Laboratory 3

Building and measuring circuits on the breadboard

rev 1.3

Purpose: Experiments on circuits built on a breadboard. Measurement of resistive dividers using the ohmmeter and the oscilloscope.

Summary of theory

1. Reading and measurement of resistors

The values of resistances are either written on the resistor or we can use the color code (fig. 1).

culoarea	banda 1	banda 2	banda 3	banda 4	banda 5
Negru	0	0	0	x 1	
Maro	1	1	1	x 10	1%
Rosu	2	2	2	x 100	2%
Portocaliu	3	3	3	x 1,000	
Galben	4	4	4	x 10,000	
Verde	5	5	5	x 100,000	0.50%
Albastru	6	6	6	x 10^6	0.25%
Violet	7	7	7	x 10^7	0.10%
Gri	8	8	8	x 10^8	0.05%
Alb	9	9	9	x 10^9	
Auriu				x 0.1	5%
Argintiu				x 0.01	10%

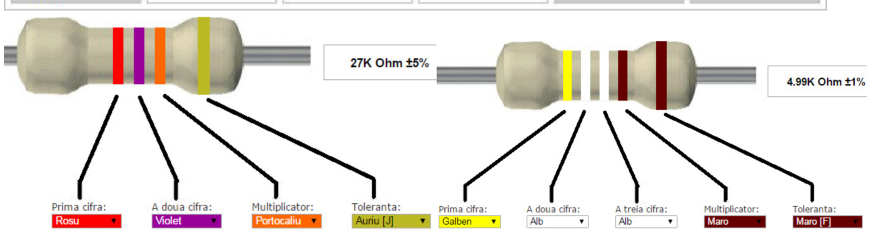


Figure 1: Color code for resistors; examples with 4 and 5 colored bands

The number of bands is variable, depending on how many significant digits are marked (2 or 3):

- the resistance is written as MN•10^K or MNP•10^K, hence resulting 3 or 4 bands for the value + one for the multiplier
- the tolerance is thus the 4th or the 5th band; if it is missing (3 bands in total), the tolerance is considered +/-20%.

At which end do we start reading?

- Usually there is a larger space between the value+multiplier digits and the tolerance digit
- Usually, the first digit is the band that is closest to an end
- The most common values for tolerance (gold and silver, 5% and 10%) are represented by colors that cannot be the first digit (there is no value for gold and silver)

2. Breadboard description

The *solderless breadboard* or *protoboard* (fig. 2) allows interconnecting electrical components without soldering. It contains a matrix of holes into which wires and the leads of components can be inserted. *Vertical* 5-hole groups are interconnected inside the board with spring clips. These clips are often called *tie points* or *contact points*. The entire area of 5-hole groups is called a *terminal strip*. There are also 2 *horizontal* 25-hole rows, on the sides, that are interconnected. These are called *bus strips*. A detail of this is given in figure 2, where the board is partially transparent (the straight lines represent the clips and conduct electricity).

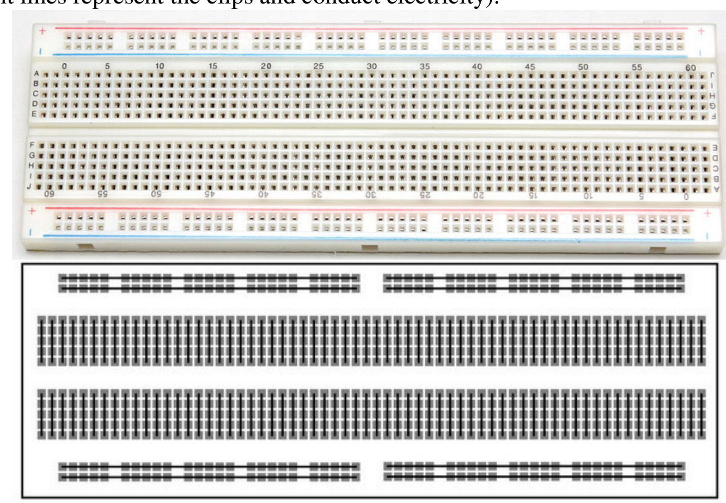


Figure 2: Breadboard (up) and its internal connections (below)

In figure 3 we can see the metallic clips which ensure the contacts.

