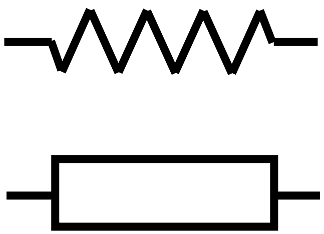
Resistors, Capacitors, Inductors, Diodes, Transistors

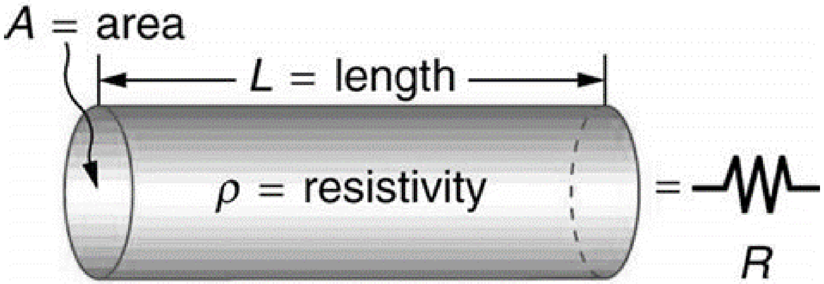
Resistors, Capacitors, Inductors

Resistors

Resistors are passive elements that oppose/restrict the flow of current.



At fixed temperature, the resistance of a conductor is: $R = \rho \frac{l}{A}$



where **l is the conductor length** in meters **A is the cross-sectional area** in square meters and **ρ is the resistivity** (the factor that depends on the material type).

Resistors

At a fixed temperature, the resistance of a conductor is

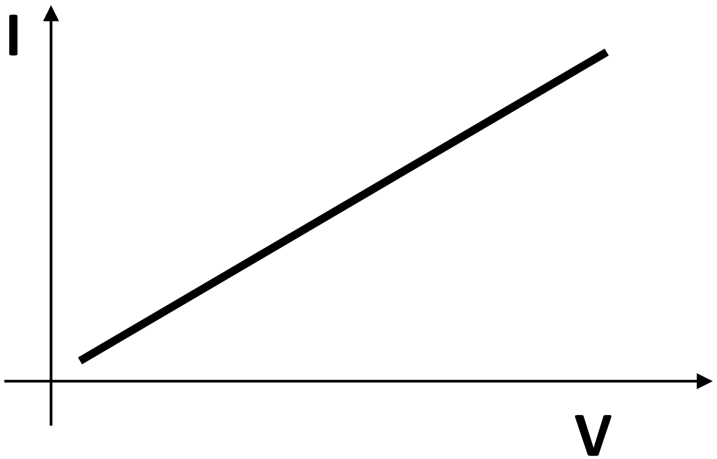
$$R = \rho \frac{l}{A}$$

- The longer the conductor, the higher the resistance.
- The larger the cross-sectional area of the conductor, so the lower the resistance.

The resistance also tends to increase with **temperature**.

Key Equation

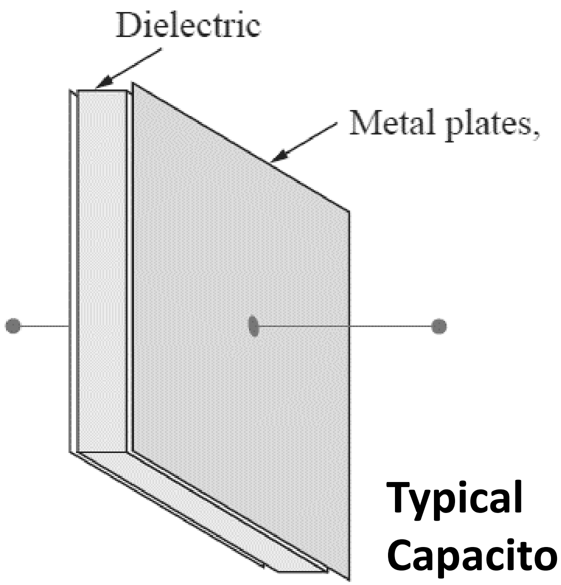
$$V = IR$$



Capacitors

Capacitors

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). In many practical applications, the plates may be aluminum foil while the dielectric may be air, ceramic, paper, or mica.



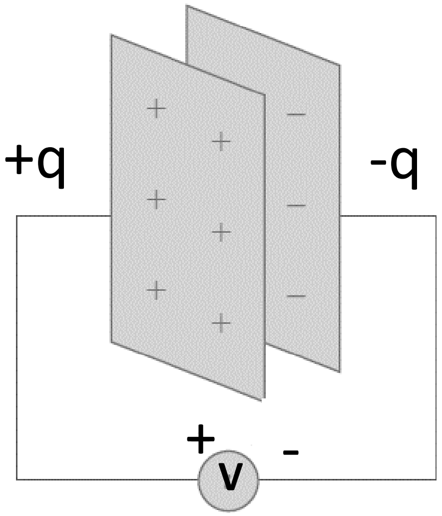
Typical Capacitor

The unit of capacitance is the farad (F).
1 farad is 1 coulomb/volt

Capacitors

An electric field is produced between the two plates when a voltage is applied. The capacitor is said to **store the electric charge**. The amount of charge stored (*q*) is directly proportional to the applied voltage (V):

$$q = CV$$



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

$$C = \frac{q}{V}$$

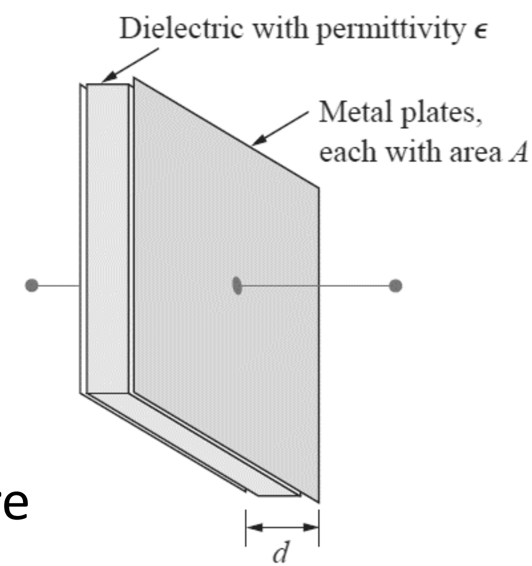
Although the capacitance C of a capacitor is the ratio of the charge q per plate to the applied voltage V, it does not depend on q or V.

Capacitors

The capacitance C depends on the physical dimensions of the capacitor.

Three factors determine the value of the capacitance:

1. The **surface area of the plates (A)**—the larger the area, the greater the capacitance.
2. The **spacing between the plates (d)**—the smaller the spacing, the greater the capacitance.
3. The **permittivity of the material (ε)**—the higher the permittivity, the greater the capacitance.

