

Dear all uTracer users,

I'm writing these lines just to share my experience building my uTracer, so that maybe someone could find it useful for his design.

The construction of my uTracer was very simple, mounting on top of the enclosure, one octal and one noval sockets, along with the nine 4mm banana jacks for the tube connections and six more banana jacks for the uTracer and heater connections. However, it has some features in the front panel, that someone could find useful. Features are:

- 1) Voltage Booster calibration banana jacks with a virtual ground
- 2) VSupply calibration banana jacks
- 3) Variable DC auxiliary heater power supply with display readout of actual voltage and current. Also, has 4mm banana Jacks for voltage and current calibration of the display.
- 4) Toggle switch for the selection between uTracer or auxiliary heater power supply

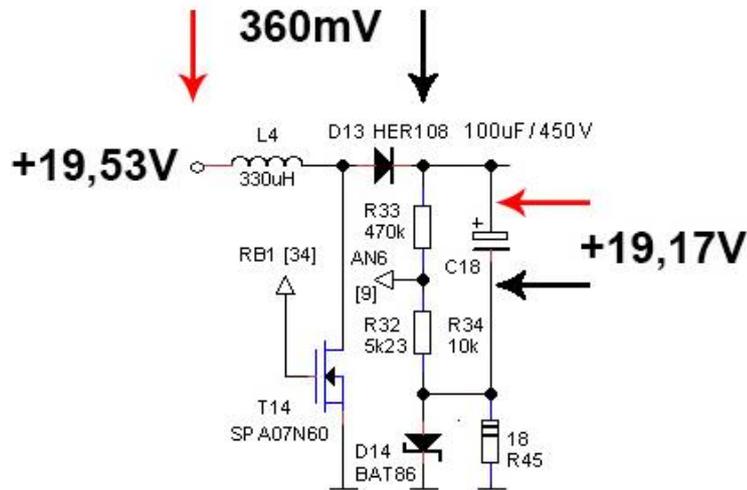
So, I think features 1 and 3, could be worth mentioning extensively here.



## Virtual Ground for HV Boosters Calibration

Once I finished the assembly of the Booster circuits and calibration were ready to be performed, I thought it would be useful to create in my uTracer enclosure, a virtual ground point for a direct reading on a DVM of the high voltages selected on the GUI. So, no need to write down the idle voltages present in the C13 or C18 high voltage capacitors and then subtract them from the final reading on the DVM. Remember that the reading on the DVM is the  $V_{idle} + V_{Boosted}$ . This could be achieved easily with a DVM that has the "Δ Relative" feature, but for those who doesn't have a DVM with this feature, the virtual ground could be a nice thing to add to the system.

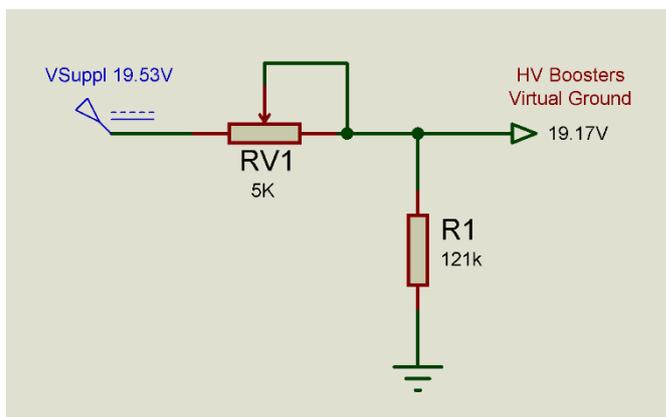
The figure below shows the voltage reading taken at the C18 capacitor and the voltage difference between C18 and the  $V_{suppl}$ . Same reading applies to the C13 high voltage capacitor.



Initially I figured out some ways to achieve that. My first guess was to connect the black probe of the DVM to the  $V_{suppl}$ , (in my case +19,53V with respect to ground), and the red lead to the positive side of the high voltage capacitors C18 or C13 that are at a potential of +19,17V with respect to ground (or what is the same, between C18 or C13 terminals). Under that conditions, the idle voltage before switch on the boosters on the GUI was -0,360V. It was pretty close to 0 volts and enough to achieve an accurate calibration of the voltage boosters, but I wanted to get as close as possible to the 0 volts at idle.

