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Student Group

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Experiment 1

DC circuit theory

Linear and non-linear resistors

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Equipment used

- Bench power supply GPS 3303
- Digital multimeter Agilent U1241A
- Breadboard GL-36
- Decade resistance box RD-1000, $\pm 1 \%$

The aim of this experiment is to become familiar with and investigate the following:

- assembling simple circuits on the GL-36 breadboard
- carrying out measurements with the Agilent U1241A digital multimeter
- using resistor standard series and the associated colour codes
- measuring resistances, voltages and currents

General measurement techniques

Voltage measurement

Procedure for voltage measurement:

1. Set the meter to the largest voltage range (check whether direct voltage or alternating voltage is to be measured; not necessary in auto range).
2. Connect the test leads to the correct meter sockets (the sockets marked COM and V).
3. Connect the test leads to the component under test with the correct polarity, so that the meter is connected in parallel with the component.
4. Read the measured value.

Current measurement

Procedure for current measurement:

1. Set the meter to the largest current range (check whether direct current or alternating current is to be measured; not necessary in auto range).
2. Connect the test leads to the correct meter sockets (the sockets marked COM and $\mu{\rm A}.{\rm mA}$).
3. Connect the test leads to the component under test with the correct polarity, so that the meter is connected in series with the component.
4. Read the measured value.

Resistance measurement

Procedure for resistance measurement:

1. Set the meter to resistance measurement.
2. Connect the resistor to be measured to the corresponding sockets on the meter (the sockets marked COM and Ω).
3. Read the measured value.

Digital multimeter Agilent U1241A

The Agilent U1241A multimeter has automatic range selection. The following measuring ranges are available:

Function	Range	Accuracy
DC voltage	$0 \ldots 1000 ~{\rm V}$	$\pm 0.1 \%$
AC voltage	$0 \ldots 1000 ~{\rm V}$	$\pm 1 \%$
DC current	$0 \ldots 10 ~{\rm A}$	$\pm 0.2 \%$
AC current	$0 \ldots 10 ~{\rm A}$	$\pm 1 \%$
Resistance	$0 \ldots 100 ~{\rm M}\Omega$	$\pm 0.3 \%$
Capacitance	$0 \ldots 10 ~{\rm mF}$	$\pm 1.2 \%$
Frequency	$30 ~{\rm Hz} \ldots 100 ~{\rm kHz}$	$\pm 0.3 \%$

Physical quantities and units used

Quantity	Symbol	Unit	Unit symbol
Voltage, potential difference	U	volt $= {\rm W}\cdot{\rm A}^{-1} = {\rm kg}\cdot{\rm m}^2\cdot{\rm s}^{-3}\cdot{\rm A}^{-1}$	${\rm V}$
Current	I	ampere (base unit)	${\rm A}$
Resistance	R	ohm $= {\rm V}\cdot{\rm A}^{-1} = {\rm kg}\cdot{\rm m}^2\cdot{\rm s}^{-3}\cdot{\rm A}^{-2}$	Ω

Conventional current direction: current flows from positive to negative.

Direct resistance measurement

Determine the nominal value and the measured value of the resistance of R_1 (brown, green, orange), R_2 (yellow, violet, red), R_3 (red, violet, red) and the incandescent lamp $R_{\rm L}$. Also measure the approximate resistance $R_{\rm K}$ of your body from your right hand to your left hand.

	R_1	R_2	R_3	$R_{\rm L}$	$R_{\rm K}$
Nominal value					
Measured value					

How do you explain the deviation between $R_{\rm L,nom}$ and $R_{\rm L,meas}$?

What consequences can $R_{\rm K}$ have?

Now also determine the series and parallel combinations of resistors R_1, R_2 and R_3. State the formulae used:

$R_{\rm series} = R_{\rm a} + R_{\rm b}$

$R_{\rm parallel} = (R_{\rm a} \parallel R_{\rm b}) = \frac{R_{\rm a} \cdot R_{\rm b}}{R_{\rm a} + R_{\rm b}}$

	$R_1 + R_2$	**$R_1 + R_3$**	**$R_2 + R_3$**	**$R_1 \parallel R_2$**	**$R_1 \parallel R_3$**	**$R_2 \parallel R_3$**
Calculated						
Measured						

Indirect resistance measurement

Resistance can also be determined by a current/voltage measurement.

Ohm's law: In a circuit, the current increases with increasing voltage and decreases with increasing resistance.

$ I = \frac{U}{R} $

Build the measurement circuit shown in Figure 2 for each of the three resistors and set the voltage on the bench power supply to $12 ~{\rm V}$.

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Measure U_n and I_n. From these values calculate R_n in each case.

$I_1 / {\rm mA}$	**$U_1 / {\rm V}$**	**$R_1 / {\rm k}\Omega$**	**$I_2 / {\rm mA}$**	**$U_2 / {\rm V}$**	**$R_2 / {\rm k}\Omega$**	**$I_3 / {\rm mA}$**	**$U_3 / {\rm V}$**	**$R_3 / {\rm k}\Omega$**

Kirchhoff's voltage law (loop law)

In every closed circuit and in every supply loop, the sum of all voltages is zero.

