

# CALIBRATION PRINCIPLES - HICKOK TRANSCONDUCTANCE TESTERS TV-10, TV-7.

A semiconductor based “ACS” – the Alternating Current Sink – 1000 $\mu$ Mho calibration tool.

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## Introduction:

The tester referred to in this article is a Hickock TV-10B, but the principles apply to all “AC types” of transconductance (*gm*) testers which operate on the principle designed & patented by Hickok, such as the TV-7 for example.

Types of *gm* testers using other operating principles are not covered in this article.

## Background:

Most vacuum tube enthusiasts like to know if the tubes they are running in their amplifiers or other equipments meet specification or have an acceptable value for *gm*.

An acceptable minimum value for *gm* is given by the manufacturer of the tube tester for any tube type. In the Hickok TV10 tester, this data is on a paper scroll built into the unit along with the knob/bias settings for each tube type. As original vintage tubes are becoming rarer, it is now customary to hang onto them, even if they are sub par for *gm* on the tester, rather than throwing them away.

A tube end user might want to match tubes for *gm* for push pull audio applications. The sellers of used vacuum tubes, particularly on Ebay, often provide the *gm* test results to help reassure the buyer that the tubes are in good condition.

A *gm* test is not the only test a tube can be subjected to, however, all around, as a *single* test, it is one of the more useful indicators of a tube’s condition. As a tube ages and loses emission not only does the average plate current for any grid bias fall away, so does the *gm* to varying extents depending on the tube type.

But how do we know that the *gm* test instruments themselves used by a tube seller or a tube end user, are in correct calibration and if the *gm* data is accurate?

One method is to have the *gm* tester sent to a Calibration Service from time to time for checks and adjustments and trusting the workmanship & skills at that facility.

One other option is to buy a “Calibration Tube” or CT with a known *gm*. The *gm* of the CT is said to be known, after being checked with various proprietary methods, or tested in other *gm* testers. The CT is then tested in your *gm* tester and the result, if not in calibration, can be used to recalibrate the tester or provide a correction factor.

The better brands of *gm* testers read the tube’s *gm* on their meters in  $\mu\text{Mhos}$  (micro-Mhos) as does the TV-10 and don’t just have a good-bad pass fail or a “relative scale system”. The Hickok TV-7 tester however, even though not calibrated in  $\mu\text{Mhos}$  on its meter face is such that 40 divisions on range B,D,E & F corresponds to  $1000\mu\text{Mhos}$ . So

it is possible to attain  $gm$  numbers from a TV-7 despite the way the meter face is calibrated. There are digital replacement modules for TV-7 meters available. These have an easier to read displays than the analog meter face, with finer resolution, but they don't affect the fundamental calibration of the tester which still must be made to be correct whatever type of meter is used.

The approach described in this article for accurate calibration of a Hickok tester is a semiconductor based device which I have called an Alternating Current Sink or ACS.

The ACS is easy to calibrate itself with nothing more than a digital DC meter. This means that the overall calibration of the Hickok tube tester can be as good as any modern digital meter, the calibration of which can be checked by an IC precision voltage reference if required.

### **What is Transconductance or $gm$ and how is it measured in Hickok AC style testers ?**

It pays to start at the beginning. The invention of the triode has been attributed to Lee De-Forest in 1906 when he placed a control grid into a vacuum diode. This version of history has been the source of a few heated debates.

Vacuum tubes, considering a triode for simplicity, have three fundamental parameters. These three parameters are the amplification factor or  $\mu$ , the transconductance or  $gm$  (also known as Mutual Conductance) and the Plate Resistance or  $rp$ .

Since conductance is the inverse of resistance it has been defined as the Mho, or Ohm spelt backwards. Typically, triodes have  $gm$  values measured in micro-mhos or  $\mu\text{Mho}$ , otherwise typical values would have to be quoted as 0.002 Mhos, which is more awkward than saying 2000 micro- Mhos.

The best way to explain triode parameters is to note that the plate current  $ip$  is a function  $f$ , of both plate voltage  $vp$  and grid voltage  $vg$ , because both of these latter parameters affect the plate current, symbolically then:

$$ip = f(vp, vg)$$

Or stated in plain English, the plate current is a function of both the plate voltage and the grid voltage.

Three basic parameters therefore emerge for a triode with a small change in plate voltage  $dv_p$ , a small change in plate current  $dip$  and a small change in grid voltage  $dv_g$ . If one variable is held as a constant, the ratio of the other two creates the measured parameter:

$$\frac{dv_p}{dip} = r_p \quad \text{Plate resistance (grid voltage constant)}$$

$$\frac{dip}{dv_g} = gm \quad \text{Transconductance (plate voltage constant)}$$

$$- \frac{dv_p}{dv_g} = \mu \quad \text{Amplification factor (plate current constant)}$$

The reason for the minus sign for the amplification factor is that when the grid voltage moves negative the plate voltage moves positive.

The above relations lead to the well known equation for the triode:

$$\mu = r_p \cdot gm$$

We see now that the  $gm$  represents the small change in plate current generated by a small change in grid voltage and is the ratio of the two, or is also the ratio  $\mu / r_p$ .

A  $gm$  measurement on a triode, in a tube tester, involves setting the *grid bias voltage* to some average value (recommended by the manufacturer) to set the tube up on part of its transfer function curve of plate current versus grid voltage. Then applying a small *grid modulation voltage* (the equivalent to  $dv_g$ ) and then measuring the alternating plate current (equivalent to  $dip$ ). The  $gm$  therefore being  $dip/dv_g$  and represents the slope of the plate current versus grid voltage curve, at the selected grid bias point.

(In the case of Pentodes or other multi-grid tubes, the other grids are supplied with appropriate voltage by the tester)

This sounds simple enough. However, in real AC type tube testers such as the Hickok, the *grid bias voltage* is not a steady DC level, it is full wave rectified AC (which is best called pulsed DC). This takes on some interesting characteristics when added to the

*grid modulation voltage*. Also the “DC” supply voltage to the plate circuit of the tube is also pulsed DC. Despite this, the basic principles remain the same.