Then, also tried to connect the black probe of the DVM to the Cathode terminal of the uTracer getting -0,100V at idle, since the cathode is at potential of +19,27 with respect to ground. It was perfect, but I didn't want to run a wire from the cathode terminal to the front panel, just to avoid extra inductance in the uTracer cathode output terminal and keep the wiring simple. So, I thought ... Could I get a precise 0 idle voltage to achieve an even more accurate calibration, but leaving intact the uTracer terminals?

The answer was this pretty simple circuit.

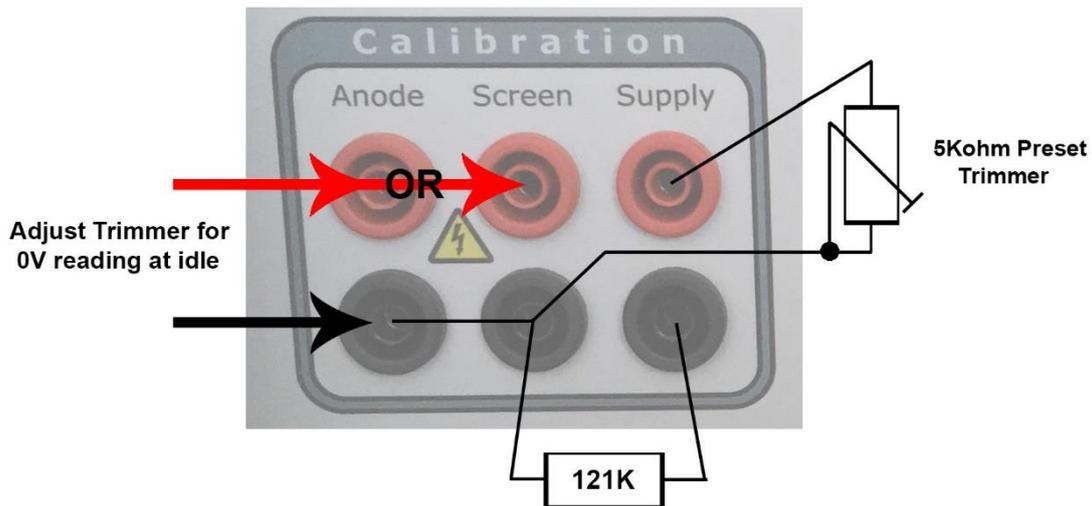


Crate a virtual ground at +19,17V potential with respect to ground, which is the same voltage present at the positive side of the high voltage booster capacitors C18 and C13 with respect to ground. Difference between the DVM terminals is then 0 Volts, showing just the boosted voltage when they are ON. Easy!!

The use of a variable voltage divider as shown in the above diagram, is quite effective to create an offset adjustment, without running wires from the cathode terminal of the uTracer. Place the DVM black probe to the new virtual ground and the red probe to the positive side of the C18 or C13 high voltage capacitors, then adjust the trimmer until you get 0 Volts.

Measurement should be performed using a very high input impedance DVM 10M $\Omega$  and avoid using oscilloscopes or grounded devices, otherwise the virtual ground becomes ground and voltage reading on the grounded instrument will be the +19,17V, which is the voltage present in the high voltage capacitors C18 or C13 with respect to ground. Also, in that case, RV1 Trimmer could be damaged due an excessive dissipation on it.

The diagram below, shows the internal connections of the banana jacks to the voltage divider network that creates the virtual ground (Black 4mm Anode and Screen jacks).



Let's do a practical example, so we can compare the original procedure and the virtual ground method.

## The Original Procedure

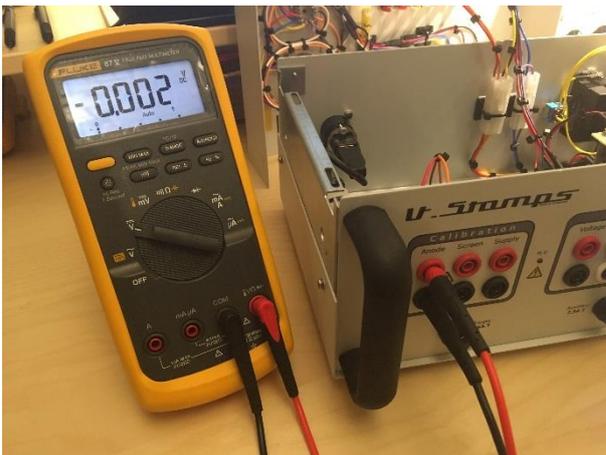


The GUI is set to generate 300V at the Anode Booster, but first let's measure the idle voltage at the C18 capacitor legs.



