General Engineering Studies laboratory

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I. The measurement panel

In this and many later subjects the students have to build electric circuits on measurement panels that contain a “breadboard” and banana plug sockets. The breadboard can be used to easily and quickly build test circuits using through-hole mounted components and simple wires (max. 0.5mm diameter solid copper), without the need to solder. The circuit is connected by wires to the banana plug sockets, from where banana plug wires are used to connect to the power supplies, multimeters etc.

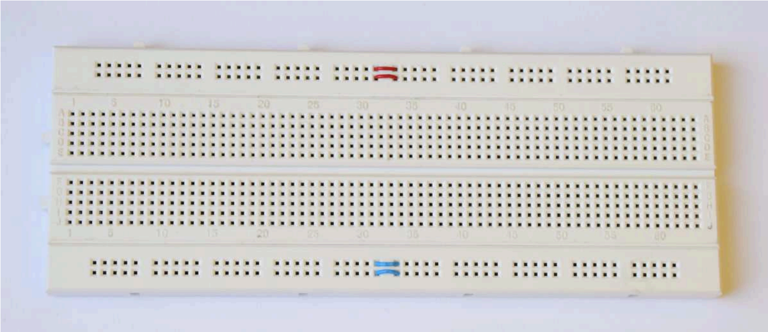


Figure 1. The so-called breadboard

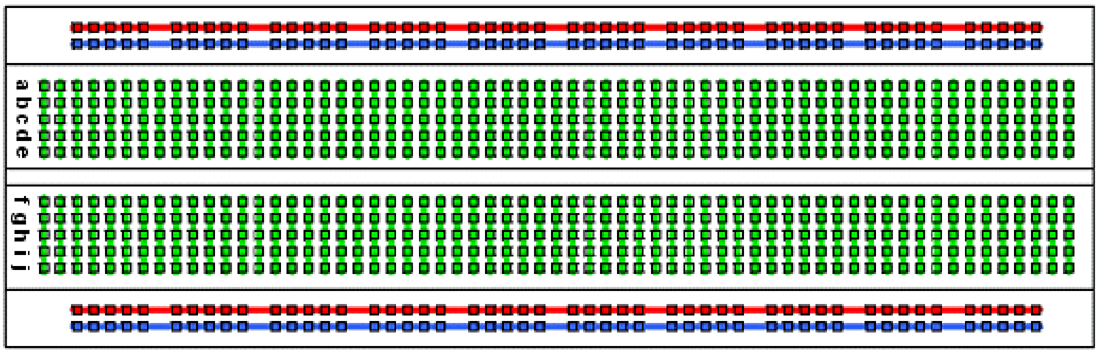


Figure 2. Internal connections of the breadboard

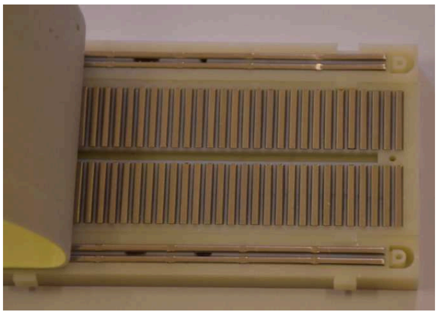


Figure 3. Internal connections of the breadboard as seen from the bottom

The breadboard used in the laboratory has the following structure:

There are two lines along both longer edges, in the figure denoted by red and blue colors (some breadboard versions have these colors on them, the currently used type in pure white, but functions the same). The 50 points along a colored line are electrically connected. The four such lines are independent. These can be useful for the voltage supply connections in cases when more than one point in the circuit needs to connect to the same potential (in some measurements for example you need plus and minus voltages plus zero, so three of the four lines can be used for these).

The inner part has 2x64 lines of 5 points each. The 5 points of a line (denoted by green on the figure, not shown on the real board) are connected electrically (these are named a..e and f..j). To use integrated circuits (IC) place them across the central division such that half of the pins are on the a..e side and the other half is on the f..j side.

The breadboard has been placed on an aluminium board that provides banana and BNC connectors for easier interfacing with instruments.

Figure 4. The measuring panel

The banana sockets are connected to small sockets, also known as female pin headers (in the photo, under the banana socket) where the small copper wires can be plugged. These wires can then be connected to the breadboard.

On the right side are three BNC connectors. These are bayonet connectors used for coaxial cables (we use RG58 cables). The coaxial cable consists of a center wire, an insulation around it, a metal mesh or foil around that (called the shielding) and finally another insulation. These are used mostly for AC purposes or when shielding from electromagnetic interference is necessary. The shield of the cable is connected to the outer cylinder of the connector, which is usually grounded on instruments. Here it is connected to the metal panel and also to the rightmost banana connector (the one which doesn't have a red or black insulator ring). Therefore when using coaxial cables, connect the rightmost banan socket to the ground or the reference zero of the power supply. The center wire of coaxial cables is connected to the pin header under the BNC connector.

