The uTracer

The User Manual

Compiled and edited by Bill van Dijk

Contents:

NOTE: The electronic version of this manual contains several internal (such as the contents menu) and external hyperlinks. These hyperlinks work, but may be disabled for security reasons in your PDF reader. To use the hyperlinks please ensure hyperlinks are enabled in your reader. When printed, these obviously don't work, and for that reason all the external links are listed in the endnotes at the end of the document. External links are marked with a roman numeral corresponding to the numeral in the end notes. Internal links are obvious enough.

1 – Introduction

To keep the hardware of the uTracer as simple as possible, the complete operation of the uTracer is performed under software control. The program which controls the uTracer is called the Graphical User Interface (GUI). The GUI is a standalone program that can be downloaded for free. The GUI communicates with the uTracer through a serial data link.

The GUI was in the first place designed to trace the curves of tubes. These curves give all the information about the condition of the tube and provide information for the design of circuits. In addition to the curve trace function, a tube testing function has been implemented which measures the most important tube parameters for a single bias point. This "Quick Test" feature has been implemented in GUI versions 3p10 and higher.

The operation of the uTracer is pretty straightforward and usually consists of four steps: 1. setting up the measurement conditions, 2. perform the actual measurement, 3. Adjusting the graphical representation if needed, and 4. storing the data. Once the GUI has been set-up for a particular tube, the complete measurement set-up can be saved to a file so that it can be recalled at a later time. The Quick-Test is even simpler: just enter your favorite bias point and nominal anode current and press "Test."

The operation of the GUI is rather intuitive. The "getting started" section of this manual will get you going as quickly as possible without going too much into details. There are however a few controls and features that need some more explaining. They will be dealt with in subsequent sections.

1.1 – GUI versions and added functions

Version:	Date:	Description:
GUI 3.11.1	17-nov-2013	• When the GUI does not find a version 11 cal file, it will search for a version 10, 9 or 8 cal file and copy that one to a version 11 cal file. • Pins form & frame names corrected. • Odd rounding of numbers in QT forms corrected (Martin) • Odd rounding of numbers in legend corrected (Fabio) • Bug in saving block format data files removed (Spence) • "store Ia" along axis changed to "stored Ia"
GUI 3.11.2	8-feb-2014	Improved grid voltage calibration procedure. Read more about it Here[i] (This is a very long external web page, you may need to scroll down manually to section 28).
GUI 3.11.3	11-feb-2014	Added the option to change the names of the electrodes on the "Pins" form. Read more about it in chapter 8.6.
GUI 3.11.4	1-aug-2014	• Added are measurement types which make is possible to measure tetrodes and pentodes with distributed loading (so called Ultra-Linear mode). Read more about it in in chapter 8.7. • Added option for a beep after a measurement is finished
GUI 3.11.5	1-sep-2014	In this version a number of important new features have been added: • A new tool has been added to determine the harmonic distortion from a set of output curves for a resistive load! Read more about it in chapter 8.9. • A measurement type has been added to evaluate directly the effect of Schade feedback. Read more about it in chapter 8.8. • The measurement as well as the stored measurement are now stored in the set-up file. This makes it possible to store a kind of "standard" tube, or to retrieve a curve for future (harmonic distortion) analysis. • Auto grid bug solved, and the number of decimals in the legend increased to 2 (Ale)
GUI 3.11.6	21-sep-2014	In this version a number of new features have been added to the quick Test: • It is now possible to enter nominal values for all currents and parameters which are all saved in the setup file.

		• The layout of the forms has been improved according to suggestions made by Martin Manning. • The measured Quick test data can be written to a file in the form of a report. • Last but not least, the end-of-measurement-beep now also signals the end of a Quickest.
GUI 3.12.1	25-mrt-2015	Plotting of point that are off-scale or that have generated a compliance error is omitted! At the same time a bug has been solved which caused measurements stored in the setup file not to be plotted.
GUI 3.12.2	8-jul-2015	The unintended resetting of the GUI when the calibration form is opened has been corrected.
GUI 3.12.3	31-jan-2018	Both the low voltage hardware option[ii] as well as the grid loupe[iii] option have been added. (follow links to external website for hardware modifications)
GUI 3.12.4	22-May-2018	Maximum value that can be entered for the axis has been increased to 1M
GUI 3.12.5	24-Dec-2018	• The maximum delay time has been increased to 30000 to facilitate re-forming of capacitors.[iv] Read instructions on external website. • Also a problem related to the quick test in combination with the low voltage version has been solved.
GUI 3.12.6	6-Jan-2019	This versions contains the necessary modifications to be able to use the uTracer for higher currents (read more here[v] on external website). Also a number of bugs in the quick test were removed. • It has become possible to specify the value of the current sense resistors in the calibration form. The values are saved to the calibration file. • A button has been added in the calibration form to reset all calibration values. • The maximum value for the nominal anode and screen current values in the quick test form have been increased to 1000. • An irritating bug that caused unnecessary warning messages in the quick test has been removed. • A bug which caused problems when the GUI was used for the Low Voltage version has been removed.

2 - Getting Started

In this section it is assumed that the GUI (version 3p10) has been installed and that the link with the uTracer hardware is functioning. To get some hands-on experience it is a good idea to have a medium-sized pentode like an EL84 (6BQ5) connected to the uTracer. You can also use a triode, but in that case it is not possible to explore the screen current measurement options.

2.1 - The GUI in overview

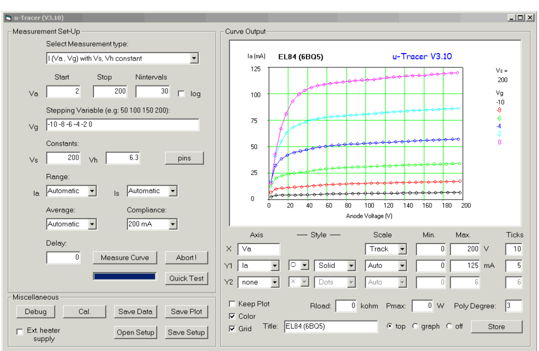


Figure 2.1.1 Main form of the uTracer 3.10 GUI.

Figure 2.1.1 shows the main "form" (a Visual Basic term) of the GUI. There are three areas (frames) on this form. The upper-left area is for the measurement set-up. Things like the type of measurement, the voltage ranges and details about range selection, averaging and current compliance can be set here.

The right side of the form is for the graphical display of the measured data. Here is specified what is plotted, and how it is plotted. By default the anode current is plotted along the left y-axis. It is also possible to select another parameter, or to activate a second y-axis on the right e.g. to simultaneously plot the screen current. Furthermore, the scaling of the axes, marker type, line style, plot title etc. can be set. By default the scaling of the axes is set to automatic so that for a quick plot you don't have to set anything.

The small section at the bottom-left is reserved for all the other stuff such as storing the measurement data or plot, storing and retrieving a measurement set-up, modifying the calibration values and debugging communications.

2.2 - Switching the heater on

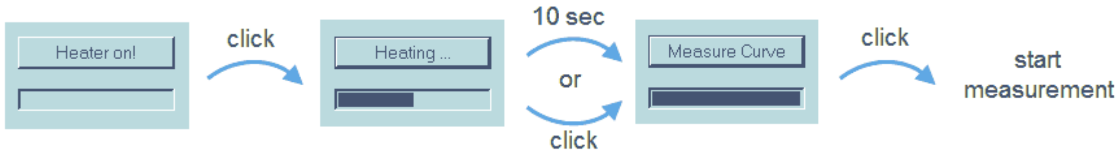


Figure 2.1.2 Switching the heater on.

Since it takes some time for the heater to switch on and stabilize, it is a good idea to first switch on the heater, and then adjust the other measurement setting. Before you switch on the heater make sure that the proper heater voltage is displayed in the field marked "Vh". If it is not, adjust the value to any value between 0 and the supply voltage of the uTracer, usually something like 19.5V. When you are satisfied that the correct heater voltage is set, press the button marked "Heater on!". The text on the button will now change to "Heating …". The GUI will start sending commands to the uTracer hardware to gradually increase the heater voltage from zero to 100% of the set point value. This "slow-start" reduces the thermal shock normally associated with switching on a cold heater from a low impedance voltage source. The progress-bar underneath the command button indicates the progress of this process.

Tip: pressing the command button again while it is displaying "Heating …" will directly switch the heater voltage to the specified set-point value.

When the heater is switched fully on, the text on the command button changes to "Measure Curve". In principle a measurement can now be started, however, it can take up to a minute or so before the heater reaches its nominal operating temperature (and thus emission). So we will use that time to set-up the measurement.

2.3 - Measuring a set of output curves

While the heater is stabilizing, the rest of the measurement set-up can be finished. The uTracer is capable of measuring and drawing any of a number of different types of curves, which can be selected from the drop-down menu at the top of the measurement section of the main form. To measure a representative set of output curves, select the third one which is marked: I(Va,Vg) Vs, Vh constant (Fig. 2.1). This is short hand for: 'measure the currents as a function of the anode voltage (x-axis), stepping the grid voltage, while keeping the screen and heater voltages constant.

When a new measurement type is selected, the GUI will automatically set the bias conditions to default values, which are usually a reasonable starting point. For a set of output curves the default screen voltage is 200 V, while the anode voltage is swept between 2 and 200 V. Any value between 2 and 300 V can be entered in these fields. In this example we may want to add some grid bias values, so replace the -10 V for the following series separated by spaces: "-10 -8 -6 -4 -2 0" (Fig. 2.1). After these preparations start the measurement by pressing the command button which now displays "Measure Curve."

The high-voltage LED will come on, indicating that high voltages are present in the uTracer circuit, and the uTracer will start acquiring data for the output curves. As the curves are being measured, they are plotted in the graphical output section of the main form. Normally there will be little need to change the settings in the output section since the axis will be automatically scaled as the measurement progresses. In section 3 the purpose of the different controls is explained. The measurement can be interrupted by pressing the “Abort” button. After the measurement (or after an abort), the uTracer hardware will discharge the high-voltage electrolytic capacitors to a safe level and the high-voltage LED will turn off.

Tip 1: tick the box “Beep” for an audio signal when the measurement is completed.

Tip 2: do not initiate a new measurement before the high-voltage LED has turned off because this may result in a “hang-up” of the software which will require a restart of the hard- and software.

If you have connected a pentode (or tetrode) select parameter “Is” from the drop-down menu in the column “Axis” next to “Y2”. The screen current will now be added to the display, along with the axis on the right-hand side of the graph. Clicking with the mouse on or near one of the curves will cause a marker to appear. The value at that point will also be displayed, interpolated between measurement points if necessary. To save the graph, click on “Save Plot” in the “miscellaneous” section of the main form. A new form will open prompting you to enter a file name and a path. Unfortunately the only format supported is “.bmp”. The measurement data can also be saved in ASCII format for further processing by pressing the “Save Data” command button. A variety of data formats are available which are discussed in section 6.1.

2.4 – A quick test

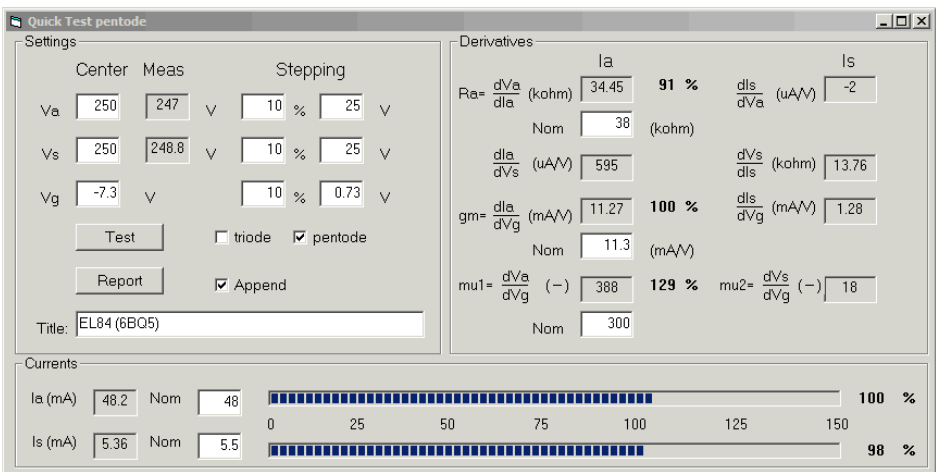


Figure 2.4.1 The Quick Test.

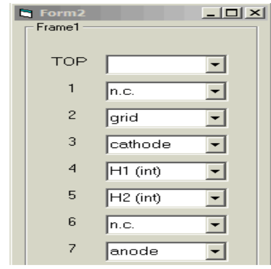
Apart from taking full curves, the uTracer can be used to measure the most important parameters such as plate resistance (Rp), transconductance (Gm), amplification (mu) and currents at a single bias point. Manufacturers of tubes often give these parameters at a bias point which they consider to be optimal. Since only a few measurements are needed to extract these parameters, a “Quick Test” only takes a few seconds.

With the heater on, the quick test can be invoked by clicking the command button labeled “Quick Test”. A new form will be displayed from which the quick test is performed. If you have hooked up a pentode to the uTracer, tick the “pentode” box, and an alternate form will appear. Now enter the bias point for the quick test. In case of an EL84 this would typically be Va = 250 V, Vs = 250 V, and Vg = -7.3 V. In the text boxes labeled “Nom” the nominal values for the anode and screen currents, as well as the nominal values for the plate resistance, the transconductance and the amplification can be entered. Now click “Test”. The GUI will now measure the currents in a few bias points in and around the specified point and extract the derivatives. If you don’t know the nominal tube parameters you can leave the nominal value at 0.

More details about the quick test function will be discussed in section 5 of this manual. For now I would only like to add that if double-triode is to be tested, both sections can be tested simultaneously. In this way information about the matching of the sections is quickly revealed.

2.5 – Saving the pinning and measurement setup.

Depending on your personal preferences you will have chosen a means to connect the uTracer to the pins of the tube sockets. Some people use a simple "banana plug" type of connector while others prefer rotary switches or a similar solution. Either way, it is useful to have a means to store information specifying which pins the terminals of the uTracer are to be connected to. GUI versions 3p9 and higher have a form on which this information can be stored. The form can be invoked by clicking the "pins" button. It displays the pin numbers, and next to each one a drop-down menu from which the appropriate uTracer terminal can be selected. Note that a number of extra and spare terminals have been included for future expansion. This feature has only been added for the convenience of the user and in no way effects the working of the uTracer or the measurement.



At this point it is possible to save the entire measurement setup and the measurements to a file so that it can be retrieved later, i.e. when another tube of the same type is to be measured. To save the set-up, simply click "Save Setup", and enter an appropriate file name, e.g. "EL84out". The file containing the set up data has the extension .uts, and it will be stored in the same directory from which the GUI was started unless another path is specified. The set-up file is a normal ASCII file and may be examined using any text-editor.

2.6 – A video tour.

For a previous version of this manual I made a series of screen recordings of the operation of the uTracer GUI. The videos were recorded using the GUI version 3.4, and are thus somewhat outdated, however the main operation of the uTracer have remained unchanged. As such they give a pretty good idea of how the uTracer is operated. Updating the screen recordings is on my (very long) list "To Do".

Measurement Setup

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Graphical Output

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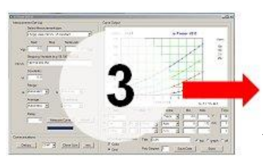
Transconductance



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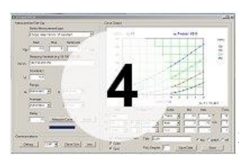
Communication



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Click on one of the images for a guided tour through the GUI!

3 – Measurement Set-Up.

This section discusses the "Measurement Set-Up" form in detail. The main features of the form will be presented in an "Overview" section, and in the following sections features needing a more in-depth explanation will be reviewed.

3.1 – Measurement set-up overview

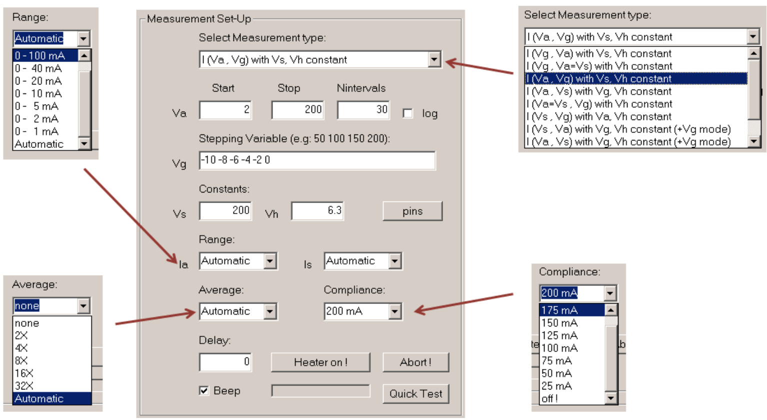


Figure 3.1.1 The "Measurement Set-Up" form

Setting up a new measurement is quite simple and intuitive. The best approach is to go through the measurement set-up form from top to bottom. Most settings have been pre-programmed or are automatically filled-in when a new measurement type is selected, so that usually very little adjustments are needed to produce a set of curves.

The first thing to specify is the measurement type. This is done by selecting one of the measurement types from the drop-down menu on the top of the form (Fig. 3.1.1). In GUI 3p10 ten different measurement types have been predefined which will be reviewed in the next section. Note that when a new measurement type is selected, the variable names and the default values in some of the other text boxes will change appropriately.

Every measurement involves a "running" variable and a "stepping" variable, and possibly one or two constant voltages. The running variable is the variable along the x-axis. This variable is specified as a range from "Start" to "Stop" comprising a number of measurement points "Nintervals." Normally the distance between these points is equidistant, however, by ticking the box marked "log," a so called logarithmic sweep is generated whereby the distance between the points increases along the curve (Fig. 3.1.2). This feature is used to generate more points in the beginning of the curves where the gradients are usually highest.

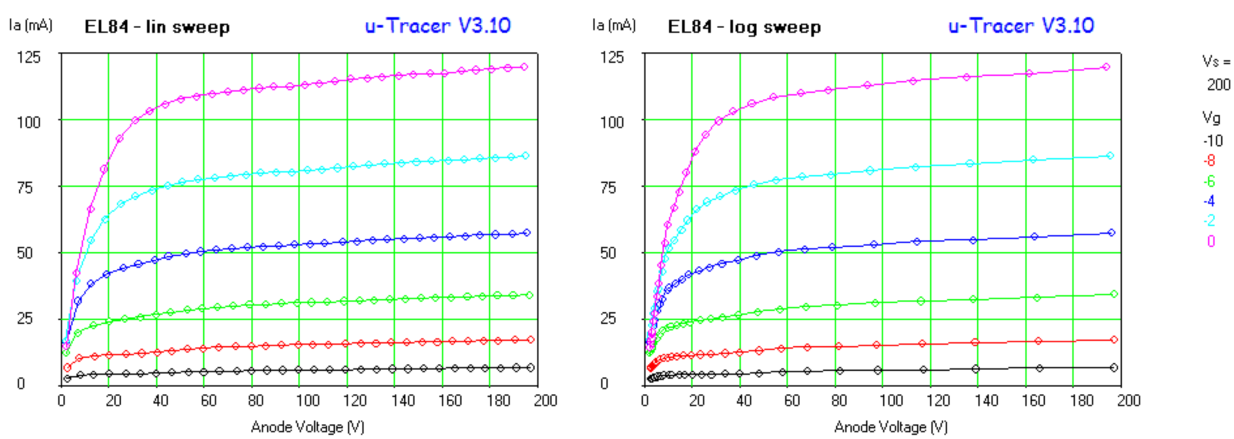


Figure 3.1.2 The difference between a linear and a logarithmic sweep

In the text field below the running variable the stepping variable is specified. Up to twenty values can be entered, separated by spaces. The stepping variable values are displayed to the right of the plot as the measurement progresses. Below the stepping variable there are usually one or two text boxes for constants.

The following ranges apply:

- High voltages (anode and screen): 2 to 300 V
- Control grid: 0 to -50 V (the minus sign must be included)
- Heater voltage: 0 to Vsupl (the uTracer supply voltage)

A lot has been said and written about the heater voltage. It appears that for very low heater voltages and high currents the actual heater voltage can be lower than the voltage specified. In a separate section this issue and some possible workaround's will be discussed.

In most cases after setting these values a measurement can be started by switching on the heater and starting a measurement as described in the "getting started" section.

Good to know: Under some conditions the high voltages actually applied to the tube can be slightly less than the voltages entered in the GUI! The reason is related to the way the uTracer works: before each measurement, the reservoir capacitors are charged to the specified set-point value. When the set-point value is reached the high voltage switch closes and the tube is connected to the reservoir capacitor. After a stabilization time of 1 ms the anode and the screen current are measured. Unfortunately the actual voltage at the terminals is slightly less than the original set-point voltages. This is because the high voltage switch and the current sense resistor both introduce small voltage drops, and also because the reservoir capacitor is slightly discharged during the 1 ms stabilization time! The actual terminal voltages can therefore be several volts less than the set-point values. For this reason the actual voltages at the end of the measurement pulse are measured. It is this measured value, corrected for the voltage drop over the switch and the current sense resistor which is used as the x-axis variable. So, suppose the set-point value was 250 V and the measured value was 247 V then the last value is used for the plot. On the "Debug" form a box can be found labeled "Voltage Corr.". By default this box is ticked, indicating that the voltage correction is on by default. If so desired it can be switched of.

So far, so good. However, when the high voltage in question is used as a stepping variable, or as a constant, there can be s small difference between the set point value and the actual voltage applied to the tube. In the "Quick Test" forms by the way the "real" voltages are displayed after the measurement. This makes it possible to correct for the voltage drop by selecting a slightly higher set-point value. One of the improvements for a next GUI version might be a provision to correct for this small error.

3.2 – Measurement types

The type of measurement can be selected in the top drop-down box of the measurement section. In GUI version 3p10 ten measurement types have been defined. A kind of shorthand notation is used to identify the measurement types. For example:

I(Vg, Va) with Vs, Vh Constant

means: measure the currents – the anode and screen current are always measured simultaneously – with Vg as running variable (along the x-axis) and stepping Va, while Vs and Vh are being held constant.

The following measurement types have been pre-defined in the GUI picklist:

1) **I(Vg, Va) with Vs, Vh Constant** Measure Ia and Is as a function of Vg, stepping Va with Vs and Vh constant. This is the normal transfer curve from which the transconductance can be derived. In case of triode the screen terminal can be left un-connected.

2) **I(Vg, Va=Vs) with Vh Constant** Measure Ia and Is as a function of Vg, stepping Va=Vs with Vh constant. This measurement type was especially added to measure the transfer curves of both sections of a double triode simultaneously. During this measurement the first anode is connected to the anode terminal of the uTracer, while the second anode is connected to the screen terminal. The screen power supply in this case acts as the anode supply for the second anode. By plotting Ia along the left y-axis and Is along the right y-axis, both anode currents can be displayed in one plot.

3) **I(Va, Vg) with Vs, Vh Constant** Measure Ia and Is as a function of anode voltage, stepping the grid voltage, with the screen voltage and heater voltage constant. This is a normal output curve measurement. From the plot the output or plate resistance can be extracted.

4) **I(Va, Vs) with Vg, Vh Constant** Measure Ia, Is as a function of anode voltage, stepping the screen voltage with the grid and heater voltage constant.

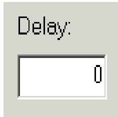
5) **I(Va=Vs, Vg) with Vh Constant** Measure Ia, Is as a function of anode voltage = screen voltage stepping the grid voltage with the heater voltage constant. This measurement type is used to simultaneously measure the output characteristics of both sections of a double-triode. During this measurement the first anode is connected to the anode terminal of the uTracer, while the second anode is connected to the screen terminal. The screen power supply in this case acts as the anode supply for the second anode. By plotting Ia along the left y-axis and Is along the right y-axis, both anode currents can be displayed in one plot.

6) **I(Vs, Vg) with Va, Vh Constant** Measure Ia and Is as a function of screen voltage, stepping the grid voltage with the anode and heater voltage constant.

7) **I(Vs, Va) with Vg, Vh Constant (+Vg mode)** This measurement type is used to measure the transfer curve of a triode in positive grid bias mode! In this case the screen power supply is connected to the grid, and the grid terminal of the uTracer is left unused. As a result the anode and grid bias curves are recorded as a function of positive grid bias stepping the anode voltage.

8) **I(Va, Vs) with Vg, Vh Constant (+Vg mode)** This measurement type is used to measure the output curve of a triode in positive grid bias mode! In this case the screen power supply is connected to the grid, and the grid terminal of the uTracer is left unused. As a result the anode and grid bias curves are recorded as a function of positive grid bias stepping the anode voltage.

9) **I(Vh, Vg) with Va, Vs Constant** Measure Ia and Is as a function of heater voltage, stepping the grid voltage with the anode and screen voltages constant. Since in general it will take some time for the heater to stabilize after a new bias point is set, a delay may be inserted between the application of the new bias point and the actual measurement. The delay can be specified in the text field marked "Delay" in the lower left corner of the form.



10) **I(Vh, Va) with Vg, Vs Constant** Measure Ia and Is as a function of heater voltage, stepping the anode voltage with the grid and screen voltages constant. Since in general it will take some time for the heater to stabilize after a new bias point is set, a delay may be inserted between the application of the new bias point and the actual measurement. The delay can be specified in the text field marked "Delay" in the lower left corner of the form.

11) **I(Vg, Va) with Vs=UL(Va,k), Vh Constant** Measure Ia and Is as a function of Vg, stepping Va with Vh constant, and Vs = Va + (1-k)*(Va,max-Va). This simulates "distributed loading" (Ultra-Linear operation) for tetrodes/pentodes. For more information see section 8.7.