Now, after start the measurement, the capacitor charges up, until reaches the 300V + Vidle, in that case  $300V + 19,17V = 319,1V$

### The Virtual Ground Method

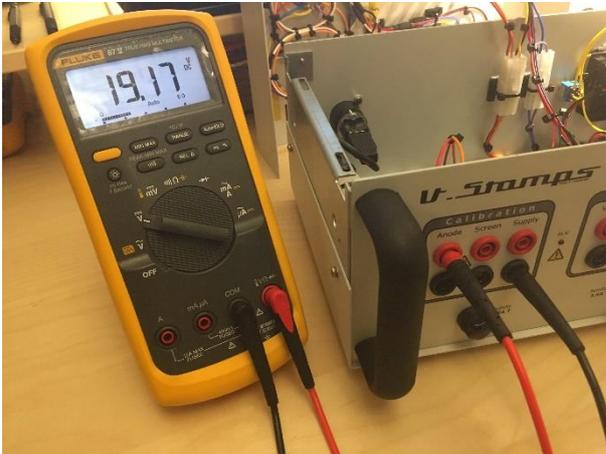


Connecting the DVM to the front calibration anode terminals, we can read at idle 0V. (If not, adjust the virtual ground trimmer for 0 Volts)

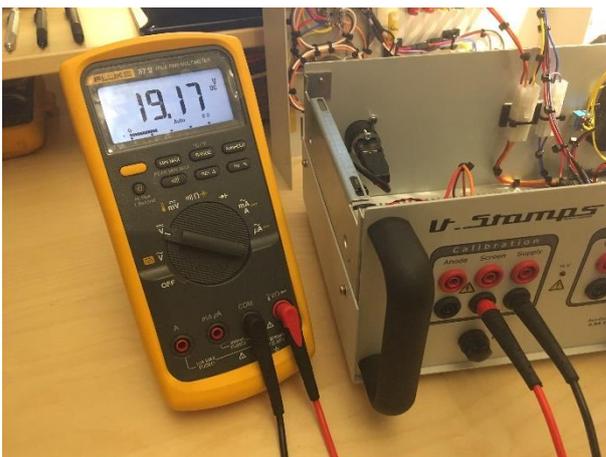


Direct measurement, using the virtual ground connection. Subtraction of the idle voltage is not required.

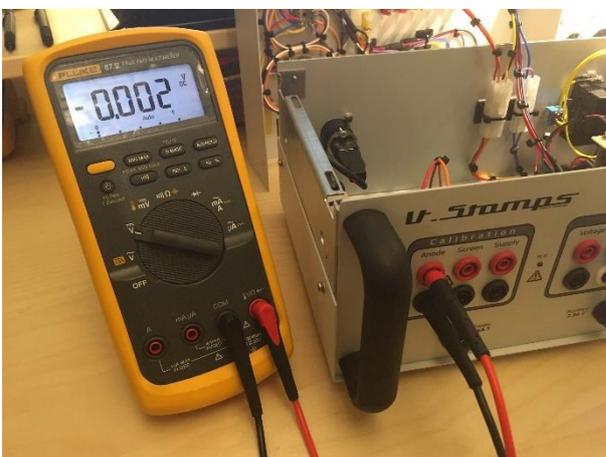
For the sake of completeness, here I attach the measurements that show the different voltages above mentioned.



This pic shows the voltage of the positive side of the C18 high voltage capacitor with respect to ground. (or between C18 legs)



This pic shows the voltage of the Virtual Ground with respect to ground.



This pic shows the 0V difference between both points, waiting to read the boosted voltage.

