

# DC circuits

# Review

- Base units
- Prefixes
- Basic electrical quantities (charge, current, voltage, resistance, power)
- Fundamental electrical laws (Ohm's law, Kirchhoff's laws)
- Resistor as an electrical component (introduction to soldering technology)
- Resistance reduction
- Resistance of conductors (wires)
- Special resistors (potentiometers, voltage-dependent resistors (VDR))

# Basic units of measurement

- The base units are defined based on the International System of Units (SI)
- There are 7 base units, and all others are derived from these:

Base quantity	Symbol	Unit of measurement	Sign
Time	t	Second	<i>s</i>
Length	l	Meter	<i>m</i>
Mass	m	Kilogramm	<i>kg</i>
Current	I	Amper	<i>A</i>
Temperature	T	Kelvin	<i>K</i>
Amount	n	Mol	<i>mol</i>
Luminous Intensity	$I_v$	Candella	<i>cd</i>

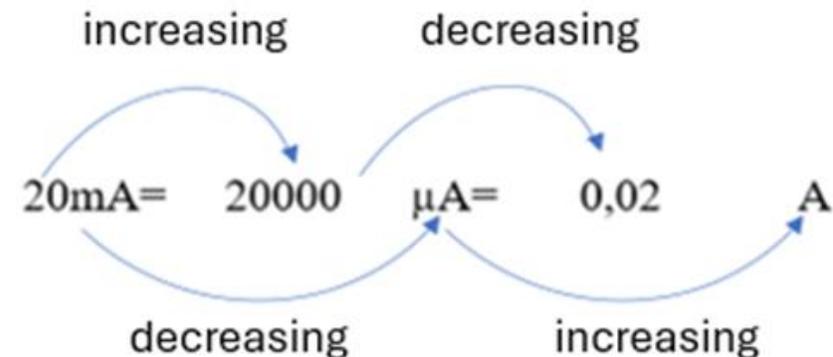
# Prefixes

Prefix name	Sign	Value
exa	E	$10^{18}$
peta	P	$10^{15}$
tera	T	$10^{12}$
giga	G	$10^9$
mega	M	$10^6$
kilo	K	$10^3$
SI		
mili	m	$10^{-3}$
mikro	$\mu$	$10^{-6}$
nano	n	$10^{-9}$
piko	p	$10^{-12}$
femto	f	$10^{-15}$
atto	a	$10^{-18}$

- All quantities are given with a measurement and unit of measurement. For example:

$$R = 100\Omega$$

- It is an unwritten rule that it is generally recommended to choose a measurement between 0.1 and 1000.
- In practice, it sometimes happens that we use fractions or multiples of the units of measurement used in the SI system, in which case the given quantity must be converted.
- The following may be useful during conversion:



# Charge/current

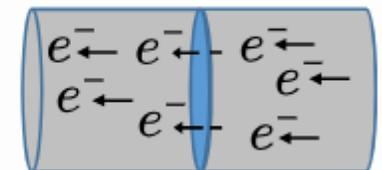
- The symbol for electric charge is  $Q$ , and its unit of measurement is C (Coulomb) or As (Ampere-second)
- $1C = 6,24 \cdot 10^{18}$  pcs electron
- Electric current is the orderly movement of electrons in one direction. :

$$i(t) = \lim_{\Delta t \rightarrow 0} \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt} \equiv \text{current} = \frac{\text{charge}}{\text{time}}$$

- The current strength signal in general cases  $i = i(t)$ , unit of measurement : A (amper)
- The current shows how much charge flows through the cross-section of the conductor in a given time unit
- In the case of direct current (DC), electrons flow from the positive terminal to the negative terminal.(+ → -)
- In the case of direct current, the designation is written in capital letters, e.  
 $I = 125mA$
- Current only flows in a CLOSED circuit (see: water tube)



current  
→



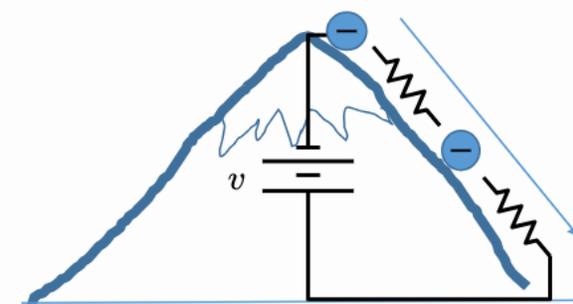
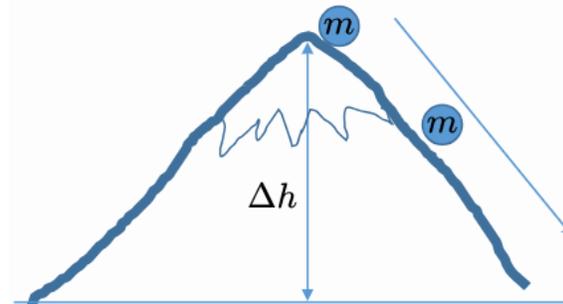
# Voltage

- Electrical voltage expresses energy relations
- Voltage is the potential difference between two points OR the ability of an electric field to do work
- 1V is the voltage between two points in an electric field when 1C of charge flows through it and does 1J of work
- The voltage signal in general  $u = u(t)$ , and its unit of measurement is : V (Volt)
- In the case of direct current, the designation is written in capital letters, e.g.:  $U = 94V$



- The voltage can be calculated by:

$$U = \frac{W}{Q} \equiv \text{voltage} = \frac{\text{electrical (field) work}}{\text{charge}}$$



# Resistance

- Resistance means blocking the flow of current
- The symbol for resistance is:  $R$ , and its unit of measurement is  $\Omega$  (Ohm)
- The resistance of a load is calculated as the ratio of the voltage measured across its terminals and the current flowing through it:

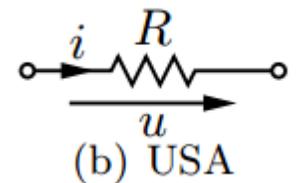
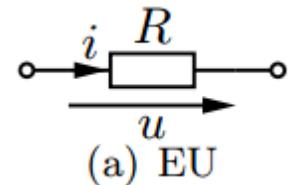
$$R = \frac{U}{I} \equiv \text{resistance} = \frac{\text{voltage}}{\text{current}}$$
$$1\Omega = \frac{1V}{1A}$$

