CHAPTER 1

Oncampus Course Lab Week 1.1: Electric Circuits: Assembling and Basic Measurements Using a Multimeter

In this assignment, you assemble a basic circuit prototyping board (more accurate name) or a PCB (printed circuit board) with reliable solder joints for electronic experimenting. Then, you will become acquainted with a number of measuring instruments for measuring voltage, current and resistance. You will perform a number of measurements on basic network components.

1.1 Study goals

After doing this assignment, you should be able to:

1. Assemble a basic PCB with reliable solder joints
2. Apply in practice the concepts of voltage and current
3. Use a multimeter and voltage source

1.2 Preparation

Being able to solder a PCB is very convenient for electrical engineers to experimentally test ideas, and is a skill you will quite often use during the lab courses. As with many things, the secret to success is practicing. The following section explains how to solder and ends with a practical assignment.

The components are connected in an electronic circuit so that a current can flow between them. Therefore, these connections should be conductive, and preferably have a very low resistance. The components are connected in a certain way by means of a conducting pattern, generally by copper tracks, which is a so-called printed circuit board (PCB). The components are soldered on the PCB. Soldering is the process wherein the components by means of a melted bond are connected with each other or with the copper tracks. In an industrial environment, soldering is done using a tin bath. For small batches or prototypes, soldering by hand with a soldering iron and solder is the way to go. This course is about soldering circuits with a soldering iron.

1.2.1 The soldering iron

The soldering iron is used to connect the two parts to each other by heating the solder well above the melting temperature. The process of connecting two parts with hot solder is called soldering. An example of a soldering iron is given in Figure 1.1. For soldering electronic components, a soldering iron with a power of 30 W is sufficient. For large components or the soldering of a component on a large surface, a soldering iron with more power is needed. A temperature-controlled soldering iron is useful but not essential. If a soldering iron delivers too much power or becomes too hot, it can destroy the component or the PCB.

1.2.2 Soldering tin

For the soldering of electronics, solder is used which consists of a mixture of tin (Sn) and lead (Pb), usually in the ratio of 60/40 (60% tin and 40% lead). Solder is used in wire form, having a diameter of 0.6-1.0 mm. This solder melts at a temperature of about 185^{o}C. In order to properly solder, the soldering iron temperature is best set between 250 to 320^{o}C. An experienced electri-

Figure 1.1: A soldering station with a holder and cleaning sponge.

cian can work faster by a somewhat higher temperature. The solder wire has a core of resin. This is called 'flux' and promotes the flow and the adhesion of the tin. For electronics, **never** use flux used by plumbers to solder copper pipes (soldering paste or the so-called S-39). This contains an aggressive acid, which results in corrosion of the connecting tracks within a short time.

Since July first 2006, the Restriction of Hazardous Substances (RoHS) applies. This states that certain hazardous substances may no longer be used in electronic devices. One of the prohibited substances is lead. For industrial applications, leaded solder may no longer be used. Instead, lead-free solder based on tin and silver (96% tin and 4% silver) is used. This has a melting point of 221^{o}C. Due to the fact that a higher melting temperature is needed a soldering iron should be set 30-40^{o}C higher than for tin/lead solder. Please note that the the introduction of the RoHS policy also implied that the components had to be made suitable to withstand the higher temperature and not be destroyed.

Because soldering with RoHS compliant materials is significantly more difficult, and because the RoHS directive does not apply to our applications in education, you will use standard lead-based solder.

1.2.3 The technique of soldering

Usually, the soldering iron is a component of a soldering station: a transformer, possibly with a temperature controller, in a box with a holder for the soldering iron and a sponge for cleaning the tip. Before you begin with soldering, the tip of the soldering iron must be at the correct temperature and cleaned. For a soldering iron without temperature display, an indication of the correct temperature is when the solder immediately melts if you hold it against the tip. If black crusts is present on the tip, first clean it with a WET sponge. The following materials can be soldered with 40/60 solder: copper, brass, bronze, tin and iron.

Before you can make a solder connection, both components should be cleaned well, otherwise the tin will not properly flow, or creates a bad connection. If necessary, clean the components by sanding them lightly with fine sandpaper or scratch them with a knife. You actually never have to do this when soldering electronics; when using older components, it may be needed. Before you start soldering, the parts should be tinned. To do this, hold the soldering iron at the end of the jumper or the surface you want to tin and add some solder. If the tin flows neatly on the wire or on the surface, you are ready to continue. The flowed solder layer ensures that the surface can be optimally heated during the making of the solder joint. Smoke indicates that the flux in the solder is evaporating. Before the smoke is gone, you can remove the iron. Now, the surface is tinned.

