AGH University of Science and Technology
im. Stanisława Staszica w Krakowie
Faculty of Computer Science, Elelctronics and Telecommunications
DEPARTMENT OF ELECTRONICS

ELECTRONIC DEVICES

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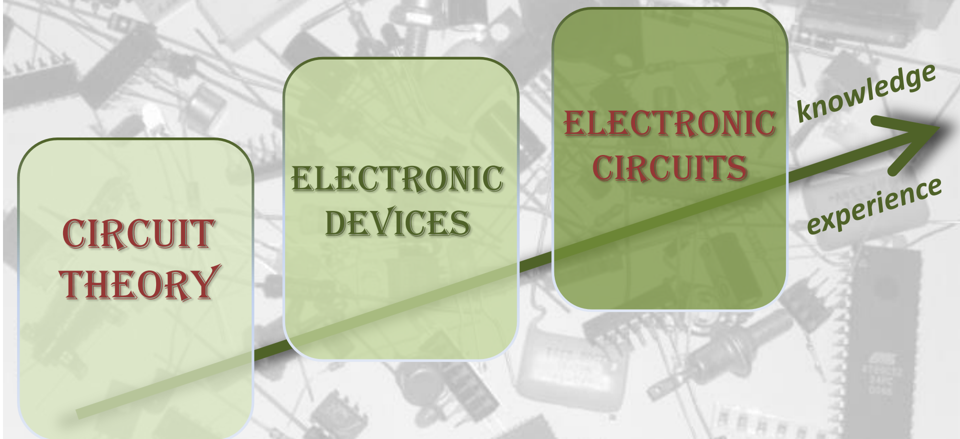
ELECTRONIC DEVICES

WHAT DO WE ALREADY KNOW, AND WHAT WE WILL LEARN ?



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ELEMENT vs DEVICE

electronic element ?= electronic device

conducts electrical current, produce an electrical field, etc. (resistor, capacitor, voltage source, etc.)

more „complicated” and sophisticated element offering additional functionalities (transistor, diode, etc.)

very often:

ELEMENT ≡ DEVICE

especially on the market ☺

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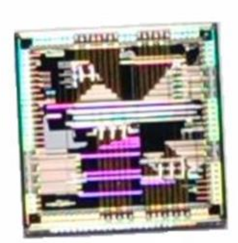
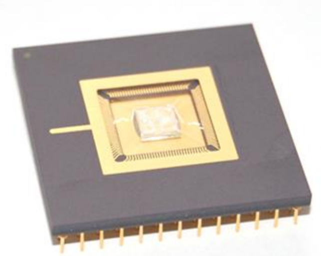
ELEMENT vs DEVICE

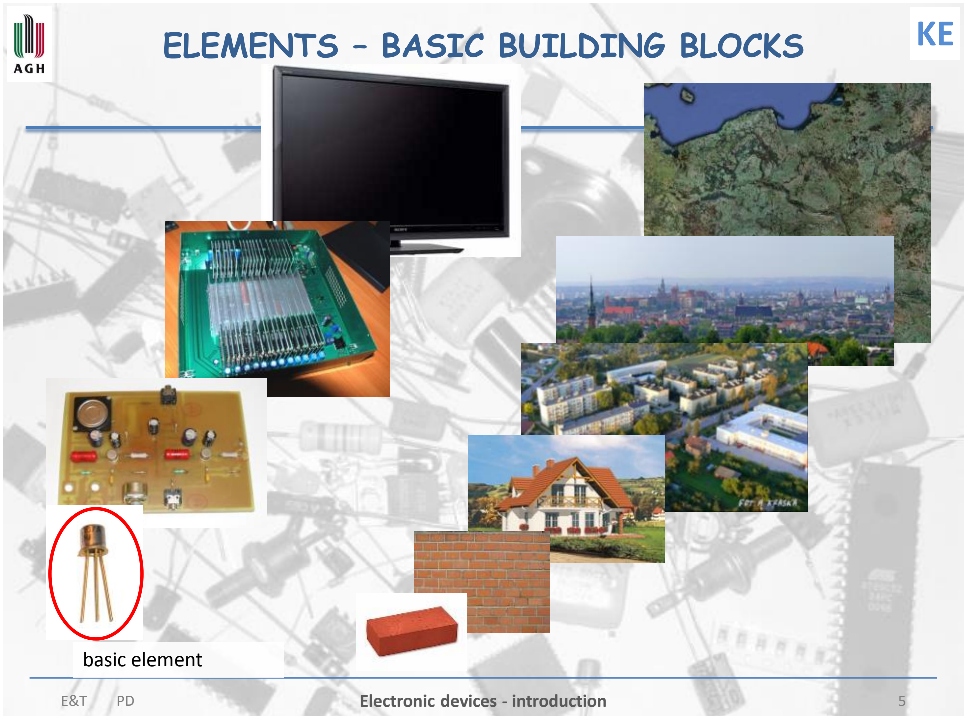


Integrated circuit substrate consisting of electronic components connected in a way to provide electrical functions



