

DC voltage and current measurements

Manual for the laboratory exercise

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1. Aim

To get acquainted with the methods of DC voltage and current measurements and influence of internal impedance of used instruments on measured results. Measurement and calculation of the resistance of parallel-serial circuits. Calculations of output impedance of voltage source. Estimation of the measurement uncertainty. Learning how to write down and process measurement data correctly.

2. Setup description

The block diagram of the measurement setup for DC voltage and current measurements is presented in Fig. 1. Printed circuit board (PCB) setup consist of three parts: DC voltage, DC currents and source resistance measurement. In addition, the following equipment will be used:

- 9V AC power supply
- bench-top digital multimeter Agilent U3401A
- hand-held digital multimeter MU-02D
- analogue multimeter YX-360TR

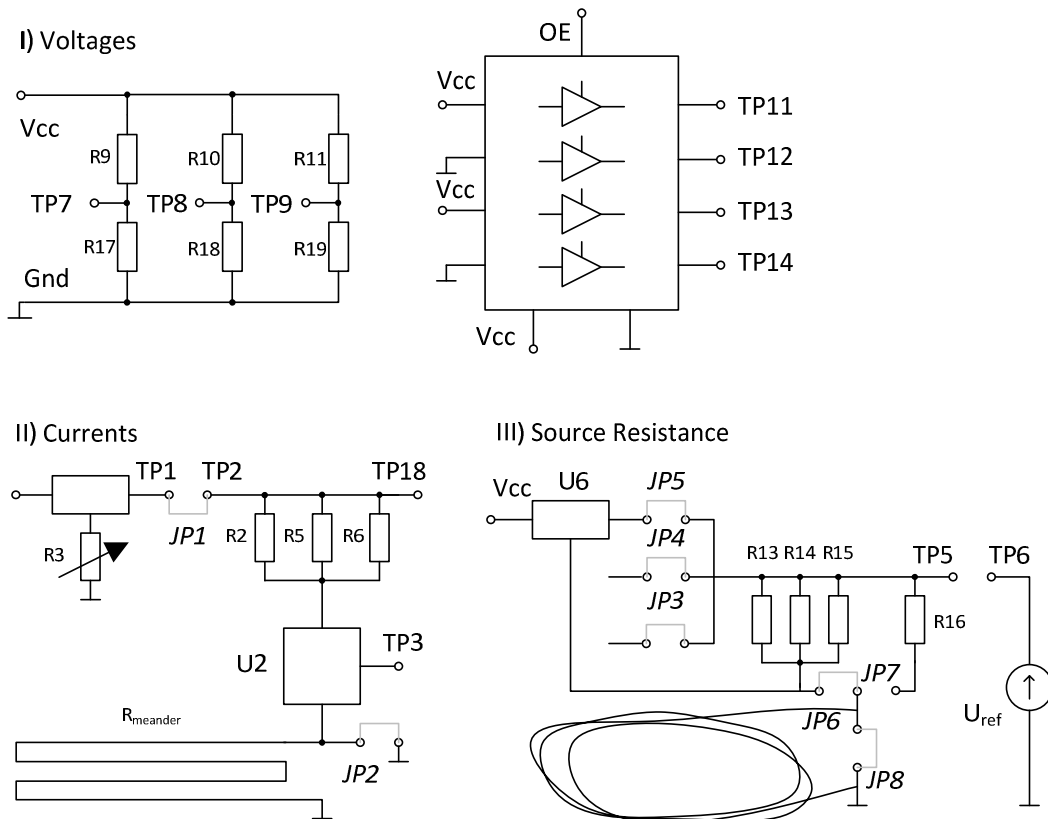


Fig. 1. Simplified schematics of the measurement setup. The complete schematic diagram with all the components, together with the PCB layout is attached in the Appendix section.

3. Exercise preparation

Points marked with (*) are obligatory, other are optional.

