charge is being removed or added to the capacitor (C4) when/because the tube is cut off. See the Measuring Transconductance, How Did Hickok Do It? section)

Even when the voltage is between -1 and -2 V the transfer curve is noticeably non-linear, and this will also contribute to the inaccuracy. So, for a 12AX7 tube this tester will not give a truly "representative" transconductance value under these test conditions. It will detect a bad tube, but the measured transconductance value will not be representative of the actual value over the usual/useful range of operating conditions for the tube. Never-the-less, if the "pass/fail" value on the roll chart for this tube is/was selected properly (so that it compensates for this effect), it will still **appropriately reject** weak/bad tubes (which is the fundamental purpose of a tube tester, after all).

Comment: These roll chart values were poorly chosen by Hickok. They could have done better. A bias voltage of about -0.45 V, for example, would keep the grid voltage excursions within most of the linear portion of the transfer curve and have avoided cutting off the tube during any part of the half cycles (It would still enter the -1 V to -2V range (where the transfer curve is non-linear but the tube would not be cut off) for the half cycles that correspond to the negative portion of the grid voltage signal). If you were to try to accurately match 12AX7 tubes or sections of a 12AX7 tube, -0.45 V would be a better bias value to use (but the corresponding transconductance value obtained would still not quite be entirely accurate). This assumes that you use range D which is what the roll chart calls for. Range C uses 0.25 VAC for the signal voltage so, for example, using range C and a bias volts of 0.6 V should be adequate/accurate if you wanted to match two 12AX7 tubes.

This issue has some ramifications that go beyond the obvious. Most tube testers, even including the Hickok 539B/C may be less that optimal for evaluating such low signal, high gain tubes for anything other than for being obviously defective, and, in particular, for trying to accurately match tubes for transconductance, and some (most) are likely do a sub optimal, if not poor, job in this respect. (This, of course, begs the question of "Why would you want to go to the trouble and expense of matching small signal tubes in the first place?") So, for this small, but important class of tubes, it would be important to know what tube tester was used to match the tubes and at what bias voltage. (**Any** tube tester that uses more than about one volt peak-to-peak for the grid signal is most likely deficient in this respect.) This is one class of tubes for which a curve tracer is likely to be superior to most tube testers for tube matching purposes (except for a few top end tube testers that use very small grid signal voltage levels) because of the way most tube testers were/are designed. The bottom line here is that for small signal, high gain tubes, if you want to use a tube tester for matching tubes, you can't necessarily rely on the roll chart values and you have to make sure that your tester is capable of doing it accurately.

Additional comments:

1. The above considerations will be a problem only for a very few "newer", high gain tubes and is not going to be a problem for most older tube types. The situation will be **much** worse in testers that use a single fixed larger grid signal of, for example, 2.5 or 5.0 VAC on all or some of their ranges (such as in some of the older Hickok testers and others).
2. I note that there is at least one source of "calibration" tubes who sells a combination package of 6L6 and 12AX7 "calibration" tubes. Because of the above considerations, the 12AX7 is an especially **bad** choice for a "calibration" tube.

What About "Noisy" Tubes And Microphonics?

The Hickok 539B/C has a pair of jacks for "noise". Actually, these should be connected to a separate A.M. radio at the antenna and ground connections. This is intended to detect fast, intermittent shorts or leakage, and will occasionally "pick up" defects that won't be detectable otherwise.

As for microphonics, as far as I know, no conventional tube tester actually tests for this. It would be no great design challenge to make a separate box to test for this for any given tube type, or general tube type, but it would a completely separate item and would be more effort and expense than most people could justify unless one were a tube vendor, so from a buyer's point of view, it would be easier to just test any given tube in place in the actual application and make sure that the seller will "take back" any tube that turns out to be significantly microphonic. *(Bear in mind, however, that a tube that is noticeably microphonic in one application might work perfectly fine in another, occasionally even in an otherwise identical piece of equipment.)*

Some Considerations (And Opinions) About The Importance Of Plate Voltage On Transconductance

One sees comments like "most tube testers only test at low plate voltages instead of the high voltages that tubes are operated at" and at least implying that no truly meaningful or accurate measurements are possible without a tester that can test at 400 V or more (or that tubes cannot be meaningfully matched without such a "special" tester). This issue is greatly exaggerated and the effect, if any, is generally small enough to ignore, especially in multi grid tubes such as pentodes and tetrodes. In addition, mostly, but not completely (45,50 2A3, 6A3, etc.), circuits using single grid tubes (triodes) are used in the voltage amplifier stages and use lower plate voltages, so the actual plate voltages used in the circuits that employ these tubes are comparable to what most tube testers actually use anyway, and the actual plate voltage used in the tester would again not be an issue.

These days, tube testers are used for basically two reasons. First is the tube "good"?, i.e. will it function adequately in most applications. I think it is pretty well accepted that most tube Hickok tube testers do a pretty good job at this, irregardless of exactly what the plate voltage they actually use in order to do it. (That is, as long as the tester does what it is designed for, it is largely irrelevant how it does it.)

The second is for matching tubes, usually for push pull amplifier applications. So the question now becomes "by how much will tubes that are well matched at lower plate voltages be unmatched at higher plate voltages?" There is a related question, which is "By how much do tubes change in transconductance between lower and higher plate voltages to begin with?" I am not aware of any reliable data regarding the first question and it undoubtedly varies somewhat, depending on the particular tube type. As for the second question, randomly perusing the tube manual, the 'book values" for transconductance for the same tube type but at different plate voltages (when they are even given in the tube manual) seem to vary by generally less than 15%, and usually substantially less, with some tube types not changing at all. So this suggests that the transconductance of two tubes matched at any reasonable/realistic plate voltage probably won't change much at a different plate voltage which in turn suggests that if two tubes were well matched at modest plate voltages, they probably won't be very different from each other at higher plate voltages either. This topic is further discussed in the Controversial Comments Section in the comments portion, part b.

The commonly used approximations or "models" of tube behavior (multi grid) do not take this plate voltage effect into account and this is invariably treated as at least a "second order effect" and not usually significant/large enough to justify any special consideration.

