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Jacobs University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2021

Lab Experiment 2 – Ohm's Law

Author of the report
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Experiment conducted by	: Ramin Udash, Dhespina Pepa Pecini
Place of execution	: Teaching Lab EE Room 1, Bench 1 and 2
Date of execution	: Sept 23, 2021

1. Introduction

The objectives of this experiment are:

- Demonstrate Ohm's law in a real circuit,
- Examine the behavior of Positive Temperature Coefficient (PTC) and Negative Temperature Coefficient (NTC) resistors in a circuit.

The Ohm's law states that the current through two points in a circuit is directly proportional to the potential difference across the two points i.e.,

$$V \propto I$$

The resistance between the two points is the proportionality constant in this equation. For strict fulfillment of this formula, the resistance and the temperature of the circuit must be constant i.e., independent from the Current(I). Only if these conditions are fulfilled, the behavior of the circuit is ohmic. The formula is:

$$V=IR$$

For a copper wire, the resistance is directly proportional to the length of the wire 'l' and inversely proportional to the cross-sectional area of the conductor 'A', establishing the relation:

$$R \propto l/A$$

In this equation, the proportionality constant is the resistivity of the conductor 'ρ' and the equation becomes:

$$R = \rho\, l/A$$

Positive Temperature Coefficient (PTC) are the type of resistors for which the resistance increases with the increasing temperature. For temperatures below 150°C, the following formula applies:

$$R_T = R_{T0}(1 + \alpha\Delta T)$$

In this equation, Rt is the resistance of the resistor in a specific temperature, Rt0 is the resistance at the reference temperature T0(in our case T0= 25°C), α is the temperature coefficient (3.85*103 °C-1) and ΔT is the difference between T and T0.

Negative Temperature Coefficient(NTC) are resistors whose resistance decreases as the temperature goes up. The following formula applies for NTC:

$$R_T = R_{25} * e^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

In this formula, Rt is the resistance of the resistor in a specific temperature, R0 is the resistance at the reference temperature T0.

2. Evaluation

Instruments used in this experiment:

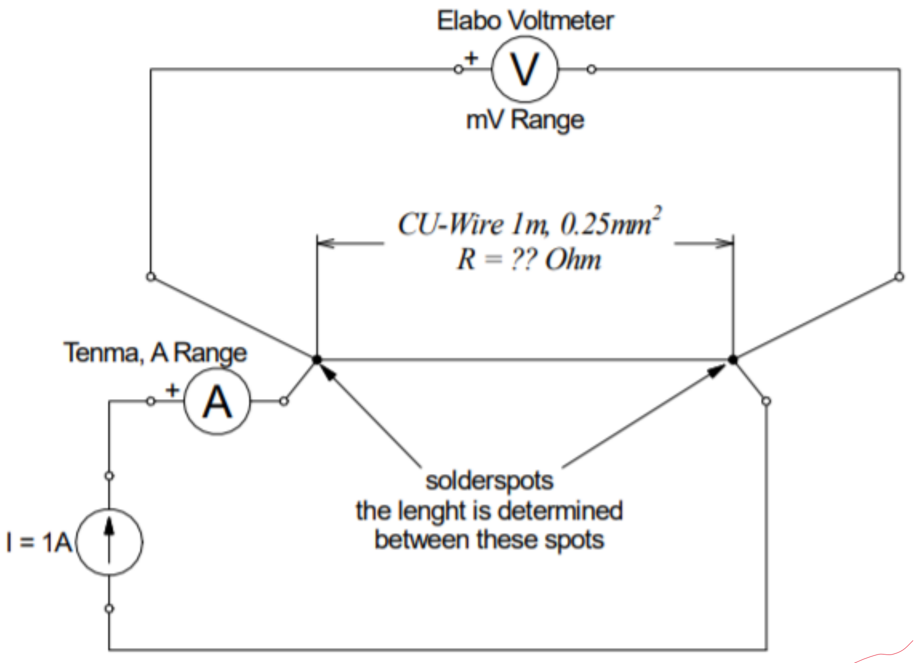
- 1m Copper Wire
- Breadboard
- 1K Ohm PTC resistor
- 1K Ohm NTC resistor
- Two 1K Ohm resistors
- One 100K Ohm resistor
- Power Supply
- Connecting Wires
- ELABO multimeter
- TENMA multimeter

Part 1: Resistance of the Copper Wire

The SETUP

In this experiment, we measure the resistance of a 1m copper wire. A special method called Kelvin(4-wire) is used since the resistance was low. When applying this method, the first step is to remove the errors that can happen from the influence of the connecting wires. The ELABO multimeter used as Voltmeter is connected in parallel with the copper wire. The voltmeter is connected to the ends of the wire at the solder spots. We measure the resistance between the solder spots.

The circuit established is shown below:



Execution and results:

The TENMA multimeter is used as the ammeter and is connected in series with the wire to measure the current. A constant current of 1A was supplied as specified by the instructions. We measured and recorded the voltage and the current after the current was supplied. After that, we switch the TENMA multimeter from Ampere to Ohms to measure the resistance of the circuit.

