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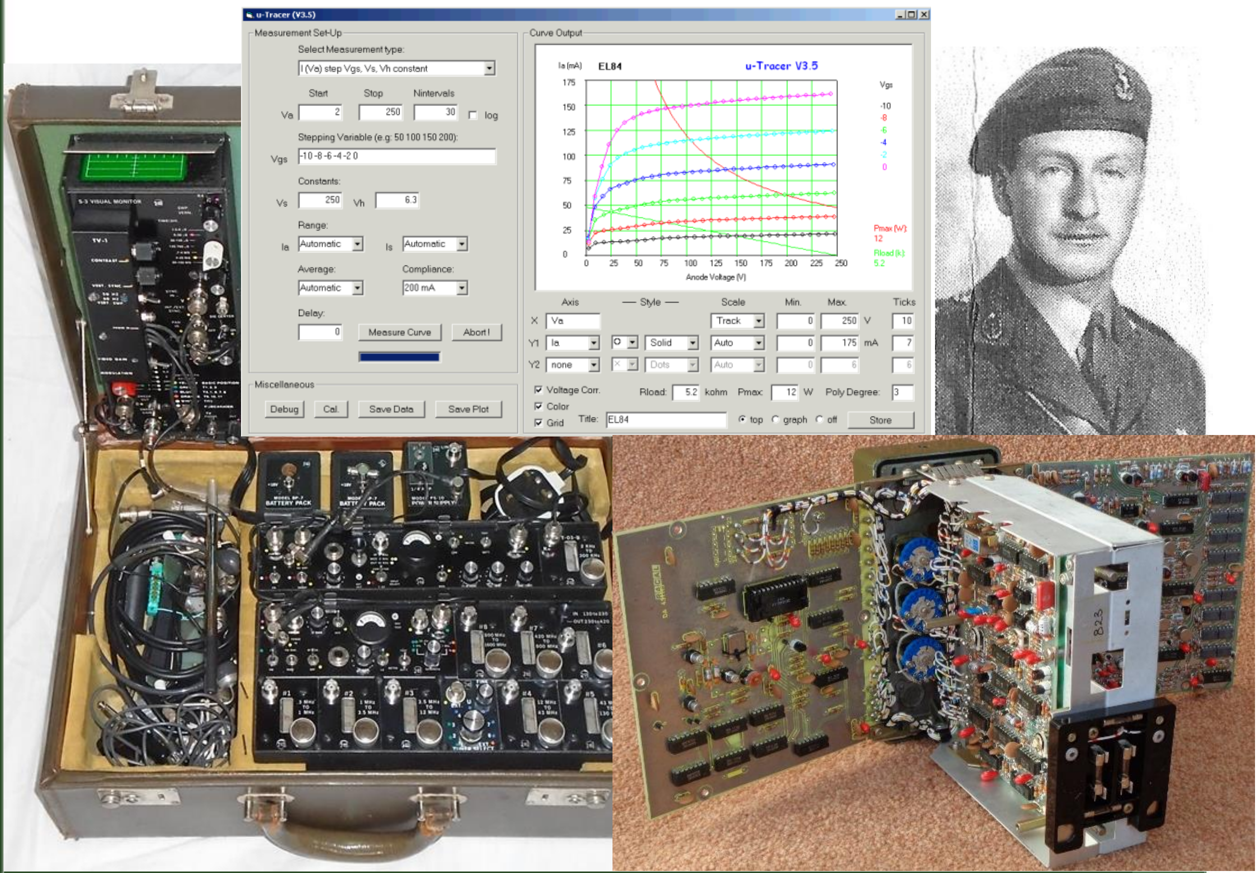

Contents

The µTracer: a versatile valve curve-tracer

Ronald Dekker

Being a third generation electronics hobbyist in his family it is no wonder that the author is the lucky owner of a rather large collection of different types of radio valves. For a long time it had been his wish to build some kind of tester to bring those old beauties to life and to see if they still function the way they did fifty years ago. This article describes an innovative solution to determine the valve characteristics in a way not possible with many traditional valve testers.