## Variable DC Auxiliary Heater Power Supply

The design of an adjustable auxiliary heater power supply, could be achieved in many different ways. I've chosen the use of a Buck Converter, that is one of the most efficient ways to get a variable power supply, hence, minimizing the typical heat and space consumption of the linear power supplies.

A dedicated 19.5V@2.33A laptop PSU is used to provide the necessary power to the system. The heart of the heater power supply is a module called Buck Converter, that steps down from the input voltage to a minimum voltage of 1.2V, adjusting the output voltage by a trimmer resistor attached to the module. The nice thing about this device is its great efficiency, being around 90 - 95%. Because of this high efficiency, power at the input of the module, could be almost maintained at the output. Then, as a rough approximation, using the 19.5V@2.33A (45W) laptop PSU as an input source and adjusting the output voltage to 6.30V, the output current that the module could source is roughly 7Amps!!

$$I_{out} \approx P / V_{out} \rightarrow I_{out} \approx 45W / 6.30V \approx 7Amps$$

Now, let's do an arbitrary measurement to check the efficiency of the module. As a voltage source, a precision lab PSU set to 20V is used. The output then is set to 10V and connected to a 3.4ohm power resistor.



The measured input power to the module was 31.2W and the measured output power was 29.33W. Then, in this case, the efficiency of the module is:

$$\eta = (W_{out} / W_{in}) \times 100 \rightarrow \eta = (29.33 / 31.2) \times 100 = 94\%$$

After 10 minutes of operation, the power resistor that is rated at 50W was pretty hot to the touch, but the module heatsinks were just cold.

Conclusion is clear, less heat is generated inside the uTracer enclosure.

The Buck Converter used in this project could be found on Ebay for about 3€, having the following performance specifications.

<https://rover.ebay.com/rover/0/0/0?mpre=https%3A%2F%2Fwww.ebay.es%2Fulk%2Fitm%2F112491146085>

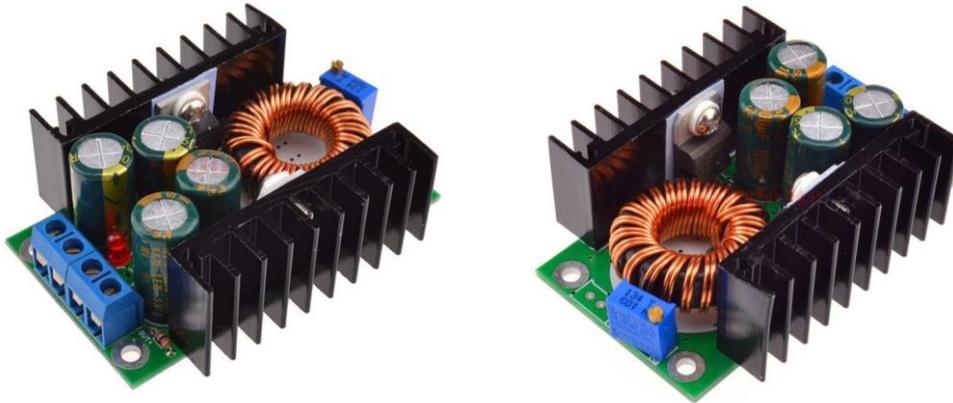
Input voltage: 7 - 40V

Output voltage: 1.2 - 35V

Maximum Output Current: 9A

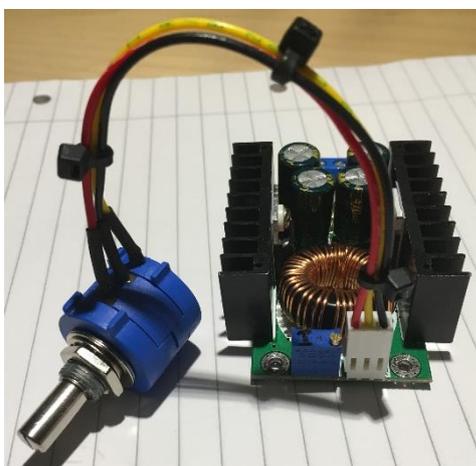
Maximum Power: 280W

Frequency: 180KHZ



As could be seen in the pictures above, the module has an input and output screw connectors as well as the trimmer resistor to adjust the output voltage. In this project, the trimmer resistor has been replaced by a Bourns 10 turn 10K $\Omega$  potentiometer ( 3590S-2-103L ) that is attached to the front panel.