- Conductivity is the reciprocal of resistance. Symbol:  $S$ , unit of measurement (S) (Siemens). A "good" conductor has low resistance..

$$G = \frac{1}{R}$$

- The three forms of Ohm's law:

- $R = \frac{U}{I}$  Higher voltage, higher current
- $I = \frac{U}{R}$  Higher voltage, higher resistance
- $U = I \cdot R$  Higher resistance, lower current



# Electrical power

- In electrical systems, power is the product of current and voltage over time, i.e. :

$$p(t) = u(t)i(t)$$

- In case of DC:

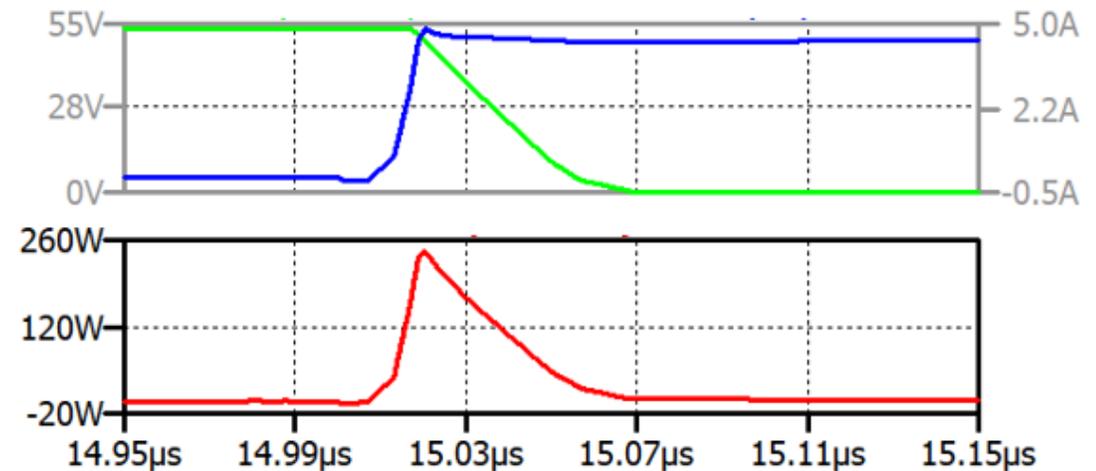
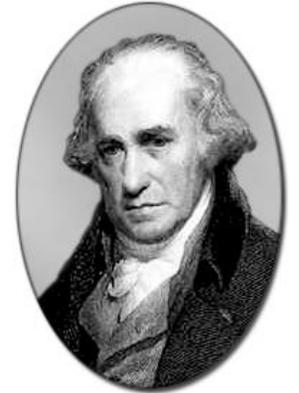
$$P = UI$$

- The symbol for e. power is therefore  $P$ , and its unit of measurement is watt (W)
- E. power can be positive (load-oriented), negative (source-oriented), or zero.
- Overall, it can be said that the principle of energy conservation also applies to electrical networks, i.e.

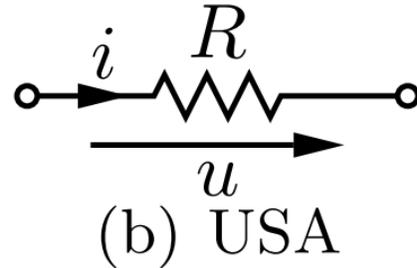
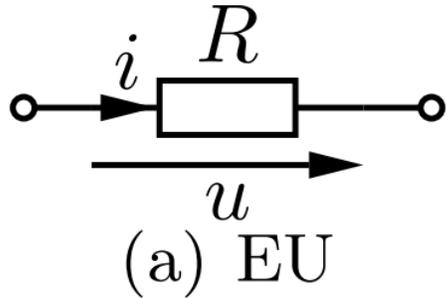
$$\sum_{i=1}^n p_i = 0$$

- Power can be calculated based on resistance and current/voltage. :

$$P = \frac{U^2}{R} = I^2 \cdot R$$



# Electrical circuit elements – resistance, catalog parameters



5% Resistor Table (E24)											
100	110	120	130	150	160	180	200	220	240	270	300
330	360	390	430	470	510	560	620	680	750	820	910
Standard Values: 1, 10, 100, 1k, 10k, 100k, 1M											

Example: The E24 series contains 24 logarithmically evenly distributed values within a range. This means that each successive value is greater than the previous one by a constant multiplier. This multiplier is E24:

$$k = 10^{\frac{1}{24}} \approx 1.096478$$

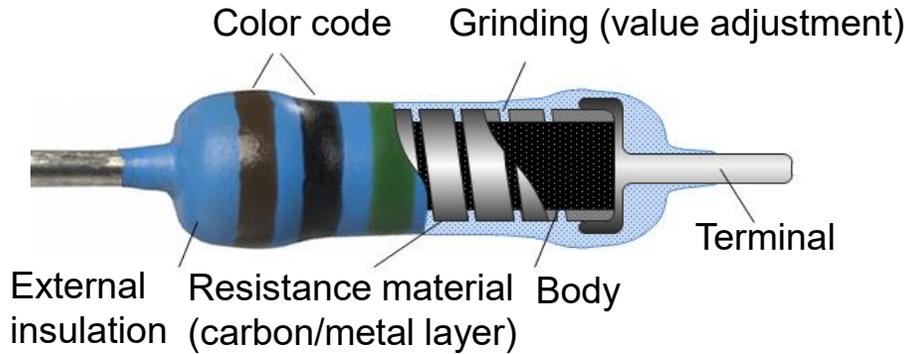
The value obtained must be rounded:

- E6 → 1 digit
- E12 → 2
- E24 → 2
- E48/E96/E192 → 3 or more digit

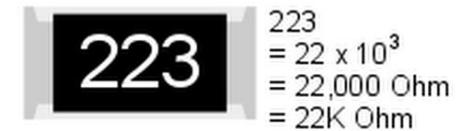
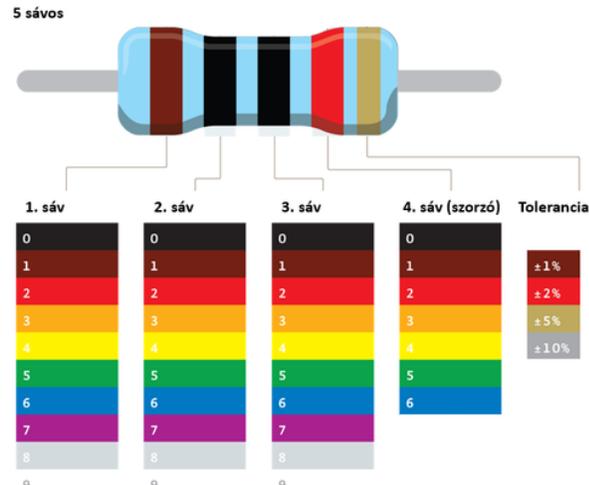
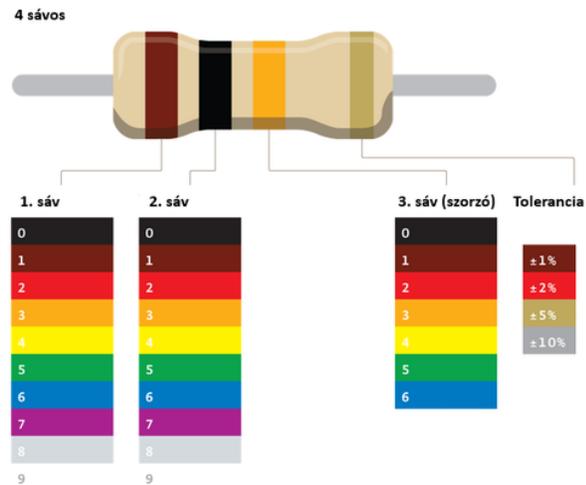
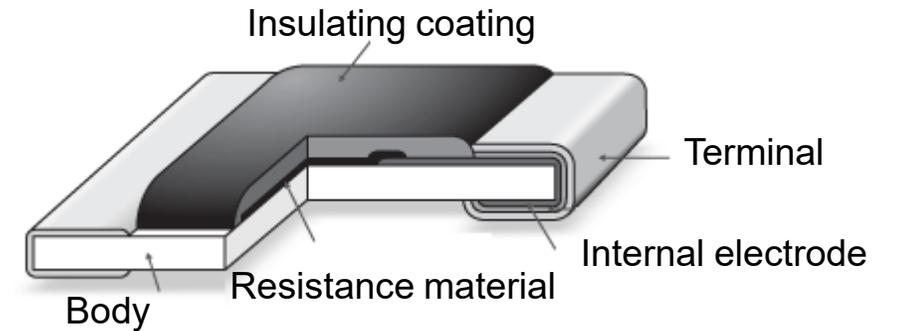
- Resistance value (e.g.: 1kΩ, 1k6, 4,7kΩ, 4R7 etc.)
- Power (e.g.: 0,25W; 20W etc.)
- Tolerance
- Value series (E series, based on IEC60063):
  - E3: 50% tolerance
  - E6: 20% tolerance
  - E12: 10% tolerance
  - E24: 5% tolerance s
  - E48: 2% tolerance
  - E96: 1% tolerance
  - E192: 0.5, 0.25, 0.1% and even less tolerance...