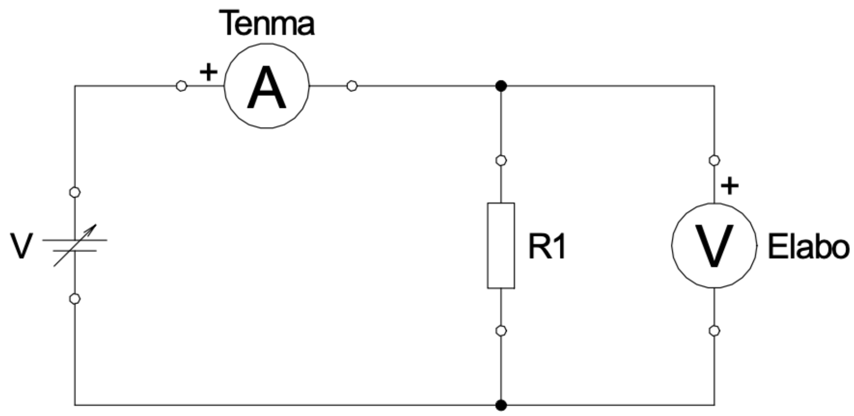
The results of the experiment are tabulated below:

Voltage /V	Current /A	Resistance/ohms
0.0682	1.0028	0.2700

Part 2: Resistance of a metal film resistor

The SETUP

For Part 2 of this experiment, we use a metal film resistor of resistance 1k00Ω as ohmic resistance even though it is not an ohmic conductor. We use the ELABO as the voltmeter connected in parallel with the metal film resistor R1 and TENMA as the ammeter connected in series with the resistor to measure the current. The circuit was setup as per the instructions in the lab manual is shown below:



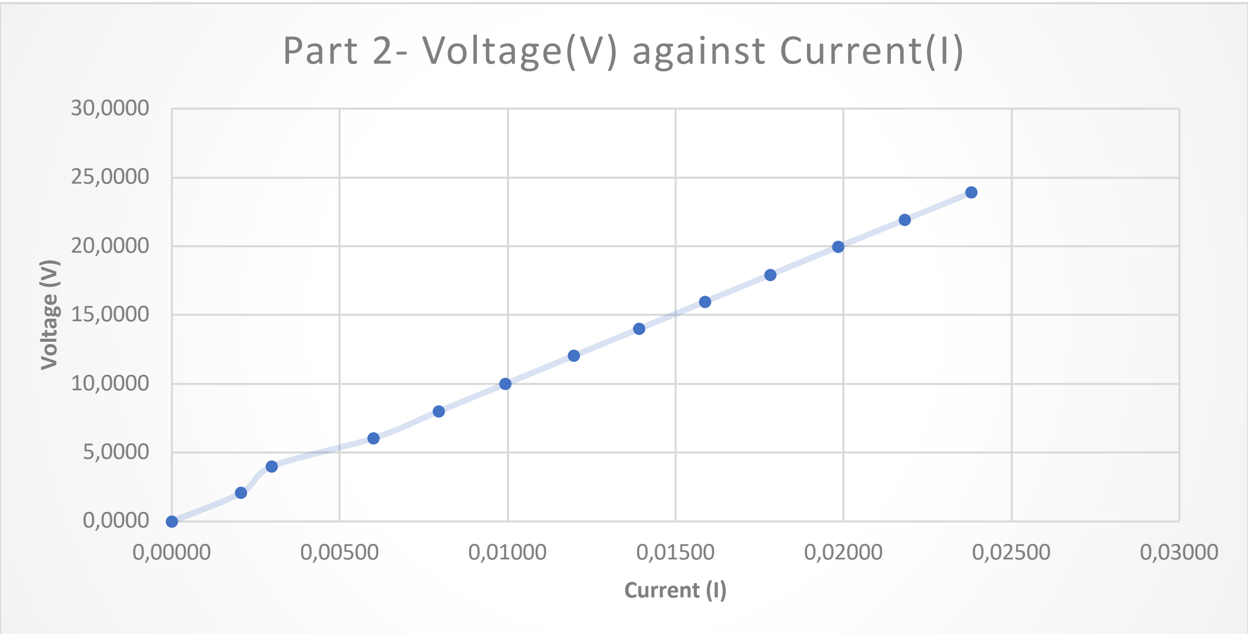
$$R_1 = 1k00\,\Omega$$

Execution and results:

We alter the voltage supply to the metal film resistor from 0V to 24V at intervals of 2V. We measure the current and the voltage over the 1k00Ω. The results are tabulated below:

Range	Voltage Source/V	Current	Voltage reading/v
0.2000	0.0000	0.0136	0.0000
20.0000	2.0000	0.0021	2.0920
20.0000	4.0000	0.0030	4.0130
20.0000	6.0000	0.0060	6.0630
20.0000	8.0000	0.0079	8.0000
20.0000	10.0000	0.0099	9.9970
20.0000	12.0000	0.0120	12.0450
20.0000	14.0000	0.0139	14.0060
20.0000	16.0000	0.0159	15.9750
20.0000	18.0000	0.0178	17.9420
20.0000	20.0000	0.0199	19.9730
200.0000	22.0000	0.0218	21.9300
200.0000	24.0000	0.0238	23.9200

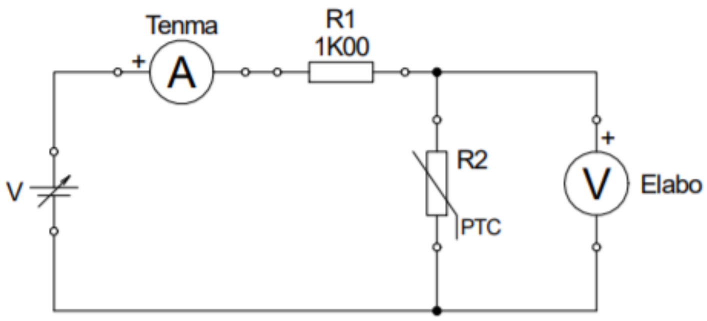
The graph below shows the graph of Voltage(V) against Current(I):



Part 3: Resistance of a PTC resistor

The SETUP

For part 3 of Experiment 2, our objective is to understand the behavior of PTC resistor. The resistance of PTC increases with the increase in temperature. We use TENMA as ammeter and ELABO as voltmeter. We connected resistor R1 of 1K Ohm in series with the PTC resistor. The voltmeter was connected in parallel across only the PTC resistor. The TENMA as ammeter was connected in series with resistor R1. The circuit setup as per the instructions in the Lab Manual is shown below:



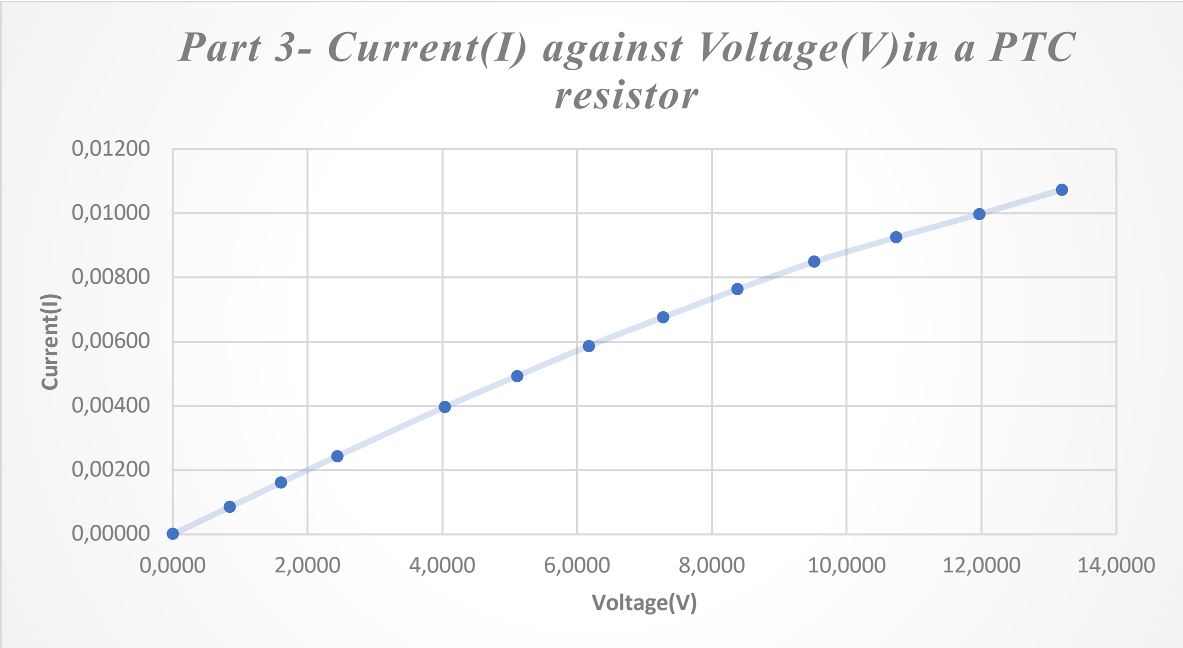
$$R_2 = 1k50\,\Omega$$

Execution and results:

The voltage source was varied from 0V to 24V at intervals of 2.0V. As stated in the Manual, the system needed to be stabilized before the values are recorded for accurate results. So, we waited 2 minutes for each value and then recorded it after a somewhat stable value was seen. The results of the experiment are tabulated below:

Range	Voltage Source/V	Current	Voltage reading/v
2000.0000	0.0000	0.00001	0.0000
2.0000	2.0000	0.00085	0.8410
2.0000	4.0000	0.00161	1.6017
20.0000	6.0000	0.00243	2.4380
20.0000	8.0000	0.00397	4.0400
20.0000	10.0000	0.00493	5.1100
20.0000	12.0000	0.00587	6.1770
20.0000	14.0000	0.00676	7.2700
20.0000	16.0000	0.00763	8.3750
20.0000	18.0000	0.00849	9.5150
20.0000	20.0000	0.00925	10.7300
20.0000	22.0000	0.00997	11.9620
20.0000	24.0000	0.01074	13.1950

The graph of Current(I) against Voltage(V) is shown below:

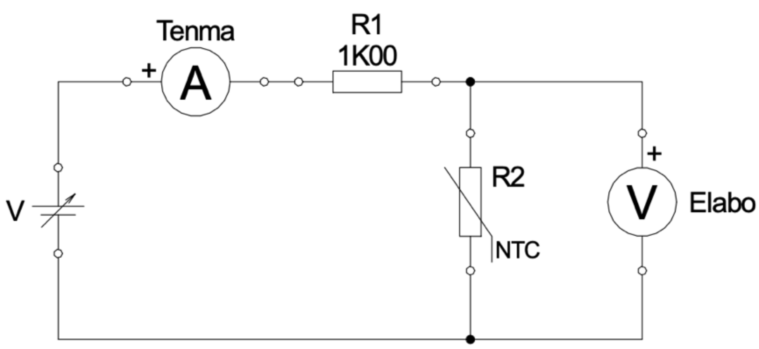


Part 4: Resistance of a NTC resistor

The SETUP

For part 3 of Experiment 2, our objective is to understand the behavior of NTC resistor. We replace the PTC resistor in the previous circuit with an NTC resistor. The resistance of NTC resistor decreases with the increase in temperature. It behaves opposite as the PTC resistor. We use TENMA as ammeter and ELABO as voltmeter. We connected resistor R1 of 1K Ohm in series with the PTC resistor. The voltmeter was connected in parallel across only the PTC resistor. The TENMA as ammeter was connected in series with resistor R1.

The circuit setup as per the instructions in the Lab Manual is shown below:



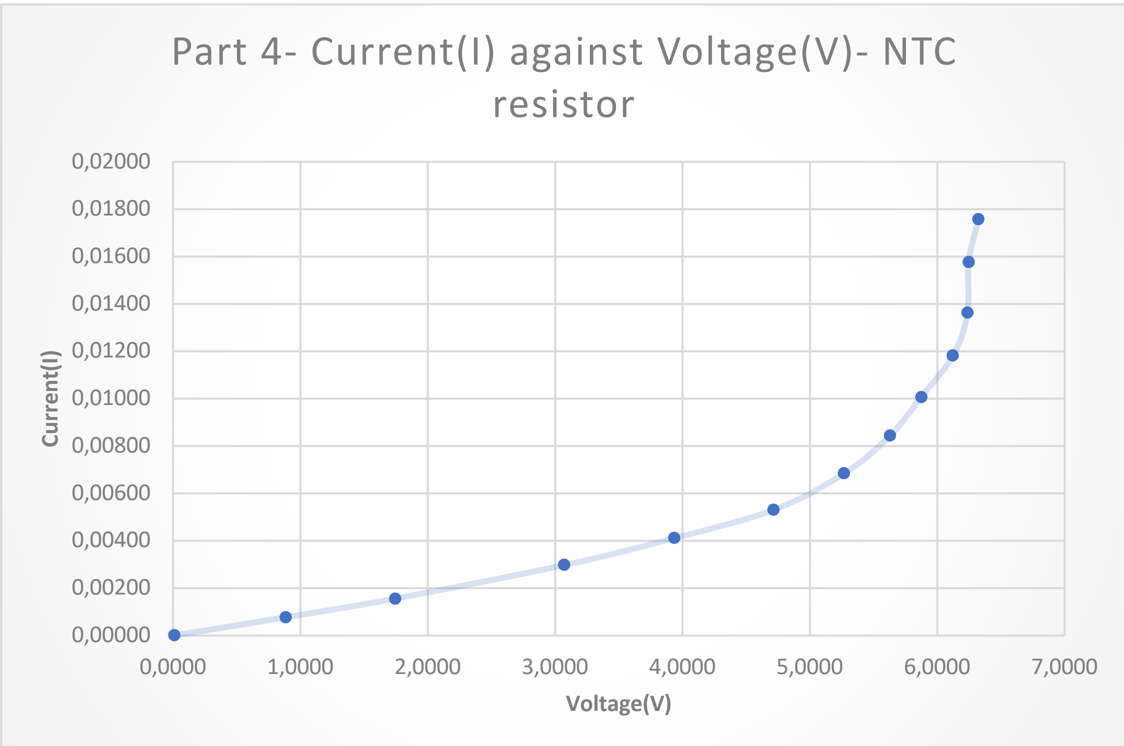
$$R_2 = 1k00\,\Omega$$

Execution and results:

