Technology

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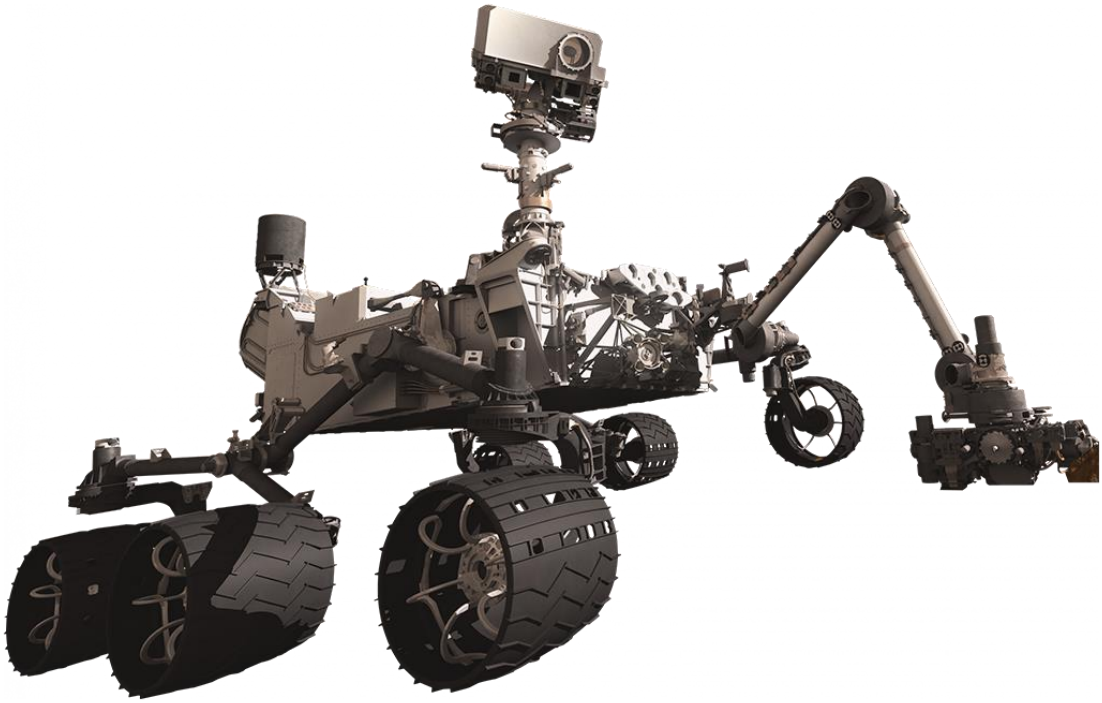

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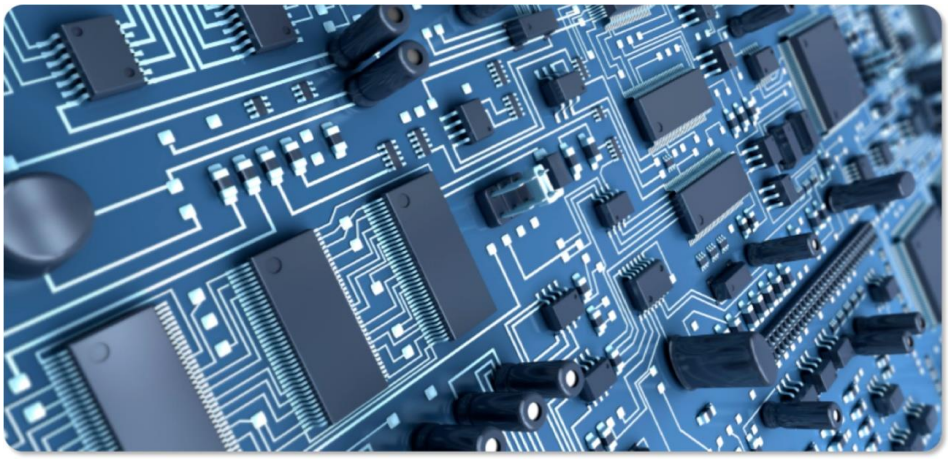
Chapter 2

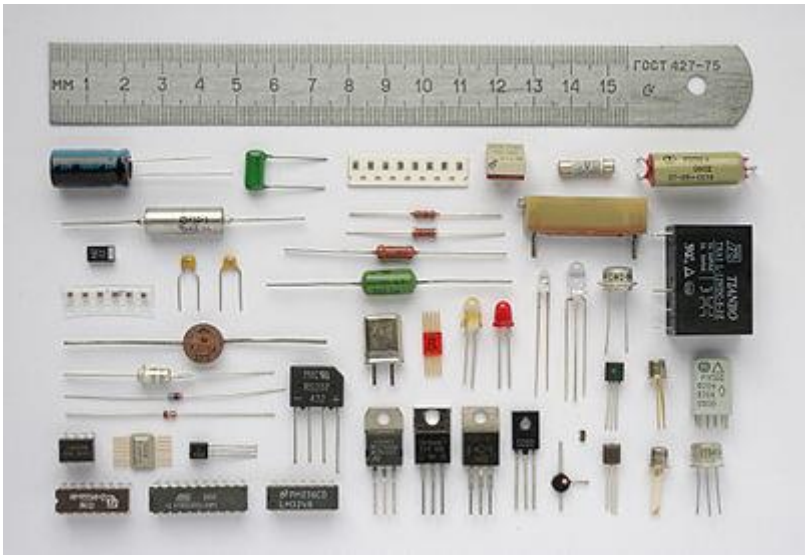
ELECTRONICS



An electronic component is anything in an electronic circuit used to affect the electric parameters.

Most electronic circuits use semiconductor components to control electric parameters.

The study of semiconductor components is a branch of “solid state physics”, and the design and construction of electronic circuits is “electronics engineering”.



Each component has a function.

The most common electronic components are resistors, capacitors, diodes and transistors.

Components are often categorized as active (transistors, thyristors…) or passive (resistors, capacitors…).

The components are connected together, usually soldered to a printed circuit board (PCB), to create an electronic circuit that has an “automatic logic”.