The same circuit packaged in a casing – electronic device

The pictures show integrated circuit designed in the Department of Electronics AGH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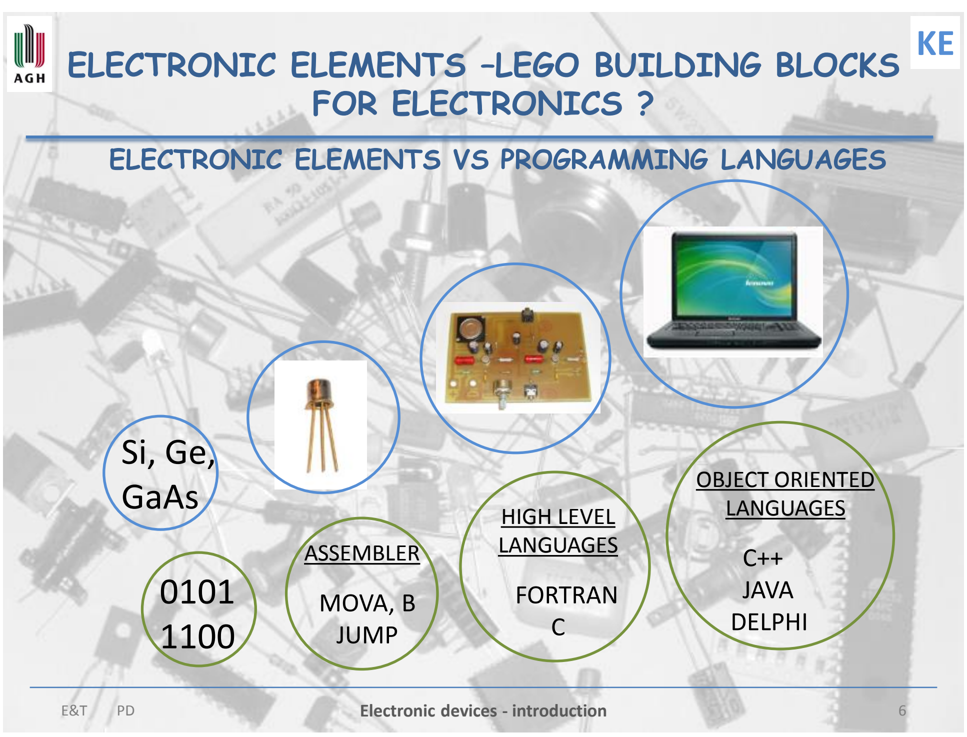
ELEMENTS – BASIC BUILDING BLOCKS
basic element
E&T PD
Electronic devices - introduction
5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ELECTRONIC ELEMENTS –LEGO BUILDING BLOCKS FOR ELECTRONICS ?
ELECTRONIC ELEMENTS VS PROGRAMMING LANGUAGES
Si, Ge, GaAs
0101
1100
ASSEMBLER
MOVA, B
JUMP
HIGH LEVEL LANGUAGES
FORTRAN
C
OBJECT ORIENTED LANGUAGES
C++
JAVA
DELPHI
E&T PD
Electronic devices - introduction
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Do they have sth in common ?

...ELECTRONICS?

...ELECTRICITY?

...AUTOMATION?

...COMPUTER SCIENCE?

...TELECOMMUNICATIONS?

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WHAT IS ELECTRONICS?

Electronics

From Wikipedia, the free encyclopedia

This article is about the technical field of electronics. For personal-use electronic devices, see consumer electronics. For the scientific magazine, see Electronics (magazine).

This article **needs additional citations for verification**. Please help improve this article by adding citations to reliable sources. Unsourced material may be challenged and removed. *(July 2012)*

Electronics deals with electrical circuits that involve active electrical components such as vacuum tubes, transistors, diodes and integrated circuits, and associated passive interconnection technologies. The nonlinear behaviour of active components and their ability to control electron flows makes amplification of weak signals possible and electronics is widely used in information processing, telecommunication, and signal processing. The ability of electronic devices to act as switches makes digital information processing possible. Interconnection technologies such as circuit boards, electronics packaging technology, and other varied forms of communication infrastructure complete circuit functionality and transform the mixed components into a regular working system.

Surface mount electronic components

Electronics is distinct from electrical and electro-mechanical science and technology, which deal with the generation, distribution, switching, storage, and conversion of electrical energy to and from other energy forms using wires, motors, generators, batteries, switches, relays, transformers, resistors, and other passive components. This distinction started around 1906 with the invention by Lee De Forest of the triode, which made electrical amplification of weak radio signals and audio signals possible with a non-mechanical device. Until 1950 this field was called "radio technology" because its principal application was the design and theory of radio transmitters, receivers, and vacuum tubes.

Today, most electronic devices use semiconductor components to perform electron control. The study of semiconductor devices and related technology is considered a branch of solid-state physics, whereas the design and construction of electronic circuits to solve practical problems come under electronics engineering. This article focuses on engineering aspects of electronics.

In Electronics, it is essential to control elelctrons flow in gases, vacuum and semiconductors.

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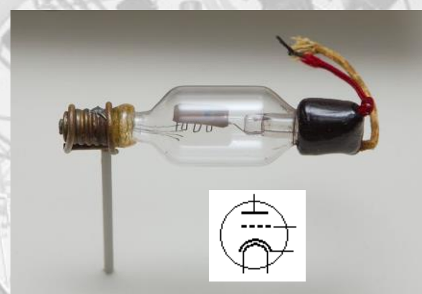
A BIT OF HISTORY

WHEN DID WE START SAYING „ELECTRONICS"?

