etracer vacuum tube curve tracer PCB user's manual

Document revision：0.4

LETHAL HIGH VOLTAGE!!!

etracer is designed for testing vacuum tubes. Its output voltage can be as high as 800 Volts. Do not touch any parts on the PCB (Printed Circuit Board) when the PCB is powered. Under powered condition if any of the NEGV_ON, HV1_ON or HV2_ON indicating LEDs is lighted it means high voltage exist on the board. Please wait until the LEDs go off before powering off the PCB. If for any reason the LEDs did not go off please recycle the power and wait for about 20 seconds.

End user agreement:

etracer is a testing equipment designed for professional use. We extensively describe the circuit architecture and the operation principle of etracer in this manual. Users shall read this manually carefully and thoroughly and understand how to operate etracer safely. We are not responsible for any electric-shock, damage to vacuum tubes, injury or loss of property caused by using etracer.

Use of the etracer implies you agree with the terms above.

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A. Introduction to etracer PCB version 1.4x

⚠ Note: Most part of this manual was written at the time of PCB revision 1.4x. Please refer to section G for PCB revision history and differences between PCB version 1.4x to later PCB versions.

The PCB measures 21 cm by 15 cm. There are six mounting holes surrounding the board each has a 5mm clearance from the center of a mounting hole to the board edge. The PCB can be roughly divided into five blocks as depicted in figure 1 and the function of each block is described below:

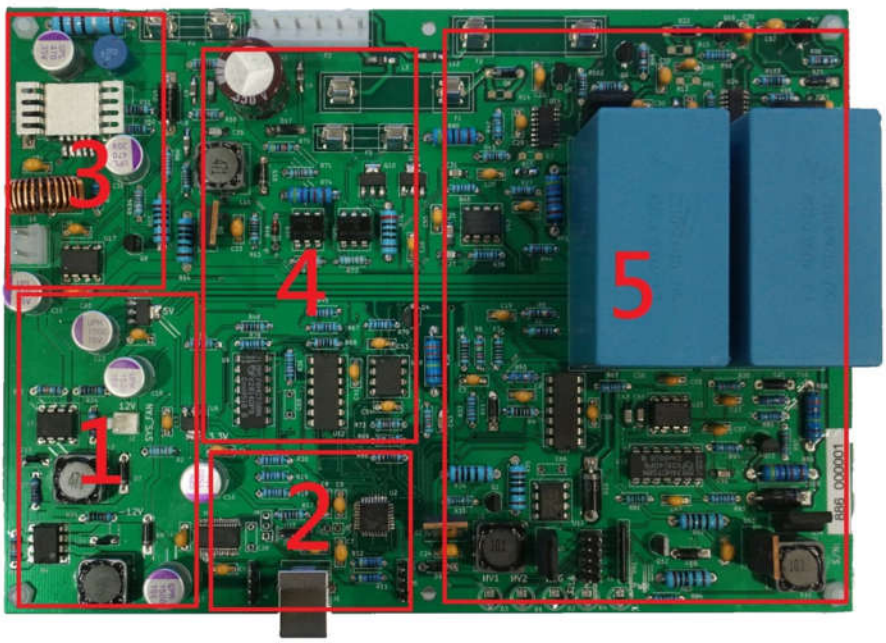


Figure 1. etracer PCB with blocks numbered

1. Block 1: Low voltages supplies block. Circuit in this block derives 12V, -12V, 5V and 3.3V DC from the 29V DC input and powers other blocks. Due to the choice of the voltage dividing resistors the actual output of the +/-12 Vdc voltages are about +/- 11.5 Vdc.
2. Block 2: Micro-controller and USB communication block. This block is formed by a micro-controller U2 and a FTDI FT232RL USB to serial converter U1. This block controls all measuring hardware on the board and communicates with a PC.
3. Block 3: Filament power supply block. The main IC (Integrated Circuit) in this block is the LM2596 (underneath the heatsink) DC-DC converter. This IC converts the 29 Vdc input to a DC output ranging from 1.5V to 27 V to supply

the filament of the vacuum tube DUT (Device Under Test). The LM2596 chip and the heatsink will become very hot when the output power is high. The maximum power output rating is 30 Watts. Please make sure adequate ventilation is in place. If more power output is needed to supply the DUT please use an external power supply.

4. Block 4: Negative voltage supply block. This block supplies a negative voltage to the grid electrode of the DUT. A capacitor C42 is used to store the pumped energy. Please not the voltage difference on this capacitor can be as high as 200V.
5. Block 5: High voltage supply block. Two big 45uF/800V MKP capacitors (the blue cubes) C26 and C46 in this block are used to supply two high voltages sources HV1 and HV2. Please note the voltages on these two capacitors can be as high as 800V.

B. Connecting the etracer PCB

etracer requires a 29Vdc/5A power input to function. The connector for the power input is P1. The recommended power supply is an EPP-200-27 200 Watts AC to DC switching mode power supply made by MEAN WELL. EPP-200-27 takes a wide range of AC input from 100 Vac to 230 Vac. The default DC output voltage is set to 27V. The output voltage can be increased to about 29 Vdc by turning a potentiometer SVR1. Please be careful about polarity when connecting P1 to the power source as there is no protection circuitry in this section and a reverse-polarity-connection might damage the board seriously. A 5A slow-blow fuse series connected to the 29 Vdc input is also recommended to protect the PCB.

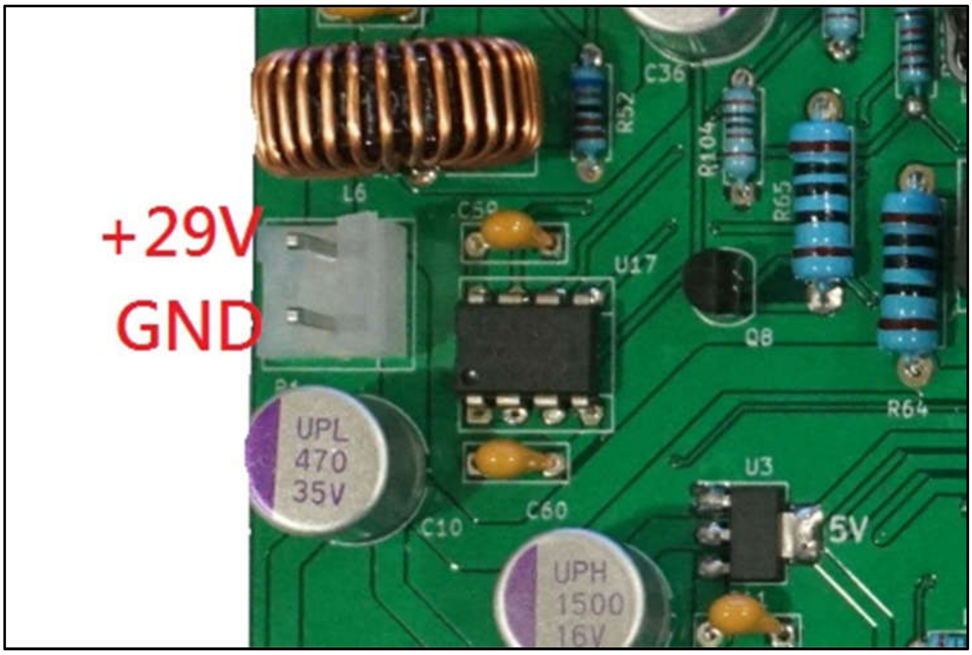


Figure 2. Polarity of the 29V input connector P1

etracer is connected to the DUT through the connector P2. There are a total of 6 pins on P2: HEATER1,HEATER2,NEGV,GND,HV1and HV2. The location of each pin in indicated in figure 3.