12) **I(Va, Vg) with Vs=UL(Va,k), Vh Constant** Measure Ia and Is as a function of Va, stepping Vg with Vh constant, and Vs = Va + (1-k)*(Va,max-Va). This simulates "distributed loading" (Ultra-Linear operation) for tetrodes/pentodes. For more information see section 8.7.

13) **I(Va, Vg) with Vs, Vh Constant (Schade FB)** Measure Ia and Is as a function of Va, stepping Vg with Vh constant, the applied Vg equals Vg_act = Vg_set + (Va – Vg_set)*SFB. This simulates Schade Feedback. For more information see section 8.8.

3.3 – Averaging and Ranging

To cover the complete measurement range of 0 to 200 mA with sufficient accuracy, the uTracer uses a Programmable Gain Amplifier (PGA) in both the anode- as well as the screen current measurement circuits. By selecting the proper gain factor, the complete measurement range is divided into 8 sub-ranges from 0-1 mA to 0-200mA which are all recorded with 10 bit resolution. Additionally, for measurements in the low current regime it is necessary to perform several measurements to reduce noise.

In normal use a special algorithm takes care of the automatic switching between ranges so that the most optimal resolution is achieved. Depending on the measurement range the algorithm will also determine the number of measurements to be averaged. For most measurements the automatic ranging and averaging works just fine, however in some cases it may be better to select the measurement ranges or averaging manually. This can be done by selecting the required measurement ranges or averaging from a drop-down menu on the measurement form.

Some examples of when you would like to consider setting ranges/averaging manually:

- If only a quick impression of the tube characteristics is required, the measurement can be speeded up by setting the averaging to "none".

- Normally the algorithm will try to measure both the anode and the screen current with the same accuracy. This implies that if a triode is measured and no screen is connected, or when a pentode is measured in the regime where the screen current is very low, the algorithm will select the lowest range for the screen current combined with high averaging to reduce the noise. The extra averages delay the measurement while they are not needed for the anode current. To speed up the measurement the range for the screen current can be manually set to 0-200 mA. In this case the algorithm will determine the number of averages only on the value of the anode current.
- Although the gains of the PGAs are quite accurate, it is still possible that small deviations from the ideal gain in different ranges may cause small dips of bumps in the graph when the algorithm changes the range in the middle of a graph. For the nicest “show pictures” it may therefore be best to set the range manually (Fig. 3.3.1).
- In the “Quick Test” the derivatives (Rp and Gm) are determined from just two points on the curve. Any noise on these two points will directly result in variations in Rp and Gm. This is especially true when the gradients are small (Rp is high, e.g. pentode). In this case it is better to make sure that the algorithm does not switch ranges from one point to the other. Additionally, regardless of the current level, it is sensible to manually set the number of averages to e.g. 16X. The best approach is to do a first quick test with ranging and averaging set to automatic just to find current levels and then to select the proper range manually, set average to 16X and redo the test.

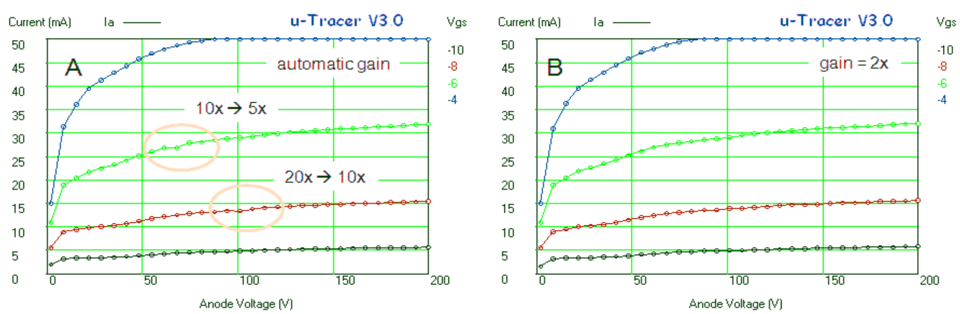


Figure 3.3.1 An Ia(Va) plot for Vg=-10V,-8V,-6V,-4V and Vs=200V.

The left set of curves was measured using the automatic gain option. The automatic selection of another gain setting causes small discontinuities in the current. Re-measuring the set of curves with a fixed gain results in a smooth set of curves.

3.4 – Compliance

No feature on the GUI has been so hard to explain as the compliance setting. To explain what it is, let’s consider a short circuit or the situation when a very heavy load is applied to the output. The first thing that will happen is that immediately the current limiting circuit around the high voltage switch will kick in, limiting the current through the tube to about 240 mA. It can only do so by biasing the transistor of the high voltage switch somewhere in between full conduction and complete cut-off. As a result almost the entire voltage will be dropped over the transistor resulting in an enormous dissipation! Suppose for example that the reservoir capacitor was charged to 300 V, then a short circuit will cause an instantaneous dissipation in the high voltage switch of about 300 x 0.24 = 75 W!

It will be clear that the high voltage switch will not like such a huge dissipation! It is therefore important to switch off the current in the circuit as quickly as possible. This is done by the second line of defense against short-circuits namely the processor itself. When the current increases beyond the value specified by the compliance setting of the GUI, an interrupt will be generated that will terminate the measurement pulse. This takes about 20μs, which in tests during the development of the uTracer, appeared to be short enough to prevent damage to the transistor.

By setting the compliance to a certain value, it is not the maximum current that is set, but rather the current level above which the processor will shut down the circuit. Thus setting the compliance to a level that is lower than 200 mA provides increased protection against overload conditions. Admittedly its use is limited, but it was an option that came absolutely for free.

3.5 – Delay

Normally when a point is measured, the GUI sends a command to the uTracer which tells it to set the required voltages and when they are reached to issue a measurement pulse. When a "Delay > 0" is specified, a delay is inserted in between the setting of the voltages and the measurement pulse. The delay is used for:

1. Measurements which use the heater voltage as running (x-axis) variable. Obviously the heater will need some time to reach the equilibrium temperature corresponding the specified voltage. For directly heated tubes the delay can be in the order of seconds, while for indirectly heated tubes something in the order of 30 seconds is more appropriate.
2. Continuous measurements e.g. for testing Magic Eye tubes. A delay of a few seconds makes it possible to better observe the tube.

4 – Graphical Output.

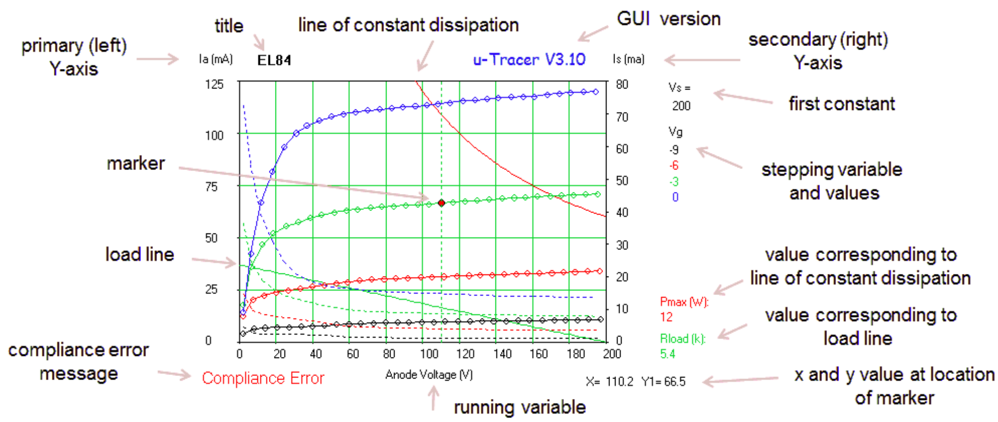


Figure 4.0.1 The graphical output control section

Figure 4.0.1 shows the main features of the graphical output control section. In this example the output characteristics of an EL84 were plotted for three different grid voltages. The primary (left) y-axis is used for the anode current, while the secondary (right) y-axis is used for the screen current. Most of the objects in the graph are obvious or intuitive, but a few objects will benefit from some further explanation.

It is possible to position a marker on the plot by positioning the mouse on the required spot and left clicking the mouse. The GUI will draw a vertical line, and jump to the line closest to the mouse pointer. This can be a line belonging to the left- or the right-axis. The X and Y values corresponding to the marker position are shown on the lower right-hand corner.

Apart from the measured curves, the user has the possibility to add a load line and a line of constant dissipation. The load resistance and the dissipation values can be entered in the proper fields in the input section below the graph. Both lines are just there for convenience of the user and *in no way further interact with the working of the uTracer.* When the maximum allowed dissipation for the tube is entered, the line of constant dissipation will show the Safe Operating Area (SOA) of the tube. In normal continuous mode, a tube may not be operated beyond this line. However, because the uTracer works in pulse mode, there is no problem at all in measuring the tube characteristics beyond the SOA are!

Apart from the anode- and screen-currents the user has the choice out of seven other parameters to plot in the graph. These purpose of these parameters will be explained in section 4.2. In the next section the other controls related to the graphical output will be discussed.

4.1 – Controlling the Graphical Output

Normally after a measurement type is chosen in the measurement section, the graphical section is initialized in such a way that the way that automatically a representable graph is obtained of the anode current versus the running variable without the need to change or set any of the controls. By default all axes are automatically scaled, or track the Start and Stop values of the running variable. Nevertheless, there are many options to adjust what is plotted, or how it is plotted.

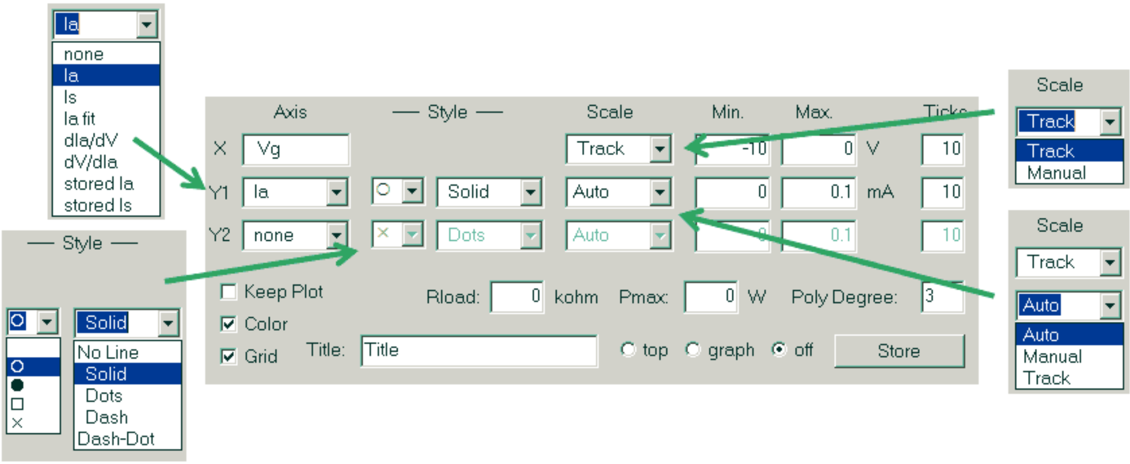


Figure 4.1.1 The controls of the graphical output section

At the heart of the graphical output control section are three lines with drop-down menus and text fields. The three lines control what is plotted along the three axes of the graph, how the data is plotted and how the axes are arranged. From top to bottom the three lines control the X-axis, the Y1-axis and the Y2-axis. What is to be plotted along the X-axis is determined by the measurement type. What is to be plotted along the two Y-axes can be chosen from two drop-down menus (Fig. 4.1.1). Most obvious are Ia and Is. The meaning of the other five variables will be explained in more detail later. By default only the primary (left) axis is used to display the anode current. The secondary (right) axis can be switched on by selecting any of the seven parameters from the Y2 drop-down menu.

The other controls in this area are quite self-explanatory: the second and third column of drop-down menus, under the heading "— Style—" determine the type of marker used and the line style.

The choices in the drop-down menus under the heading "Scale" perhaps need some explanation. There are three choices: "Auto", "Manual", and "Track". In "Auto" the scaling of the axis is automatic and depends on the largest value measured. There is a special algorithm which ensures that sensible and "round numbers" are used along each axis. Using the "Track" setting, the Min and Max values of the axis are determined by the values chosen in the measurement section. When "Manual" is selected, the axis is scaled according to the values specified in the fields of the columns marked "Min" and "Max." The number in the column marked "Ticks" specifies the number of sub-divisions on the axis.

The user has the option to add a title either above or in the plot by entering the text in the field labeled "Title" and by ticking one of the radio-buttons "top" or "graph". The function of the boxes marked "Color" and "Grid" are straightforward. The values entered in the boxes labeled Rload and Pmax respectively determine the locations of a resistive load line and a line of constant dissipation on the graph. As mentioned, these in no way affect the working of the circuit, and are just there for the convenience of the user. Entering a zero value in one of the fields will remove the corresponding line from the graph. The other features of the graphical output section will be discussed in more detail in the next sections.

4.2 – Keep Plot

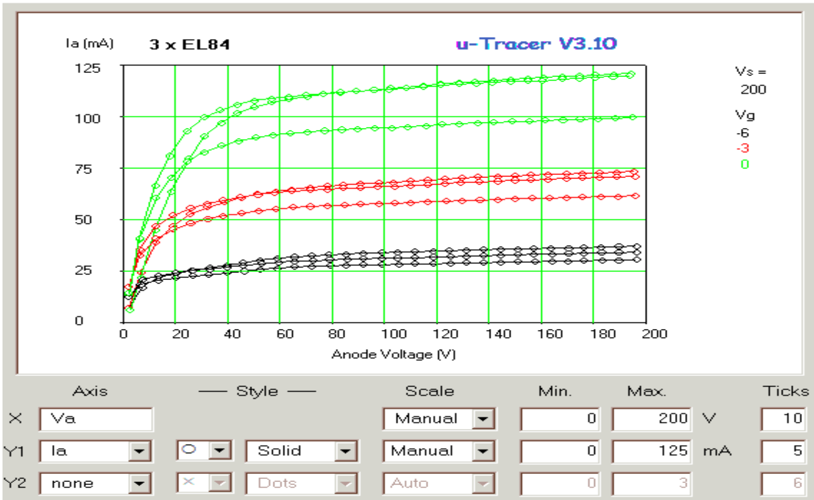


Figure 4.2.1 Three EL84's compared using the "Keep Plot" option. Note how the scaling of the axes has been set to manual.

The "Keep Plot" option has been added as a crude method of comparing the characteristics of several tubes in one plot. The working is very simple, but the proper use of this feature requires a bit of practice. During normal operation of the uTracer, any existing graph is erased every time a new object or measurement is added to the plot. When the "Keep Plot" box is ticked this erasure is omitted so that objects can only be added to the graph. The "Keep Plot" option does not work in combination with the auto-scaling of the axes, because every time one of the axes is redrawn it will be added to all existing ones, resulting in an enormous mess (try it for yourself). The proper use of the "Keep Plot" option is as follows:

1. Make an orienting plot of the first tube using the standard auto-scaling of the axes.
2. Switch the scaling of the axes to manual, and adjust the Min and Max values if needed
3. Tick the "Keep Plot" box
4. Remove the first tube from its socket and insert the next one. There is no need to first switch of the heater supply and then to switch it on again (that is if you are not too squeamish about the heater).
5. Perform a new measurement. The new graph will now be added to the first one.
6. Insert, measure, and display results for additional tubes as needed

Figure 4.2.1 (above) by way of illustration shows a comparison in one plot of the output characteristics of three EL84's I had lying around

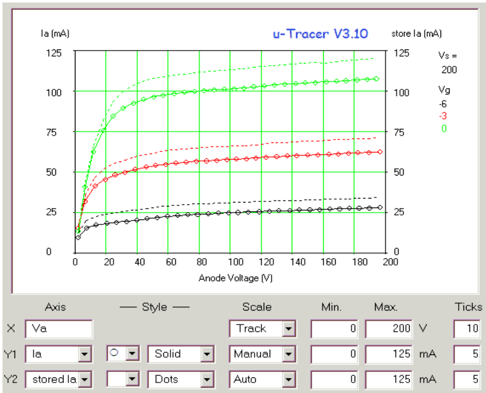


Figure 4.2.2 In this graph the output characteristics of an EL84 with heater voltage 5 V (solid lines with markers, left axis) is compared to the stored reference curves measured at a heater voltage of 6.3 V (dashed lines, right axis).

4.3 – Matching of tubes (Storing a Graph)

It is possible to store the complete data of an entire measurement to RAM memory so that it can be retrieved at a later stage e.g. to investigate the matching of two tubes. This option is not to be confused with the "Save Plot" or "Save Data" functions which save the plot or data to a file for further processing by other programs.

Pressing the command button labeled "Store" causes the current plot to be copied to memory. After the data has been stored it can be retrieved by selecting "stored Ia" or "stored Is" in the drop-down menu underneath the heading "Axis" in the graphical output control section (Fig. 4.2.2). The stored values can be plotted against the secondary Y-axis to enable easy comparison to a new graph. In Fig. 4.3.1 the "Store" option was used to compare two sets of curves measured at different heater voltages.

Caveat: Balanced valves? Might be – might not! By: Robin Simmons

Example of valves appearing to be fairly closely matched when comparing characteristics at the manufacturers' nominal bias/current operating point compared with what happens when measuring at the amplifiers design operating point.

Traces below were obtained when measuring the characteristic of 4 valves in an old 'Fender Twin Reverb' guitar amp using 6L6GC valves stamped as 'International C Servicemaster' (USSR). First impression is that the valves have a similar characteristic and should be OK for further use in a push-pull amp configuration.

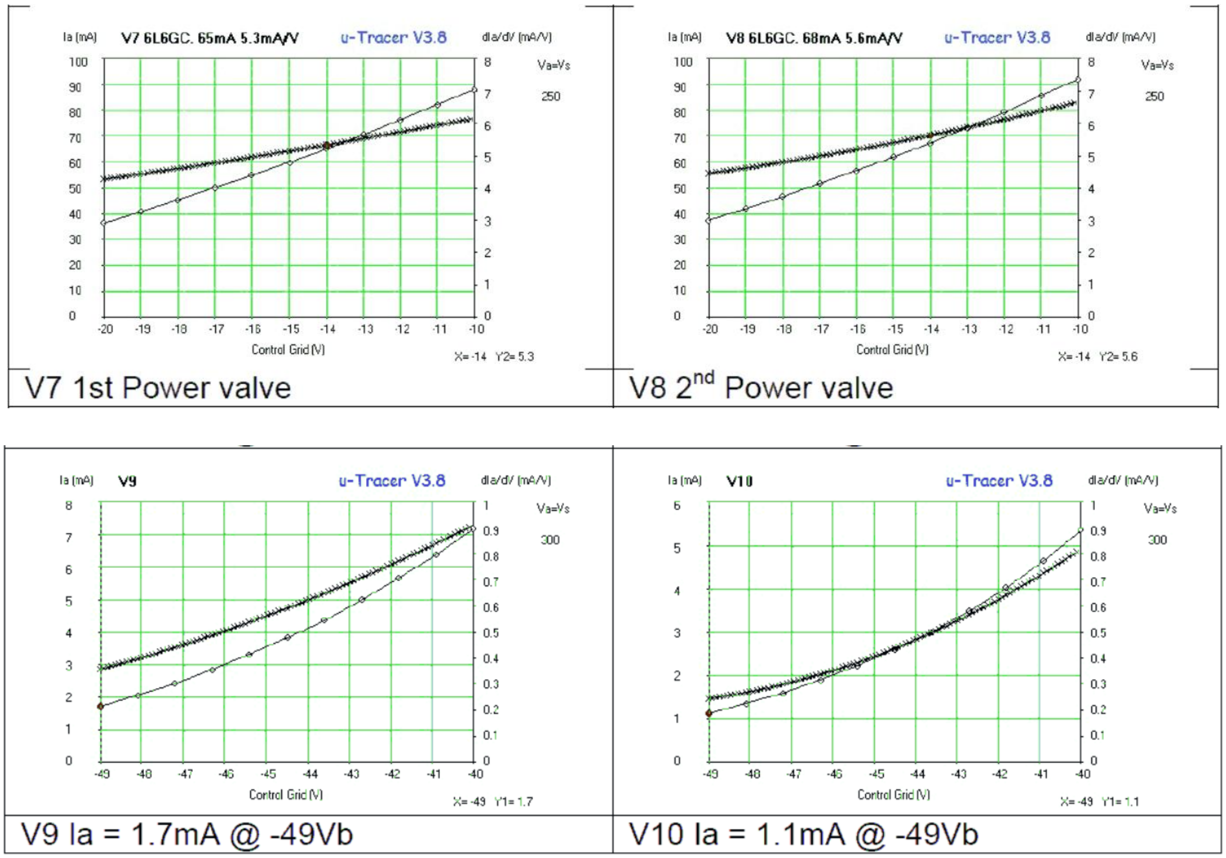


Figure 4.3.1

After carrying out some repairs, the amp was turned on and after warming up, the anode current was checked for each valve at the amps normal bias operating point of approximately -52V. Anode voltage is 440V. The following results were obtained.

Valve	Ia	Static Pd
V7	18mA	8W
V8	32mA	14W
V9	24mA	11W
V10	23mA	10W

Obviously the anode currents are significantly different than might be anticipated from the previous test results. The valves were then re-tested under the nearest conditions to the amps operating point as could be obtained with the uTracer. The results are shown below.

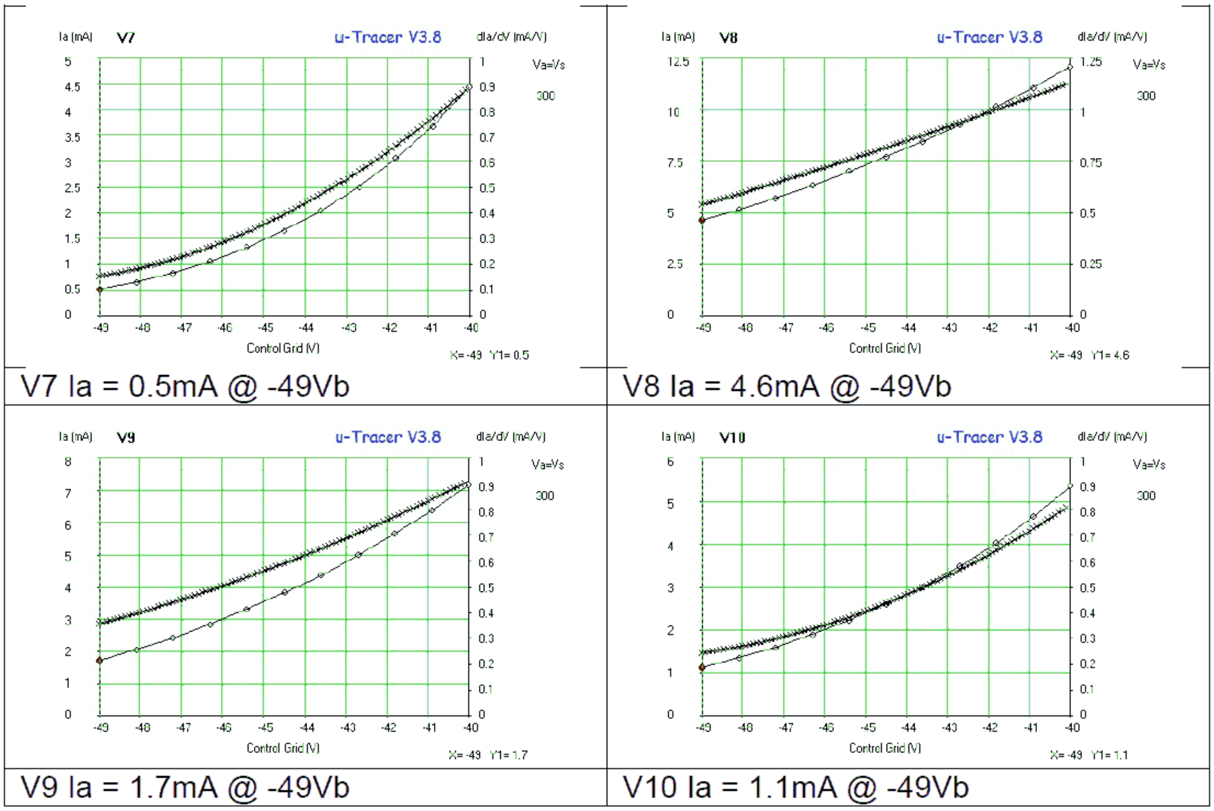


Figure 4.3.2

This shows how misleading it can be to test valves against data sheet performance compared with how they may actually be used in real world applications. It is also 'ammunition' in the argument for uTracer to have a wider range of grid bias capability plus higher anode voltages as has already been discussed on the blog. This would enable testing of valves such as EL34's and 6L6's under conditions much closer to how they are actually used in audio amps and hence reveal problems that may not otherwise be so obvious.

4.4 – Transconductance and plate-resistance

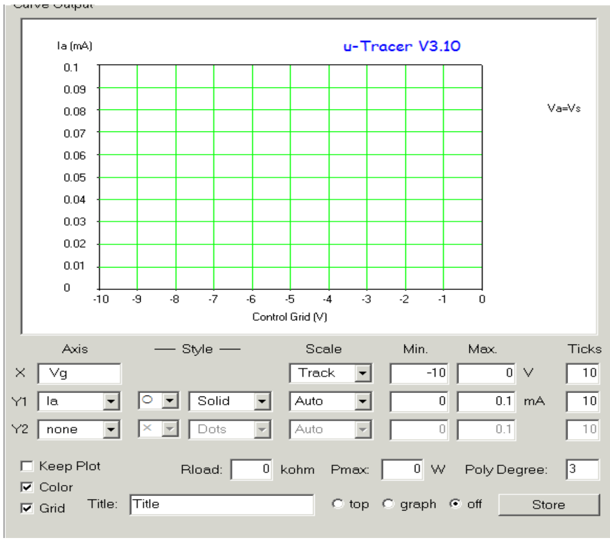
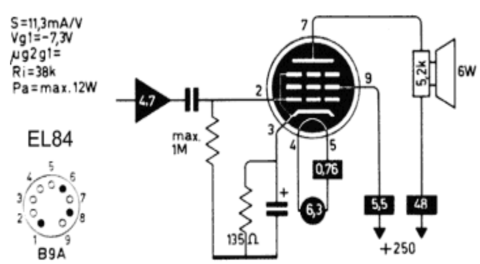


Figure 4.4.1

The transconductance of a tube is the variation in anode current as a result of a small variation in grid voltage at a given bias point. In other words, it is the slope of the anode current versus grid voltage at that bias point. In mathematical terms, the transconductance is the first derivative of the anode current with respect to the grid voltage.