Another thing to keep in mind is that the Hickok method actually measures the transconductance at constantly changing plate voltages and is really a weighted average of the the transconductance at plate voltages up to about 210 volts and is weighted toward the higher values.

In case there might still be some lingering doubts about this topic, considering how often one sees this particular piece of mis-information on the internet and other places, consider the following quote from the textbook *Radio Engineering*, copyrighted 1937, by Frederick Emmons Terman, Sc.D., Professor of Electrical Engineering, Stanford University, page 142: "The mutual conductance is the most important single constant of screen grid and pentode tubes when operated in the usual manner with sufficient plate voltage to make the plate current substantially independent of plate voltage. Under such conditions, the plate current is very nearly equal to the total space current. The mutual conductance will then depend primarily upon the magnitude of the plate current, but not upon the combination of control-grid, screen, and plate potentials required to produce the current."

Yet another way of addressing the issue is this: If it really was necessary to employ very high voltages to adequately evaluate most vacuum tubes, the majority of the tube testers would use 300 or 400 or 500 volts. Most tube testers do not use excessively high voltages and the obvious reason is simply that there is no good reason to do so or to justify the extra expense that would be involved.

Some Facts About Transconductance From Back In The "Good Old Days" That May Put Things In Better Perspective For "Modern" Thinking

1. When a tube manufacturer made a batch of tubes of some given tube type, if the measured transconductance was within +/- 40% of the average or "bogey" value for that manufacturer for that tube type, it might be sold as

a good, new tube. (There was no enforced standard for this. Each tube manufacturer could set these limits to whatever they wanted, but around -20% to +40% seems to have been pretty much the standard practice.) (Actually, the specification would probably have been given in terms of the acceptable standard deviation from the mean, but the above explanation is easier to understand and adequate for non-statisticians.)

2. When a new tube type was registered, each manufacturer would submit the average of his production runs for certain characteristics, including transconductance, to the JEDEC (Joint Electron Device Engineering Committee of the EIA) and the "book value" was usually chosen as the average of the values submitted by each manufacturer (thus the average of the averages of all the manufacturers of a given tube type). Thus, the official "tube book value" might be different from **any** of the individual manufactures' actual average or "bogey" values for that tube type.

Food For Thought

Since transconductance actually varies significantly with plate current (and **not**, by the way, with the plate voltage, at least in multi grid tubes), the question arises "What operating conditions and corresponding values of transconductance should be considered"normal" or "appropriate" for judging the merits of any given tube? Probably the most reasonable criterion to use is "How close does the actual tube come to the"published" values at the "published" operating conditions?" Using this as the "gold standard" still might not be as reasonable as it seems. This is because the transconductance increases (slowly) as the the plate current increases, and since the tube manufacturers always wanted their tubes to have the best possible "specs", the "official" values may have been made at or given for higher plate currents than would be normally used in most applications in order to get the highest "official" transconductance values for their tube. So the actual transconductance of a perfectly good tube may well be considerably less than the "tube book" value when it is actually being used under reasonable circuit application conditions and plate currents. It is also quite possible that a tube might read as "marginal" or even "bad" at the higher plate currents of the tube book values/specifications but still function perfectly well at the lower plate currents of most actual applications.

How To Measure Transconductance Without Even Using The Main Meter (The "Grid Shift" Method)

If you should desire an independent "check" of the tester, it is possible to very accurately measure the transconductance of a tube without even using the MAIN METER or the transconductance measuring circuitry. This method requires that you have a DC milliammeter and a calculator. Connect the meter to the plate current posts and remove the shorting link. Press the P4 button and take a plate current reading at whatever grid bias voltage level is desired and then take a new reading at a slightly different bias voltage, for example at one volt larger or smaller. Calculate the difference in plate current and divide it by the change in grid bias voltage and the ratio is (approximately) the transconductance. This should be very close to the reading (taken in the usual way) at a grid bias voltage about half way in between the two bias voltages that were used in the measurement. (If the tube was actually completely linear at these operating conditions, then the transconductance values would be identical.) This is almost as easy as using a "calibration" tube and is cheaper and, in general, more accurate too. In fact, this method could be used to accurately calibrate just about any tester, but it would be a bit cumbersome and inconvenient. *(This simple method is based on the fact that the transconductance at any point is just the slope of a line tangent to the characteristics curve at that point.)*

Transconductance, Mutual Conductance, Proportional, Dynamic; All This Is Confusing. What Do These Mean?

First, the easiest. Mutual conductance and transconductance are the same thing. The usual unit of measurement in the U.S. is micromhos and in Europe, Siemens, or, as just mA/Volt The last is, in some ways, more "meaningful", but I have tried to stick to the U.S. convention for consistency. In formulas, it is usually represented by a upper case or lower case G with a subscript m, or Gm (e.g. mu = Rp X Gm). (See also the section What Does "Transconductance" Really Mean . . .).

Comment: The "American" convention is, in a sense, misleading, since expressing transconductance as a 4 decimal value (e.g. "5100 micromho"), as is commonly done, seems to imply 4 decimal places of accuracy (whereas, for example, "5.1 mA/Volt", does not).

Second, "dynamic" simply means "changing" or "non-static". In the definition of transconductance, when making a measurement, all the voltages are constant (DC) except for the AC control grid signal (and except for the filament, of course). In dynamic testers most or all of these are changing regardless of whether a "test signal" is present on the control grid. Or, to put it another way, in these testers, the waveforms are usually pulsating DC rather than "pure" DC. Most dynamic tube testers are also proportional or partly proportional testers. The Hickok 539B/C is a "dynamic" tester.

A "proportional" tester is a dynamic tester in which all the voltages present including the grid bias voltage and the grid AC test signal change with time but are of the same frequency and phase and thus each voltage is the same percentage of it's peak voltage as all the other voltages (and currents) are at each instant in time. The majority of the Hickok testers, including the Hickok 539B/C are purely "proportional" testers. Obviously, all proportional testers are dynamic as well. (See also the section Some Thoughts About "Proportional" Transconductance Tube Testing).

