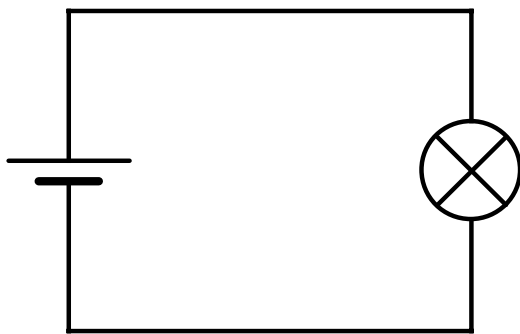


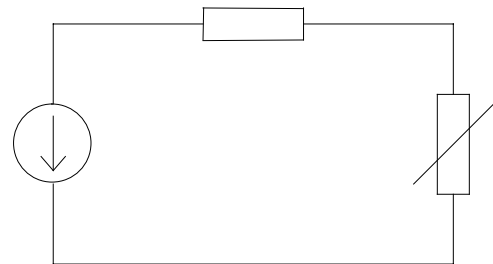
ELECTRICAL CIRCUIT, BASIC CIRCUIT QUANTITIES, CHARACTERISTIC QUANTITIES



Electrical device



Scheme



Electrical circuit

Electrical device

- a kind of technical device, that utilize the conversions of electrical energy
- it utilize the properties of the **electromagnetic field**
- **physical approach** of description of the circuit
- **system approach** of description of the circuit

physical approach – basic quantities:

- the electric field intensity vector \vec{E} [V/m]
- magnetic flux density vector \vec{B} [T]

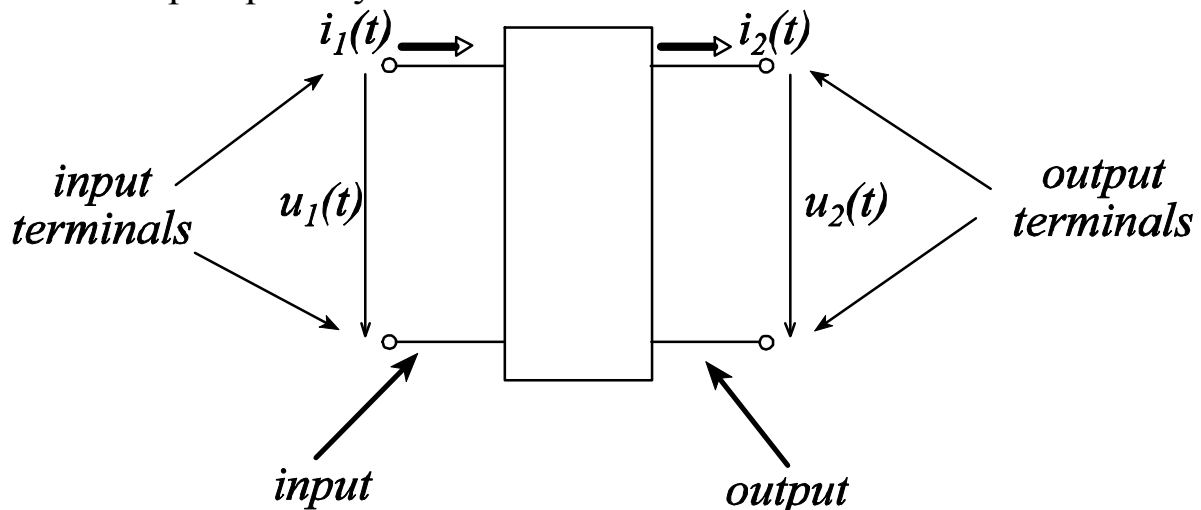
⇒ **Maxwell's equations, Electromagnetic wave equation, the continuity equation** ⇒ **very hard and laborious to perform**

