Electrical Circuits

Ahmad Salmanogli
Room: NC08
salmanogli@cankaya.edu.tr

Introduction

Short Review on Physics

Organization

- Prerequisite: physics II
- Books:
  1. Introductory Circuit Analysis, Robert L. Boylestad, Prentice Hall PTR, 2000, 2003, 2007, 2010;
  2. AC and DC Network Theory, A. J. Pointon, H. M. Howarth, Springer Netherlands, 1991;
  3. Electrical Circuit Theory and Technology, Bird, John, Elsevier Newnes, 2003;
- Assessment:
  - Final Exam: 50%
  - Midterm (one exam): 30%
  - Lab: 20%
  - Work in Class (Bonus): 10%

Basic bibliography:

1. *Introductory Circuit Analysis*, Robert L. Boylestad, Prentice Hall PTR, 2000, 2003, 2007, 2010;

2. *AC and DC Network Theory*, A. J. Pointon, H. M. Howarth, Springer Netherlands, 1991;

3. *Electrical Circuit Theory and Technology*, Bird, John, Elsevier Newnes, 2003;

Additional bibliography:

1. *Circuits Systems with Matlab and PSpice*, Won Y. Yang, Seung C. Lee, Wiley, Asia, 2007.

2. *Linear and Nonlinear Circuits*, L.O. Chua, C.A. Desoer, E.S. Kuh , McGraw-Hill Inc., 1987.

3. *Analog and digital filters: design and realization*, H. Y.,-F. Lam , Prentice_Hall, Inc., Englewood Cliffs, New Jersey, 1979.

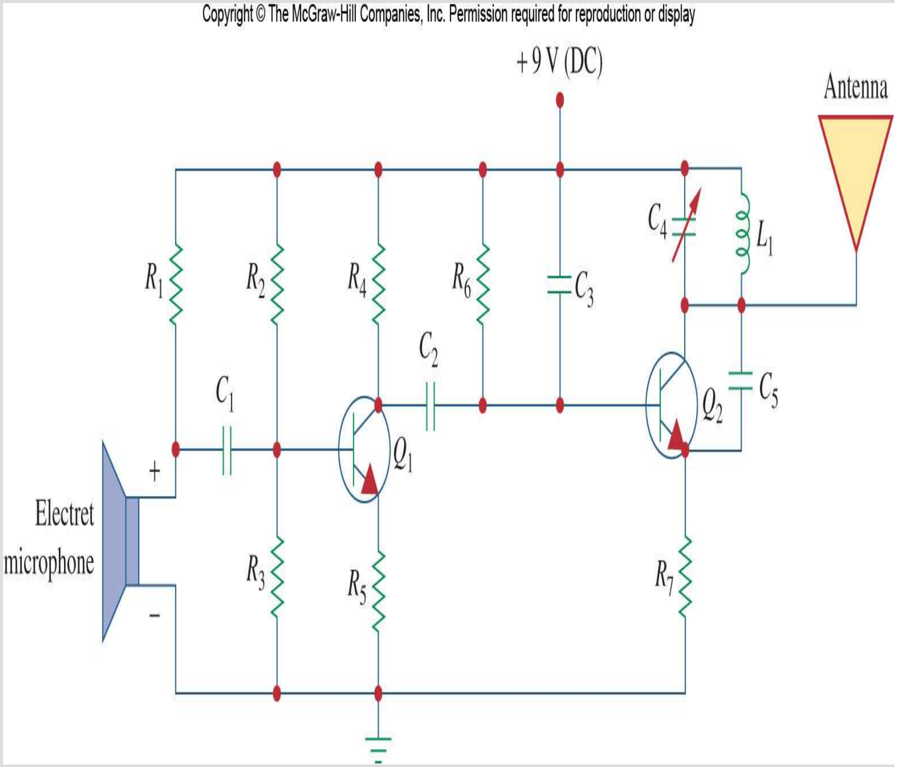
4. *Classical Circuit Theory*, Omar Wing, Springer US, 2009

Course description

1. Basic laws in circuit theory: voltage and current Kirchoff's laws. Real circuit and its mathematical model, Thevenin and Norton theorem.
2. Linear and non-linear passive components and active elements of analog circuits. The basic principles, theorems and methods in the analysis of resistive circuits.
3. Circuits with harmonic currents in steady state - Method of complex numbers, phasor diagrams. Coupled and resonant circuits.
4. Transients, analysis in time and frequency domain
5. The concept of transfer function, amplitude and phase characteristics.
6. Basic concepts of circuits stability.