# Electrical circuit elements, resistance, structure

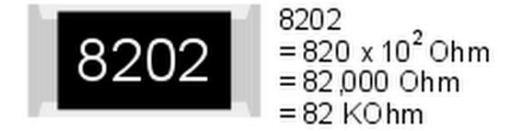
## Through hole



## Surface-Mount Device – SMD



3 digit



4 digit



Decimal point notation

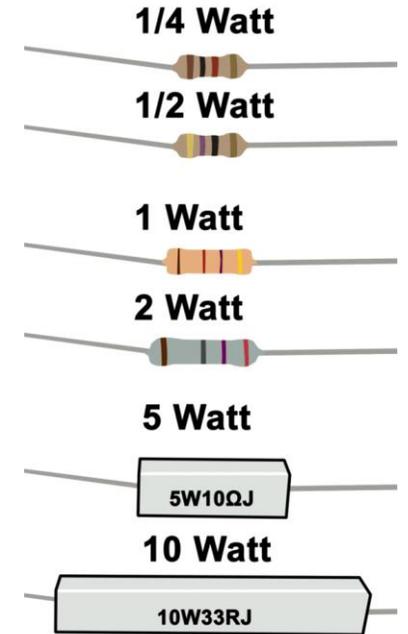


0Ω resistance marking

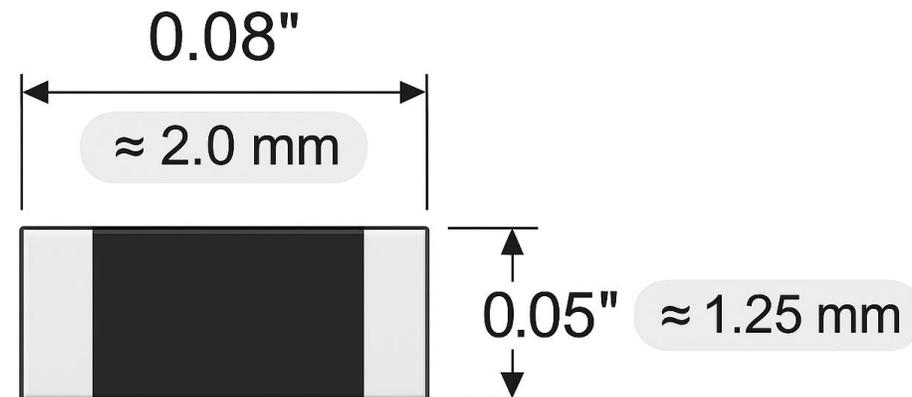


# Electrical circuit components, resistance, casing, performance

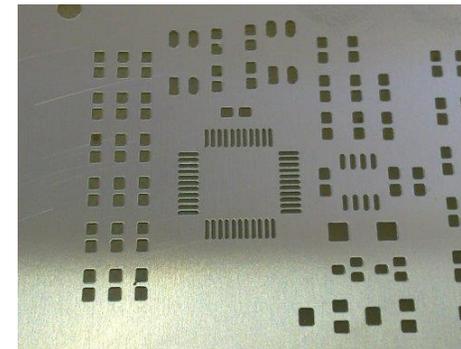
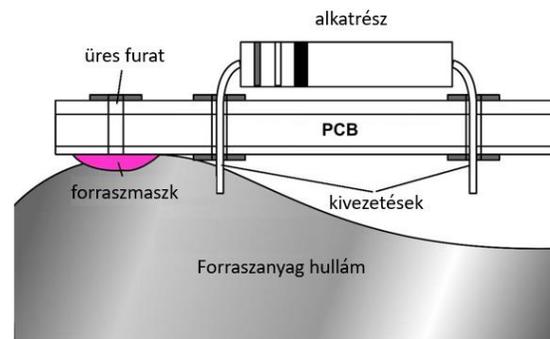
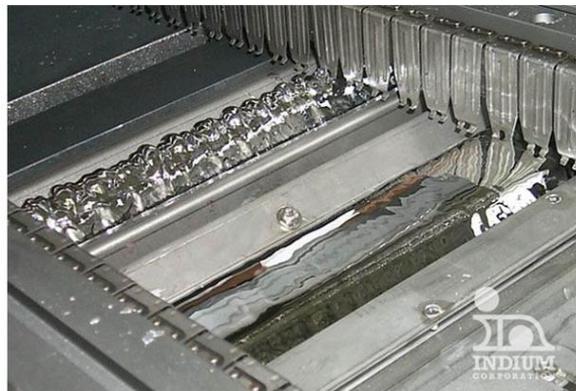
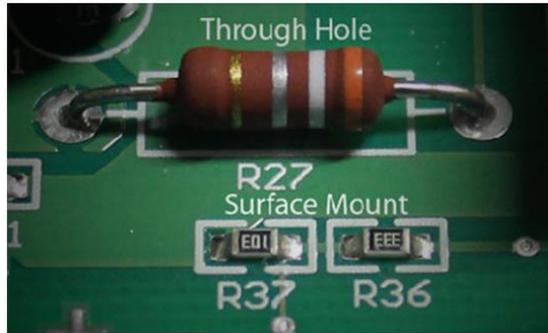
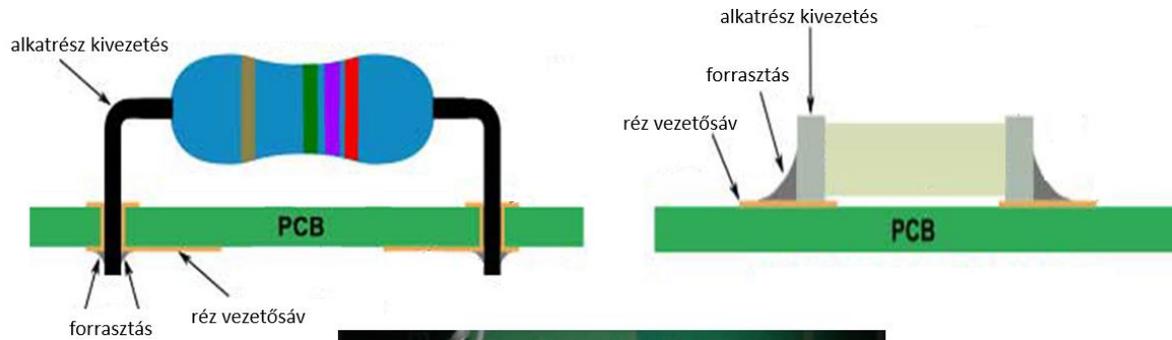
- The size of the casing is closely related to the dissipated (heat) power
- Smaller resistors range from a few tenths of a watt to several watts (carbon and metal layer), while more powerful ones can reach several tens of watts (wire resistance)
- The latter contains a resistance wire (usually a nickel-chromium alloy) wound around a ceramic body. This is fixed with cement or ceramic paste, which is a very good heat conductor, mechanically stable and protects against external influences
- The maximum values that can be connected to the resistor (voltage and current) can be calculated based on Ohm's law and the power of the resistor
- The casing of surface-mounted resistors is measured inches



<b>0201</b>	0.02" × 0.01" 0,6 × 0,3
<b>0402</b>	0.04" × 0.02" 1,0 × 0,5
<b>0603</b>	0.06" × 0.05" 1,6 × 0,8
<b>0805</b>	0.08" × 0.05" 2,0 × 1,25
<b>1206</b>	0.12" × 0.06" 3,2 × 1,6
<b>1210</b>	0.12" × 0.10" 3,2 × 2,5



# Printed circuit board design/soldering – for through-hole/surface-mounted components

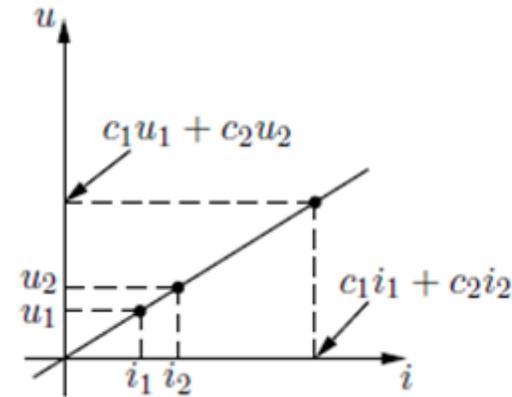


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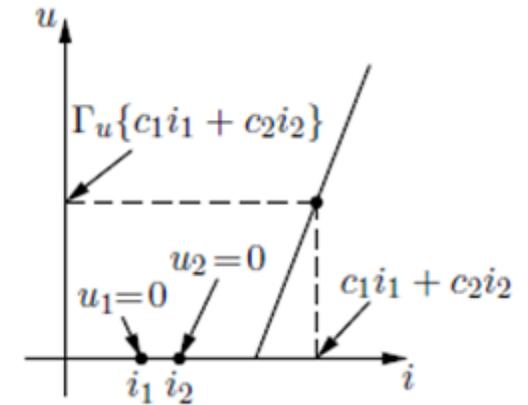