1 www.esobook.es/technology4/activity05

2 True or false? If false, explain why.

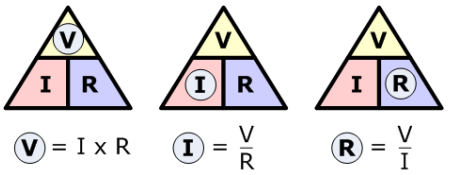
a) The study of semiconductor components is a branch of chemistry.

b) Each component of an electronic circuit has a particular function.

Remember… there are three electric parameters, Tension, Current and Resistance.

- Tension (V) is the difference in potential energy between two points.
- Current (I) is the amount of charge that passes through a conductor.
- Resistance (R) is the opposition to current flow.

The three units are related by "Ohm's Law".



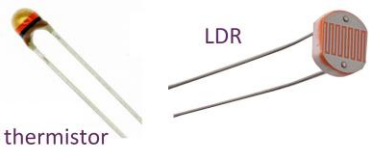
Digital or analog

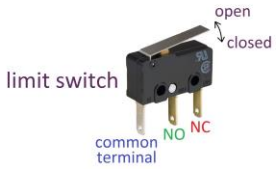
- Analog electronics work with a continuous "signal" that fluctuates.
- Digital electronics work with a discontinuous (discreet) signal that has a 0 value (0 V) or a set voltage (for example 5 V).

In electronics we often call the current "signal".

The 3 parts of an electronic circuit:

- Input: To detect external data automatically the circuit uses sensors. External parameters (light, temperature, position…) change the electrical characteristics of sensors, so they change the electrical current that passes through them and goes to the process part of the circuit.
  For example, if nothing is touching the "limit switch", current flows from the common terminal to the normally open terminal, but if something touches the switch the current flows from the common terminal to the normally closed terminal; this way the limit switch detects position.
- Process: The circuit transforms the current (called "signal") following the "logic" that it is designed for.
- Output: The output is the current (signal) resulting from the process.





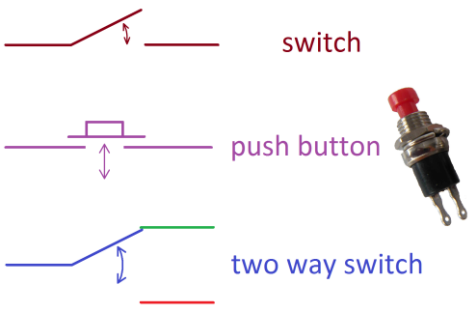
In complex electronic circuits (for example microchips) where there are many circuits connected, the output of one circuit is normally the input for the next circuit. All the circuits together process a more complex logic.

In simple automatisms the output of the electronic circuit normally controls a relay, which is the switch for an actuator.

Control elements

We use them to manually (sometimes mechanically) control the input current.

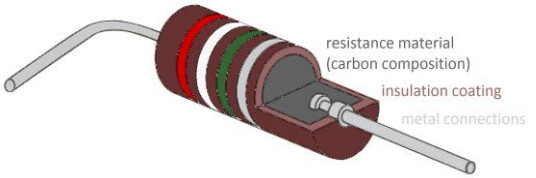
- Switches: they are open (off) or closed (on).
- Push buttons: they are closed (on) only while we are pressing the button.
- Two way switches: the circuit has two branches. If the commuter is open, the current flows from the common terminal to the "normally open terminal". If the commuter is closed the current flows to the "normally closed terminal".



3 Give three examples of sensors used in electronic circuits.

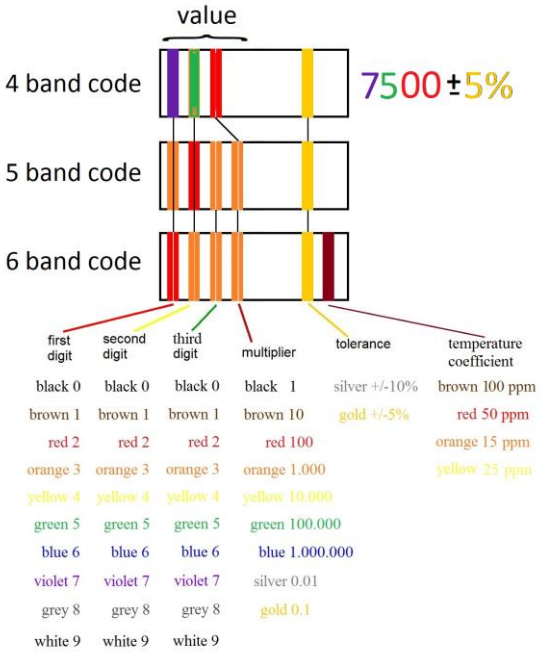
4 What does it mean when a switch is "normally open"?

5 In a microchip, what is the output of one circuit?



2.1 Resistors

The resistance of the resistors limits the current in the circuit.



2.1.1 Fixed value resistors

Simple fixed value resistors have 4 colour bands to indicate their resistance value and the tolerance, but more complex resistors have 5 or 6 colour bands.

- Value: 3 or 4 colour bands indicate the resistance value of the resistor.
  - The first band is the first digit.
  - The second band is the second digit.
  - If there are four bands, the third band is the third digit.
  - The last band is the number of 0´s after the first 2 or 3 digits.
- Tolerance: this band indicates the tolerance of the value.
- Temperature coefficient: Some resistors have a band to indicate the temperature coefficient in parts per million (ppm).

2.1.2 Potentiometers

We can manually vary the resistance value of a potentiometer by turning the dial, from 0 Ω to maximum.

The dial slides over a fixed value resistor.

The dial has a connection to one part of the circuit.

The resistor has a connection to the other part of the circuit.

If the dial is close to the contact of the resistor the current travels a short distance through the resistor and the resistance is small.

If we move the dial far from the contact we increase the resistance.

We use potentiometers to manually adjust resistance in electronic circuits so that we can calibrate them.

Potentiometers sometimes have two contacts to the fixed value resistor, one at each end of the resistor so that we can choose the direction of increasing or lowering resistance (by choosing which connection of the resistor we use).