II. The instruments at the electronics laboratory

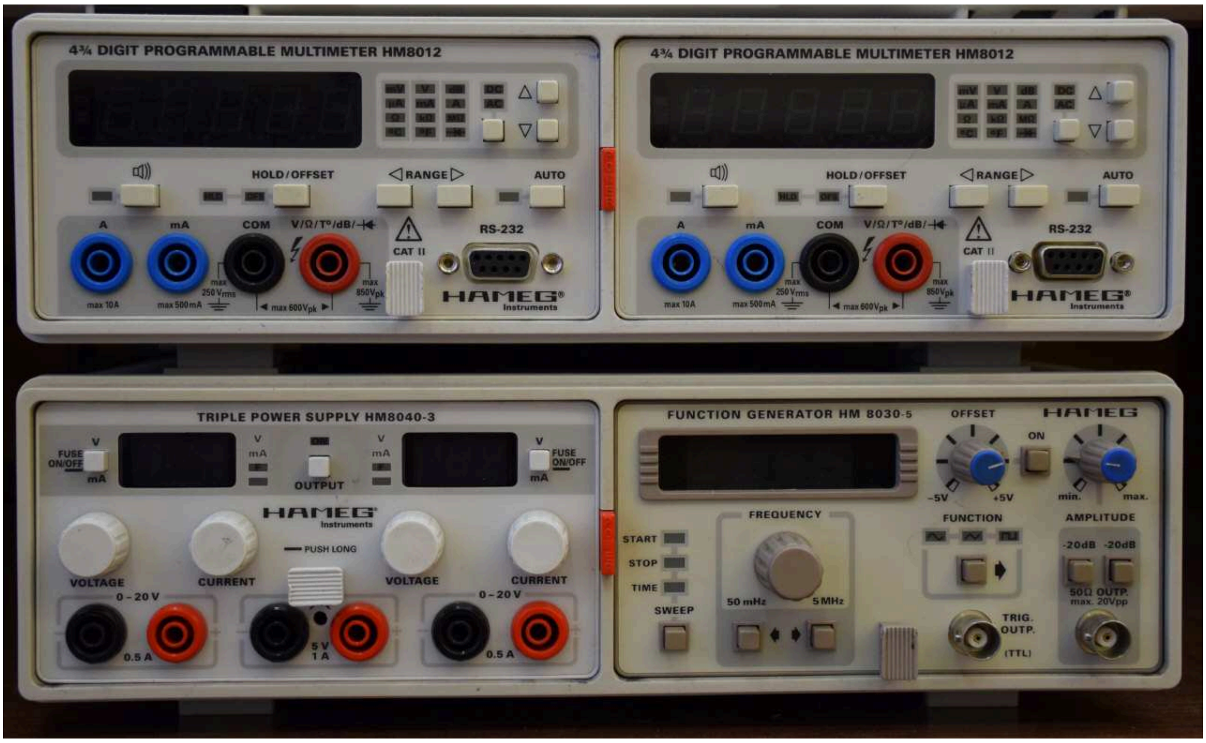


Figure 5.: The electrical instruments at the lab TA105, without the oscilloscopes

The HM8040-3 triple power supply

A power supply unit (PSU) is one of the most important instruments for laboratory work. It supplies the operational voltages and currents to the measured circuits. We are using the HM8040-3 type triple power supply. Its operation is similar to other types of power supplies.

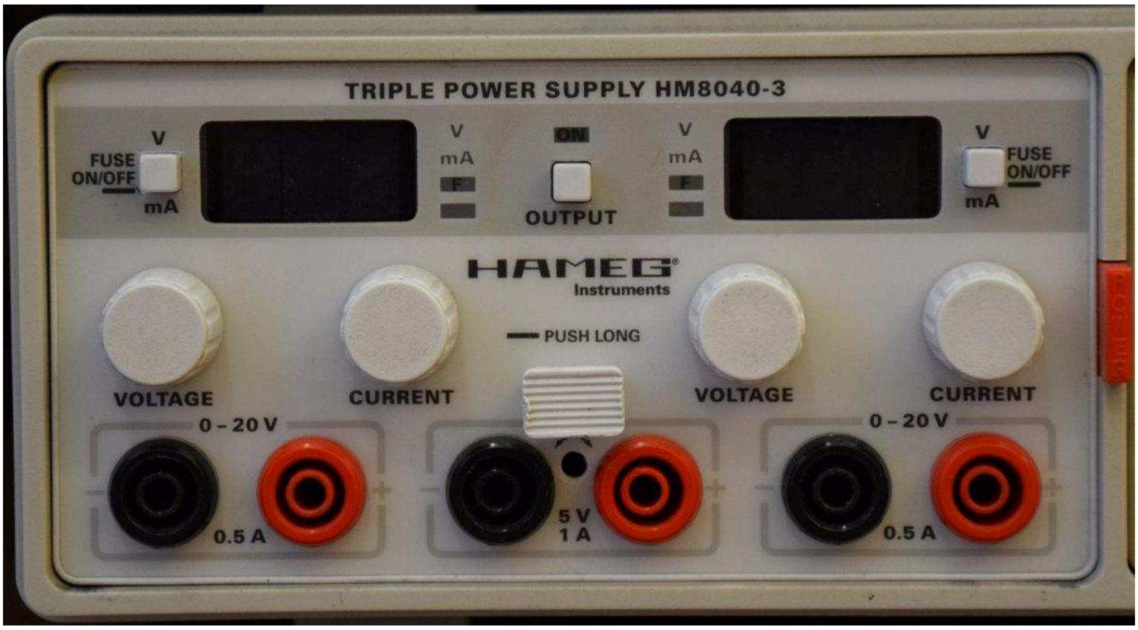


Figure 6. The Hameg HM8040-3 power supply unit

The triple power supply has one fix voltage output and two controllable. The middle output is constant 5V with a current limit of 1A. This can be useful for digital circuits (which often need 5V), however be careful that the current limit is very large, thus if there is some wrong connection, your circuit elements can be damaged even though the power supply will be saved by the limit. In our laboratory measurements the middle output is not needed and not advised to be used.

The other two outputs are identical in operation. The voltages can be set continuosly between 0...20V with 0.1V displayed precision using the “VOLTAGE” knob. The current limits can be set up between 0...500mA using the “CURRENT” knob.

All three outputs are galvanically independent from each other and from the mains. This way it is possible to connect them in series, creating for example a 40V output or creating -20V,0V,+20V double supply.