# Basic concepts of network theory: two-pole, four-pole

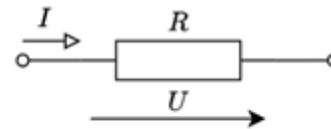
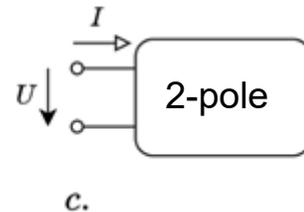
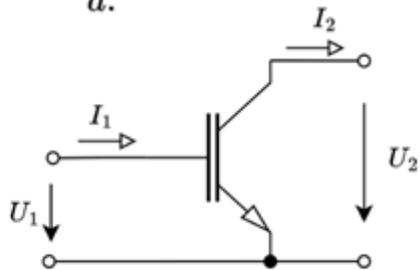
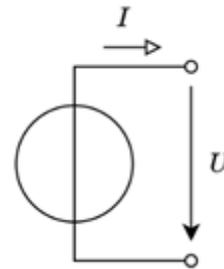
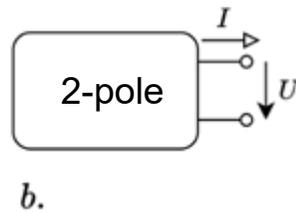
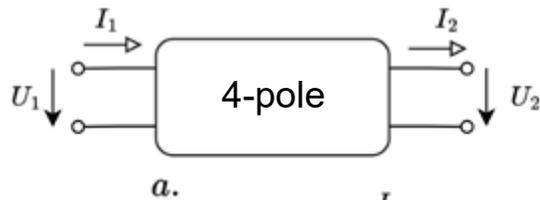
- \*By characteristics:
  - Active
  - Passive
- By linearity:
  - Linearity
  - Non-linearity



Linear



Non-linear



The two poles can be classified according to many other electrical criteria, but for simplicity's sake, we will only consider these for now.

Source: Dr. Kuczmann Miklós – Kovács Gergely: Villamosságtan

# Basic concepts of network theory: Kirchhoff's laws



- It consists of connecting arbitrary network components ("parts")
- The individual components are connected to each other at the network nodes, which are usually marked with a solid circle (dot)
- The network equations can be expressed using the so-called Kirchhoff equations:
  - Node law: the sum of the currents flowing into a node is equal to the sum of the currents flowing out of it. Outgoing currents are usually considered positive, while incoming currents are considered negative.

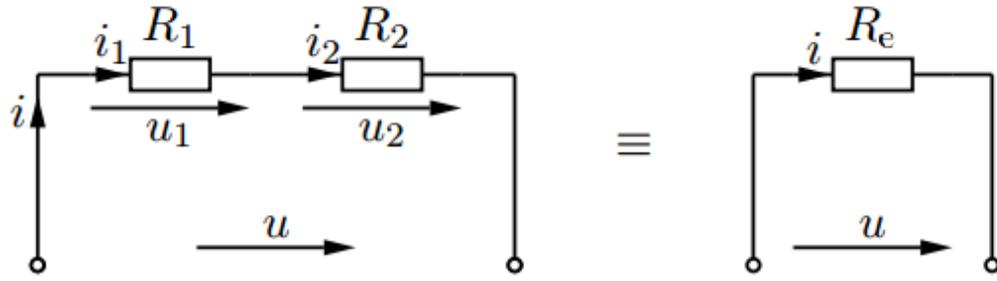
$$\sum_{k=1}^m i_k(t) = 0$$

- Loop law: the loop law states that in a closed loop, the sum of the voltages is zero. The direction of the loop can be arbitrary.

$$\sum_{k=1}^m u_k(t) = 0$$

$m$  represents the number of components in the network in both cases

# Resistor connection – Series connection



- The currents flowing through the resistors (circuit elements) are equal, i.e.:

$$i_1 = I_2$$

- The voltages are distributed proportionally to the resistances, but we can conclude that

$$u = u_1 + u_2 + \dots + U_n = \sum_{k=1}^n u_k$$

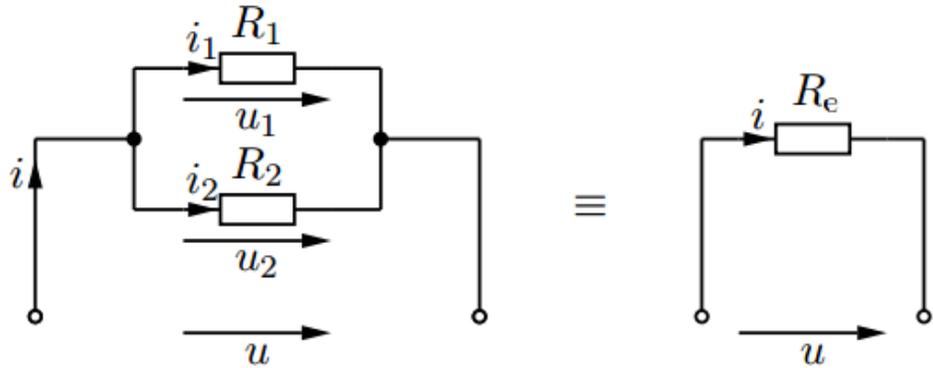
- The resistors can be replaced with a single resistor, i.e.:

$$R_e = \frac{u_1 + u_2}{i} = \frac{u_1}{i} + \frac{u_2}{i} = R_1 + R_2$$

- It can be concluded that the equivalent resistance is:

$$R_e = R_1 + R_2 + R_3 + \dots + R_n$$

# Resistor connection – Parallel connection



- The voltages across the resistors (circuit elements) are equal, i.e.:

$$u_1 = u_2$$

- The currents are distributed in proportion to the conductances ( $G=1/R$ ), but we can conclude that

$$i = i_1 + i_2 + \dots + i_n = \sum_{k=1}^n i_k$$

- The resistors can be replaced with a single resistor, i.e.:

$$R_e = R_1 \otimes R_2 = G_1 + G_2 = \frac{i_1 + i_2}{u} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_1 + R_2}$$

- It can be concluded that the equivalent resistance:

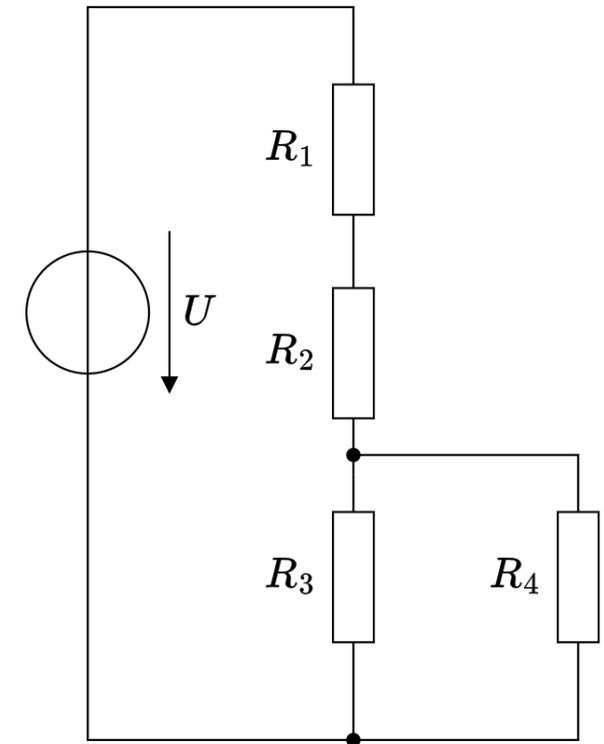
$$R_e = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