The voltage source was varied from 0V to 24V at intervals of 2.0V. As stated in the Manual, the system needed to be stabilized before the values are recorded for accurate results. So, we waited 2 minutes for each value and then recorded it after a somewhat stable value was seen. The results of the experiment are tabulated below:

Range	Voltage Source/V	Voltage reading/v	Current
20.0000	0.0000	0.0110	0.00001
20.0000	2.0000	0.8860	0.00078
20.0000	4.0000	1.7450	0.00156
20.0000	6.0000	3.0750	0.00298
20.0000	8.0000	3.9400	0.00412
20.0000	10.0000	4.7160	0.00531
20.0000	12.0000	5.2700	0.00685
20.0000	14.0000	5.6300	0.00845
20.0000	16.0000	5.8750	0.01008
20.0000	18.0000	6.1260	0.01184
20.0000	20.0000	6.2370	0.01364
20.0000	22.0000	6.2470	0.01577
20.0000	24.0000	6.3230	0.01758

The graph of Current(I) against Voltage(V) of the NTC resistor is shown below:



3. Evaluation

3.1 Part 1: Resistance of copper wire

Question:1 Calculate the resistance of the wire using the values from the 4-wire measurement.

Solution:

Using Ohm's law:

Voltage /V	Current /A	Resistance/ohms
0.0682	1.0028	0.2700

$$V=I*R,$$

$$\text{So, } R=V/I = (0.0682/\ 1.0028)\ \Omega$$

$$= 0.0680\ \Omega$$

Question:2 Calculate the relative error of R using the values from the 4-wire measurement (error propagation!).

Solution:

Absolute error of the voltage= **0.025% * rdg+(5 * dgt)**

=(0.025/100)*0.0682+5*0.00001= 0.0000671

Relative error of the voltage= **(Absolute error)/(Recorded value) *100**

=(0.0000671/0.0682)*100=0.09830303%

Absolute error of the current= **(0.15% * f.Value) + (0.01% * f.Range)**

= (0.15/100*1.0028)+(2*0.01/100)= 0.002008+0.003 = 0.0017042

Relative error of the current= **(Absolute error)/(Recorded value) * 100**

=(0.0017042/1.0028)*100=0.1699%

Question:3 Calculate the theoretical resistance of the wire (l = 1 m − A = 0.25 mm^2). Use the ρ given in the experiment section.

Solution:

$$R = \rho \frac{l}{A}$$

We know,

ρ = 0.0195 $\Omega mm^{2}/m$, A=0.25mm^2, l = 1.0 m

So, Theoretical Resistance (R)= 0.0195*(1/0.25) = 0.07800

Question:4 The experimental taken R value should be very accurate. Why there are differences to the theoretical value?

Solution:

The theoretical resistance of the wire is 0.078 Ω whereas the value we calculated from the measurements of the results of the 4-wire method is 0.0680 Ω. This is because the true value of the resistivity of the wires we used to get data i.e., ρ is not exactly 0.0195 Ωmm^2/m for the wires we used. In addition, the values of cross-sectional area and the length of the wire may have been different.

Another cause for this error might be that the values we got from the ammeter and from the voltmeter have not been accurate enough.

Question:5 The experimental taken R value should be very accurate. Why there are differences to the theoretical value?

Solution:

The value of R we got from the Tenma multimeter was 0.1 Ohms. This value has a considerable difference from the value of our experimental resistance which was 0.06843625 Ohms. The TENMA multimeter is not used for this type of small resistances. The resistance of our 1-m wire is very similar to that of the wires inside the multimeter, saying that it results in systematical error. Also, using wires in the same length as the wire we are trying to measure, it results in methodical error. The error using 4-wire measurement was very low (0.05008%) and surely it is lower than the error we get when using the multimeter to measure the resistance.

3.2 Part 2, 3, and 4: Resistance of different components

Question:1 Draw the graph R = f(I) for all resistors. Put all three graphs in one diagram.

Solution: The data for the metal film resistor is tabulated below:

Range	Voltage Source/V	Current	Voltage reading/v	Resistance
0.2000	0.0000	0.00000	0.0000	0.0000000
20.0000	2.0000	0.00208	2.0920	1008.1927711
20.0000	4.0000	0.00299	4.0130	1344.3886097
20.0000	6.0000	0.00602	6.0630	1006.8083693
20.0000	8.0000	0.00795	8.0000	1006.5425264
20.0000	10.0000	0.00993	9.9970	1006.3418563
20.0000	12.0000	0.01197	12.0450	1006.1816055
20.0000	14.0000	0.01392	14.0060	1006.1058832
20.0000	16.0000	0.01588	15.9750	1006.0457208
20.0000	18.0000	0.01784	17.9420	1005.9994393
20.0000	20.0000	0.01986	19.9730	1005.9430874
200.0000	22.0000	0.02183	21.9300	1004.3968123
200.0000	24.0000	0.02382	23.9200	1004.0716954