The display either shows the output voltage or the output current. Switch between these modes using the “V/mA” button. Note that pressing that button for too long turns on the “FUSE” function (an orange LED will show this mode is active). This mode means that upon reaching the current limit the power supply unit will turn off the output.

There is an “OUTPUT” button in the middle. The configured voltage appears on the outputs only when the output is on (signified by a green LED). Whenever you change your circuit, turn off the output using this button, do the changes then turn the output back on.

The laboratory power supply used in this lab are capable of both voltage generator and current generator mode. The current generator mode is also called a current limit mode. The unit will normally behave as a voltage generator, and will change into current generator when the current limit is reached. This is shown in Figure 7.

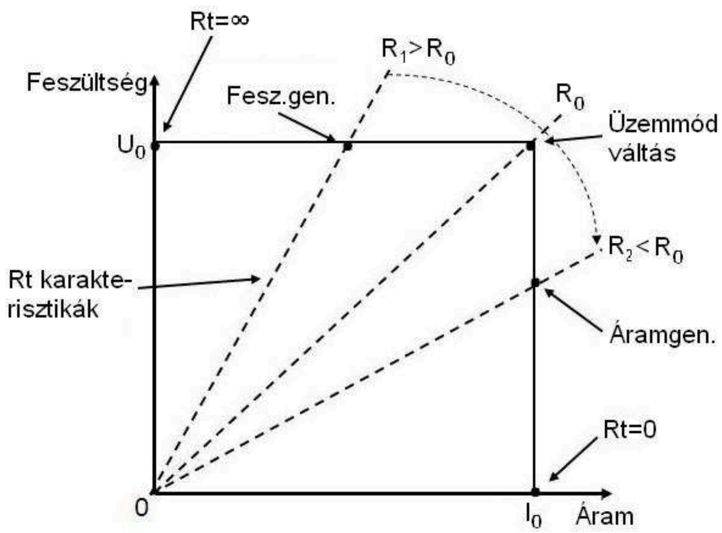


Figure 7. I-V characteristics of a laboratory power supply

In these type of supplies, the voltage (V_{set}) can be set up when the Output is set to Off, however the current limit (I_{set}) can only be set up when the Output is On, and there is current flowing. For this reason, we need to short-circuit the + and – outputs (with a banan plug wire) and change to mA display mode, turn the OUTPUT ON and then we can use the CURRENT knob to set up the current limit.

In figure Figure 7. , in the horizontal section, the output voltage is constant (V_{set}), and the current is dependent on the load. This is called CV (Constant Voltage) mode (or voltage generator). In the vertical section, the output current is constant (I_{set}) and the voltage is dependent on the load. This is called CC (Constant Current) mode (or current generator or current limit). The change between the two modes occurs when the load resistance is $R_L=V_{set}/I_{set}$. If the load is larger resistance than this, then we have CV, if the load is smaller resistance, then we have CC mode.

The current limit enables you to protect your supply unit and your components (such as transistors and ICs) from too large current if you connect something wrong. For all measurements in this laboratory, you will be required to set up a current limit before starting the measurements. This will usually be around 20...30mA (this is usually small enough not to damage any component you will be using).

The HM8012 digital multimeter (DMM)

The other very important instrument for electrical engineers is the multimeter. Today we mostly use digital ones, but analogue instruments still have some uses and advantages. Multimeters are instruments which usually measure voltage, current, resistance and optionally some other quantities (diode forward voltage, temperature, etc.)

Figure 8. Hameg HM8012 digital multimeter

Many general purpose multimeters (and as such, the HM8012) have four input connectors: a common ("COM", black), two current inputs (A and mA, blue) and a voltage/resistance/diode (red). In all measurements, one of the measuring cables has to be connected to the common input. Multimeters are usually also galvanically independent, therefore you can measure voltages between any two points as long as the maximum allowed input voltage is not exceeded. The maximum voltages/currents are indicated on the front panel of the instruments.

The "HOLD" button is used to keep the last measured value on the display. (So if you see no change when you should, check this mode.) A 3x4 LED matrix to the right of the display shows which quantity we are currently measuring. The arrow buttons on the right are used to select between these modes. Left of these, two buttons can be used to change between AC and DC measurements. In DC (Direct Current) mode only the DC component of the input signal is measured. In AC (Alternating Current) mode only the AC component is measured (the DC part is removed, similary as in an oscilloscope in AC setting). This multimeter measures true RMS (effective value) of the voltage. If both AC and DC are turned on, then the true RMS of the total, unchanged signal is measured. Please note that there is an upper frequency limit of AC measurements.

The “RANGE” buttons are used to set the measurement range (that is, the interval in which we can measure). In a lower range (indicated by smaller L number) the precision is increased and the maximum measurable value is decreased. Also the internal resistance of the unit can be different in different ranges. The “AUTO” button enables automatic range control (that is, the instrument will try to select the best range). This has its advantages and disadvantages and for latter reason it is generally not allowed to be used in these measurement sessions.

In case we set up a range in which the maximum measurable value is smaller than the input, an “OFL” (overflow) text will be displayed. In this case, increase the range.

An important attribute of multimeters is the internal resistance (in voltage and current modes). A general voltage meter has az internal resistance (input resistance) of 10..12MΩ. (The HM8012 has 10MΩ in most ranges and 1GΩ in L1 and L2 ranges.) This resistance can be approximated as infinite for most usual purposes (unless the measured circuit is composed of resistors of similar values). The current meter should ideally have 0 internal resistance. We usually also suppose it’s true. Know however, that the smaller ranges (bigger precision) have bigger internal resistances, which can result in increased error in some current measurement cases.