The use of a single turn potentiometer makes the adjustment very tricky, so 10 turns type is perfect for that purpose.

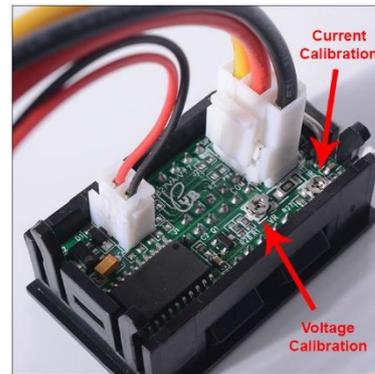


In this picture could be seen the way I attached the potentiometer to the Buck Converter, using a Molex three pin header connector for a quick connection to the module.

(Ignore the left trimmer potentiometer seen on the picture. This module has a current limiter feature, but I do recommend the use of the non-current limiter capability version)

## Voltage and Current Digital Meter

For an actual voltage and current measurement of the heater supply, a cheap digital panel meter is used. Despite of the cheapness, using the voltage and current internal trimmers, a very accurate adjustment could be achieved for a precise voltage and current readout.



The pictures above, show the meter I used in the project. Many different meters with the same look could be found on Ebay, but I highly recommend to purchase this exact model. I ordered this one and other two similar displays. This one resulted in a very good performance and accuracy, but other two were not very linear, so they were just useless.

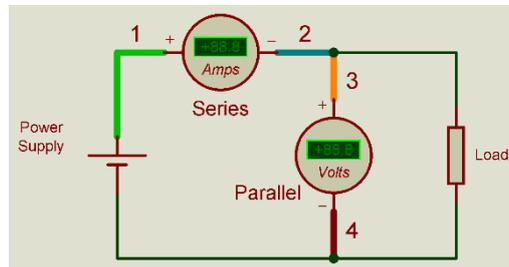
In order to identify the correct one, search on Ebay a display meter so you can see a picture of the PCB where the connectors and calibration trimmers are located. You should find the following logo (Right picture) printed on it. Also try to include in the search the reference "0-100V 10A TE192".



The performance specifications are:

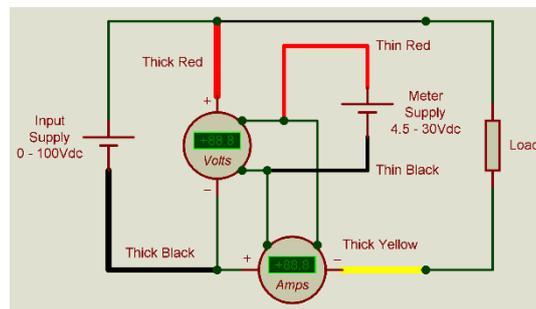
- Display: 0.28" LED digital
- Display color: Red (dual display)
- Operating voltage: DC 4.5 ~ 30V
- Measure voltage: DC 0 ~ 100V
- Minimum resolution (V): 0.1V
- Refresh rate:  $\geq 500$ ms / times
- Measure accuracy: 1% ( $\pm 1$  digit)
- Minimum resolution (A): 0.01A
- Operating Current:  $< 20$ mA
- Measure current: 10A (direct measurement, built-in shunt)
- Operating temperature: -10 to 65° c
- Operating Humidity: 10 to 80% (non-condensing)
- Mounting cutout: 45.5 x 26.5mm
- Dimensions: 48 x 29 x 21mm

When we think about how to connect a voltmeter and an ammeter, connections are really straightforward. Voltmeter is connected in parallel and ammeter is connected in series, this results in 4 wires for our connections.



Unfortunately, the voltage and current meters existing in this device are not isolated from each other, the ammeter forms part of the negative output of the panel meter, forming a common ground configuration between the two meters. Since the ammeter is linked internally to the voltmeter, this results in 3 wires for the voltmeter and ammeter connections, three thick Black, Red and Yellow wires and two thin black and red wires for the supply of the panel meter itself.

The following diagram shows the way the panel is connected to the voltage source and the load. The ammeter is linked to the voltmeter in the low side of the circuit.