1. Print (or redraw) the tables 1 to 6 included in the Appendix 2 of this manual. (*)
2. Sketch a schematic of simple voltage divider with two resistors R_L and R_H . Write down the formula for the voltage at the output of the divider together with its uncertainty. Take into account the uncertainty of the measured voltage and the tolerances of the resistors values. (*)
3. Sketch a schematic of a voltage divider circuit with a voltmeter including its finite internal resistance R_V (read the internal resistance from the datasheet of Agilent U3401A / Rigol DM3068 multimeter). Give the formula for the measured voltage, together with its uncertainty (one should consider tolerances of R_L and R_H resistors tolerance, and the uncertainty of the voltage supplying the divider; uncertainty of the voltmeter internal resistance can be neglected). (*)
4. Calculate the correction taking into account the effect of the internal resistance of the voltmeter on the measurement result in the voltage divider. Determine the uncertainty of this correction on the basis of the tolerances of the resistors. The correction applied to the voltmeter reading should remove the loading effect caused by voltmeter internal resistance. (*)
5. From the datasheet of Agilent U3401A / Rigol DM3068 multimeter (available on the website of the course) find the following: internal resistance of ammeter at various measuring ranges, the uncertainty of measurement of DC voltage, current and resistance at various ranges. (*)
6. Learn the operation of a three-state logic gate and the meaning of the term "high impedance".
7. Write the formula for the resistance of the parallel connection of three resistors and its uncertainty by taking into account the resistance tolerance (assume 5%).
8. Write down the equation current measurement based on using the Ohm's law and its uncertainty. (*)
9. Calculate the resistance of the copper wire on the PCB with length of 120 cm, width of 0.5 mm and the thickness of 35 μm (assuming copper resistivity at room temperature).
10. Get familiar with following terms: standard uncertainty, extended uncertainty and limiting uncertainty. Learn how to write down correctly the measurement results including uncertainty. (*)

4. Measurement plan

Connect the AC power supply to the measurement setup. Proper operation will be indicated by a LED.

1. DC voltage measurements

- 1.1. Read resistance values of the resistors forming three voltage dividers R9-R11 and R17-R19

(marked on the PCB), write them down in Table together with corresponding uncertainties.

- 1.2. Using Agilent U3401A / Rigol DM3068 multimeter measure the output voltage of the three voltage dividers (using measurement points TP7-TP9 with respect to GND). Write down the measured values together with their uncertainties (use accuracy data from the multimeter manual) in Table 1. Measure the supply voltage (Vcc) and include it in the Table 1. Repeat this procedure for the hand-held multimeter MU-02D and the analogue multimeter YX-360TR.
 - 1.3. Measure the voltage on the outputs of the buffer gates 74HC125 using measurement points TP11 – TP14 with respect to GND and the supply voltage (Vcc) using both Agilent U3401A and the analogue voltmeter YX-360TR. Put the voltage values in Table 2.
2. DC current measurement
 - 2.1. On the basis of resistors color code (in Appendix) identify the values of the three resistors in the current measurement circuit (R2, R5, R6) and write them down with corresponding uncertainties in Table 3.
 - 2.2. Disconnect jumper JP1, connect jumper JP2. Using ohmmeter measure the load resistance $R_L = R2 \parallel R5 \parallel R6$ between the points TP2 and TP18. Write down the measured values, together with corresponding uncertainties, in Table 3.
 - 2.3. Using the variable resistor R3 set the output voltage of the voltage regulator U1 between 1 -2 V when measured at the TP1 point with respect to ground. Write down the measured voltage and its uncertainty in Table 4. Next, measure the load current between measurement points TP1 and TP2 using two different ammeter ranges: 500 mA and 10A (this requires changing both the range on the front panel of the multimeter and the input terminals). Repeat this measurement with the jumper JP2 opened.
 - 2.4. Changing the load current using R3 potentiometer, measure 10 pair of points: voltage on the load resistance (between points TP2 and TP18) and the output voltage of U2 Hall sensor ACS712. Write down the voltage values with their uncertainties in Table 5.
 - 2.5. Check and comment the influence of magnetic elements in the proximity of the Hall sensor on the measurement results (for example, you can use a magnet that is the speaker of your mobile phone).
 - 2.6. With a power supply disconnected, measure the resistance of the meander wire between TP18 and GND and write them down, with corresponding uncertainty, in Table 4.
 3. Measurement of output resistance of the voltage source
 - 3.1. With all jumpers disconnected, measure the load resistance of the voltage source: three resistors connected in parallel $R_{L2} = R13 \parallel R14 \parallel R15$ and resistor R16. Write down their values, together with the uncertainties in Table 6.
 - 3.2. Next, with jumper JP8 connected, measure the output voltage of the voltage regulators:
 - regulated (U1 – NCP5662, jumper JP3),
 - LDO (Low-Dropout, U4, jumper JP4),
 - a reference voltage source (parallel, band gap voltage regulator – U6, jumper JP5)Write down the voltages and their uncertainties in Table 6 (first column).
 - 3.3. Repeat the measurements from point 3.2 when loading the voltage regulators with R_{L2}