This simplest way to measure the transconductance is to draw a line through two consecutive data points on the Ia(Vg) curve. The transconductance is then nothing more than the slope of this line. However, differentiating a measured curve this way usually results in a very noisy transconductance curve as a result of noise in the measured data. This is especially true when the gradient of the curve is very small. In the version 3 uTracer therefore a better approach is used: After measurement of a set of Ia(Vg) curves, a polynomial is fitted through the measurement points. This polynomial smoothes out the fluctuations in the measured data. The order of the polynomial is chosen such that the polynomial accurately represents the measured data. After the fit the polynomial is analytically differentiated resulting in a perfect - noise free - transconductance curve [MORE][x].

The figure to the left shows in an animation the step-by-step the extraction of the transconductance curves from a set of Ia(Vg) curves of an EL84 (Va=Vs). After the measurement of the Ia(Vg) curves the line is switched off so that only the markers remain. Next the fitted curve is selected to be plotted against the right axis. The optimal order of the polynomial is determined experimentally, and usually something between 3 and 6 gives a good result. The order of the polynomial should not be too high, however, because that can result in oscillations in the transconductance curve. When the fit is ok, the derivative of the current to the voltage (dIa/dV) can be plotted. An alternative way to find the optimum polynomial degree is to directly plot the transconductance, and then to vary the polynomial degree. At first increasing the order of the polynomial should result in a significant change in the transconductance curves. After a certain point the curves will not change much when the order is increased. As the order is increased further, oscillations in the transconductance curves will begin to appear. The optimum is somewhere in the range where the transconductance is relatively independent of the degree of the polynomial. Finally, the marker is seen to exactly match the transconductance at the bias point recommended in my "Muiderkring" tube handbook, 11.6 mA/V! (see inset, Vg = -7.3 V and Va = Vs = 250 V).



The same procedure can be used to extract the output or plate resistance from a set of output curves. In this case the inverse of dIa/dV is plotted: dV/dIa. Extracting the output resistance of a triode is relatively straightforward since the gradient of the curves is usually relatively high. The left graph in Fig. 4.4.2 shows the extracted output resistance of an EL84 connected as triode. The curves are nice and smooth, apart from some noise in the low current regime. In normal pentode mode the extraction of the plate resistance is more difficult. The fitted anode current curves look ok, but they contain small fluctuations that show up as oscillations in the plate resistance. It doesn't require a lot of imagination to conclude that the plate resistance is somewhere in the range of 25-30 kohm. In this case an 11th order polynomial was found to be optimal. Note that a conventional extraction of the plate resistance from the tangent of a line drawn through two neighboring measurement points would result in a much noisier plot.

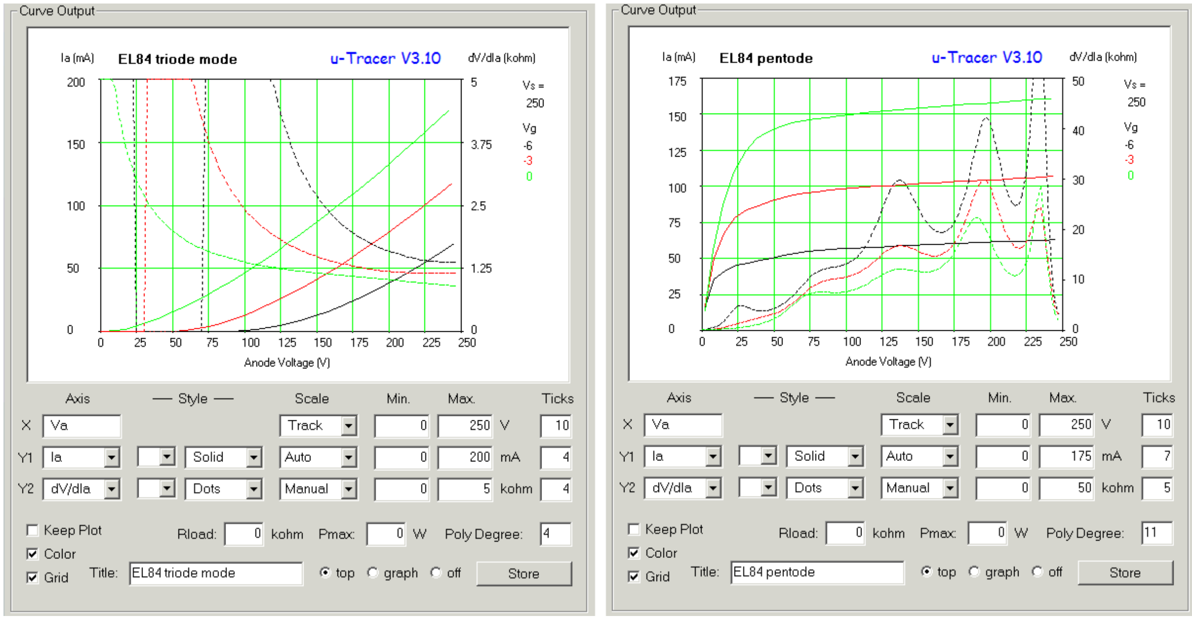


Figure 4.4.2 Output resistance versus anode voltage (dotted line) for an EL84 switched as triode (left) and pentode (right). Number of averages 16 with anode range fixed to 0-200 mA.

5 – Quick Testing

Using the "Quick Test" option it is possible to quickly determine the most important parameters of a tube (nominal currents, gm, Rp and mu) without having to plot a complete set of curves, or having to go through the complete curve fitting procedure. Starting from GUI version 3p10 the "Quick Test" has been added as an additional feature to the GUI. In this section we will review how it works, what is measured, and how the Quick Test option can be used.

5.1 – Quick Test introduction

Most quick reference tube manuals don't give complete sets of curves for tubes, but only cite the most important parameters in an optimal bias point. If we take the EL84 as an example, then the optimal bias point is given as Va=250 V, Vs=250 V, and Vg = -7.3V, and the most important parameters in that point are Ia=48 mA, Is=5.5 mA, gm=11.3 mA/V, Rp=38 kohm. We distinguish between directly measurable parameters, and indirectly measurable parameters. Two parameters which can be measured directly at the given bias point are the anode and the screen currents. The plate resistance, transconductance, the amplification (mu) cannot be measured directly, but are derived from the tube's characteristics at the specified bias point. The transconductance for example is the first derivative of the anode current with respect to the control grid voltage (∂Ia/∂Vg) at the specified bias point, and the plate resistance is the inverse of first derivative of the anode current with respect to the anode voltage (∂Va/∂Ia) at the bias point.

For a triode we have only the anode current as function of the grid and the anode voltages, or Ia(Vg,Va), so there are only two derivatives: the transconductance (gm) and the plate resistance (Rp). The amplification factor mu can simply be calculated from mu = gm*Rp. For a tetrode or pentode, the situation is much more complex. Here we have to deal with the anode current (Ia) as well as the screen current (Is), which in principle are functions of all three terminal voltages so: Ia(Vg, Va, Vs) and Is(Vg, Va, Vs). Now there are no less than six derivatives which all have a physical meaning and which all may be relevant for the design of a circuit:

	I_a	I_s
V_a	$\frac{\partial I_a}{\partial V_a}$	$\frac{\partial I_s}{\partial V_a}$
V_s	$\frac{\partial I_a}{\partial V_s}$	$\frac{\partial I_s}{\partial V_s}$
V_g	$\frac{\partial I_a}{\partial V_g}$	$\frac{\partial I_s}{\partial V_g}$

$$\Longrightarrow$$

	I_a	I_s
V_a	$R_p = \frac{\partial V_a}{\partial I_a}$	$\frac{\partial I_s}{\partial V_a}$
V_s	$\frac{\partial I_a}{\partial V_s}$	$R_s = \frac{\partial V_s}{\partial I_s}$
V_g	$g_m = \frac{\partial I_a}{\partial V_g}$	$\frac{\partial I_s}{\partial V_g}$

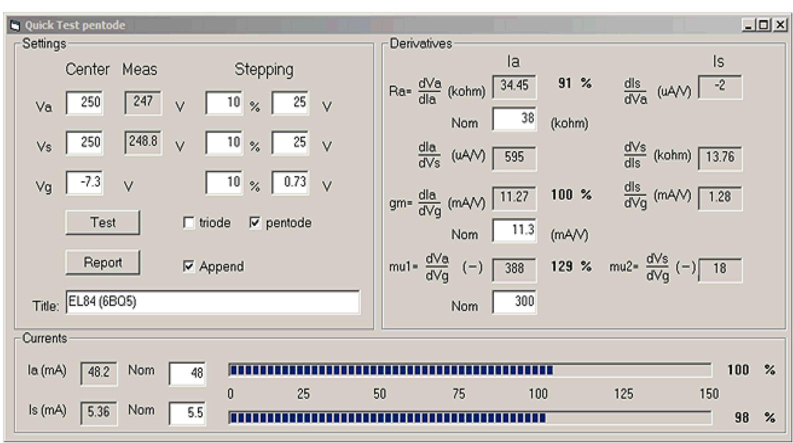
Figure 5.1.1 Possible derivatives for a pentode

Some of these derivatives are more naturally presented as a *resistance* such as the plate and screen resistances, while the others are better presented as *transconductances.* In the "standard" GUI the derivatives are obtained by first measuring the complete curve, fitting a polynomial to the curve, analytically differentiating the curve and finally plotting the derivative. Although this method produces nice smooth curves as a function of bias, it is in most cases sufficient to know the derivatives at a particular bias point. In this case the derivative can be *approximated* by drawing a straight-line through two points Vo-δV and Vo+δV, where Vo is the bias point and δV is a small offset. As an example the transconductance can be approximated with:

$$g_m = \frac{I_a(V_g + \delta V_g, V_a, V_s) - I_a(V_g - \delta V_g, V_a, V_s)}{2\delta V_g}$$

The smaller δV is chosen, the more accurate the approximation will be, but also the more sensitive the result will be to noise in the measured data. In principle now only six measurements are required to calculate all the derivatives for a pentode as shown in Figure 5.1.1, and a seventh measurement gives the currents in the bias points itself. For a triode only five measurements in total are needed.

5.2 – Using Quick Test



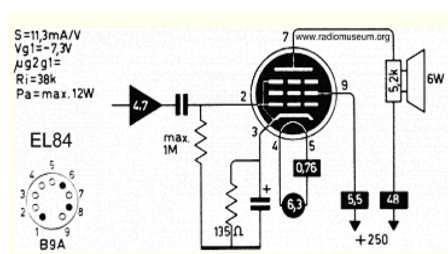


Figure 5.2.1 Quick Test of an excellent EL84 (6BQ5)

The "Quick Test" option which measures all the derivatives in a specified bias point has been implemented as an alternative to a full curve characterization. The Quick Test is started by clicking the corresponding command button in the measurement section. Note that the heater must be activated to perform a Quick Test measurement. The use of the Quick Test option is pretty straightforward:

1. Connect a tube to the uTracer, and start the GUI
2. Set the desired heater voltage. There is no need to select a particular measurement type, or to set any other bias value in the main measurement form since these are set in the Quick Test form. However, the “Range”, “Compliance” and “Average” selections retain their original functions, and the results of the Quick Test may depend on their settings. Using the default values is usually a good starting point.
3. Switch on the heater in the normal way
4. Click “Quick Test.” This will open the Quick Test form;
5. Select triode or pentode (=tetrode) depending on what type of tube is tested
6. Enter the desired bias point values in the appropriate fields. By default the GUI uses δV’s which are 10% of the bias value inputs. The δV’s may be increased or decreased for each input as required by entering either a new percentage value or by entering a δV directly. In both cases the other fields will be updated automatically.
7. When the nominal values for the currents and derivatives are known they can be entered in the fields labeled “Nom.” These nominal values are used at the end of the test to calculate the relative deviation of the measured value from the nominal value. The values entered do not affect the measurement. When the nominal values are not known these values can be left at 0 so that they are not taken into account.
8. Start the test by pressing “Test.” A triode test will take approximately five seconds, while a pentode test will take about eight seconds

All of the Quick Test bias values and settings are stored when the “Save Settings” function in the main GUI form is executed.

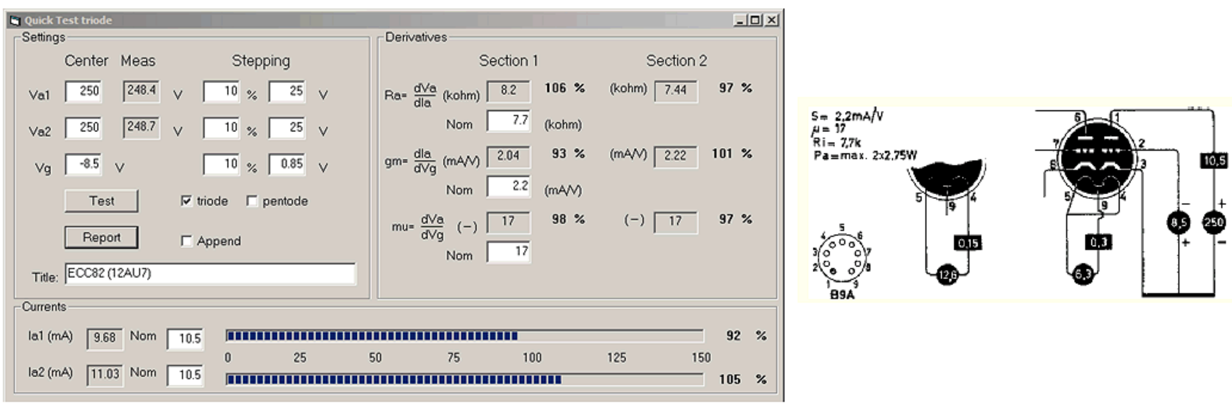


Figure 5.2.2 Quick Test of an ECC82 (12AU7) double triode.

The plate resistance (Rp), transconductance (gm) and voltage amplification (mu) are simultaneously measured for both sections.

Tips and things to keep in Mind:

1. The triode Quick Test has been designed so that both sections in double-triodes are tested simultaneously (Fig. 5.2.2). In this case the anode of the second section is connected to the screen terminal of the uTracer. When single triodes are tested the fields for the second triode can simply be ignored.
2. Plate and screen resistances larger than 1M ohm are displayed as “>1M”. Transconductances larger than 200 mA/V are displayed as “>200”.
3. To test triodes in A2 mode (positive grid bias), the pentode Quick Test is used and the grid is connected to the screen terminal of the uTracer. In this case ∂Ia/∂Vs gives the transconductance while ∂Vs/∂Is gives the grid impedance!

4. The measured currents used to calculate the derivatives can be stored and viewed by storing the Measurement Matrix: press “Save Data” followed by “Save Measurement Matrix.”
5. Especially for high plate resistances (pentodes/tetrodes), the measured value can be significantly affected by a tiny current fluctuations. It can therefore be better to fix the measurement range to a certain value to avoid gain switching in between two measurement points and to manually set the averaging to a high value.
6. When a δV value is entered that would result in a bias setting beyond the capabilities of the uTracer, the value is adjusted to stay within the maximum and a warning message is generated.

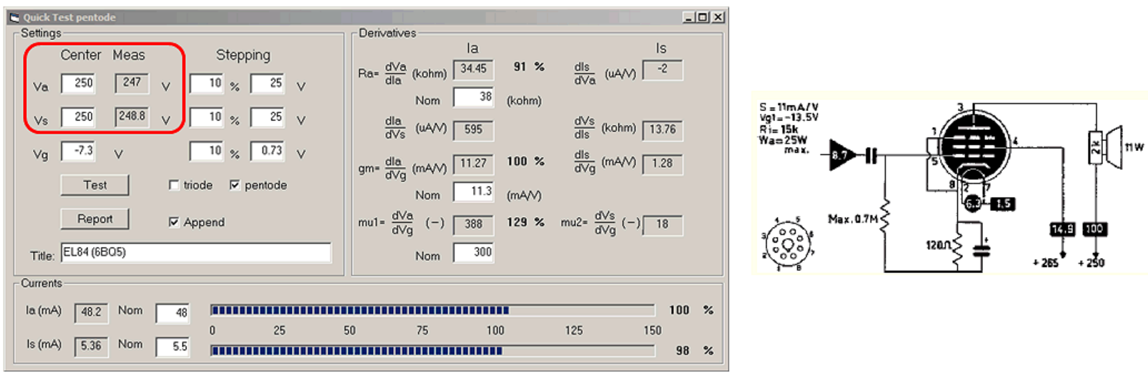


Figure 5.2.3 Quick Test of an excellent EL34 (6CA7).

To obtain the desired bias voltages: Va=250 V, Vs=250 V it may be necessary to increase the set point values slightly.

As a result of the measurement principle of the uTracer, the actual voltages used in the measurement will be slightly lower than the set point anode and screen voltages. This is caused by the fact that during the measurement pulse the anode and screen currents drain the reservoir capacitors a bit. The higher the current, the higher the difference will be. In a normal plot this is not a problem, since the actual voltages at the end of the pulse are measured and used in the plot. However, in the Quick test the difference can be annoying and may require compensation. In Fig. 5.2.3 the red circle shows how the actually measured voltages are displayed next to the set point values. If needed, the set point values can now be increased manually so that the measured values match the required test conditions.

5.3 – Printing the results to a report file

After the measurement the collected data can be saved to a file in the form of a simple report. Figure 5.3.1 gives an example of such a report file for an EL84. The user can optionally enter a title which is printed below the header line. By ticking the “Append” box the report is appended to the file selected. In this way the measurement data of a number of tubes can be collected in a single file in a simple way.

```
20-9-2014 21:20:40    uTracer3, GUI  V3.11.6  Pentode Quick Test

EL84 (6BQ5)

Test conditions:
Va  : 250 (V)                 Swing +/- 25 V (10%)
Vs  : 250 (V)                 Swing +/- 25 V (10%)
Vg  : -7.3 (V)                Swing +/- 0.73 V (10%)

Test results:
Ia  : 48.2 (mA)               100 % of nominal 48 (mA)
Gma : 11.27 (mA/V)            100 % of nominal 11.3 (mA)      Gma = dIa/dVg
Ra  : 34.45 (kohm)            91 % of nominal 38 (kohm)       Ra  = dVa/dIa
mu1 : 388 (-)                 129 % of nominal 300 (-)        mu1 = Gma*Ra
Gm1 : 595 (uA/V)                                              Gm1 = dIa/dVs

Is  : 5.36 (mA)               98 % of nominal 5.5 (mA)
Gms : 1.28 (mA/V)                                             Gma = dIs/dVg
Rs  : 13.76 (kohm)                                            Rs  = dVs/dIs
mu2 : 18 (-)                                                  mu2 = Gms*Rs
Gm2 : -2 (uA/V)                                               Gm2 = dIs/dVa
```

Figure 5.3.1 Example of a report file for an EL84 pentode

6 – Saving Plots and Measurement data

In the main form's "Miscellaneous" section there are a number of command buttons which are used to store the plot or the measured data to a file, or to save and retrieve the complete measurement set-up. These options are explained below. Note that in all cases the default location for the files is the folder into which the uTracer was installed, but any other folder may be specified.

6.1 – Saving a Plot

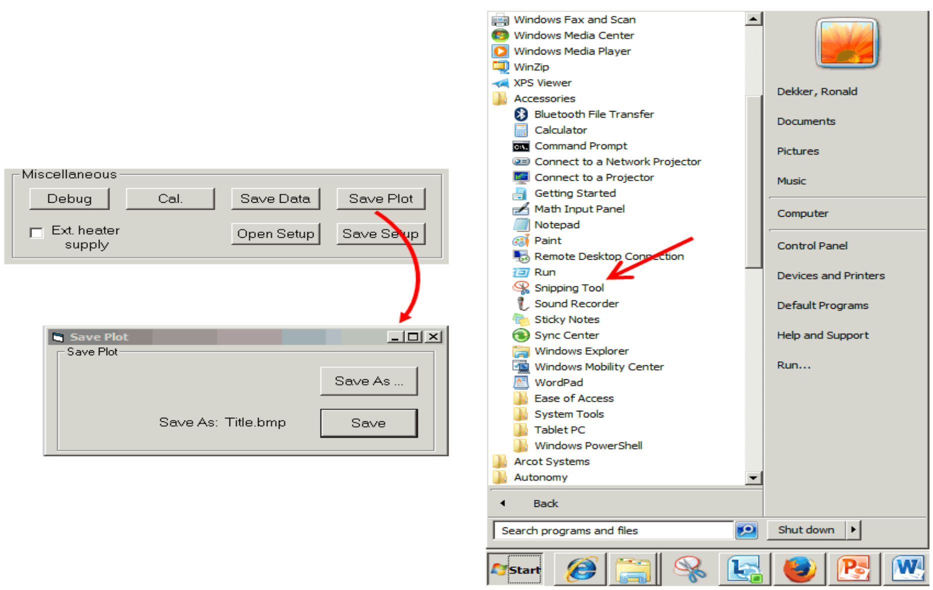


Figure 6.1.1 Left: plotting the graph to a bmp file. Right: location of the snipping tool which can be used to grab the graph from the screen.

A limitation of Visual Basic, the programming language of the GUI, is that it can only save graphics in bit map (bmp) format. Personally I do not think that is a problem, since bit map format graphics can easily be imported into standard programs like Word and PowerPoint. On clicking the "Save Plot" button the small form shown in the left half of Fig. 6.1.1 opens. By clicking "Save As", A Dialog Control opens which allows the user to browse for a particular folder and to specify a file name. The extension will be .bmp

Personally I prefer to use the "Snipping Tool" which is a standard Windows tool that can be found under "Accessories". I even have this tool permanently copied to the taskbar at the bottom of the windows screen. It can be used to grab an arbitrary part of the screen and write it to a file in .jpg or .gif format, or to copy the selected graphic directly into Word or PowerPoint. In fact most of the images in this manual were made by first grabbing a graphic from the screen, copying it to PowerPoint for editing (adding text, arrows or other pictures), and then grabbing the final image and writing it to a file.

6.2 – Saving measurement data

Very likely the user will want to save the measurement data to import it into another application or program, such as e.g. Excel. There are a number of ways that the measured data can be written to a file, and in this section the different possibilities and formats will be discussed. Importation of the data into Excel will also be explained. A very simple measurement consisting of two curves with four points each (Fig. 6.2.1, right) will be used to illustrate the different file formats.

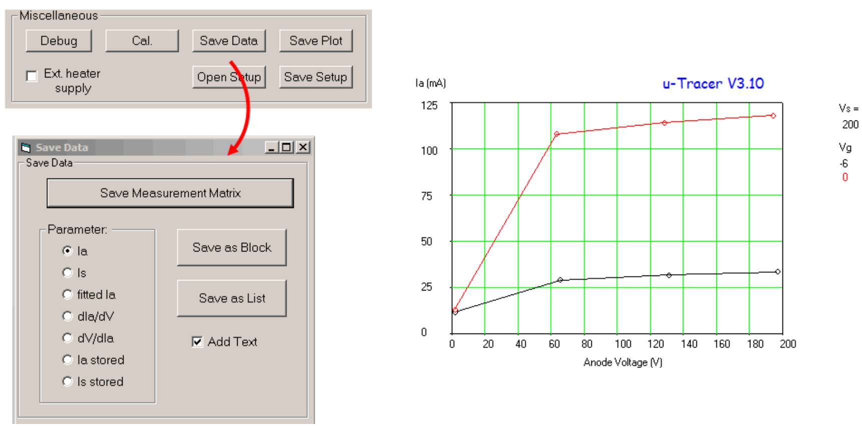


Figure 6.2.1 The "Save Data" form (left) and the test measurement used to illustrate the file formats in this section (right).

The "Save Data" form is opened by clicking the "Save Data" button in the "Miscellaneous" section in the main form (Fig. 6.2 left). There are three formats in which the measured data can be saved: Measurement Matrix, Block, and List. The different formats are selected by clicking the corresponding command button. Both the points to be measured and the measured data are contained in the Measurement Matrix, an array used internally by the GUI. By pressing the "Save Measurement Matrix" button, the contents of this array are written to the specified file. This file, and all measurement data files, will have the extension .utd (**uT**racer **d**ata).

man1mx - Notepad

File Edit Format View Help

Point	Curve	Ia (mA)	Is (mA)	Vg (V)	Va (V)	Vs (V)	Vf (V)
1	1	11.75	15.1	-6	1.89	198.69	6.29
2	1	28.94	4.74	-6	65.61	198.19	6.29
3	1	31.65	3.95	-6	131.29	198.21	6.29
4	1	33.54	3.73	-6	197	198.55	6.29
1	2	13.05	71.87	0	1.87	197	6.29
2	2	107.94	15.91	0	63.17	198	6.29
3	2	113.97	14.26	0	128.46	198.37	6.29
4	2	117.95	13.41	0	194.47	198.38	6.29

Figure 6.2.2 Example showing the format of the saved measurement matrix

Figure 6.2.2 shows the format of the saved Measurement Matrix. The data is stored in eight columns. The first column gives the measurement point number within each curve, while the second column gives the curve number. The third and fourth columns are the anode and screen currents in mA. The last four columns contain the grid, anode, screen, and filament voltages. Note that the grid and filament voltages displayed are the set point values, while the anode and screen voltages are actually measured.