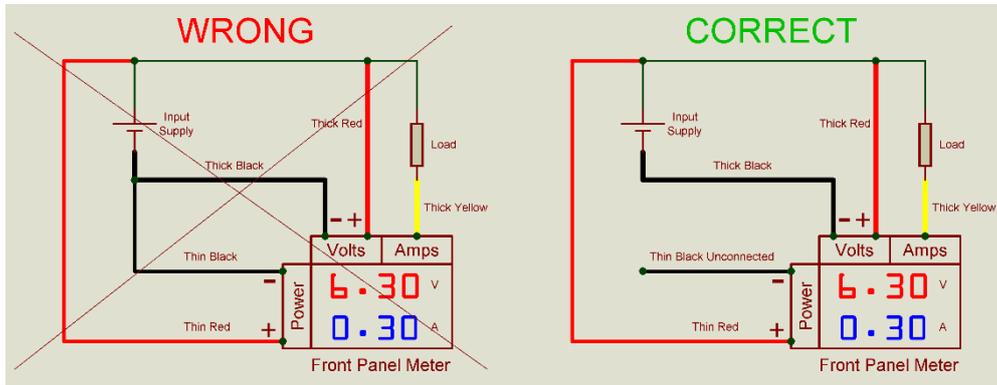


Notice that in the above diagram, two power supplies are connected to the meter. First one is the voltage source for our heater supply circuit and the second one is the supply for the panel meter itself. It doesn't mean that we need to use two power supplies to run our panel meter, we can use a single power supply with no issues, but, some considerations must be taken into account to make our panel meter to operate correctly and accurately.

When I received the panel meter and started to play with it, I rapidly realised that the readings displayed on it were not really accurate, so I decided to adjust the calibration trimmers located on the rear side of the meter. Some minutes after, I saw that the readings were not linear, at low currents readings were ok, but at high currents they were not. Clearly, I was doing something wrong.

After some online research, I found what the problem was. I was connecting the two red and black thin wires to the voltage source, but for some reason, the black wire shouldn't be connected. Another solution for this problem, could be the use of a dc/dc isolated converter just for the panel meter supply. It isolates the ground connection for the panel supply, avoiding the error on the readings.

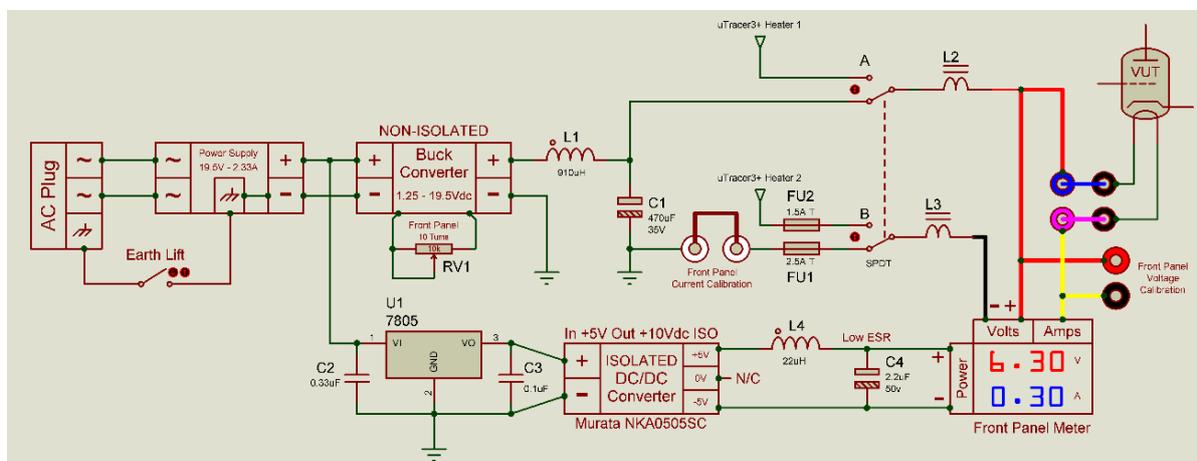
The next diagrams show graphically what is explained above. The dc/dc converter is not included to keep the diagram simple.



In my case, I decided to use the dc/dc method for the power supply of the meter. When I designed the features on the front panel, a “power on” LED was not included in the final design, so was clear that I needed some indication to show the system was switched On. Then, I decided that the meter (switched On), would be the main “switch On” indicator.