Some examples:

The Hickok 539C variant, the much prized Western Electric KS-15750, is actually somewhat a hybrid since the control grid bias voltage is true DC rather than using the same waveform as is present on the other grids and the plate voltage. (This *sounds* like an improvement, but might actually be the opposite since this means that that tester is neither a completely dynamic nor a completely static tester and it's hard to know what effect this might have on the accuracy or "scalability" of the results since this also means that it is not a completely "proportional" tester, either.)

A difference between Hickok and some other "dynamic / dynamic conductance" testers (e.g. the popular EICO 666 and 667 models - and others) is that the Hickok method modulates the control grid signal and uses circuitry in the plate circuit to measure transconductance while these other types of testers put a pulsating DC bias voltage on the control grid (and other grids) but no test AC voltage, and the meter in the plate circuit merely measures the total plate current and not transconductance. So these models, while still "dynamic" and "proportional", are essentially modified emissions testers. Even so, in my opinion, the proportional emissions type method is still much better than merely tying the grids and plate together and measuring the total current, as some of the really cheap testers do it. In this modified emissions method, more of the current goes to the plate, which is designed to handle higher currents, and less to the grids, which are not designed to carry much current.

(The above explanation of the Eico circuit is essentially correct, but AC not DC voltages are applied to all the tube elements whenever the test switch is pushed. When the voltages are negative, no current flows because the DUT acts as a rectifier, so, in effect, it is only receiving positive voltage pulsating DC.)

Further Possible Modifications And Idea Circuits For The Hickok 539B/C

1. Having to manually re-adjust the line adjust control is a bit of a pain. The following circuit does it automatically (See Figure 21 *Circuit to Replace External Variac*). My design criteria was that it be as simple as possible and use inexpensive, readily available components. The 2N3055 transistor is almost "ubiquitous" and is inexpensive, but it's Vceo rating is less than line voltage (60 V). The zener diodes are to prevent the collector emitter voltage from ever exceeding about 35-40 V. If you use an (enough) higher voltage transistor, you don't need the zener diodes. *(Also, the capacitor has a very small effect and can be omitted without much degradation of the performance of the circuit.)* Even with hand selecting the transistors for high gain using a curve tracer, this circuit still only regulated to a little worse than 1%, which is pretty good, but not as good as using the panel meter on the set and manually adjusting the voltage (about 0.7%), so I ended up not using it. You must be sure to use a big enough heat sink and make sure that the 2N3055 is properly insulated from the heat sink. Putting the pass transistor within the bridge rectifier insures

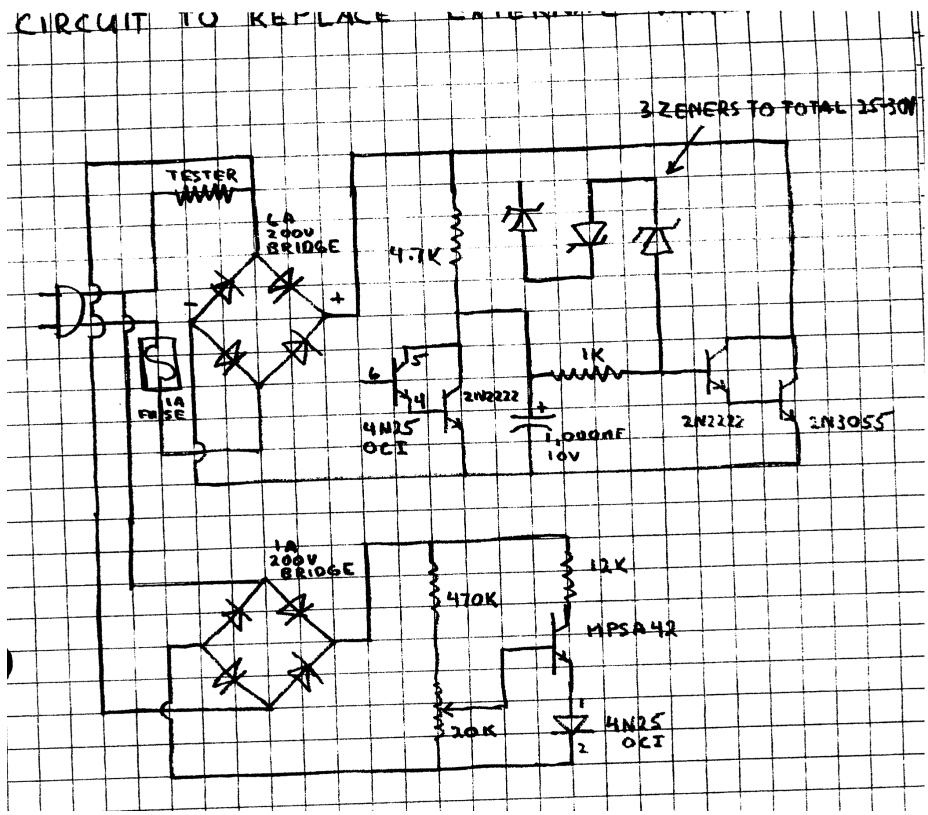

Figure 21: This circuit could be used in place of an external variac to keep the voltage at a (relatively) constant line voltage for testers that lack a line voltage adjustment

that each half cycle is treated the same *(This is important for the Hickok transconductance measuring circuitry)* and allows a DC device, a bipolar junction transistor, to be used in a AC application.

This circuit would make more sense to use with some of the lower grade service testers that have only one transformer and don't have any way of adjusting the primary voltage to this one transformer to compensate for the loading caused when testing higher power tubes. It can easily be modified to work on such testers. If necessary, a low voltage filament transformer could be used to slightly increase the voltage to the set in order to have enough voltage for this circuit to be used (to make sure that it has enough "head room"). In most cases, it would probably not be needed. Figure 22 *Circuit to automatically adjust the line voltage for a 539B* is a circuit modification that should work, but I haven't had time to actually try it. In such applications, this circuit would probably still be more accurate and certainly less trouble than using an external "variac" AC voltage source to power the set, (which requires an adjustment of the variac each time before making a measurement) as some have suggested.