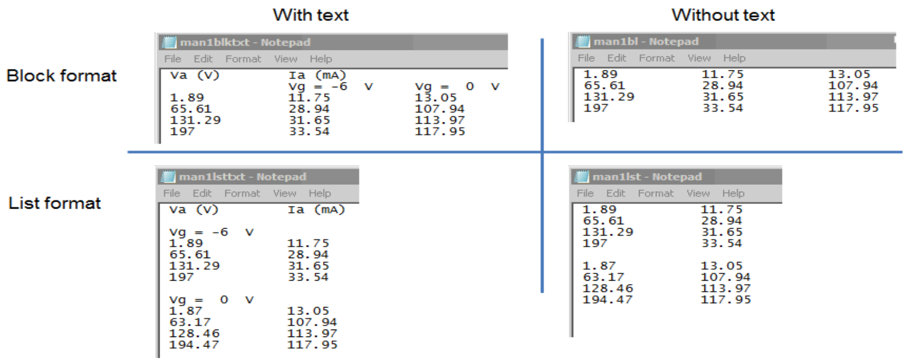
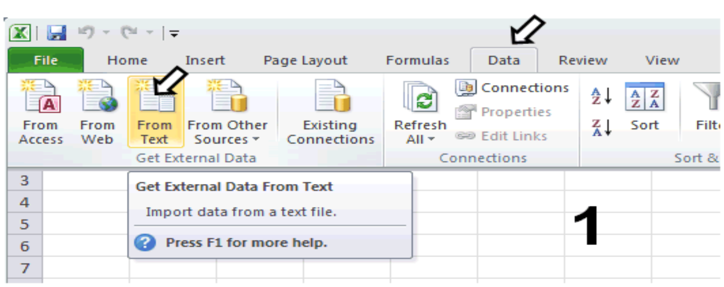


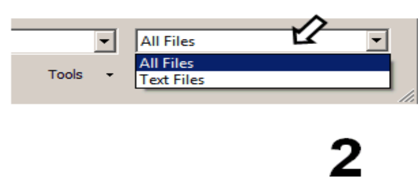
Figure 6.2.3 Examples of the "block" format (top row) and "list" format (bottom row). Both formats can be generated with and without text.

Figure 6.2.3 illustrates the "block" and "list" formats: In the "block" format the first column is the running (x-axis) variable of the first curve, and the following columns are the measured data for each curve. In the "list" format the data for both the running variable and the measured data for each curve are stored sequentially. Since the actual value of the running variable depends on the current, there can be a slight error in the current-voltage relationships in the block format. In the list format both the voltages and currents are stored in exactly the way that they are measured. To facilitate importing data into another application, the text in the files can be omitted by unselecting the tick box marked "Add Text" (Fig. 6.4). Instead of the anode current, any one of the variables in the "radio button" list on the form may be selected for saving.

6.5 – Importing data into Microsoft Excel

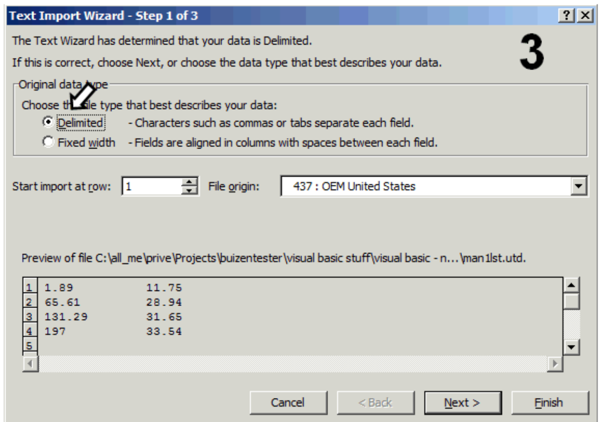
Importing data from a .utd file into Excel is very easy, and this section shows the process step-by-step using a file that has been saved with the "List" format. I am not particularly experienced with Excel, and it may be that there are simpler ways to import the data. For incidental use, this method works fine.

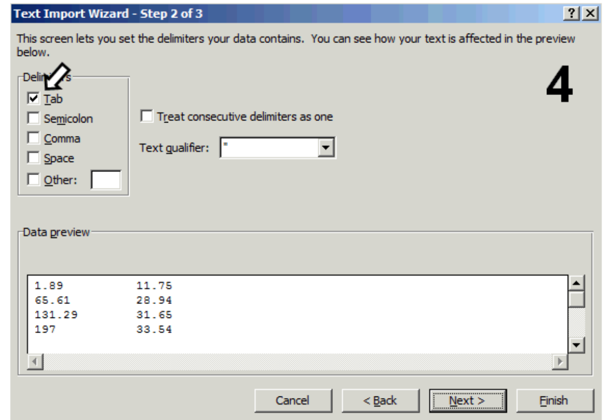




1. Under tab "data" select "From Text" from "Get External Data".

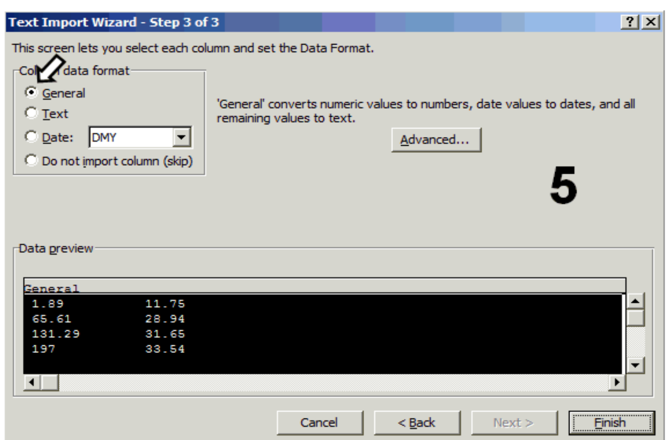
2. In the file browser make sure to select "All Files".

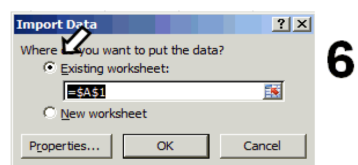


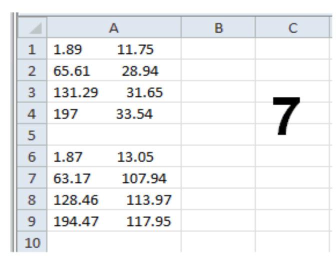


3. **Select "Delimited" (default),**

4. **by "Tabs" (default)**







5. **Select "General" for data format (default),**

6. **in "existing worksheet" (default);**

7. **Finished!**

6.4 – Saving the Measurement Setup

By pressing the "Save Setup" command button in the miscellaneous section all the setup information (the complete measurement setup, pinning information, graphical output settings and Quick Test settings) as well as the current measurement displayed in the graph and the stored measurement are stored in a set-up file. In this way it is possible:

1. To simply save the measurement set-up for a particularly type of tube;
2. To include a stored "reference" measurement for a particular type of tube against which future measurements can be bench marked;

3. To save a set of measurements for future analysis, e.g. using the distortion analysis tool.

After pressing the "Save Setup" command button in the miscellaneous section, the user is prompted to enter a file name after which the complete setup, and the measurements (if present) are stored to a file. This file is a standard ASCII file, which can be read with any text editor. The file has the default extension .uts (uTracer Setup). Note that to avoid decimal delimiter problems, all reals are stored as integers multiplied by 1000. A value of -1 is used to indicate the end of file, which makes it possible to extend the file in the future. Any saved measurement setup can be reloaded by clicking "Open Setup" followed by the selection of the particular setup file.

6.5 – The Calibration File

Small variations in component values make it necessary to calibrate the uTracer for optimal accuracy. To accomplish this, a set of variables is adjusted by means of a graphical "Calibration" form where slide bars are moved to set precise values for currents and voltages [MORE][xi]. The exact procedure to find the correct calibration values is described in the chapter 8.5 the calibration procedure. The default value for each slide bar is 1.0 (center position), and each can be adjusted over a range from 0.9 to 1.1, or +/- 10%. The variables VaGain and VsGain adjust the anode and screen voltages while IaGain and IsGain adjust the measured currents. Vsuppl and Vgrid allow the exact supply and grid voltages to be set, and Vsat adjusts the voltage drop over the high voltage switch during the measurement pulse.

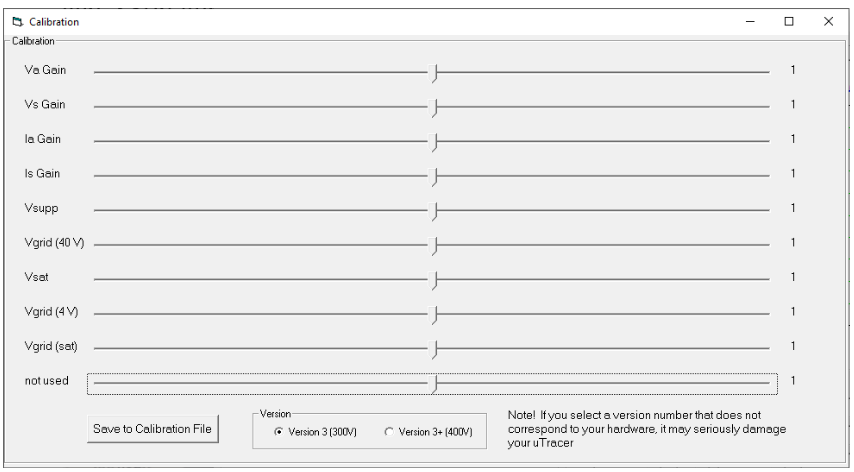


Figure 6.5.1 The calibration form (V3.11)

By clicking the "Save to Calibration File" button on the calibration form, the calibration data is saved to the file "uTracer_3pX.cal," where "X" denotes the current GUI version number. The file is stored in the same folder in which the GUI executable is located, which is usually in the "program files" folder [MORE}[xii].

Tip:
Always record the calibration values on a piece of paper or in a text file! Although it is possible to copy & rename the old calibration file name to the new name after a new GUI release has been installed, it is by far quicker and easier to just re-enter the correct values after a new GUI release has been installed.

Note 1:
The COM port number is also stored in the calibration file. This means that if the COM port selection is changed, the calibration form must be opened and the "Save to Calibration File" button pressed if the new port selection is to be stored.

Note 2: Please ensure the correct uTracer version (3 or 3+) is selected.

6.6 – Location of the Files

Windows 7: If the User Account Control (UAC) feature is enabled (which is default) than any attempt by an application to write to system directories is secretly re-directed to a user-specific "virtual store" that is read/write for that user. This is done to prevent users from corrupting installed applications, and the same thing has been done on UNIX for years.

The default location for your virtual store is: "C:\Users\<username>\AppData\Local\VirtualStore\Program Files" or "C:\Users\<username>\AppData\Local\VirtualStore\Program Files (x86)" where <username> is your login username.

The virtual store is designed to shadow the directory structure under "C:\Program Files" but is qualified by the login username. If you are running 32-bit Windows 7 or have some 32-bit applications installed, you will see the "Program Files (x86)" directory, where 64-bit Windows 7 uses the "Program Files" directory.

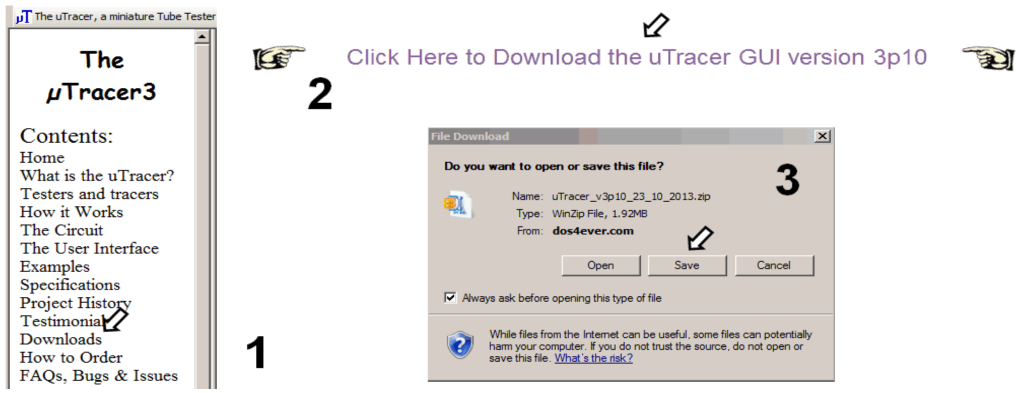
Note that the "AppData" directory is by default hidden from view, as it is a system folder. You can make it visible in Explorer by doing the following: Navigate to "C:\Users\" then from the "Organize" menu select "Folders and search options". From the dialogue box that then pops up, select the "View" tab. In the "Advanced setting" window under "Hidden files and folders", select the "Show hidden files, folders, and drives" radio button - then click "OK".

Under the "Program files" directory above, you will see a further directory called "uTracer_v3px". This is where the calibration file and plot/data files are stored.

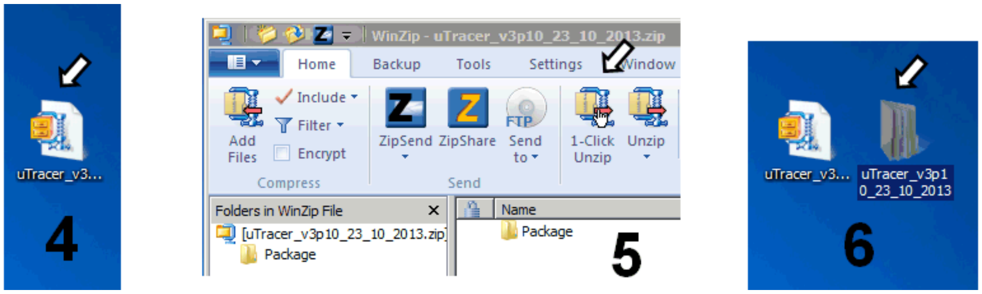
7 – Installation of the GUI

The installation of the GUI is normally quite straightforward. Just unzip the download to the desktop or a temporary directory. There are three files in the unzipped download: a CAB (cabinet) file, an LST listing file and a Setup application. The CAB file is just another zipped file that contains the GUI executable and some ActiveX components (.OCX files) that the executable needs to run. Most important are the mscomm32.ocx and MSCOMCTL.OCX, which deal with the serial communications. Normally double clicking the “SETUP” application should be sufficient to install the program and register the new components in the registry.

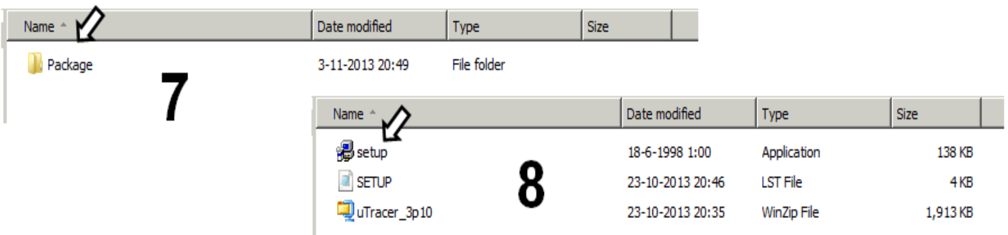
Here is the installation process for the GUI, illustrated with screen shots:



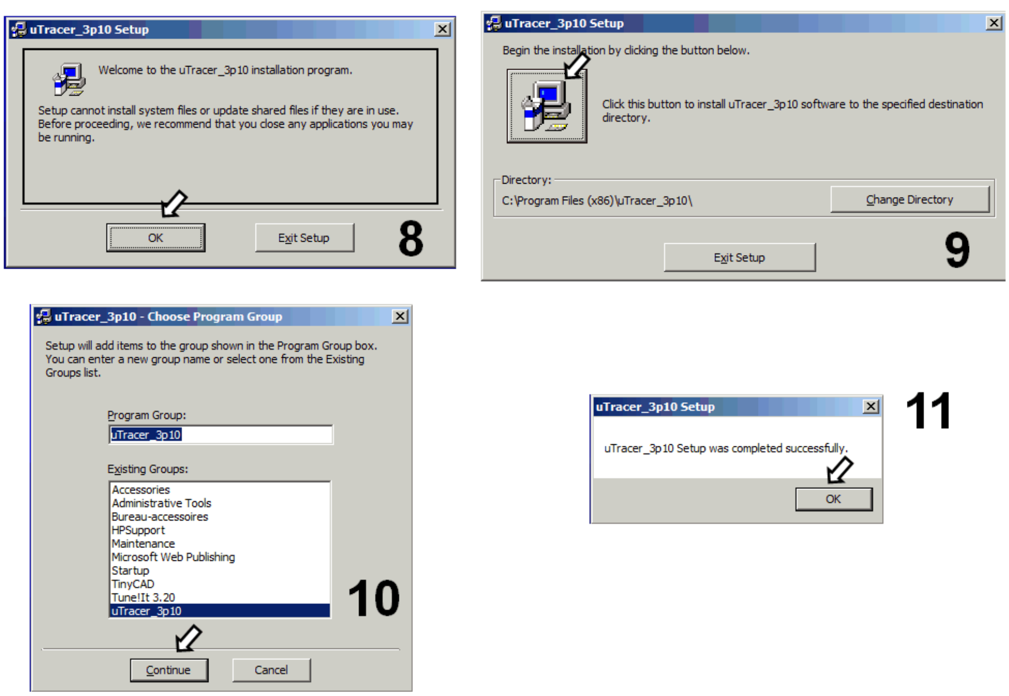
1- On the uTracer webpage navigate to the “Download” page.
2- Click the link to download the zip file with the GUI (The actual GUI version number may differ from the one displayed here).
3- Save the zip file to a suitable location, e.g. the desktop



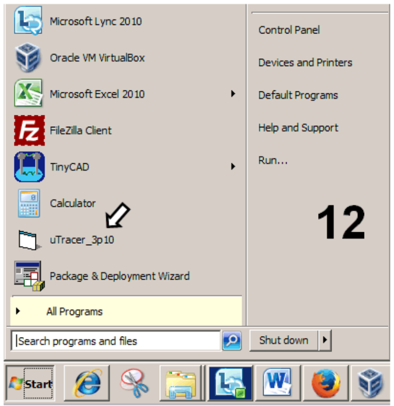
4- Double click the zip file to unzip the file e.g. using winzip.
5- Click “1-Click Unzip”, a folder with the setup files will be generated.
6- Open the folder.

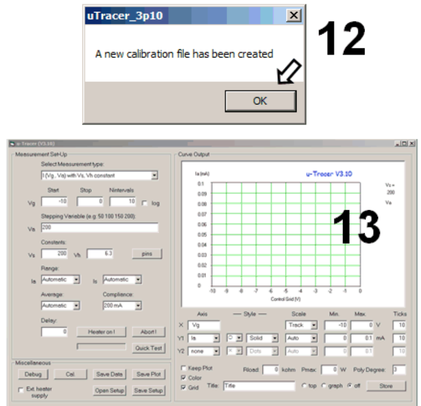


7- Open folder Package
8- Double click the Setup application



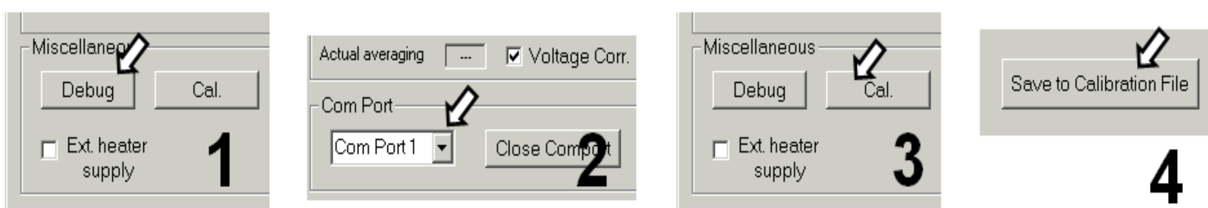
9- 10, The installation program now installs the GUI. It basically only requires our OK clicks.
11- The GUI successfully installed!





12- A uTracer icon should have appeared in your Program list. Double Click it. On first time start, the GUI will create a blank calibration file. Click OK
13- The main form of the GUI should now appear.

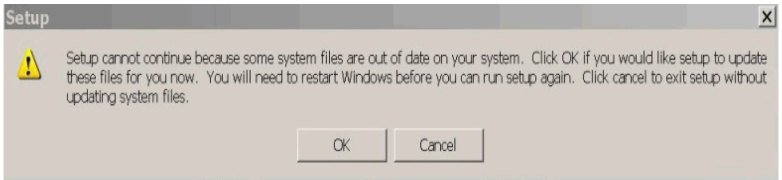
Lastly, the proper COM port has to be set so that the GUI can communicate with the uTracer. This is done on the communications form, which can be opened by pressing "Debug" in the main form (1). After selection of the correct COM port (2), the selected COM port number is saved in the calibration file by opening the calibration form (3) and clicking "Save to Calibration File" (4).



7.1 – Trouble shooting

Normally the installation of the GUI should proceed smoothly, but in practice some difficulties may be experienced. In this section some tips have been collected from users who found solutions to problems they experienced.

If the "Setup.exe" installer supplied with the download doesn't work at all, you can create a directory "uTracer3px" in the root of your system by hand. This directory should be created in the "Program Files" directory for XP, and in "Program Files (x86)" For Windows 7. Then simply unzip the CAB file into this directory. With a bit of luck the necessary OCX components have been already installed and registered in the past by some other program, and the GUI will run by simply double clicking the executable "uTracer3px.exe". Most of the time, however, one or two OCX components are missing and they will need to be installed by hand. Note that manual installation of these missing files is also required if during the normal setup procedure the following message is displayed:



Since this has never happened on one of my own systems, I can only relay the solutions others have found! The error message is probably related to a problem with your registry!

The first thing to do is check to see if the setup application has made a directory "uTracer3px" in your "Program Files" (Windows XP) or "Program Files (x86)" (Windows 7) directory. If not, you will have to create it yourself, and unzip the uTracer3px executable into it.

Next the missing components need to be installed. Joe Neil has given me a description of how this can be done manually:

In order for this app to work, you need to "register" mscomm32.ocx with regsvr32.exe.You should be able to do this with a command line but sometimes that doesn't work. Here's an alternate way: For Win XP, regsvr32.exe should be in the \WINNT\system32 folder. mscomm32.ocx should be there as well, but you may need to download it.

I got it here http://www.nodevice.com/dll/MSCOMM32_OCX/item12152.html .To "register" mscomm32, put your cursor on the mscomm32 file, hold the left mouse button down, "drag" the file on top of the regsvr32 file, and release the button (drop). You should get a window that mscomm32 has been successfully registered.

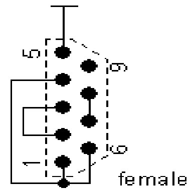
7.2 – Installing a new release

If you already have the GUI installed and working, there is no need to go through the complete installation procedure when a new version is released, since all the necessary OCX components have already been installed. It is enough to simply create a directory, preferably in the "Program Files" (Windows XP) or "Program Files (x86)" (Windows 7) directory, with a suitable name (e.g. uTracer_3p8), and unzip the "v3p8-executable-only-zip-file" (available on the download page[xiii]) directly into that folder. Double click the executable and it should work.

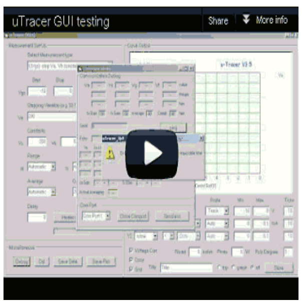
I strongly recommend the following approach to port the calibration values to the new GUI: Start the old version of the GUI, and from the calibration form note down all the calibration values (on a piece of paper). Next, open the new version, set all of the calibration values accordingly, and press "Save to calibration file". Exit and restart the GUI, then open the calibration form and verify that all the calibration values have been properly saved.

7.3 – Testing the USB to Serial converter

Unfortunately the use of a USB to serial converter has proven to be problematic. This is not the fault of the GUI or the uTracer, it is purely related to the converter hardware / software, sometimes in combination with the Windows installation. It is therefore recommended to first test the converter with the procedure described in this section.



A particular problem occurred with a USB to Serial converter that used the “Prolific” chipset. When the GUI tried to read the COM port, the program crashed with a “Run time error 8020, Error reading comm device.” A search on the Internet revealed that this particular problem only occurs for USB to serial converters based on the [xiv] “Prolific” chipset, and only under Windows Vista or Windows 7.



If you consider building your own uTracer I strongly recommend that you download the GUI and test it first. It is very easy to test the GUI and its communication without having the actual uTracer hardware by using an emulated COM port. Although it is possible to test the GUI with the COM port just open, a more thorough check is possible if the COM port is fooled by connecting the transmit pin to the receive pin. The small dummy uTracer circuit on the right shows how such a circuit can be wired on a 9-pin female RS232 (DB9) connector. Pins 2 and 3 are the data pins, and the other wiring makes sure that the handshake signals are properly bypassed.

After installing the GUI as described above, two configurations should be tried in order to have a 100% fail-safe test of the GUI communication:

With the COM port open, start the uTracer and click the “Debug” command button. Select the proper COM port number and press the “Ping” command button. Pressing the Ping button will cause the GUI to send two command strings to the uTracer. The first string is a <00> “start measurement sequence” command, and the second string is a <50> “read out all analog channels” command. The GUI will transmit the first character (the first “0” in “00”) and then wait for uTracer to echo it. When the COM port is open nothing is echoed, so after 2 seconds the GUI will detect a timeout and give a timeout error.

Connect the “dummy uTracer” circuit to the COM port, and press the “ping” command on the Debug form. In this case the GUI will successfully transmit the two command sequences, and then after 10 seconds give a timeout error because it expects a result string to be sent back by the uTracer.

If the GUI responds as above in both cases, the GUI and its communication with the COM port are functioning properly.