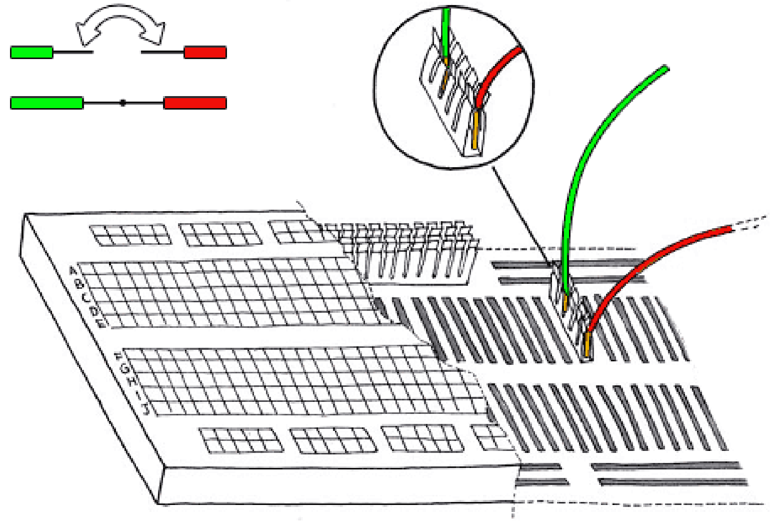


Figure 3: Breadboard:internal contacts
By connecting them in the same group of 5 connection points, the 2 wires are electrically connected

Notice how, in the center of the board, a groove runs parallel to the long side. This groove (between rows "E" and "F" on fig. 3) separates the 5-holes groups.

Fig. 4 shows two examples of how to construct simple circuits: 3 series resistances and 3 parallel resistances. Notice how the groove in the middle of the board acts as a separator, with the 5-hole groups from above and below not being connected *among* themselves – otherwise, for the parallel circuit, the resistances would have been short-circuited.

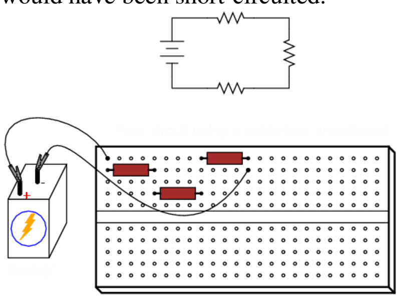


Figure 4a: series circuit

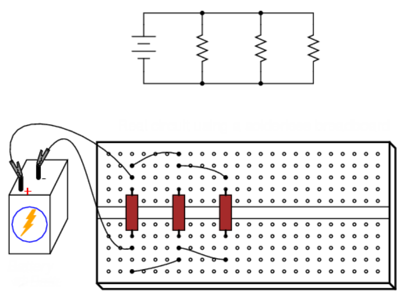


Figure 4b: parallel circuit

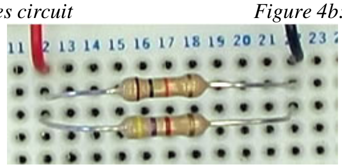


Figure 5 : another example of connecting 2 resistors in parallel – photo

Remark: never place both terminals of a component in 2 connection points from the *same* group of 5 holes, which would mean to short-circuit the component! *(see figure 6)*

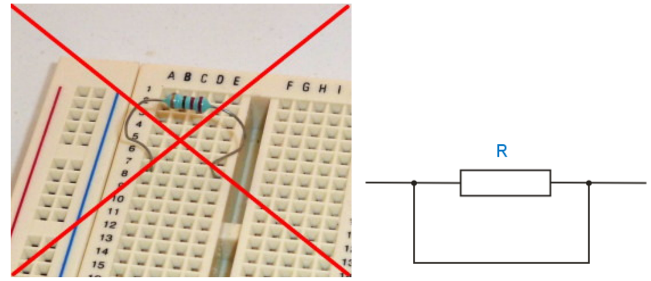


Figure 6: wrongly connected component, in short-circuit, and the equivalent schematic

Measurements

1. Reading the color code and measuring resistors

Read the *nominal* values (marked on the resistor) of the resistors specified on the blackboard (R_1, R_2), by using the color code or the written value, depending on which one is available. Read also the tolerance. Determine, by using the ohmmeter from the digital multimeter (Key Ω – see annex C) the *measured* value of these resistances (R_{1m}, R_{2m}).