6 Calculate the resistance value and tolerances of these resistors:

a)

b)

c)

7 www.esobook.es/technology4/activity06

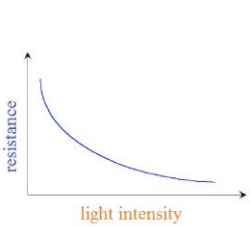
2.1.3 LDR's

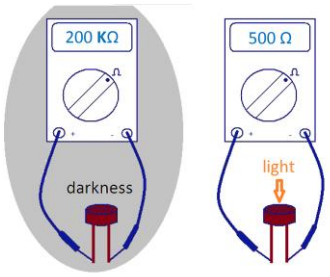
The resistance of a light dependent resistor (LDR) is inversely proportional to the luminous intensity that it receives.

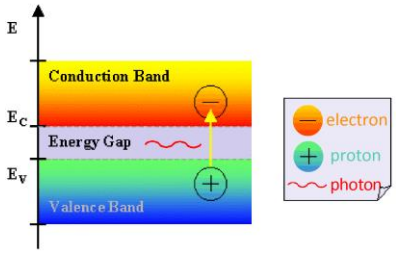
An LDR (also called "photoresistor") is made of a semiconductor material whose resistivity decreases with increasing incident light intensity. It is "photoconductive".

The photons absorbed by the semiconductor give electrons enough energy to jump into the conduction band, reducing the resistivity of the material.

We use LDR's, for example to detect light in security lights.







2.1.4 Thermistors

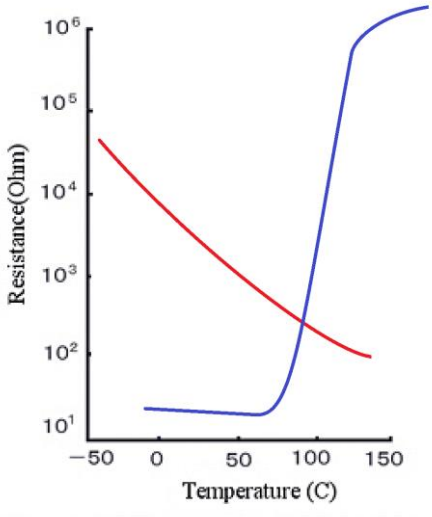
Thermistors vary their resistance (R) with changes in temperature.

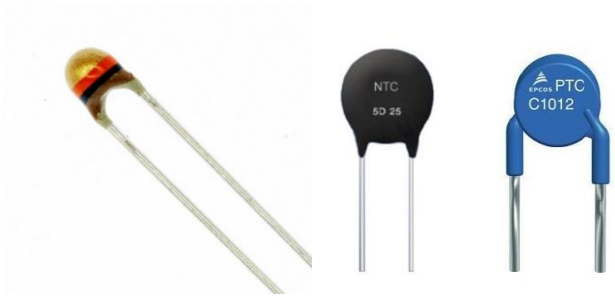
Negative Temperature Coefficient (NTC) thermistors decrease their resistance as the temperature increases.

Positive Temperature Coefficient (PTC) thermistors increase their resistance as the temperature increases.

Circuits "know" what the temperature is by sensing the value of the electric current (I) which varies if the resistance varies.

We use thermistors, for example to detect temperature in thermostats or fire alarms.





8 What is a "photoconductive" material? What do the photons give to the electrons?

9 www.esobook.es/technology4/activity07

10 What type of thermistor would be best if we want to detect:

a) Temperature changes between 0°C and 30°C. Explain why.

b) Temperature changes between 90°C and 110°C. Explain why.

2.2 Capacitors

Capacitors store electric energy. The maximum amount of energy that they can store is the capacitance (C).

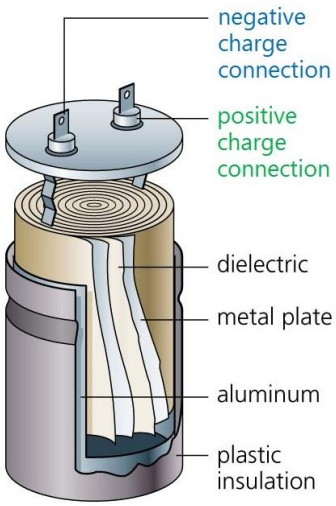
The unit of capacitance is the farad (F), but capacitors don't store much energy so we use the millifarad (mF) =0.001 F ; the microfarad (µF) = 0.000001 F ; the nanofarad (nF) = 10^{-9} F and the picofarad (pF) = 10^{-12} F .

We use capacitors, for example, in:

- Radio, television and mobile phone receivers to filter interferences.
- Battery chargers to smooth the current.

The voltage between terminals must never exceed a maximum value, this is especially important in electrolytic capacitors.

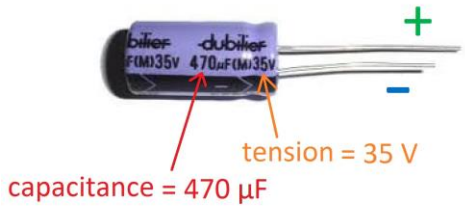
2.2.1 Polarised capacitors (Electrolytic capacitors)



Polarised capacitors have polarity: the longer leg must be connected to the positive and the shorter leg to the negative.

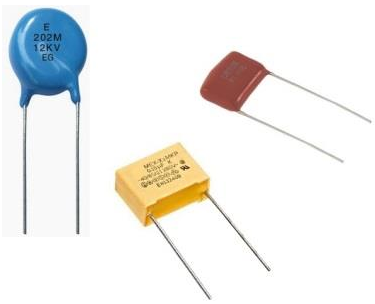
They are usually cylindrical, made of a liquid electrode with a thin layer of oxide as the dielectric. The liquid is a source for a lot of problems.

Electrolytic capacitors are always marked with their maximum working voltage.



Electrolytic capacitors have more capacitance than non-polarised capacitors.

2.2.2 Non-polarised capacitors



Non-polarised capacitors don't have a positive and a negative connection, so we don't have to worry about the position of the polarity when we connect them in the circuit.

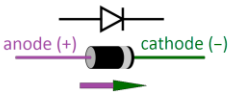
They have a smaller capacitance than polarised capacitors.

They usually have a disc or rectangular shape. There are many different technologies to make non-polarised capacitors, but they are normally made of ceramic or polyester.

11 Search for information and find which are the most common problems caused by the liquid in polarised capacitors.

12 www.esobook.es/technology4/activity08

2.3 Diodes



Diodes are components that only allow current flow in one direction, the convention says that current flows from the anode terminal (+) to the cathode terminal (+).