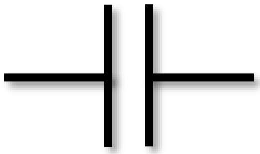


$$C = \frac{\epsilon A}{d}$$

A capacitor tends to be immune to temperature

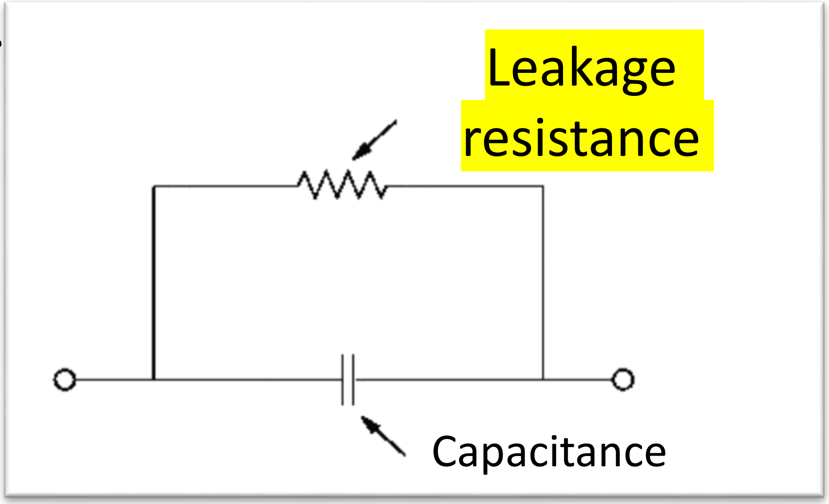
Capacitors

Ideal Capacitors have no mechanism for dissipating energy, they can only store energy which must then be released. The energy is stored in the electric field.



Capacitance

In practice capacitors tend to have a large parallel resistance which means energy can dissipate from the capacitor.



Capacitors

Key Equation

The current-voltage relationship for a capacitor is: $$i = C\frac{dV}{dt}$$

Note: if V is constant, then I is zero.

A capacitor tends to block constant signals and appears more "transparent" to rapidly changing signals.

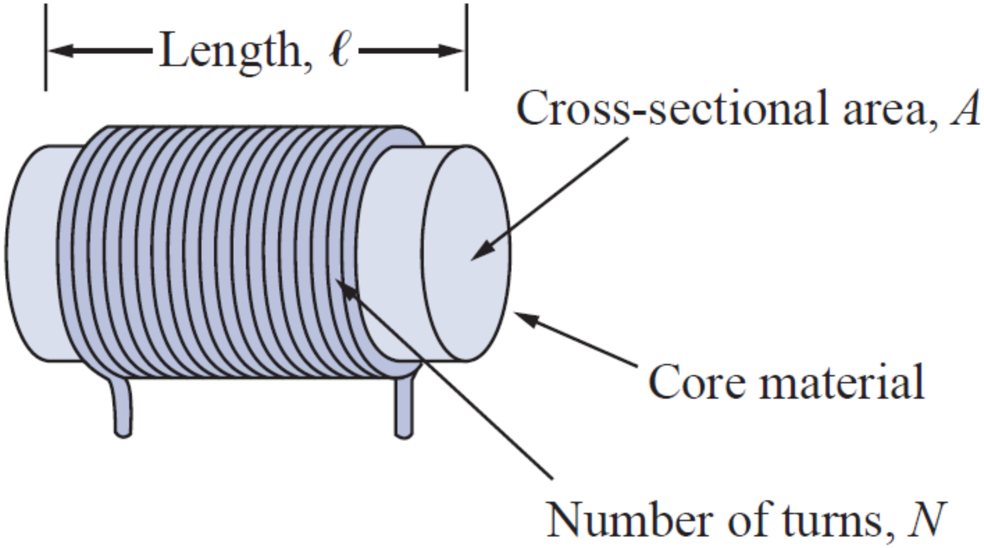
Capacitors are used for energy storage, signal conditioning (blocking dc, filters) and rapid energy delivery.

Inductors

An inductor is a passive element designed to store energy in its magnetic field.

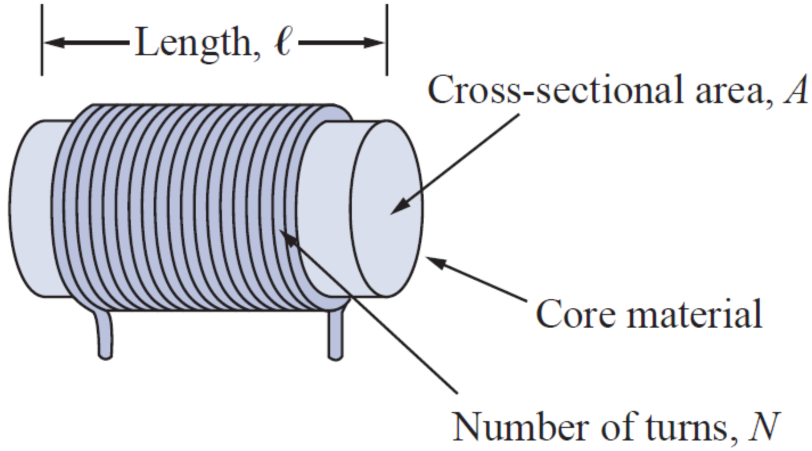
A magnetic field is produced when current passes through a conductor/ wire. This occurs in all wires. You will get inductance in all wires, especially coils of wires.

But in order to enhance the inductive effect, a practical inductor is usually formed as shown below:



Inductors

The inductance of an inductor depends on its physical dimension and construction. The inductance can be calculated as:



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

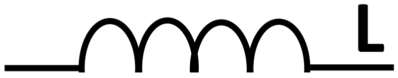
where N is the number of turns, l is the length, A is the cross-sectional area, and μ is the permeability of the core material.

The inductance can be increased by increasing the number of turns of coil, using material with higher permeability as the core, increasing the cross-sectional area, or reducing the length of the coil.

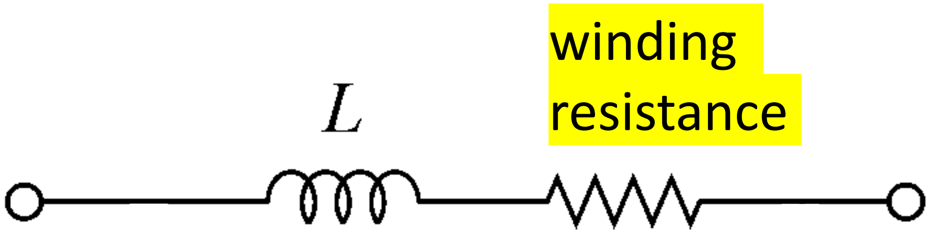
Inductors tend to be immune to temperature.