Figure 1 below shows a simplified version of the *gm* test system invented and patented by Hickok. The Hickok system is ingenious due to the meter bridge system and the use of AC voltages and pulsed DC voltages supplied directly by **one** mains operated power transformer T101:

### Hickok Transconductance testing system:

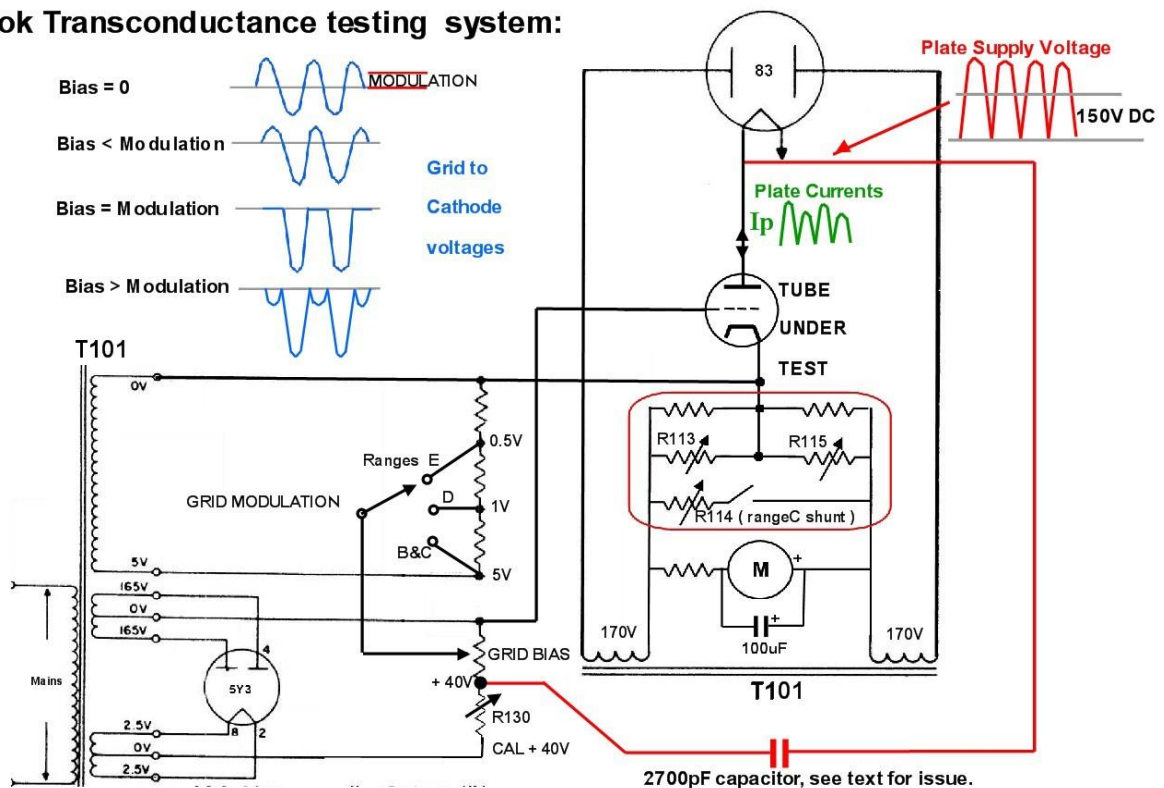


FIGURE 1.

Due to the fact that all of the voltages used inside the Hickok tester are derived from the one precision wound power transformer (it's a masterpiece), then when one voltage is correct so are all the others throughout the tester. A rheostat in series with the transformer's primary winding allows this adjustment, regardless of the exact mains or "Line Voltage".

It could be tempting to assume, that to satisfy the definition of  $gm$ , that the tester would measure the alternating plate current and the alternating grid voltage and divide the grid voltage into the plate current and compute and display that value of  $gm$  on the instrument's meter. This is not the case. Hickok's designers realised that such a computation notion, involving a mathematical division of data, was completely unnecessary. (A division of digital data or analog voltage is easy with modern electronics, but it is more difficult and sometimes cumbersome with vintage electronics).

Instead, Hickok's solution was not to calculate a ratio at all, but merely fix the grid modulation voltages in the instrument at exact levels for all tube testing at the recommended bias points on each of the meter ranges. This way the grid modulation voltage is made a *constant* and no ratio calculation is required. The only requirement then being the accurate measurement of the plate circuit difference currents on alternate half cycles. The correct grid modulation voltages are always present in the TV-10 (or TV-7) instrument when the LINE (mains) voltage is set *correctly* (see below).

So it might be a surprise for some to learn that the Hickok  $gm$  tester calibration principle is not actually based on a  $gm$  test of a  $gm$  device at all, but primarily based on accurate measurement of difference currents in the meter bridge circuit.

### **The implication of the above is as follows:**

1) Due to the fact that the grid modulation voltage in an AC type tube tester is a constant (or can easily be made the correct value by alteration of the LINE control) and the DC bias voltage easily checked to be standard with a meter and is also easily adjusted to be correct, then a calibration tube or CT, is not actually required or useful for calibration of a Hickok  $gm$  tester. To use one adds additional variables.

2) A better calibration device or tool would simply supply or generate the correct value of alternating plate difference currents to check the calibration of the meter bridge circuit. This is a job for an alternating current sink or ACS. This device is simply calibrated with a DC meter. Hickok's calibration method, also satisfactory, requires an external 50V rms transformer controlled by a variac and a 10K power resistor.

At best, a CT can only be regarded as having a reasonable approximation to its stated  $gm$ . The testing methodology varies between testers and the tubes themselves are subject to warm up drift and ageing. The main point being though, a  $gm$  error value as it relates to compatibility with the Hickok tester's conditions, if there is an error present, is *not measurable* by the end user of the CT and *unknown* to the end user of the CT.

One could argue though that many DC digital meters have errors and not be in calibration, but at least it is easy to check the meter against a precision voltage reference IC to confirm the values displayed by the meter are sensibly accurate.

### Standardization of Grid Modulation & Bias Voltage in Hickok testers:

The grid modulation voltages are fixed and known values in the Hickok TV-10 for example, they are 5V, 5V, 1v and 0.5V rms AC signals on the available test ranges B,C,D & E respectively. For example Hickok specified the tolerances of all of the voltages in their tester (derived from the one power transformer) measured at the Noval socket, when the Line voltage is set correctly; figure 2 below:

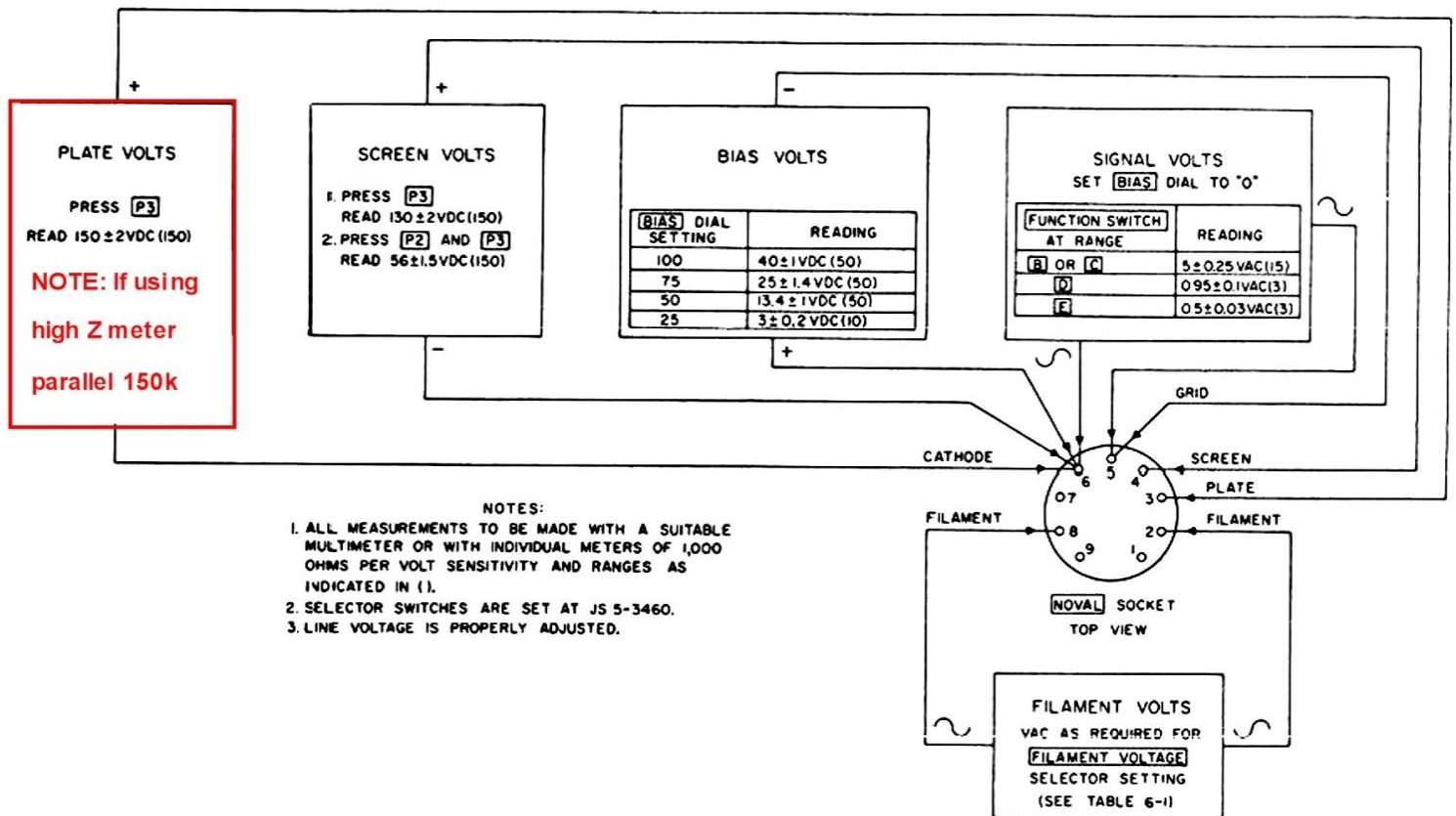


FIGURE 2.

To set the LINE voltage correctly simply set the Bias knob to zero, set the meter range to B. Measure the AC rms voltage with a digital meter between pins 6 and 5 of the Noval socket on the TV10 and adjust the LINE voltage control until it reads 5V +/- 0.25V. It is best to adjust it to 5.0 +/- 0.1V. That is the correct LINE setting. Ranges D &

E can be checked to be 1v and 0.5V respectively. These are simply set by the ratio of fixed resistors in the unit across the 5V output from the transformer.

If, after the LINE voltage is set this way, then pushing the ADJUST LINE button does not result in 50% deflection of the meter, then R134 in the LINE meter circuit needs adjusting. This is done so that 50% deflection on pushing the Adjust Line button corresponds to the correct grid modulation voltages at the tube socket. In some Hickok units, as the diodes (CR101) age, the value of R124 might require adjusting (with a parallel resistor) if R134 is out of range. In all Hickok testers, the 100uF electrolytic capacitor in parallel with the meter should be replaced unless it has already been in recent years.

The Meter LINE TEST circuit is shown in figure 3 below:

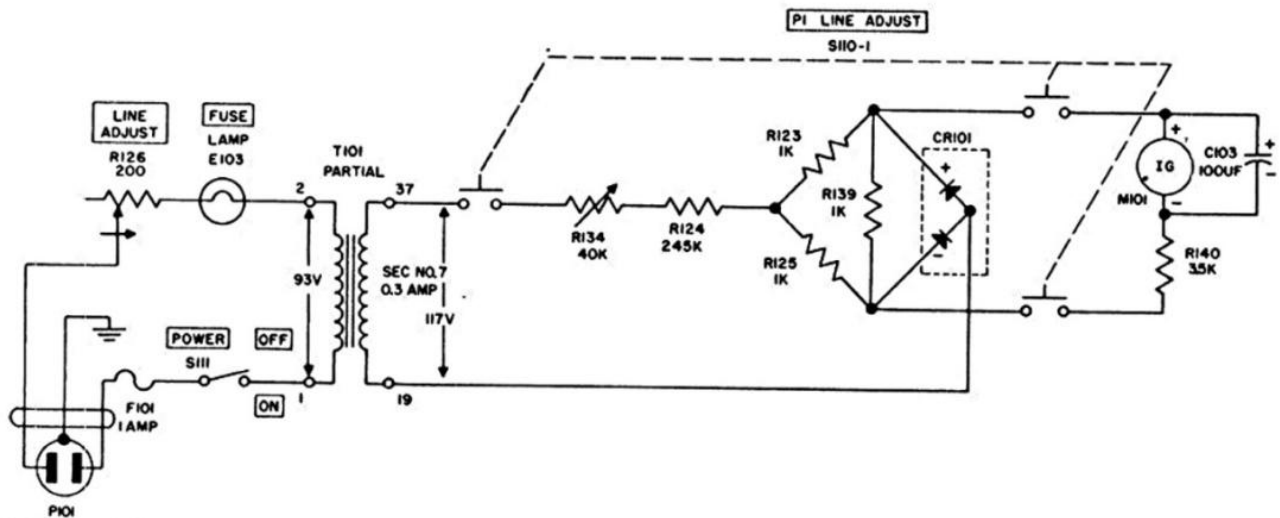


FIGURE 3.

### How Hickok's Transconductance Test works:

The grid modulation voltage results in an increase and decrease of grid voltage on alternate half cycles and therefore the tube under test has an increase and decrease of plate current on alternate half cycles. Hickok's circuit configuration for their meter bridge results in the meter coil current flowing in opposite directions on alternate half cycles. The result being that the average value of meter deflection is proportional to the ***difference between the average plate current*** on each half cycle.



The resistors inside the red box in the simplified circuit diagram of Figure 1 are the calibration resistors and not all fixed resistors are included for simplicity. When a known plate current difference on alternate half cycles is applied during the manufacturer's recommended calibration procedure (or with the ACS described in this article) the calibration pots R113, R114 and R115 can be adjusted.