The anode and the cathode are made of two different semiconductor materials. A "barrier tension" forms between these two parts.

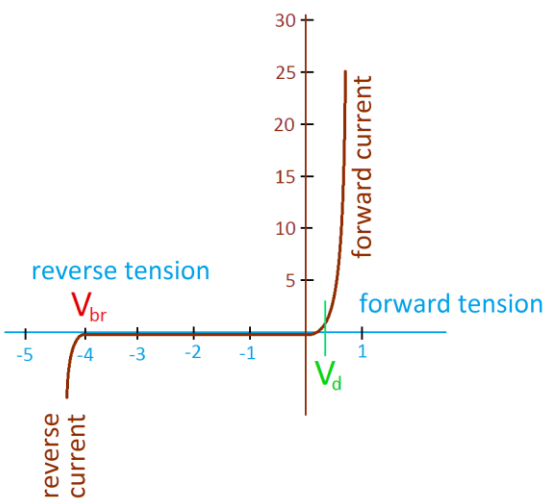
Electrons can flow from the anode to the cathode if the tension difference is higher than the "barrier tension".

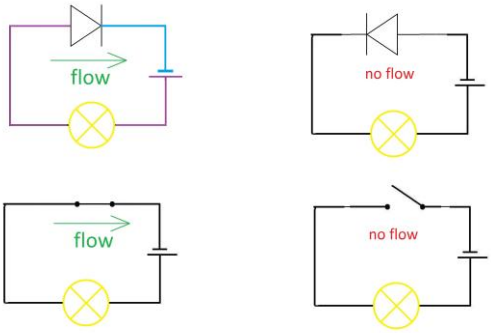
The "barrier tension" is a tension drop called "threshold tension" (V_d).

Normally, electrons can't flow from the cathode to the anode, but if there is a reverse voltage greater than the breakdown Voltage (V_{br}) then there is a "reverse current" (flowing from cathode to anode.

Electronic circuits are designed to have only "forward current".

We can represent a diode in a circuit as a closed switch when the forward tension is above the "threshold tension", or as an open switch if not.





2.3.1 LED

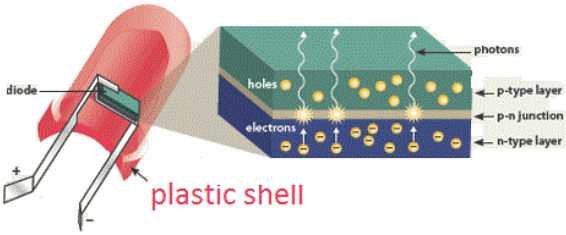
Light emitting diodes (LEDs) are a type of diode, they emit light when a current flows through them.

As with any other diode, current can only flow in one direction and they have a "barrier tension" which is also a tension drop when current flows.

When electrons cross the p-n junction to fill the holes in the p-type layer, they lose energy because of the barrier tension. That energy is transformed into photons emitted by the diode.

The plastic shell diffuses the photons out.

In electronics we use LEDs as indicators (if the LED shines we know there is current).

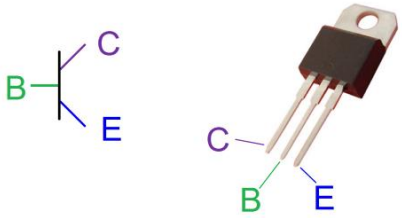


13 What are the terminals of a diode?

14 Do diodes have polarity? Give reasons for your answer.

15 In a diode, when is there a "reverse current"?

2.4 Transistors



A transistor can work as:

- An amplifier: an electric current increases proportionally to something.
- A switch: it can stop current (switch open) or let current flow (switch closed).

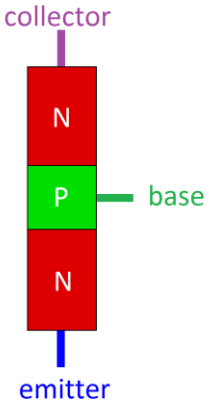
A transistor is made of three parts of semiconductor material.

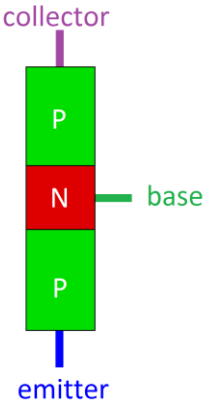
We say that semiconductor materials are:

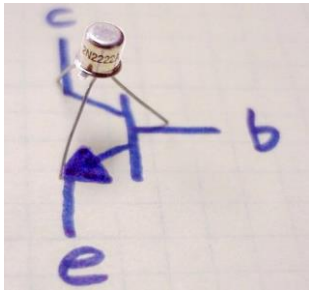
- Positive (P) if they have holes (lack of electrons) or
- Negative (N) if they have an excess of electrons.

Depending on what type of material we use for each of the three parts, they can be NPN or PNP:

- NPN transistors: the base is connected to positive semiconductor material which is between two layers of negative material.
  The collector and the emitter are connected to each of the negative material layers.
  Current flows from the collector to the emitter (remember that the convention says that the direction of current is in reverse to the true flow of electrons, so electrons flow from the emitter to the collector).
- PNP transistors: the base is connected to negative semiconductor material which is between two layers of positive material.
  The collector and the emitter are connected to each of the positive material layers.
  Current flows from the emitter to the collector.
  The control current flows from emitter to the base.







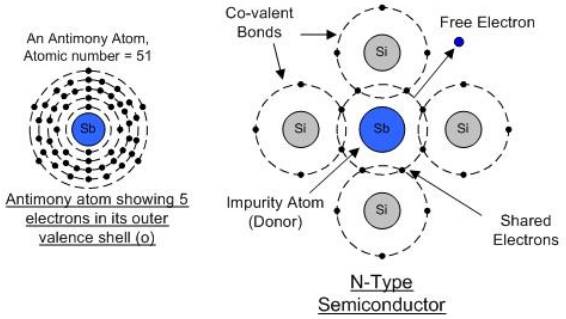
NPN transistors are more used than PNP transistors because, in semiconductor materials, electrons move more easily than holes, so we can have higher currents and operational speeds.
For example, the "2N2222" (in the picture) is a common NPN transistor used for general purpose low-power amplifying or switching applications.

