IALP 2011 – Analog Electronics

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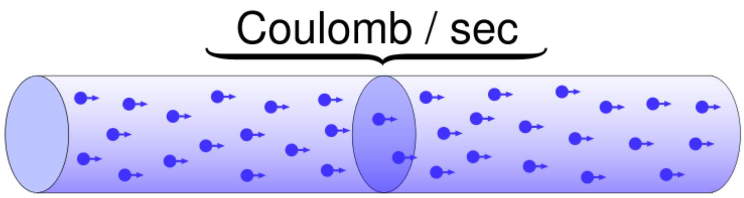
The world as we know it would be completely different without electronics. Imagine. No television. No radio. No telephone, mobile or fixed. No computer. Maybe many things can be done without electronics – communication, for example, can be done with pen and paper; no telephone is needed – but with electronics it goes nearly with the speed of light.

As explained in the theoretical lectures, electronics is based on the movement of charge. Current is by definition the amount of charge passing per second. Voltage is by definition the force applied to the charge to make them move.



Ohms Law

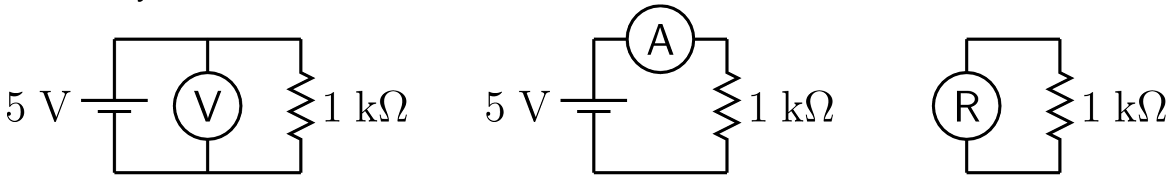
The first thing that was noted is that there exists a relation between current (*I*) and voltage (*V*), named the 'resistance' (*R*), since it is the objects quality to 'resist' the force applied. George Simon Ohm (pictured) found out that in many cases there exists a linear relation between the three, it can be expressed in the following three forms

$$R = V/I$$
$$V = IR$$
$$I = V/R$$

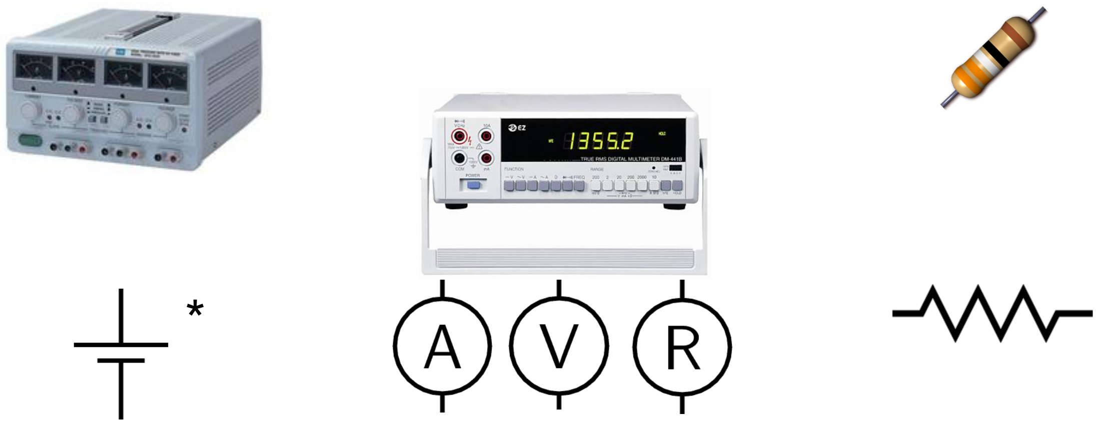
Whenever we know two, the third one follows from the above relations. If we apply a voltage *V*, for instance by connecting a battery, and measure the current *I* with an amperimeter, we can calculate the resistance *R* the component has. The other way around. If we apply a known voltage *V* to a know resistance *R*, we can predict the current, even without measuring it.