First amplifying electronic tube was designed in (**1906** or **1908**) by Lee de Forest – it was a **TRIODE**



First electronic vacuum tube was invented in **1904** by John Ambrose Fleming – it was a **DIODE**

Source: http://narrator.up.pl/

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A BIT OF HISTORY

FIRST TRANSISTOR

16.12.1947, Bell Telephone Laboratories

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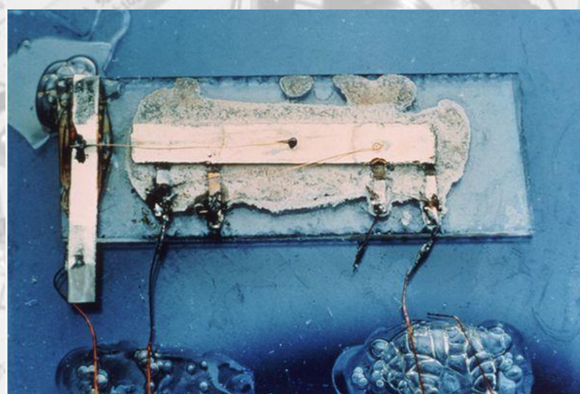
A BIT OF HISTORY

FIRST SOLID STATE CIRCUIT (INTEGRATED CIRCUIT)



07.1958, Jack Kilby, Texas Instruments

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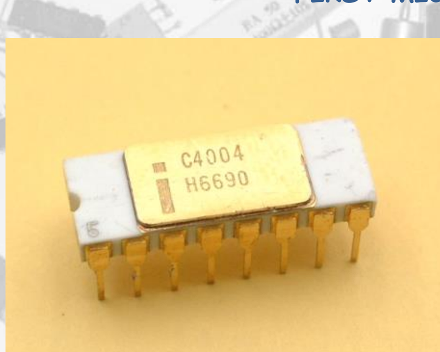
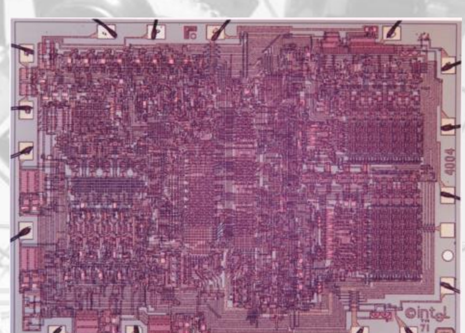
A BIT OF HISTORY

FIRST MICROPROCESSOR





1971, INTEL (**INT**egrated **EL**ectronics)

2300 transistors,
PMOS technology,
gate 10µm,
Operating frequency 108kHz

Source: http://www.cpu-zone.com/4004.htm, INTEL (http://www.intel.com/museum)

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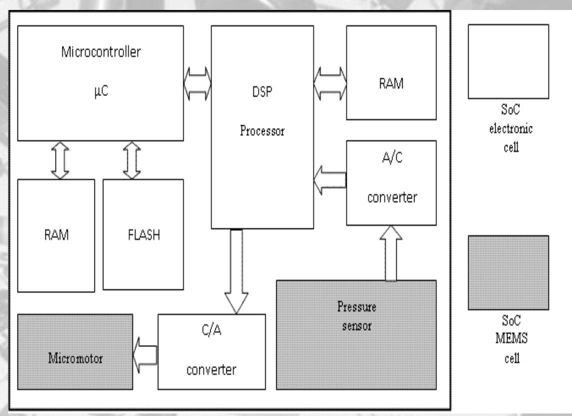
ELELCTRONICS NOWADAYS

SYSTEMS ON CHIP (SOC)



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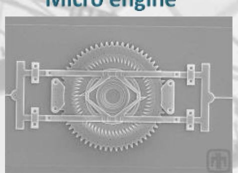
ELELCTRONICS NOWADAYS

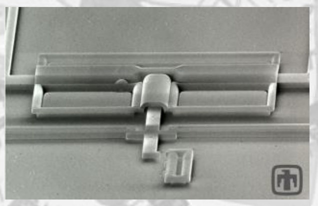
MICROMECHANICAL SYSTEMS MEMS

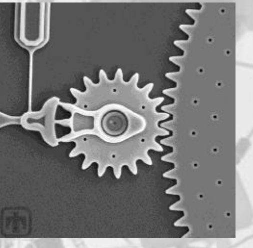
Micro engine



1 µm

Micro pump





Micro gear

'Courtesy of Sandia National Laboratories, SUMMiT(TM) Technologies, www.mems.sandia.gov'

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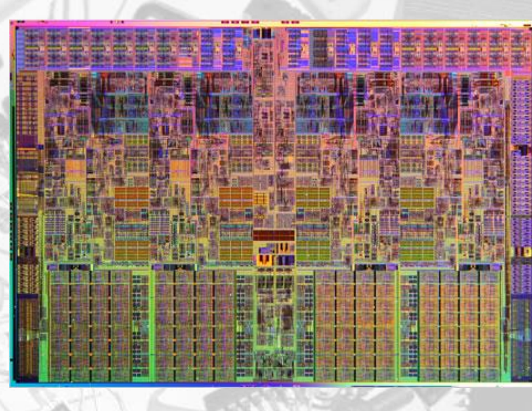
ELELCTRONICS NOWADADAYS