16 www.esobook.es/technology4/activity09

17 Search for information and find what are "holes" as opposed to "electrons".

18 Why are NPN transistors more common than PNP transistors?

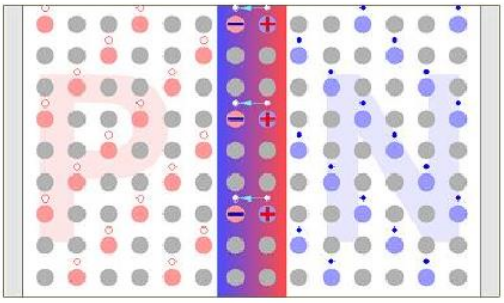
2.4.1 Semiconductor materials



Semiconductor materials are made of Silicon or Germanium, to make them positive or negative we dope them (add a small amount of other substances).

For example, if we dope the silicon with antimony, it becomes negative (N-Type semiconductor material), because the antimony has 5 electrons in its valence band, but it only links with 4 silicon atoms, so there is 1 free electron.

When we unite a negative and a positive semiconductor, near the union some electrons jump to the other side and some holes do the same. These electrons and holes "in the wrong side" create a voltage barrier called "threshold tension".



2.4.2 Transistor "gain"

The "gain" (β) of a transistor is the relation between the output current and the controlling current, when it is working as an amplifier (the output current is directly proportional to the controlling current).

We express the gain as a fraction.

$$\beta = \frac{I_C}{I_B}$$

2.4.3 The 3 working modes of the transistor

- Open switch

If the tension at the base (V_B) is lower than the tension between base and emitter ("threshold tension" (V_{BE})), then no current flows from the base to the emitter ($I_B = 0$).

If there is no current from the base, then no current can flow from the collector to the emitter ($I_C = 0$), so there is no output current ($I_E = 0$).

$$I_E = 0$$

- Amplifier

If the tension at the base (V_B) is higher than the threshold tension (V_{BE}), then some current flows from the base to the emitter (I_B).

If there is current on the base, then there is current on the collector. The amount of current in the collector is proportional the current on the base and to the gain factor of the transistor (β).

$$I_C = \beta \cdot I_B$$

$$I_E = I_C + I_B = \beta \cdot I_B + I_B$$

- Closed switch

When I_B is so big that the transistor would let more I_C pass than the power source can give, (also consider the resistances before the collector (R_C)), then the transistor is simply acting as a closed switch.

$$I_E = I_{C\,max} + I_B$$

19 In which working mode of the transistor does it have the highest current through the emitter? Why?

20 Calculate I_E for a transistor working as an amplifier. $\beta = 100$; $I_B = 0.2$ mA

2.5 Integrated circuits

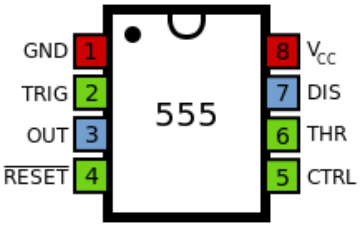
Also called “microchips”, the integrated circuits contain many electronic components (transistors, diodes, resistors…) interconnected in a very small space.

This technology reduces space, processing time, probability of error and electrical power consumption. An example of an integrated circuit is the “555 integrated circuit”.

2.5.1 555 integrated circuit

The 555 is an integrated circuit (chip) used in a variety of timer, pulse generation, and oscillator applications.

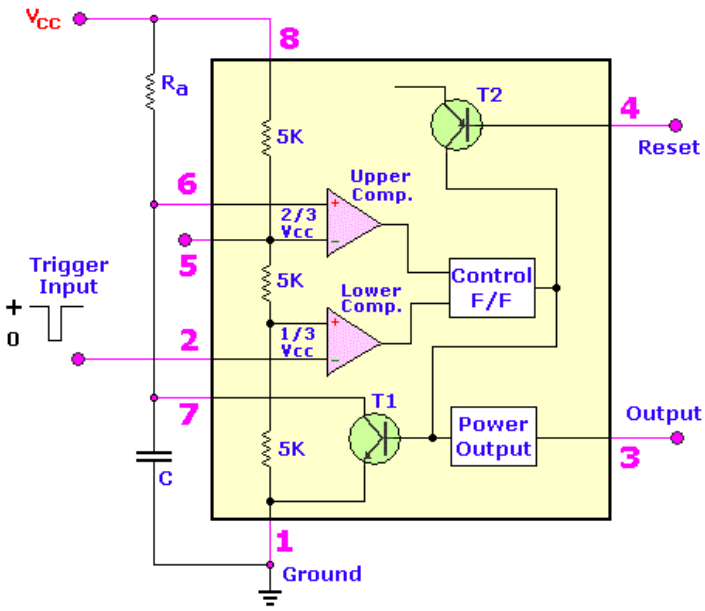
Invented in 1971, today 2,000,000,000 555 integrated circuits are manufactured every year.



It is cheap, stable and easy to use.

The 555 is composed of 23 transistors, 2 diodes and 16 resistors.

The “pinout” is composed of 8 pins.



Pin	Name	Purpose
1	GND	Ground reference voltage, low level (0 V)
2	TRIG	The OUT pin goes high and a timing interval starts when this input falls below 1/2 of CTRL voltage.
3	OUT	This output goes to approximately 1.7V below $+V_{CC}$ or GND.
4	RESET	A timing interval may be reset by taking this input to GND, but the timing does not begin again until RESET rises above approximately 0.7 volts.
5	CTRL	Provides "control" access to the internal voltage divider.
6	THR	The timing (OUT high) interval ends when the voltage at THR is greater than that at CTRL.
7	DIS	Open collector output which may discharge a capacitor between intervals. In phase with output.
8	V_{CC}	Positive supply voltage, usually between 3 and 15 V.

21 What electronic components are contained in microchips?

22 What are the applications of the 555 chip?

2.5.2 The three operating modes of the 555:

- Astable mode (or “555 timer”): This is the most common mode of the 555.

  In this mode, the 555 is an oscillator (it switches the output current on and off periodically, generating periodic rectangular pulses of specified frequency).