Inductors

Ideal inductors have no mechanism for dissipating energy, they can only store energy which must then be released. The energy is stored in the magnetic field.



In practice inductors tend to have a series resistance (winding resistance) which means energy can dissipate from the inductor.



Their series resistance can absorb a lot of energy.

Inductors

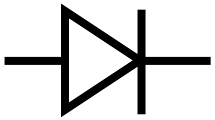
If current is allowed to pass through an inductor, it is found that the voltage across the inductor is directly proportional to the time rate of change of the current:

Key Equation $$v = L\frac{di}{dt}$$

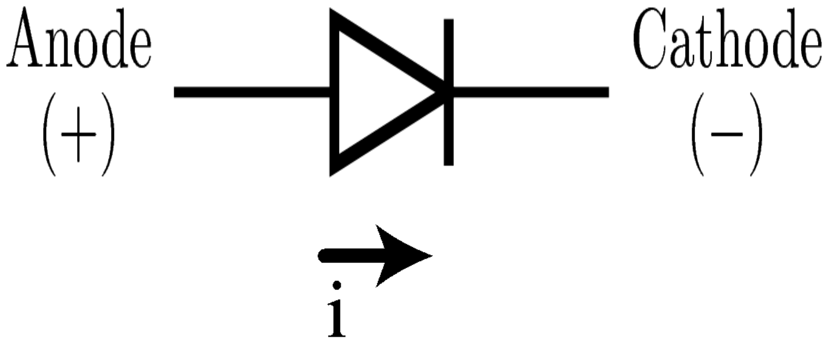
Inductors appear more “transparent” to slowly changing signals.

They are discovered accidently in long power cables, electric motors.

Diode



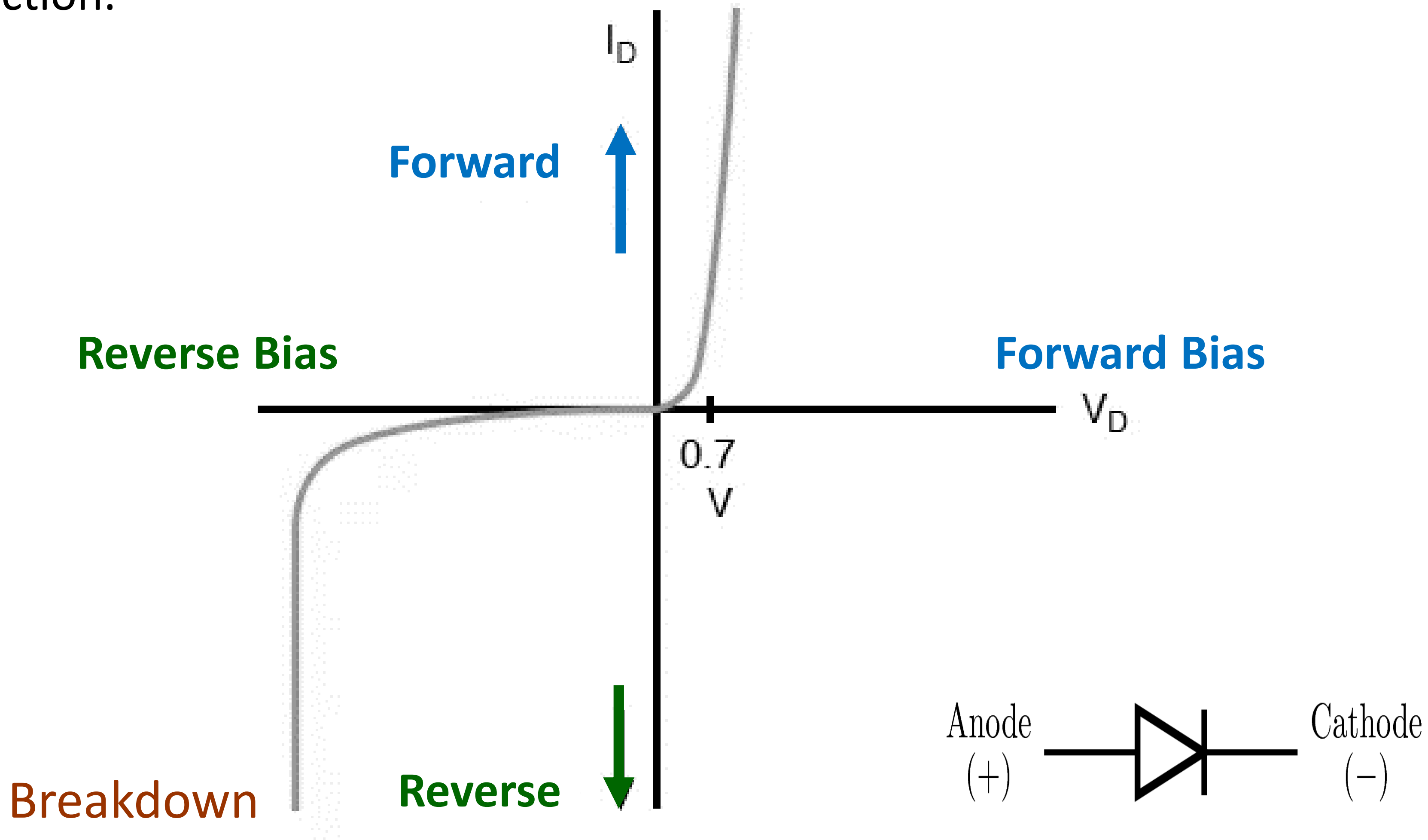
Without going into details, **diodes are fundamentally semiconductor devices which allow current to only flow one way**. There is a lot of maths and physics to this. Physics allows the current to flow in one direction over not the other. Thus, we could treat diodes like valves, one way flow.



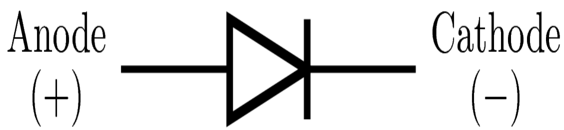
The diode's arrow ▶ (the anode terminal) points in the direction of forward current flow.