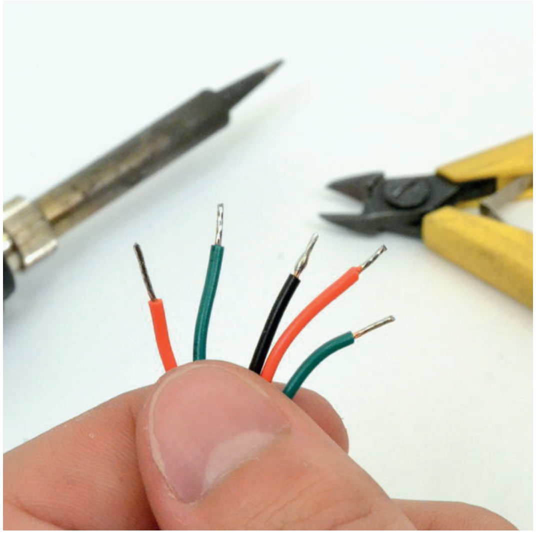


Figure 1.2: Tinning a wire.

Before soldering a wire, it will first be tinned. For this purpose, you first twist the fine copper wires together and then heat the wire and add your solder. Increase the amount of solder until the wire is completely filled; you will see the solder flow between the fine wires, see Figure 1.2. If the wire is fully tinned, you remove the solder and soldering iron. **Note:** never tin a connecting wire with a screw connector, such a connector works best with non-tinned wires. When both components are tinned, bring them together without moving, then press the soldering iron against both components and make them hot. If it is hot enough, add some extra solder by holding the solder to the location where the connection has to come. If the solder neatly flows between the components, you remove the soldering iron and the connection is ready. Upon removal of the soldering iron, the components must not move during process of cooling down relative to each other, otherwise you get a bad connection. If this happens accidentally, you can just re-solder the joint with the soldering iron to heat up the solder again and possibly add a little bit of new solder, and allow it to cool.

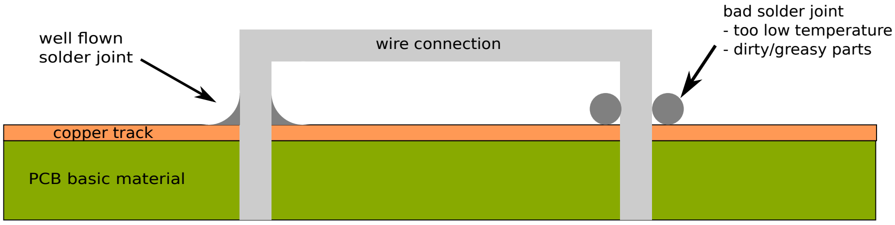


Figure 1.3: Schematic representation of a correct and incorrect solder connection.

New electronic components are often already tinned. PCB's are usually delivered with a protective lacquer (so-called solder lacquer), which prevents the oxidation on places of the print where a solder point must come. The solder lacquer also ensures that the solder flows out neatly. With a good joint, you will see that the solder has 'crept up' along the wire due to the cohesive force (see Figure 1.3). With old components, it is often advisable to tin them first, because the tin which is already on there has probably become dirty and greasy. If the tin after heating does not flow properly, then this is a sign that the wire is not clean; re-tinning or even first cleaning as mentioned earlier is the only solution. A solder joint with dirty connecting wires results in a poor unreliable connection; sometimes not immediately, but it could become unreliable over time.