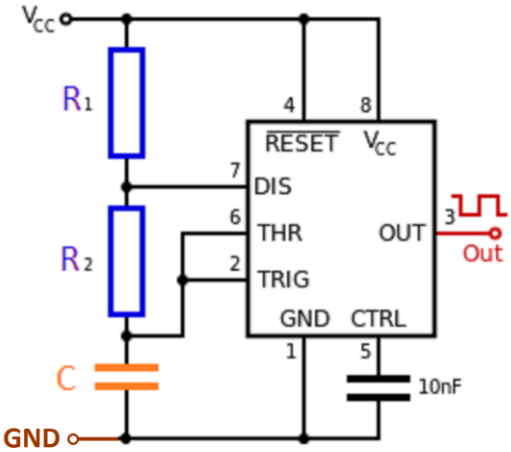
  Uses include flashing lights, pulse generation, logic clocks...

  Resistor R_1 is connected between V_{CC} and the discharge pin (pin 7).

  Resistor R_2 is connected between the discharge pin (pin 7), and the trigger (pin 2) and threshold (pin 6) pins.

  The capacitor is charged through R_1 and R_2, and discharged only through R_2.

  The frequency of the pulses depends on the values of R_1, R_2 and C.

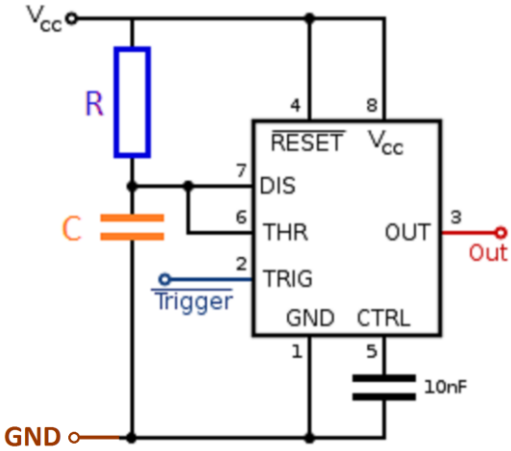


- Monostable mode: The 555 functions as a "one-shot" pulse generator. Applications include timers, touch switches…

  The pulse begins when the 555 timer receives a signal at the trigger input.

  The length of the output pulse is determined by the time constant of an RC combination, which consists of a resistor (R) and a capacitor (C).

  The output pulse ends when the voltage on the capacitor equals 2/3 of the supply voltage.



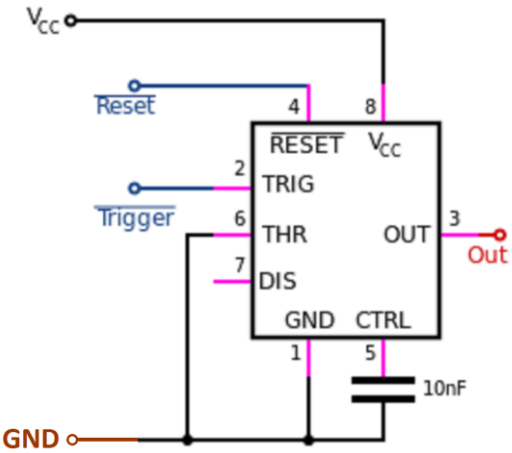
- Bistable mode (or “Schmitt trigger”): The 555 functions as a flip-flop. Uses include bounce-free latched switches.

  The trigger and reset inputs (pins 2 and 4) are in high level.

  The threshold input (pin 6) is grounded.

  Connecting the trigger momentarily to ground acts as a 'set' and transitions the output pin (pin 3) to Vcc (high state).

  Connecting the reset input to ground acts as a 'reset' and transitions the output pin (pin 3) to ground (low state).



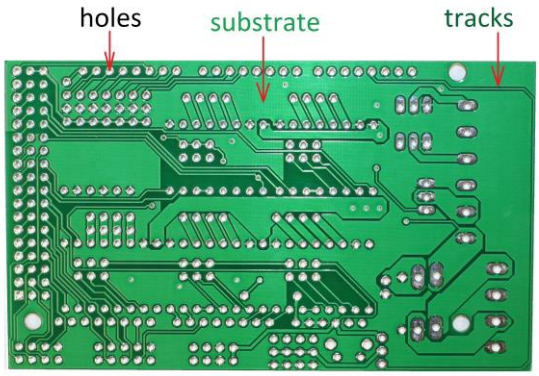
23 When does the 555 start to work if it is in:

a) Astable mode? b) Monostable mode? c) Bistable mode?

24 In a 555 in monostable mode, what is the function of:

a) The trigger b) The capacitor.

2.6 Printed circuit board



A Printed Circuit Board (PCB) is a green board that we use as substrate for electronic circuits.

On the board there are copper conductive tracks which are the connections of the circuit.

The electronic components: chips (integrated circuits), capacitors, resistors, diodes… are soldered to the board.

The advantage of PCBs as a form of connecting all the components of an electronic circuit is that it is easy to automate the manufacture of the board and the assembly of the components on the board, so the final complete product is cheap and reliable and we can make it fast.

Advanced PCB's contain components (capacitors, resistors, transistors…) in the substrate.

When the board has only copper connections and no embedded components it is technically called "Printed Wiring Board" (PWB), but we often keep calling them PCB.

When the circuit is complete (the PCB has the electronic components assembled on it), it is called a "Printed Circuit Assembly" (PCA) or a "Printed Circuit Board Assembly" (PCBA).

The IPC organization sets the standards for the design, assembly, and quality control of PCBs.

Printed Circuit Boards are used in nearly all electronic products.

2.6.1 Types of PCBs

- Single-sided boards have the components on one side of the substrate.
- When the number of components is excessive for a single-sided board, we use a double-sided board. Electrical connections between the circuits on each side are made by drilling holes through the substrate and filling the holes with a conducting material.
- The multi-layered board has layers of substrate with printed circuits. This simplifies the circuit pattern.