Figure 3. Pins names and pins numbers for P2

HEATER1 and HEATER2 are the output of the filament supply. HEATER1 is connected to PCB ground (GND) through a 0.1 Ohm resistor. This resistor is used for current sensing. When testing a DHT (Directly Heated Tube) HEATER1 provides a ground path for the DUT's cathode. HEATER2 is the positive output of the filament supply. A diode that withstands a reverse bias of 1kV is connected in series in the output path of HEATER2 to protect the circuit from any high voltage source applied externally (eg. a short from HV1 to HEATER2). This diode causes a voltage drop in the output and it is compensated by the software. The default compensation value is 0.7V. There is a 5A slow-blow fuse in the output path to protect the LM2596. LM2596 has over-current and over-temperature protection circuits built-in and the over-current protection circuit kicks-in at about 4.5A hence F4 should not blow under normal operation. Note in this manual we use the terms heater and filament interchangeably. Figure 4 shows an equivalent circuit of the heater supply.

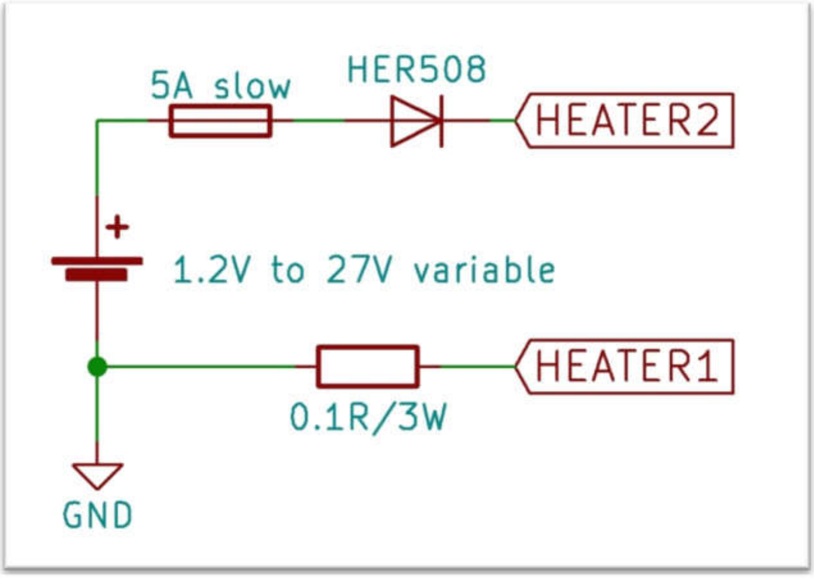


Figure 4. Equivalent circuit of the heater supply

GND pin is the ground reference for all voltages on the PCB. When testing an indirectly-heated tube the cathode of the DUT should be connected to this pin.

NEGV, HV1 and HV2 are the negative voltage output and high voltage outputs. The outputs of these three pins are grounded during non-testing time. This prevents the user from accidently touching these output pins when connecting the testing leads.

Figure 5 illustrates the basic circuit topology of HV1 and HV2. Q1, Q2, D1 and D2 form a circuit similar to a Four-Switch buck-boost converter. By switching the signal on the base of Q3 C1 is charged by the current in the inductor L1. Theoretically the voltage on C1 can be charged to any voltage from 0 to infinitely high. During the charging period SW2 is open. This design not only prevents waste of electricity (and hence reduce the overall power consumption) but also ensures a safe operation environment.

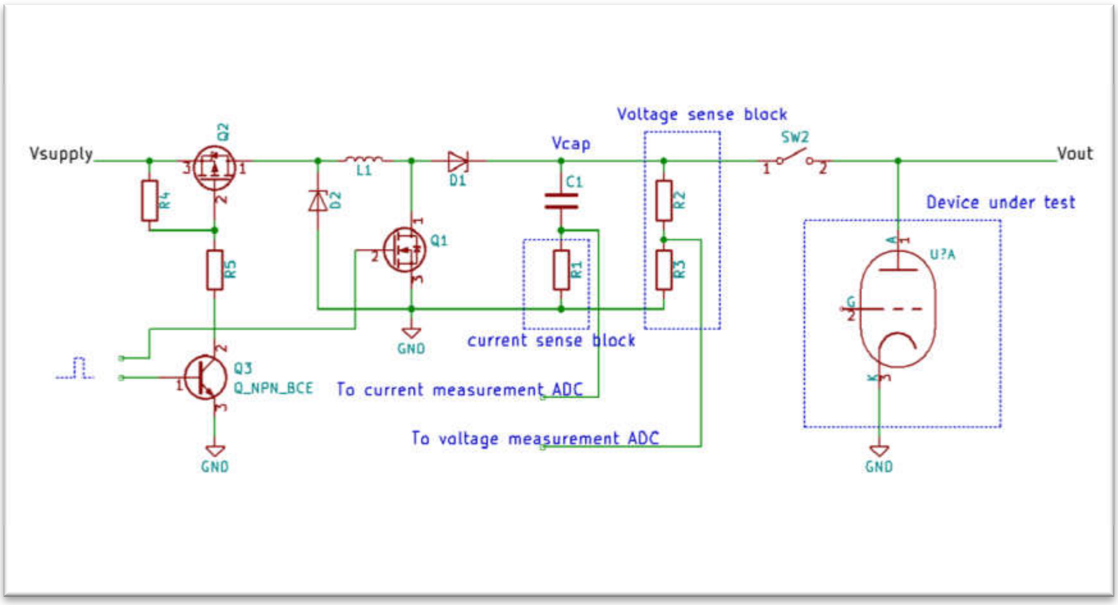


Figure 5. Operation principle of HV1 and HV2

The way etracer performs test is by switching on (short circuit) SW2 temporally and hence connects the positive terminal of C1 to the DUT. The conducting time of SW2 is not only controlled by the micro-controller U2 but also by a capacitor. If for any reason the micro-controller fails to operate correctly SW2 would still be switched off after about 5ms when the capacitor is discharged. This capacitor provides an extra layer of protection. There is also a current limit circuit that kicks-in at a current output above 500mA to 600mA. A 315mA fast-blow fuse is used to provide physical protection.

Figure 6 is the complete output circuit of HV1. The circuit of HV2 is identical to HV1. Q7 plays the role of SW2 in figure 5. During testing time Q7 conducts and Q5 opens (open-circuit). Diode D6 protects the internal circuitry from exposure to high voltage sources outside. The measurement error caused by this diode is compensated by the PC software. Although not recommended, the user can solder a 0 ohm resistor to the footprint of R14 to short-circuit D6 if he/she believes there is a need (eg. needs an accurate positive grid bias on HV2). Doing so eliminates the inaccuracy introduced by the diode at a price of risk of damage to the board. R48 and Q6 form a current-limiting circuit. When the current flowing through R48 is high the voltage drop across R48 will turn Q6 on (conducting), short the gate and source of Q7 and thus turns Q7 off. The fuse F1 is a 315mA/1kV fast-blow type and it should not blow under normal operation. If F1 is blown it means some component on the PCB is gone bad. Please stop using etracer immediately and contact us.