Indication: if there are more than 1 resistor of the same value, choose and measure only one of them.

Compute the tolerance of the resistors, which is the absolute value of the relative error, expressed in percentage:

$$\varepsilon = \frac{|R_m - R|}{R} \cdot 100 \ [\%]$$

Verify whether the obtained value is smaller or equal to the one specified on the resistor; if not, then the measurement is probably wrong. Do not touch the terminals/the metallic part of the alligator clips during the measurement!

2. Study of connections on the breadboard

To get acquainted with the breadboard, do the following:

- connect the 2 alligator clips of the digital multimeter to 2 terminals of the breadboard, as seen in figure 7. Place the multimeter in mode "continuity" (using key **15** – Annex C). The 2 wires already connected to screws at one end are used for the following tests:

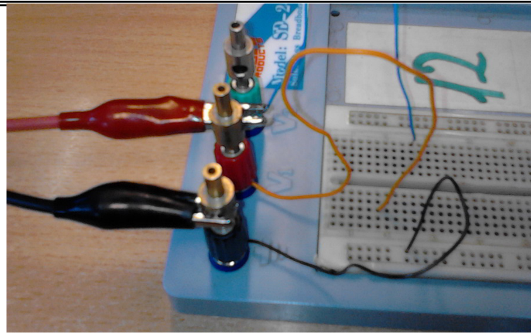


Figure 7: connecting the alligator clips to the breadboard

- touch the 2 wires together. The built-in buzzer of the multimeter will sound, indicating that the resistance between the test terminals is very small (continuity).

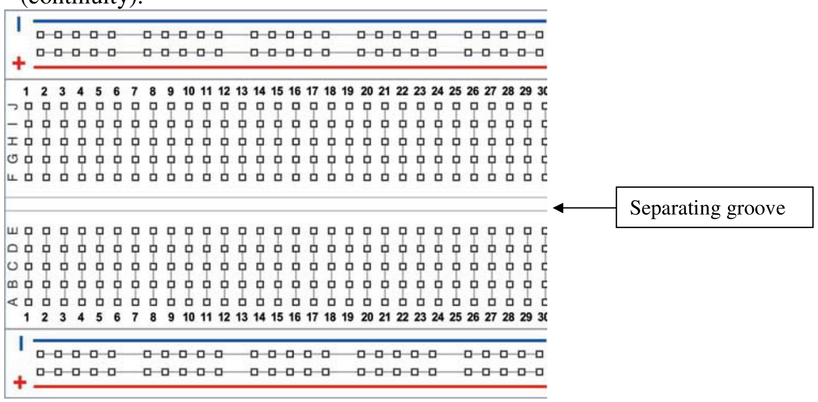


Figure 8: exploring the internal connections of the breadboard (on the drawing, a line that connects holes means a connection on the inside of the breadboard).

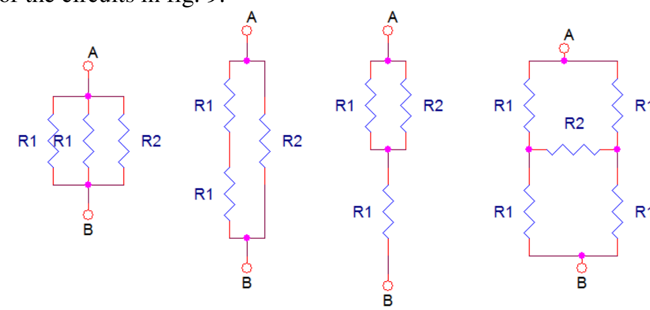
- explore the way in which the holes of the breadboard are interconnected inside the board (verify the correspondence with figure 8): insert the 2 wires in any 2 holes and, using continuity beeper mode, verify if there is a connection or not. Try the following:
    - holes from a group of 5 from the central area of the breadboard, on one side of the notch that splits the breadboard in two, for example A5 and C5 on figure 8 – buzzer must sound;
    - holes from different sides of the notch, for example A5 and F5 – buzzer must not sound;
    - holes that are not part of the same group of 5, for example A5 and B6 – buzzer must not sound;
    - holes from the horizontal bus strips on the top/bottom of the breadboard – buzzer must sound as long as they're in the same half of the board;