Electric Circuit

- An electric circuit is an interconnection of electrical elements.
- A circuit consists of a mesh of loops
- Represented as branches and nodes in an undirected graph.
- Circuit components reside in the branches
- Connectivity resides in the nodes and nodes represent wires



Charge

$q = ne$

- Basic SI unit, measured in Coulombs (C)
- "e" charge of electron and "n" is the number
- Counts the number of electrons (or positive charges) present.
- Charge of single electron is $1.602 * 10^{-19}$ C
- One Coulomb = $6.24 * 10^{18}$ electrons.
- Charge is always multiple of electron charge
- Charge cannot be created or destroyed, only transferred.

Current

- The movement of charge.
- We always note the direction of the equivalent positive charges, even if the moving charges are negative.
- It is the time derivative of charge passing through a circuit branch

$$i \equiv \frac{dq}{dt}$$

- Unit is Ampere (A), is one Coulomb/second
- Customarily represented by *i (AC)* or *I (DC)*.

Voltage

- a *difference* in electric potential

  always taken between two points.
- It is a line integral of the force exerted by an electric field on a unit charge.
- $$v = \int E_f dx$$ E_f electric field
- Customarily represented by *u (AC)* or U (DC) or v and V alternativelly.
- The SI unit is the Volt [V].

Power

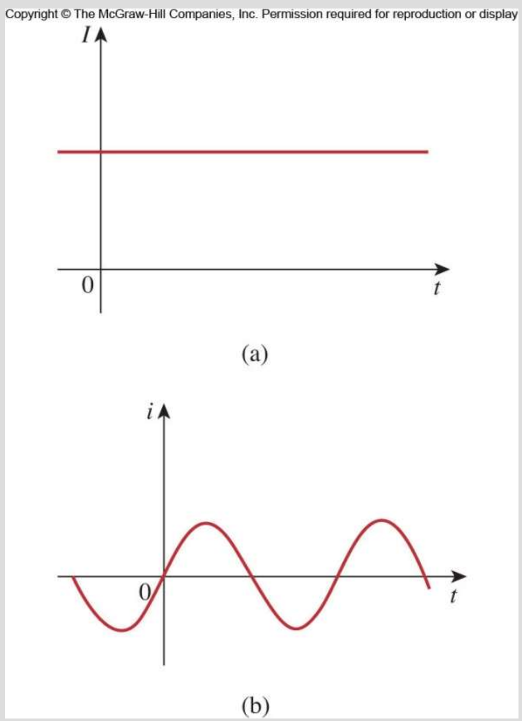
- **Power** is the product of voltage by current.
- It is the time derivative of energy delivered to or extracted from a circuit branch.

$$P \equiv \frac{dE}{dt}$$

- Customarily represented by *P* or S or W.
- The SI unit is the Watt [W].

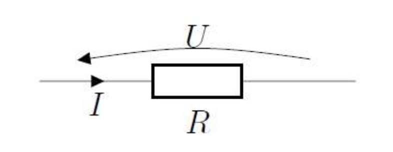
AC vs. DC circuits

- **Direct Current (DC)** is a current that remains constant with time
- A common source of DC is a battery.
- A current that varies sinusoidally with time is called **Alternating Current (AC)**



Basic circuit elements - resistor

Resistors are circuit elements that resist the flow of current. When this is done a voltage appears across the resistor's two wires.
A pure resistor turns electrical energy into heat. Devices similar to resistors turn this energy into light, motion, heat, and other forms of energy.