Testers and tracers

There are two types of valve-tester. The first, and most common, type is basically a go/no-go tester. It tests the quality of a valve, often expressed in term of cathode emission, at one typical bias point. The second, far less common, is the valve curve-tracer. It measures the anode and screen currents at many different bias points and reproduces the graphs found in the manufacturer's datasheet. The latter type of tester is of special interest to anybody designing and building their own valve circuits. Having worked his whole life in semiconductor research where semiconductor curve-tracers can be found in every laboratory, the author became fascinated by the idea of building one for valves.

The idea of a curve-tracer sounds nice until one realizes what is involved. The biasing of the anode, for instance, requires a regulated voltage source which can be adjusted from zero to at least 400 V, preferably higher, and which needs to source up to 200 mA. This means an 80 W power supply at least, and we need two of those, one for the screen grid as well. Then there is the heater which needs any voltage between 1.5 and 60 V at currents up to several Amps, although 6.3 V and 12 V heaters are most common. So, the building of a valve curve-tracer is quite an undertaking, involving large transformers, heat-sinks and fans.

The circuit

The idea to approach the problem in a completely different way, was born. Apart from the heater, which has to be switched on all the time, the anode and screen-grid only need to be biased for a fraction of a second while the actual current measurement takes place. Imagine a small boost converter which, in itself, cannot deliver much current, charging a large reservoir capacitor to the desired bias voltage. A high voltage switch connects the reservoir capacitor to the valve for a short time, *e.g*. a millisecond during which time the current is measured. After the measurement the boost converter charges the capacitor to the next bias point, and so on, until the full set of curves is measured. A small microcontroller is in charge of the whole process and sends the data to a personal computer which takes care of the user-interface and the graphical representation of the measurement data.

Figure 1 shows a block diagram of the pulsed valve curve-tracer circuit for which was coined the name 'the µTracer'. It consists of two pulsed high-voltage supplies, one for the anode and one for the screen grid. Both the anode and the screen-grid current are measured by means of a small current sense resistor inserted in the ground terminal of the reservoir capacitors. The control grid bias is generated by one of the two 10-bit pulse-width modulated (PWM) outputs of a 16F874 PIC microcontroller. After low-pass filtering the 0–5 V analog voltage is inverted and amplified to generate a 0 to –50V control-grid bias. The heater is powered directly by the PWM power supply voltage which is obtained from an old 19.5 V laptop power supply. The negative voltages required in the circuit are generated by a third inverting boost converter. A microcontroller takes care of the measurement of the voltages and currents, the control of the boost converters, the grid-bias and heater supply circuits, the high voltage switches and the communication with the PC.

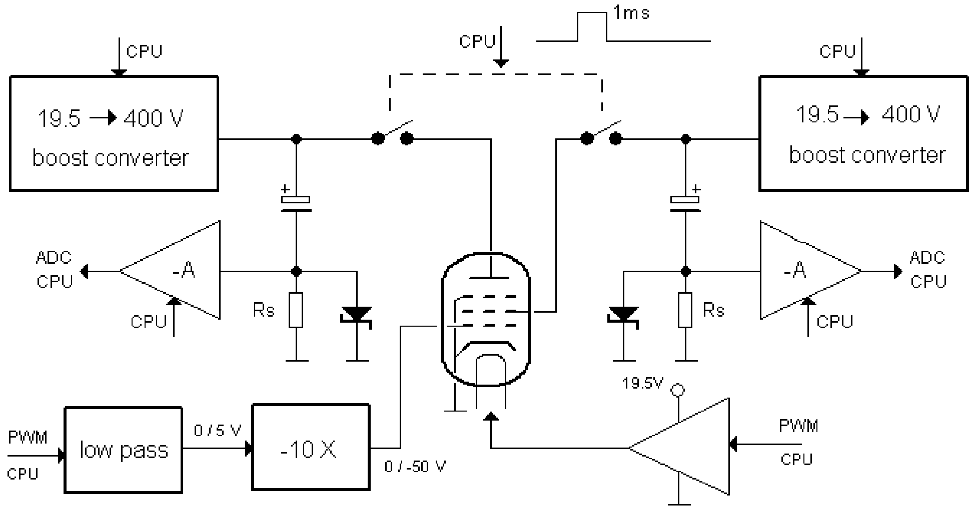

Figure 1. Block diagram of the µTracer

At first sight, the complete circuit diagram of the µTracer can be intimidating (**Figure 2**). Fortunately it consists of a number of well-defined sub-circuits which can be built, tested and calibrated individually. With only one exception, standard 'through-hole' components were used and the complete circuit fits onto a relatively small 10x16 cm 'Eurocard' format printed circuit board PCB (**Figure 3**).