Multimeter

A multimeter has the property that it can measure the voltage, or measure the current. Moreover, it can apply a voltage, measure the current and do the calculation above for us and give us the value of the resistance. Many multimeters have more functionalities, as we will see shortly.



Measuring voltage, current and resistance with a multimeter



Used Equipment

Exercise

1) Take a resistance from the box of unknown resistances and measure it with a multimeter (Right image above). Is it close to the 'nominal' value given by the color code on the resistance?

Resistance:

Difference between measurement and color code (%):

Is this within the error limit?:

2) Measure the resistance of the human body with a multimeter

Resistance:

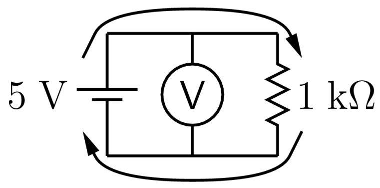
3) Take a 1 kΩ resistance and apply a 5 V voltage. Measure the voltage **across** the resistance and the current **through** the resistance, see images above. Make sure the multimeter is set to measure DC (= instead of ~)

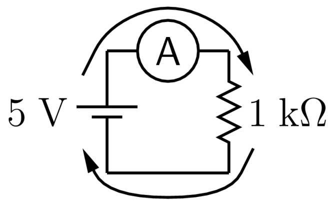
What is the resistance according to Ohm's Law? What is the real resistance? Remember: to measure the current we have to open the circuit and insert the amperimeter there

* Technically speaking, this is the symbol for a battery – there is another symbol for a voltage source – but it'll do for the moment

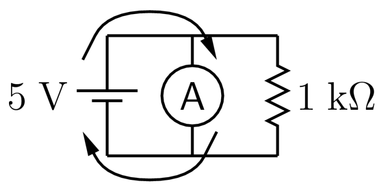
where we want to measure the current.
Voltage:
Current:
Resistance:

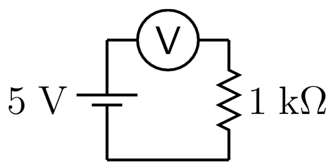
Note 1: It is very important how we connect the multimeter. The connection is different when we use it as an amperimeter than when we use it as a voltmeter. Look at the flow of current in the image below





A **voltmeter has infinite resistance**, an **amperimeter has zero resistance**. In the image above the connections are correct. On the left: the electrons chose the easiest path and flow through the resistor. The voltmeter measures the force. On the right: the amperimeter does not interfere with the current, it does not 'resist' the force and the current is the same it would have been if the amperimeter had not been there. Now imagine what happens if we connect the multimeter wrongly, like this:



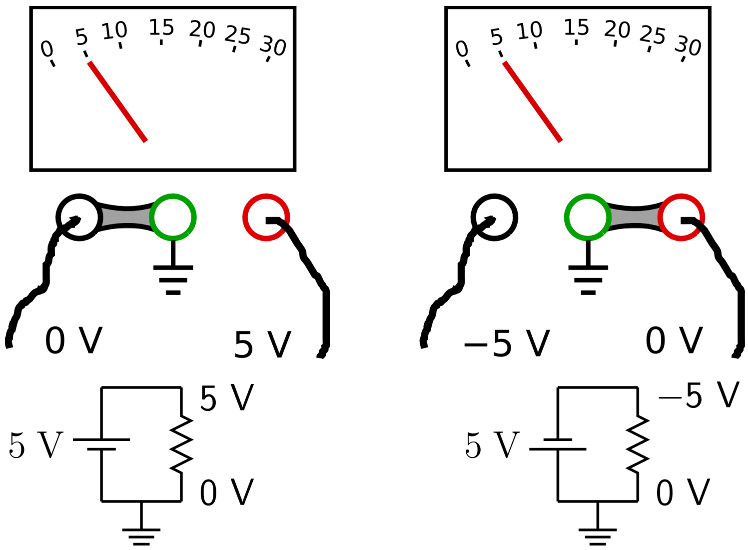


On the left we put an amperimeter in the place of a voltmeter. An amperimeter has zero resistance. The current flows there where there is least resistance, entirely through the amperimeter. This current through the amperimeter is given by Ohm's Law