2. You could easily monitor the plate current routinely by putting a 1 ohm resistor and a 0-200 mv digital panel meter across the plate current posts. It would then read directly 0-200 ma. You would have to power this from a separate power supply using a transformer to electrically isolate it, (or possibly a battery to power it). *(Or you could just routinely connect a multimeter or other current meter to the plate current posts.)*

3. It would also be relatively easy to add a digital panel meter to routinely monitor the plate or screen grid voltages or to add a more accurate digital DC voltmeter to replace or parallel the built-in analog control grid bias voltage meter. *(Again, the power supplies would have to be electrically isolated.)*

4. One could use two separate windings or transformers in series with or in place of the existing two 170 V windings to test at higher voltages and currents while keeping everything else the same. This shouldn't make much difference, but it would be interesting to know if, whether, and to what extent this might affect the actual transconductance readings and would't be too hard to do. If the extra H.V. transformers were fed from a variable AC voltage source (variac), testing could easily be done over a wide range of voltages, including the "tube book" values.

5. Another modification that is often suggested is to protect the bias/screen voltage supply with a (series) low current miniature light bulb (used as a fuse). That way, if the supply becomes accidentally shorted for any reason, it "blows" the bulb rather than doing possibly irreparable damage to the power supply components. I think this is an excellent idea and one of these days, I'me going to get around to doing it on my set!

6. I brought the 5Y3 power supply zero adjustment potentiometer R15 to

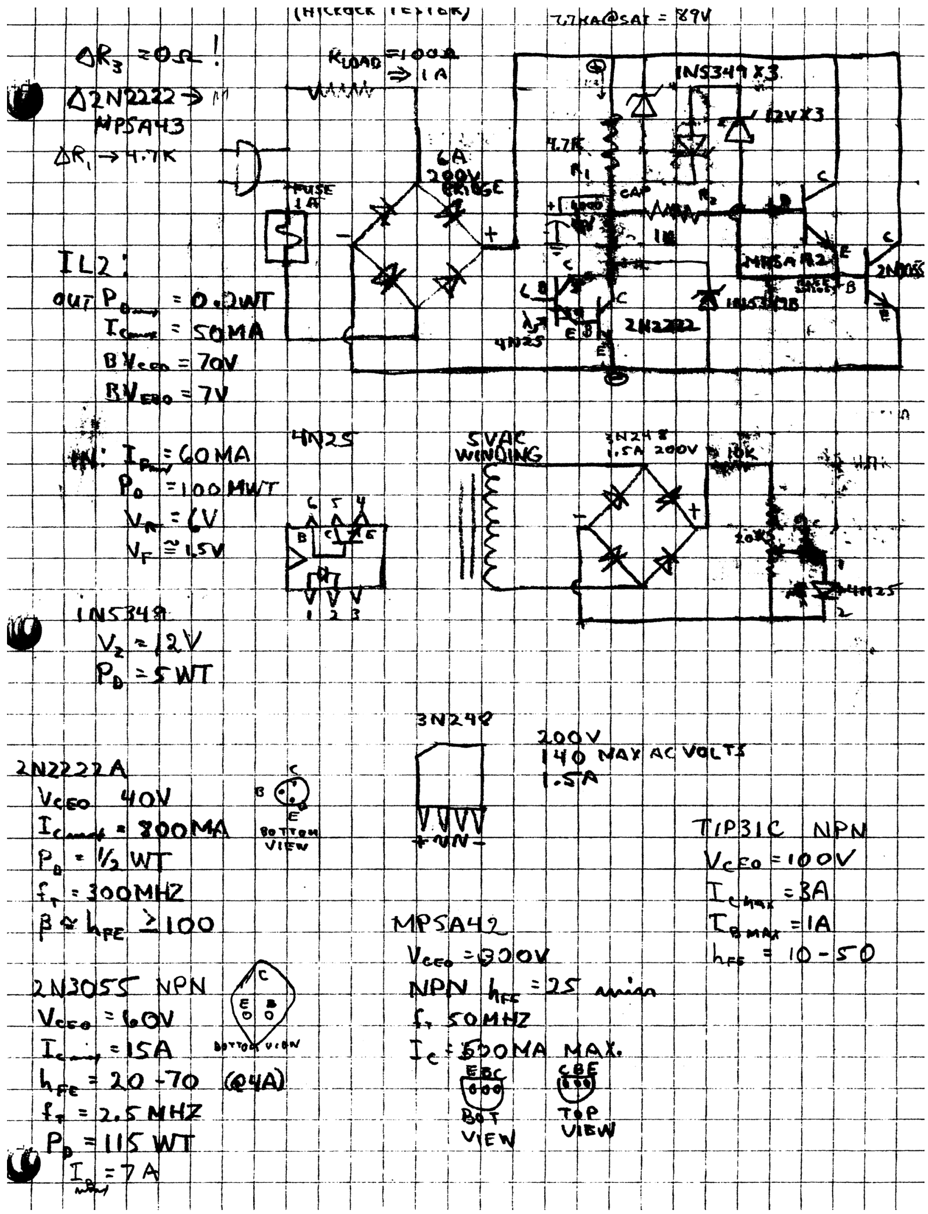

Figure 22: Circuit to automatically adjust the line voltage for a 539B in order to keep the control grid test voltage constant

the front of the set and put a switch on the front panel which allows me to zero the AC grid voltage signal to the tube I am testing in order to check the symmetry of the 5Y3 power supply and, if necessary, adjust the zero as measured by/on the transconductance measuring circuit (using the tube to be tested) just before I make a reading. This is important because I was not able to adjust my set to get a “good enough” zero on all the transconductance ranges simultaneously with a single adjustment of R15. Any offset remaining after calibration (which used a 10 K resistor - with no “multiplication”) is also “multiplied” by the transconductance of the tube under test and can sometimes be significant, and this modification allows me to easily and quickly compensate for this effect.