Resistors don't care which leg is connected to positive or negative. We note the current flow opposite to the voltage. This is called the an "positive charge" sign convention. Some circuit theory books assume "electron flow" flow sign convention.

Basic circuit elements - **resistor**

Resistance is measured in terms of units called "Ohms" (volts per ampere), which is commonly abbreviated with the Greek letter Ω ("Omega"). Ohms are also used to measure the quantities of impedance and reactance. The variable most commonly used to represent resistance is "r" or "R". Resistance is defined as:

$$r = \frac{\rho L}{A}$$

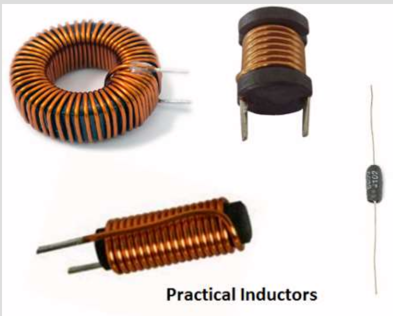
where ρ is the resistivity of the material, L is the length of the resistor, and A is the cross-sectional area of the resistor.

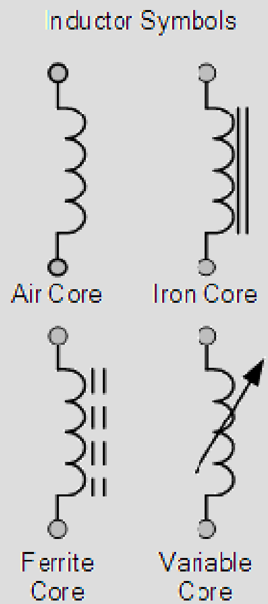
Conductance is the inverse of resistance. Conductance has units of "Siemens" (S). The associated variable is "G":

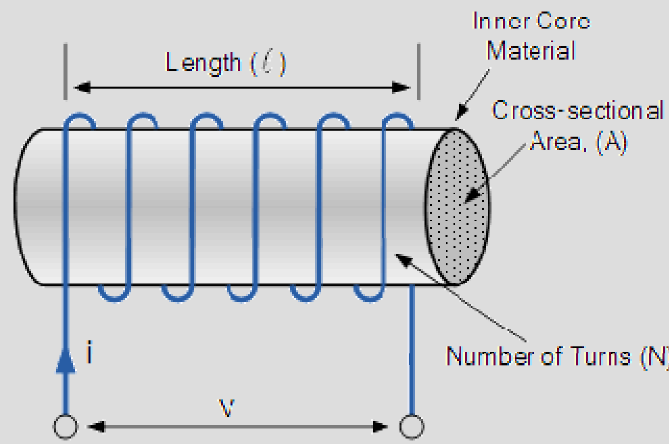
$$G = \frac{1}{r}$$

The relation between voltage and current: V = r*I

Basic circuit elements - **inductor**







Inductance is the property whereby an inductor exhibits opposition to the change of current flowing through it, measured in henrys (H).

$$L = \frac{N^2 \mu A}{l}$$

Where μ is the permeability of the dielectric material

Basic circuit elements – **inductor (2)**

- The dependence between the current and the voltage of the inductor is described by the equations:

$$v = L\frac{d\,i}{d\,t} \qquad i = \frac{1}{L}\int_{t_0}^{t} v(t)\,d\,t + i(t_0)$$

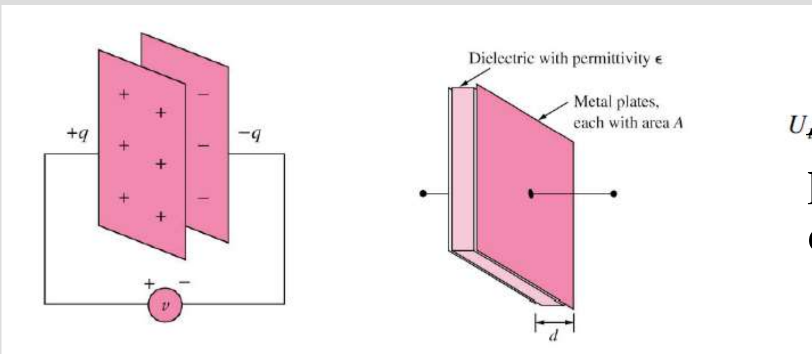
- The power stored by an inductor:

$$w = \frac{1}{2}L\,i^2$$

An inductor acts like a short circuit to dc (di/dt = 0) and its current cannot change abruptly.