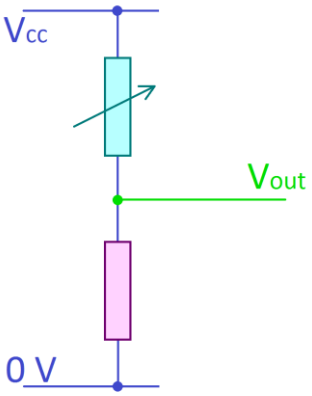
2.6.2 How we make the tracks on the PCB

- Additive process: copper is plated to the surface of the substrate by photochemical deposition (like a photocopy with copper instead of ink).
- Subtractive process: the surface of the substrate is copper plated. Then the tracks are painted with protective paint, and the PCB is etched to remove the rest of the copper.

25 Why do we use PCBs to make electronic circuits?

26 www.esobook.es/technology4/activity10

2.7 Voltage divider



The voltage divider is a sensor circuit that varies the tension that it sends to the processor (V_o) if the resistance in a variable resistor changes.

It has two resistances (one fixed and one variable) connected in series. Between them is the wire that goes to the processor.

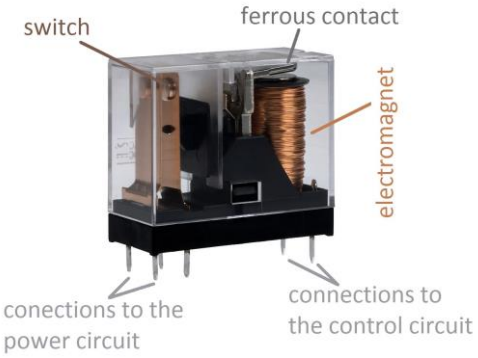
$V_{out} = V_{cc} \cdot R_{Fixed} / (R_{Variable} + R_{Fixed})$

If $R_{Variable}$ is very large, the value of V_o is near 0 V.

If $R_{Variable}$ is very small, the value of V_o is near V_{cc}.

2.8 Relays

Relays are electric devices, not electronic, but we often use them in simple automatisms where the output of an electronic circuit (control circuit) (for example the control of an automatic door) must control an electric appliance (power circuit) (for example the motor that moves the door).



A relay is an electric switch controlled by an electromagnet. The switch has a ferrous contact. The electromagnet attracts or repels the ferrous contact of the switch, opening or closing the switch.

The output current from the electronic control circuit flows through the electromagnet.

Example

We build a voltage divider with a light dependent resistor and a fixed value resistor (6 KΩ) and a 5 V power source (V_{cc}). Calculate the tension out (V_o) when:

a) V_{LDR} = 200 KΩ

$V_o = V_{cc} \cdot R_{Fixed} / (R_{variable} + R_{Fixed})$

$V_o = 5 \cdot 6 / (200 + 6)$

$V_o = 30 / 206 = 0.15$ V

b) V_{LDR} = 800 Ω

$V_o = V_{cc} \cdot R_{Fixed} / (R_{variable} + R_{Fixed})$

$V_o = 5 \cdot 6 / (0.8 + 6)$

$V_o = 30 / 6.8 = 4.41$ V

27 We build a voltage divider with a light dependent resistor and a fixed value resistor (8 KΩ) and a 6 V power source (Vcc). Calculate the tension out (Vo) when:

a) V_{LDR} = 300 KΩ
b) V_{LDR} = 80 KΩ
c) V_{LDR} = 4 KΩ
d) V_{LDR} = 500 Ω

28 We want to control a street light so that it is on during the night and off during the day.
The control circuit must have at least an 8 V power source, an LDR, a transistor… its output operates a relay.
The relay is the switch for the 400 V light bulb of the street light.
Draw all the circuits.

Activities

29 What are the two categories of electronic components?

30 In simple automatisms, what does the output of the electronic circuit normally control?

31 What type of control element would you use as button to call a lift? Why?

32 www.esobook.es/technology4/activity11

33 www.esobook.es/technology4/activity12

34 Read the values of these capacitors and write them in order from smaller capacitance to larger capacitance. Say if you think that they are polarised or non-polarised and explain the reasons.

a)

b)

c)

d)

e)

35 What type of capacitors store more electric energy?

36 What do you think are the advantages and disadvantages of polarised capacitors compared to non-polarised capacitors?

37 How are photons produced in an LED?

38 What is the "threshold tension" in semiconductor materials?

39 Calculate IE for a transistor working as an amplifier with:

a) $\beta = 50$; $I_B = 0.5$ mA

b) $\beta = 200$; $I_B = 0.1$ mA

40 $I_{C\ max}$ for a transistor in a circuit is 0.06 A ; $\beta = 50$; IB = 0.8 mA
In which mode is the transistor working? Why?

41 Most electronic devices now have their circuits "integrated". Which are the advantages of "integrated circuits"?

42 What integrated circuit could we use to control a flashing light? Why?

flashing light

43 Which are the three operating modes of the 555 integrated circuit?

44 What does it mean that the integrated circuit 555 can work as an oscillator?

45 What happens if we connect the trigger of a 555 integrated circuit in bistable mode to ground?

46 Describe the output of a 555 integrated circuit when it is working as:

a) A timer.
b) A "one shot" pulse generator.
c) A "Schmitt trigger".

47 We normally say "PCB" to refer to printed circuit boards, finished or not. But, when would it be more correct to call them "PCA"?

48 When designing a PCA, in which cases would you choose a:

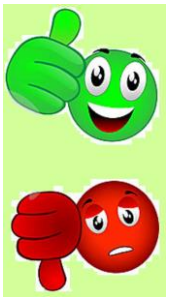
a) Single-sided board
b) Double-sided board.
c) Multi-layered board.

49 One of the processes to make PCBs is chemical "etching".
Search for information about "etching" and describe what it is and how we use it in PCB manufacture.