Comment: In terms of accuracy, this change turned out to be the second most important change after changing the transconductance measuring circuit resistance values (and using the corrected calibration values).

Important safety consideration if you decide to make this modification: Make very sure that the resistive elements of the variable resistor that you use are well insulated from the case and mounting hardware. *(Sometimes small value, high power variable resistors actually have the movable contact connected to the metal shaft and thus electrically connected with the mounting assembly and case.)* If so, or if its insulation fails, about 170 volts will be present at the front panel and thus dangerous and potentially lethal voltage will be present and could/would represent a serious safety hazard.

Additional Figures

Controversial Comments Section

This section reflects my opinions on various topics and things that I have seen on the internet that I consider to be noteworthy or, in some cases, egregiously wrong or incorrect. (And they are subject to change, especially if someone convinces me that I was wrong or if I come to think that there was a better approach or another way of looking at that topic.)

1. There is a claim (by “Randy Jamz” at at a site <tone-lizard.com>) that “Many testers, like Hickok, give chart numbers assuming you do not reset the ‘Line Adjust’ control; you set it immediately after inserting the tube (this gives you something to do while the tube is warming up), and leave this setting alone”. This may apply to some other Hickok testers but is misleading as it clearly does not apply to all Hickok testers and certainly not to this model Hickok tester.

   Even Alan Douglas missed this in his book on test equipment (column 1 page 6 where he says “However Hickok always specified making the line adjustment once, and the roll chart data assumes this.” and on page 10: “For models with separate line-voltage meters, or models whose line voltage can be checked during Gm test, it is tempting to reset the line under load, but Hickok never recommended this, and it may give misleading results for some tubes.” I pointed this out to Mr. Douglas on the Antique Radio Forums site and he acknowledged that that statement was an error in his book.

2. I have seen on the internet that there is one “expert” who says he measures the transconductance values for the “calibration tubes” he sells by measuring them immediately after pressing the “test” button because the values will change as the tube elements (especially the plate, he says) heat up and he apparently doesn’t want to wait “15 minutes” for everything to stabilize. The fallacy of this approach should be obvious. (Actually, this is a really bad idea for several reasons.) Also, if you are going to pay $65 + shipping for a calibration tube, in my opinion, you have a right to expect that the seller spends the extra time to make sure he has measured the values as accurately as possible, even if it takes him an extra few minutes!

3. From a site <Radiolaguy.com>: “BOTTOM LINE - If you value accuracy in your tube testing, save yourself some grief, it’s best to use the tubes.” As you have already seen by this point, correct calibration of the set is at least equally accurate if you use appropriate SS replacement tubes. If you use the above calibration procedure with the “correct” SS replacement, it is going to be **more** accurate because the corrected calibration values assume and are based on the SS replacement. The calibration is likely to remain stable for a much longer time too. *(I think the point that he was*