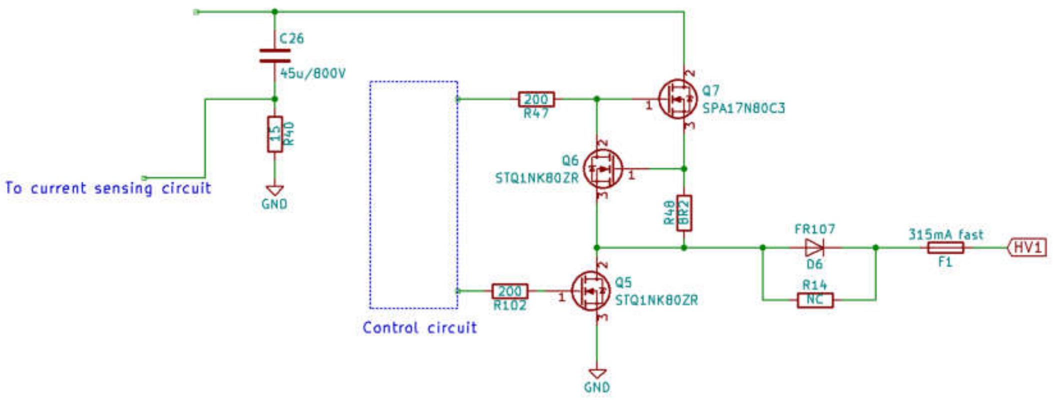


Figure 6. The output circuit of HV1

The operation principle of NEGV is similar to HV1 and HV2. Because the output voltage is negative only one switching transistor is used to charge a capacitor from 0V to -180V. The output circuit of NEGV is depicted in figure 7.

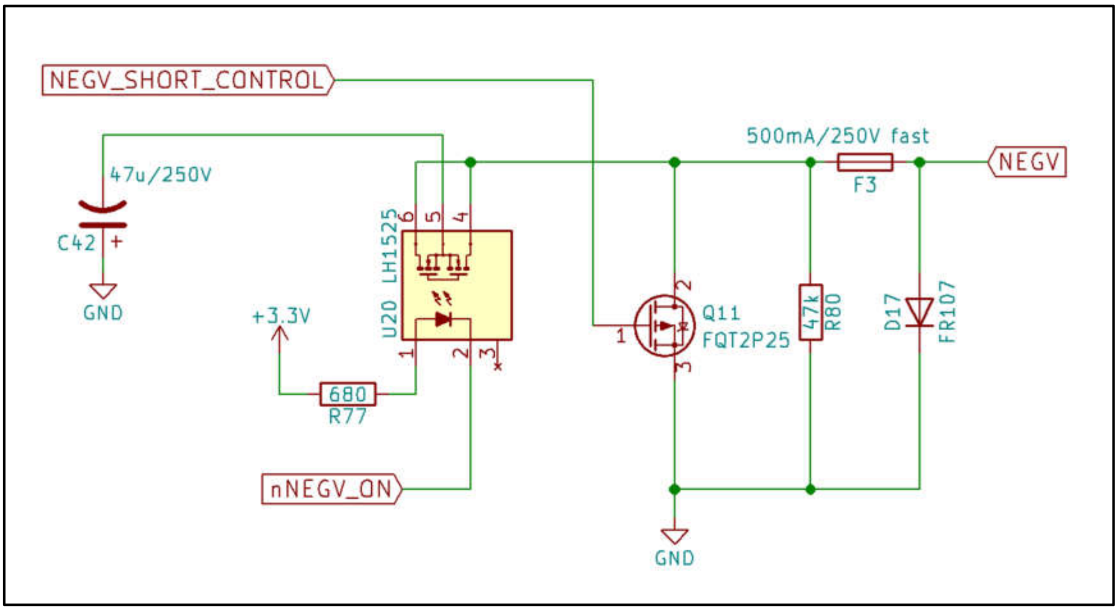


Figure 7. The output circuit of the negative supply NEGV

The signal nNEGV_ON switches the output of NEGV on and off. U20, the LH1525 SSR (Solid-State-Relay) has a built-in current-limiting circuit that is activated at about 250mA. There is a 500mA/250V fast blow fuse F3 connected serially in the output path of NEGV. If for any reason the current-limiting circuit inside U20 did not work F3 protects the NEGV circuit from excessive current flowing through it. D17 provides a short-to GND path in case HV1, HV2 or HEATER2 is accidentally connected to NEGV. Under normal operation F3 should never blow. If F3 blows frequently please stop using etracer and contact us.

C42 in the NEGV circuit sets up the grid voltage for the DUT. Because of the choice of circuit design C42 can not set the negative grid voltage to the desired value if the there exists a negative voltage that is lower than the desired value at the grid. When a vacuum tube is heated there will be an induced negative voltage on the grid due to grid current. The amount of negative voltage induced depends on the plate voltage and is not a constant value. R80 provides a leakage path for the grid current but it can not eliminate the induced negative voltage completely. It is observed that a value of about -0.3V on the grid is common and hence in reality it is only a problem to measure the curve at zero volt for the grid. To overcome this issue Q11 is inserted to the circuit. When the desired (configured) test voltage is 0 Q11 will turn on (short-circuit) and hence force the grid of the DUT to ground. The zero-biased curve is marked differently in the software to remind the user such a phenomenon.

There are several connectors/headers on the etracer PCB for LEDs and communications to the outside. The pitches for the headers are all 2.54mm except J1. The placements of the connectors/headers are depicted in figure 8.

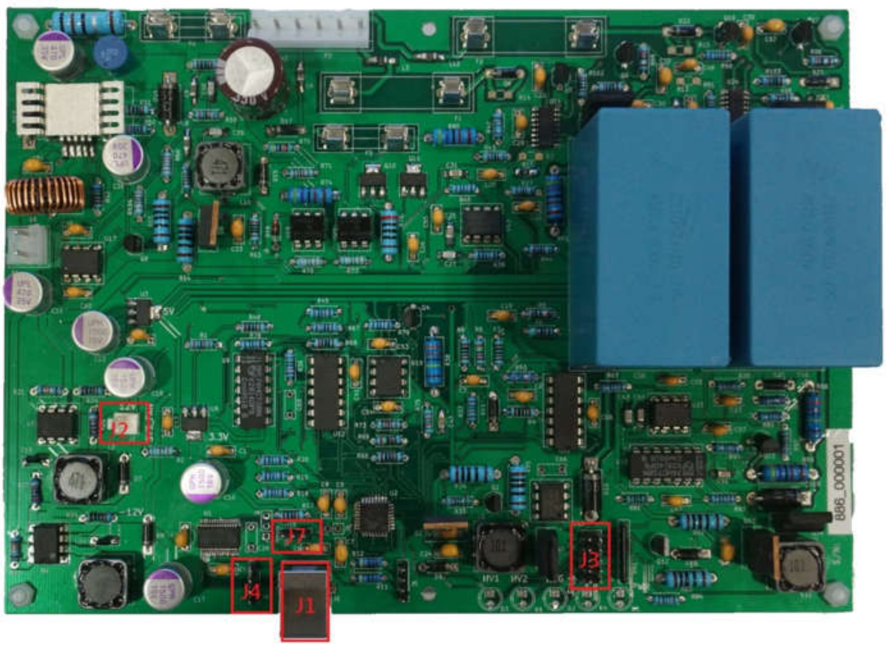


Figure 8. Locations for the headers/connectors

For the 2.54mm headers pin one is marked differently from the rest of the pins as depicted in figure 9.