$$I = V/R = (5\ \text{V})/(0\ \Omega) = \infty$$

As you can see on the multimeter, the maximum current it can stand is 10 ampere (10 A). Yes, that is right, you have just burned the multimeter! And the power supply probably was protesting as well (indicating a red light, 'CC' for short circuit, or something like that). Fortunately, they come protected with fuses and they can be repaired easily.
On the right we have put a voltmeter in the place of an amperimeter. This is not so bad because nothing will get destroyed. Since the voltmeter has infinite resistance, no current is flowing in the circuit, but the voltmeter will indicate 5 V.

Note 2: To make 5 volt with our power supply, we have to connect the negative pole to ground and the positive pole will be the voltage indicated in the display. See the figure below. If we want –5 volt instead, we have to connect the positive side to ground and the negative terminal will be –5 V.



Generating +5 V (left) and –5 V (right)

AC/DC

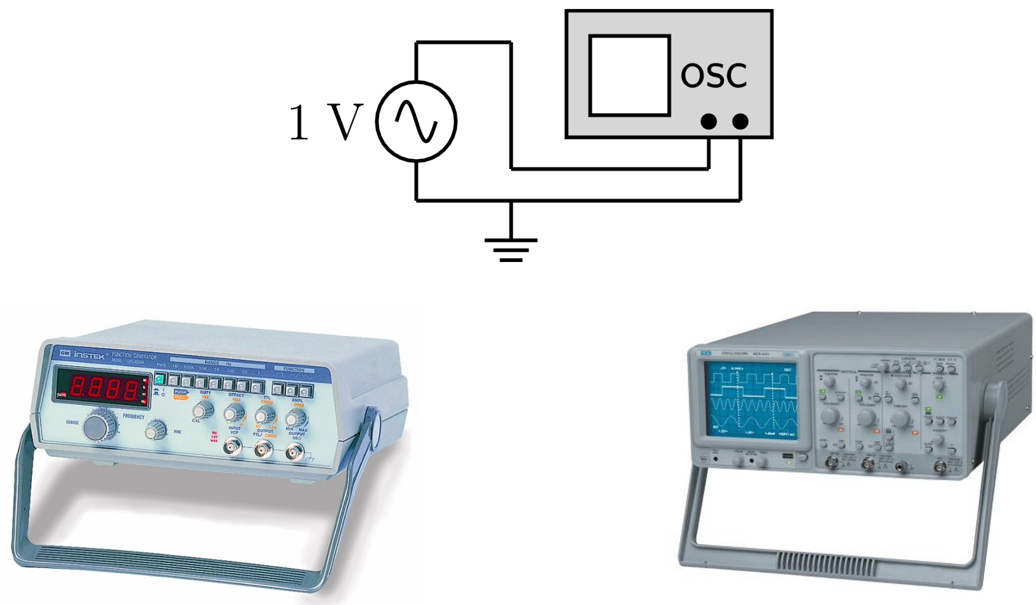
The above exercise was done with DC voltages. 'DC' stands for 'direct current'. What this confusing name means is constant voltage and current. In other words, 'not changing with time'.

$$V(t) = V_0$$

Generally speaking, voltages and currents can change with time. This is what we call AC ('alternating current', which stands for sinusoidal signals both current and voltage), for example the sinusoid

$$V(t) = V_0 \sin(2\pi f t)$$

with f the frequency of the signal and t time.