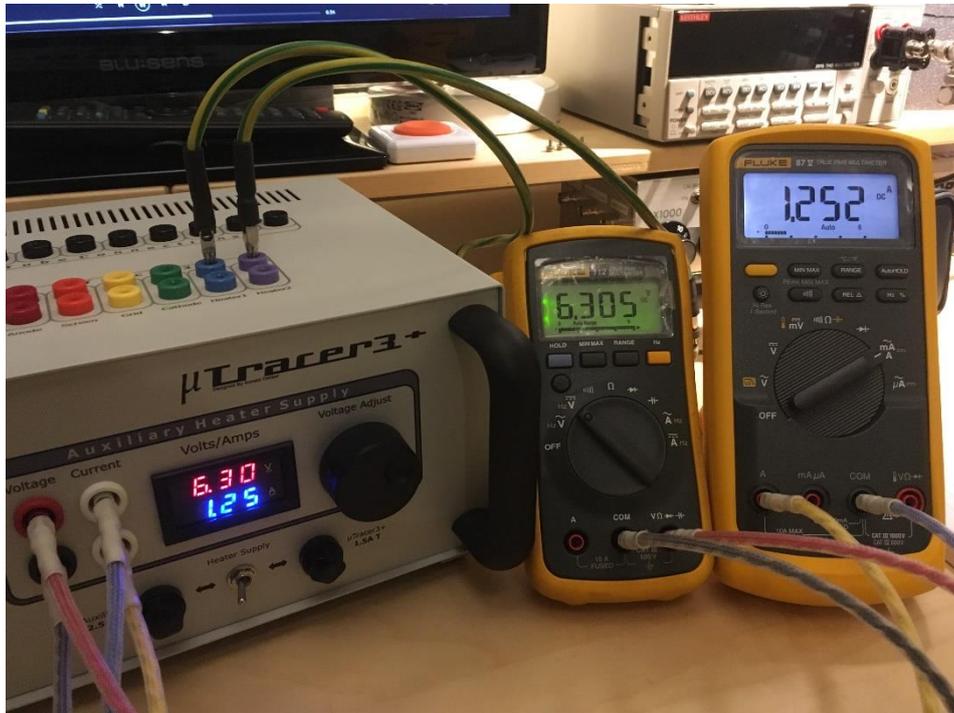
But, a problem came across when the circuit was tested. When the heater source was switched to the internal heater of the uTracer, the panel meter switched Off. The uTracer and the auxiliary heater supply, use two separated laptop power supplies, then, when the internal uTracer heater supply is selected, the display meter is not referenced to ground anymore, until the MOSFET of the uTracer heater circuit enters in conduction. It is done in a switched mode supply fashion, so, it couldn't keep the display On, even when the internal heater is switched ON. I wanted the meter to be On all the time, regardless the position of the heater switch. So, I included the isolated dc/dc converter, keeping the panel meter switched On all the time. Is obvious that when the meter gets the switched mode internal supply, the readings doesn't tell very much about the voltage that is going to the heater, but now I can notice when the uTracer is ON.

The following diagram shows the complete heater supply circuit, where the dc/dc isolated converter and the buck converter are included.



Notice in the above diagram, there are two calibration points for the current and voltage readings. They are labelled as “Front Panel Current Calibration” and Front Panel Voltage Calibration. The calibration points are two 4mm banana jacks mounted in the front panel. Placing two external meters, the calibration of the display could be done precisely.

The following picture shows a very accurate adjustment of the panel meter. A 5ohm power resistor is used as a dummy load.



Finally, it is worth mentioning that the best point in the heater circuit to place the meter connection, is the end of the circuit. Just after the fuse, selector switch and calibration points. I placed the connections right to the blue (+) and purple (-) banana jacks shown in the above picture. Placing it early in the heater circuit, results in a non-accurate read out of the values, due to extra resistance of the wires and contacts. As the current gets higher, the more voltage drop happens in the wires, then the less linear performance is obtained. Placing it at the very end, results in a very good performance.

Find in the end of this document a high-resolution schematic of the complete auxiliary heater power supply.