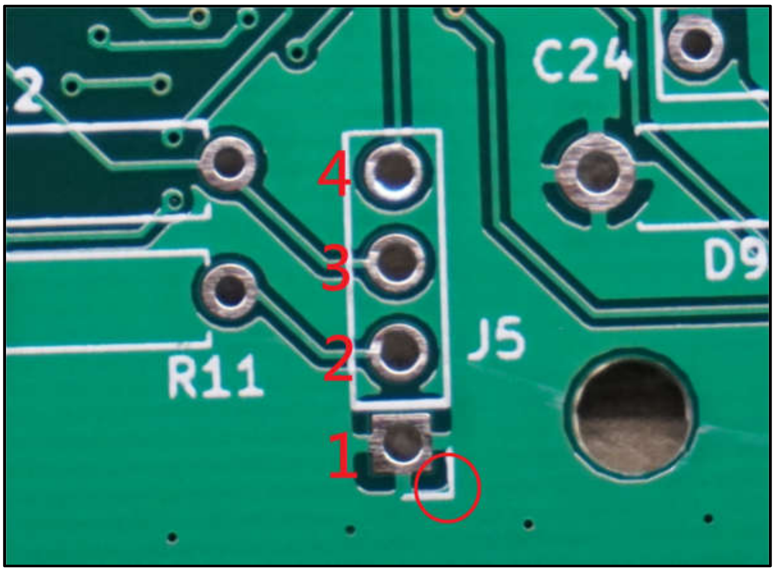


Figure 9. Identifying pin 1 for the 2.5mm headers

J1 is an USB connector. The etracer communicates to a PC when connected by a USB cable through J1. If the user wants to change the placement of J1 the USB signals on J4 can be used. The signals on J4 are as follows:

- pin 1: Vcc
- Pin 2: USB D-
- Pin 3: USB D+
- Pin 4: GND

J7 is a communication port for the micro-controller U2. The pins on J7 shall be left open for normal operation. In case a firmware-update failure or a need to force the micro-controller to enter the firmware-update mode the following steps should be carried out in sequence:

1. Power off etracer
2. Short circuit pin 2 and pin 3 on J7
3. Power up etracer,
4. Remove the short-circuit on pin 2 and pin 3 on J7 after 1 to 2 seconds.

J3 is the connector for the LEDs. The user can route the LED signals to the LEDs on the chassis. J3 is parallel-connected to the 5 LEDs on the PCB. If the LEDs are to be mounted on the chassis LEDs D1 to D5 on the PCB shall not be mounted. The pin assignment for J3 is depicted in figure 10. Note the positive(+) signal connects to the anode of a LED and the negative(-) signal connects to the cathode of the LED:

- Pin 1 (+) and Pin 2(-): D4, Heater power on indicator
- Pin 3 (+) and Pin 4(-): D2, NEGV high voltage output indicator
- Pin 5 (+) and Pin 6(-): D1, HV2 high voltage output indicator
- Pin 7 (+) and Pin 8(-): D3, HV1 high voltage output indicator
- Pin 9 (+) and Pin 10(-):D5, System power (5V) indicator

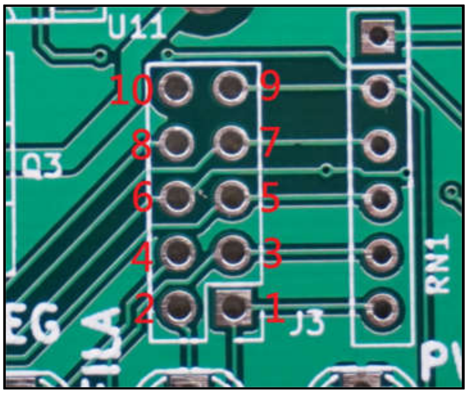


Figure 10. Pin assignment for J3

J2 supplies 12 Vdc (actually about 11.4V) for a chasis fan. Please make sure the fan does not draw a current more than 300mA and confirm the polarity of the fan before connecting it to J2. The polarity of J2 is illustrated in figure 11 with texts in red.

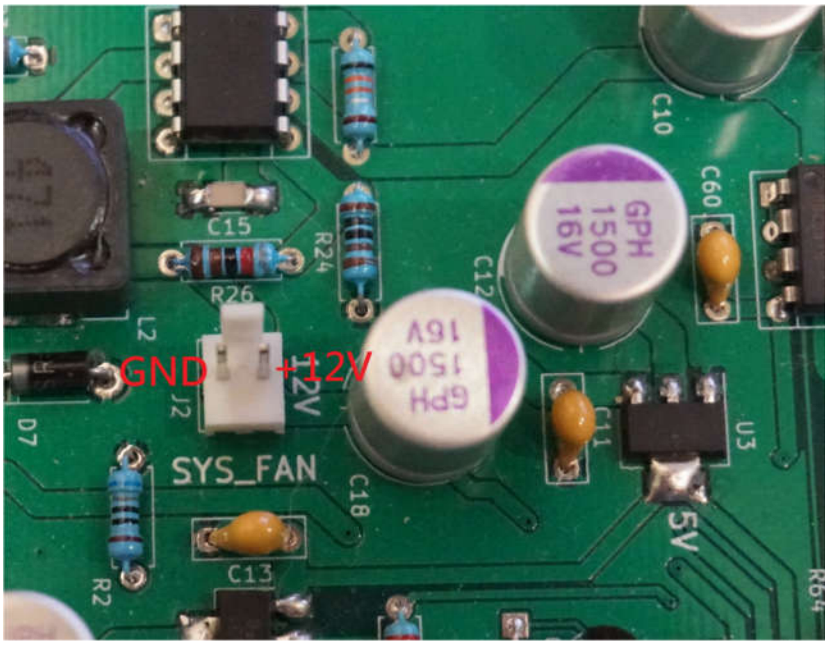


Figure 11. Polarity of connector J2

It is observed that the polarity of J2 is different from the polarity of chassis fans currently used in the personal computer (PC) market. For a two-pin fan for a PC with red(positive) and black(negative) wires the wires might need to be swapped. For a three pin PC fan with a speed sensing wire (usually yellow) the red and black wires might need to be swapped and the speed sensing wire shall be left unconnected. Please consult the datasheet of the fan if there is any doubt. Failure to wire the fan correctly may severely damage the etracer PCB.

There are a total of 4 fuses, F1 to F4 on the etracer PCB. As described above these fuses should not blow under normal operation. If any fuse blow up frequently please stop using etracer and contact us.

Note: Short circuits between the 6 pins of P2 are considered as a “normal” operation as it might happen due to erroneous wiring or a bad DUT.