7.4 – Stacking of COM ports

It sometimes happens that some devices claim a COM port and then not “release” it when the device is removed. Especially (cheap) Bluetooth serial communications modules have this nasty habit. The result is that the lower COM ports numbers become occupied by devices which are not there. Since the COM port number selected on the GUI has to be in the range of 1-10, it can happen that you run out of COM ports. Here is a way to release unused COM port numbers:

1. First thing is to see if hidden devices are taking up the COM ports: Click Start > All Programs > Accessories and then click Command Prompt.
2. Type "set devmgr_show_nonpresent_devices=1" in the Command Prompt and then press Enter. (you might have to restart your computer after this)
3. Type "cd \Windows\system32" in the Command Prompt and then press Enter
4. Type "start devmgmt.msc" in the Command Prompt and then press Enter
5. Click View > Show hidden devices. This will display devices that are not connected to your computer
6. Now if you expand the section on COM ports, all the COM ports that have ever been created will be displayed, the non-present ones being in grey. You can uninstall away anything that you don't want (right click, select uninstall).
7.

8 – Capita Selecta

In this section a number of selected topics will be discussed which highlight some special features of the GUI.

8.1 – The communications form

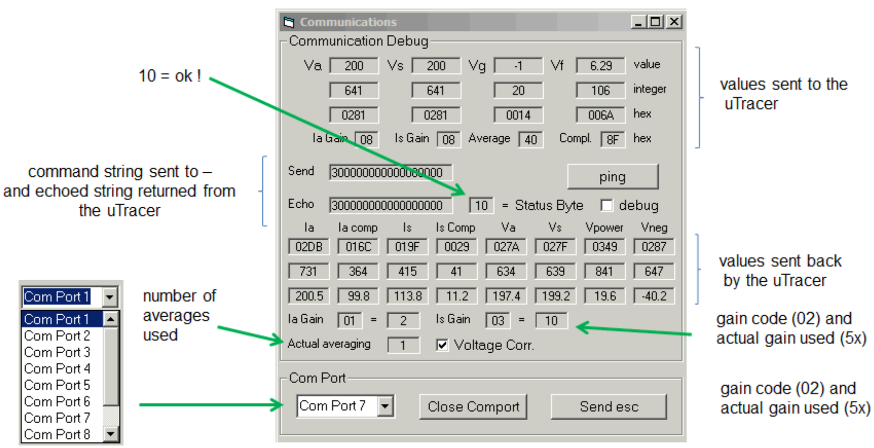


Figure 8.1.1 Communication debug form.

The "Communications form" is opened by clicking "Debug" in the miscellaneous section on the main form. The top of the form displays detailed information about the communication between the GUI and the uTracer. This window was used extensively during the debugging phase of the program development, and I still use it regularly to check what is going on in detail. The form has three areas, the top part displays data that is send to the uTracer by the GUI [MORE][xv]. In the four columns we find the set-points of the voltages which together determine the bias point of the tube. The top row gives the decimal value. The row below that gives an integer representation of the set-point which has been translated to a value which makes sense for the 10-bit on-chip AD/PWM converters. The row below that just gives the hex representation of the integer value. The last row gives the values for the gain, averaging and compliance settings which are sent to the uTracer in the command string. These last values are already coded so that the uTracer can easily interpret them.

The four set-points, headed by a command byte are combined into a command string which is shown in the middle section of the form [MORE][xvi]. Normally the uTracer echoes every character sent to it. This process is monitored in the line below the command string which shows the echoed characters.

In the bottom section of the form, the data sent back by the uTracer in the result string is displayed. The result string is composed of three parts. It is headed by a status word which is displayed separately. A value of 10 indicates a successful measurement, while 11 indicates that a compliance error occurred. The bulk of the data in the result string is the readout of the 8 AD channels. The hex readout and the integer representations are shown in the top two lines. In the row beneath that the decimal values are shown, where the conversion from AD readout to real voltages and currents has been done. In the boxes at the bottom the actual gain and averaging values which were used for that particular measurement point are shown. They may vary from point to point when the automatic ranging and averaging options have been chosen, and it is instructive to see them change during a measurement.

In the bottom part of the form the COM port number can be selected from a drop down menu. Note that after a new COM port is selected, the number will not be saved to the calibration file unless the calibration form is opened and "Save to Calibration File" is pressed. Furthermore, there is a button to "close" the current COM port or to send an escape character to the uTracer. An escape character always forces the uTracer to return to its reset state.

8.2 – Magic eyes & continuous mode measurements

The uTracer is actually very suitable for "testing," a better word is "viewing," magic eyes. To do this the uTracer is used in continuous mode. This has caused some confusion amongst users who were looking for a "continuous mode" button on the GUI. Here I will try to explain what is meant by it.

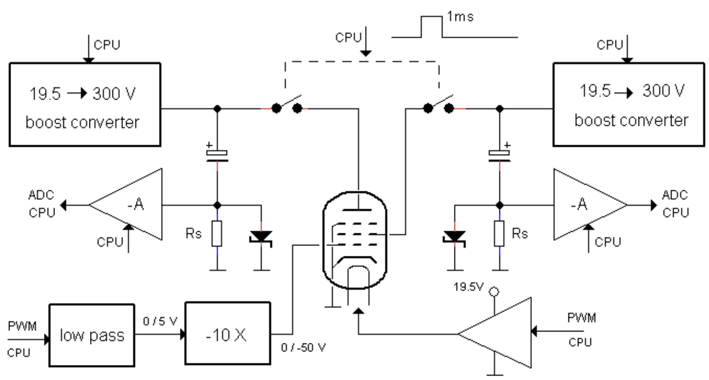


Figure 8.2.1 Normal pulsed operation of the uTracer

Figure 8.2.1 shows the normal "pulsed" operating principle of the uTracer. Two low-power boost converters charge two 100uF reservoir capacitors to the desired anode and screen voltages. During the actual measurement the reservoir capacitors are connected to the anode and the screen by closing of high voltage switches for a duration of one millisecond. During this millisecond the anode and screen currents are supplied by the reservoir capacitors and the currents are measured.

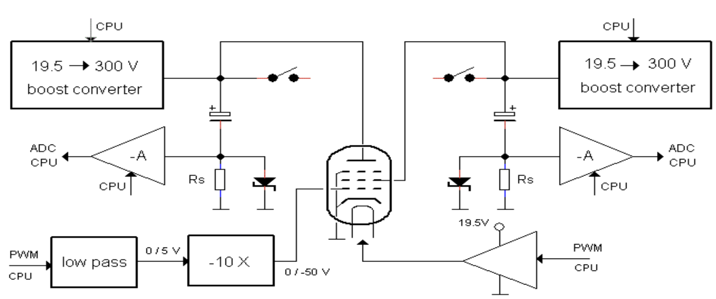


Figure 8.2.2 Continuous mode operation of the uTracer

In continuous mode operation (Fig. 8.2.2) the high voltage switches are not used, but instead the anode and the screen are directly connected to the boost converters. Since the boost converters can only supply approximately 3 mA, this mode can only be used for low current tubes. There are no terminals on the PCB for direct connection to the boost converters. If you want to use the device in continuous mode, the best point to "tap" the boost converters is on the anodes of the 100uF reservoir capacitors (see also the construction manual under "Wiring the uTracer"). To use the uTracer in continuous mode there is no need to push a button, set a tick box, or anything since the GUI does not know the difference between pulsed and continuous mode. Note that if the tube draws too much current the boost converter(s) will not be able to reach the set point value, which will result in a "time-out" error.

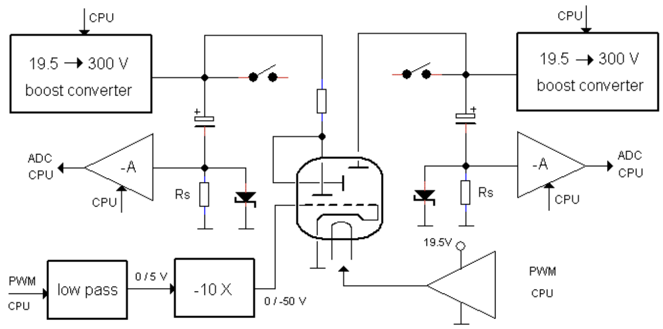


Figure 8.2.3 Testing Magic Eyes in continuous mode

Most magic eye tubes only draw a milliamp of anode current or even less, so they can be tested (and viewed) in continuous mode. The schematic drawing above gives a suggestion for how a magic eye can be connected to the uTracer. In this case the triode and CRT sections are driven independently. The only thing that needs to be added is an anode load resistor to set the gain of the triode section. The proper value for this resistor can be found in the datasheet of the tube.

8.3 – Heater considerations

I received a number of questions from people who have questions or issues related to the power supply of the heater, especially in combination with directly heated, low voltage (< 4 V), high current filaments. The heater supply was originally designed with ordinary 6.3 – 12 V radio/television type of tubes in mind. For these tubes there is no issue with the heater supply, but if a low voltage / high current combination is needed this will push the supply to the limits of its performance. Fortunately a simple external heater supply can be used instead. Finally, it seems that the uTracer connections required for testing directly heated tubes needs some explanation.

How does the heater supply work?

The temperature of the heater, and thus the emission, is a function of the amount of energy which is dissipated in it. The heater is basically a resistive load with a large thermal constant, and in the uTracer these properties are used to realize a very simple supply circuit. In its simplest representation it is nothing more than a power MOSFET with a very low on resistance which directly connects the 19.5 V power supply to the heater. The MOSFET is driven with a 19.5 kHz signal with a variable duty-cycle. The switching frequency is so high that the temperature of the filament cannot follow the switching, and in this way assumes a temperature which relates to the average dissipated power. By varying the duty-cycle, the amount of power dissipated in the heater can be varied. The relation between the duty-cycle, the set point heater voltage, and the supply voltage is derived here.[xvii] Note that the duty-cycle is equal to the square of the ratio of the set point voltage to the power supply voltage! So, if a heater voltage of 10 V is specified, and the power supply voltage is 20 V, the duty-cycle is set to (10/20)^2=(0.5)^2=0.25 or 25%!

Some people have tried to check the heater supply voltage of the uTracer with a normal voltmeter and find very strange values. That is because the output of the heater supply is pulsed. You cannot check the heater supply voltage of the uTracer using an ordinary voltmeter! Only a voltmeter which can measure the true rms (Root Mean Square) value of an AC signal with a sufficiently high bandwidth can be used. I don't have such a voltmeter, but a few people have reported on it (Link1[xviii], Link2[xix]).

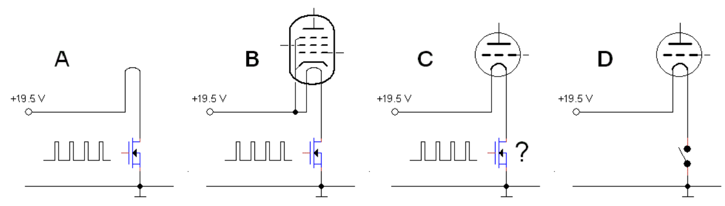


Figure 8.3.1 Principle of the heater supply

The heater supply of the uTracer obviously cannot be floating and has to be connected to the rest of the circuit. Figure 8.3.1 shows the principle of how that is done. Since the output voltage of a boost converter can never be lower than the supply voltage, the cathode of the tube is referenced to the positive supply voltage (more here[xx]). For indirectly heated tubes this is obviously no problem at all (Fig. 8.3.1B). For directly heated tubes there seems to be a problem because in this case the heater also serves as cathode, and what is the cathode potential if the heater is continuously switching on and off between zero and the maximum supply voltage (Fig. 8.3.1C)? The solution is simple: During the 1 ms measurement pulse when the high voltages are applied to the tube, the heater supply is completely switched off so the cathode/filament is at ground potential (Fig. 8.3.1D)! Note that this is a rather strange situation normally never occurring in any practical circuit using directly heated tubes. In normal circuits the heater voltage will always cause a voltage gradient along the filament resulting in a gradient of the grid-heater bias. So the currents in a real circuit will differ slightly from the currents measured with the uTracer! How serious that is depends on the heater voltage and the grid bias.

Low Voltages, High Currents:

A problem arises for heaters which combine a low voltage with a high current. The root of the problem is that as the heater voltage decreases, the duty-cycle of the PWM heater supply, and thus the heater supply pulse-width decreases according to an inverse square law. The pulse width becomes so short that even a small inductance in the wiring of the heater circuit prevents the heater current from rising to its maximum value. Some of this inductance may have even been added intentionally in the form of RFI suppression beads to avoid oscillations! Note that for higher heater voltages there is no problem at all. A 6.3 V / 1.5 A heater in an EL34 works perfectly, the problem is only in the combination of low-voltage and high-current. More information can be found in the weblog section 23[xxi].

Several measures can be taken to minimize the problem:

1. For the heater connection do not use RFI suppression beads. Unfortunately this conflicts with an AVO style wiring of "tube-board" where RFI beads are included in every wire to suppress oscillations.
2. Use as short as possible and twisted wires for the connection between the uTracer and the tube socket.
3. Simply increase the set-point voltage for the heater! The question then is to what value. I will come back to that in a moment.
4. Use an external DC power supply. It is perfectly possible to do so, for both indirect as well as directly heated tubes. This is by far the best, and safest solution for both the tube, as well as the uTracer.

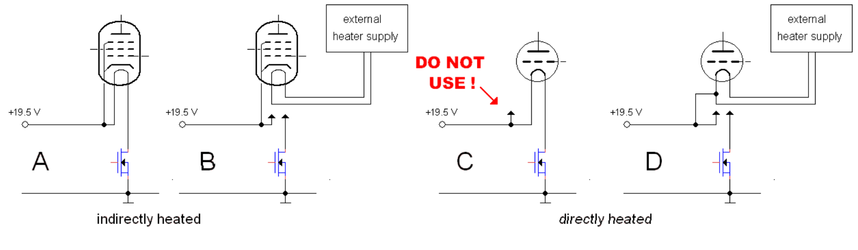


Figure 8.3.2 Connection diagram of indirectly / directly heated tubes with internal / external power supplies.

Testing Indirectly Heated Tubes:

To test an indirectly heated tube with the uTracer, connect the heater and the cathode of the tube to the corresponding terminals of the uTracer (Fig. 8.3.2A). When an external heater supply is used, it can be simply connected to the heater of the tube, leaving the uTracer's heater terminals unconnected. The cathode of the tube obviously remains connected to the uTracer (Fig. 8.3.2B).

Testing Directly Heated Tubes:

To test a directly heated tube the heater of the tube is connected to the heater terminals of the uTracer, but the cathode terminal of the uTracer is not used (Fig. 8.3.2C)! Connecting the cathode terminal to one of the heater connections can short-circuit the heater supply, which in one case has destroyed a complete uTracer, **DON'T DO IT!**

The situation is different when an external heater supply which is electrically floating with respect to the uTracer is used. In this case the cathode connection must be connected to one of the heater connections on the tube (Fig. 8.3.2D). The resulting curves may vary depending on which heater terminal is connected to the cathode due to asymmetries in the tube. You may even consider placing a low-resistivity potentiometer in parallel with the heater, connecting the uTracer's cathode terminal to the slider.

Another note of caution is needed when delicate battery tubes are measured! As explained before, the heater duty-cycle becomes very short for low heater voltages. Small variations in the duty-cycle will thus result in relatively large variations is the dissipated power. So when I measure delicate battery tubes like the DAF96 (1AH5), Russian pencil-tubes etc, I simply use a 1.5 V battery as heater supply, In that way nothing whatsoever can go wrong.

A Simple Calibration Procedure:

A simple trick to compensate for the inductances in the circuit is just to increase the set-point value of the heater voltage until the proper heater temperature is reached! The question is how much the heater voltage has to be increased? Unfortunately that differs from tube to tube, and since everything so very much depends on stray inductances, even from uTracer to uTracer. If it is your plan to test only a limited number of different types of tube, the following calibration procedure can be followed:

1. Connect a "known good tube" to the uTracer and use an external heater supply, set to the nominal heater voltage.
2. Measure a set of curves for relevant settings, and store the measurement.
3. Remove the external supply and connect the internal supply.
4. Iteratively increase the heater voltage until the curves overlap with the stored curves.
5. Note down the set-point heater voltage for this particular type of tube.

The external heater supply option:

In the previous section it was explained that the heater "problem" occurs for heater voltages which are small compared to the supply voltage (19.5 V). For low heater voltages this results in a very low duty-cycle of the PWM heater voltage which, in combination with inductances in the circuit and the high currents, causes the problems. Use of an external heater supply solves this problem, but also makes it impossible to do an automatic heater voltage sweep. Fortunately there is a kind of compromise solution. The trick is to use the external heater supply to feed the heater PWM circuit, and to set this supply voltage as low as possible. For instance, if a heater voltage sweep from 0 to 6 V is desired, the heater supply voltage should be set to something like 7 V. In this way the pulses of the PWM modulated heater voltage do not become too short.

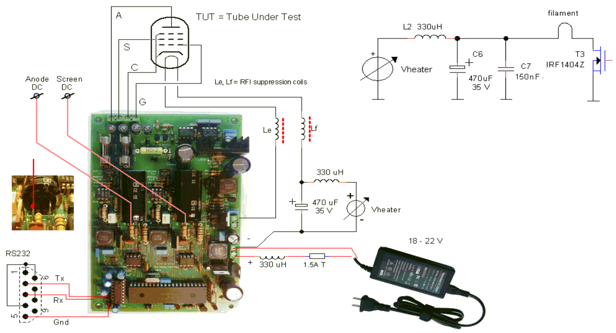


Figure 8.3.3 Connection diagram for the low-voltage external heater

Figure 8.3.3 explains the idea. The insert shows the heater circuit of the uTracer. Instead of using the 19.5 V supply voltage for the heater circuit, in this case an external power supply is used. The “floor plan” shows how with an extra inductor and a capacitor, the modification can be implemented without modifying the PCB. With a switch it is even possible to switch between the internal and the external heater supply. For the inductor any high current inductor of a few hundred uH can be used, e.g. one salvaged from an old PC power supply. *Note that this option only works in combination with tubes with an indirectly heated cathode* since this case the cathode remains connected to Vsupl. For directly heated cathodes the heater is no longer referenced to Vsupl, but to a lower potential.

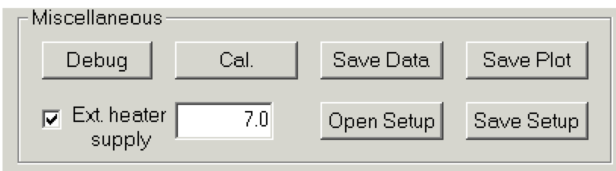


Figure 8.3.4 After activating the external heater supply option a field appears where the voltage of the external heater supply can be entered.

Using this method requires a special path in the GUI software because normally the 19.5 V supply voltage of the uTracer is taken as a reference. To activate this option tick the box “Ext. heater supl.” in the miscellaneous section on the main form. A new field will appear in which the voltage of the external heater supply can be specified. The actual heater voltage specified in the field “Vh” can now be set to any value between 0 and Vhsupl. If now under “Select Measurement type” a heater sweep is selected (I(Vh)), the heater voltage can be swept from 0 to maximal Vhsupl.

8.4 – Three point grid bias calibration

In GUI 3.10 a single point calibration for the grid bias was used. Although this is reasonably accurate, it appeared that at low voltages there could be an error as large as several tenths of a volt. This especially possess a problem for tubes with a low pinch-off voltage and high transconductance like the ECC83 (12AX7). Therefore starting from GUI 3.11 a three point calibration procedure was implemented. This section explains how it works. The actual calibration procedure is described in the next section.

How the new calibration procedure works:

The first observation is that, because of the way the grid bias is generated, there is a limit to the accuracy that can be achieved. It will be remembered that the grid bias is obtained by low-pass filtering and amplifying a Pulse Width Modulated (PWM) signal generated by one of the one-board PWM generators of the PIC in such a way that a duty-cycle of 0% corresponds to a grid bias of 0V, while a duty-cycle of 100% corresponds to -50V. The PWM generator has a resolution of 10 bits which means that the duty-cycle can have 1024 values. Consequently the smallest step in the grid bias is 50/1024 ≈ 50mV. At first sight that doesn’t sound too bad. Certainly for higher grid bias values this results in a pretty good resolution, however, as the grid-bias decreases the relative resolution dramatically decreases. For a grid-bias of -0.2 V e.g. a step of 50 mV amounts to 25% relative resolution! So with the uTracer hardware we can never do better than that.

This doesn't mean that there is no room for improvement. The way the grid bias is calibrated at the moment is based on an approximation whereby the transfer function between the set-point grid bias is related to the PWM duty-cycle by a single straight line. Figure 8.4.1A shows how it is done. The relation between the duty-cycle (n) and the set-point grid-bias (Vset) is given by a n = Vset · C · λ40, with C = 1023/50. During the calibration, the actual grid bias is measured, and the user adjust the value of λ40 in such a way that a set-point of -40V exactly corresponds to a measured value of -40V. Although this gives a pretty good result for grid-biases down to several volts, it was found that for very low grid bias values the error could by quite significant, especially when tubes with a high transconductance and/or low pinch-off voltage are traced.

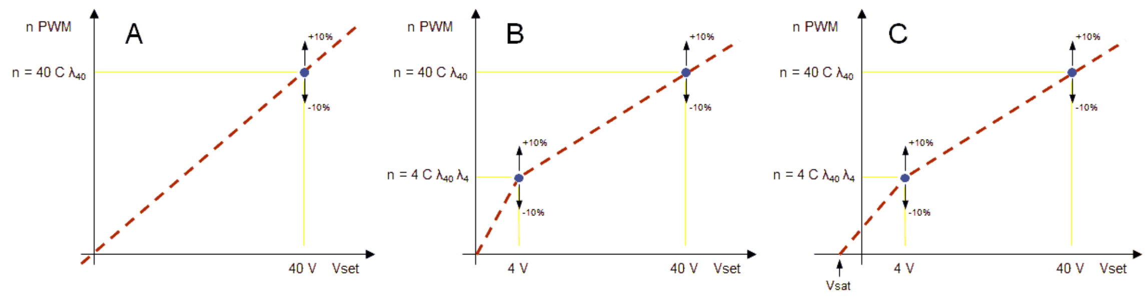


Figure 8.4.1 (A) Current grid bias calibration, and improved calibration based on two (B) and three (C) points.

A first step to improve the calibration procedure was to introduce a second calibration point at a much lower voltage. Since the first calibration is done at -40 V, The second calibration point was chosen at a tenth of that value at -4 V. The transfer function between the set-point value and the PWM duty-cycle is now approximated by two straight lines as shown in Fig. 8.4.1B. The relation between the set-point and the PWM duty-cycle in the second calibration point is given by n = 4.0 · C · λ40 · λ4. After the user has calibrated the grid-bias at -40V, the grid bias is next calibrated at -4V by adjusting λ4. For λ4 one of the three spare calibration values on the Calibration form is used. Note that the default value for the calibration values is 1.0. So if the default value of 1.0 is used the value in duty-cycle in the second calibration point reduces to n = 4.0 · C · λ40 which coincides with the original calibration curve (Fig. 8.4.1A). In this way the new software remain compatible with the old calibration file meaning that if the user for one reason or the other does not feel the need to perform the extended calibration procedure, the old calibration file can be used resulting in the old grid bias values.

Unfortunately that is not the end of the story. As explained in one of the previous sections[xxii] the output voltage of the grid-bias circuit can never exactly become zero. The saturation voltage of T6 and T7 limit the minimum grid voltage to approximately -50 mV. The saturation of T6 becomes noticeable for very low grid-bias values, and needs to be compensated for. This is done by introducing a third calibration value (Fig. 8.4.1C). By giving Vsat a value in the order of -80 mV, it is possible to somewhat compensate for the saturation of T7, although an output voltage of exactly zero volt can never be reached. Vsat is set by using one of the remaining two spare calibration parameters on the calibration form in such a way that the range of 0.9 – 1 - 1.1 of the calibration parameter corresponds to a Vsat range of -0.2 - 0.0 - 0.2 Volt so that the default calibration parameter value of 1.0 again corresponds to the old situation ensuring backward compatibility of the calibration file.

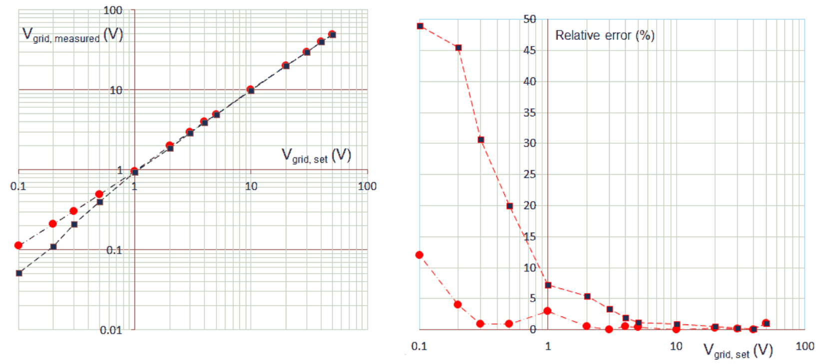


Figure 8.4.2 The accuracy of the new calibration procedure (red) compared to the old procedure (black).

In Fig. 8.4.2 the accuracy of the grid-bias voltage using the old single point calibration procedure is compared to the new procedure. Figure 28.3A shows - on a log-log scale - the measured grid-bias versus the set-point values. Figure 28.3B compares the relative accuracy of the two methods versus the set-point values. Down to -0.1 V the accuracy is within the theoretical limit of 50 mV.

8.5 – The calibration procedure

Martin Manning has compiled the calibration processes for the uTracer into the following procedure (also available for download here[xxiii]):

PC-to-microcontroller Communication

If a calibration is to be performed, begin with this test:

1. Connect the uTracer to the PC
2. Connect the power supply to the uTracer (~20VDC, 1A)
3. Start the GUI
4. Switch on the uTracer power supply
5. Open the Debug/Communications window by pressing the “Debug” button in the Miscellaneous section of the main window
6. Select the appropriate Com port if necessary
7. Press the “Ping” button
8. Verify that the Debug form shows the following values: The “Send” and “Echo” strings should both read 500000000000000000 In the third row below “Vpower,” the supply voltage should appear. In the third row below “Vneg,” a value of approximately -40V should appear

Calibration Procedures:

A calibration must be performed if the calibration data file is lost through a software re-load or upgrade, which will be indicated by all of the sliders on the calibration form being centered. Otherwise, a check of the calibration should be made on an annual basis.