Set the voltage on the bench power supply to $12 ~{\rm V}$ and measure this voltage accurately with a multimeter. Build the measurement circuit shown in Figure 3.

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Complete the voltage arrows and measure U, U_1 and U_2.

U	**U_1**	**U_2**

What is the loop equation here?

Verify the formula using the measured values:

The resistors R_1 and R_2 connected in series form a voltage divider. In what ratio are the voltages U_1 and U_2?

$U_1 / U_2 =$

$=$

Kirchhoff's current law (node law)

At every branch point, the sum of all currents flowing into and out of the node is zero.

Set the voltage on the bench power supply to $12 ~{\rm V}$ and measure the voltage accurately with a multimeter. As a first step, build the measurement circuit shown in Figure 4.

Draw the arrows for the directions of currents I_1 and I_2 in Figure 4. On both multimeters the DC current range and the polarity must be set before switching on. Then measure currents I_1 and I_2 and enter the measured values in Table 5.

In what ratio are currents I_1 and I_2?

$I_1 / I_2 =$

$=$

Switch the bench power supply on again and measure the current I. Enter its value in Table 5.

I	I_1	I_2

Determine the node equation for node K and verify its validity.

Using the measured values of resistors R_1, R_2 and R_3, calculate the total resistance $R_{\rm KP}$.

Using the calculated value of $R_{\rm KP}$, verify the measured value of the total current:

$I = \frac{U}{R_{\rm KP}} =$

$=$

Voltage divider as a voltage source (a)

The voltage divider shown in Figure 6 is initially in the unloaded condition, because the entire current supplied by the bench power supply flows through the series-connected resistors R_1 and R_2. A resistor connected in parallel with R_2 loads the voltage divider.

Set the voltage on the bench power supply to $12 ~{\rm V}$ and measure the exact voltage with a multimeter. Build the measurement circuit shown in Figure 6.

For the connected load $R_{\rm L} = 10 ~{\rm k}\Omega$, the voltage divider represents a voltage source. Like any voltage source, it has a source voltage (open-circuit voltage) U_0 and an internal resistance $R_{\rm i}$. The internal resistance of the voltage divider, regarded as a voltage source, results from the parallel connection of divider resistors R_1 and R_2:

$R_{\rm i} = R_1 \parallel R_2 = \frac{R_1 \cdot R_2}{R_1 + R_2}$

Using the measured values of resistors R_1 and R_2, calculate the internal resistance of the voltage source and determine the source voltage:

$R_{\rm i} =$

$U_0 =$

The power supplied by the bench power supply P_0 can be calculated using the following equation:

$P_0 = U \cdot I_1$

The power consumed by the load resistor can be determined using the following equation:

$P_{\rm L} = R_{\rm L} \cdot I_2^2$

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Voltage divider as a voltage source (b)

Draw the equivalent voltage source of the voltage divider:

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What value would U_2 have without $R_{\rm L}$? $U_{2,0} =$

Calculate $U_{2{\rm L}}$ and I_2 for $R_{\rm L} = 10 ~{\rm k}\Omega$ using the values of the equivalent voltage source. State the formulae used.

$U_{2{\rm L}}:$

$I_2:$

Verify the values by measurement:

$U_{2{\rm L},meas}:$

$I_{2,{\rm meas}}:$

Verify the values using Kirchhoff's laws. State the formulae used.

$U_{2{\rm L}}:$

$I_2:$

Non-linear resistors

All resistors investigated so far are linear resistors, for which the characteristic $I = f(U)$ is a straight line. See Figure 7. The resistance value of a linear resistor is independent of the current I flowing through it or of the applied voltage U.

For non-linear resistors there is no proportionality between current and voltage. The characteristic of such a resistor is shown in Figure 8. For these resistors one speaks of the static resistance R and the dynamic (or differential) resistance r.

The static resistance is determined for a particular operating point: at a given voltage, the current is read from the resistance characteristic. The calculation is carried out according to Ohm's law:

$R = \frac{U}{I}$

The differential resistance around the operating point is calculated from the current difference caused by a change in the applied voltage:

$r = \frac{\Delta U}{\Delta I}$

As an example of a non-linear resistor, an incandescent lamp is investigated. Build the measurement circuit shown in Figure 9.

Set the bench power supply to the voltage values from Table 7. Measure the corresponding current values and enter them in Table 7.

$U / {\rm V}$	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**
$I / {\rm mA}$									

Plot the characteristic $I = f(U)$.

Calculate the static resistance R at the operating point $U = 7.0 ~{\rm V}$.

Calculate the dynamic resistance r at the operating point $U = 7.0 ~{\rm V}$.

Compare the values with those from Section 1.2 (direct resistance measurement).