On the following website: learn.adafruit.com/adafruit-guide-excellent-soldering/common-problems, some pictures of problems that can occur during soldering are shown. Some more examples can be found at www.popschoolmaastricht.nl/college_solderen.php:

- First, melt some tin to the tip of the soldering iron and then heat the component(s) which you want to solder, by pressing the tip against the component. Apply the solder to the heated part and let some tin flow out, but not too much! If the solder on both parts has flowed out nicely, remove the soldering iron. Keep the two parts at rest for a few seconds. If the tin becomes dull, you can release the components. If the items are moved during cooling, or if the tin looks gray, re-melt the tin with the tip and let it cool down, otherwise you have a weak connection with small (often invisible) cracks in it.
- Tin both parts separately first.
- Solder fast and let the parts not become too hot. Insulation can melt or carbonize and cause a short circuit without being directly visible. Many electronic components (particularly semiconductors such as transistors and Incs) are vulnerable to heat and can therefore fail.
- If you were to solder components susceptible to heat, you can dissipate some of the heat by holding a wire with pliers.
- A desoldering pump can be useful to suck away excess tin. There is also a desoldering wire, with which you can suck melted tin. Cut off and discard the used wire.
- Note: Do not burn your fingers on a hot soldering iron or hot work pieces.
- If you are working with very sensitive electronics, they can be damaged by high voltages caused by static electrical charge. To prevent this, there are special wristbands to drain this charge to earth. In certified laboratories, wearing these wristbands is mandatory.
- Check connections with a multimeter to see if there is no short circuit. Set it to the lowest resistance measuring range. Some multimeters have a connection tester with a beep. To test whether the insulation between terminals which must not be connected is correct, choose the highest resistance range.
- With a magnifying glass, you can take a better look to see if a soldered connection has, for example, a small tear in it.
- The tip of the soldering iron must be cleaned by removing it along a damp sponge. Then retin it with solder. A soldering station often has such a sponge. Note: Do not use sandpaper or sharp objects to clean the bolt! Most good soldering stations today have a ”long life tip” which is provided with a coating against oxidation. If you damage it, your fine soldering tip has become useless!

1.3 Required theory

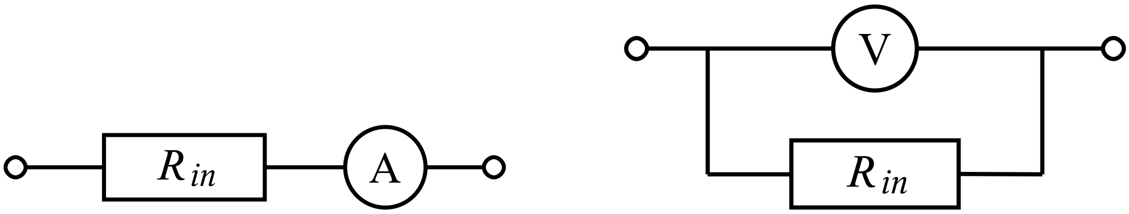
1.3.1 Ohm’s law, equivalent resistance, and Kirchhoff’s laws

For this assignment you will need to apply some theory that will be treated in Week 1.2: Ohm’s law, equivalent resistances of resistors in parallel and in series, and Kirchhoff’s laws on voltages and currents. However, you will probably remember them from secondary school, and the assignments won’t go very deep. However, if needed, please consult your book on Linear Circuits.

1.3.2 Non ideal input resistance of a multimeter

There is a deviation between the ideal measurements and the already-measured values. This is due to the fact that the instrument becomes a load to the system. For example, the input of the oscilloscope has a finite resistance (1 MΩ) and will draw some current from the source that may cause a measurable drop. Also between the wires of the oscilloscope an undesired (parasitic) capacitance exists that, above a certain frequency will start to dampen the signal and influence the measurement.

Voltmeters have an input resistance that is finite. This means that, unwantedly, they draw some current from the circuit to which they are connected. In the same way, real ammeters have an input resistance that is nonzero (note: the ammeter, taken from Ampere Meter, is an instrument to measure the electrical current in a circuit); see Figure 1.4. This means that the current they sense causes some undesired voltage drop across the terminals.



(a) Equivalent circuit of non-ideal ammeter.

(b) Equivalent circuit of non-ideal voltmeter.

Figure 1.4: Equivalent circuits for realistic voltage and ammeters. The circuits consist of ideal meters in combination with some input resistance R_{in}.

In this assignment you will apply Ohm's law to investigate the non ideal input resistance of a multimeter. You will work with a modern digital multimeter.

Most instruments have various ranges, which makes it possible to measure with sufficient resolution. **Please use an instrument within its range!** A voltage or current out of range can blow a fuse or even destroy it.