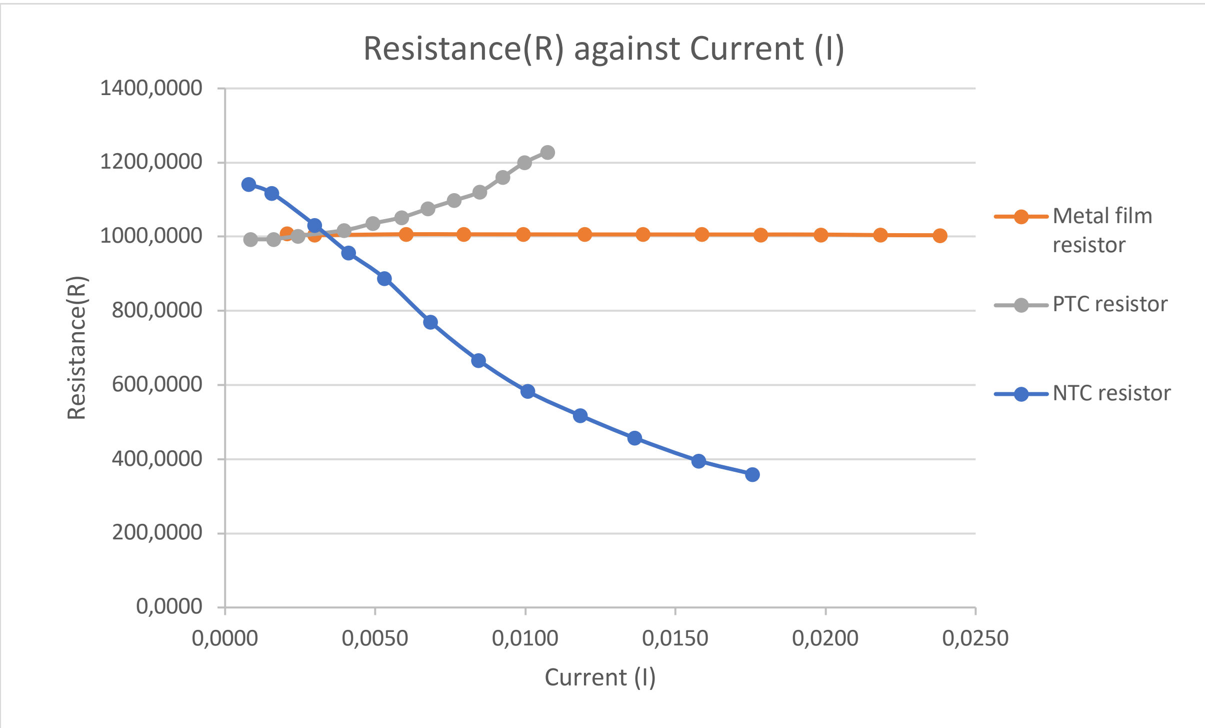
The data for the PTC resistor is tabulated below:

Range	Voltage Source/V	Current	Voltage reading/v	Resistance
2000.0000	0.0000	0.00001	0.0000	0.0000000
2.0000	2.0000	0.00085	0.8410	992.9161747
2.0000	4.0000	0.00161	1.6017	993.7953713
20.0000	6.0000	0.00243	2.4380	1002.0138917
20.0000	8.0000	0.00397	4.0400	1017.3759758
20.0000	10.0000	0.00493	5.1100	1035.8808028
20.0000	12.0000	0.00587	6.1770	1051.9414169
20.0000	14.0000	0.00676	7.2700	1075.4437870
20.0000	16.0000	0.00763	8.3750	1097.6408912
20.0000	18.0000	0.00849	9.5150	1120.9943450
20.0000	20.0000	0.00925	10.7300	1160.6273661
20.0000	22.0000	0.00997	11.9620	1199.5587645
20.0000	24.0000	0.01074	13.1950	1228.8135593

The data for the NTC resistor is tabulated below:

Range	Voltage Source/V	Voltage reading/v	Current	Resistance
20.0000	0.0000	0.0110	0.00001	1434.1590613
20.0000	2.0000	0.8860	0.00078	1141.6054632
20.0000	4.0000	1.7450	0.00156	1117.0144668
20.0000	6.0000	3.0750	0.00298	1031.8791946
20.0000	8.0000	3.9400	0.00412	956.3106796
20.0000	10.0000	4.7160	0.00531	887.9683675
20.0000	12.0000	5.2700	0.00685	769.5677570
20.0000	14.0000	5.6300	0.00845	666.6666667
20.0000	16.0000	5.8750	0.01008	582.8373016
20.0000	18.0000	6.1260	0.01184	517.5735046
20.0000	20.0000	6.2370	0.01364	457.1575167
20.0000	22.0000	6.2470	0.01577	396.0816637
20.0000	24.0000	6.3230	0.01758	359.7519345

The combined diagram of all three resistors is below:



Question:2 Do the graphs show expected behavior?