731 000 000 transistors,
CMOS technology,
gate 45nm,
operating frequency 3,2 GHz

Źródło: INTEL

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CLASSIFICATION OF ELEKTRONIC DEVICES

Electronic Devices

Passive

- Resistor
- Capacitor
- Coil
- Diode

Active

- Bipolar transistor
- Field effect transistor
- Tiristor

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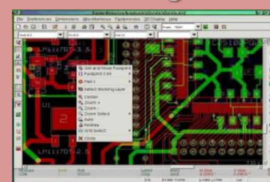
DIFFERENT LOOKS ON ELELCTRONIC DEVICES

Technology

Design



Service

Source : http://www.zgapa.pl,

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SCOPE OF THE COURSE

- Resistor, capacitor, coil
- Physics of semiconductors, *p-n* junction
- Diode
- Field effect transistors
- Bipolar junction transistor
- Other semiconductor devices
  - termistor, piezoresistor, gaussotron, hallotron
  - IGBT, tiristor, triak, V-MOS, D-MOS, Peltier module, CCD, etc.
- Electronic elements in integrated circuits

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ORGANIZATIONAL ISSUES

- **Lecture**
  - Exam
    (written test, or oral form)
- **Laboratory**
  - grade, credit
    (practical exercises according to a schedule)

Final grade is estimated according to:

exam results 60% and laboratory 40%

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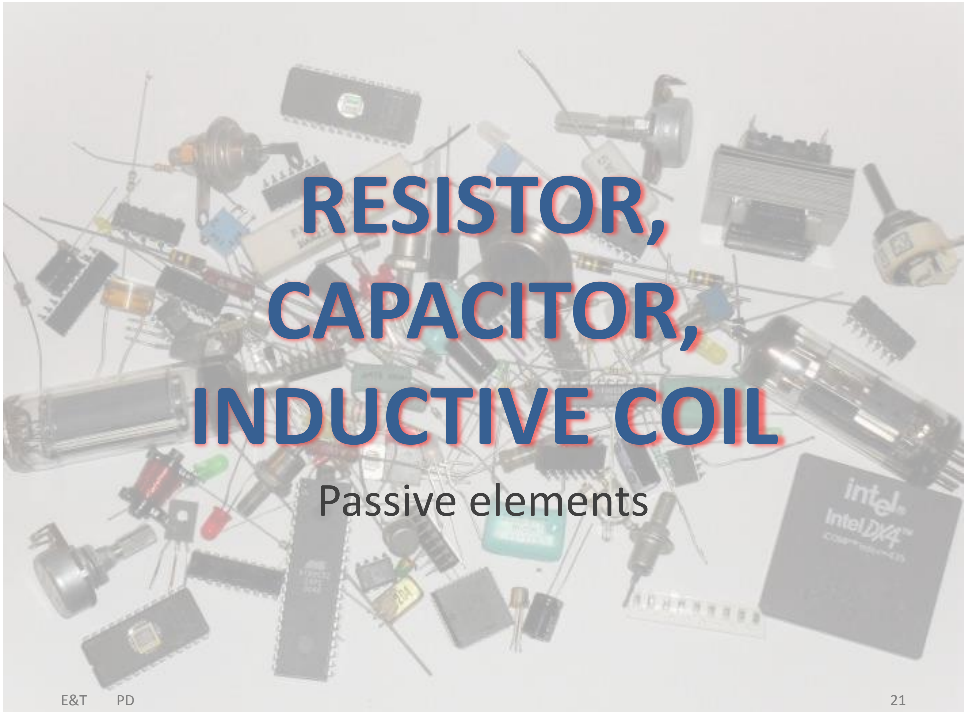
WHERE YOU CAN FIND MORE INFORMATION?

- Biblioteka - podręczniki akademickie
  - Marciniak W. „Przyrządy półprzewodnikowe i układy scalone ”, Warszawa, WNT, 1987
  - Polowczyk M., Klugmann E. „Przyrządy półprzewodnikowe”, Gdańsk, Wyd. PG, 2001
  - Polowczyk M. „Elementy i przyrządy półprzewodnikowe powszechnego zastosowania”, Warszawa, WKŁ, 1986
  - Świt A., Pułtorak J. „Przyrządy półprzewodnikowe”, Warszawa, WNT, 1979
  - Horowitz P., Hill W. „Sztuka elektroniki. Cz. 1”, Warszawa, WKŁ, 2003
  - Tietze U., Schenk Ch. „Układy półprzewodnikowe”, Warszawa ,WNT, 2009
  - Koprowski J. „Podstawowe przyrządy półprzewodnikowe”, Kraków, Wyd. AGH, 2009
- Internet
  - Our web page (http://www.scalak.elektro.agh.edu.pl/?q=pl/node/464)
  - Other web portals



RESISTOR, CAPACITOR, INDUCTIVE COIL

Passive elements

RESISTOR

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passing through a hole, threaded

SMD
Surface Mount Device

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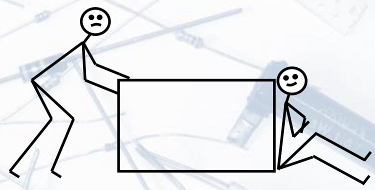
RESISTOR

łac. resistere – to impose resistance



Resistor imposes resistance on the way of electrical current in an circuit

It is characterized by an electrical resistance

The higher resistance the lower the current flowing in a circuit

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RESISTOR

Why do we need and use elements that are obstacles on the way of electrical current?