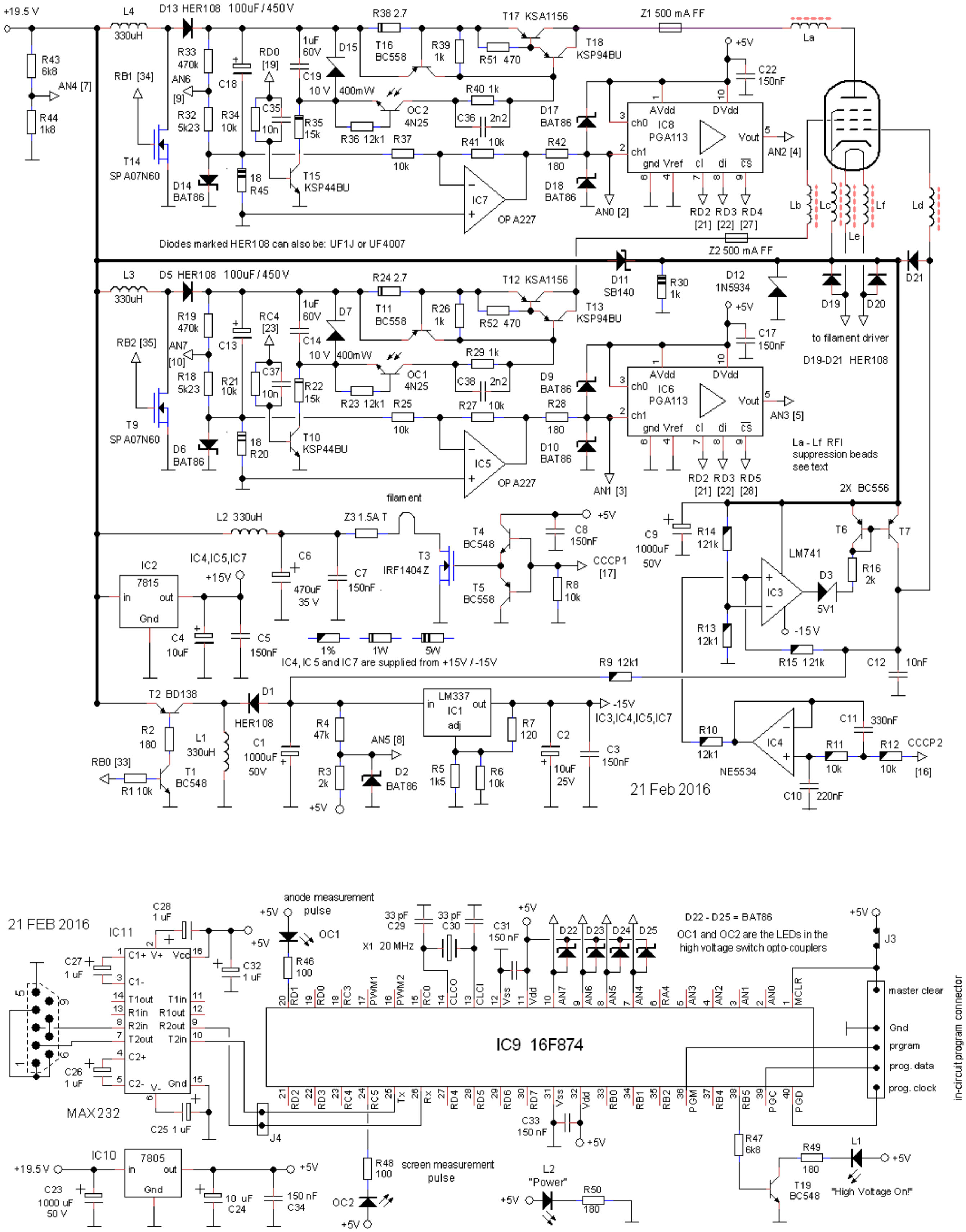

Figure 2. Complete circuit diagram of the μTracer

Figure 3. The complete µTracer circuit fits on a 10x16 cm PCB

Pulsed high voltage supplies

The most interesting parts of the circuit are the pulsed high-voltage sources. The top part of the circuit diagram in **Figure 2** shows the high voltage source for the anode. The 'heart' of the circuit is the 100 µF/450 V electrolytic reservoir capacitor C18. On the left hand side of the capacitor we find the boost converter consisting of L4, T14, D13. The voltage on the reservoir capacitor is measured by the microcontroller *via* a resistive voltage divider. When the voltage on the reservoir capacitor is too low, the microcontroller pulses T14 with 20 µs pulses until the set-point value is reached. When the voltage is too high, T15 is switched on to discharge the capacitor *via* D15 and R35. On the right hand side of C18 we find the high-voltage switch and the current amplifier. As mentioned, the current flowing out of the reservoir capacitor is measured by means of a small sense resistor (R45) in series with the cathode lead. Since the voltage drop over the sense resistor is negative with respect to ground, it is first inverted by operational amplifier IC7 and then amplified by a Programmable Gain Amplifier (PGA). The PGA can be programmed to fixed gains of 1, 2, 5, 10, 20, 50, 100 so that the current measurement covers more than three orders of magnitude from 0–100 µA to 0–200 mA. The current measurement principle used in this circuit only functions correctly when the high-voltage switch, consisting of PNP Darlington T17/T18, is galvanically isolated from the rest of the circuit: the current flowing through the capacitor has to be exactly the same as the current flowing to the anode (or screen). The high voltage switch is, therefore, controlled by opto-coupler OC2. During the 1 ms measurement pulse, the high-voltage switch is powered by the charge stored in C19. Every new measurement is, therefore, preceded by a short discharge pulse by T15 to ensure that C19 is fully charged to 10 V. Since the output voltage of a boost converter can never be lower than the supply voltage, the cathode of the valve is referenced to the positive supply voltage, rather than to ground.

The three boost converters in the µTracer are completely software-controlled by an interrupt service routine in the PIC which is called every 100 µs. The routine measures the output voltages and, if needed, issues a 20 µs 'boost' pulse. Since the analog to digital (AD) converter set-up and conversion time is too long to evaluate each boost converter every 100 µs, they are measured by rotation. The interrupt service routine was written in such a way that it could handle eight boost converters simultaneously, if needed.