50 We build a voltage divider with a light dependent resistor and a fixed value resistor (12 KΩ) and a 9 V power source (V_{cc}). Calculate the tension out (V_o) when:

a) V_{LDR} = 100 KΩ
b) V_{LDR} = 10 KΩ
c) V_{LDR} = 400 Ω
d) V_{LDR} = 50 Ω

51 What is the function of relays?

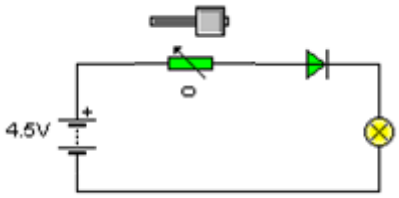


52 True or false? (If false explain why):

a) All electronic components have the same function.
b) Electronic components are often categorized as active or passive
c) Digital electronics can work with signals of 0 V and 5 V.
d) The "output" is the signal resulting from the process.
e) Push buttons: they are only on while we are pressing the button.
f) Simple fixed value resistors have 2 colour bands to indicate their resistance value and the tolerance.
g) The dial is part of the fixed value resistor in a potentiometer.
h) The resistivity of a photoresistor decreases with increasing incident light intensity.
i) Thermistors vary their resistance (R) with changes in pressure.
j) The maximum amount of energy that a capacitor can store is its resistivity.
k) Electrolytic capacitors are a type of polarised capacitor.
l) Non-polarised capacitors have positive and negative poles.
m) A "barrier tension" forms between the anode and the cathode of a diode.
n) LEDs consume photons to produce electricity.
o) In PNP transistors the positive semiconductor material is between two layers of negative material.
p) Integrated circuits increase processing time.
q) The 555 integrated circuit has a variety of applications.
r) In monostable mode, the 555 switches the output current on and off periodically.

Projects

1 Diode and potentiometer.



Using simulation software or in the workshop, construct the circuit shown in the image.

Materials:

100 KΩ potentiometer

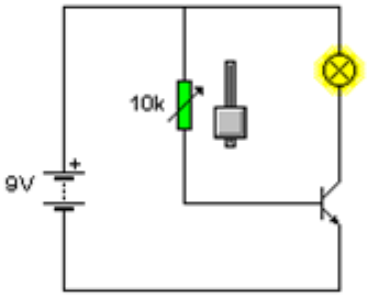
Diode

Light

9 V Battery

- Turn the dial of the potentiometer. What happens to the light?
- Measure the resistance and the tension of the three elements in the circuit when we set the potentiometer at 5 KΩ and at 20 KΩ.
- What happens if we eliminate the diode from the circuit?

2 Transistor and potentiometer controlling a light.



Using simulation software or in the workshop, construct the circuit shown in the image.

Materials:

100 KΩ potentiometer

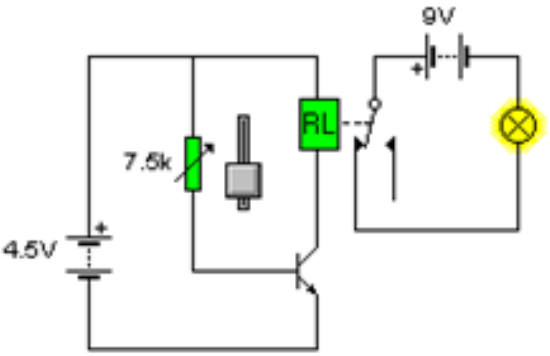
Transistor

Light

9 V Battery

- What happens when we vary the position of the potentiometer?
- Find a position of the potentiometer for which the transistor is working as an amplifier. Measure the current on the potentiometer and on the light, then calculate β.

3 Transistor and potentiometer controlling a relay.



Using simulation software or in the workshop, construct the circuit shown in the image.

Materials:

100 KΩ potentiometer

Transistor

Relay

220 V alternate current power supply

Light

9 V Battery

- What happens when we vary the position of the potentiometer?
- With the help of a multimeter, find the minimum current in the coil of the relay that changes the position of the switch of the relay.

4 Transistor, LDR and potentiometer controlling a relay.

Using simulation software or in the workshop, construct the circuit shown in the image.

Materials:

100 KΩ potentiometer

Transistor

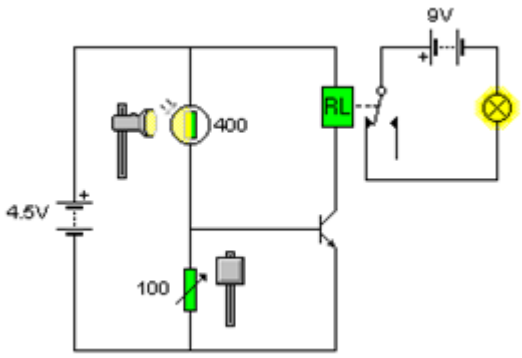
Relay

220 V alternate current power supply

LDR

Light

9 V Battery



If the light is intense on the LDR, its resistance is small and the current on the base of the transistor is enough to activate the transistor.

When the transistor activates, it activates the relay, which switches off the light.

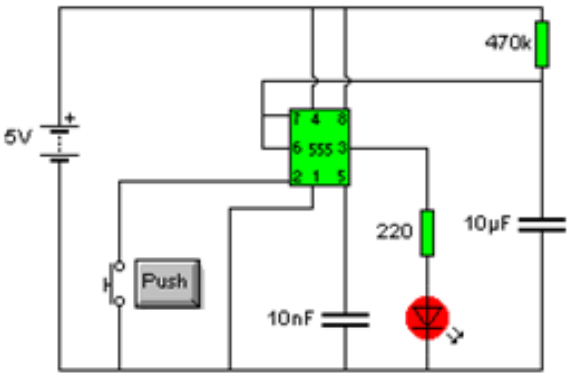
- When the light is on, measure: the resistance value of the resistors, the current in the relay coil and the current in the power circuit.
- Also measure the resistance value of the resistors when the light is off.

5 555 monostable timer circuit.

Using simulation software or in the workshop, construct the circuit shown in the image.

The LED shines for a while each time we press the push button.

- Think of a few different applications for this circuit.
- What happens if we change the value of the resistors or capacitors?



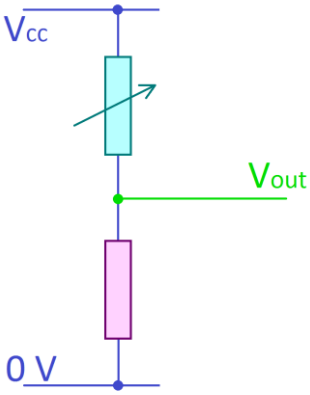
6 Voltage divider.

Using simulation software or in the workshop, construct the circuit shown in the image.

Materials:

Potentiometer

6 KΩ resistor



Connect the components as in the diagram.

We can change the resistance of the potentiometer.

- Set the potentiometers in three different positions and for each position measure the resistance and the tension values.