- limited velocity of EM wave propagation – at the most velocity of the light c – **space considerations could be very important**
- in some volumes is the energy of the **magnetic field** much greater than the energy of the electric field → simplification – we will solve only magnetic field separately – we can introduce **inductance** to characterize properties of the field
- in other volumes is the energy of the **electric field** much greater than the energy of the magnetic field → simplification – we will solve only electric field separately – we can introduce **capacitance** to characterize properties of the field
- **resistance**, in this regard, is quantity, which characterize ratio of integral variables, which describes EM field – **voltage** and **current** – **circuit quantities**

system approach – parts of the device are considered as collection of simpler units that realize partial functions

units has input and output terminals and voltages and currents are *input* and *output* (*exciting* and *excited*) quantities

response – output quantity



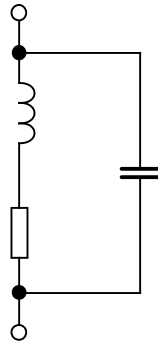
Decomposition – unit is considered as connection of more simple parts

Elements – simple parts that cannot be decomposed, their properties are described by the relations between input and output quantities

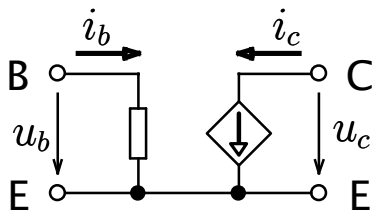
Models – circuit approximation of some units (transistors, diodes, etc.) by simple elements

Models – circuit approximation of some units with complex physical description (transistors, diodes ...) by combination of distinct number of simple circuit elements (different complexity in different cases and degree of omission of the less important qualities of the circuit element)

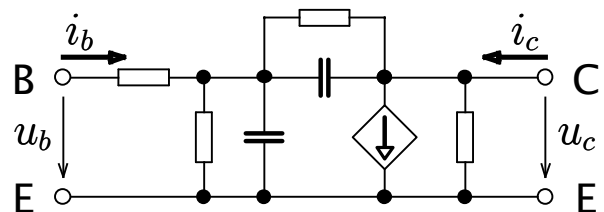
Model of the coil (coil winding)



Two different examples of bipolar transistor models

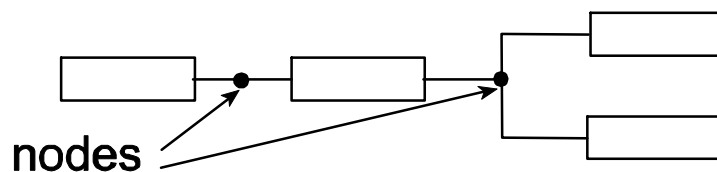


Simplified model of bipolar transistor for small signal and low frequencies

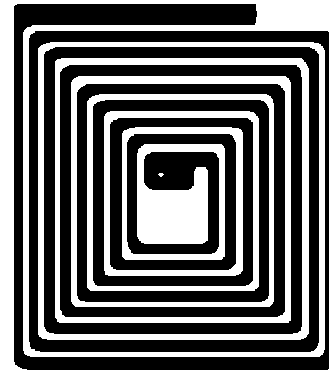
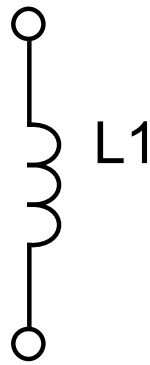