Diode

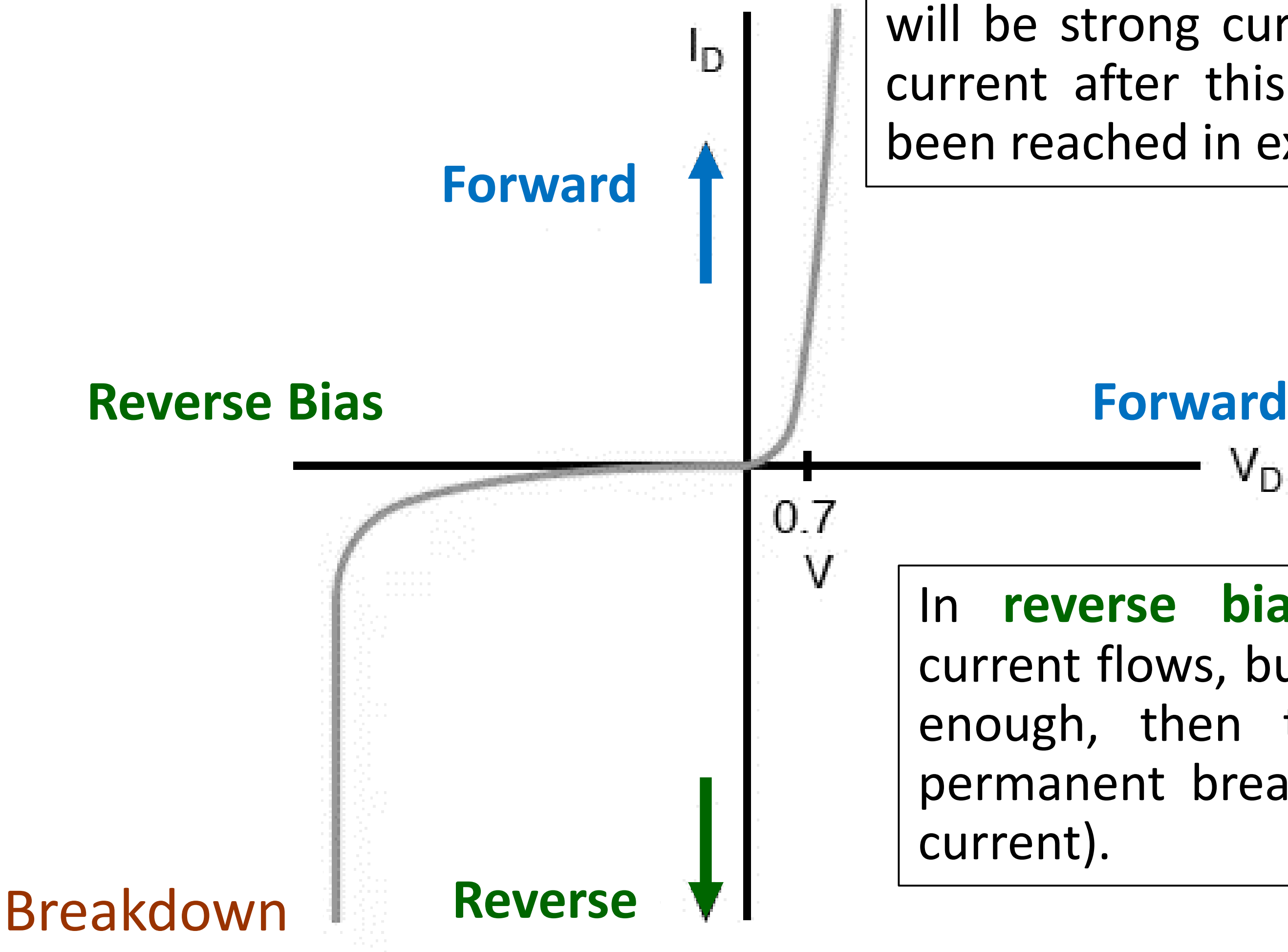
A **small positive voltage** at the diode's terminal biases the diode in the forward direction. A **negative voltage** biases the diode in the reverse direction.



Diode

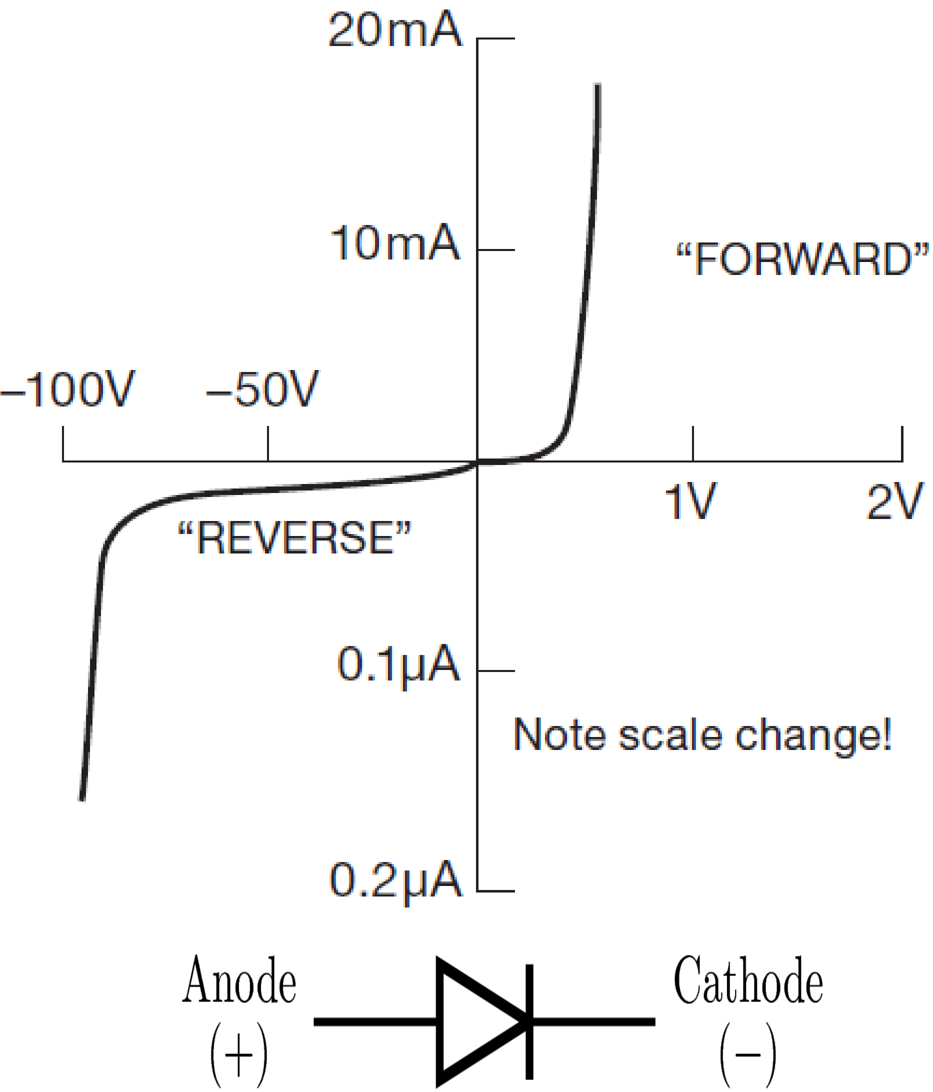


In **forward bias** (with the positive end with the higher voltage), there is a fixed voltage drop caused. Exceeding this value there will be strong current flow. The growth in current after this “threshold” voltage has been reached in exponential.