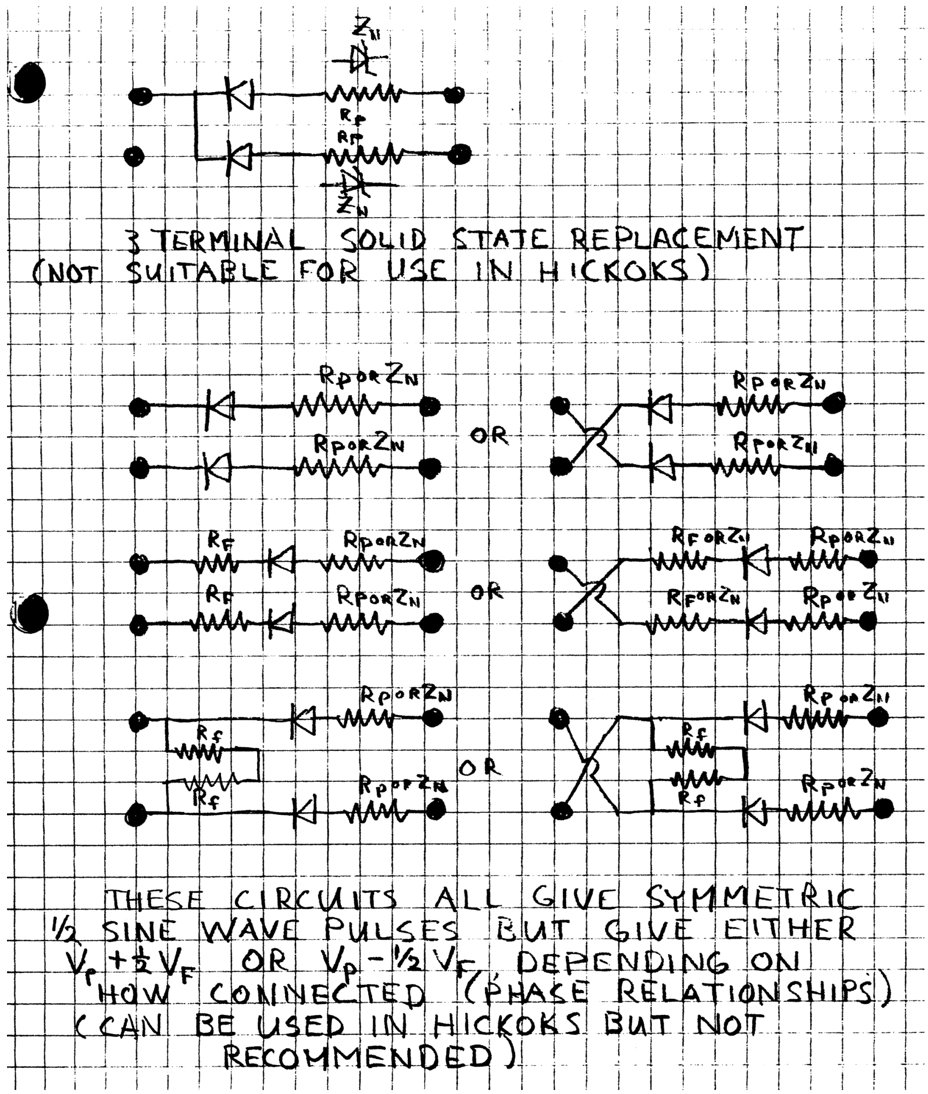

Figure 23: Some Rectifier Replacement Circuits to be Avoided

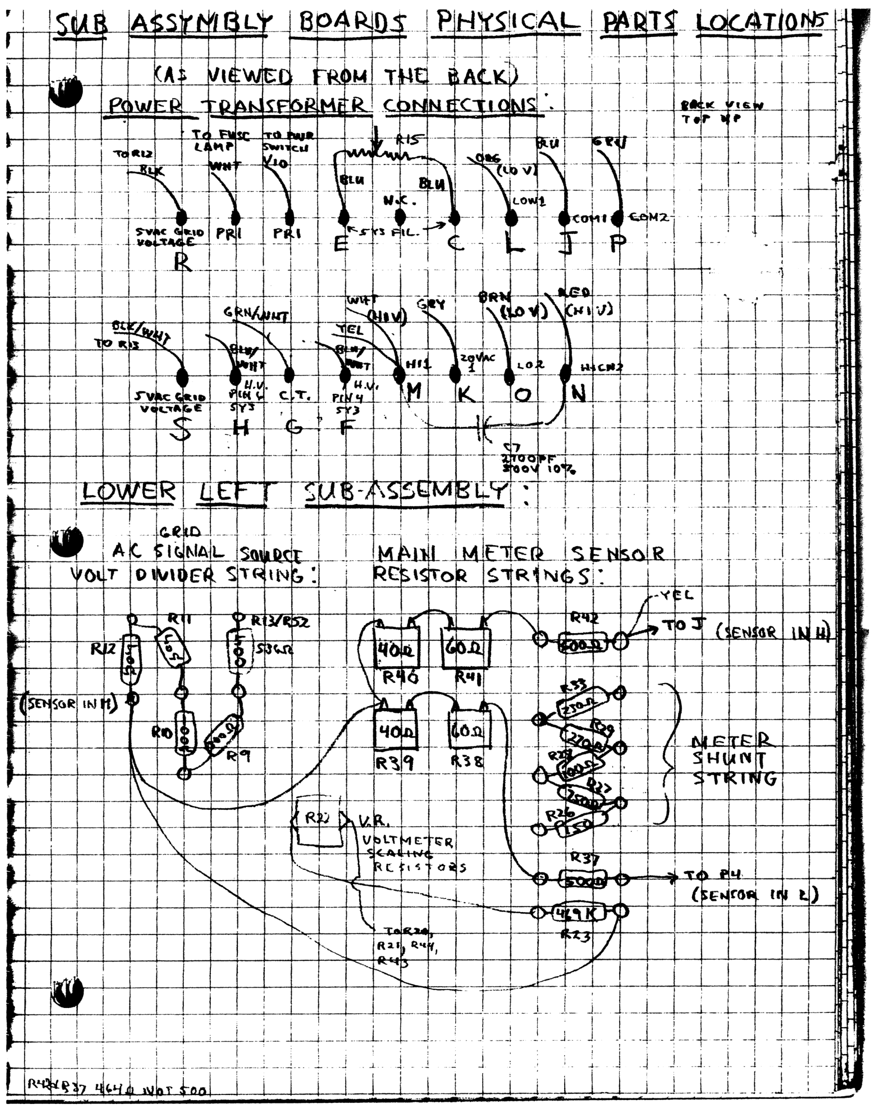

Figure 24: Subassembly Boards Physical Parts Locations, Part 1

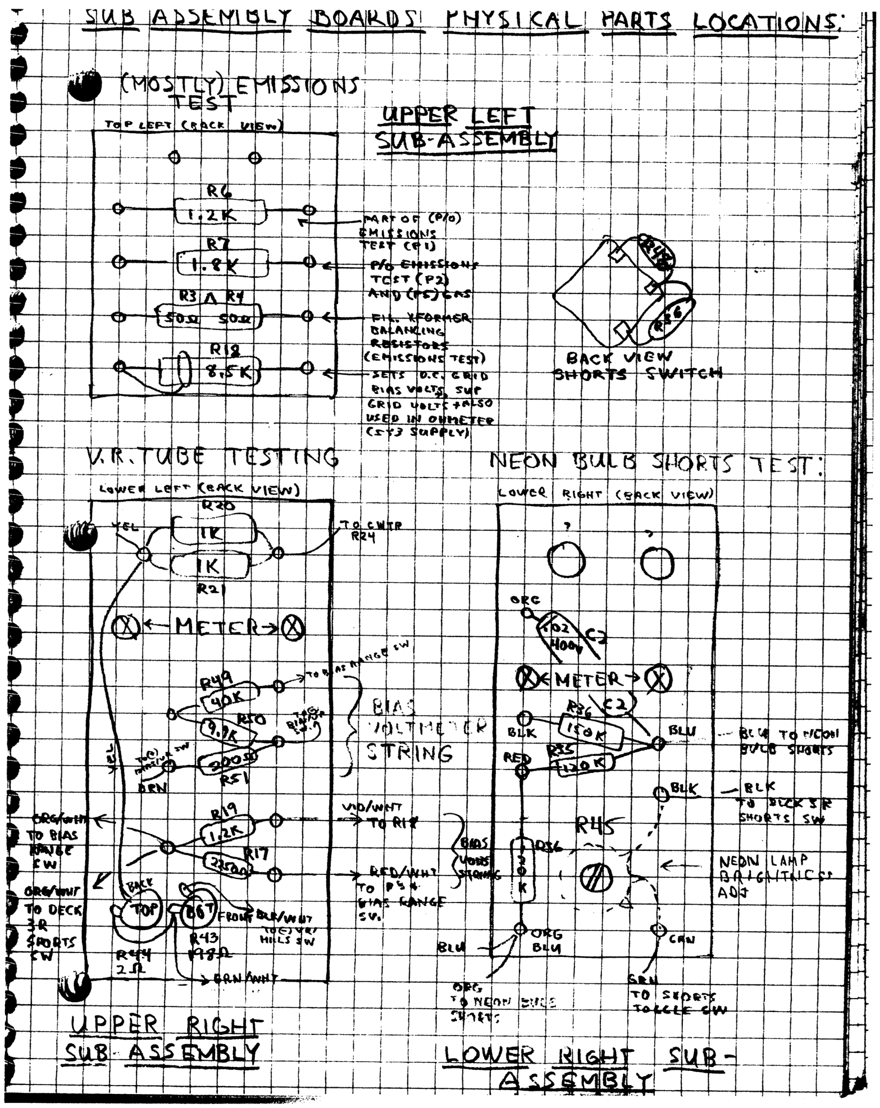

Figure 25: Subassembly Boards Physical Parts Locations, Part 2

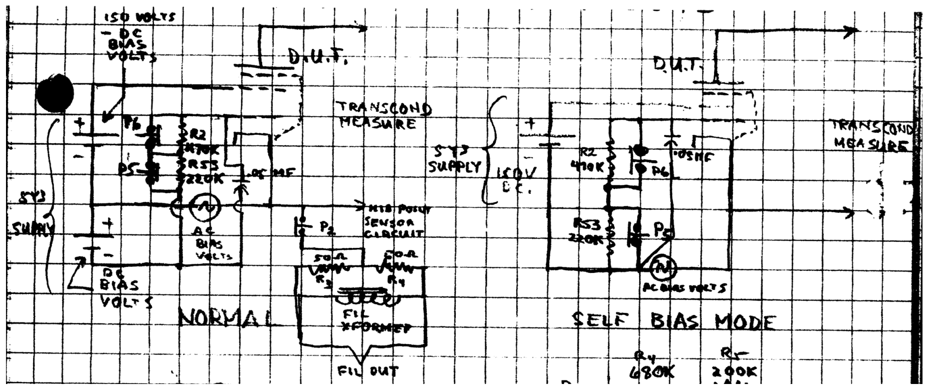

Figure 26: Fixed Bias Vs. Self Bias Configurations

trying to make is that some "randomly" purchased SS replacement is likely not to work as well as the correct rectifier tube, and in this respect, if so, I would agree with him.)

4. As yet another example of the mis-information on the internet, consider the following quote from a site called <Jacmusic.com>: "There is NO OTHER WAY to calibrate a Hickok or an AVO than use a precisely known tube." **This statement is absolutely untrue**. There is a lot of good information on this site and the author is clearly a very sharp individual, but, in my opinion, the above statement goes far beyond a mere exaggeration. It is just plain wrong! As has already been shown, there **is** another way (actually more than one), and in addition, **more** accurate! To me, this is yet another example of incorrect information being promulgated on the internet. *(It also appears that he is trying hard to promote his "calibration tube set" business.)*

5. Putting a trimpot in the "bridge" as Daniel Schoo did in his article (Audio Express, 2007) will allow yet another way of affecting the zero (as if you needed it!), but it also affects the transconductance readings of **all** the ranges (and the size of this effect will vary depending on the range) unless zeroed at the electrical center point (in which case it would be the electrical equivalent of not having put the trimpot in in the first place.) If you use it to compensate for bad adjustment of R15 of the 5Y3 voltage supply voltage peaks, you could get around this by reversing the phase of the signal on the grid and averaging, as mentioned in his article, but you will get exactly the same result as you would if you didn't put the trimpot in and simply had adjusted both R15 and R8 correctly to begin with! Besides, his results were from changing the phase relationships of the **filament** voltage, which suggests that something else was going on (a "hum" voltage coming somehow from the filament of the tube, presumably - see the An Interesting (And Puzzling) Heater Cathode Interaction section)