Due to intrinsic inductance and capacitance in wires and tube socket pins the fast on/off switching during testing might induce oscillation in the DUT and in the test circuit. Although the oscillation energy is small and poses no harm to the DUT it might render the measurement result useless. The oscillation tends to take place when the DUT is a high gain tube such as a 6C45. To prevent the high frequency oscillation the output trace of NEGV, HV1 HV2 has a ferrite bead connected in series. When wiring the sockets please wire through a hollow ferrite bead every 2 to 3 wires as illustrated below. If the wire on the test lead is very long (>30cm) please use hollow ferrite beads as well. Ferrite bead is conductive hence it is advisable to use glue to fix the beads to the wires.

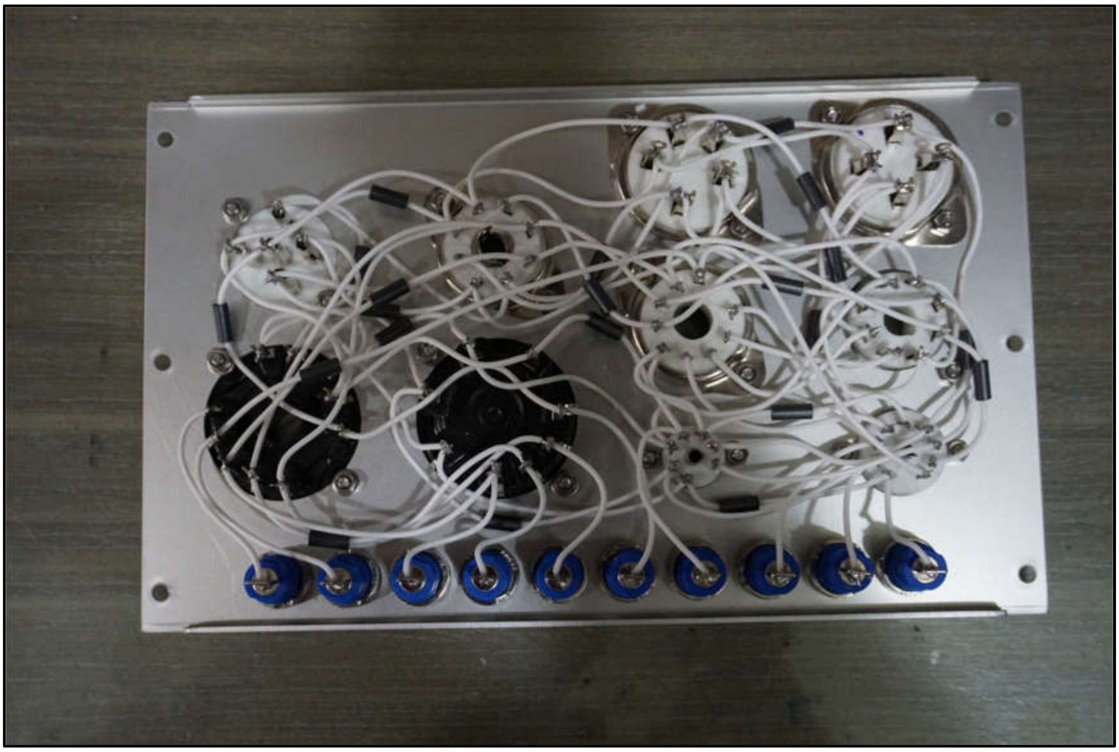


Figure 12. Put a hollow ferrite bead ever few wires to prevent HF oscillation

The etracer PCB can be used in conjunction with the Model-01 chassis supplied by essuse Technologies and use wires with banana plugs to connect the DUT to the PCB. The users can design their own housing. The design goal for the housing is to provide a mean to connect the DUT's pins to the 6 output pins on the PCB. Besides wires with banana plugs, relays or multi-step switches are candidates for achieving such a connection. When selecting the connecting devices please make sure these devices have at least a voltage rating of 1000V and a current rating of 5A.

C. Factory voltage calibration

The four voltage sources (heater, NEGV, HV1 and HV2) on the etracer PCB are calibrated by a Fluke 8808A bench-top digital multi-meter before the PCB is shipped. The calibration data is stored in the flash memory of the micro-controller. The accuracy after calibration is max(2%,0.2V) for HV1 and HV2, max(2%,0.02V) for NEGV and max(0.1V,2%) for HEATER. The long-term drifts for these voltages are unknown.

Note 1: max(a,b) is a function which outputs the bigger one between a and b.
Note 2: Only voltages are calibrated. Calibration for current is done in software. Please refer to the software user's manual for the procedure of current calibration.

D. Grounding for the etracer system

In general the etracer PCB does not require any grounding. However, it is recommended to ground the PCB for safety consideration. If the etracer PCB is used in conjunction with the Model-01 chassis from essues Technologies the GND reference point of the PCB is tied to the chassis when the USB type B cable is fixed to the back plate of the chassis. Hence the chassis and the PCB GND are at the same potential. There is no special insulation measure required when mounting the PCB to a metal chassis. The mounting holes on the PCB are all surrounded by the GND plane. Even if the insulation layer is scuffed the mounting screws would cause the GND plane of the PCB short to the chassis. If grounding the AC inlet is desired the earth reference point of the AC inlet can be tied to the metal chassis assuming the PCB GND is also tied to the chassis.

E. Wiring examples for testing tubes

1. Testing a directly heated full-wave rectifier (5Z3 is used as an example)

With two high voltage supplies HV1 and HV2 etracer can test both sections of the DUT simultaneously. Connect HV1 and HV2 to the plate electrodes (pin 2 and pin3) of the DUT and connect HEATER1 and HEATER2 to the filament (pin 1 and pin4) of the DUT. No wiring for NEGV and GND is needed. The complete wiring is illustrated in figure 12.

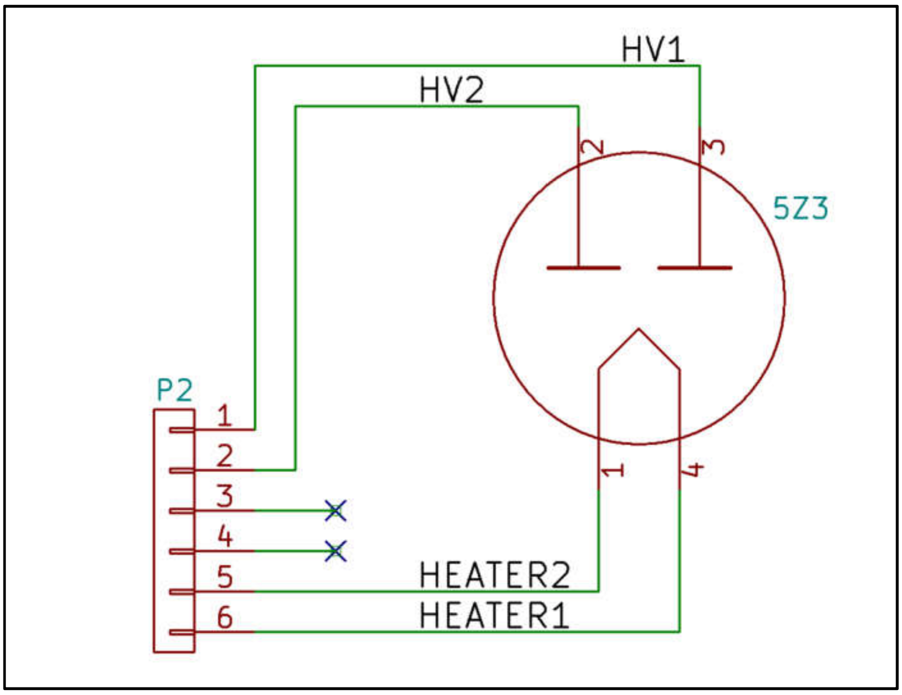


Figure 13. Wiring diagram for testing a 5Z3

Note: There is an inevitable measurement difference between HV1 and HV2. If a perfect match is desired please use only HV1 to measure both sections.