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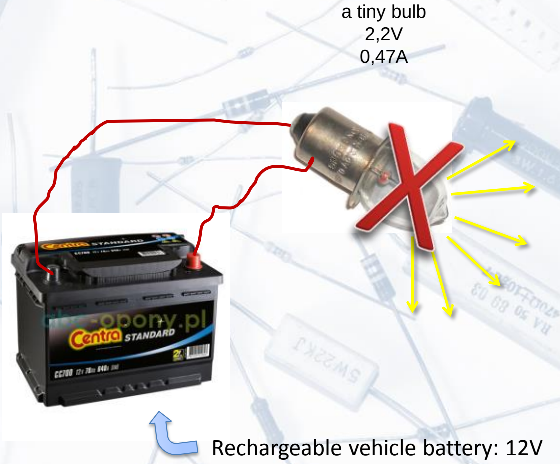
RESISTOR – what is it for?



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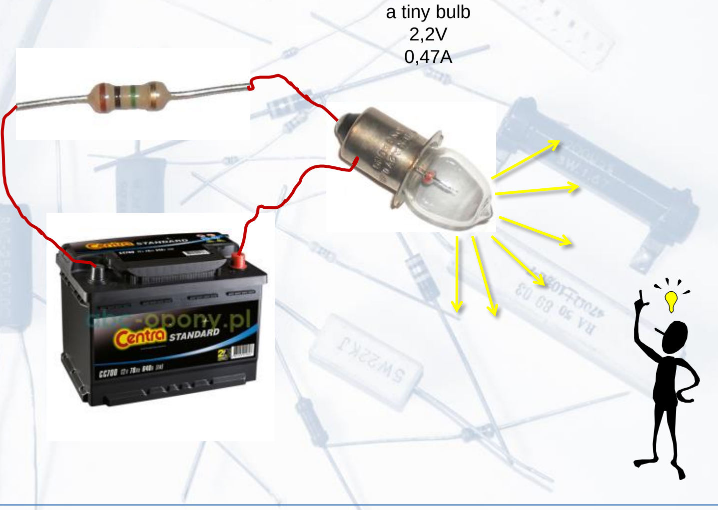
RESISTOR – what is it for?



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RESISTOR

It is a two-terminal passive dissipating element, it converts electrical energy to heat (thermal energy, it is described by resistance in ohms [Ω]

Passive element consumes electrical energy

- The total electrical energy provided to the element during period from -∞ to *t* is non-negative for any character of voltage signal at its terminals and current flowing through it.
- Until the supply voltage is connected to the resistor, there is no current flowing through it. And vice versa, there is no voltage drop at its terminals until any current is provided to it.

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RESISTOR – graphic symbol

In the schematic diagrams you can meet:

Not recommended
it can be easily
confused with a coil

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RESISTOR – mathematical description

Ohm's Law

Direct Current (DC) I is proportional to the voltage drop U at the resistor terminals

$$I \sim U, \quad I = GU, \qquad I = \frac{U}{R}$$

G – proportionality factor: ***electrical conductance*** [S]

$R = \frac{1}{G}$ – ***resistance*** [Ω]

Georg Simon Ohm
1789-1854
(Wikipedia)

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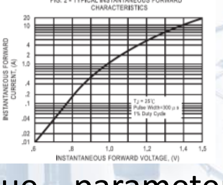
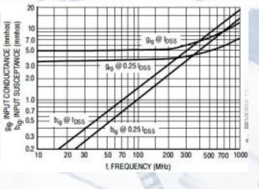
DESCRIPTION OF ELECTRONIC DEVICES

- Mathematical – equation: $I = f(U)$, $par = f(f)$
- Graphical – characteristic (plot, graph)





- Catalogue – parameters
  - acceptable (maximum voltages and currents)
  - typical
  - thermal
  - mechanical
  - other

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Drain–Source Voltage	V_{DS}	25	Vdc
Drain–Gate Voltage	V_{DG}	25	Vdc
Gate–Source Voltage	V_{GS}	25	Vdc
Drain Current	I_D	100	mAdc
Forward Gate Current	$I_{G(f)}$	10	mAdc
Total Device Dissipation @ $T_A = 25°C$	P_D	350	mW