There are two common methods for measuring voltage between two given points of a circuit. First, you can simply measure the voltage between the two points, that is, put the two probes of the multimeter to these points (that is, connect the voltmeter in parallel with the two-pole to be measured). Second, you can use the mthod of node potentials, that is, measure the potential of different points (their voltage relative to a common or reference node which will be defined as the zero potential). Then the voltage between any two points will be the difference of their potentials. This method is commonly used as there are often too many nodes to measure voltages between any two of them, it is simpler to note the node potentials and then later the voltages can be easily calculated. The common node is often the negative pole of the power supply or the ground potential if it is available. This type of measurement will be used for example with transistor circuits.

Current measurement is done by connecting the ampermeter in series with the two-pole whose current we want to measure (similarly like we would connect a water flow meter). Take care to connect the proper input of the ampermeter: the "A" if measuring more than 0,5 ampers (and set the measurement range to "A" also); the "mA" if measuring less than 500mA (and set the range to "mA" also). Most measurements in this laboratory will be done in mA setting. (There are fuses in the ampermeter which can blow if not using the proper setting.)

The third function of the multimeter is resistance measurement. We have to take care to only measure the needed resistance - that is, make sure there are no other elements connected between the two poles of the resistor. Therefore we should remove the resistor from the circuit before measuring it, otherwise the other circuit elements may falsify our reading.
Also if the circuit has turned on power supply connected to it, we may even damage the instrument, because the ohmmeter is itself a current generator). Also make sure not to touch the two poles (ends, legs, pins) of the resistor with your hands, as this means our body resistance (in the magnitude of 100kΩ) will be connected in parallel. Before removing the resistor from the circuit, turn off the output of the connected power supply.

The HM8030-5 Function Generator

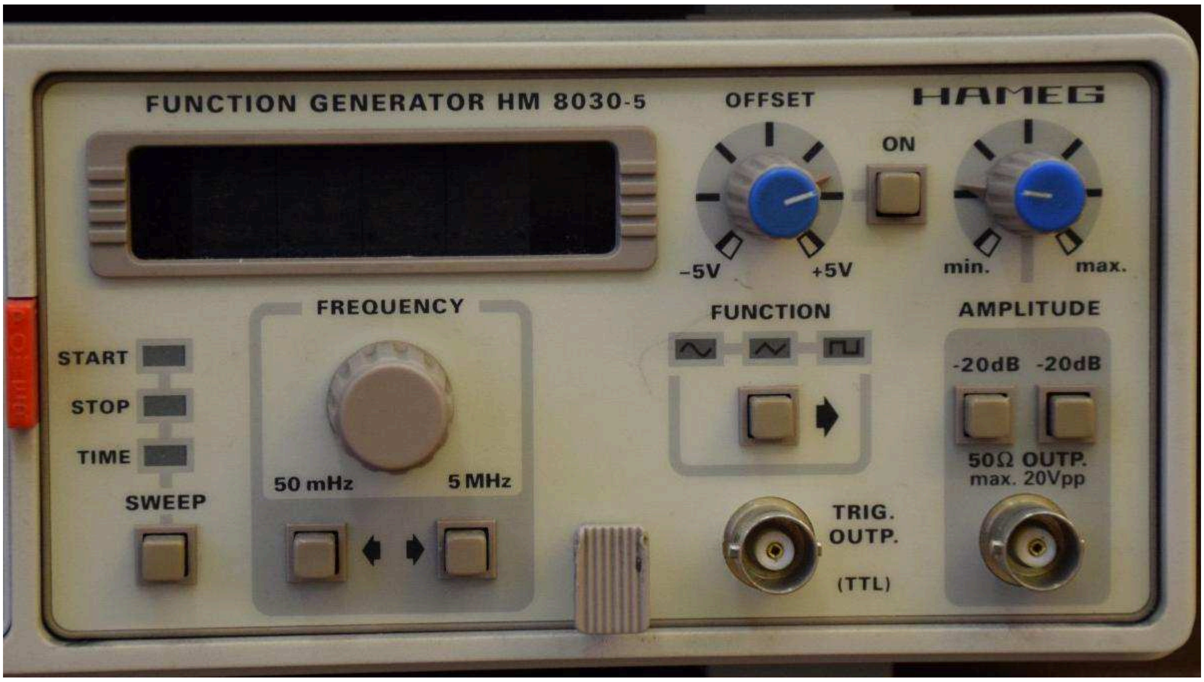


Figure 9. The Hameg HM 8030-5 function generator

The function of the function generator is to supply test signals to our circuits. This can be for example a sinusoidal signal for an audio amplifier or a TTL level square wave for digital circuits, a triangle wave for comparators and control circuits etc. The laboratory includes a HM8030-5 generator at each setup, as seen in Figure 9.

The most important control is the "FREQUENCY". This instrument can output alternating voltage from 50mHz to 5MHz. The left and right arrows under the potmeter change the "decade", that is, the order or magnitude of the frequency (the place of the decimal point). The potmeter provides a continous frequency setting withing the current range. The actual frequency is shown above these controls in a seven segment display. To the right of it three or four LEDs show the actual output waveform: sine, triangle or square (with 50% duty cycle) (for some types a fourth waveform is squarewave with non-50% duty cycle, also called impulse). The mode can be changed by the button under the LEDs. When none of the LEDs is on, there will be no output signal.

The controls on the left side are used for the SWEEP mode. This provides an output that changes its frequency in time. We are not going to use these in this laboratory course.

The rightmost potmeter ("AMPLITUDE") changes the amplitude (voltage) of the output signal. It can be rotated about 270° between the "MIN" and "MAX" values. The two buttons under ("-20dB") it can each divide the output voltage by ten (so when pressed together, they divide by hundred). (-20 decibels mean divide by ten, -40dB means divide by hundred, -60dB means divide by thousand and so on.) The maximum output voltage is about 20Vpp (peak-to-peak), the minimum is around a few mV. (As you can see the function generator doesn't display the actual output voltage - you have to measure it yourself using an oscilloscope or AC voltmeter).