2. Testing an indirectly heated full-wave rectifier (GZ34 is used as an example)

One leg of the filament is connected to the cathode internally for GZ34 and hence there is no external wiring required. The wiring is the same as testing a directly heated full-wave rectifier.

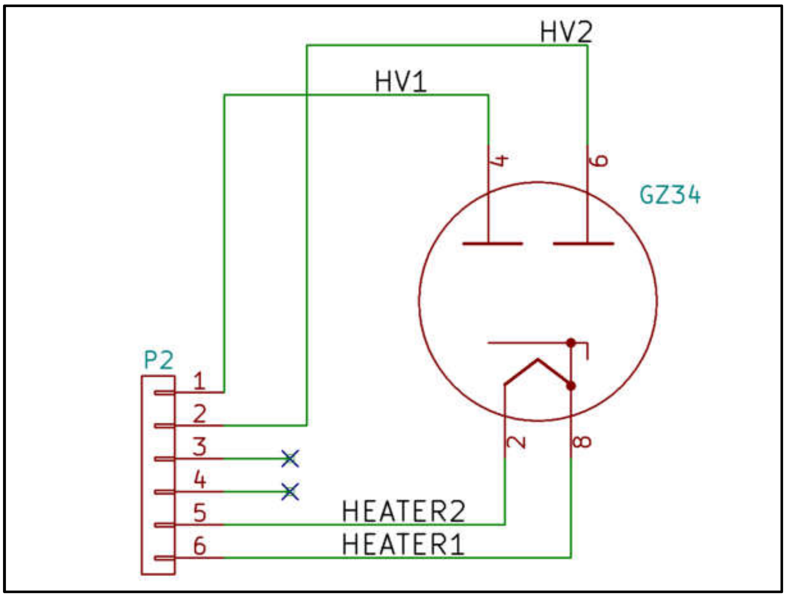


Figure 14. Wiring diagram for testing a GZ34

3. Testing a full-wave rectifier tube with separate cathode and heater leads(6CA4 is used as an example)

6CA4 has separate cathode and heater leads to share the filament power supply with other tubes. Hence the cathode electrode of the DUT needs to be connected to GND of the PCB. The wiring is depicted below:

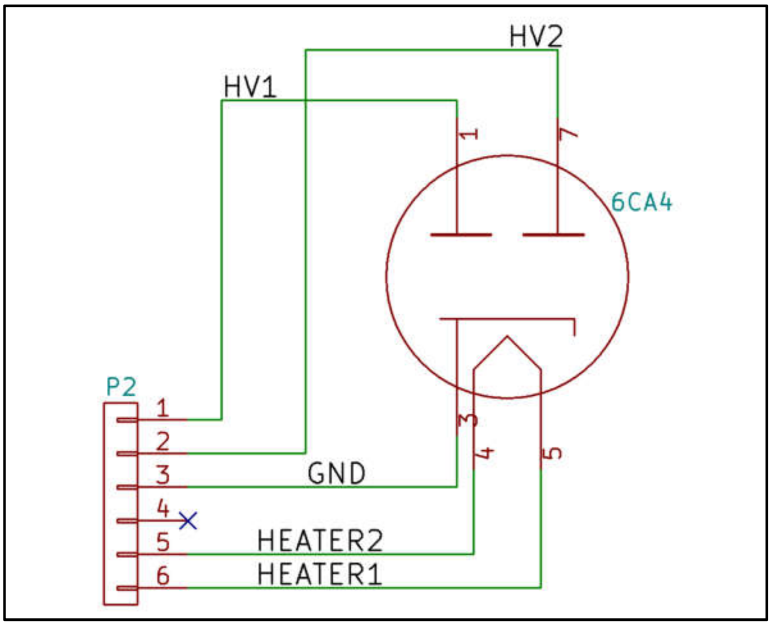


Figure 15. Wiring diagram for testing a 6CA4

4. Testing a DHT (directly heated triode) (300B is used as an example)

For a DHT the heater is also the cathode and hence there no wiring needed to connect the cathode of the DUT to GND. Connect HV1 to the plate electrode (pin 2), connect NEGV to the grid electrode (pin 3) and connect HEATER1 and HEATER2 to the filament (pin 1 and pin 4) as illustrated below:

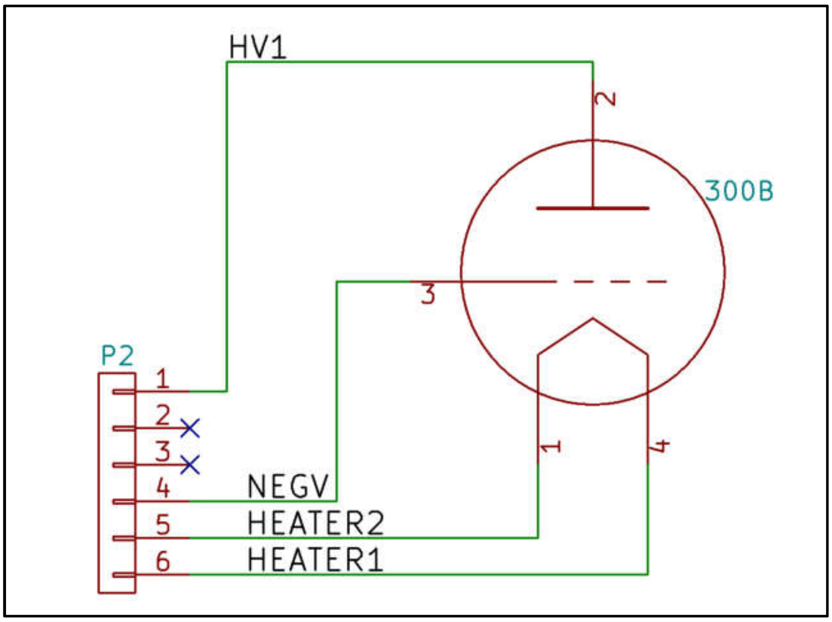


Figure 16. Wiring diagram for testing a 300B

5. Testing an indirectly heated triode (6C45 is used as an example)

For an indirectly heated triode the cathode of the DUT should be connected to the GND pin of the PCB.