Since the bias voltage is full wave rectified DC that is added to the modulation voltage which is AC, the grid to cathode voltage can take on an interesting appearance depending on the relative values of the two voltages. Some of these combinations are shown in figure 1 with the waveforms drawn in blue.

Obviously with this system, for it to be accurate, even if the meter bridge resistors are perfectly set, the measurement relies on the assumption that the grid modulation voltages and bias voltages are correct.

The absolute value of plate voltage is less critical, though it is closely correlated with all the other voltages because it is derived from the same transformer that powers the entire tester. However, it does fall a little under load during a *gm* test and this fact was taken into account in deciding which ACS circuit design might be the better one.

### **Before Moving On - Three Interesting Considerations:**

*1) The calibration test setup in the TV-10 manual suggests measuring the 150V DC plate supply rather than the 5V modulation supply when calibrating the LINE test. This also works but beware that if a high input impedance meter is used it will give a grossly high reading around 190V. This is because the 2700pF capacitor stores charge between the voltage pulses elevating the average DC level. It wasn't a problem with 1000 Ohm per volt vintage meters used by service engineers at the time for calibration because the meter itself discharged the capacitor. Placing a 150k resistor in parallel with a modern digital meter (or the 2700pF) capacitor solves this problem, so that a modern digital meter can be used.*

*2) When a meter (digital or analog technician's lab meter) measures AC voltage, it normally displays rms voltage. This is a voltage value which produces the same heating effect, as the same value of DC voltage applied to a resistor. For a sine wave this rms value is about 70.7% of the peak value of the sine wave.*

*When a sine wave is subject to full wave rectification however the resultant wave peaks twice per cycle. It still has the same rms heating effect if applied to a resistive load (ignoring rectifier voltage drops) as the original AC it was derived from. It is just that the*

current flows in the same direction on each half cycle rather than in opposite directions on each half cycle like it does with AC.

However, since full wave rectified AC is now a version of “pulsed” direct current, then a DC meter must be used to measure it. The value of the DC voltage displayed by the meter though, in this case, is the **average** of the voltage. This is lower than the rms value of the AC voltage that the pulsed DC wave was derived from. The average for a sine wave is about 63.7% of its peak value .So the average value is about 90% of the rms value.

Moving coil meters automatically average (integrate) or smooth out pulsed DC. So for example when the “DC” plate voltage in the tube tester is measured at 150v on the DC range of the technician’s meter, the peak voltage there is about  $150/0.637$  or 234.48v.

Due to mains sine-wave distortion, it is unwise to measure the waveform’s peak on a scope and multiply by 0.637 to attempt to calculate an average voltage because the distortion corrupts this test and calculation. The better way is to use a DC meter which averages the value of the pulsed DC waveform even if there is distortion present. The same averaging occurs with the actual uMho meter in the tube tester.

3) The average value of **half wave** pulsed DC is  $0.637/2$  or 0.3185 of the peak value. A DC meter measures exactly half the voltage on half waved pulsed DC as it does on full wave pulsed DC. This feature is used as a way to calibrate the ACS by measuring the voltage across 2k0 resistors because the currents in each arm of the ACS device are **half wave** pulsed DC so the scale factor here is 1V per milliamp using a 2k0 resistor, just as it is 1V per milliamp for **full wave** pulsed DC current if the voltage is measured across a 1k0 resistor.

### **Calibration of a TV-10 tester, according to Hickok:**

The first task, as noted above, is making sure the grid modulation voltages are correct (or the 150V DC level is correct) when the Line test shows 50% deflection on the meter.

Once that is done, Hickok recommend setting the maximum bias voltage with the bias control set to 100 by adjusting R130 (as shown on figure 1) to attain +40V +/-1V bias supply. This is measured at the grid & cathode or pin 5 & 6 of the Noval tube socket. It is better to do it on range D as there is less of a % AC disturbance from the grid modulation voltage. R130 is a wire wound resistor with sliding taps. It also has (not shown in the simplified diagram) two other taps at 56V and 130V for screen supply voltages for testing pentodes and these voltages can also be checked and the taps moved as required.

Once the above is done it is then a matter of adjusting the calibration resistors (potentiometers) in the meter bridge circuit shown in figure 1 so the meter has the correct sensitivity to un-balanced *average* AC currents.

To achieve this Hickok recommended to start on range B (3000 $\mu$ Mho scale) and to set (with the instrument de-powered) the resistance measured across R113 and R115 both to be 41 $\pm$  0.41 Ohms. Then they suggest using a 50V rms AC signal (derived from an independent external transformer with variac control to get it accurate) with a series 10K (10W) resistor connected into the plate & cathode connections on the noval socket.

RMS calculation: With the 50Vrms transformer and the 10k resistor, it produces a 50v rms alternating voltage via the meter bridge circuit with an alternating rms current of 5mA. Since on range B the alternating grid voltage is 5V rms, then the *gm* is simulated at 5mA/5V or 1000 $\mu$ Mhos. (This is true, but it is better to work with **average currents** because that is what the actual meter circuit reads - see below). If the meter reads higher than 1000 $\mu$ Mhos then R113 is adjusted. If the meter reads lower then R115 is adjusted so that the meter displays 1000 $\mu$ Mhos on the B meter scale.

The meter is then switched to range C. This applies a preset potentiometer R114 as a shunt to the meter bridge circuit halving its sensitivity, so the meter deflection should drop in half and display 500 $\mu$ Mhos on the same B scale, if not R114 is adjusted.

Another method to check range C is to set up a 6L6 tube on range B with a *gm* test, and adjust the bias control for 3000 $\mu$ Mhos seen on range B, then switch to range C and it should show 1500 $\mu$ Mhos on the range B scale (in other words, half the sensitivity on range C). Both ranges D & E have the same meter network variables as range B. So on both of these ranges the meter should still show 1000 $\mu$ Mhos read off on the meter's B scale.

### Average Meter Currents:

When the 50V **rms** external transformer signal, current limited by the 10K resistor, is added to the pulsed DC plate supply voltage for Hickok's suggested calibration method, the overall voltage waveform becomes unbalanced.