1.4 Assignments

1.4.1 Lab Preparation: Resistors in series and parallel

1. Write down the equation to calculate the resistance depending on the resistivity, cross-sectional area, and length.
2. Calculate and explain how the equivalent resistance of two resistors in parallel, as shown in Figure 1.5, can be obtained using the above equation. If the resistivity is assumed to be the same in two resistors, how will the area and length of the equivalent resistor be related to the ones of two resistors?

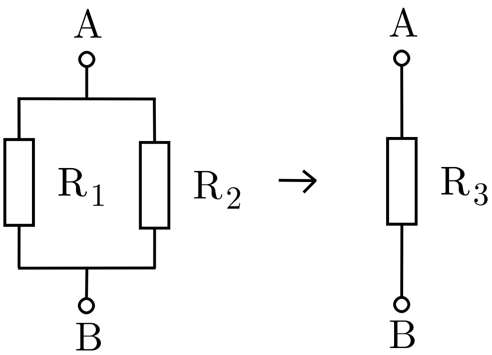


Figure 1.5: Equivalent resistance of two resistors in parallel.

3. Calculate and explain how the equivalent resistance of two resistors in series can be obtained using the above equation. If the resistivity is assumed to be the same in two resistors, how will the area and length of the equivalent resistor be related to the ones of two resistors?
4. Taking into account the above questions, calculate R_{eq} in Figure 1.6.

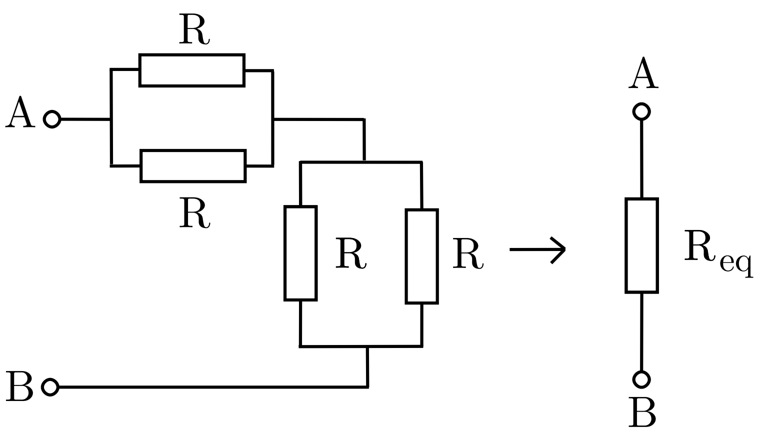


Figure 1.6: Equivalent resistance of resistors in series and parallel.

1.4.2 Circuit Assembly

In this assignment, you will build a circuit that is often referred to as a five-bit R-2R ladder network [1]. It can be found in e.g. digital-to-analog converters, where it is used to convert the '1'-value bits in corresponding portions of 1/2, 1/4, 1/8 .. of the reference voltage Vref and add them together to get the analog output voltage. You will use it in the multimeter assignment later. Please assemble *one PCB per student*.

1. Collect 16 resistors of 100 Ω and a maximum power rating of 0.25 W. To find out how those components look like, please consult Appendix A and B.
2. Prepare the initial circuit's configuration according to Figure 1.7
   Make sure that you make connect the resistors exactly as it is shown in Figure 1.3 to the prototyping board.
   To connect several resistors, you must create the so-called "Islands of solder". A good solder is acquired when you let the solder get up to temperature so it can stick correctly.

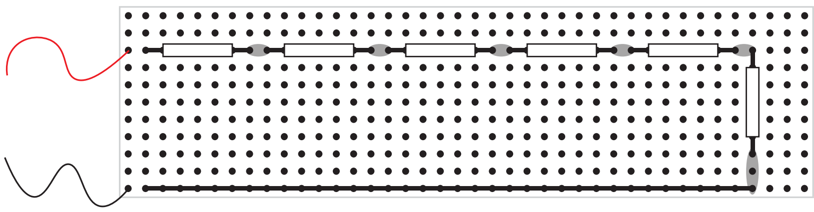


Figure 1.7: Initial circuit with six resistors. **Note**: This circuit is still not the full configuration of the ladder network.

3. Select the resistance measurement (Ω) in your multimeter. Then, measure the resistance between the red and black wires with Fluke 117 mulitmeter.

[1] https://en.wikipedia.org/wiki/Resistor_ladder

4. Add the resistors from 1 to 10 as it is shown in Figure 1.8. What is the value of the final resistance (between the two terminals)?