6. Here is an egregious - in my opinion - example from a site <audio-tubes.com>: "These hand selected NOS tubes can not only be used wherever the Hickok Reference 6L6 tube is called for in calibration procedures, but can also be used on **any** tube tester as a reference"new" 6L6 to check the accuracy of your tester. It is perfect for checking the results of your calibration on any brand of tester as well." They charge $65 for one of these "miracle" tubes! One could purchase a small isolation transformer, meter and resistors - most of what you need to calibrate a set accurately - for only a little more than the cost of one of these tubes.

   If you think this is an isolated example, consider the following from <alltubetesters.com>: "The tube is used to check accurate calibration on any tube tester and used to calibrate the tester." ... "6L6 Bogey tube measured at actual tube values compared to the manufacturers printed specifications. This tube is measured with two laboratory testers to an accuracy of 1.5% of the tubes true/actual Mutual Conductance (Gm) value."

Comments:

a. Both statements imply that there is a single "right" or "true" transconductance value, which, as we know, is **never** true in reality.

b. The second says that his results are comparable to the "manufacturers printed specification". The 1959 Sylvania tube book gives **seven** different "official" values for the transconductance of a 6L6 tube under various operating conditions, ranging from 4700 to 6000 micromhos! The lowest plate voltage for which I could even find a published transconductance value for a 6L6 was in the RCA tube book and was for 200 V. (In the 539B/C, the average plate voltage is about 150 V and the peak plate voltage is about 210 V.) The voltage vs. transconductance values are seemingly randomly related! The "book" value at 200 V and 300 V is 5300 micromho but half way in between, at 250 V, it is 6000 micromho and at 350 V it is back down to 5200 micromho. So here is another question to consider: If a 6L6 (or any) tube reads exactly the "book" value at, say, 350 plate volts, but something different from the "book" value at, say, 200 plate volts, does that mean that it is "good" or "bad"?