Visualizing an AC signal with an oscilloscope (note, the two lines are **one** cable) and equipment used

Exercise

4) Connect a function generator to an oscilloscope. Find out what all the buttons do. What is the meaning of the vertical scale “V/DIV” and horizontal scale “s/DIV”?
Produce a signal with
- 1 V amplitude
- 1 kHz frequency
- sinusoidal (also try rectangular and triangular)

Draw here what you found, including the description of the scales:

H-scale:
V-scale:

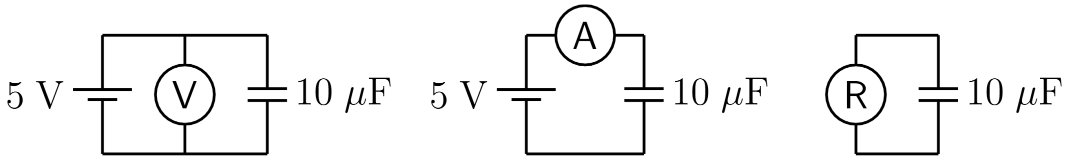
Non-ohmic components

The above circuits were all ohmic. That is to say, they have a certain resistance and when we apply a constant voltage, they pass a constant current. The current is always proportional to the voltage. Not all components are like that. The most familiar non-ohmic component is the capacitor, which is an element that can store charge. Instead of a constant **current**, these components have a constant **charge**. Given a certain applied voltage V, the charge Q in the capacitor is given by the capacitors capacitance C (unit: farad)

$$Q = C\ V$$
$$C = Q\ /\ V$$
$$V = Q\ /\ C$$

where we again used three equivalent formats to show that if we know two, we know the last one.

Exercise



5) Measure a capacitor with the multimeter

Voltage V =
Current I =
Resistance R =

The exercise gave zero result. Voltage, but no current. Go back to the middle setup above and vary the voltage. What do you see happening with the current? On basis of the capacitance definition it is not difficult to calculate the current. If

$$Q = C\ V$$

then changes in V will cause changes in Q (if C is constant):

$$\Delta Q = C \times \Delta V$$

Imagine we change V by a quantity ΔV in a time Δt, we get

$$\Delta Q / \Delta t = C \times \Delta V / \Delta t$$

or in the limit ($\Delta t \rightarrow 0$)

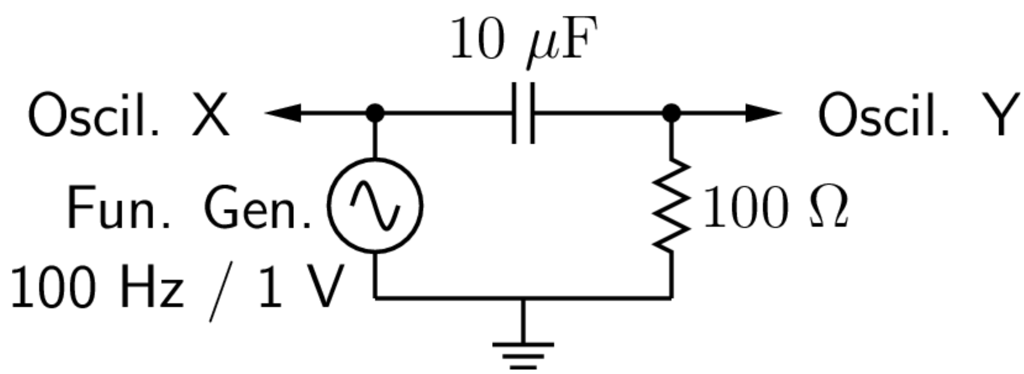
$$\mathrm{d}Q / \mathrm{d}t = C \times \mathrm{d}V / \mathrm{d}t$$

but the term on the left is the definition of current! Thus

$$I = C \times \mathrm{d}V / \mathrm{d}t$$

In other words, the **current is proportional to the speed of changes of the voltage**. That explains that we saw current when we changed the voltage in the experiment above.

Exercise



6) Measure the above circuit. What do you see?

H-scale:
V-Scale:

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