To the left of the amplitude knob is the "OFFSET" control, together with an "ON" button to enable this option. The offset option, when turned on, adds a DC component to the output signal (shifts it in DC) which can be changed between -5V and +5V.

The function generator doesn't have an output on button, therefore to output signal is alway present at the output connector (except when none of the waveform LEDs are on, as mentioned). There are actually two outputs. One (the BNC connector on the right) is the normal (analogue) output, with the frequency, amplitude and waveform that we have set up. The connector to the left of it is called "TRIG. OUTP." or "TTL". It provides a TTL level (0-5V) 50% duty cycle square wave with the actual frequency. (Therefore it is independent of the amplitude and offset and waveform controls.) In digital technics, TTL levels mean that logical 0 is 0 volts, logical 1 is +5 volts.

III. Measurement exercises

1. Measuring the characteristics of the power suppy

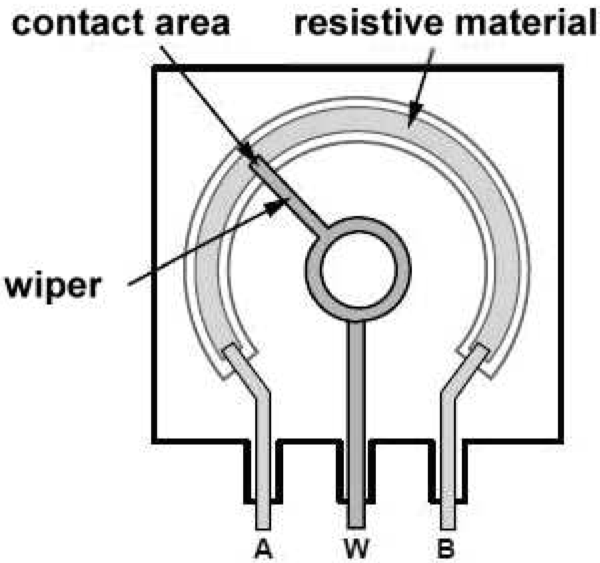


Figure 10. structure of a potentiometer

For this measurement we need the power supply, a multimeter and a potentiometer.

The *potentiometer* is a variable resistor with three poles: two are the ends, between which the resistance if constant. The third is the wiper, which is connected to a sliding or rotating contact. Thus the resistance between an end and the wiper is adjustable. The wiper with the two ends forms an adjustable voltage divider. If only one end and the wiper is used, then we get a simple variable resistor, the resistance of which can in principle be continously changed from 0 to the nominal value.

In this measurement we only use one end and the wiper, thus using it as a variable resistor (only these two connections will be found on the provided device).

The potentiometer (in short: potmeter) provided for this session has a value $R=470\Omega\pm20\%$. Thus the nominal maximal value of its resistance is 470 Ω and it can differ from it by about 20% max, due to manufacturing variations. The minimal resistance value should be very close to zero. (It's useful to check both extreme values before using the potmeter.)

1.1 First measure the maximum resistance of the potmeter. Turn the multimeter to resistance measurement mode and connect the two ends to the COM (black) and V/Ω (red) inputs, turn the wiper to maximum setting and measure the resistance in the maximum precision possible. Calculate the difference from the nominal value in absoute and relative terms.

1.2 Choose one of the variable output pairs of the power supply (left or right) and set its voltage to $\underline{V_0=15V}$. Connect the + and – outputs with a measuring cable (create a short circuit). Enable the power supply's output. A red LED will signal that the current limit is in effect. Change the display mode from V to mA for the actually used output and set up the current limit to be I_0=70mA. After this, we can disconnect the short circuit. (For each later laboratory sessions, you will have to setup a current limit in a similar way.)

1.3 Connect the potentiometer to the previously used output of the power supply. Enable the output. Start decreasing the potentiometer's resistance until the current limit (red) LED just turns on, stop at this point and write down the voltage and current from the power supply's display. Disable the power output; disconnect the potmeter and connect it to the multimeter and measure the precise resistance. This resistance will be the R_0 value known from the power supply characteristisc (see the instrument guide!). Compare the value with calculation (using the V_0 and I_0 values).

1.4 Now set approximately 350Ω resistance on the potmeter (measure and note the precise value) and connect the potmeter to the power supply again. Enable power and write down the voltage and current values. As this R value is greater than R_0, the power supply will be in voltage generator mode.

1.5 Now setup about 150Ω value. This is smaller than R_0 and thus the power supply will be in current generator mode.

In the lab report, draw the characteristics (see also Figure 7) of the power supply using the measured values and draw the operating line of the three load resistance values used.

2. Simple measurements with resistors

In the previous measurement, we have used the power supply's display for voltage and current. It is not very accurate (not being intended for measurements) and so from now on, we are only using it for approximate settings. In many exercises, the voltage of the power supply does not necessarily have to be equal to the prescribed value, as long as we measure it using a voltmeter and note it, then use this value for the required calculations. This can be done because we are learning about linear circuits, so for example Ohm's law and the voltage divider will work the same way with 11V instead of 12V supply.

From now on, always measure the power supply voltage using a multimeter and write down the value (with higher precision than that of the power supply display, obviously – we recommend 0,001V precision). Use this value for the calculations part of the lab report. Also always measure the resistors used in the circuits and similarly, use these values in your lab report calculations (except where the lab guide tells otherwise).