ELECTRICAL CHARACTERISTICS (T_{amb} = 25 °C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CBO}	Collector Cutoff Current ($I_E = 0$)	V_{CB} = 50 V V_{CB} = 50 V T_{amb} = 150 °C			10 10	nA µA
I_{EBO}	Emitter Cutoff Current ($I_C = 0$)	V_{EB} = 3 V			10	nA
$V_{(BR)CBO}$	Collector-base Breakdown Voltage ($I_E = 0$)	I_C = 10 µA	60			V
$V_{(BR)CEO}$*	Collector-emitter Breakdown Voltage ($I_B = 0$)	I_C = 10 mA	30			V
$V_{(BR)EBO}$	Emitter-base Breakdown Voltage ($I_C = 0$)	I_E = 10 µA	5			V
$V_{CE(sat)}$*	Collector-emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA			0.4 1.6	V V
$V_{BE(sat)}$*	Base-emitter Saturation Voltage	I_C = 150 mA I_B = 15 mA I_C = 500 mA I_B = 50 mA			1.3 2.6	V V
h_{FE}*	DC Current Gain	for 2N2218 and 2N2221 I_C = 0.1 mA V_{CE} = 10 V I_C = 1 mA V_{CE} = 10 V	20 25			

GRAPHS AND PLOTS

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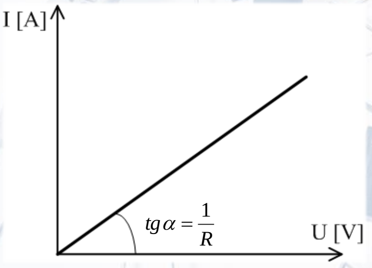
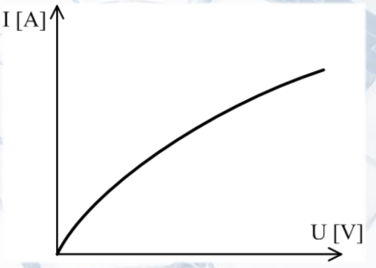
- **Current against voltage**

RESISTOR



linear resistor



non-linear resistor

GRAPHS AND PLOTS

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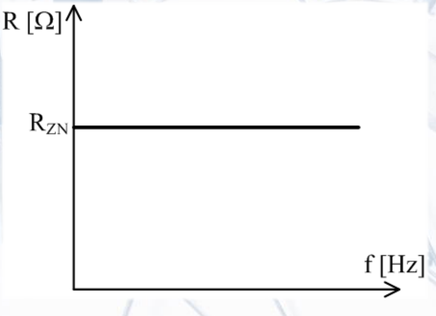
- **In frequency domain** – specific parameter against frequency

RESISTOR



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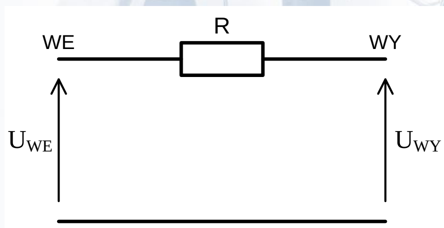
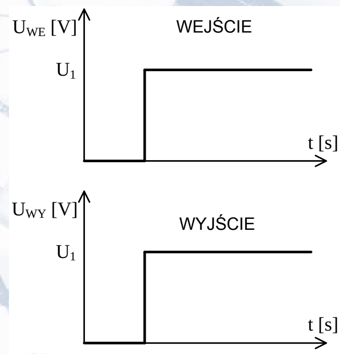
GRAPHS AND PLOTS

- **In time domain** – time response of a specific physical quantity to a given stimuli

RESISTOR





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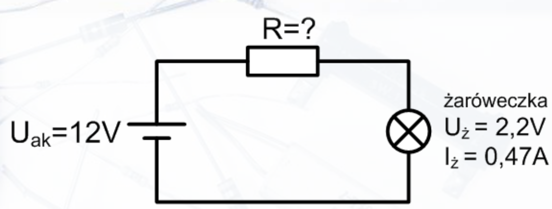
RESISTOR – the example (cont.)

What should be the proper value of resistance to light the bulb?



$$U_{ak} = I_ż R + U_ż$$

$$R = \frac{U_{ak} - U_ż}{I_ż}$$

R = (12V – 2,2V) /0,47A = 20,85Ω

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RESISTOR - parameters

- Nominal resistance
- Nominal power
- Acceptable voltage
- Tolerance
- TCR (temperature coefficient)
- Noise coefficient
- Dimensions
- Other

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RESISTOR - parameters

Nominal resistance – the value that is seen on the resistor case

Tolerance – acceptable difference between real and nominal value of the resistance

$$R_{nom} \neq R_{real}$$

$$R_{real} \in [R_{nom} - tol, R_{nom} + tol]$$

R_{nom} – nominal resistance, R_{real} – real resistance

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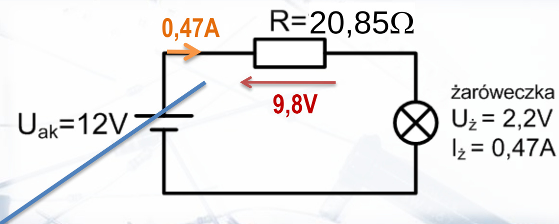
RESISTOR – the example (cont.)