Basic circuit elements - capacitor

A capacitor is a passive element designed to **store energy** in its **electric field.**



A **capacitor consists of two conducting plates separated** by an insulator (or dielectric).

- **Capacitance** *C* is the ratio of the charge *q* on one plate of a capacitor to the voltage difference *v* between the two plates, measured in farads (F).

$$C = \frac{\varepsilon\ A}{d}$$

Where ε is the permittivity of the dielectric material between the plates, A is the surface area of each plate, d is the distance between the plates.

Basic circuit elements – capacitor (2)

- The dependence between the charge and voltage is:

$$q = C\,v$$

- Then current –voltage relationship of the capacitor is described by the equations:

$$i = C\frac{d\,v}{d\,t} \quad \text{and} \quad v = \frac{1}{C}\int_{t_0}^{t} i\,d\,t + v(t_0)$$

- The power stored by an inductor:

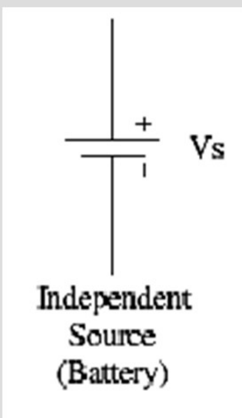
$$w = \frac{1}{2} C\,v^2$$

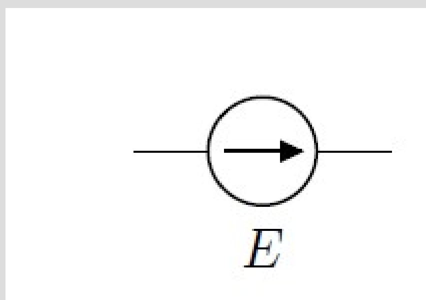
A capacitor is an **open circuit to dc (dv/dt = 0). And** its voltage **cannot change abruptly (depends on integral of i).**

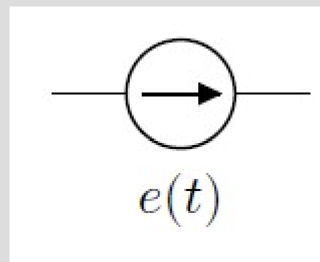
Circuit Elements **Ideal**

Independent Voltage Source

- provides a specified voltage or current that is completely independent of other circuit variables
- The voltage at the nodes is strictly defined by voltage of the source, the current flow depends on the other elements in the circuit







$$e(t) = A\sin(\omega t + \varphi)$$

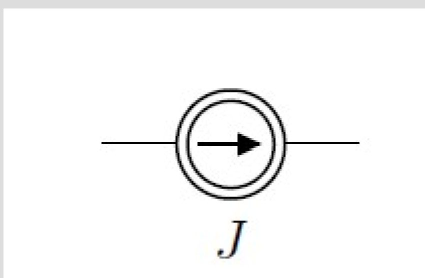
The ideal voltage source is only a mathematical model.

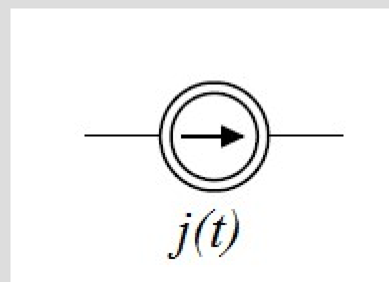
Generally we can divide the voltage sources into three groups:

- Batteries
- Generators
- Supplies

Circuit Elements **Ideal independent current source**

- The current flow in the branch is strictly defined by current of the source, the voltage at the nodes of the source depends on the other elements in the circuit
- The symbols used for AC current sources (similarly as for voltage sources) are the same as for the DC current sources, but described with noncapital letters (e.g. j(t)).