   This "official", very disjointed/discontinuous published 6L6 transconductance behavior data is is not what you would expect, all other things being equal. If you were to plot the tube book values for transconductance vs. plate voltage, you will get anything but the relatively smooth curve that characterizes essentially every other measurable characteristic of a tube. There are several reasons for this. For example, part of the answer may lie in the way the published characteristics were determined (see the SOme Facts About Transconductance From Back In The "Good Old Days" That May Put Things In Better Perspective For "Modern" Thinking section). Part of the answer probably relates to the fact that some of the data is given for usages that differ from each other. For example, the tube book gives transconductances for push-pull amplifier service for class A1, AB1, and AB2 applications as well as triode connected. Most of these would not would apply for a tube tester or for a curve tracer, as both evaluate a tube as if it were being used in simple, single-ended (i.e. non push-pull), class A1 service.

The over all point is that when someone says that his tubes or tester is/are checked (or matched) at “book” values, it may not mean as much as you might think or expect (or wish).

c. This second individual must have looked hard to find two “1.5%” tube testers that tested at sufficiently similar operating conditions to get the “same” measurement on very many tubes unless the testers were the same make and model. (It is also possible that he was simply persistent enough to go through a lot of tubes to find some that happened to be close to the same “book value” (or one of them) at whatever the conditions were that those testers used.) The point here is that, in my opinion, it is a waste of time and money (and effort) to even use a calibration tube when a better, less expensive, and more accurate alternative is readily available. At least his calibration tubes only cost $50.

   Personal comment: this person has obviously put a lot of thought into how best to generate and use his calibration/bogey tubes. It's just that a calibration tube is definitely NOT the most accurate way to calibrate a tube tester, at least not a Hickok 539B/C, for the many reasons already given.

7. Consider the following from what I consider to be the source of some of the most (in my opinion) outrageous tube “disinformation” on the internet. For example: “Most of the Tube Testers in circulation today were made for the mobile TV repair man. The good ones, like Hickok, did an excellent job of detecting bad tubes.”. . . “But detecting a bad tube is not the same qualifying a good audio tube, and that is what you must know before you buy.”. . . “The best way to test is to listen with the tube in the actual amplifier for an extended time. Unfortunately this is a very expensive and time consuming process. A close second is to examine the tube dynamic traces. Running a very, very distant third, fourth, and fifth is using a tube tester. If you are replacing a TV tube trust the Hickok. If you are buying audio or guitar tubes, you need better tests.” etc., etc., etc.

   This is from a site <www.oldstockaudio.com>. This person obviously possesses a fancy and probably expensive curve tracer. See the Is A Curve Tracer Better Than A Tube Tester For Matching Tubes? section for additional discussion of this topic. *(By the way, how does one “qualify” an audio tube, or any tube, for that matter?)*

   Personal comment: I consider some of the comments/opinions made at this site to be so greatly exaggerated as to be considered falsehoods, but some of the information at this site, for example the “Basic Vacuum Tube Amplifier

Design Principles", is very accurate and even helpful. The difference seems to be that in one case there is some expensive merchandise involved. As always on the internet one has to "consider the source" when evaluating the accuracy (or just about anything else).

This brings us to the next section, which is…

Who Is The Idiot That Wrote This And Why Should You Believe Anything He Says?

I initially intended to leave this section out because it might sound egotistical. Also, it might sound as if I never make mistakes, which couldn't be farther from the truth. However, the more I read on the internet about Hickok tube testers and tube testers in general, the more incensed I become at the level of inaccuracy. I suspect that most of these "experts" are technicians or people with even poorer technical backgrounds who are simply unable to understand the operation of the circuits or who just never bothered to undertake the effort involved to really "figure them out". Also, a goodly number of them just happen to sell calibration tubes or calibration services or have calibration devices for sale. "Consider the source."

So, me: I have been interested in electronics (initially tube electronics) since the 5th grade. I double majored in Physics and Mathematics as an undergraduate, initially at Columbia University in New York and subsequently at the University of Colorado. My graduate degrees are in Physics and Electrical Engineering. I worked for Texas Instruments and Dupont as an engineer and as Instrument and Electrical supervisor. I have experience in design and maintenance engineering and with analog and digital devices. I am now (happily) retired and so (finally) have some time to play with things like tube testers. *(And I'm not interested in trying to sell you anything!)*

I ended up spending a lot of time and effort on this project and my motivation is simply to share what I discovered and learned.

Some Final, General Comments

In the process of doing this project I have come to, and expressed above, several opinions that will probably be considered iconoclastic and may rub some people the wrong way, for example, the comments on calibration tubes and their use (or lack of) and the usefulness of solid state replacement rectifiers (and which might impact some of these "experts" in their pocketbooks). I make no apologies for this and I have tried to make clear what was opinion and what was not and to make clear why I espouse those opinions. It also may offend some people that I "dare" to disagree with some of the original Hickok engineering and calibration methods, but I've worked in similar environments and I can assure you that in the real world of engineering, that far larger mistakes make it "out the door" all the time, even from "good" companies!

I must say that there were multiple times that I thought that I had some part of the circuitry all figured out and the computer simulation showed that I was looking at it the wrong way and my "understanding" was completely wrong.

Furthermore, I also had the advantage of the “junker” set that made it easier for me to actually follow the wires when the schematic was wrong or unclear (or parts of it were missing). *(That is, I didn’t have to worry about damaging my good set to trace some obscure wire or connection.)*

I realize that much of the above discussions are rather technical, but I don’t know how to explain/use some of the concepts without being technical, at least to some extent. I have tried to “summarize” the results for those who (otherwise) lack the technical background and also to give the reasons/reasoning so that they can at least be assured that there were reasons behind the opinions expressed, and that they are not arbitrary opinions. *(They might be wrong, but they’re not arbitrary!)*

Some people seem to approach tubes and the devices that test them as some kind of “magical” or “mystical” devices. I don’t think that this is a very useful approach. I have tried in the above discussions to approach them using the same engineering concepts and methods that can be used to analyze (and design) any electronic devices, and which certainly includes tube electronic devices.

Mike Higgins

last revised 1/16/19

Version 0.6

Revision History

- Version 0.5: Revised figure 20. Removed italics from figure captions. Removed list of figures from html, added list of tables to PDF.
- Version 0.6: Restored in-line links in PDF, added page breaks to avoid `pdfendlink ended up in different nesting level than pdfstartlink` error.