One point to keep in mind is that the meter movement itself in the tester, or a DC meter used in calibration, responds to **averages**, not rms values. Figure 3 below shows approximately what happens when the 50V rms calibration signal is added to the pulsed DC plate supply voltage:

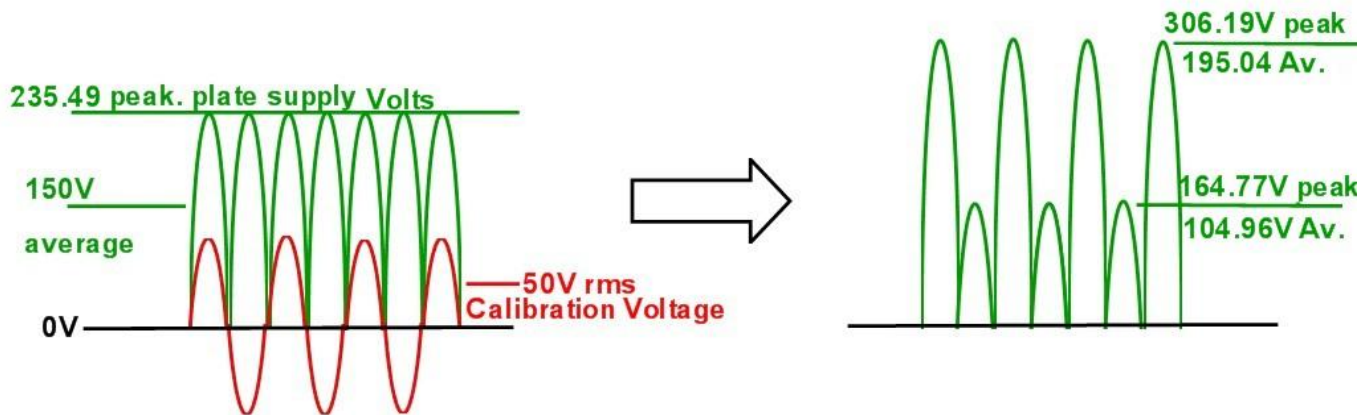


FIGURE 3.

It turns out that the *average* voltage on each half cycle is 195.04V and then 104.96v. The average meter current is very close to 19.504mA on one half cycle and 10.496 mA on the next half cycle or a dynamic change of 9.008 mA average current from one half cycle to the next.

The dynamic grid voltage is specified at 5V **rms AC** on range B. But one cannot compare apples with pears. This means that for any ratio calculation it must be average values compared with average, rms compared with rms, peak with peak etc.

5V rms has an average value of 4.504V. So it has a dynamic range +/-4.504V or 9.008V average volts comparing each half cycle. So by definition the *gm* is: 9.008 *average* milli-amps divided by 9.008 *average* volts = 1000 $\mu$ Mhos.

*So very close to 9mA of unbalanced **average current in the meter bridge circuit** corresponds with 1000uMhos on the meter scale if the meter bridge circuit is properly calibrated.*

Of course this is the meter bridge circuit current, the actual current via the meter movement is much lower.

Another way to have derived these values is to note that the ratio of average to rms voltage is  $0.637/0.7071$  or very close to  $0.9008$  So that a difference in 9mA (not 10mA from the rms calculation) on alternate half cycles in the meter circuit should display 1000uMhos on the meter in ranges B, D and E and 500uMhos on range C.

If an alternating current sink (ACS) is made, it must operate on the principle of **average currents**. This fact turns out to be very helpful because it means the ACS can be easily calibrated itself, with a DC meter.

### **Hickok Tube Tester Calibration with an ACS:**

The ACS described here is simply used during the calibration process at the point Hickok suggest using a 50V rms source and a 10k power resistor. Instead the ACS device is simply plugged in. It does not require the separate variac voltage controlled mains transformer to get exactly 50V rms or the 10k 10w resistor recommended by Hickok. , instead it is powered by the tester itself.

The ACS device is a plug in module which generates a standard 9mA alternating **average** plate current difference in the meter bridge circuit. This can be achieved with a two transistor circuit which can make use of the heater voltage provided at the test tube socket to co-ordinate its activities. This works because the heater winding on the main power transformer (for voltages below 12.6V) has a 100R centre-tapped resistor connected across it, the tap connects to the tube under test's cathode.

Otherwise, if the actual grid modulation voltages were used as a signal source to drive the transistors, then it would require an additional transformer with a centre-tapped secondary and additional semiconductors/parts to reduce the loading on the grid to cathode voltage supply which has a much higher source impedance than the heater supply.

Also, a good voltage for this application is to set the heater voltage switch to 10V (see reasons below).

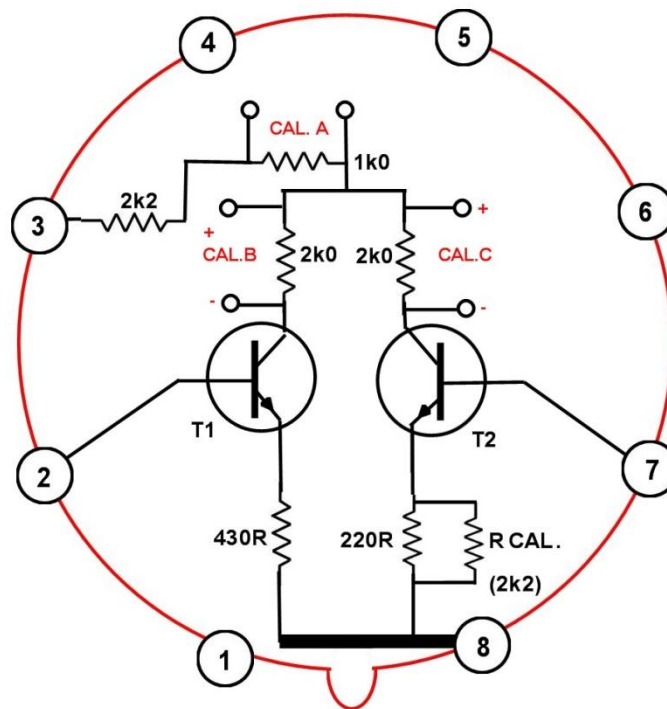
The ACS is built on an octal base, so the tester can simple be set to the settings for a 6J5 tbe, but the filament switched to 10V instead of 6.3v and the device plugged in and

the mutual conductance button pushed. If in calibration, the tester's meter will read exactly  $1000\mu\text{Mho}$ 's on the B scale with the range switch on either B,D or E and  $500\mu\text{MHO}$ s (again read on B scale) if the range switch is on C.

(Don't forget after using the ACS or testing any tube in a *gm* tester with higher than 6.3 volt heaters, it always pays to set the heater voltage knob back to 6.3 volts as a habit, to reduce the chance of accidental over-voltage of the heater on the next real tube tested)

The diagram below shows the circuit for the ACS:

**1000  $\mu\text{Mho}$  ALTERNATING CURRENT SINK.**



Octal base bottom view.  
CAL A, B & C and T1 & T2, see text.

**To ensure the ACS unit is accurately calibrated itself:**

As is usual the LINE test is done and the meter set to 50% (assuming this has already been calibrated so that a 50% meter deflection on the Line Test corresponds to a 5 +/-

0.1 V rms grid modulation voltage on meter ranges B or C). Then a digital DC meter is placed across the connections CAL.B of the ACS and the Mutual Conductance button pushed. The measured voltage will be close to 9V, call this value "CalB" and write it down.