Measuring the resistors is also important because they don't have labels[1] and you'll have to find them first in your component box. Don't forget that all components have a certain tolerance. For example, the resistors here are, according to the manufacturer, of ±1% tolerance. This means that a 1 kΩ resistor can be expected to have a value between 990 and 1010 ohms.

<u>Set up 50mA current limit on the power supply and keep it for the rest of the measurement!</u>

2.1) Measuring voltages

Voltage is measured between two points, in this case the end-points of a resistor. Therefore the voltmeter is connected parallel to the resistor, without breaking the circuit. Connect the voltmeter with the expected correct polarity (the Hameg digital multimeter will display negative numbers if the polarity is opposite, but some multimeters can not do this, especially analog ones). In simpler circuits generally the point closer to the positive pole of the power supply should be connected to the positive pole (red connector) of the voltmeter.

The voltmeter has a very high internal resistance in all ranges and therefore is is usually a good idea to measure in the highest precision available (we can always round the results afterwards – but hard to do the opposite). However, in the mV ranges the internal resistance is 1GΩ (compared to 10MΩ in others), which means that it can „gather" noise more easily, ie. it will show non-zero voltages even if the cables are not connected to the circuit. For this reason it may be better to stay in L3 range (0.001V precision).

[1] Note.: most through-hole mounted resistors have a colour code, however, this can sometimes be falsely read. It is easy to mistake the brown, red and orange colours on them, which could lead to errors of 10x or more. The direction of reading is also not obvious.

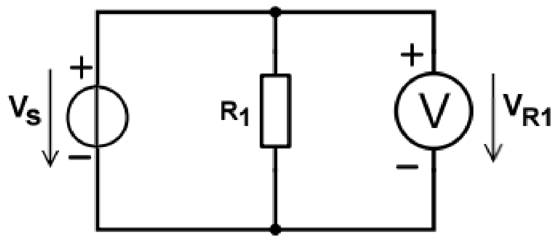


Figure 11. Measuring voltage on a resistor

Measure the voltage across a resistor according to figure Figure 11. V_0=3V, R_1=1kΩ.

2.1.1 Measure V_{R1}. (Remember: the COM is the negative pole of the voltmeter.) Compare it to the voltage seen on the power supply's display.

2.2) Measuring current

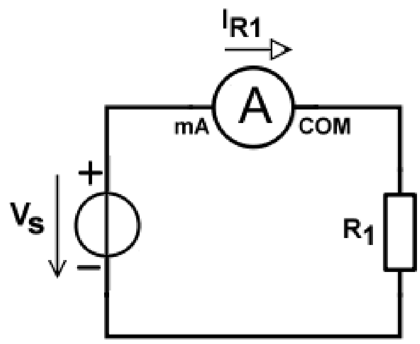


Figure 12. measuring current

Current is measured as flowing across the cross-section of the conductor, so practically in one point. It is required to break to circuit to do this with traditional methods.[2]
In printed circuits this can be problematic. In that case we can often get help from Ohm's law: if we can find a known resistor, across which the current to be measured flows, we can measure its voltage and then calculate current. This is also good for reducing the error from the internal resistance of the multimeter (the voltmeter is closer to the ideal than the ampermeter).

Connect the circuit according the figure Figure 12. The connection from the generator to the ampermeter doesn't need to go the breadboard and back, simply connect them with one banana plug cable. (Later we'll experience that more and longer wires mean more errors.) Remember: the blue „mA" socket is the positive, the COM is the negative pole of the milliampermeter. Don't forget to switch the LED matrix to mA mode as well.

V_0=3V , R_1=1kΩ.

2.2.1 Measure I_{R1} and compare to the current displayed on the power supply.

[2] Current can be measured without breaking the circuit by measuring the magnetic field, however this works best for large currents.

2.3) Combined measurement

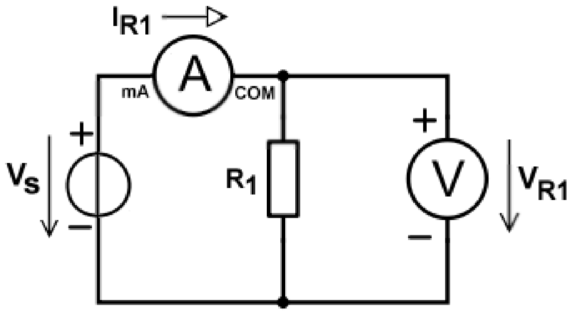


Figure 13. Combined measurement of current and voltage

Measure voltage and current at the same time, as in figure Figure 13. Always connect the generator/ampermeter cables to the breadboard first, and only then the voltmeter. The reason is that this way later (with more complicated circuits) it will be easier to move the voltmeter's connections between points without having to remove the generator.

V_0=3V , R_1=1kΩ.

2.3.1 Measure I_{R1} and V_{R1}. Calculate R_1 from these. Compare this value with the nominal and measured value of R_1. ellenállást. *(Remember: Don't measure resistors inside circuits if possible; and never measure resistors that are under voltage! It could cause damage and false reading (because the ohmmeter is also a current generator).)* Calculate the relative difference of measured and nominal value and compare it to the 1% given by the manufacturer.

2.4) Voltage divider

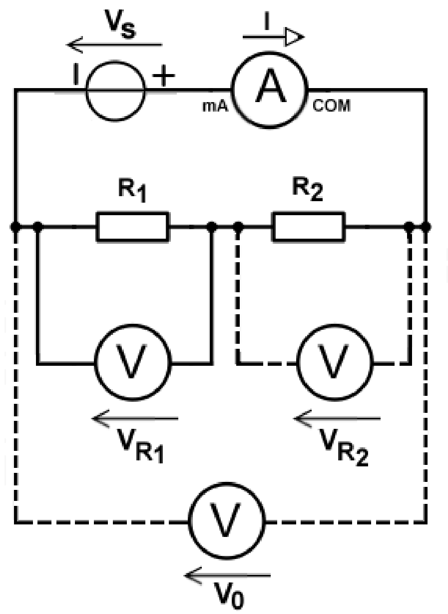


Figure 14. Series resistors as voltage divider

Build the circuit according to figure Figure 14. The mA meter will stay connected throughout this, so we only have one voltmeter to use. Therefore we have to measure the three voltages in three steps. Measure the resistors before building the circuit.