Simplified model of bipolar transistor for high frequencies

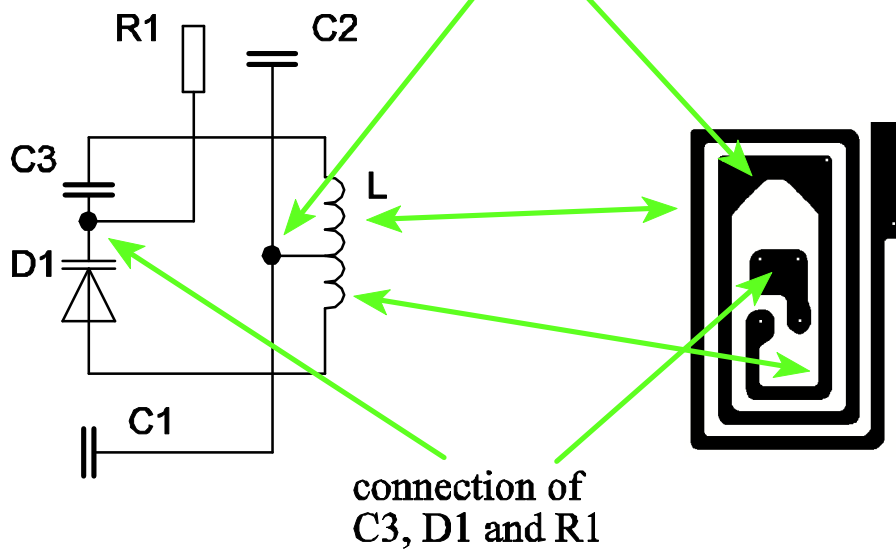
Scheme – drawing, in which the elements are represented by **agreed graphical symbols**, connection of terminals by solid lines and connection of wires by the dot



Two examples of coil implementation on printed circuit
 (generally, printed circuit implements interconnections between circuit elements, and inductances and capacitances are **parasitic** and unwanted)



Simple coil implementation
connection of
C1, C2 and L



This combines both implementation of two coils and simple wire interconnection

Analysis

- circuit elements, the structure of the circuit and the waveforms of the input quantities are given
- the aim is to find waveforms of the output quantities

Synthesis

- the relation between input and output quantities is given
- the aim is to find appropriate structure of the circuit

Classification of circuits

energetic devices – used to produce, transfer and utilize electrical energy

devices for transfer and processing of information – sources of electrical energy that carries an information are **transmitters**, components for evaluation **receivers**

analogue – waveforms are continuous functions of real time

discrete in time – waveforms are defined only at distinct time instants

digital – waveforms are sampled and quantified (defined only at distinct time instants, acquired finite number of distinct values, expressed by numbers)

linear – the relationship between input and output quantities is linear

non-linear – the relationship between input and output quantities is not linear function

lumped circuits – finite number of circuit elements, its spatial arrangement usually is not important

distributed circuits (circuits with distributed elements) – infinite number of infinitesimally small elements, spatial arrangement is essential, limited velocity of propagation of electricity, e.g. TV coaxial cable

Basic circuit quantities and parameters

Charge

symbol: q

unit: coulomb [C]

basic particles: electrons – negative, protons – positive
⇒ attractive and repulsive forces

elementary charge: $e \doteq 1.6021 \cdot 10^{-19} \text{ C}$

irreplaceable, uncreateable property of elementary particles – **charge conservation law**

Current

¿ What the current is ? – Current passing metal conductor, vacuum, dielectric of capacitor ...
⇒ current electric, Maxwell's (displacement), polarization

Electric – organized motion of charged particles $i = \frac{dq}{dt}$

symbol: i

unit: ampere [A] (is equal to a flow of one coulomb of charge per second)



Take a think: the velocity of electron movement in metal is just about mm / s ($v = \frac{I}{neS}$), but velocity of propagation of electricity is near velocity of the light c (velocity of propagation depends on spatial arrangement of conductors, and parameters of insulator between it!!!)

Maxwell's (displacement) – capacitor: $i_M = \epsilon_0 \frac{\partial E}{\partial t}$

Total – one of Maxwell's equations: $\text{rot } \mathbf{H} = \nabla \times \mathbf{H} = \mathbf{i} + \epsilon_0 \frac{\partial \mathbf{E}}{\partial t}$, $\mathbf{i} = \sigma \mathbf{E}$

Scalar variable, BUT – positive orientation is defined as a flow of positive charge (opposite to the electron motion in metal) – current is passing from positive terminal to the negative one

force effects on charges:

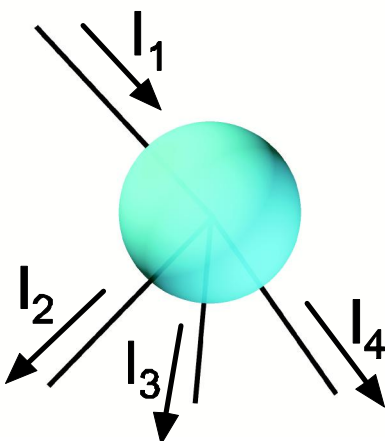
the force acting in electric field on a constant point charge Q is

$$\mathbf{F}_e = Q \mathbf{E} \text{ [N]},$$

\mathbf{E} [V/m] is electric flux density

The force acting on charged particle moving through a magnetic field with a velocity \mathbf{v} [ms^{-1}]:

$$\mathbf{F}_m = Q [\mathbf{v} \times \mathbf{B}] \text{ [N]}$$



Current Kirchhoff law (KCL)

$$\sum_{k=1}^n i_k = 0$$

Voltage

Scalar quantity, rate of work effects of the electric field (work of the electric field intensity vector along a certain path from the point A to the point B)

unit: volt [V]

$$u_{AB} = \frac{A}{q}$$

where A [J] work that is done by the forces of electric field

q [C] moved charge

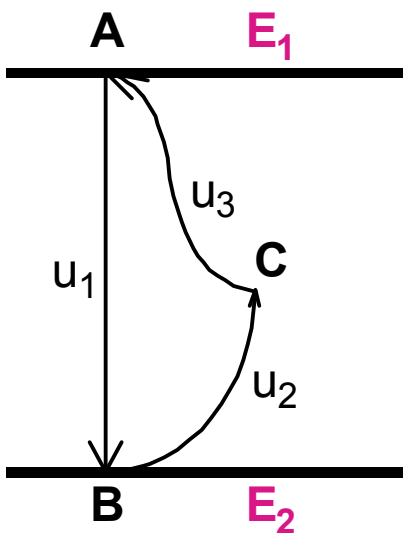
AB points along a certain path

$$A = \int_{A(s)}^B \mathbf{F}_e \cdot d\mathbf{s} = q \int_{A(s)}^B \mathbf{E}_e \cdot d\mathbf{s} = q u_{AB}$$

$$u_{AB(s)} = \int_{A(s)}^B \mathbf{E} \cdot d\mathbf{s}$$

$$u_0 = \oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_C}{dt}$$

where $\Phi = \int_S \mathbf{B} \cdot d\mathbf{S}$ is magnetic flux of vector \mathbf{B} threading through area S [m²].



$$u_{AB} = \int_A^B \mathbf{E} ds$$

$$u_{BC} = \int_B^C \mathbf{E} ds$$

$$u_{CA} = \int_C^A \mathbf{E} ds$$

$$u_{AB} + u_{BC} + u_{CA} = 0$$

Voltage Kirchhoff law (KVL)

$$\sum_{k=1}^n u_k = 0$$

Power

$$p(t) = \frac{dA}{dt} = \frac{dA}{dq} \frac{dq}{dt} = u(t)i(t)$$

Resistance

characterize parameters of the electric field in the conducting media

... with respect to energy converted into heat

circuit element: **resistor**

unit: ohm [Ω]

Ohm's law (only linear media!): $u = Ri$

Capacitance

characterize parameters of the electric field in the non-conducting media (dielectrics)

... with respect to the stored energy of electric field

circuit element: **capacitor**

charge: $q = Cu$

unit: Farad [F]

stored energy: $W_e(t) = \frac{1}{2}Cu^2(t)$

Inductance

characterize parameters of the magnetic field of the conductors flowed through by currents

... with respect to the stored energy of magnetic field

circuit element: inductor

magnetic flux: $\Phi_c = Li$

unit: Henry [H]

stored energy: $W_m(t) = \frac{1}{2}Li^2(t)$

Circuit variables

Determined – can be expressed by a mathematical functions

Non-determined (stochastic) – random process

Determined:

- continuous
- discontinuous

Determined:

- **stationary** – do not change their magnitude and direction during the time interval of observation – **direct current DC**
- **periodic** – repeat their instantaneous values from the time interval T (period), so $u(t + kT) = u(t)$
- **non-periodic**

Periodic:

- general
- pulsing
- alternating AC