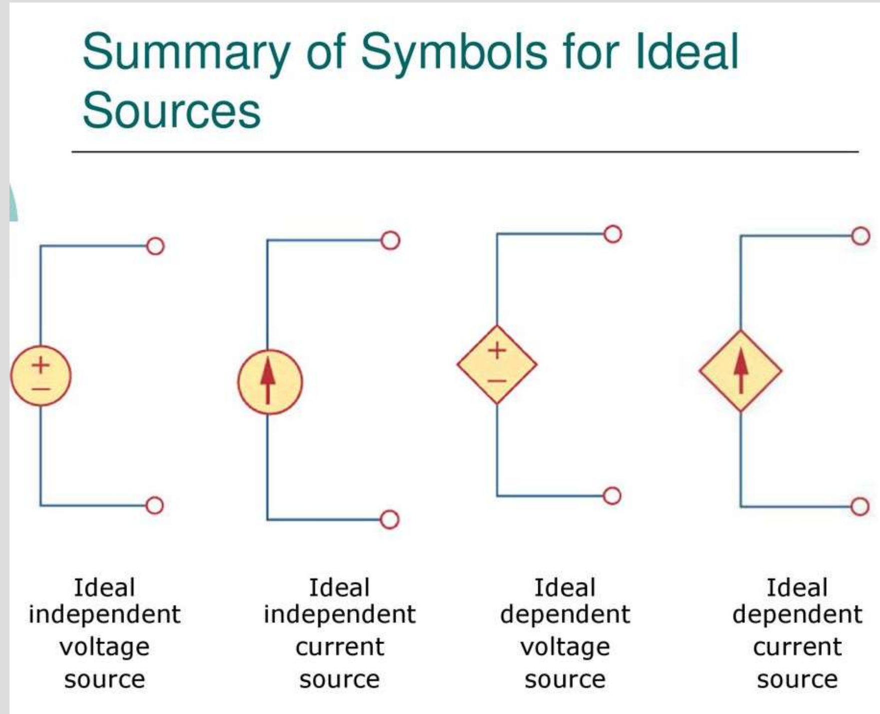


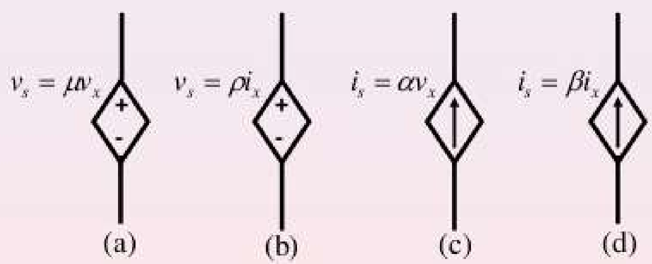


$$j(t) = A\sin(\omega t + \varphi)$$

The ideal current source similarly to ideal voltage source is only a mathematical model.

Circuit Elements – **dependent sources**





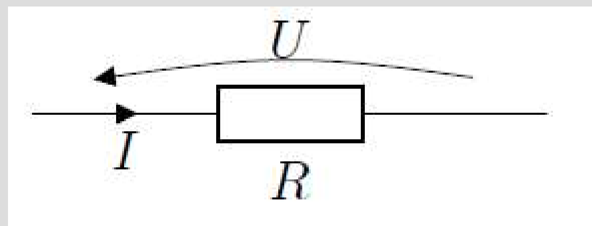
Symbol for (a) ideal voltage controlled voltage source , (b) ideal current controlled voltage source, (c) ideal voltage controlled current source, (d) ideal current controlled current source.

Ohms Law

The potential difference (voltage) across an ideal conductor is proportional to the current through it.