In the case of two parallel resistors, the following formula can also be used to calculate the equivalent resistance:

$$R_e = \frac{R_1 R_2}{R_1 + R_2}$$

# Examination of complex networks –reference directions

- When examining a complex network, it is most often necessary to calculate the equivalent resistance, current, and voltage values, either for part of the network or for the entire network
- Based on Kirchhoff's laws, we know that currents flowing into a node are negative, while currents flowing out of it are positive, and that the voltage component corresponding to the loop is positive, while the opposite is negative.
- But how do I know the direction of current and voltage in an unknown network? We arbitrarily assign these directions (reference directions): If we get a positive sign at the end of the calculation, the sign of the recorded variable is positive, so it shows the actual direction. If it is negative, the recorded direction is opposite to the actual direction
- What does this mean? In practice, we verify the magnitude and direction of current and voltage values by measurement. For example, if we connect the current of  $R_1$  in accordance with the actual current direction, the indicator will deviate in a positive direction (or, in the case of a DMM, the value will be positive); otherwise, the indicator would "deviate to the left" (which is, of course, to be avoided) or, in the case of a DMM, the value would be negative.
- Two important rules must also be kept in mind:
  - **The reference direction of the sources must not be changed!**
  - **The voltage and current direction must be the same on the consumers!**



# Complete system of network equations

- For each network, it is possible to determine how many node equations and how many loop equations can be written; these together form the complete system of network equations.

- If the network contains  $n$  nodes, the number of node equations is:

$$r = n - 1$$

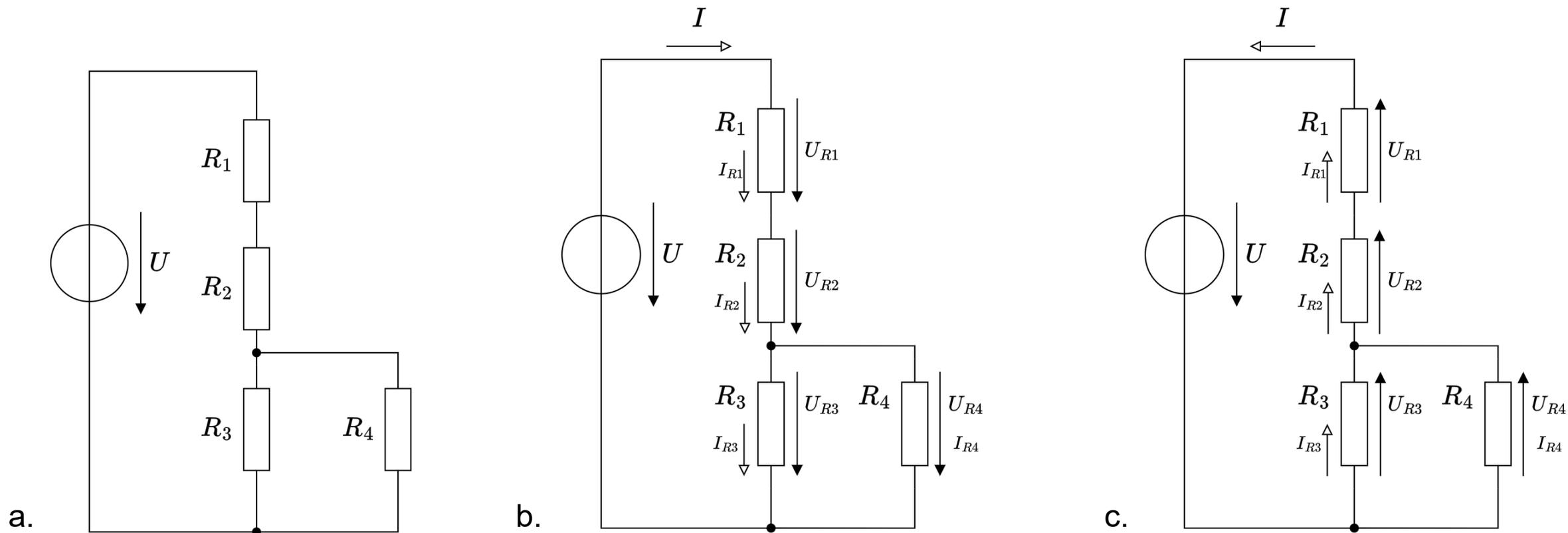
- If there are  $b$  two-pole branches ( $b$  – branch) in the network, then the number of loop equations is:

$$l = b - n + 1$$

- It is important to note that the complete system of equations is not always necessary; in some cases, a reduced form can be used.

# Example

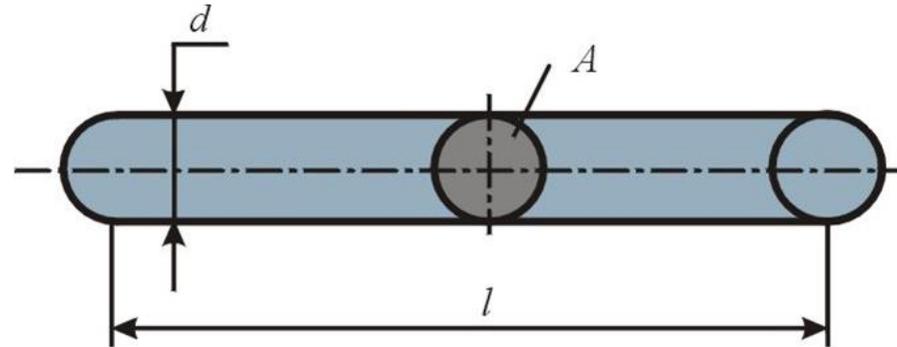
- Reference directions can be recorded in two ways; in both cases (b, c) we get a good solution, but only one gives the actual (real) direction
- The direction of the sources is therefore fixed, since, for example, the terminals of a voltage source cannot be changed, and we connect to it in one way.
- Accordingly, with a little practice, we know that the connection marked with reference directions b corresponds to the actual direction. This is what we should strive for in the solution.