(jumper JP6) and R16 (jumper JP7). Put the measured voltages in Table 6 (second and third column).

3.4. Next, with jumpers JP6 and JP7 disconnected, measure the voltage V_1 between TP5 and TP6 (that is the difference between a reference voltage $U(\text{TP5})$ and the voltage regulator under test) by connecting jumpers:

- regulated (U_1 – NCP5662, jumper JP3),
- LDO (Low-Dropout, U_4 , jumper JP4),
- reference voltage source (parallel voltage regulator, band gap – U_6 , jumper JP5)

Voltages and their uncertainties write down in Table 6 (fourth column)

3.5. Repeat the measurements from point 3.4 with R_{L2} connected (jumper JP6). Put the measured voltages in Table 6 (fifth column).

3.6. Observe and comment the influence of the cabling on measurement results (on the measurement setup an additional cabling is mimicked by folded wire installed on the PCB connected via JP8)

5. Data processing

1. Values of resistances R_9 - R_{11} and R_{17} - R_{19} (localize them using the schematics shown in the Appendix) together with their tolerances write down in Table 1. Calculate theoretical values of voltage on measurement point TP7 and TP9 with respect to ground. Compare measured values with the theoretical calculations. Comment any discrepancies. (*)
2. Based on your preparation to the exercise, calculate the voltage correction value, which has to be taken into account due to a finite resistance of the voltmeter (given in the multimeter manual). Compare the theoretical values with the corrected measured results. (*)
3. Comment on the results obtained for the 74HC125 buffer gates. Can you explain why in some cases the sum of the gate output voltages measured with respect to ground and V_{CC} is not equal to V_{CC} ?
4. Calculate the load resistance R_L of current measurement setup (R_2 , R_5 , R_6 connected in parallel) including the resistors tolerances. Compare the calculated value with the measured one (with jumper JP2 connected) – Table 3. (*)
5. Calculate theoretical value of current that flows through the resistive load using Ohm's law. Compare it with measured values – Table 4. Compare the measured resistance of a meander PCB track with the theoretical calculations made in the preparation part. (*)
6. Calculate the internal resistance of the ammeter set to 10A and 500mA range, respectively. Compare calculated values with those given in the manual of Agilent U3401A/Rigol DM3068. (*)
7. Using Ohm's law calculate the current flowing through the resistive load (three resistors R_2 , R_5 and R_6 connected in parallel) and write it down in Table 5. Next, using two-parameter linear regression method calculate the ACS712 Hall sensor sensitivity, defined as the ratio of the output voltage to the input current.
8. Write down the measured values of voltage regulators output voltages with different loads in Table 6. Calculate the output resistances of the power supplies using suggestions given in

Appendix1. (*)

9. For curious and advanced students: calculate the output resistance of voltage regulator U4 when the jumper JP8 is disconnected. Comment obtained results. Can one expect similar effect for the regulator U6? Justify your answer.

Appendix 1

Derivation of output resistance of a voltage source using a difference method.

The small output resistance of a voltage source V_S can be determined by comparing the voltage drop on a resistance R_L with an auxiliary reference voltage source V_R of a similar output voltage. A diagram of such a measurement setup is sketched in Fig. 2.

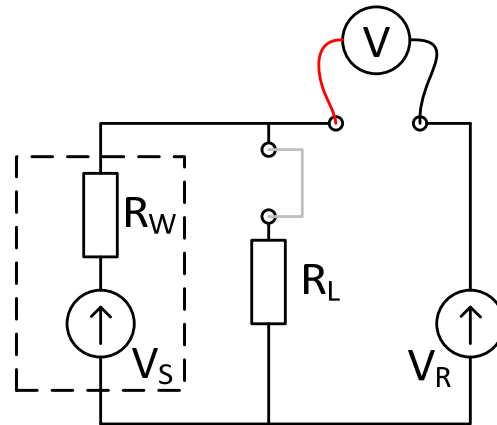


Fig. 2. Diagram of differential method for voltage source output resistance measurement.