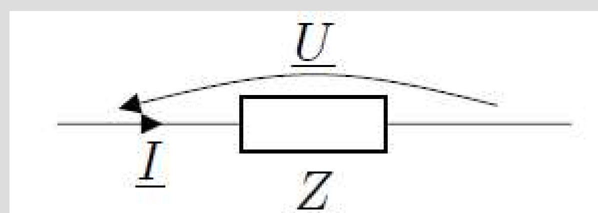
For the DC

$$U = IR$$



For the AC

$$\underline{U} = \underline{I} \cdot \underline{Z}$$



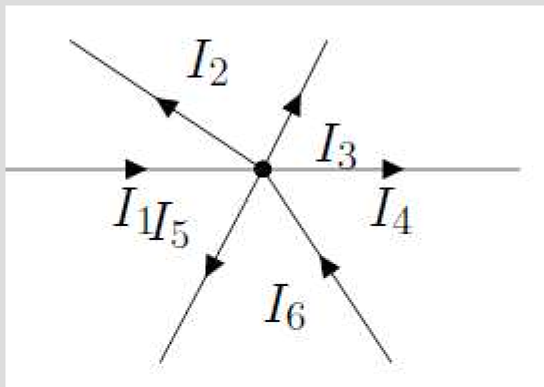
where: *U - voltage I - current R – resistance, Z- inductance*

Kirchhoff’s Circuit Laws

- Kirchhoff’s circuit laws were first described in 1845 by Gustav Kirchhoff. They consist from two equalities for the lumped element model of electrical circuits. They describe the current and voltage behaviour in the circuit.

Kirchhoff's First Law - Kirchhoff's Current Law (KCL)

- The algebraic sum of currents in a network of conductors meeting at a node is zero.



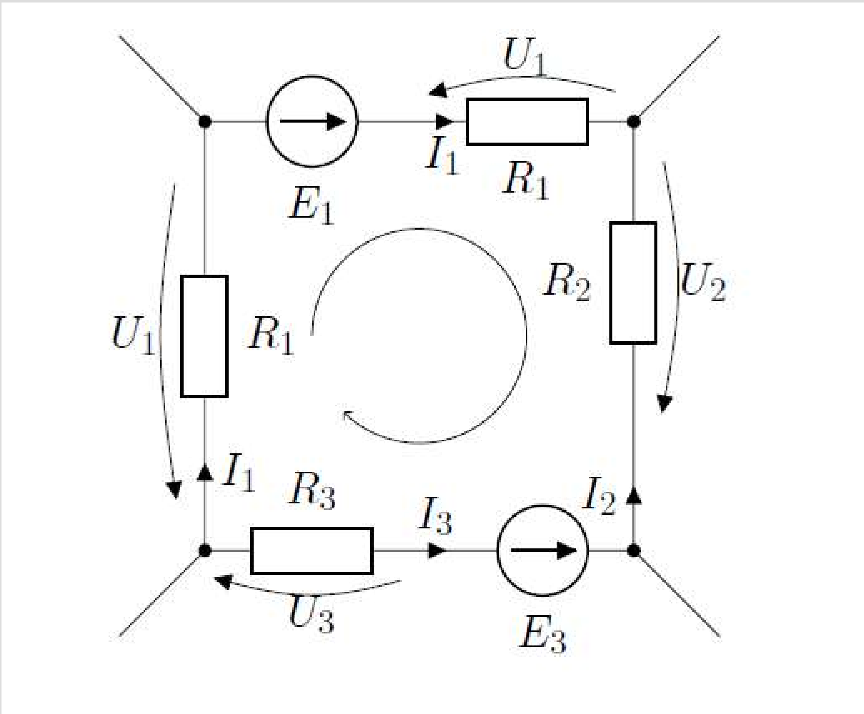
It can be described by the equation:

$$\sum_i I_i = 0$$

The currents flowing into the node (*I1, I6) we describe as positive, the currents* flowing out the node (*I2, I3, I4, I5) we describe as negative.*

Kirchhoff's Second Law - Kirchhoff's Voltage Law (KVL)

- The algebraic sum of the potential rises and drops around a closed loop or path is zero.