In **reverse bias**, normally very little current flows, but if the voltage gets high enough, then the diode has a non-permanent breakdown (we get a lot of current).

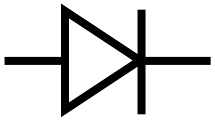
Diode: An example



In this example, if 10mA is flowing from anode to cathode, then the anode is approximately 0.6V more positive than the cathode; this is called the "forward voltage drop."

Usually, the reverse current is not of any consequence until you reach the reverse breakdown voltage (here around 75 V).

Diode

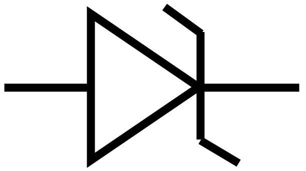


Used to direct current flow to convert AC signals to DC in dc-dc power supplies.

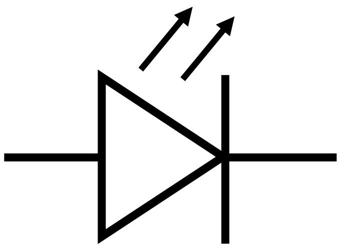
Diode Types - Examples

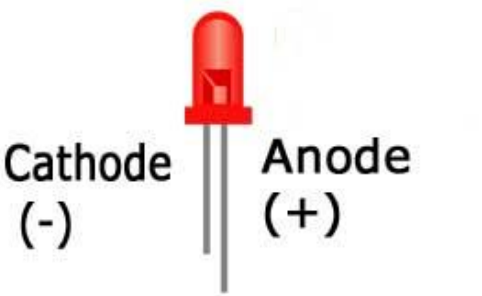
There are different diode types. We will see a few examples here.

- **Zener diode**: when forward or reverse biased, it works just like an ordinary diode. However, beyond a certain amount of negative voltage, the diode starts conducting strongly - this is **a design feature**. Zener diodes are designed to allow current to flow **as part of a protection mechanism** and will function in a standard way also.



- **LEDs** (Light Emitting Diodes) operate like a diode. Once they turn on in forward-bias (0.7 volts) they will start to emit light





Transistor

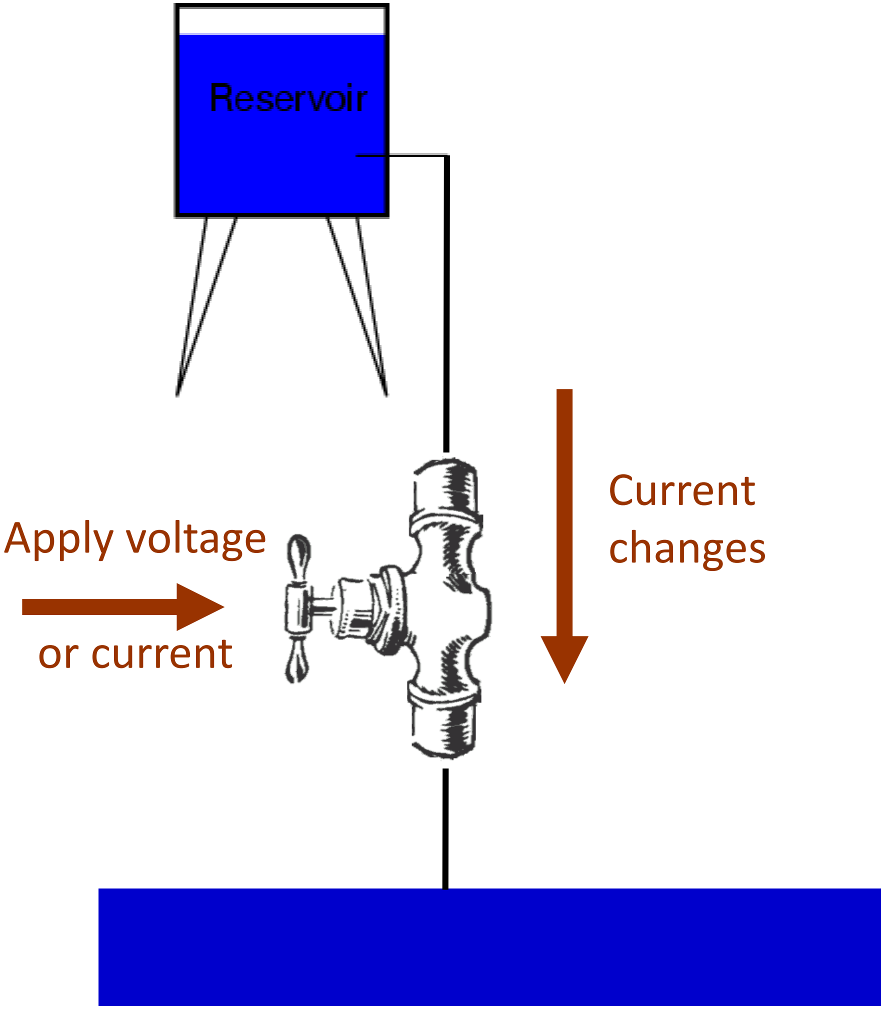
A basic component found in electronics and computers is the **transistor**. Understanding the transistor is essential before an engineer can start an electronic circuit design. Transistors are three terminal devices made from different semiconductor materials that can act as either an insulator or a conductor.

Why do we need transistors?

- A transistor acts as a switch (ON/OFF) to choose between available options.
- Signal amplification (increasing the signal strength) is done by transistors.

There are two basic types of transistors: **bipolar junction transistors (BJTs)** and **field-effect transistors (FETs)**.

Transistor



Think of a transistor as a tap or a valve.

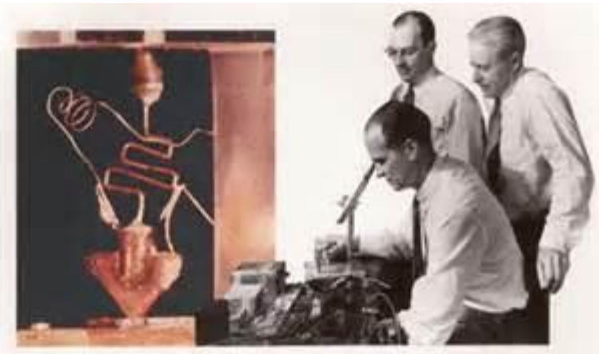
A small change in the tap setting can control a much larger current flowing.