When the load resistor R_L is disconnected, the voltmeter V indicates the difference between the voltage sources:

$$V_1 = V_R - V_S \quad (1)$$

When one connects the load resistor R_L , the indication of the voltmeter changes to the value, which is the difference between the voltage drop on R_L :

$$V_{RL} = V_S \cdot (R_L / (R_W + R_L)) \quad (2)$$

and the voltage on the reference voltage source V_R :

$$V_2 = V_S \cdot R_L / (R_W + R_L) - V_R \quad (3)$$

Rearranging the equation (3) one can calculate the output resistance of voltage source R_W .

Appendix 2

Measurement tables:

Supply voltage: $V_{TP4} (V_{CC}) =$

	R_H ± uncertainty	R_L ± uncertainty	$V_{calculated}$ ± uncertainty	$V_{digital}$ ± uncertainty	$V_{portable}$ ± uncertainty	V_{analog} ± uncertainty
R9-R17, TP7						
	±	±	±	±	±	±
R10-R18, TP8						
	±	±	±	±	±	±
R11-R19, TP9						
	±	±	±	±	±	±

Table 1.

	Measured V with respect to GND		Measured V with respect to Vcc		Comment
	U3401A	YX-360TR	U3401A	YX-360TR	
TP11					
TP12					
TP13					
TP14					

Table 2

R2 ± uncertainty	R5 ± uncertainty	R6 ± uncertainty	R_L – measured ± uncertainty	$R_L = R2 R5 R6$ – calculated ± uncertainty
±	±	±	±	±

Table 3.

Voltage set using potentiometer R3: $V_{TP1} =$

I mA range JP2 connected	I A range JP2 connected	I mA range JP2 disconnected	I A range JP2 disconnected	I calculated

Table 4.

Meander resistance measurement: $R_{meander} =$

No.	1	2	3	4	5	6	7	8	9	10
V_{RL}										
I_L										
V_{Hall}										

Table 5.

	V_{TP6} unloaded	V_{TP6} loaded JP6 (R_{L2})	V_{TP6} loaded JP7 (R_{16})	V_1 TP5 – TP6	V_2 TP5 – TP6	R_w calculate
U1 – NCP5662 <i>variable</i>						
U4 – LDO <i>fixed</i>						
U6 – band gap <i>fixed</i>						

Table 6.

$R_{16} =$

$R_{L2} =$

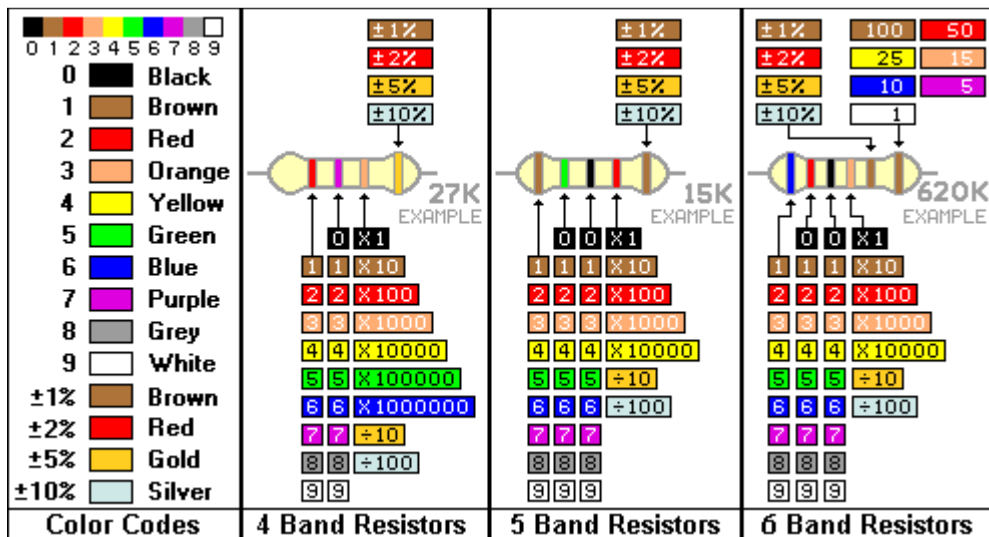


Fig. 3. Color code of resistance value.