# Solving the example problem

- -see lecture-

# Determining resistance based on geometric parameters



- The resistance of the wires can also be calculated from the geometric parameters. To do this, you need to know:
  - The length of the wire:  $l$  [m]
  - The material:  $\rho$  [ $\Omega \frac{mm^2}{m}$ ] (This is also usually specified in  $\Omega m$ .  $1\Omega m = 10^6 \Omega \frac{mm^2}{m}$ .)
  - The cross section:  $A$  [ $mm^2$ ]
- Knowing the parameters, the resistance of the wire can be calculated using the following formula (in practice, it is advisable to substitute the length of the wire in meters and the cross-section in  $mm^2$ , which will give the resistance in  $\Omega$ ):

$$R = \rho \cdot \frac{l}{A} \equiv \left[ \Omega \frac{mm^2}{m} \right]$$

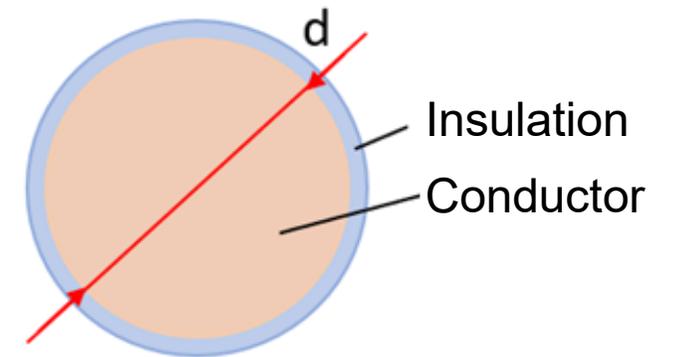
## - continued-

- If the cross-sectional area of the conductor is not given, it must be determined by calculation.
- This can be calculated from the area of the circle (if the conductor is circular in shape) using the radius ( $r=d/2$ ) or the diameter ( $d$ ):

$$A = \frac{d^2\pi}{4} \text{ vagy } A = r^2\pi$$

(the two are equivalent to each other)

- It is important that insulation should not be included in the useful cross-section!
- During calculations, the specific resistance of materials (e.g. copper) is given.



Material	Chemical symbol	$\rho \left( \frac{\Omega \text{mm}^2}{\text{m}} \right)$
Copper	Cu	0,0178
Aluminum	Al	0,0286
Silver	Ag	0,016
Gold	Au	0,022

# Current density of wires

- An important parameter of wires is current density, which specifies the amount of current per unit cross-sectional area of the conductor (wire).

- Symbol:  $J$ , unit of measurement:  $A/mm^2$ .

- Formula:

$$J = \frac{I}{A}$$

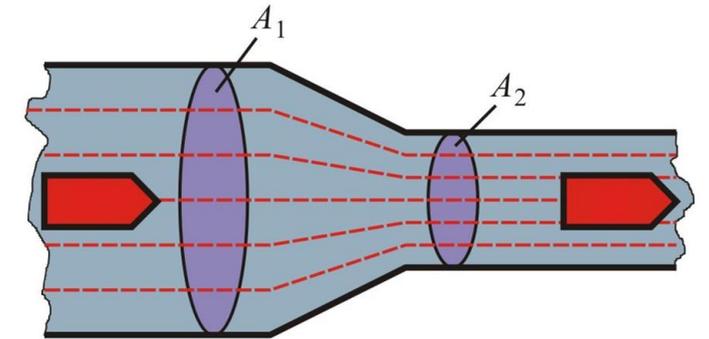
- The permissible value is specified by a standard, which may depend, for example, on:

- The type of installation (free conductor or conductor built into a wall);
- The conductor material (Cu, Al);

- If we are talking about general sizing, 4-5A/mm<sup>2</sup> is a good starting point.

- At the same current, the current density will be higher for a smaller cross-section.

- Furthermore, at higher current densities, the conductor (wire) will heat up more.