Will the resistor be safe under current load?

$$P_R = 9{,}8V \cdot 0{,}47A = 4{,}606W$$

The power dissipated in the resistor

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RESISTOR - parameters

Nominal power – the value of electrical power than can be dissipated in form of heat in the resistor, without damaging it

Acceptable voltage – the highest value of DC voltage (or effective value of the alternating voltage), that can be applied to the resistor without damaging it

Temperature coefficient (TCR) – it describes dependence of resistance against temperature. [ppm/K] (1ppm/K = 10^{-6}/K)

$$TWR = \frac{dR}{R \cdot dT}$$

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Marking the RESISTORS

- On the case:
  - letter-number code

    np.: 2R2 ≡ 2,2Ω, K91≡ 910Ω, 3K6 ≡ 3,6kΩ
  - number code

    np.: 202 ≡ $20*10^{2}\Omega$ = 2000Ω = 2kΩ,

    330 ≡ $33*10^{0}\Omega$ = 33Ω,

    1541 ≡ $154*10^{1}\Omega$ = 1,54kΩ

useful for SMD resistors

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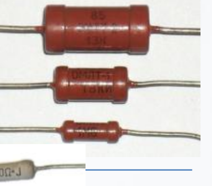
Marking the RESISTORS

example

http://www.edw.com.pl/pdf/k01/02_09.pdf

Według IEC	Według MIL	
R22	-	0,22Ω
3R9	3R9	3,9Ω
75R	750	75Ω
910R lub K91	911	910Ω
1K8	182	1,8kΩ
62K	623	62kΩ
470K lub M47	474	470kΩ
5M6	565	5,6MΩ
36M	366	36MΩ
1K54	1541	1,54kΩ
43K2	4322	43,2kΩ
931K	9313	931Ω
1M24	1244	1,24MΩ

Tolerancja	Współczynnik temperaturowy	kod
N - ±30%	100ppm/K	TO
M - ±20%	50ppm/K	T2
K - ±10%	25ppm/K	T9
J - ±5%	15ppm/K	T10
G - ±2%	10ppm/K	T13
F - ±1%	5ppm/K	T16
D - ±0,5%	2ppm/K	T18
C - ±0,25%		
B - ±0,1%		
W - ±0,05%		
P - ±0,002%		
L - ±0,001%		



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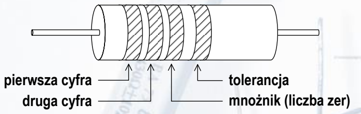
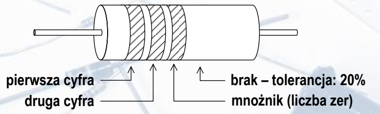
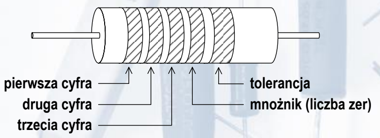
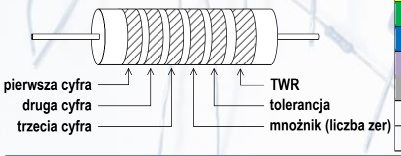
Marking the RESISTORS

- Colour code (lines)









kolor	cyfra	mnożnik	tolerancja	TWR
srebrny	-	$x10^{-2}$	±10%	-
złoty	-	$x10^{-1}$	±5%	-
czarny	0	$x10^{0}$	-	250ppm/K
brązowy	1	$x10^{1}$	±1%	100ppm/K
czerwony	2	$x10^{2}$	±2%	50ppm/K
pomarańczowy	3	$x10^{3}$	±15%	-
żółty	4	$x10^{4}$	-	25ppm/K
zielony	5	$x10^{5}$	±0,5%	20ppm/K
niebieski	6	$x10^{6}$	±0,25%	10ppm/K
fioletowy	7	$x10^{7}$	±0,1%	5ppm/K
szary	8	$x10^{8}$	-	1ppm/K
biały	9	$x10^{9}$	-	-
brak	-	-	±20%	-

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Marking the RESISTORS

- Colour code (lines)

kolor	cyfra	mnożnik	tolerancja	TWR
srebrny	-	$x10^{-2}$	±10%	-
złoty	-	$x10^{-1}$	±5%	-
czarny	0	$x10^{0}$	-	250ppm/K
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pomarańczowy	3	$x10^{3}$	±15%	-
żółty	4	$x10^{4}$	-	25ppm/K
zielony	5	$x10^{5}$	±0,5%	20ppm/K
niebieski	6	$x10^{6}$	±0,25%	10ppm/K
fioletowy	7	$x10^{7}$	±0,1%	5ppm/K
szary	8	$x10^{8}$	-	1ppm/K
biały	9	$x10^{9}$	-	-
brak	-	-	±20%	-

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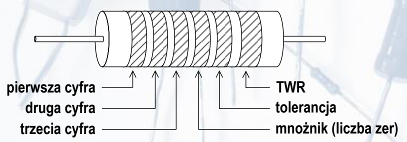
RESISTORS – resistance values

Why do we need so many colour lines to describe values of resistance?

What kind of resistors can we get on the market?

Do we have a chance to get the resistor R=20,85Ω for our light bulb?



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RESISTOR VALUES CHAINS

The values of nominal resistances are normalized and they create values chains, marked as: E3, E6, E12, E24 itd.