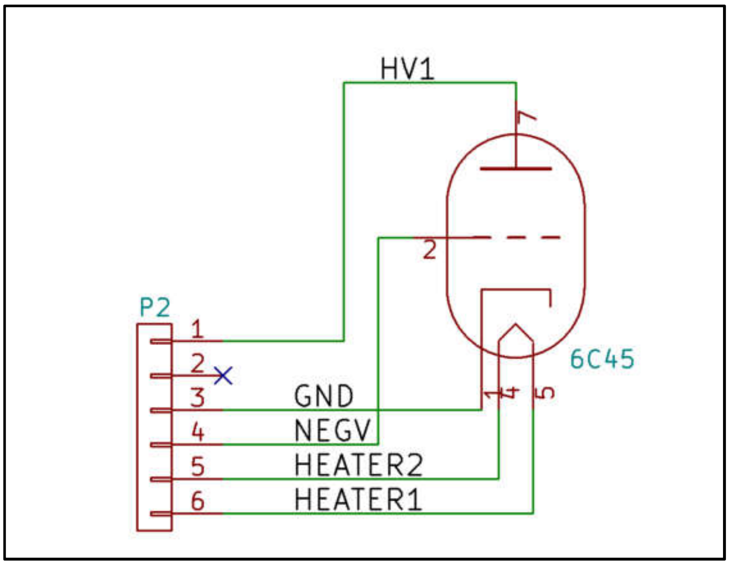


Figure 17. Wiring diagram for testing a 6C45

6. Testing an indirectly heated twin-triode (12AX7 is used as an example)
HV2 on the etracer can be configured to sync with HV1 by software. This allows simultaneously testing both section of a twin-triode. Connect HV1 and HV2 to the plate electrodes of the DUT (pin 1 and pin 6). Connect NEGV to the grid electrodes of both sections of the DUT(pin 2 and pin 7) and connect GND to the cathode electrodes of both sections of the DUT (pin 3 and pin8). HEATER1 and HEATER2 power the filament of the DUT (pin 4 and pin 5). Note for this connection the voltage output of the heater supply should be configured to 12.6V.

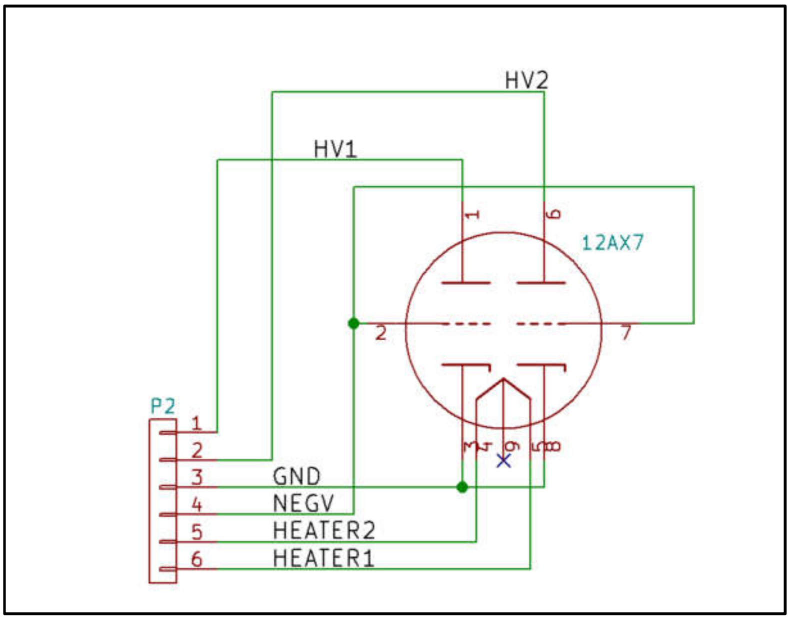


Figure 18. Wiring diagram for testing a 12AX7

Note: There is an inevitable measurement difference between HV1 and HV2. If a perfect match is desired please use only HV1 to measure both sections.

7. Testing a pentode (6L6 illustrated)

etracer can test a pentode under the two commonly used configurations: triode connection and pentode connection. For triode connection the voltage applied on the screen electrode of the DUT should be the same as the voltage applied on the plate electrode of the DUT. For pentode connection the voltage applied on the screen electrode of the DUT should be kept constant. The HV2 output of etracer supports both types of connections. The behavior of HV2 is controlled by the PC software.

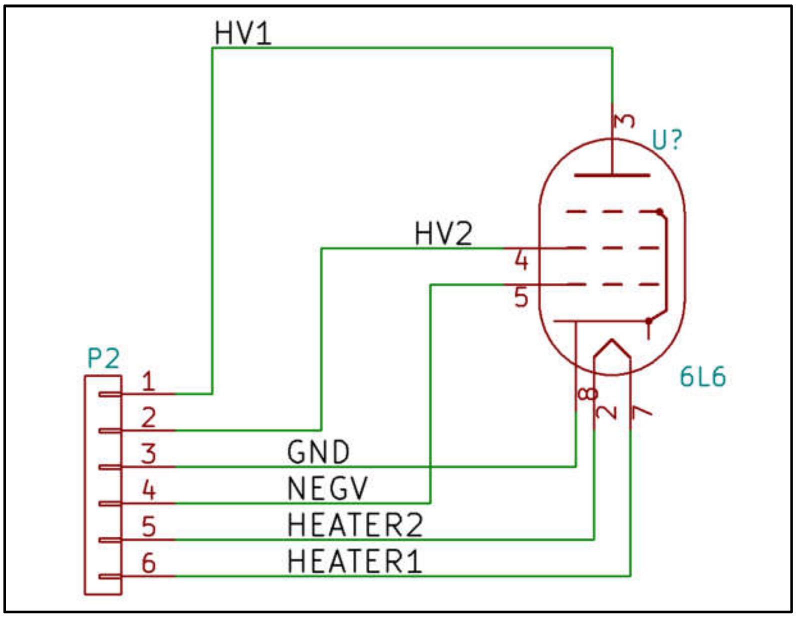


Figure 19. Wiring diagram for testing a 6L6

8. Testing a triode under positive grid bias

Software is under development.

9. Using an external heater power supply.

If the current or voltage requirements for a DUT exceed the heater power supply capacity of etracer (26.5V/3A/30Watts) an external DC power supply can be used to power the filament of the DUT. The output of this DC power supply should be absolutely isolated from the AC mains.

If the DUT is indirectly heated there is no need to ground the external DC power supply. But for safety reason and reduction of EMI noise it is advisable to connect the negative lead of the DC supply to GND. If the DUT is directly heated the negative lead of the external DC power supply must be connected to GND.

One leg of the DUT's filament can be connected to GND or connected to HEATER1. If it is connected to HEATER1 then the current flowing through the filament can be monitored by the software by measuring the voltage drop on a 0.1 ohms resistor. The influence to the measurement accuracy for this 0.1ohms is negligible. The following figure illustrates the wiring to monitor the filament current with an external power supply.