Supply voltage:

1. Measure the supply voltage using a DVM.
2. Compare the measurement to the voltage as displayed on the Debug form as in step 8) above.
3. If there is a discrepancy, open the calibration form by pressing “Cal” in the miscellaneous section of the main form.

4. Adjust the slider labeled "Vsupp" in the direction to reduce the error (i.e. move the slider to the right to increase the display value).
5. Press "Ping" on the Debug/Calibration form and observe the supply voltage display.
6. Repeat steps 4) and 5) as necessary until the display is in agreement with the DVM measurement.
7. Press the "Save to Calibration File" button on the calibration form.

Grid bias circuit:

1. Connect a DVM to the uTracer's cathode terminal (positive lead) and grid terminal (negative lead).
2. Select measurement type I(Va, Vg), with Vs, Vh constant, and set measurement parameters for Va Start = 2, Stop = 25, Nintervals = 30, Vg = -40, Vs = 25, Vh = 6.3.
3. Open the Calibration form by pressing the "Cal" button in the miscellaneous section of the main form.
4. Switch on the uTracer power supply.
5. Press the "Heater On!" button on the main form twice. The second press of the "Heater On!" button will cause the uTracer to skip the delayed heating function, which is not necessary for this test.
6. Press "Measure Curve" (which was formerly "Heater On!") on the main form.
7. Read the actual grid voltage on the DVM. After reading the voltage the measurement can be interrupted by pressing Abort. Make sure not to start a new measurement before the HV LED is off, otherwise this will "hang" the firmware"
8. Adjust the "Vgrid (40V)" gain slider on the calibration form in the appropriate direction to close any discrepancy between the DVM measurement and the -40V set value (i.e. move the slider to the right to increase the measured grid voltage).
9. Repeat steps 6) through 8) as necessary until the measured voltage is -40V.
10. Set the "Vgrid (sat)" slider to 0.96 as a starting value
11. Set the grid voltage to -4 V.
12. Press "Measure Curve" on the main form.
13. Read the actual grid voltage on the DVM
14. Adjust the "Vgrid (4V)" gain slider on the calibration form in the appropriate direction to close any discrepancy between the DVM measurement and the -4V set value.
15. Repeat steps 12) through 14) as necessary until the measured voltage is -4V.
16. Check different grid voltages between -0.2 and -1.0 and adjust "Vgrid (sat)" to see if the calibration can be improved any further.
17. Press the "Save to Calibration File" button on the calibration form.

The set-up for the grid bias voltage calibration can be saved under an appropriate name such as "Cal Grid Bias" for future use.

Screen grid boost converter:

Warning: High voltages will be present and measured during this test!

1. Connect a DVM to the exposed leads of the screen reservoir capacitor C13.
2. Switch the uTracer power supply on and note the idle state voltage on the DVM.
3. Select measurement type I(Va=Vs, Vg), with Vh constant, and set measurement parameters for Va = Vs Start = 100, Stop = 200, Nintervals = 1, Vg = -1, Vh = 6.3. Set Range and Averaging = Auto, Compliance = 200 mA, and Delay = 5 (sec).
4. Open the Calibration form by pressing the "Cal" button in the miscellaneous section of the main form.
5. Press "Heater On!" twice.
6. Press "Measure Curve" and observe the voltage measured by the DVM during the 200V phase of the measurement, comparing it to a value of Vidle + 200V, where Vidle is the voltage observed in step 2).
7. Adjust the Vs Gain slider on the calibration form in the appropriate direction to close any discrepancy between the DVM measurement and Vidle + 200 (i.e. move the slider to the right to increase the measured screen voltage).
8. Repeat steps 6) and 7) as necessary until the voltage measured during the 200V phase equals Vidle + 200V.
9. Press the "Save to Calibration File" button on the calibration form.

10. After the “HV On” indicator goes out, switch off the uTracer power supply and disconnect the DVM.

Anode boost converter:

Warning: High voltages will be present and measured during this test!

1. Repeat the procedure above, except in step 1) connect the DVM to the anode reservoir capacitor C18, and in step 7) adjust the Va Gain slider on the calibration form so that the DVM measurement equals Vidle + 200V.

The set-up for the screen and anode voltage calibrations can be saved under an appropriate name such as “Cal Boost Converters” for future use.

Current amplifiers:

Warning: High voltages will be present during this test!

1. Make sure that the power supply is off and that the reservoir capacitors are discharged
2. Connect a 10k, 1% resistor between the anode terminal and the cathode terminal
3. Connect a 10k, 1% resistor between the screen terminal and the cathode terminal
4. Select Measurement type I(Va = Vs, Vg), with Vh constant, and set measurement parameters for Va = Vs Start = 195, Stop = 210, Nintervals = 4, Vgs = -1, Vh = 6.3. Set Range Ia = 0 – 40 mA, Is = 0 – 40 mA, Average = 4X, Compliance = 200 mA, and Delay = 0 (sec).
5. Set plot controls: Display Ia on the left Y-axis and Is on right Y-axis. Set all axes scale ranges to manual. Set the X-axis scale range for 190 to 210V, with 2 tick marks. Set both Y-axis scale ranges for 19 to 21 mA, with 2 tick marks.
6. Open the calibration form by pressing “Cal” in the miscellaneous section of the main form.
7. Switch on the uTracer power supply and press “Heater On!” twice.
8. Press “Measure Curve” on the main form to start the measurement.
9. Observe the resulting plot and adjust the Ia and Is gain sliders on the calibration form in the appropriate direction so that the straight lines on the plot (indicating a pure resistance) will pass through 200V at 20 mA at the center of the plot.
10. Repeat from step 8) until both the Ia and Is lines pass through 200V and 20 mA.
11. Press the “Save to Calibration File” button on the calibration form.

The set-up for the current amplifier calibrations can be saved under an appropriate name such as “Cal Current Amps” for future use.

8.6 – Customizing the “Pins” form

Ever since the introduction of the “Pins” form in the GUI, people have been asking me for a means to customize this form so that more or other electrodes can be included or renamed or to use the names of the electrodes in their own language. Even the English speaking countries cannot make up their mind how to name the electrodes (Plate vs. Anode). In the GUI 3.10 this is not possible, since the names in the drop-down menu are coded directly in the GUI program.

To enable customization of the form a different approach was followed in the GUI 3.11. Now when the “Pins” form is opened, the GUI searches for the file “pins.uts” in the directory from in which the GUI was installed, and uses the names in this file for the labels in the drop-down menus (see also section ”location of the files”). When the GUI does not find the file, e.g. after a fresh installation of the GUI, it generates one using the default names. When a newly generated file is opened with a text editor it will look like this:

```
 -- blank line --
anode
screen
grid
cathode
H1 (int)
H2 (int)
H1 (ext)
H2 (ext)
H1 (bat)
H2 (bat)
aux 1
aux 2
aux 3
n.c.
```

Note that the first line is empty just as in the drop-down menu. The names in the file may be modified as desired, but note that only the first 10 characters of every line are used. Changing the pinning information does not affect the way the pinning information is stored in the setup file where only the position in the drop down menu is stored for every pin.

8.7 – Distributed loading (Ultra-Linear Mode)

Tetrodes and Pentodes offer a high output power efficiency at the cost of an increased plate resistance and a relatively high distortion requiring considerable feedback. Triodes on the other hand perform much better with respect to distortion but are far less efficient. The difference between two classes of tubes is of course the screen grid. If we take a Tetrode/pentode and connect the screen grid to a fixed high voltage we obtain Tetrode/pentode behavior and if we tie the screen grid to the anode triode characteristics are obtained.

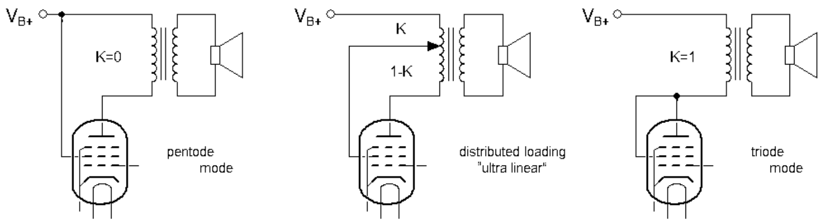


Figure 8.7.1 Principle of distributed loading

Hafler and Keroes[xxiv] found that if the screen is connected to a point somewhere between a fixed B+ high voltage and the anode, so e.g. on a tap. on the output transformer, characteristics may be obtained which are somewhere in between Tetrode/pentode and triode behavior. Further analysis has shown that by carefully selecting the position k of the tap, a high efficiency can be combined with a low distortion. Hereby represents k=0 the situation when the screen is connected to the constant high voltage (tetrode/pentode), and k=1 the situation when the screen is connected to the anode (triode).

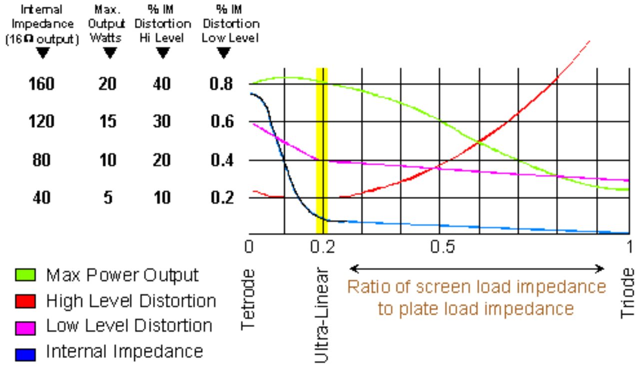


Figure 8.7.2 Output power and distortion of a 6V6 as a function of k (taken from Hafler and Keroes.[xxv])

Figure 8.7.2 is from the publication from [Hafler and Keroes.][xxvi] It shows how for a 6V6 the output power and the distortion vary for different values of k. For increasing k the distortion quickly drops, while the power output is still high. For the 6V6 they found the optimum to be around 21%.

Special measurement types for both the output characteristics (Ia(Va)) as well as the transfer characteristics have been incorporated to demonstrate the effect of a variable degree of distributed loading:

- **I(Va, Vg) with Vs=UL(Va,k), Vh Constant:** In this measurement Ia and Is are measured as a function of Va while stepping Vg. The screen voltage Vs is calculated in every point from:

  $$V_s = V_a + (1 - k)(V_{a,max} - V_a)$$

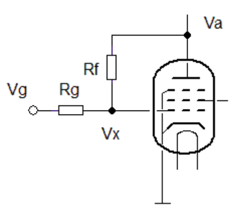
  With Va,max the stop value of Va that is specified in the measurement setup. So for k=1 the tube operates in triode mode (Vs=Va). For k=0 the screen voltage is constant and equal to Va,max. For values of k in between 0 and 1 the operation gradually shifts from pentode to triode mode.

- **I(Vg, Va) with Vs=UL(Va,k), Vh Constant:** In this measurement Ia and Is are measured as a function of Vg while stepping Va. The screen voltage is calculated in exactly the same way as the first measurement, but now Va,max is determined from the maximum value of Va entered in the stepping list.

For more reading: Mullard Circuits for Audio Amplifiers[xxvii]

8.8 – Simulating Schade Feedback

In Schade feedback a small amount of the anode voltage is fed back to the grid (Fig. 8.8.1). It was invented by O.H. Schade (see original paper[xxviii]), and it is used to decrease the output resistance of pentodes at the expense of a lower transconductance, and a grid current! The effect is claimed to give a better damping and bass control, while it also reduces some of the higher order odd harmonics.

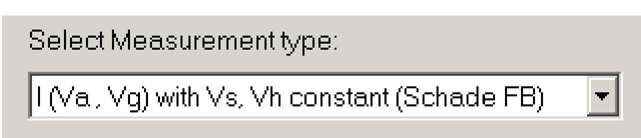


$$V_x = V_g + (V_a - V_g)\frac{R_g}{R_g + R_f} \quad \text{or:}$$

$$V_x = V_g + (V_a - V_g)SFB \quad \text{with} \quad SFB = \frac{R_g}{R_g + R_f}$$

Figure 8.8.1 Principle of Schade Feedback.

With the GUI it is possible to assess the effect of a certain percentage of Schade Feedback on the output characteristics of a pentode without the need to actually add the feedback and grid resistors. Instead the GUI calculates the actual grid voltage (Vx) for a certain set-point grid (Vg) and anode (Va) voltage for the required percentage of feedback (F) according to the formula given in Fig. 8.14. To measure a tube with Schade Feedback select to following measurement type:



In the field "SFB" the "Schade Feed-Back" factor as defined by the equation in Fig. 8.14 can be entered. The feedback factor needs to have a value between 10-6 and 1. When a high feedback factor is selected, it can occur that the grid voltage according to the equation becomes positive. Since the uTracer is not capable of supplying positive grid voltages, the grid voltage is in that case clipped to 0V, and a warning message is issued. In order to be able to implement this measurement without modifying the GUI too much, it was necessary to remove the heater voltage from the selection form for this measurement type. In practice this is not a problem since the GUI remembers the heater voltage when another measurement type is selected. The proper way to set the heater voltage to another voltage than 6.3 V (the default voltage) therefore is to first select another measurement type, set the heater voltage for that measurement, and then to select the Schade Feedback measurement.

8.9 – Calculating harmonic distortion

Every radio tube exhibits a certain degree of non-linearity. As a result the output signal is distorted as compared to the input signal. Mathematically this means that when a pure sine wave signal with a certain frequency ω (=2πf) is applied to the grid, the anode not only carries a sine wave with the amplified fundamental frequency ω, but also sine waves with frequency components 2ω, 3ω, 4ω etc. These are called harmonics, and the whole process is called harmonic distortion. The amount of distortion is an important figure of merit for amplifiers, and it is therefore of interest to know how much, and what type of distortion a certain tube introduces.

Really the best way to obtain that information that is to build and test the amplifier! The second best thing is to perform a (number of) DC measurements on the tube, and to extract an accurate equivalent circuit model e.g. using the ExtractModel[xxix] models and software. The behavior of the circuit can now be simulated using a circuit simulator such as LTSPICE.[xxx] When all the non-idealities of all components such as parasitic capacitances and inductances are included in the simulation, this method provides an accurate prediction of the circuit behavior, including its non-idealities.

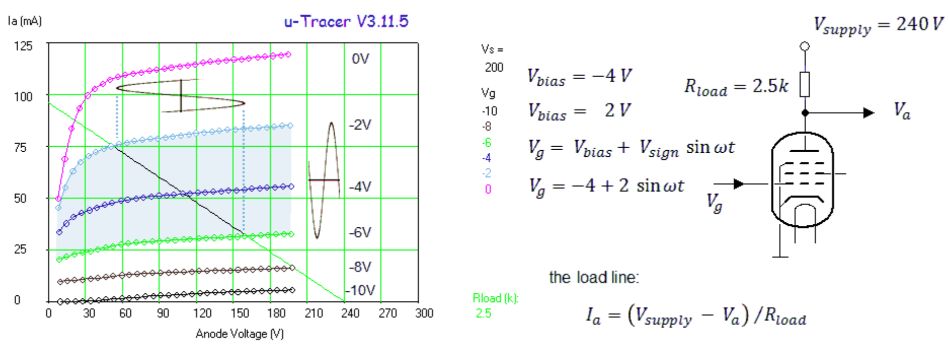


Figure 8.9.1 Graphical evaluation of the anode voltage as a function of the grid voltage.

Although the circuit simulation route is very accurate, most designers will start with a straightforward visual analysis of the output characteristics of a tube. A study of this set of curves will give experienced designers an idea of the gain and linearity, and the optimal load impedance, power supply voltage and bias point. The first step is to assume that the anode of the tube is connected to the high-voltage power supply by means of a simple resistor. This resistor "translates" the current sinked by the tube into a voltage, and fixes the relation between the anode current and anode voltage to a straight line which can be drawn in the set of curves. Note that the slope of this line is completely determined by the value of the load resistor and the supply voltage. The transfer characteristic of the tube from grid voltage to anode voltage can now be constructed by intersecting the set of curves with the load line. In the example of Fig. 8.9.1 a grid bias voltage of -4 V was used onto which an AC signal with an amplitude of 2 V was superimposed. From the intersection with the lines corresponding to grid voltages of -4+2 = -2 V and -4-2 = -6 V the swing of the anode voltage is found. At first inspection the average anode voltage is about 105 V, and the amplitude of the AC signal is about 55 V, corresponding to a gain of ca. 25. The selection of the optimal load line and the bias point obviously depends on many factors, and a full discussion is beyond the scope of this manual. A nice design example can be found here.[xxxi]

Apart from the gain, also the distortion can be estimated from the output characteristics and the load line. In the areas where the distance between equal steps in the grid voltage corresponds to equal steps in the anode current, the distortion is expected to be low. In the pre-computer area people have come up with all kind of ingenious schemes to determine the distortion directly from the output characteristics by means of graphical analysis. An extensive explanation of how that can be done is given by Reich in Theory and Applications of Radio Tubes (1944)[xxxii]. It requires an evaluation of the anode current in a large number of strategically chosen bias points along the load line followed by some straightforward algebra. Not really complicated, but cumbersome and prone to mistakes. What is even worse, the method requires a large number of curves for different grid voltages, or a visual interpolation between curves. All-in-all not really a practical method to get a quick impression of the distortion.

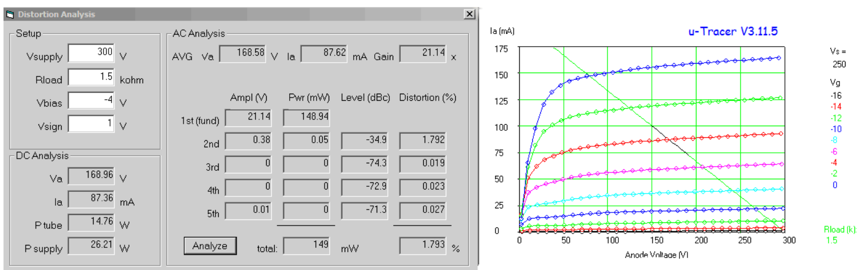
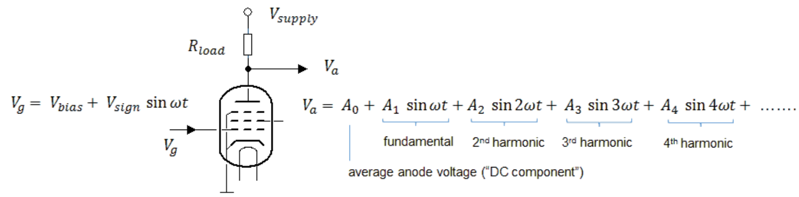


Figure 8.9.2 Example of the "distortion analysis form" and a corresponding set of curves.

The distortion analysis tool in the uTracer GUI pretty much follows the same route, but uses the advantages of the massive computing power available in modern computers. First the program takes the measured output curves and calculates a 2D qubic spline matrix. With this matrix it is possible to accurately interpolate the anode current Ia for any combination of anode voltage (Va) and grid voltage (Vg), provided that they fall within the minimum and maximum values of Va and Vg used for the measurement. Next a linear solver determines the intersection points between the load line and the output curves for a large number of points using the qubic 2D spline to interpolate between the actually measured points. Again a spline is used to provide a smooth transfer curve from grid voltage to anode voltage. This transfer curve is used to calculate the anode voltage resulting from a pure sine wave grid voltage. Finally a Fast Fourier Transform (FFT) is used to determine the harmonics in the output signal. It sounds complicated, but it is really pretty straightforward and only takes a fraction of a second.

The distortion analysis can only be performed when a valid set of output curves is displayed in the graph on the main form. The set of curves can be a measurement performed in the same session, or a set of curves reloaded from a setup file. The distortion analysis form is opened by pressing the "Distortion" button in the measurement analysis section on the main form. The distortion analysis form consists of three sections: "Setup," "DC Analysis," and "AC Analysis." In the setup section the supply voltage (Vsupply) and the load resistor (Rload) for the load line can be specified, as well as the DC grid bias (Vbias) and the amplitude of the sine wave grid excitation (Vsign). Note that the amplitude is defined as shown in Fig. 8.9.2. Pressing the "Analysis" button plots the load line into the graph, and performs the DC and AC analysis. Note that on the load line the swing of the grid voltage is highlighted. The DC values of the anode current and voltage are directly obtained from the intersect point between the load line and the output curve corresponding to the grid bias voltage (Vbias). The power dissipated in the tube (Ptube) and the power supplied by the power supply (Vsupply) are calculated from the DC anode current and voltage and the power supply voltage.



Amplitude	Power	Level	Distortion
A_n [V]	$P_n = A_n^2/2R_{load}$ [W]	$L_n = 20 \log_{10} \frac{A_n}{A_1}$ [dBc]	$d_n = 100 \cdot \frac{A_n}{A_1}$ [%]
$n = 1,2,\ldots,5$	$n = 1,2,\ldots,5$	$n = 2,\ldots,5$	$n = 2,\ldots,5$
	$P_{tot} = P_1 + P_2 + \cdots P_5$		$d_{tot} = \sqrt{d_2^2 + d_3^2 + \cdots d_5^2}$

$V_{av} = A_0$ [V] $\quad I_{av} = (V_{supply} - A_0)/R_{load}$ [A] $\quad Gain = A_1/V_{sign}$ [-]

Figure 8.9.3 Formulas behind the distortion analysis form.

The section "AC analysis" shows the results of the FFT calculation. From Fourier analysis theory it is known that any periodic signal with frequency ω can be written as an (infinite) sum of sine wave functions with frequencies ω, 2ω, 3ω, …, with amplitudes A0, A1, A2, A3 …. The first term A0 represents the average anode voltage. For very small signal amplitudes the average anode voltage equals the DC anode voltage. However, when the signal amplitude increases, part of the AC anode signal will be rectified due to non-linearities of the tube. The rectified voltage will add to the DC voltage causing a shift in the average anode voltage. The second term in the Fouriers expansion is the fundamental frequency component. It is basically the "wanted" component in the output signal. The amplitude of this component divided by the amplitude of the AC grid signal determines the gain (A1/Vgrid).

The other terms represent the second, third and higher harmonics. On the form the second up to the 5th harmonic have been included. Of every harmonic, (including the fundamental) the power it generates in the load is listed. Furthermore, for every harmonic its distance below the carrier (in dBc) is given. Finally, the distortion factor, which is the ratio of the amplitude of the harmonic with respect to the fundamental component, is calculated.

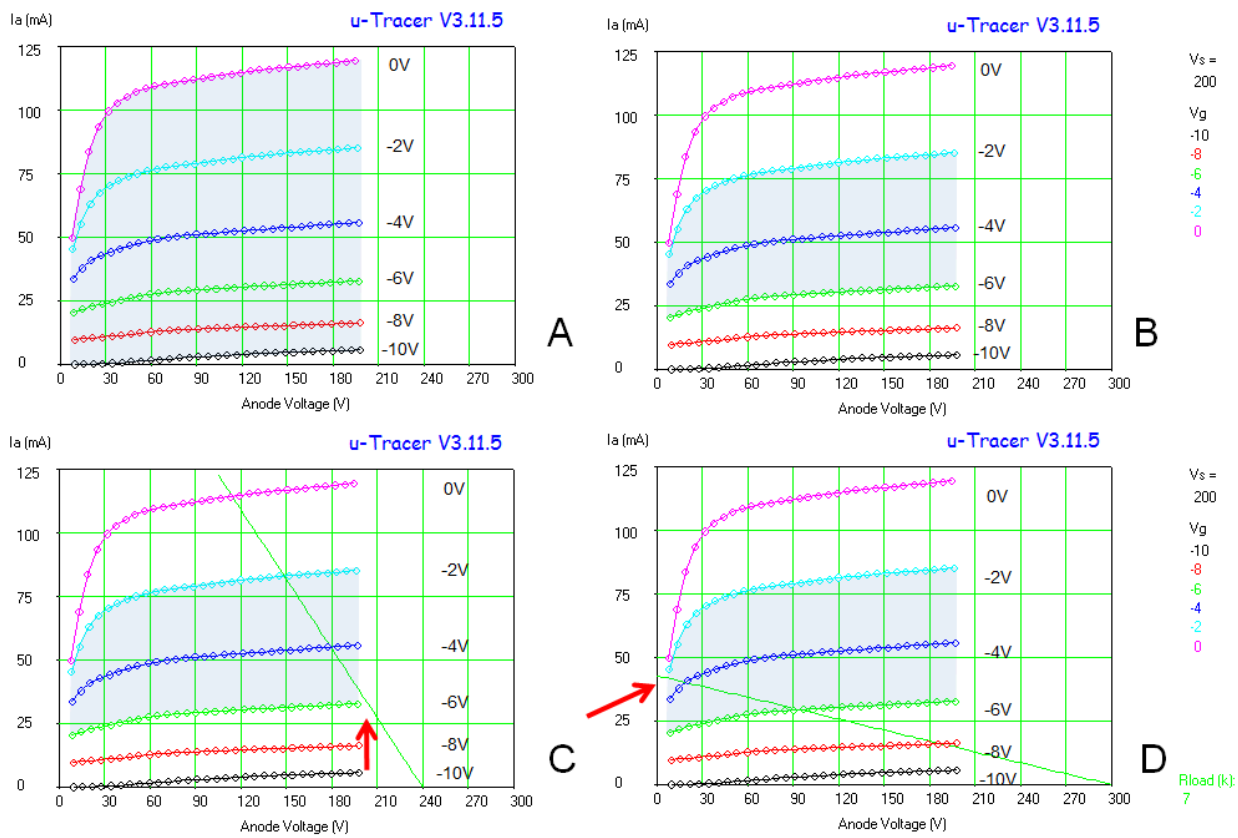


Figure 8.9.4 The measurement area and the load line.