    - holes from different halves of the breadboard, from the same horizontal bus strip – buzzer must not sound (obs.: in fig. 7 only a part of the breadboard is shown, up to column 30);
    - holes from 2 different bus strips, from the 2 horizontal strips above and/or the 2 below – buzzer must not sound;

Where (at which column number) are the 2 long top and bottom horizontal rows interrupted? (**Pay attention:** *the interruption is present **only** for long breadboards, for which the length is much larger than the width)*

3. Building given circuits on the breadboard

For each of the circuits in fig. 9:



circuit 1 circuit 2 circuit 3 circuit 4

Figure 9: circuits to be built on the breadboard

- compute the equivalent resistance between points A and B, according to the *nominal* (not the measured) value of the resistances in the circuit. *The nominal values of R_1 and R_2 are written on the blackboard, next to the number of the desk.*
- build the circuit on the breadboard and draw the way it was done on your worksheets (**OBS:** obviously, there is no unique solution); write the values of the resistances next to the resistor symbols!
- measure the resistance between points A and B, using the ohmmeter of the digital multimeter. Keep the alligator clip cables of the multimeter connected to the two screw connectors and connect their respective wires to the holes that correspond to points A and B on the implemented circuit.
Indication: you are not required to compute the relative error, but if the measured value differs from the computed value by more than a few percent, it is more than likely that there is an error, either in your calculations or in the way you built the circuit; find and eliminate the mistake!

4. Designing and building resistive circuits on the breadboard

Design circuits made up of resistor this way:
- for each of the values of R_{AB} from table 1 (*values written on the blackboard*), design a circuit using only resistors of value R_1, R_2 *according to the number of your desk*

(you may choose more than one resistor of a certain value) that has the respective equivalent resistance of R_{AB}; draw the circuit on your worksheet.
- build the circuit on the breadboard and draw it on your worksheet (including the choice of points A and B and the values of the resistors).
- measure the obtained R_{AB} value, to confirm the correctness of your computation and the circuit.

circuit	R_{AB} [KΩ]
1	
2	
3	

Table 1

5. Building and measuring resistive dividers

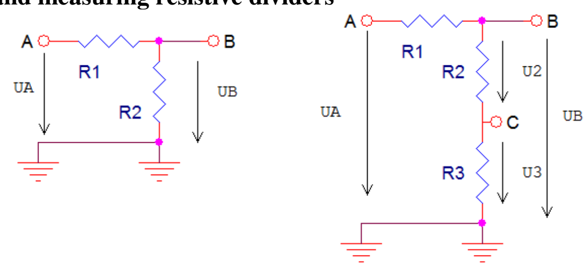


Figure 10a *Figure 10b*
Resistive dividers with 2/3 resistors

The circuits from figure 10 are called *resistive dividers* (or, more general, *voltage dividers*) since they allow the division of voltages by using resistors. The arrows show that both voltages U_A, U_B are measured against the same ground terminal ( ).
In figure 10a, if we denote $U_{1,2}$ respectively as the voltages across $R_{1,2}$:

$$\frac{U_B}{U_A} = \frac{U_2}{U_1 + U_2} = \frac{R_2}{R_1 + R_2}$$

Therefore, the voltage (or division) ratio can be determined, either by measuring the resistances, either by measuring the voltages.

OBS: A circuit with 2 input terminals and 2 output terminals is, generally, called a *two-port network*. For any two-port network, the ratio U_B/U_A (output/input) is, generally, called a *transfer function*.

a) measuring the divider in fig. 10a
- compute the division ratio $R_2/(R_1+R_2)$ based on the values of R_1, R_2 (*according to the number of your desk* – same as before).
- build the divider in fig. 10a on the breadboard; it is recommended to connect the points A and B, by using wires, to the screw connectors **V1**, **V2** and ground on the breadboard (fig. 7); the ground is common for input and output:

- connect the black alligator clips from both devices to the ground (black) screw connector. Do not forget to connect the wire from this connector to the ground point in your circuit!
- Connect the red alligator clip from the generator to **V1** and from then on to point A from the circuit
- Connect the red alligator clip from the oscilloscope to **V2**; *by moving the wire* connected to **V2** alternatively from points A to B you can view on the oscilloscope the input and output voltage, respectively.