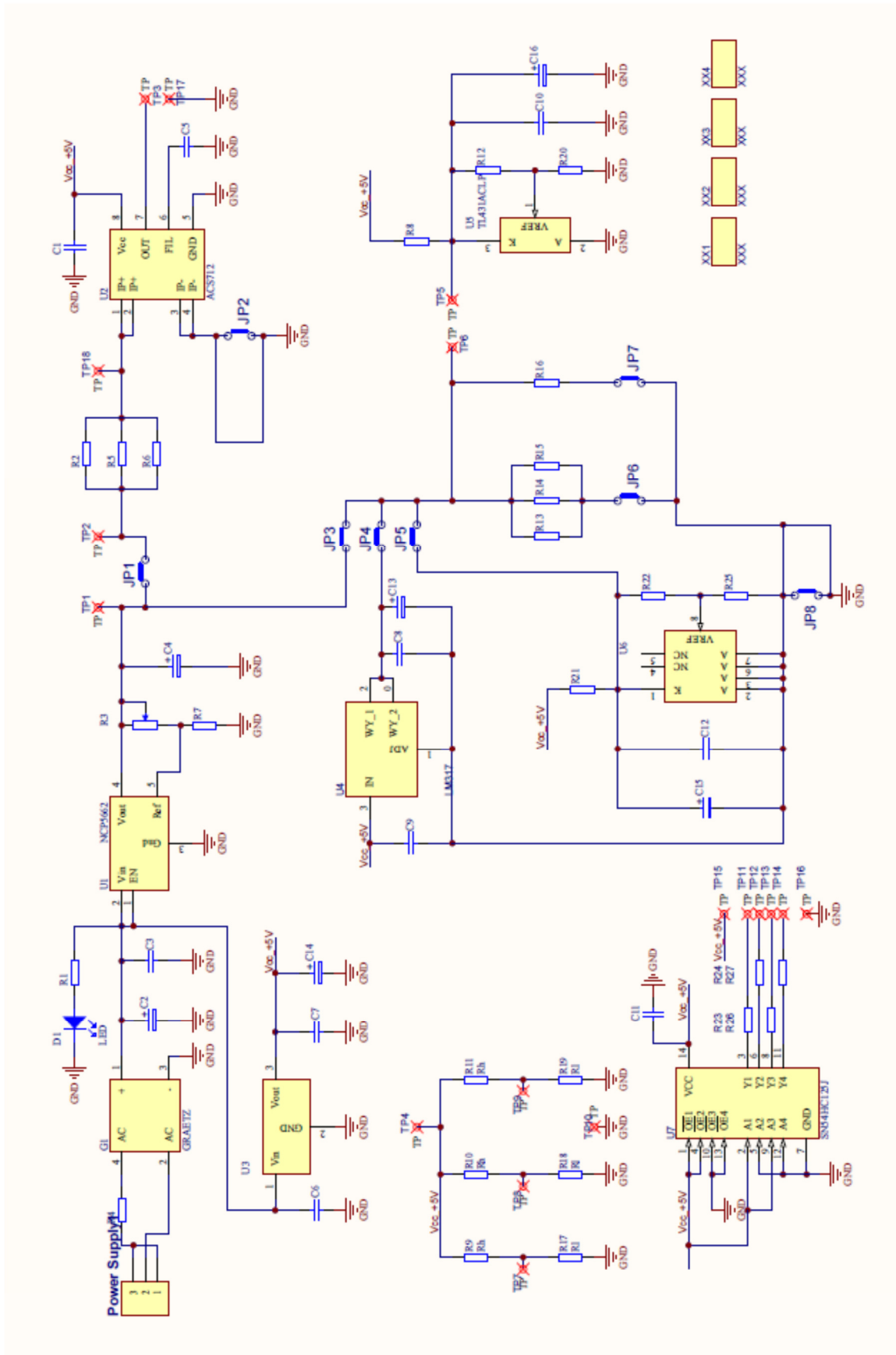


Fig. 4. Schematic of the measurement setup PCB