(9 volts measured across the 2k0 corresponds to 9 average milliamps because it is half wave pulsed DC. This was one purpose of using 2k0 1% resistor as a value here, making it 1V per average milli-amp scale factor).

Then move the meter to CAL.C and push the mutual conductance button. The voltage measured here is set by the resistor combination in T2's emitter, and adjusted to be a value of ("CalB" + 9V) which works out at a CAL C voltage of around 18V.

This means that the *difference in the average* currents flowing via T1 and T2 is 9mA on each half cycle. The value for T2's emitter resistor in my unit was very close to 200R so a 200R could be used, or fixed combination of resistors works, or a series 150R and 100R pot can be used in T2's emitter instead. I tend to avoid trim-pots and use fixed resistor combinations once the exact value is known.

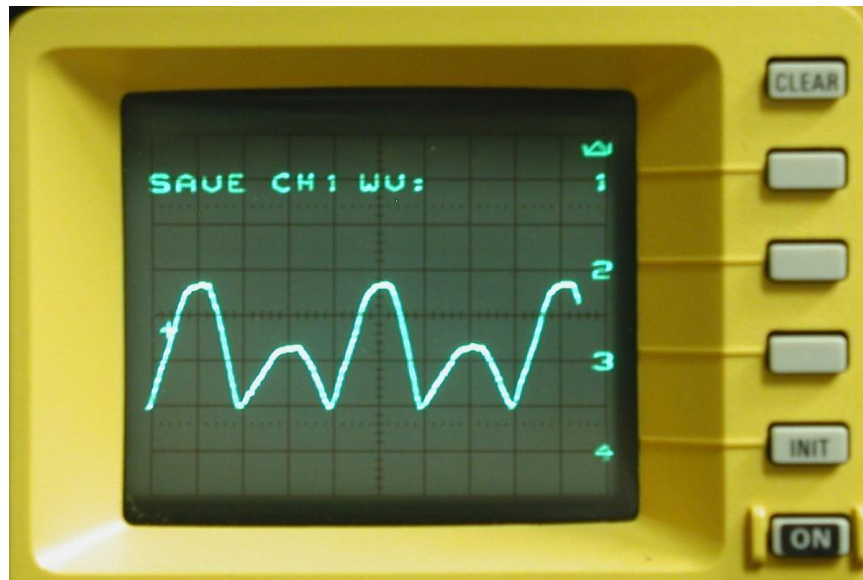
Once the ACS is calibrated then likely it will stay that way, but it could be checked easily again. When plugged into the tester (don't forget the heater voltage is set to 10V to use the ACS) and the mutual conductance button pressed, the meter should show 1000uMho's on ranges B D & E and 500 uMho's on range C, if not then R113,R115 and R114 in the meter bridge circuit require adjusting.

The transistors T1 and T2 used in the ACS must be 300V to 450V rated NPN silicon types and about 5W capable at least rather than being signal transistors. I simply used some vintage TO-66 2N6079's because I'm fond of the TO-66 package. And for this application they don't require a heat sink. The resistances in the collectors do not determine the collector currents. They allow easy measurements and also lower the collector voltages taking dissipation away from the transistors (shifting heat to the resistors) and also providing current limiting in the event of failures or shorts. 1/4 watt metal film resistors are fine for the unit throughout except for the 2k2 which is better a 1 or 2W metal film type. The 2k0 resistors should be 1% metal film types.

There is the possibility in a tube tester that the phase of the heater windings could be reversed. If this was the case the meter would deflect backwards, if that happens then T1 and T2's base connections would need to be swapped.

The CAL A test point is only for interest's sake. It is not needed to calibrate the ACS. It allows a simultaneous scope view of each half cycle of current. To look at this requires a completely isolated scope. I have the Tek Power Scout for this. The earth and the probe tip can be connected anywhere in nearly all circuits as they are both high voltage

isolated. The recording below is the voltage measured across the CAL A connections with the ACS running. This is the same pattern of anode currents seen when the Hickok tester tests a tube's *gm*:



### How the ACS works:

The transistors T1 and T2 are configured as programmable current sinks. The current is programmed by the voltage applied to the bases and developed across the emitter resistors. This is one reason the 10V rms AC drive signal is selected rather than just using the common 6.3V. This allows the emitter voltages and emitter resistors to be as high as possible in value. This minimises the proportional effect of changes in base-emitter voltage with temperature and minimises the Early Effect. Yet, at the same time, not so high in drive voltage that there is the risk of zenering of the B-E junction when the junction is reverse biased and the transistor cut off on the next half cycle, when the other transistor is conducting.

One important feature of a current sink or source is that the programming voltage is sourced from a low internal impedance supply. It certainly is in this case as it is sourced from the heater supply transformer in the tester present, at the tube socket.

*The ACS is quite unique as a calibration tool because the ACS itself can be calibrated in the same tube tester (with the aid of a digital meter) which the ACS is then used to calibrate after that. This also means if there is any systematic offset voltage, say of the 10V heater supply voltage with respect to the standard grid modulation voltages in the*



particular Hickok tube tester (due to small differences in the mains transformer), this effect is cancelled. There shouldn't be any differences here as the voltages are derived from the same precision transformer, but it is not impossible. This is quite different than using a calibration tube, where the tube is calibrated in someone else's tester and associated the variables increase and are unknowns.

The photo below shows the ACS checking the calibration on my Hickok TV-10:



### Can the ACS design be improved?

There are many ways to improve a current sink or source and the question is for the specific application are the additional parts worth it, or will adding parts improve the

performance ? When a simple circuit like this is presented its tempting to think that it could be improved for one reason or another. But there is an interesting history sometimes behind a simple looking circuit. I have built many other versions before settling on the ACS described in this article.

### 1) A more elaborate Current Sink ACS ?

I used a two transistor configuration (4 total) to pin the collector voltage of T1 & T2 at a fixed voltage to eliminate the Early Effect (the dependence of  $V_{be}$  on the collector voltage). This is the Cascode configuration. This also eliminates the Miller Effect, but not important here as it is not an RF circuit. There was no practical improvement or advantage, it just used more parts.

### 2) A Switched Current Sink ACS ?

Another version was trialled with three transistors on each side, or a total of 6 transistors. Two of the transistor's switched in a constant current sink on alternate half cycles. Each constant current sink was composed of the typical two transistors with a current sensing resistor to generate the  $V_{be}$  for one transistor to turn off the other. Again no practical improvement was detected, just more parts used.

### 3) A Switch-Mode ACS ?

Yet another version which simply used two transistors in a saturated switching mode, driven by the heater voltage supply, to switch in two resistor values for 9 and 18mA on alternate half cycles. However, during the  $gm$  test, the plate supply voltage falls with load and the amount it does partly depends on the condition of the 83 vapour rectifier in the particular Hickok unit. Though this method does work and also has minimal parts, it would be less likely that an ACS calibrated in one Hickok tester would also be in perfect calibration in another, because of that variable. With the programmable current sink method, the actual value of the plate voltage is not very important.