Solution:

Comprehending the diagram above, it can be said the resistors show the expected behavior. In this experiment, with the increasing voltage supply, the temperature in the resistor increases too. For the metal film resistor, the resistance does not depend on the temperature so the value should stay constant and that is what can be seen on the graph. For the PTC resistor, the resistance increases with temperature as it can be observed on the graph with the increase being nearly exponential. The NTC acts opposite to the PTC resistor. Some values might not exactly reflect the exponential behavior because of external environmental conditions that might affect the resistor.

Question:3 Draw the temperature at the PTC as a function of the resistance of the PTC resistor.

Solution:

$$R_T = R_{25}(1+\alpha\Delta T))$$

Where R_{25}=1K00Ω, α= 0.0038724, T=Temperature of the PTC resistor, and R_T = Recorded Temperature.

Equation of temperature at the PTC as of function of resistance of the PTC:

$$\Delta T=((R_T/R_{25})-1)/\alpha$$

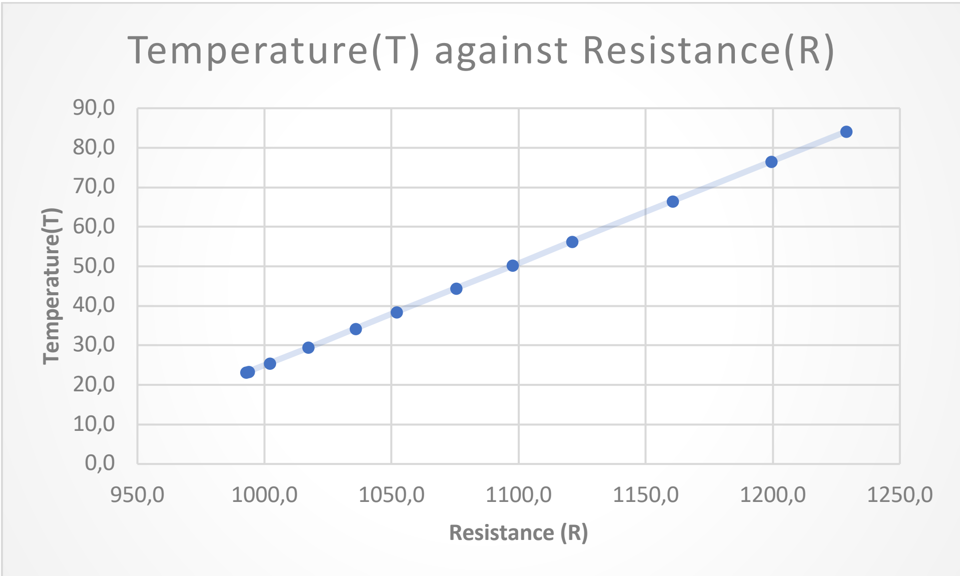
Example:

=((992.916/1000-1)/ 0.0038724)+25=23.11046

The results of the temperature as a function of resistance are tabulated in the next page:

Resistance	Temperature(T)
0.000	0.000
992.916	23.171
993.795	23.398
1002.014	25.520
1017.376	29.487
1035.881	34.266
1051.941	38.413
1075.444	44.482
1097.641	50.215
1120.994	56.245
1160.627	66.480
1199.559	76.534
1228.814	84.088

The graph of Temperature as a function of Resistance of the PTC is tabulated below:



Question:4 Draw the temperature at the NTC as a function of the resistance of the NTC resistor.

Solution:

$$R_T = R_{25} * e\text{^}(B(1/T-1/To)$$

Where R_{25}=1K00Ω, B= 3930K, To= 298.15 °K, T=Temperature of the NTC resistor and R_T = Recorded Temperature.

Equation of temperature at the NTC as of function of resistance of the PTC:

$$T = \frac{B * T_0}{\ln\left(\frac{R_T}{R_0}\right) * T_0 + B}$$

Example:

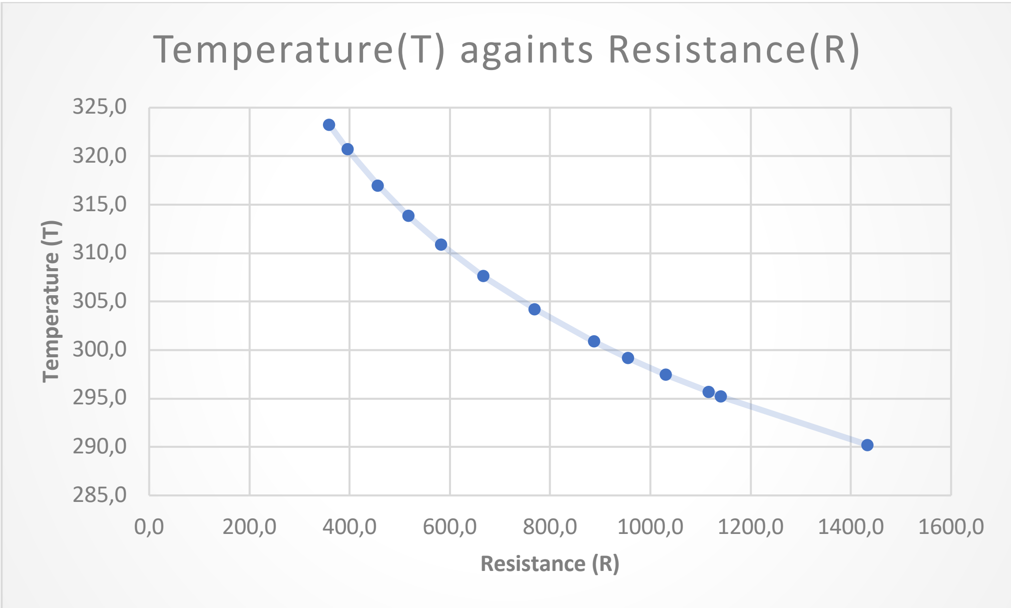
=(3930*298.15)/((ln(1434.2/1000)*298.15)+3930)