So little changes can make big changes happen.

There are two basic types of transistors:

1. Bipolar Junction Transistors (BJTs)
2. Field-Effect Transistors (FETs).

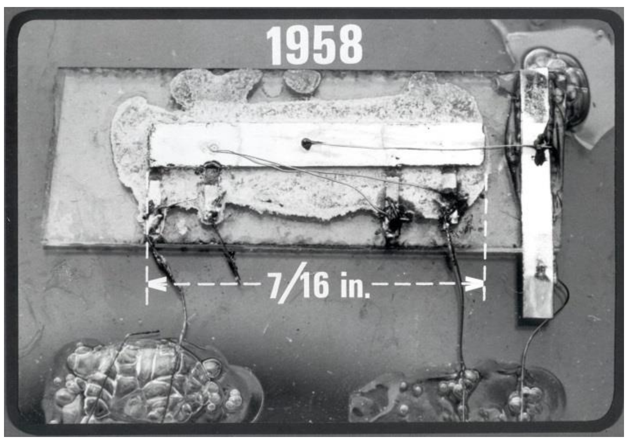
Transistor History



1cm

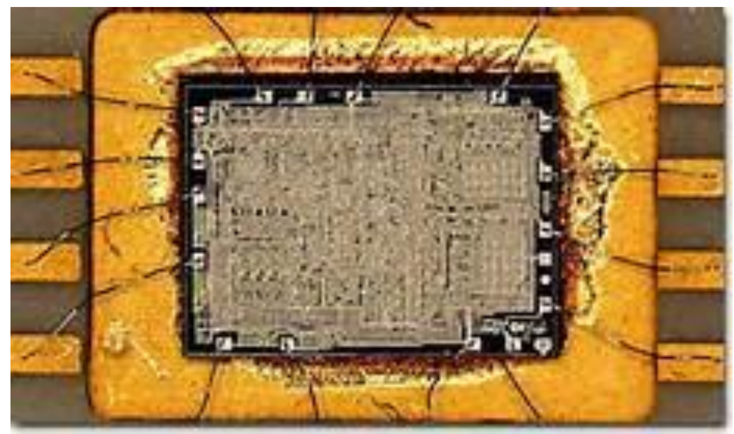
1947 (Bell Labs)

John Bardeen, William Shockley, Walter Brattain,
Schockley was the boss, claimed all the research was his, claimed the glory, but the first patents did not have his name. In 1948 he created a new type of transistor (the BJT). A great theorist, a terrible person**.**
Bardeen later won a second nobel prize for superconductivity



1958 Texas Instruments

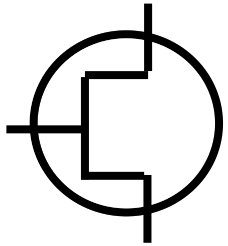
First integrated transistor, the transistor is approximately 1 cm in size.



1971 Intel 4004

First fully integrated proper CPU, 4 bit processing,
Adding **TWO** 8 bit numbers took 1ms.
2300 transistors, smallest size 10μm
10μm is half the width of a blonde hair, the size of a red blood cell, width of a cotton fibre.

Transistor (FET)

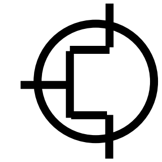


- FETs are three terminal devices. They have three pins: gate (G), source (S) and drain (D).

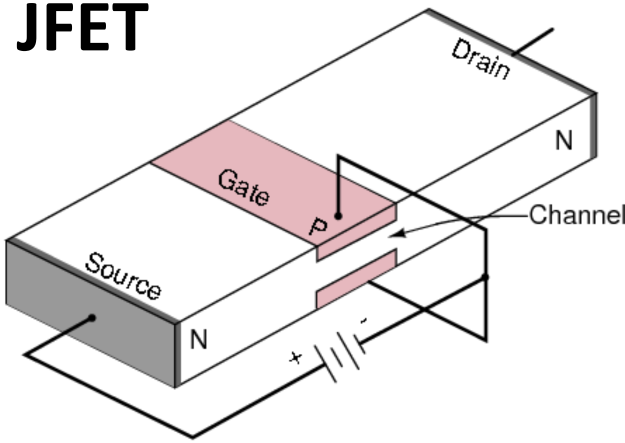
- FET is categorized into JFET (Junction Field Effect Transistor) and MOSFET (Metal Oxide Semiconductor Field Effect Transistor).

- JFET and MOSFET have quite similar in operating principles, but they have a slight different composition.

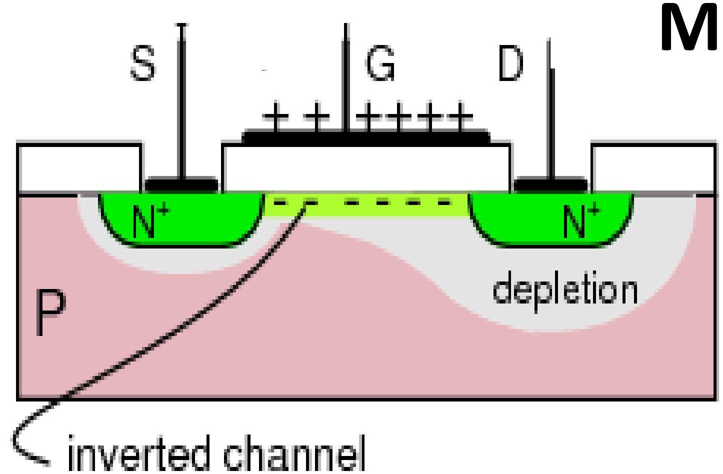
Transistor (FET)



JFET



MOSFET

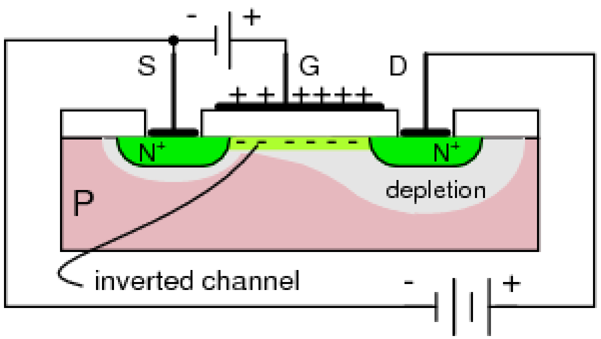


Field-Effect transistors utilise electric fields to change the property of the semiconductor thereby allowing more or less current to flow.