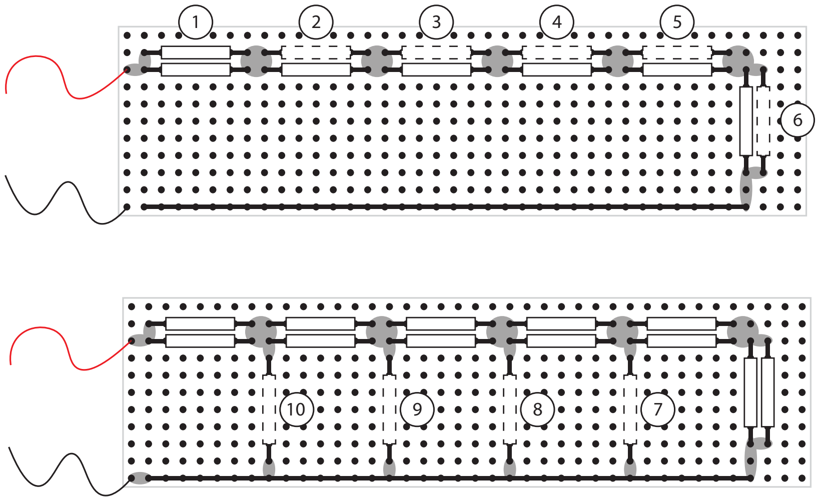


Figure 1.8: Completion of the initial circuit to the full ladder network.

5. Use a pencil or a marker with a white tape, write your name on your PCB.
6. Let your soldering work be verified by the tutor or teaching assistant.

1.4.3 Ladder network characterization

1. Make your table clean of any metal parts and clippings.
2. Connect your ladder network of the previous assignment to a voltage source of 5 V (Farnell TOPS). More precisely: connect the red wire to the '+' of the power supply using a cable with a banana jack on one side and a clip on the other side. Connect the black wire to the '−' of the power supply (0 V).
3. With a digital multimeter, measure the voltages on all nodes of the network (found in Figure 1.9) with respect to the '−'. Write them down in your logbook, in a table.
4. With three extra resistors, it would be possible to extend the ladder network with an extra module, hence an extra bit.**Attention: Before you connect the digital multimeter to the circuit, make sure that you select the voltmeter option (i.e. measuring the voltage). If you select the ammeter option (ie measuring the electric current) in the parallel connection, then you are likely to seriously damage the multimeter.** Based on your previous measurements, predict how this would change the voltage across the resistor on the right hand side.
5. Ask the TA of your group to explain this part first to you and firstly check your circuit before you turn on the voltage supply. With a digital multimeter, measure the currents through both of the input wires of the ladder network, i_{in} and i_{out} as indicated in Figure 1.9. Compare them.
6. Based on the *measurements* of voltage and current, calculate the equivalent input resistance

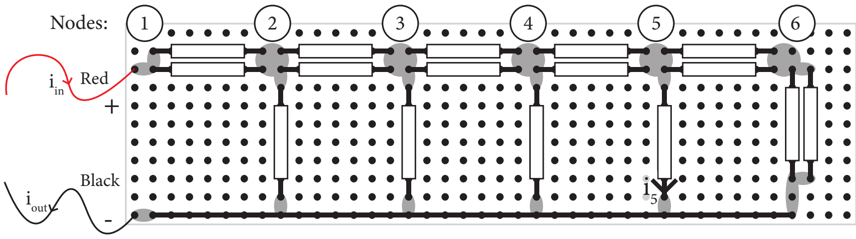


Figure 1.9: Ladder network including six nodes.

of the network.

7. Disconnect the circuit from the power supply. Switch a digital multimeter to the 'Ohm' domain and measure the resistance between the input wires. Compare the value with the one you calculated. Explain the similarities and -perhaps- the differences with the calculated value of the previous question.
8. Calculate the current i_5 as indicated in Figure 1.9. Can you compare the value of the current from the previously done voltage measurements?
9. *Optional:* from Ohm's law and Kirchhoff's laws reason what is the equivalent input resistance of the 5-bit ladder network. Compare with the value calculated from the measurements. *Hint:* call the resistance value R, and start combining resistors to equivalent resistances on the right hand of the network.
10. *Optional:* from Ohm's law and Kirchhoff's laws reason what is the smallest current in a ladder network with n bits.