V_0=6V , R_1=1kΩ, R_2=2.2kΩ.

2.4.1 Measure the resistors before building the circuit. Measure V0. Use these to calculate the current and the net resistance. Now measure the current and compare it with the calculated value. Calculate a net resistance from the measured V_0 and I and compare this value to the net resistance calculated from the measured resistor values.

2.4.2 Measure V_{R1} and $V_{R2.}$. Check for $V_{R1}+V_{R2}=V_0$! Also compare the measured voltages to those gained from the voltage divider formula.

2.5) Current divider

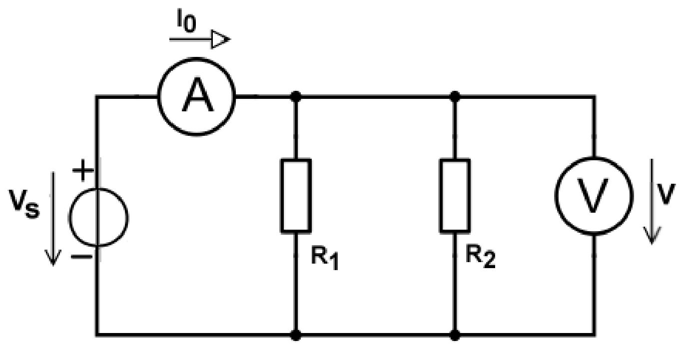


Figure 15.: Measuring voltage and main branch current

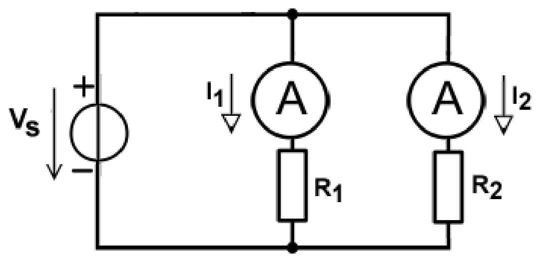


Figure 16.: Measuring branch currents

Build the circuit according to figure Figure 15. U_0=6V , R_1=1kΩ, R_2=2.2kΩ

2.5.1 Measure the voltage and the main current I_0 according to figure Figure 15.

2.5.2 Measure the branch currents (I_1 and I_2) according to figure Figure 16.

2.5.3 Calculate the net resistance from the measured values of the resistors. Find the net resistance from V and I_0, compare this with the previous calculation's results. Calculate I_1 and I_2 from I_0 and the resistor values using the current divider formula. Compare these to the measured values.

3. Resistor networks

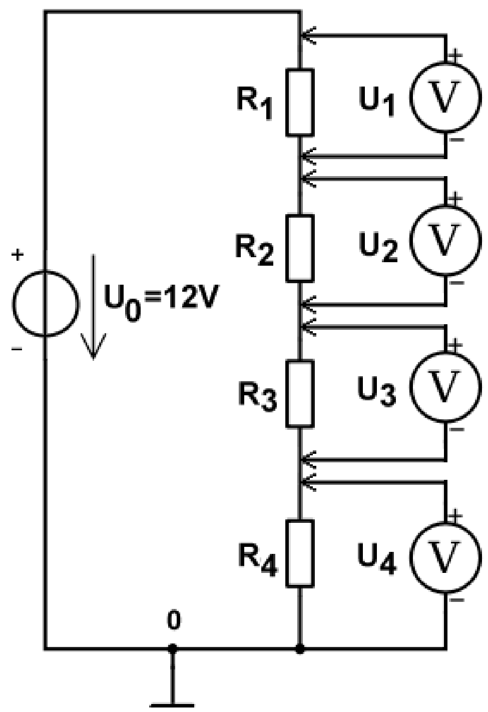
These measurements have homework, to be done in advance. (See left column of tables 3.1.2, 3.1.3 and 3.3.1). You can't start the measurements without having done the homework.

3.1 Series resistor network

In the next exercise a voltage divider made from four resistors is used.

Before creating the circuit, set up 30mA current limit on the power supply. Keep this limit for the rest of the laboratory session!

The **+** and **–** symbols on the schematics indicate the V and COM inputs of the multimeter and make sure the polarities are correct.



Parameters:

V_0 = 12V
R_1 = 2.2kΩ ±1%
R_2 = 1kΩ ±1%
R_3 = 620Ω ±1%
R_4 = 390Ω ±1%

Figure 17. series resistor network measurement 1.

3.1.1 After setting up the current limit, setup 12V output voltage on the power supply. (Measure the supply voltage with multimeter as well and note the value in the second column of the tables in 3.1.2 and 3.1.3.) Measure the precise resistance of the four resistors (before creating the circuit!).

R_1=	**R_2=**	**R_3=**	**R_4=**

3.1.2 Connect the four resistors in series as shown in figure Figure 17. One voltmeter will be enough for this measurement. The points between each neighbouring resistor pair should be connected to one of to the banana sockets on the measuring panel for easy measurement.

	Calculated value (from nominal values)	Calculated values (from 3.1.1)	Measured values
V_0	12V		
V_1			
V_2			
V_3			
V_4			

Fill the first column with calculated voltages using the nominal R values, the second column with calculations using the V_0 and R values measured in 3.1.1. Compare the sum of the four voltages (in each column) to V_0 (first column to nominal, then second and third column to measured value of V_0).