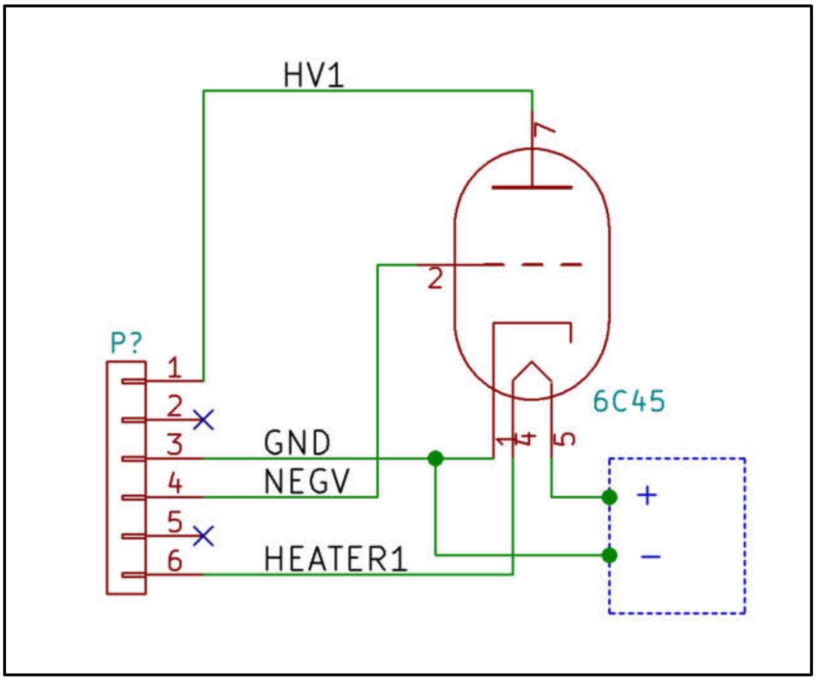


Figure 20. Filament power supplied externally. Current monitored by software.

If monitoring of the filament current is not required (eg. The external power supply already provides a current reading) the wiring can be simplified to the following figure. The dashed wire is recommended to reduce noise.

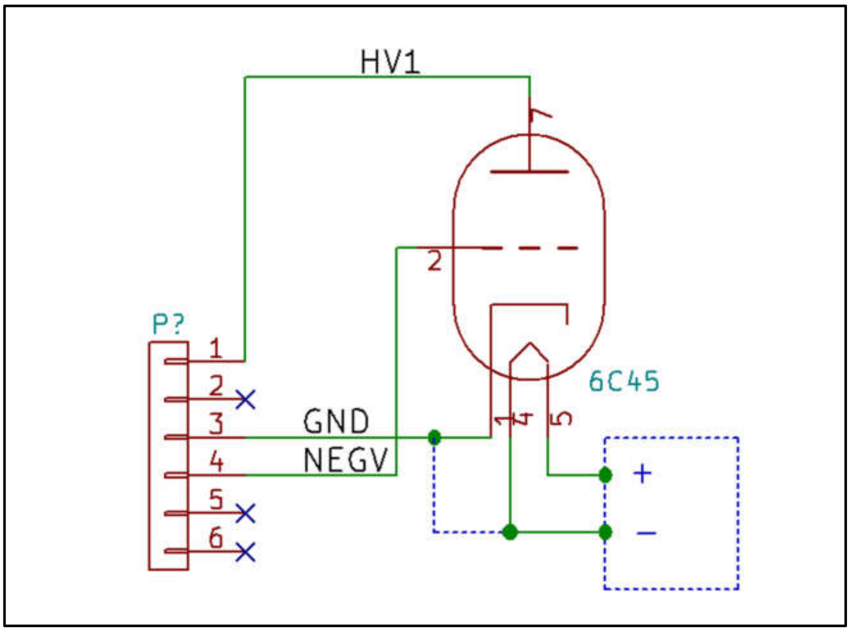


Figure 21. Filament power supplied externally. Current not monitored by software.

F. Hardware specification

1. ADC: 14bits, 900k samples/second with 24dB gain control(For voltage outputs and current measurements)
2. DAC: 12 bits (Filament supply control)
3. HV1/HV2 output voltage accuracy: 2%+/ - 0.3V after calibration.
4. HV1/HV2 current measurement accuracy: 5% before calibration.
5. NEGV output voltage accuracy: 2%+/-0.02V after calibration.
6. Heater supply: 1.5V to 27V with a maximum output current of 3A and a maximum output power of 30 Watts. 。
7. HV1/HV2 output: 5V to 768V with a maximum output current of 300mA.
8. NEGV: 0V, -0.5V to -180V.
9. Protection measures: Fuses, over-current protection, over-voltage protection and short-circuit protection for the etracer output pins.

G. PCB revision history

1. Identifying etracer PCB version number

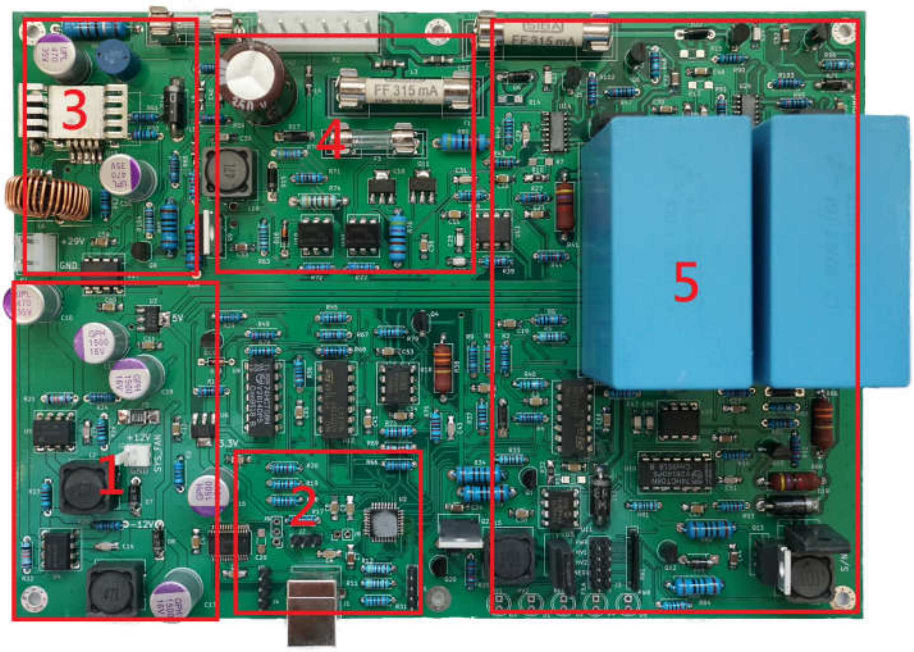
The PCB version is printed on one of the short side of the PCB next to the big blue rectangular capacitor as depicted below:

Location of PCB version information on the etracer PCB

2. etracer PCB versions revision history:
   - 1.4d: Initial version.
   - 1.4e: Fixed voltage spike issue in the heater supply during the power-on transition.
   - 1.5: Released on July 2019

   The differences between PCB version 1.4e and version 1.5 are insignificant and are summarized below:
   1. All MLCC capacitors are changed to 1206 SMD type to simplify our company's inventory management.
   2. Added a PTC auto-reset fuse on the 12V power supply connector J2 to prevent a short from damaging the board.
   3. Replace all 6 mounting holes with exposed-ground type.

3. The following material for PCB version 1.5x serve as a delta to the etracer PCB manual:
   Section A:
   The following figure replaces Figure 1 in section A



(Replacement) Figure 1. etracer PCB 1.5

Section D:
The following paragraph replaces section D.
The mounting holes on the PCB are surrounded by a circle of exposed ground. When the PCB is mounted on a metal chassis such as the Model-01 chassis from our company the ground plane of the etracer PCB will be at the same potential as the chassis. If grounding the AC inlet is desired the earth reference point of the AC inlet can be tied to the metal chassis or to the PCB ground by one of the mounting screws.