= 290.2

The results of the temperature as a function of resistance at NTC are tabulated below:

Resistance	Temperature(T)
1434.2	290.2
1141.6	295.2
1117.0	295.7
1031.9	297.4
956.3	299.2
888.0	300.9
769.6	304.2
666.7	307.6
582.8	310.9
517.6	313.8
457.2	317.0
396.1	320.7
359.8	323.2

The graph of Temperature as a function of Resistance of the NTC is tabulated below:



Question:5 Why might it be dangerous to connect a NTC resistor to higher voltages?

Solution:

The resistance of the NTC resistor increases significantly with the increase in the power supplied. When we use higher voltages, the resistance of the resistor gets very low which means the current flow will be very high. A higher current flow means the setup will be dangerous.

Question:6 What kind of 'resistor' is the copper wire? What are the consequences when using it with high currents or with hight temperatures.

Solution:

The copper wire acts like a PTC resistor i.e., the resistance increases with increasing power supplied. At some point, if the voltage supplied gets very high, the temperature will get very high i.e., reach a critical value and the wire will start to melt. This would lead to an open circuit with infinite resistance.

4. Conclusion

For part 1 of experiment 2, we used a specific 4-wire copper wire circuit to determine the resistance of a 1metre copper wire. After collecting and analyzing the data, we can say that the use of this specific 4-wire circuit yielded the most accurate results.

For part 2 of experiment 2, we measured the voltage and current through a metal film resistor. After gathering the results and calculating the resistance, we concluded that the resistance of the metal film resistor is independent of the amount of current passing through it i.e., it is independent of the temperature. It was also reflected in the graph of resistance as a function of current with a constant resistance throughout the graph. In short, we can say that this type of resistor has a constant value for resistance.

The purpose of part 3 of this experiment was to determine and analyze the behavior of Positive Temperature Coefficient (PTC) resistor. We increased the value of the voltage supplied and recorded the values of voltage and current reading. We calculated the resistance, and we could see the resistance increasing with increasing voltage supplied i.e., the resistance increased with the increase in temperature. The graph we constructed confirms the relation mentioned above.

In part 4 of experiment 2, we analyzed the behavior of NTC resistor just the way we did for the PTC resistor. After recording the values and creating the graph, we concluded that with increasing temperature, the resistance decreases. This type of resistor can be very dangerous if a high voltage is supplied as the temperature will get very high and the resistance will get very small causing the current flow to be very high.

In conclusion, doing these experiments we encountered several errors which are thought to be normal, when analyzing these types of resistors. The general type of errors were methodical errors, errors caused by temperature change in the environment which might have affected our readings for the PTC and NTC resistor.

5. References

I. Lab Manual

Jacobs University Bremen

Natural Science Laboratory
Electrical Engineering Module I

Fall Semester 2021

Lab Experiment 3 – Thevenin's
And Norton Circuit(Data)

Author of the report
Ramin Udash

Experiment conducted by	: Ramin Udash, Dhespina Pepa Pecini
Place of execution	: Teaching Lab EE Room 1, Bench 1 and 2
Date of execution	: Sept 24, 2021

Part 1: A Linear Network

Vs/ V	Elabo/V	Vab/V	Range(Elabo)
20	20.02	12.512	200

Part 2: Determine Thevenin's and Norton's parameters

Vsupply/ V	Range	Velabo/ V	Vth/ V	I(no)/A	Rth & Rno/ ohm
20	200	20.05	16.985	4.74E-02	352.67

Part 3: Determine V_{AB} using Th´evenin's Circuit

V supply/ V	Range	Vth/ V	Vab/ V	Rth in decade/ohm
16.9	20	16.983	12.474	353

Part 4: Determine V_{AB} using Norton's Circuit

V supply/ V	Range	Rno(using the decade)/ ohms	Ino/ A	Vab/ V	Vab(from table 1)
16.9	20	353	4.76E-02	12.469	12.512