En

n – describes the number of resistance values for a decade

generally: $a_i = a_{i-1} \sqrt[n]{10}$

RESISTOR VALUES CHAINS

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example

E6 → n = 6

10 10

$$10 \cdot \sqrt[6]{10} = 10 \cdot 1{,}4678\ldots = 14{,}678\ldots \approx 15$$

$$15 \cdot \sqrt[6]{10} = 15 \cdot 1{,}4678\ldots = 22{,}016\ldots \approx 22$$

$$22 \cdot \sqrt[6]{10} = 22 \cdot 1{,}4678\ldots = 32{,}291\ldots \approx 33$$

$$33 \cdot \sqrt[6]{10} = 33 \cdot 1{,}4678\ldots = 48{,}437\ldots \approx 47$$

$$47 \cdot \sqrt[6]{10} = 47 \cdot 1{,}4678\ldots = 68{,}986\ldots \approx 68$$

~~$68 \cdot \sqrt[6]{10} = 68 \cdot 1{,}4678\ldots = 99{,}810\ldots \approx 100$~~

E48	E96	E192	E48	E96	E192
100	100	100	162	162	162
		101			164
	102	102		165	165
		104			167
105	105	105	169	169	169
		106			172
	107	107		174	174
		109			176
110	110	110	178	178	178
		111			180
	113	113		182	182
		114			184
115	115	115	187	187	187
		117			189
	118	118		191	191
		120			193
121	121	121	196	196	196
		123			198
	124	124		200	200
		126			203
127	127	127	205	205	205
		129			208
	130	130		210	210
		132			213
133	133	133	215	215	215
		135			218
	137	137		221	221
		138			223
140	140	140	226	226	226
		142			229
	143	143		232	232
		145			234
147	147	147	237	237	237
		149			240
150		150		243	243
		152			246
154	154	154	249	249	249
		156			252
	158	158		255	255
		160			258

http://www.edw.com.pl/pdf/k01/02_09.pdf

RESISTOR – the example (cont.)

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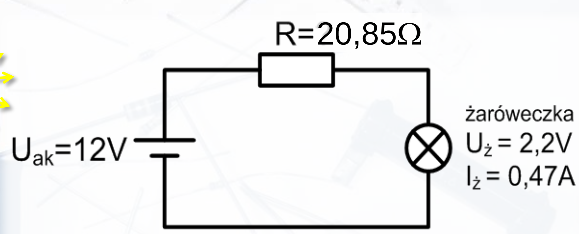

chain:

E6 → 22Ω
E12 → 22Ω
E24 → 22Ω
E48 → 21,5Ω
E96 → 21Ω
E192 → 20,8Ω

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RESISTIVITY

Do all conducting materials „hinder” electrical current flow?

YES

RESISTIVITY – determines counteracting against electrical current flow.

It is a property of each conducting material.

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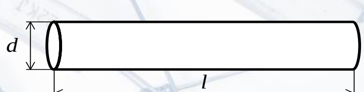
RESISTIVITY

def.:

Resistance of a conducting element made of a homogeneous material with the cross-section surface 1 square meter and length 1 metre.

designation: ρ , *unit:* **[Ω·m]**

resistance: $R = \rho \frac{l}{S}$



$S = \pi \frac{d^2}{4}$

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Classification of RESISTORS

in relation to a function:

a. constant resistance value
b. regulated resistance value (potentiometers)
c. semiconductor
   termistors (NTC,PTC), varistors, gausotrons, fotoresistors

in relation to a voltage vs. current characteristic:

a. linear
b. non-linear

in relation to a construction:

a. wired
b. layered
c. bulk

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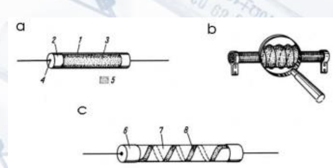
How are resistors made

- wired – a resistive wire is wound on the body
  – nikrotal (CrNi), kantal (CrAlFe), konstantan (CuNi), etc.
- layered – a resistive layer is coated on the body
  – carbon
  – metal
- bulk – a resistor as a whole is made from resistive material (e.g. carbon)

The construction of the resistors influences on the parasitic elements parameters



http://zwarcie.prv.pl/rezystor.htm

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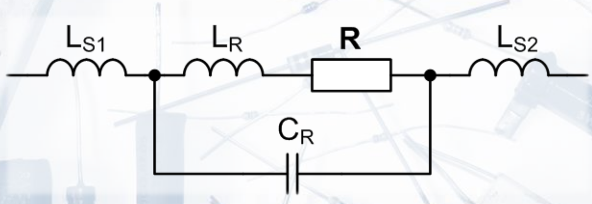
Harsh realities on resistors

REAL RESISTOR



- Parasitic elements influencing operation of a real resistor
  - C_R – self-capacitance (also known as leakage capacitor),
  - L_R – self-inductance
  - L_{s1}, L_{s2} – inductance introduced by terminals

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w Internecie

- Papers on resistors
  http://www.eres.alpha.pl/elektronika/readarticle.php?article_id=2 – cz1.
  http://www.eres.alpha.pl/elektronika/readarticle.php?article_id=3 – cz.2
  http://www.eres.alpha.pl/elektronika/readarticle.php?article_id=382 – cz.3
- For beginners
  http://www.edw.com.pl/ea/rezystor.html
- Basics of electronics for beginners and advanced users
  http://www.edw.com.pl/index.php?module=ContentExpress&file=index&func=display&ceid=60&meid=13
- For hobbyist
  http://www.elektronika.ne555.bitmar.net/o_nas.htm