Set the generator for a sine wave, f=1KHz, input (peak) amplitude U_A= 4V, no offset. Set the oscilloscope for a C_y s.t. the image occupied the entire vertical screen, and C_x to have 5 signal cycles on the screen.

- measure and compute the ratio U_B / U_A and compare it with $R_2/(R_1+R_2)$.

b) measuring the divider in fig. 10b
For the circuit in Fig. 10b we want to measure the ratio:

$$\frac{U_2}{U_A} = \frac{U_2}{U_1 + U_2 + U_3} = \frac{R_2}{R_1 + R_2 + R_3}$$

The computation and the principle are the same, but voltage U_2 ***is not referenced to the ground*** like until now, but it is the voltage difference between any two points (B and C), none of them a ground termination:

$$U_2 = U_B - U_C = U_B - U_3$$

The oscilloscope does not allow the ***direct*** measurement of a voltage, only the voltage between a terminal to which the red alligator clip is connected, and ground; the black alligator clip ***must*** be connected to ground, therefore, any voltage will be referenced to the ground. So, you will not measure directly U_2, but instead U_B and U_C, and perform subtraction (measuring the voltage between any 2 points, none of them ground, is also called *differential measurement*).

OBS: *this is necessary for any device that has BNC input jacks (the jack that you have at the oscilloscope and generator), since the metallic outer terminal of these jacks is already internally connected to the device ground. The devices that have a differential input, do not use this type of jack– see e.g. the digital voltmeter on your desk!*

Proceed as follows:
- compute the ratio $R_2/(R_1+R_2+R_3)$ based on the available resistance values; for R_3 choose the same value as R_2;
- build the circuit on the breadboard;
- connect the generator as until now, between point A and ground, (same setting for amplitude, frequency and C_y);
- connect the two oscilloscope channels CH1 and CH2 to points B and C, respectively (black alligator clips are connected to ground, along with the generator).
- make the two vertical coefficients equal: $C_{y2} = C_{y1}$; set the display of the difference signal CH1-CH2 = U_B-U_C = U_2 on the oscilloscope using **MATH MENU→ Operation "-"**

You may have to adjust the vertical position of CH1, CH2 to view the entire image (certain parts of the image do not „fall out of view”). For a better read, you may „turn off” the image of CH1 and CH2, by repeatedly pressing buttons CH1, CH2, s.t. only MATH is displayed. If the image becomes unsynchronized, press **SET TO 50%.** The difference signal is displayed with a small arrow marked **M** (Math) next to its ground level (to the left), for identification. Measure the amplitude of this signal.

- compute the ratio U_2 / U_A and compare it with $R_2/(R_1+R_2+R_3)$.
- stop the **MATH MENU** display

6. Measurement of the input resistence of the oscilloscope – application of the resistive voltage divider

Oscilloscopes do not have infinite input impedances, but high valued equivalent input resistences R_i. In order to measure R_i, one uses a resistive divider as in Fig. 11:

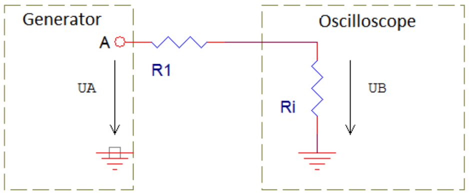


Fig. 11: Measurement of R_i using a resistive divider.