#### 4) A Mosfet ACS ?

It might seem intuitive to try to build an ACS with high voltage mosfets because they are in essence a *gm* device. The common reflex reaction many Engineers have to a circuit with BJT's always seems to be "I could build a better one with mosfets". However the biasing to get these to work from the signals at the tube socket in the tester is awkward and requires capacitors and more resistors and some diodes.

One benefit of the BJT's driven by the heater supply voltage is that the input threshold being so low (0.6V) allows the ACS to generate controlled pulsed DC currents over nearly the full half cycle with minimal component count. Also to remind oneself, that the basis of Hickok's *calibration principle* is not actually to "*gm* test" a "*gm* device" at all, but instead it is based on accurate measurement of alternate half cycle difference currents in the meter bridge circuit.

#### 5) A Tube ACS ?

Once again this returns to the notion of a CT. And the same issues as a mosfet ACS apply. But in this case a twin triode can be configured or wired as an ACS with alternate half cycle plate currents so it can pass itself off for a single triode under test. Then its real calibration can be properly checked because the alternate half cycle plate currents can be measured for each triode section across a 2k0 resistor, with a DC meter. This again needs more parts to assist the tube bias and is more complex than required and not as stable as the transistor ACS presented here.

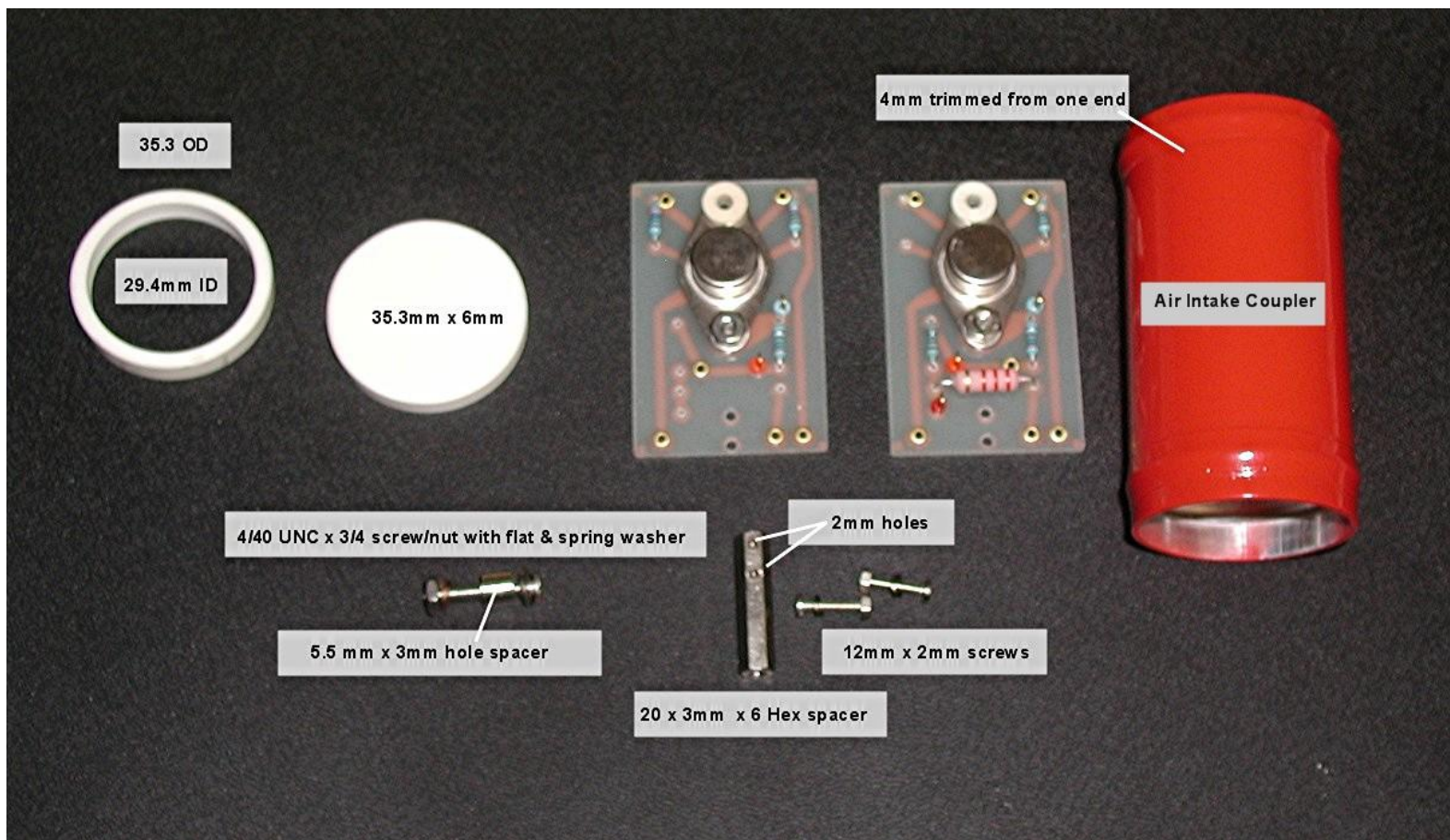
So the ACS presented here beats all my other versions for the combination of performance, simplicity economy of design.

## Physically building the ACS:

Due to the fact the ACS is a simple circuit it could be built in a number of ways. For a quality job though it is better built into a metal housing with an octal base.

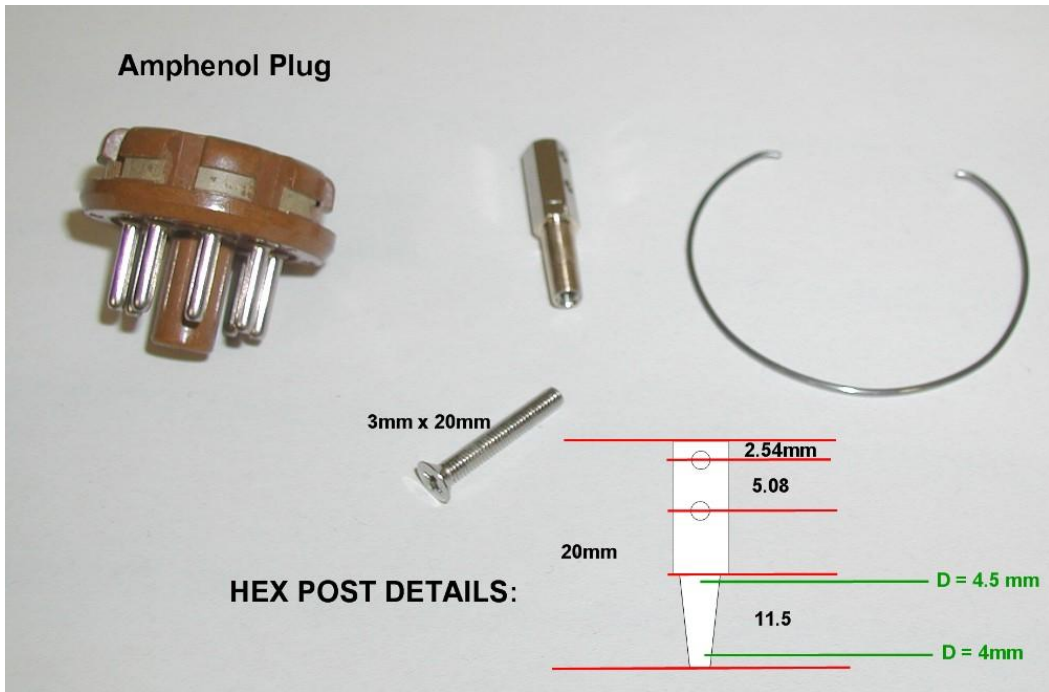
The photo below, sans the octal base and the spring clip that retains it, shows the basic parts required. The PCB's were made with iron on film printed in a Laser printer and etched with ferric chloride. Brass rivets (1.6mm diameter) are used where the wires attach in lieu of plated through holes.