The circuit of the heater supply is extremely simple and basically nothing more than a power MOSFET with a very low on-resistance which pulse width modulates the 19.5 V power supply voltage. Some find it hard to believe that subjecting a low-voltage heater to such a high voltage for a fraction of a second is not harmful to the delicate filament. A heater is, however, nothing more than a resistive load with, compared to the PWM frequency, a large thermal constant, so that the temperature of the heater is only determined by the amount of power which is dissipated in it.

The intelligence in the PIC controller is very limited. All data conversion and mathematics are done in the Graphical User Interface (GUI) which is written in Visual Basic 6 (VB6). For each bias point, the GUI issues the setting values in binary AD and PWM converter compatible representations. The PIC loads these values into the PWM generators and then waits until the interrupt service routine gives the signal that the reservoir capacitors have reached their set-point values. At that moment, all boost converters, as well as the heater supply are switched off for 2 ms to eliminate switching noise in the circuit. After 1 ms for stabilization, the high-voltage sources are switched on for 1 ms. The currents are measured near the end of the measurement pulse. During the measurement the reservoir capacitors will, depending on the currents, discharge to a small extent. So, directly after the measurement pulse, their voltages are measured for a second time. Immediately after the measurement event, all interrupts are enabled again. A big advantage of this pulsed technique is that valves can be tested at maximum load conditions and even far beyond their 'Safe Operating Area' (SOA) without any additional heating other than by the filament itself.

Graphical User Interface (GUI)

Figure 4 shows a screen-dump of the GUI. The type of measurement and the measurement ranges can be entered in the top left form. All common measurements, such as: anode/screen current versus control-grid bias or anode voltage are possible, as well as more exotic variants (anode current versus heater voltage). In normal operation, the measurements are completely auto-ranging so that the gain, but also the averaging of the measurements, is adjusted automatically according to the current levels. It is also possible to select the measurement ranges and the averaging factor manually. The data are plotted in the top right hand side of the window. Again, here the axes are auto-scaled and the plot can have up to two axes so that more than one quantity can be plotted on the same graph. A measurement can be stored to compare valves or can be written to an external file in a variety of formats.