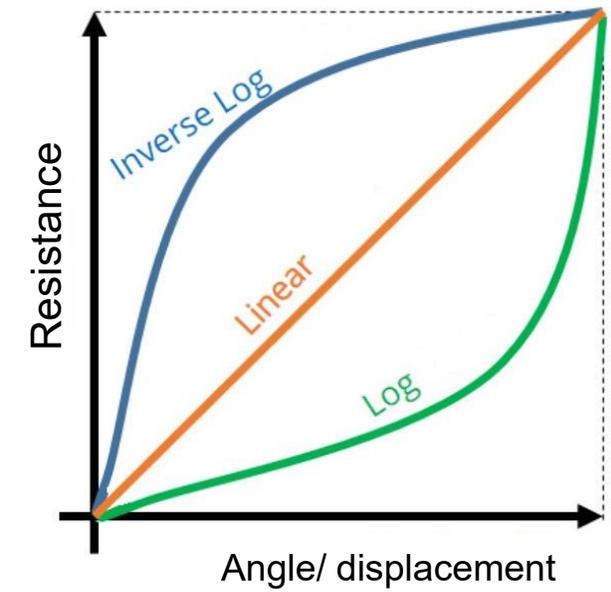
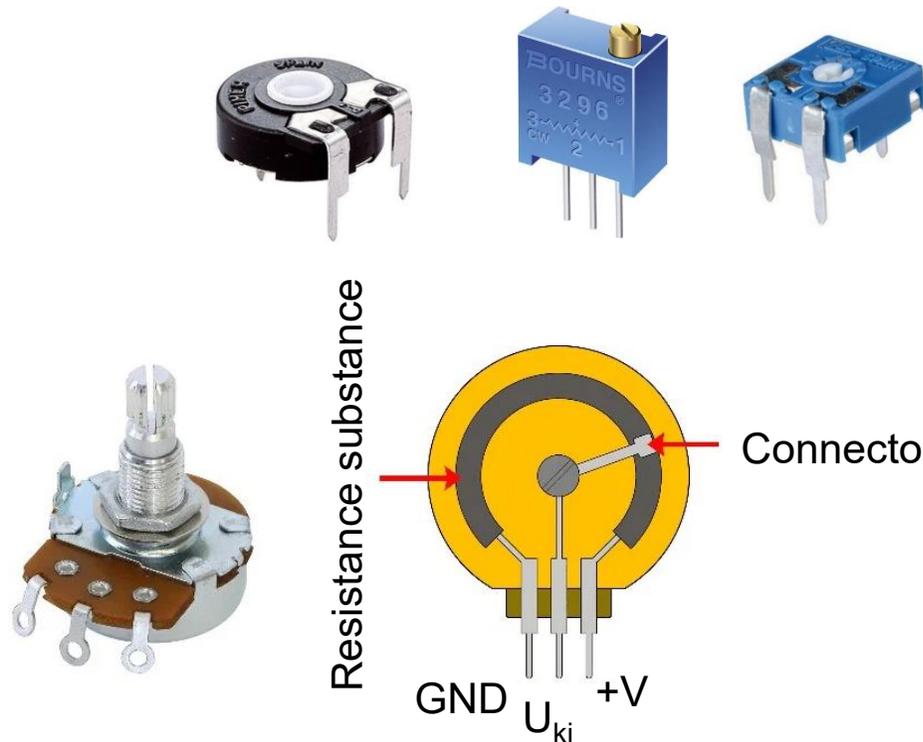
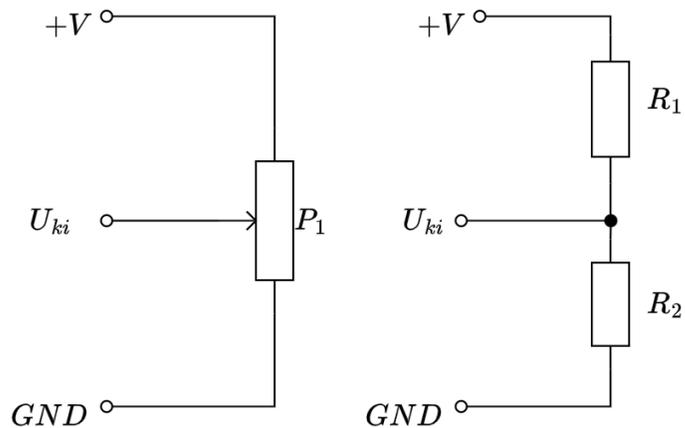
$$J_1 = \frac{I}{A_1} \quad J_1 < J_2 \quad J_2 = \frac{I}{A_2}$$

# Special resistance

- In addition to resistors in the classic sense, there are many other types of resistors
  - Potentiometers, trimmers
  - Voltage-dependent resistors... etc.

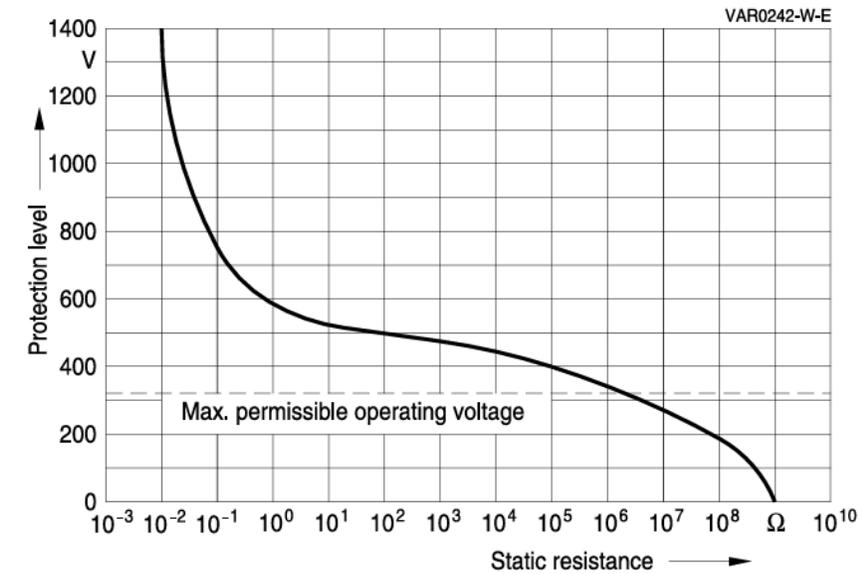
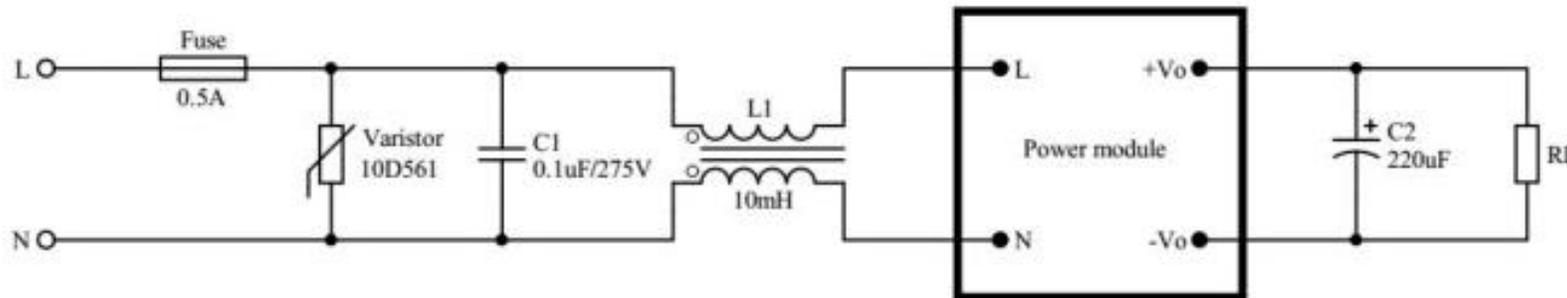
# Potentiometers, trimmers

- Potentiometers and trimmers are variable resistors where the output resistance is a function of angular rotation or displacement
- Potentiometers are generally larger in size, while trimmers can be built directly into the circuit (PCB).
- In terms of their output characteristics, they can be:
  - Linear
  - Logarithmic
  - Inverse logarithmic



# Voltage-dependent resistors

- A voltage-dependent resistor, or VDR (Voltage Dependent Resistor), also known as a varistor, is a voltage-dependent resistor whose resistance varies depending on the amount of voltage applied to it
- At high voltages, its resistance decreases sharply, making it ideal for surge protection and current limiting, but how?



Forrás: tdk-electronics.tdk.com