The aluminium tube is a common piece of motorcycle air intake coupler. 4mm was trimmed off one end and the coupler painted with high quality VHT red paint and oven baked. The white insulating material is a unique Australian 6mm thick insulating material called Bramite (now rare) but Paxolin or Fibreglass or many other plastics would suit. The PCB's have test points across the 2k0 resistors for calibration:



The 35.3 X 29.4 x 6mm ring is attached to the octal socket with 24 Hr Araldite (JB Weld in the USA).

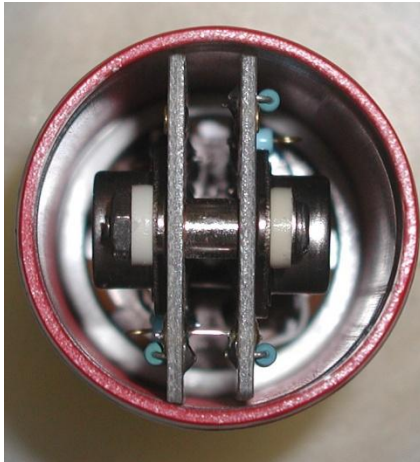
The retaining spring clip is made from very springy piano string wire that is about 1mm in diameter. The air intake coupler (available on Ebay) has the pre-formed grooves which are handy to fit a spring clip. The hex spacer needs a taper machined on it to fit into the Amphenol plug:



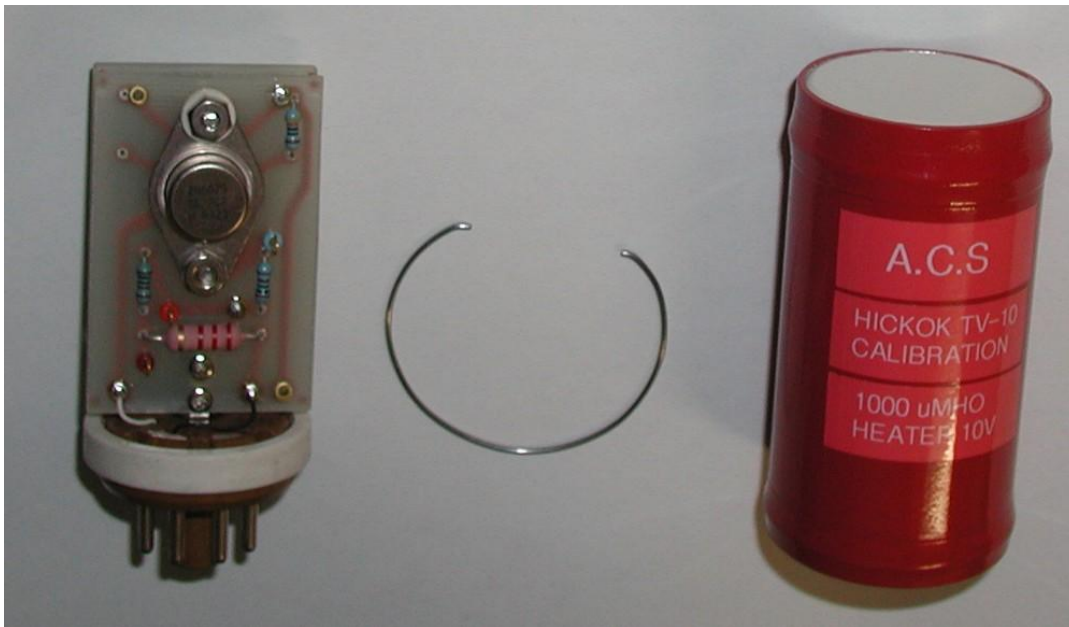
The photos below show the assembled ACS out of its housing:



The photo below shows the view looking down into the housing before the top cover is fitted. It also shows how the spring clip retains the unit inside its housing:

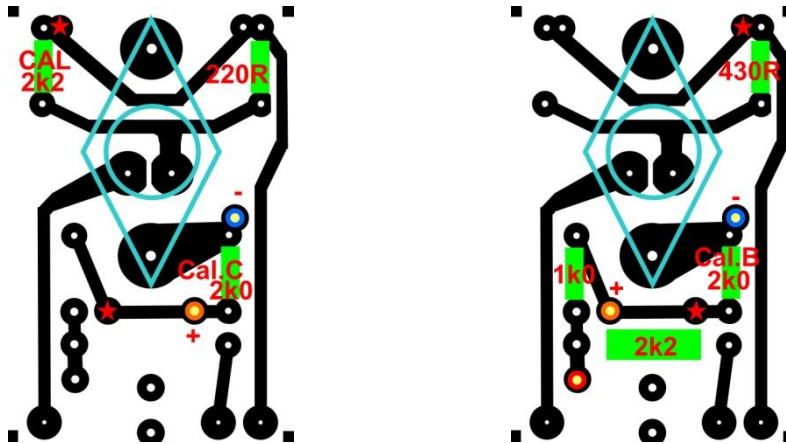


The photo below shows the ACS ready for insertion into its housing:



## ACS PCB design:

For economy each pcb is the same and has been designed with some symmetry so that when they flip around and face each other then two of the connections line up for a short section of tinned copper wire to pass between them. These points are shown on the pcb images below as the red stars. Also either pcb can carry the common parts, which are the 2k2 1W or 2W resistor and the 1k0 ¼ watt resistor. Loop test points (gold plated loops with glass bead stand offs) are added for easy connection of clips from meter leads for initial calibration of the ACS unit. The pcb's are 53 x 34 mm in size. The images show the top view:



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