The important thing is that…

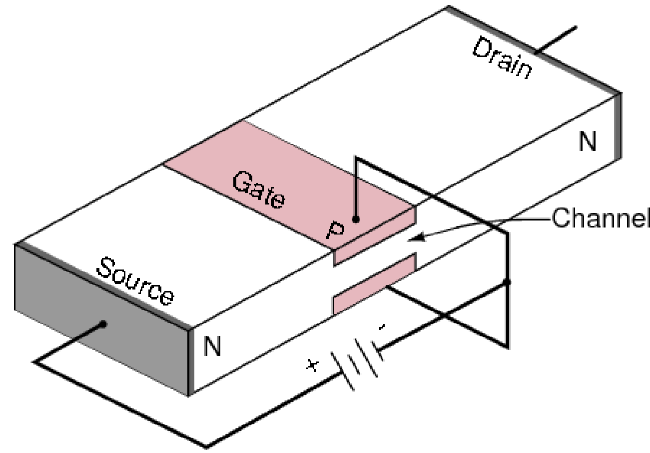
VOLTAGE CONTROLS THE AMOUNT OF CURRENT THAT CAN FLOW

Transistor (FET)



MOSFET

Metal-Oxide-Semiconductor Field Effect Transistor



JFET

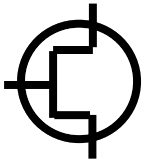
Junction Field Effect Transistor

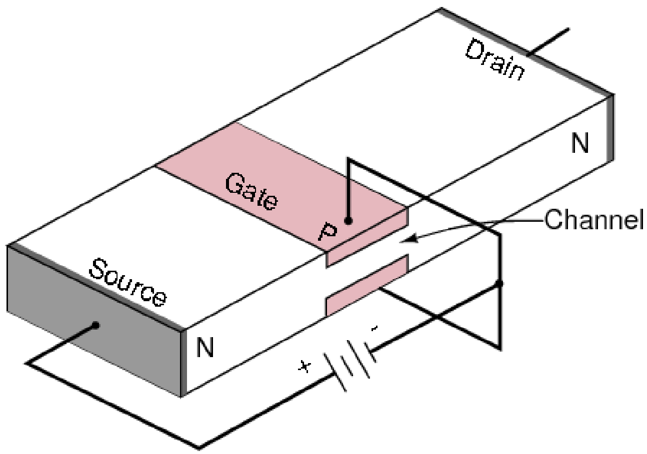
Field-Effect transistors utilise electric fields to change the property of the semiconductor thereby allowing more or less current to flow.

The important thing is that…

VOLTAGE CONTROLS THE AMOUNT OF CURRENT THAT CAN FLOW

Transistor (FET)





All FET's have three pins

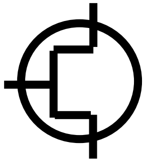
SOURCE where the carriers come from
DRAIN where the carriers go
GATE the controller

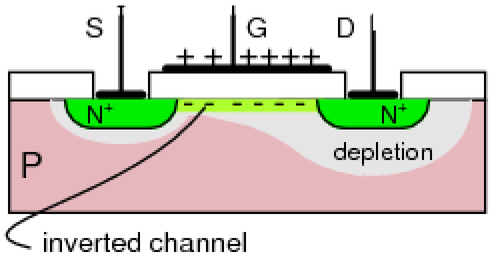
If we use the physics that electricity is carried by "positive" charge, then the source of electronics is the EARTH and the drain is the positive voltage supply.

In a JFET, we have a piece of semiconductor sandwiched between two other pieces. By applying a voltage we "squeeze" the channel in the middle and reduced its available area for conduction. Changing the area changes the resistance…

Increasing the gate voltage
reduces the area,
increases the resistance
reduces the current that can flow

Transistor (FET)





All FET's have three pins

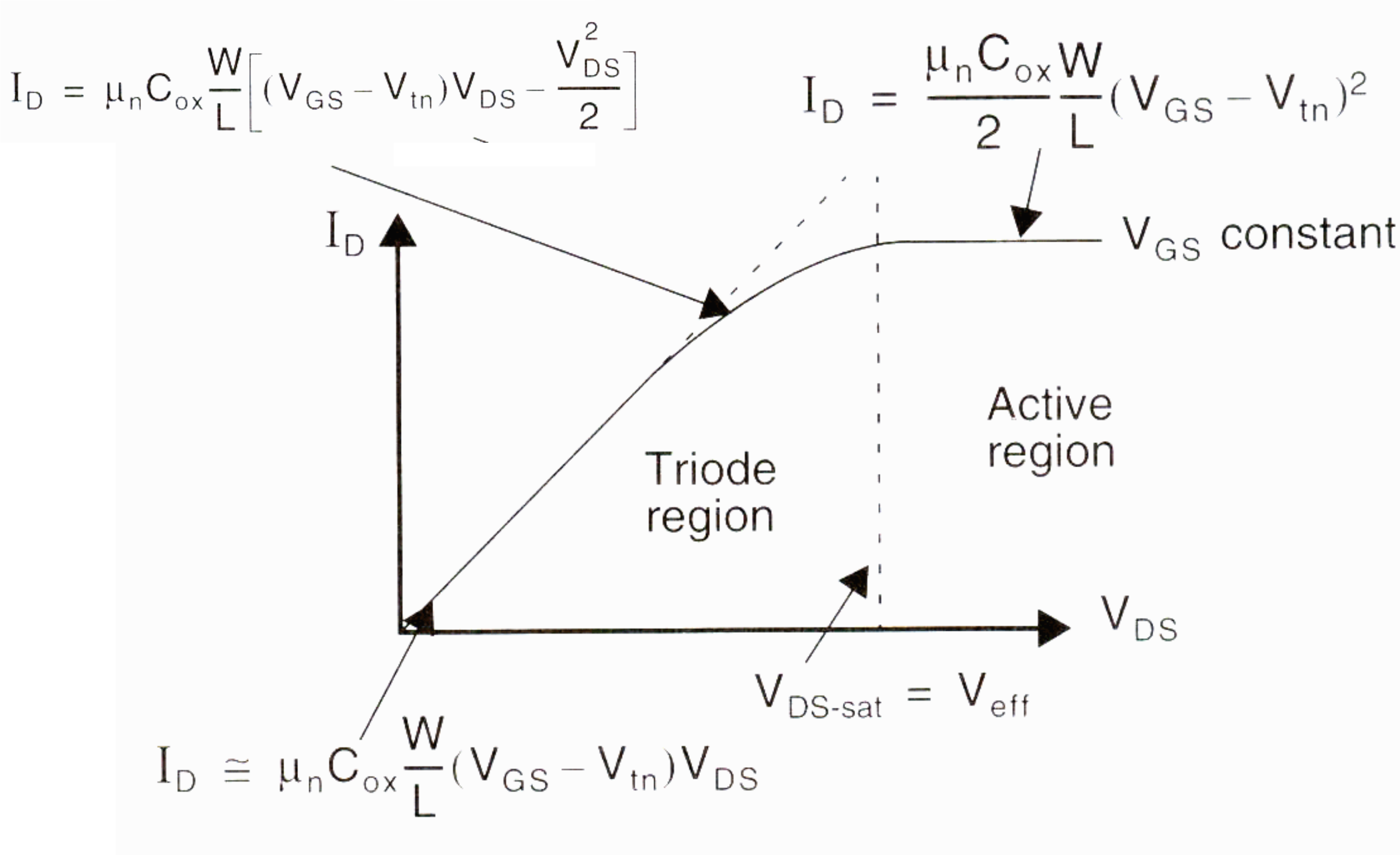
SOURCE where the carriers come from
DRAIN where the carriers go
GATE the controller