Limitations:

Although the distortion analysis tool can accurately interpolate between measurement points within the measurement dataset, it cannot extrapolate outside of it! Fig. 8.9.4A shows an example of a measured set of output curves. For the point of illustration, the anode voltage was swept starting from 10 V; normally the lowest anode voltage of 2 V would always be used. In this example, the grid voltage was stepped from -10 V to 0 V. The colored area gives the range of the measured data set. All intersections of the load line with the curves for the selected grid bias and grid signal amplitude have to fall within this colored area! For the proper use of the distortion analysis tool a number of guidelines and limitations have to be taken into account. When these limitations are violated a warning message is issued. In this section these limitations will be discussed in relation to the warning messages issued:

>>> The x-axis variable must be Va or Vs!

A fairly obvious requirement. The distortion analysis form can only be evoked when an output-characteristic type of measurement has been selected.

>>> At least 3 curves with each 5 points required!

To make the spline algorithm work, a minimum set of curves and a minimum set of points per curve is necessary. Here, a bit arbitrary, the minimum number of curves has been set to three, with a minimum of five points per curve.

This raises the question what number of curves and number of points per curve is optimal. Obviously more curves and more points per curve will result in a higher accuracy, but also increase the measurement time. In the EL84 examples in this section, the grid voltage was incremented with steps of 2 V. In a test the interpolated values at the 1 V intervals were calculated and compared to measured values. The error in all cases was less than 1%. In general the Ia(Va,Vg) characteristics of tubes are rather smooth and well behaved. A limited number of curves and points is therefore in most cases sufficient to "capture" the tube, and the example shown in this section gives a good idea of an optimal set of curves and points.

As already mentioned, it is possible to store the measurement together with the measurement set up. In this way it is possible to analyze a set of curves that was obtained in a previous measurement session.

>>> Signal amplitude below minimum measured Vg! & Signal amplitude above maximum measured Vg!

This simply means that the maximum input signal (Vbias + Vsign) has to be equal or less than than the maximum grid voltage used in the measurement, and that the minimum input signal (Vbias – Vsign) has to be equal or higher than the minimum grid voltage used in the measurement.

>>> Vgrid outside measurement plane, right-side. Decrease Vsupl or Vsign; or increase Rload!

This situation is best explained by an example. Assume that for the set of curves of Fig 8.9.4B a grid bias (Vbias) is applied of -4 V, and that the amplitude of the input signal (Vsign) is 2 V. The input voltage will now swing between the grid bias lines marked with -6 V and -2 V (colored area). The left side demarcation of this area is given by the minimum anode voltage that was specified in the measurement, while the right side border is determined by the maximum anode voltage used. For certain combinations of Vsign, Rload and Vsupply it is possible that the load line does not intersect with the all the curves in the colored area. This situation is shown in Fig 8.9.4C. Note that for low input voltages the load line does not intersect the curves for the lowest grid voltages. In this situation a warning message is given and no further calculations are made, and the user has to decrease the supply voltage or the signal amplitude, or to increase the load resistance.

>>> Vgrid outside measurement plane, left-side. Increase Vsupl; or decrease Vsign or Rload!

A similar condition can occur on the left side of the graph. Figure 8.9.4D shows the situation where the load line fails to intersect the highest grid bias curves. The remedy here is to increase the supply voltage or to decrease the input amplitude or load resistance.

>>> Maximum number of iterations exceeded, please save problem and report.

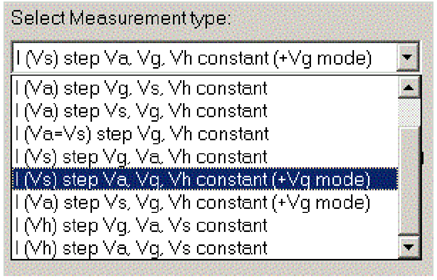
Please save the problem and report the problem!

8.10 – Positive grid bias (A2 mode)

Certain types of class-B audio amplifiers and most class-B and class-C high-power RF transmitters work in a positive bias mode, so testing tubes in this regime is obviously of interest. The problem is that when the grid becomes positive, it starts act as a kind of anode, attracting electrons. As a result a grid current will start to flow and the grid will start to dissipate!

The grid bias circuit of the uTracer is designed for negative grid biases only. Some people have suggested "fooling" the circuit by adding a positive floating voltage source in series with the grid terminal so that e.g. the range of -50 to 0 V is shifted to -25 to 25 V (using a 50 V battery). Unfortunately this doesn't work since the grid bias circuit is also not capable of delivering the substantial currents which would flow to the grid for positive biases. Note, by the way, that this trick does work to extend the grid bias range of the uTracer towards more negative biases!

This was the situation until James Hill on the Audio-Talk forum[xxxiii] had had the fantastic idea of using the screen supply to drive the grid for positive biases! Why didn't I think of that before, the idea is indeed brilliant! The screen supply is capable of delivering positive grid bias pulses and what is more important: capable of accurately measuring the resulting grid current. Another important, and even necessary feature is that in this way the grid bias is pulsed so that the excessive dissipation in the grid, which would occur if DC biases were used, is prevented. So far as I could see, the idea only had two problems: The first one was that the GUI software didn't provide for such a measurement. The second one was that the screen, as well as the anode supply loos a bit of accuracy for low voltage due to the limited resolution of the AD converter and the principle behind the circuit. Finally, needless to say, since there is only one screen supply the method is only suitable for testing triodes.



The first problem was easily remedied. Since I was working on a new release of the GUI anyway, the two new measurement types could easily be implemented in version 3p8. Two new measurement types were implemented to allow for I(Vg) and I(Va) measurements in positive grid bias mode (+Vg mode). In the "+Vg mode" the grid is connected to the screen terminal of the uTracer. The normal grid bias output is working (constant voltage), but in most cases not used. Note that for the "+Vg mode" measurements in the measurement type select box (screen capture left), "Vs" is used to denote the grid connection. I thought this more logical since the grid of the tube has to be connected to the screen pulse output of the uTracer. Also In the graph "+Vg" has replaced Vg. The only thing that was rather hard to change was the axis-name for the grid current. So for these two measurements Is represents the grid current, sorry for that!

When James proposed to use the screen supply for positive grid biases, I was afraid that it would result in "noisy" curves. The reason was that I have the impression that both the anode, as well as the screen supply lose some accuracy for low voltages. There are two reasons for my suspicion. The first reason is that for low voltages the relative error of any AD converter increases. There is always an uncertainty of one LSB in this case corresponding to approximately 0.3 V. Add to that that there might be some noise in the reference voltages of the AD converter, and the total uncertainty of can easily amount to a volt or so. At 300 V this is a relatively small error; however, at say ten volts the error is enormous! The second source of noise can be found in the way the boost converters operate.[xxxiv] Current pulses, four at a time, charge the reservoir capacitors until the required voltage is reached. Especially for low voltages, this can result in a small overshoot. Needless to say that when the screen supply is used to bias the grid that these small variations are amplified by the tube!

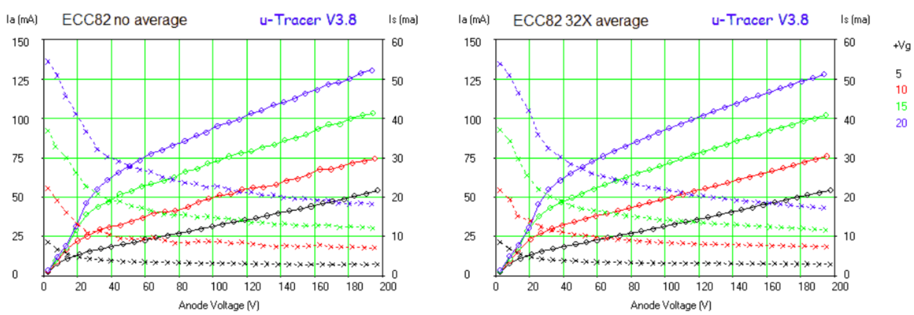


Figure 8.10.1 Eliminating noise from the curves by increasing the number of averages.

As it turned out, the problem was much less serious than I had feared. A nice indication that the anode and screen supplies are not that bad at all! The curves of Figs. 8.10.1 are actually quite nice and smooth. However, for very low grid voltages (Fig. 8.10.1 left) indeed some fluctuations can be observed. The most obvious method to reduce the fluctuations is to average the measurements. Normally the average feature of the uTracer[xxxv] is used to average out noise in the low current regime. When the averaging is set to automatic, the PIC automatically reduces the number of averages when the current that is measured increases. Figure 8.10.1 illustrates how manually setting the number of averages to some value higher than 1X can help to reduce noise in the curves caused by the "grid supply."

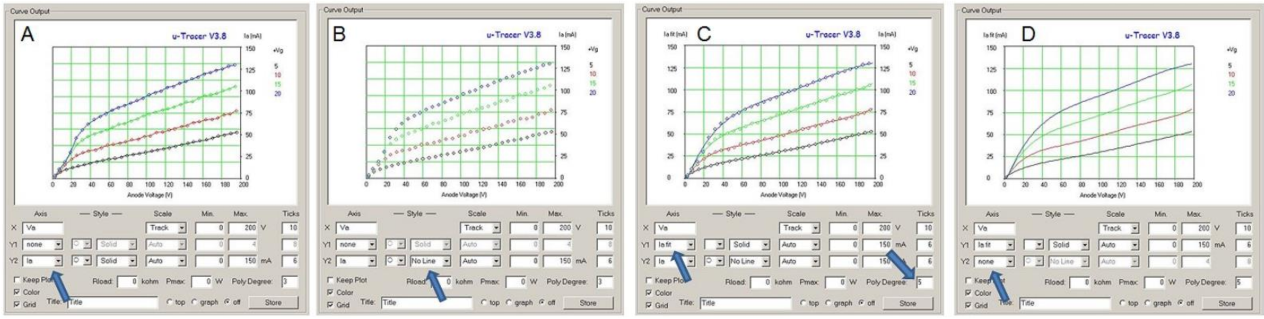


Figure 8.10.2 The straightening out of curves by means of polynomial fitting.

The curve-fitting function which is built-in in the GUI to produce noise free transconductance curves can also be used to straighten-out noisy or wobbly curves. Figure 8.10.2 illustrates how it is done. We start by first plotting the measured data along the second Y-axes (Fig. 8.10.2A). Next the solid lines are removed, leaving only the markers (Fig. 8.10.2B). We then select the fitted current to be displayed along the primary Y-axis, and the polynomial degree is set to such a value that a nice set of curves is obtained (Fig. 8.10.2C). Finally the markers belonging to the original measurement are also switched off (Fig. 8.10.2D).

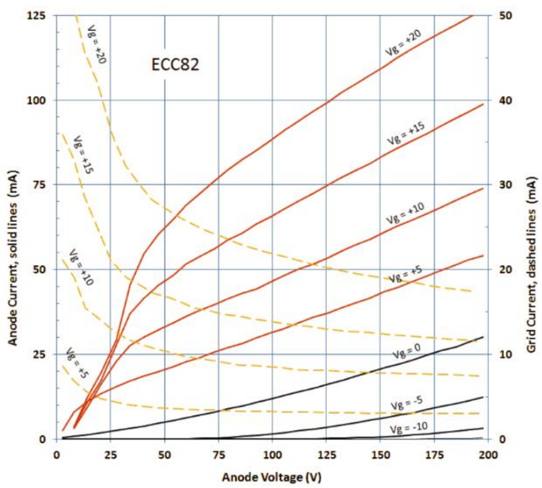


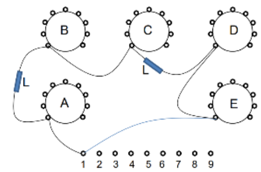
Figure 8.10.3 ECC82 measured with positive and negative grid biases.

Unfortunately it is not possible to combine in one graph positive and negative grid bias curves. However, Fig. 8.10.3 shows that by combining the data from several measurements in Excel, impressive graphs may be obtained. In this case an ECC82 was tested resulting in a set of curves that very few tube curve tracers could have produced without destroying the grid, or possibly the whole tube.

8.11 – Suppressing oscillations

One of the biggest threats to any tube tester are unwanted oscillations which can occur because the tubes are tested under realistic bias conditions while they are connected by long wires which contain many parasitic resonance circuits. With conventional tube testers, it can very well happen that a tube is destroyed because a destructive oscillation occurs! A big advantage of the uTracer is that the maximum energy stored in the reservoir capacitors is very small, too small to destroy a tube. The oscillations can however disturb the measurement so it is important that they are prevented. One of the most effective ways to achieve this is to include RF suppression coils in the tube connections. At DC the resistance of these coils is almost zero, while the resistive losses quickly increase for increasing frequencies.

Furthermore, I strongly recommend using the wiring scheme that AVO uses (and patented) in their tube-testers. The schematic diagram below shows the basic idea for one terminal. The wire connecting say pin one of each tube socket runs in a loop which also connects to the banana plug or rotary switch. At certain intervals an RF suppression bead (e.g. Wuerth no: 74270015) is shifted over the wires. The physical lengths of all the loops has to be approximately the same. The figure on the next page gives an impression of the wiring scheme of my version of the uTracer. If during testing of a tube the resulting curves seem really strange, oscillations may be the problem. Try adding an extra bead to see if that fixes the problem.



For the heater connection do not use RFI suppression beads. Unfortunately this conflicts with an AVO style wiring of “tube-board” where RFI beads are included in every wire to suppress oscillations. The reason is that the RFI suppression beads have a detrimental effect on the heater current which is switch-mode regulated at 19.5kHz. Also note that for this reason the effective heater voltage CANNOT be measured with an ordinary (even RMS) type volt meter. If high accuracy or high current low voltages are required, an external power supply is preferred.

Use as short as possible and twisted wires for the connection between the uTracer and the tube socket.

8.12 – testing diode tubes

So far I neglected the effect that the anode and screen currents have on the anode and screen voltages. There are three effects: in the first place there is the voltage drop over the current sense resistor. In the second place the currents discharge the buffer capacitors, and finally there is the voltage drop over the high voltage switch. All these three effects lower the effective anode and screen voltages. Fortunately the three voltages drop can easily be measured or calculated (Fig. 8.12.1). The voltage drop over the sense resistor simply equals the measured current times the resistance of the sense resistor. The approximate voltage of the buffer capacitor at the moment of the current measurement is also known because the voltage of the buffer capacitors is measured immediately after the measurement pulse. The voltage over the high voltage switch is approximately constant (0.7 V).

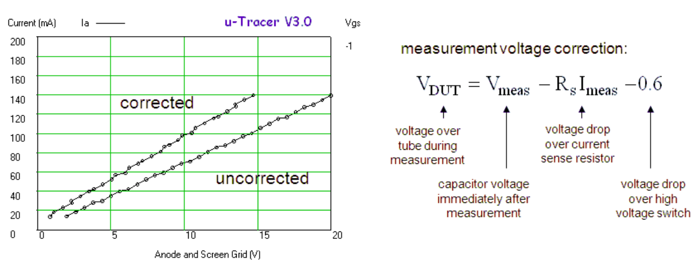


Figure 8.12.1 I(V) curve of a 100 ohm resistor showing the impact of the anode/screen voltage correction for low voltages.

So far I have neglected these effects and just plotted the currents versus the set-point voltages. The error is usually very small; for most tubes the currents are rather small, while the voltages are high. However there is at least one type of tubes for which the error can be rather large: diodes! Evidently diodes are designed to conduct high currents with a low voltage drop over the diode. The voltage drops over the sense resistor, switch and buffer capacitor can in this case be very significant.

Figure 8.12.1 shows two I(V) measurements of a 100 ohm resistor connected between anode and cathode connections of the uTracer, with and without correction of the measurement voltage. Note the large difference between the curves! Both lines appear to be less “smooth” than the normal uTracer curves. There are a number of factors involved here. First we have to realize that we are at the limits of the AD converter. With a 10 bit AD converter sized for a 380 V range the voltage step per bit is ca. 0.4 V. Looking at the “uncorrected curve” we can observe small jumps in the line about every 4 measurement points. Clearly aliasing effect related to the AD converter. The “corrected curve” obviously also suffers from the limitations of the AD converter, but additionally a correction voltage, which in itself also contains an error, is subtracted from the set-point voltage resulting in a rather ragged curve. Although the curves certainly wouldn't make it in a beauty contest they are certainly still very acceptable and at least good enough for me.

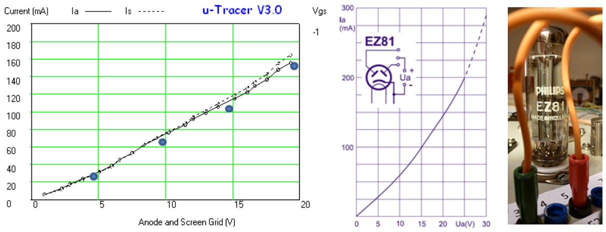


Figure 8.12.2 EZ81 full-wave power rectifier tested and compared to datasheet.

In Fig. 8.12.2 the I(V) curve of the diodes of a single EZ81 are compared to the curve from one of the datasheets. Like in the measurement of double triodes, one of the anodes is connected to the anode connection of the uTracer, while the other anode is connected to the screen connection. In this way both measurements can be compared in one measurement.

8.13 – Testing a Thyratron

The EC50, Thyratron.

The EC50 is a helium filled thyratron introduced around 1939. A thyratron is a high voltage power switch very comparable to a thyristor. When the anode current is raised with the grid at a negative potential there is no anode current. However, is the grid is shortly made positive a plasma ignites and a current starts to flow limited by an external resistor. The current continues to flow even if the grid is made negative again. The plasma only extinguishes when the anode voltage is reduced to zero again. When the tube is ignited there is a voltage drop of about 33 V between anode and cathode.

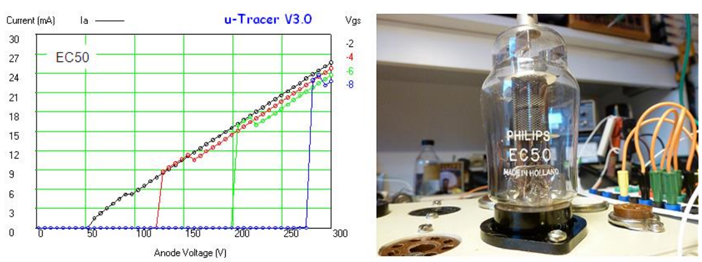


Figure 8.13.1 Ia(Va) curve of the EC50 for different Vg with an anode series resistor of 10k.

The tube can however also ignite when the anode voltage is increased beyond a certain critical value. This value depends on the negative grid bias. The more negative the grid, the higher the ignition voltage. The relation between the negative grid bias and the ignition voltage is almost linear. In Fig. 8.13.1 an Ia(Va) curve is measured of an EC50 for different grid bias values. To limit the current a 10k resistor was switched in series with the anode lead as represented by the slope of the straight line.

8.14 – Testing Directly Heated Tubes

To test a directly heated tube you again connect the heater of the tube to the heater connections of the uTracer, but in this case the cathode connection on the uTracer is not used (Fig. 8.14.1C)! Connecting the cathode connection to one of the heater connections can short-circuit the heater supply, which in one case destroyed a complete uTracer, **DON'T DO IT!**

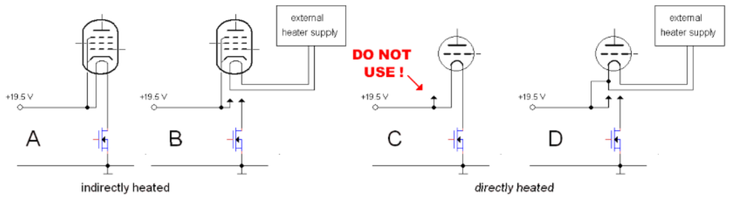


Figure 8.14.1 Connection diagram of indirectly / directly heated tubes with internal / external power supplies.

The situation is different when an external heater supply is used which is electrically floating with respect to the uTracer. In that case the cathode connection has to be connected to one of the heater connections on the tube (Fig. 8.14.1D). The curves may vary depending on which heater connection is connected to the cathode, due to asymmetries in the tube. You may even consider placing a low-resistivity potentiometer in parallel to the heater with the slider connected to the cathode connection.

Another note of caution is needed when delicate battery tubes are measured! As explained before, the heater duty-cycle becomes very short for low heater voltages. Small variations in the duty-cycle will thus result in relatively large variations is the dissipated power. So when I measure delicate battery tubes like the DAF96 (1AH5), Russian pencil-tubes etc, I simply use a 1.5 V battery as heater supply, in that way nothing can go wrong whatsoever.

8.15 - Testing a 12SA7 hexode ("pentagrid")

Decent testing of the 12SA7 hexode ("pentagrid") frequency changer tube was a bit less straightforward. Philips e.g. publishes DC curves of their hexodes, but these were not available for the 12SA7. However, probably for testing purposes, the datasheet states some DC characteristics of the tube in "non-oscillating" mode. With the anode and screens connected to 100 V, and the grids to 0 V, the cathode current should be around 25 mA (I assumed that the suppressor grid was kept floating). Figure 21 shows a set of Ia(Va) curves of the 12SA7 tested in this configuration whereby the anode voltage was varied between 0 and 100 V, and the first control grid voltage was stepped from -7 to 0 V. The very last point measured corresponds to the point mentioned in the datasheet, and the anode very nicely matches the current specified in the datasheet (25 mA).

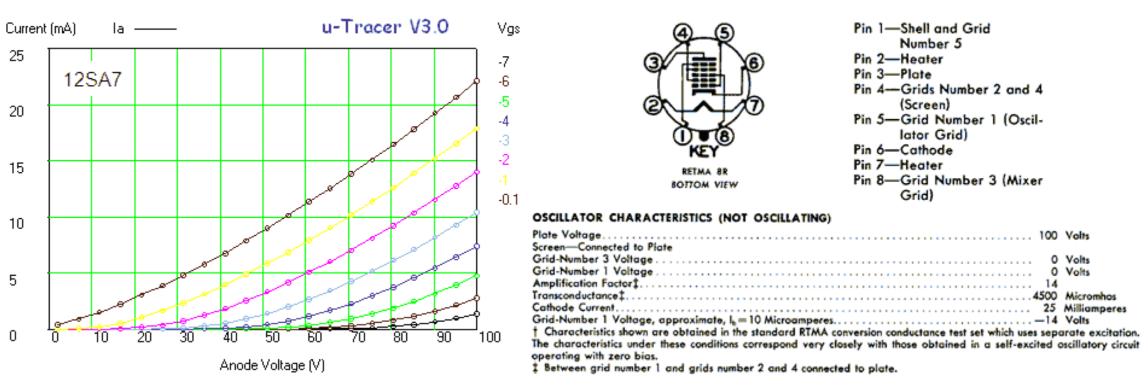


Figure 8.15.1 12SA7 RF mixer/oscillator.

8.16 - Reforming Electrolytic Capacitors

Fortunately, it is very easy to check capacitors for their proper working. All that needs to be done is to limit the current for example with a high value resistor. In its simplest form you take a high voltage supply and connect that via a resistor of say 10 kohm to the capacitor, while the current is monitored. When the capacitor is ok, the current should quickly drop to a value in the tens of micro amp range. A 100 uF capacitor for example should be 99% charged in 3RC = 3*100E-6*10E3 = 3 seconds. In most cases, however, it takes a much longer to obtain a current in the micro-amp range. What is happening is that slowly the dielectric is being restored to its original thickness. It may very well be that a sufficiently low current is never obtained. In that case the damage to the capacitor was too large and it will need to be replaced. To maintain the original look of the instrument some people go as far as hollowing out the defective capacitor and filling it with a new replacement type. This is often possible since modern capacitors are much smaller that vintage ones. Capacitor development obviously also has seen a continuous innovation and you will find that capacitors from the seventies onward are much more stable and robust

So the good news is that in many cases old vintage capacitors can be brought to life by carefully applying a voltage to them while limiting the current. This process is called (re-)forming. There is no commonly agreed upon best strategy how to do this. Some people simply leave the capacitor in the circuit and power the piece of equipment via a variac and then slowly increase the power supply voltage. Others remove the capacitor from the circuit and connect it via a high value resistor to the maximum working voltage.

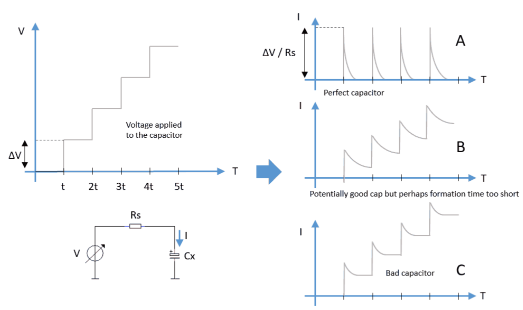


Figure 8.16.1 Preferred method of forming vintage electrolytic capacitators.

I personally favor a method where the capacitor is connected via a resistor to an adjustable voltage source whereby the voltage is increased in steps, while at each step the capacitor is given time to stabilize (Fig. 8.16.1 left). Depending on the state of the capacitor a variety of current responses is possible. In the right of Fig. 8.16.1 (A, B, and C) a selection of responses is sketched. A perfect capacitor will have a current response as depicted in Fig. 8.16.1A. Every increment of the voltage results in a current spike with an amplitude Vstep/Rs. The capacitor will quickly charge, and in about three times the time constant (3*Rs*Cx) the current will drop to almost zero.

Figure 8.16.1B shows the current response of a capacitor that is far from perfect. Note that the current spikes have decreased in amplitude because of the voltage drop over the series resistance of the capacitor. Note also that the current doesn’t drop to zero. If the time delays have been chosen such that t >> 3RC, it indicates that the capacitor is forming itself and that likely more time is needed to complete the healing. In this case the time increments can be increased in length to see if eventually the current drops to nearly zero. Mind, this can take hours!