3.1.3 Using the same circuit, now connect the COM input of the voltage meter to the reference point of the circuit indicated by a 0 (the negative pole of the power supply) as in figure Figure 18.

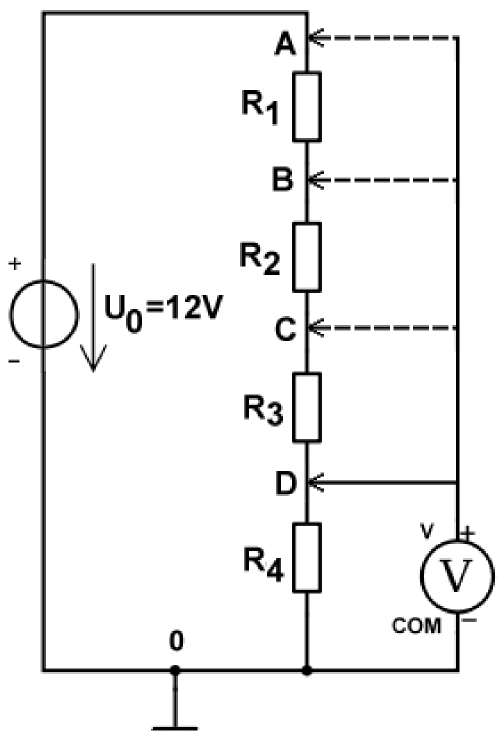


Figure 18. series resistor network measurement 2.

Leaving the COM input in place, use the V input on the four nodes (A to D) to measure four node potentials.

(V_A=V_0)	Calculated value (from nominal values)	Calculated values (from 3.1.1)	Measured values
V_A	12V		
U_B			
U_C			
U_D			

Similarly to the previous exercise, fill the first column using nominal, the second column using measured R values. In the lab report, include all calculations and check the validity of Kirchoff laws (eg. $V_C=V_3+V_4$ etc.).

3.2 Measuring the internal resistance of the milliampermeter

The value of the internal resistance of the milliampermeter is needed for exercise 3.3. As it is not given in the multimeter's manual (though you can find it from the schematics in the service manual) , we are going to measure it.

The milliampermeter actually has a different resistance in each measurement range, we are going to measure all of them. We'll need both multimeters for this. Set up one of them as mA meter, the other as Ω meter. Connect the COM to COM; mA to Ω. On the ohmmeter, try using always the most precise measurement range. Before starting the measurement, connect the two ends of the cables coming from the ohmmeter, thus measuring the resistance of the two cables. Note this value and later subtract it from all measurements. (Alternatively you can use the *offset* option on the ohmmeter.)

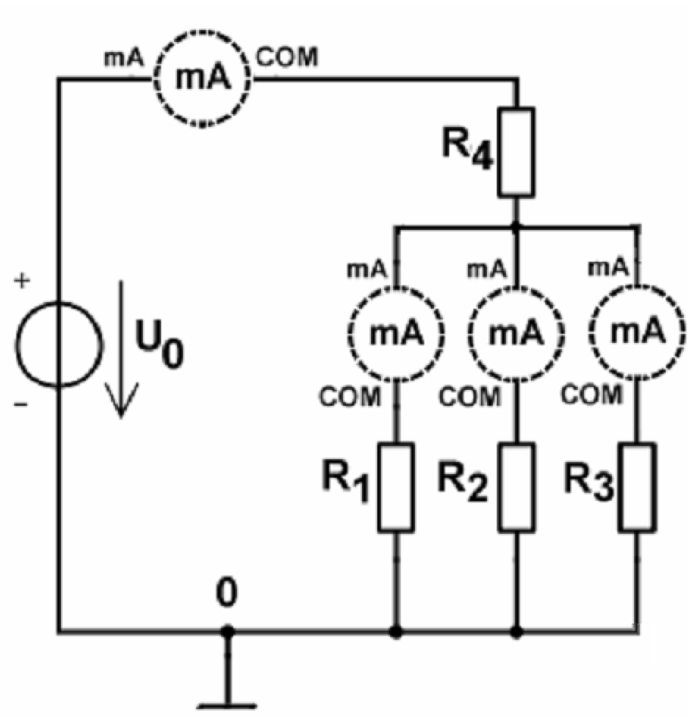
The ohmmeter is actually a current generator, as such, its measuring current will be shown on the milliampmeter, note this number as well in the second table:

Range of milliampermeter:	L1	L2	L3	L4
$R_{internal}$:				

Range of ohmmeter:	L1	L2	L3	L4
Measuring current of ohmmeter				

3.3 Parallel resistor network

3.3.1 Build the circuit seen in figure 19. ábra. We'll do the measurement in four steps, using only one milliampermeter. In each step, connect the current meter in series with one of the resistors, while leaving its space in short circuit in the other branches. Set up V_0=1V and measure and note its value.



19. ábra: series and parallel resistor network

V_0 = 1V
R_1 = 2,2kΩ ±1%
R_2 = 1kΩ ±1%
R_3 = 620Ω ±1%
R_4 = 390Ω ±1%

	Calculated (nominal R)	Calculated (measured R)
I_1		
I_2		
I_3		
I_4		
U_0	1V	

As previously, fill the first column using the nominal resistor values, the second column using the measured resistor values and the measured V_0. For the calculations, treat the milliampermeter as ideal.

Measure the currents in each range of the milliampermeter. Compare the values with the calculated (ideal) ones. Compare I_4 to $I_1+I_2+I_3$.

	L1	L2	L3	L4
I1				
I2				
I3				
I4				
I1+I2+I3				