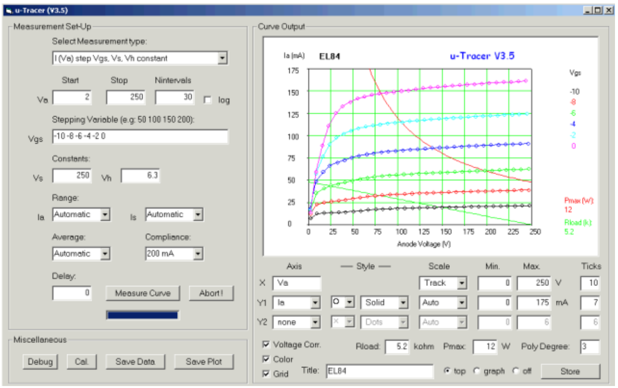

Figure 4. Screen-dump of the GUI

The GUI can plot directly the transconductance (mutual conductance) as well as the output resistance of the valve. To plot the transconductance for instance, first the anode current versus the control grid bias is measured. The transconductance is basically nothing more than the slope of this curve in any point. The easiest way to calculate the transconductance would have been to calculate the slope of a line going through two consecutive measurement points. This method of constructing the transconductance can easily result in 'noisy' curves. The approach followed here is that, first, an n-th order polynomial is fitted through the measurement data, which is then analytically differentiated resulting in beautifully smooth and accurate curves (**Figure 5**). In addition to drawing a full set of curves, there is the possibility to do a "Quicktest" whereby all relevant parameters such as current, trans-conductance, gain and anode resistance can be determined at a predetermined bias point for direct comparison to values given in datasheets.

Conclusion

During the development of the µTracer, the author kept a weblog which received a good deal of attention. Many people liked the idea and asked him to make a kit of this project. After many considerations, his children finally persuaded him to do so. As a result the better part of his 2012 summer holidays was spent on designing a PCB to replace the perforated-board used for the prototype. In October the first kits were sold and, in the meantime, almost 100 µTracers have found their way to enthusiastic valve-lovers. The kit contains the PCB (with SMD PGAs already soldered on to it), the programmed microcontroller and other components and a detailed construction manual. The only other components needed are a laptop power cord, valve sockets and some means to connect the vale sockets to the PCB. These are not included in the kit because everybody seems to have his (or her) own idea about which sockets to use and how to connect them. The most popular method seems to be the 'banana plug' method used by the author himself, but thumbwheel and rotary switches and even crossbar switches have been used. Some people, like Kurt Schmid from Germany, design and build cases for the µTracer that the author can only dream of (**Figure 6**). Using a special 'bogey' calibration valve (**Figure 7**), Kurt found the measured anode currents and the transconductance to be accurate to within 1.8%.

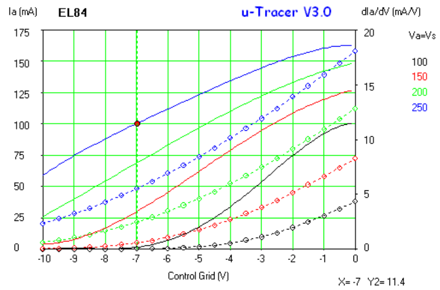

Figure 5. Example of a transconductance measurement. The dashed lines show the anode current versus control grid voltage of an EL84 (6BQ5). The solid lines represent the transconductance. In the reference (datasheet) bias point at Vg = –7V, Va=Vs=250 V, the transconductance is 11.4 mA/V

Figure 6 Kurt Schmid has designed a beautiful case for the uTracer. He used a crossbar switch to connect the uTracer to the valve and a modular socket system

Figure 7 Accuracy check of the uTracer with a special 'bogey'calibration valve (courtesy Kurt Schmid)

The project has been a great opportunity to exchange ideas and experiences with many people all over the world, but the author has to admit that the whole venture, which is basically a spare time activity, has cost him much more time than he could have ever imagined!

Link

www.uTracer.nl