The capacitor in Figure 8.16.1C is obviously hopelessly lost. Only a little bit of capacitive behavior is left and the capacitor mostly exhibits a resistive behavior with the current not dropping even if the “forming time” is increased. This capacitor is obviously “a capacitor on the blink.”

The basic circuit

It will be recalled that the anode and screen high voltage supplies of the uTracer consist of two low current programmable boost converters that charge the two 100 uF reservoir capacitors of the uTracer to the desired voltages. The boost converters can supply a current of a few milliamps, which is more than enough to re-form capacitors!

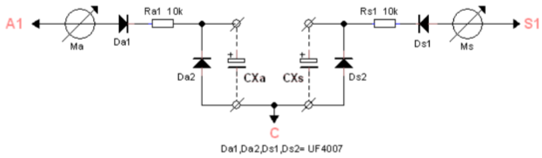


Figure 8.16.2

Figure 8.16.2 shows the idea in its simplest form. The cathode of the capacitor to be reformed is connected to the cathode terminal of the uTracer, while the anode is connected, via a 10k resistor, to the anode of one of the 100uF reservoir capacitors of the uTracer. By specifying a delay in the "delay" field, the uTracer will charge the capacitors to the desired voltage and then hold that value before continuing to the next "measurement point." Read more about the delay function here. Since the uTracer has two independent high voltage sources, it is possible to re-form two capacitors at the same time. Handy when reforming "combined" vintage electrolytic capacitors! The two "re-forming circuits" are obviously identical, so here I will only discuss one. Diode Da1 prevents current flowing back from the capacitor that is being reformed back into the uTracer which might disturb the voltage regulation of the circuit. Diode Da2 makes sure that the capacitor can never be revers biased. Current meter Ma is used to monitor the current. Personally I prefer an old fashioned dial instrument because it gives a better and faster idea of the progression of the current, but of course a digital current meter may also be used.

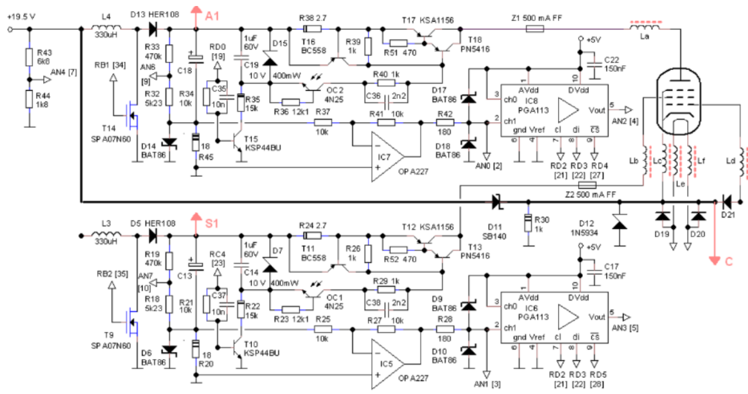


Figure 8.16.3 Showing where the circuit 8.16.2 connects to the uTracer

To operate the circuit, you:

1) Select measurement **"I(Va=Vs,Vg) with Vh constant"**
2) Enter the voltage range in the "Start" and "Stop" fields and specify the number of steps. Use as start value at least 20V, because with the added capacitor the uTracer has problems stabilizing the voltage for lower values.
3) Preferably set the number of averages to "none".
4) The values in the fields "Vg" and "Vh" are irrelevant.
5) Set the desired delay that you want in between voltage increments in the field "Delay" (in seconds). *Note: in the standard GUI version this delay is limited to 300 sec. To enter delays up to 30.000 seconds (about 8 hours), you need to download and run the beta version GUI 3.12.5 (or higher). Installing the beta GUI is very easy, click here to download it and for installation instructions.*
6) Double click the measurement button to skip the heating cycle and start the re-forming process.

On the uTracer website is a description of a "Deluxe" version[xxxvi] capable of recording the current at the end of each step. This involves minor surgery to the uTracer itself.

8.17 – Grid Loupe

The grid supply of the uTracer is not really adequate when it comes to studying the behavior of tubes at very low plate voltages. The grid supply of the uTracer was designed to generate bias voltages over the range of -50 to 0V and it cannot supply or sink any significant currents. However, at (very) low plate voltages most tubes only start to show a noticeable anode current for grid biases in the range of -2 to 0V. Besides this, at low plate voltages, the grid starts to draw significant currents for grid biases below -0.5V (I think the mathematical correct way of saying this would be: for grid biases higher than -0.5V). The reason is that for low plate voltages less electrons are pulled to the plate, so that they can contribute to the grid current. As mentioned, the grid bias supply of the uTracer was never designed to supply substantial amounts of current, resulting in measurement artefacts. Finally, people who are interested in using tubes at very low plate voltages may be interested in the characteristics of tubes at slightly positive grid biases since it appears that, apart from the fact that the grid starts to draw significant grid currents, the main properties of the tube - including the special "tube sound" - are preserved. The idea developed to design a small adapter circuit – a grid loupe – to study tubes at low and even positive grid biases. The wish list for the "grid loupe" are:

- Accurate grid voltage generation from -10V to +5V
- Capable of sourcing and sinking several tens of mA
- Monitoring of the grid current
- To be used as an extension to the existing uTracer3+ hardware (and GUI)
- As simple as possible

For details of building the Grid Loupe option[xxxvii] please see the uTracer website.

8.18 – Transistor Curve tracer

As it turns out it is surprisingly simple to convert the uTracer into a transistor curve tracer! In its simplest form it really does not take more than a few resistors and a few test clips. Figure 10.1 shows the principle by which npn bipolars, N-channel MOSFETs and n-channel JFETs can be connected to the uTracer and be traced.

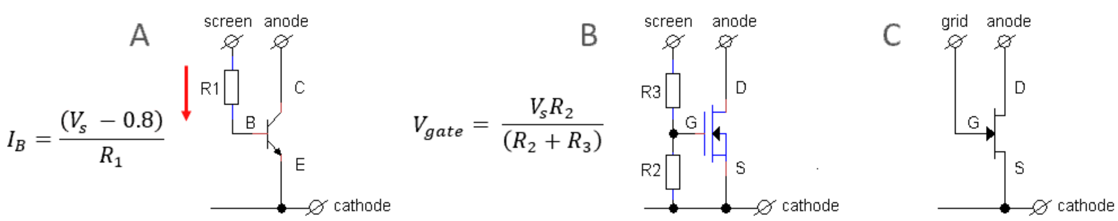


Figure 8.18.1 A few simple resistors turn the uTracer into a transistor tester.

Bipolar transistors are current amplifiers. The base of the transistor is supplied with a current, and as a result a larger collector current will flow. The ratio between the collector and the base current is called the DC current gain or Beta or hFE. The grid supply of the uTracer is not at all suitable to drive the base of bipolar transistors. First of all, it generates negative voltages and then again at near zero currents. However, it turns out that it is quite simple to convert the screen supply into a (near ideal) programmable current source that can be used to drive the base of npn transistors, the only thing that is needed is a resistor! Figure 10.1A shows the principle which makes use of the fact that the emitter-base voltage of a silicon bipolar transistor is almost constant between 0.7 and 1.0 V. A simple resistor can now be used to convert a screen voltage into a base current. If we program the screen supply to a series of not too small voltages, then the emitter-base voltage variation will be negligible so that the base current Ib = (Vs-0.8)/R. If Vs >> 0.8V this can be simplified to Ib = Vs/R.

The testing of an n-channel MOSFETs is just as simple. We again use the unused screen supply to generate positive gate voltages. To increase the accuracy of the gate voltage, a voltage divider is used to reduce the screen voltage by a factor of 10 so that the screen voltage range of 0 to 200 V translates to a practical gate voltage range of 0 to 20 V. Since the gate current is zero, a simple resistive voltage divider will be just fine. The only thing to take into account is that the impedance of the voltage divider is low enough to charge the gate capacitance well within the 1 ms measurement pulse. Measuring n-channel JFETs is even simpler. In this case the grid bias of the uTracer can be directly used to drive the gate of the FET.

Circuit and construction

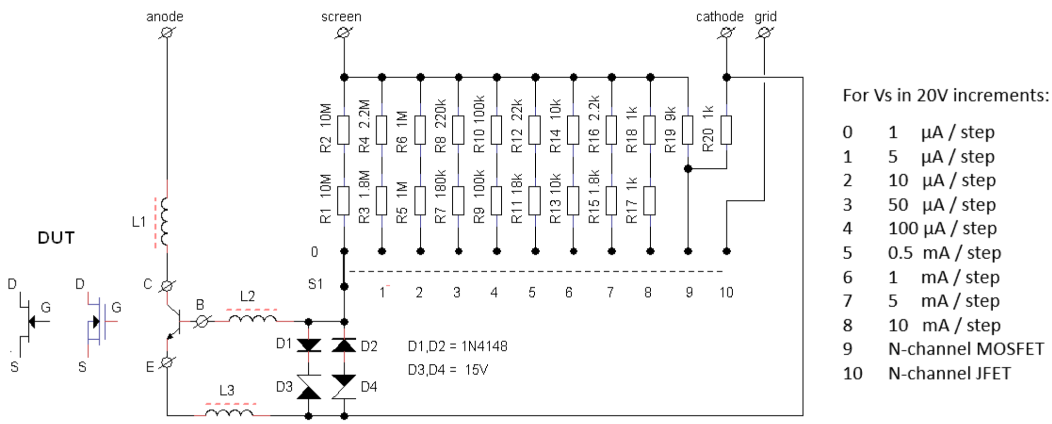


Figure 8.18.2 Example of an implementation of the transistor adapter module.

The concept translates into a simple circuit that most people can build for free after a dive into their junk box. In my case I was lucky to find a rotary switch with 11 positions (well actually 12, but I didn't use the last one). Positions 0 to 8 of the rotary switch are used to select the desired base current range. More about the selection of the resistors R1 to R18 and the base current ranges at the end of this section. Position 9 of the rotary switch is reserved for the characterization of MOSFETs. The resistive divider consisting of R19 and R20 reduce the screen voltage by a factor of 10 before it is applied to the gate of the transistor. The odd value of 9k by the way, is obtained by placing a 10k, 100k and 1M resistor in parallel. Position 10 of the rotary switch is reserved for n-channel JFETs. In this case the negative grid voltage is directly connected to the gate of the FET. Most common (power) MOSFETs I know have a maximum allowable gate voltage of +/- 20V. To make sure that in case of a mistake the gate of the MOSFET under test is always protected, I inserted D1-D4. This tiny circuit clamps the maximum gate source voltage to +/- 15V (I didn't bother to implement it).

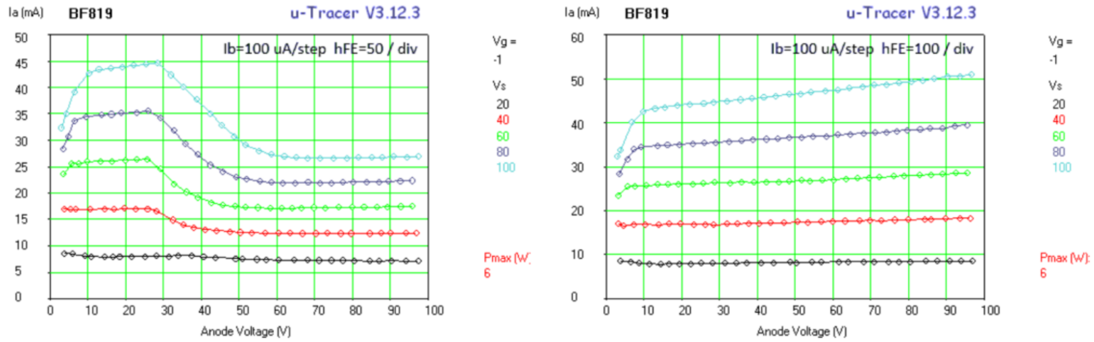


Figure 8.18.3 Left, typical result when the transistor oscillates for in a certain bias regime. In that case the uTracer will also often give compliance errors. Right, the transistor could be silenced with a few simple RFI ferrite beads.

The adaptor circuit proved to be quite prone to oscillations. Oscillations are a common problem in transistor curve tracers (read more here[xxxviii]). Figure 8.18.3 shows a trace of a BF819, a 90MHz fT, 250V line driver transistor that was used in color televisions. The left trace in Fig. 8.18.3 shows erratic behavior at medium currents. At high currents the curves look normal. What happens is that for the medium currents the transistor is biased for maximum fT and will tend to oscillate. For higher currents the transistor is driven into (quasi) saturation resulting in a sharp decrease of fT and as a result the oscillations subside. A few ferrite RFI beads in the leads to the transistor were sufficient to stop the oscillations (Fig. 8.18.3 right).

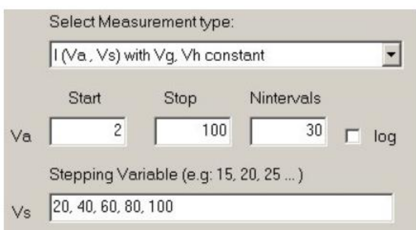
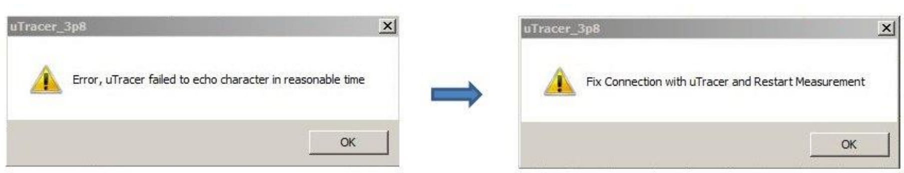


Figure 8.18.4 To measure a set of bipolar or n-channel MOSFET output curves the **I(Va,Vs) measurement** type is selected.

9 – Hardware Troubleshooting

What are the symptoms that something is wrong? The most common symptom that something is wrong is that in a new measurement, the GUI will draw one or two points and then display a “time-out” message, followed by a message saying that there is a communication problem. In this case the high voltage switch has probably been damaged, and is conducting continuously.



In cases when the high-voltage switch has been less-severely damaged, very strange curves will be produced which can sometimes even “fold-back.”

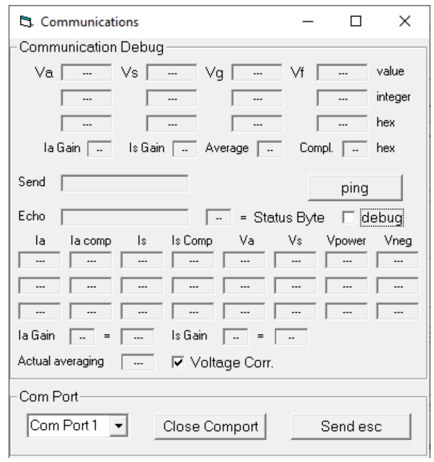
Systematic Testing:

When you suspect that there is something wrong with the high voltage sources there are some simple tests that can be performed to localize the problem. The only equipment needed is a digital voltmeter (DVM), plus two 100k resistors, two 10k resistors, and some test clips. It is best to perform the tests in the sequence described below, and where appropriate, store the resulting plots from each test so that they can be e-mailed if necessary. Unless otherwise indicated, the DVM's negative lead is connected to ground (the negative side of the uTracer's supply voltage).

<u>Warning: High voltages are produced and measured. For every test, make sure the HV LED is off before connecting, removing, or even touching anything!</u>

Step 1: Isolate the uTracer circuit board Disconnect the tube socket array from the uTracer so that the cathode, grid, screen grid, and anode terminals are not connected to anything. If a patch cord connection technique is used, just remove all patch cords from the uTracer terminals. Otherwise, disconnect the socket array leads at the A, S, C, and G screw terminals.

Step 2: Establish that the CPU is still alive Start the GUI and the hardware fresh. Open the "debug" form and press the "ping" button. If the CPU responds, it is safe to conclude that the PIC is functioning. Read out the values in the third row under Vpower and Vneg on the debug form. Vpower should correspond to the supply voltage, and Vneg should be approximately -40 V (see Figure below).



Step 3: Test the grid bias circuit. In steps 3 through 6, the hardware is exercised by performing a measurement sequence in which the anode and screen voltages are swept with stepping grid bias.

To set up the measurement select measurement type: I(Va=Vs, Vg) with Vh Constant

Set anode and screen voltages to sweep from 2 to 200 V in 4 intervals, and define grid bias steps 0, -20, and -40. Set the plot controls to display anode current on the left axis, screen current on the right axis, and the scale controls to "Track" or "Auto". For future reference, this test setup can be saved under an appropriate name such as "System Check".

Use measurement clips, and make sure the HV LED is off before touching anything.

Connect the negative lead of the voltmeter to the cathode terminal, and the positive lead to the grid terminal. Press "Heater On" twice, and "Measure Curve" to run the measurement sequence, and verify that the specified grid bias voltages are generated.

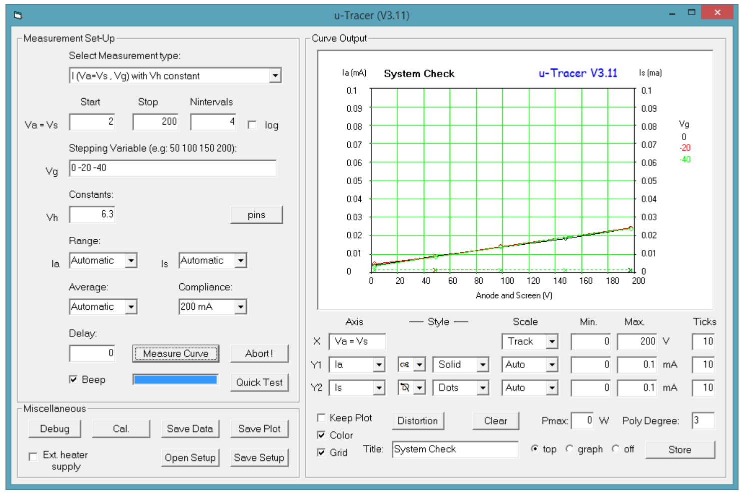
If the grid bias voltage is in error or does not appear, check the "raw" negative supply voltage to see if it is approximately -40 V. This voltage can be found at the negative end of R4 (47 k), which is the end nearest to the vertically mounted 1000 uF radial capacitor C1. Also check the regulated negative supply voltage to see if it is -15V. This voltage can be found at the negative end of R7 (120 ohm), which is the end furthest from the 1000 uF radial capacitor C1. These components are all located near IC1, the LM337 voltage regulator with the heat sink attached to it. These measurements will clearly indicate which part of the grid bias circuit is malfunctioning.

Step 4: Test the boost converters Connect the voltmeter to the anode (the positive lead) of the 100 uF anode reservoir capacitor C18. Run the measurement sequence and verify that the capacitor is properly charged up to ~220 V (the set voltage plus the supply voltage) for each grid voltage step.

The plot window should show linear responses (straight lines) with voltages stepping up in increments of ~50 V to ~200 V, and very low (<< 0.01 mA) current for the boost converter which is not being measured by the DVM. The measured boost converter will show a higher current (~0.05 mA) depending upon the input impedance of the DVM. Similarly, check the screen boost converter by connecting the voltmeter to the positive lead of the screen reservoir capacitor C13.

Note: If a "Continuous Mode" switch that connects the reservoir capacitors directly to panel terminals for the anode and screen has been included, the panel terminals can be used to make these measurements. Select Continuous Mode and connect the DVM first to the anode and cathode terminals and then to the screen and cathode terminals. In this case the maximum voltage observed on the DVM should be ~200 V (the set voltage).

Step 5: Test the current measuring circuit. Since the boost converters can generate a few milliamps of current, they can directly drive a 100 k resistor in continuous mode. In this way the current measurement circuit can be tested without using the high voltage switches.

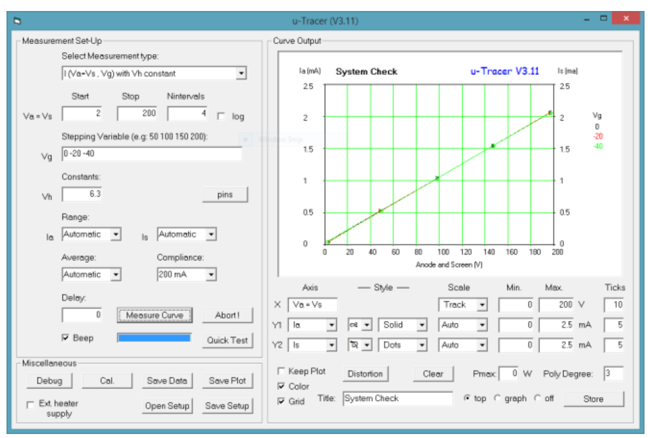


Connect 100 k resistors from the anodes (positive leads) of the 100uF reservoir capacitors C18 and C13 to ground, and repeat the measurement sequence. This test should produce a linear response in both the screen and the anode current from ~0 to ~2 mA.

If either current is significantly less than 2 mA, most likely BAT86 diode D14 (anode section) or BAT86 diode D6 (screen section) has failed and is leaking or short-circuited.

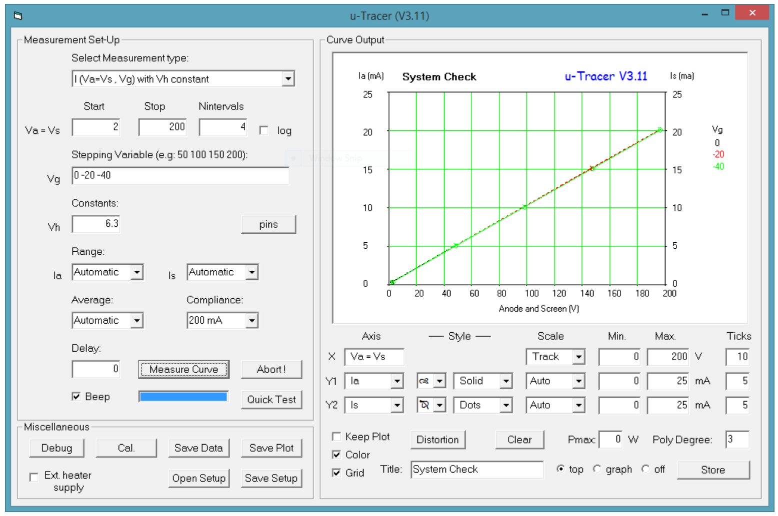
If a "Continuous Mode" switch has been included, select Continuous Mode and connect the two 100 k resistors to the panel terminals, from the anode and the screen terminals to the cathode.

Step 6: Test the high voltage switches Connect 10 k resistors between the anode and cathode terminals and the screen and cathode terminals and repeat the measurement sequence. If the switches are functioning properly, the sweep will result in linear responses in current from ~0 to 20 mA.



If a "Continuous Mode" switch has been included the panel terminals can be used, but select "Normal" (pulsed) mode before starting the measurement sequence.

If the response is not as expected, there are two possibilities:



One is that the switch is completely broken (short circuited), in which case the GUI may plot one or two points and then return "time-out" and "connection" error messages as described above. The boost converter tries to charge the reservoir capacitor to the specified voltage, but a significant leakage path allows the charge to trickle away faster than it can be replenished, and the set-point voltage cannot be reached. A few seconds after the GUI has issued the command to charge the capacitor to a certain voltage, it will notice that the PIC processor has not returned a measurement. It will then conclude that something is wrong, and give an error message saying that the uTracer hardware has failed to respond in a reasonable time. Finally it will conclude that one way or another the communication with the uTracer has been lost, in this case because the uTracer was waiting for the capacitor to be charged.

The second possibility is that the high voltage switch is not completely broken. The measurement sequence may run to completion, but the result is strange looking curves.

In either case, it is recommended that T16, T17, and T18 (the anode switch transistors), and/or T11, T12, and T13 (the screen switch transistors) be replaced as indicated by the testing. It's possible that not all of the transistors in a switch are damaged, but it is generally more trouble to find out which ones have failed than to simply replace them all.

Endnotes:

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[i] http://dos4ever.com/uTracerlog/tubetester2.html#bias
[ii] http://dos4ever.com/uTracerNotebook/Notebook.html#uTracerLV1
[iii] http://dos4ever.com/uTracerNotebook/Notebook.html#grid2
[iv] http://dos4ever.com/uTracerNotebook/Notebook.html#Former
[v] http://dos4ever.com/uTracerNotebook/Notebook.html#Current1
[vi] http://youtu.be/0xAO-PUcQbs
[vii] http://youtu.be/MU0lEq5u3Ro
[viii] http://youtu.be/JLY931P5L1w
[ix] http://youtu.be/RsF4z73PaKQ
[x] https://www.dos4ever.com/uTracerlog/tubetester2.html#more27
[xi] https://www.dos4ever.com/uTracerlog/tubetester2.html#more25
[xii] http://dos4ever.com/uTracer3/uTracer3_pag12.html#FAQ5
[xiii] https://www.dos4ever.com/uTracer3/uTracer3_pag10.html
[xiv] http://www.youtube.com/watch?feature=player_embedded&v=1onusMPwOkk
[xv] https://www.dos4ever.com/uTracerlog/tubetester2.html#more22
[xvi] https://www.dos4ever.com/uTracerlog/tubetester2.html#more22
[xvii] http://dos4ever.com/uTracerlog/tubetester.html#fil1
[xviii] http://www.diyaudio.com/forums/tubes-valves/227013-utracer.html
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[xx] http://www.dos4ever.com/uTracerlog/tubetester2.html#highv
[xxi] http://dos4ever.com/uTracerlog/tubetester2.html#heater
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[xxvii] http://basaudio.net/blog/wp-content/uploads/2013/01/19400164-Mullard-Circuits-for-Audio-Amplifiers.pdf
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[xxxv] http://www.dos4ever.com/uTracerlog/tubetester2.html#range
[xxxvi] https://www.dos4ever.com/uTracerNotebook/Notebook.html#Former
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[xxxviii] https://www.microwaves101.com/encyclopedias/controlling-curve-tracer-oscillations