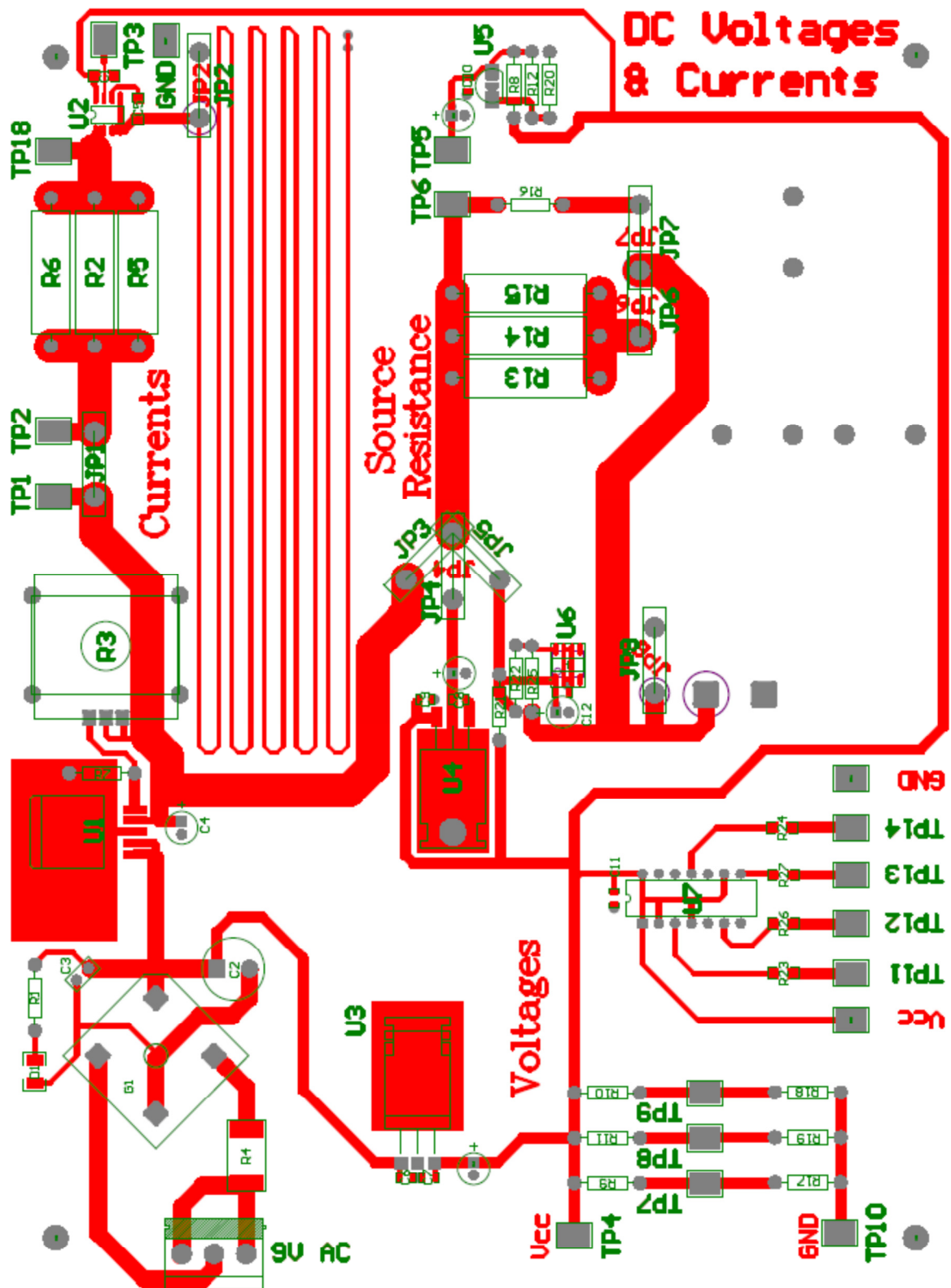


Fig. 5. PCB with element layout.