On Fig. 11, R_1 is the ***high valued*** (greater than 400KΩ) resistor available at the table. Resistence R_i is *equivalent*, it exists „inside” the oscilloscope, it is no physical resistor. Due to the U_A voltage from the generator dividing on R_1 and R_i, the signal on the oscilloscope will be:

$$\frac{U_B}{U_A}=\frac{R_i}{R_i+R_1} \Rightarrow \quad U_B=U_A\frac{R_i}{R_i+R_1}$$

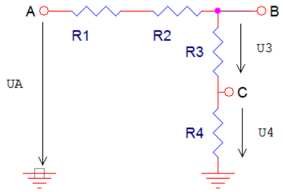
To measure follow the steps:

- use the ohmeter inside the digital multimeter to measure the resistance R_1;
- connect the generator and CH1 of the oscilloscope to the breadboard (terminals **V1** and **V2**), in parallel (without R_1 connected) and set the amplitudinea U_A from the generator at 4V; set C_y such that the image occupiesd the entire vertical area of the display. Stop the displaying of CH2 by sucessively pressing **CH2 Menu**.
- insert R_1 on the breadboard as in Fig. 11 (in series between the generator and the oscilloscope; all the black aligators remain connected at the ground terminal). Now the oscilloscope „sees” the voltage U_B, having a reduced value when compared to U_A because of the effect of the divider.

Remark: the „classical” connexion of the oscilloscope and the generator, without R_1 between them, is equivalent to $R_1=0$. In this case, the division ratio, becomes 1, such that on the oscilloscope you will see the exact voltage from the generator.

- measure U_B , the amplitude on the display of the oscilloscope.
- compute R_i from the formula deduced for the above voltage divider.

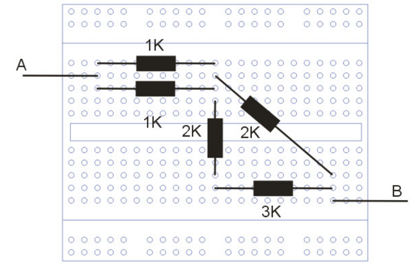
Preparatory questions



1. For the voltage divider in the figure, R_1=1K, R_2=2K, R_3=3K, R_4=4K. Compute the ratio: a) U_3/U_A; b) U_3/U_4.

2. Define the nominal value of a resistor.

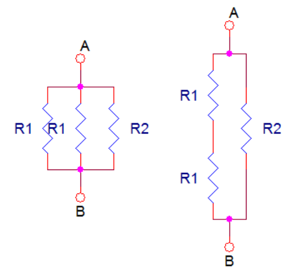
3. Explain what does a differential measurement mean and give an example for its utility.



4. Knowing the value (in KΩ) for the resistors in the circuit in the figure, built on a breadboard, compute the equivalent resistance between A and B.

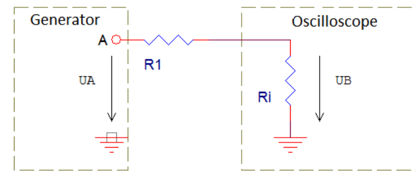
5. Connecting the terminals of a resistor R at 2 holes of *the same* vertical group of 5 holes of a breadboard, which is the value of the measured resistance, using an ohmmeter?

6. Which is the type of measurement *not allowed* by a meter using BNC input terminals?



7. The voltage between A and B on the figure is U_{AB}=10V. Which is the value for the voltage drop on R_1 in the two cases?

8. Define the tolerance of a resistance (formula). How is it marked on the resistor?

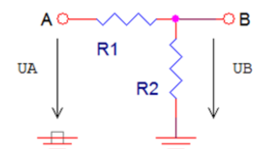


9. On a voltage divider used to determine the oscilloscope’s input resistance: a) using R_1=1MΩ, the amplitude measured on the screen is half of the amplitude from the generator. Compute R_i. b) using $R_1=R_i/5$, the amplitude from the generator is 10V. Determine the amplitude displayed on the scope.

10. Explain what would happen if the oscilloscope’s input resistance would be infinite; which would be the value of the ratio between the value measured on the display of the oscilloscope and the one from the generator?

11. With resistors R_1=5KΩ and R_2=2KΩ (as many as you whish), design and draw the schematic with equivalent resistance: a) R_{AB}=4.5 KΩ; b) R_{AB}=11 KΩ. Draw the connections necesary on a breadboard.

12. Define the transfer function of a two-port circuit. Determine the transfer function for the two-port in the figure



13. Compute the equivalent resistance (AB, CD respectively) of the circuits in the figure. *Hint: $R_{AB}=\infty$, $R_{CD}=0$*