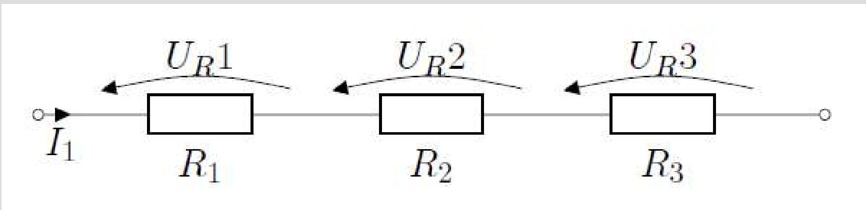
$$\sum_i U_i = 0$$

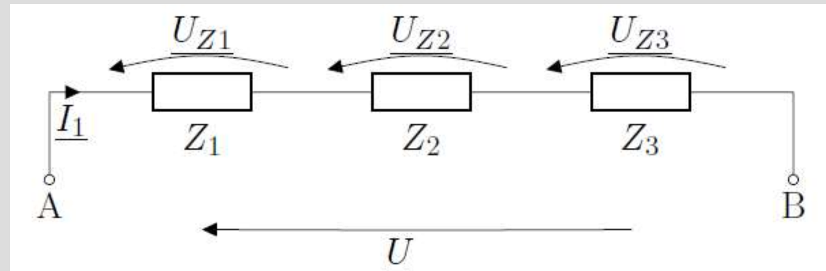
where U_i *describes both the potential drops at the elements and the voltages generated* by sources.

To use the KVL one need to set up a rotation in the circuit. Potentials with direction of the circuit have a positive sign, voltage opposite to the direction of circulation of the circuit have a negative sign.

Series Connection

- All components are connected end-to-end.





- Voltage drops add to total voltage.

$$U_1 + U_2 + U_3 + ... = U$$

- Due to all components goes the same (equal) current.

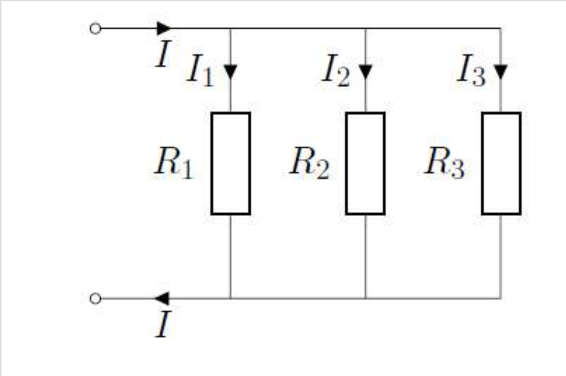
$$I_1 = I_2 = I_3 = ...$$

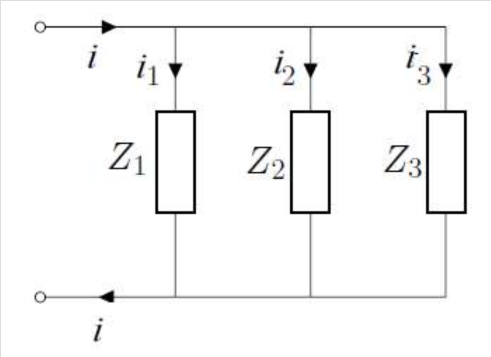
- Impedance (or simply resistance in DC) add to total impedance (resistance).

$$R_1 + R_2 + R_3 + ... = R$$

Parallel Connection

- All components are conected between the same two sets of electrically common points.





- Currents add to total current.

$$I_1 + I_2 + I_3 + \ldots = I$$

- Voltage drop on the components are the same.

$$U_1 = U_2 = U_3 = \ldots = U$$

- Conductances (inverse of resistance) add to total conductance.

$$G_1 + G_2 + G_3 + \ldots = G$$

or

$$\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots = \frac{1}{R}$$

Series-Parallel Connection

- Typical circuits have some series connected components in some parts of the circuit and parallel in others. Then it is impossible to apply a single set of rules to the all circuit. Instead, it is possible to identify which parts of that circuit are series and which parts are parallel, then selectively apply series and parallel rules.