In a MOSFET, we use a capacitive effect to attract charge to the bottom plate of the capacitor and all this accumulated charge (electrons) will allow current to flow.

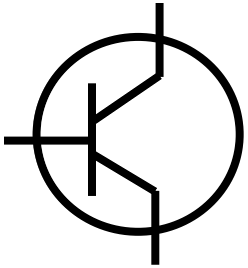
What we are doing is CREATING a path for current to flow in what should be an insulator. The more electrons attracted, the easier it is for current to flow.

Increasing the gate voltage
attracts electrons, creates a conductive path
reduces the resistance
increases the current that can flow

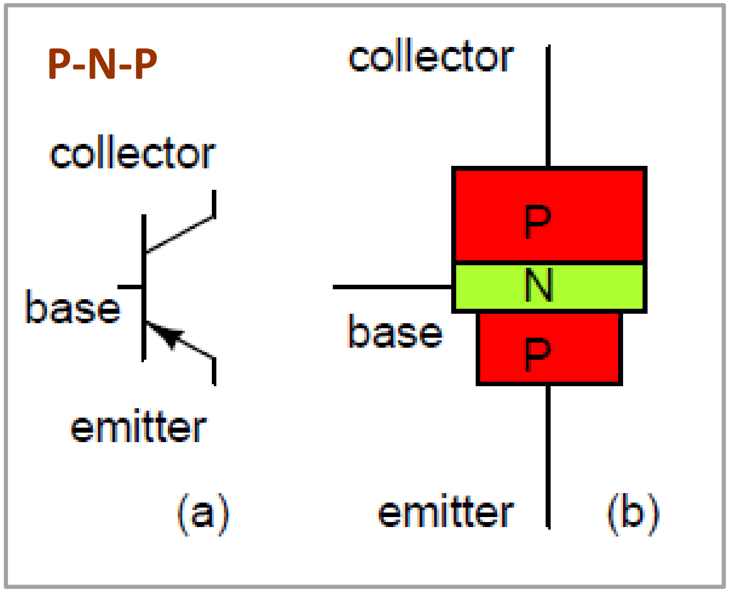
Transistor (FET)

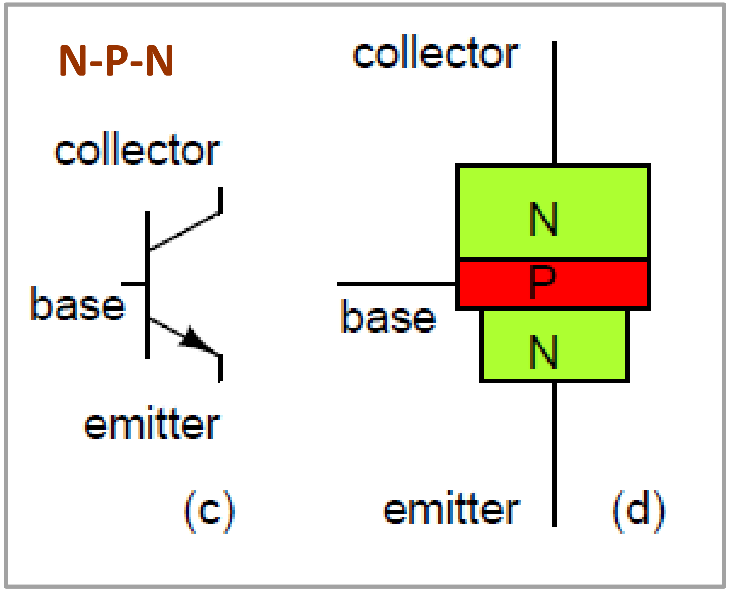


Transistor (BJT)

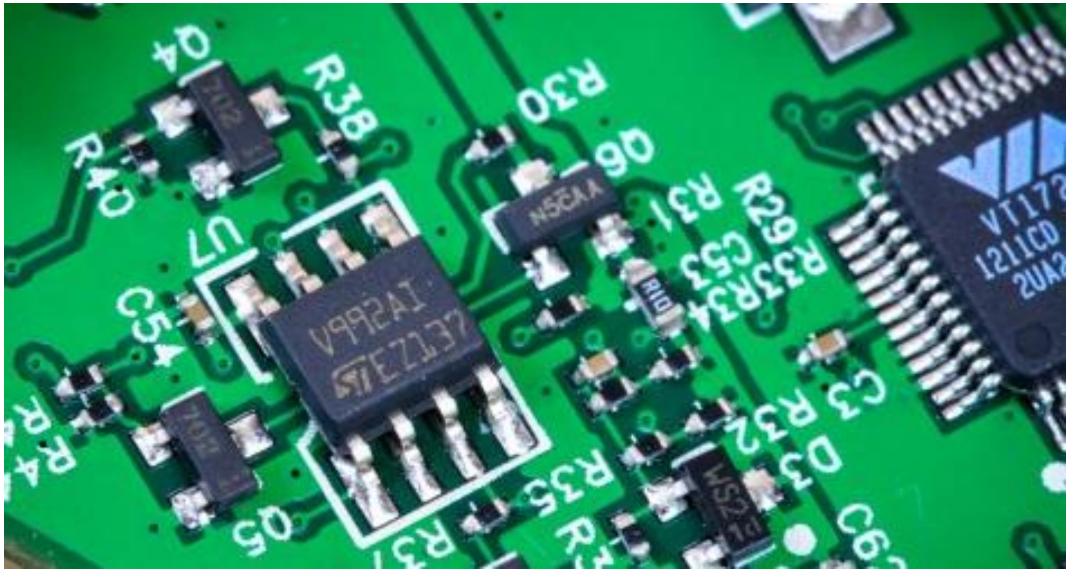


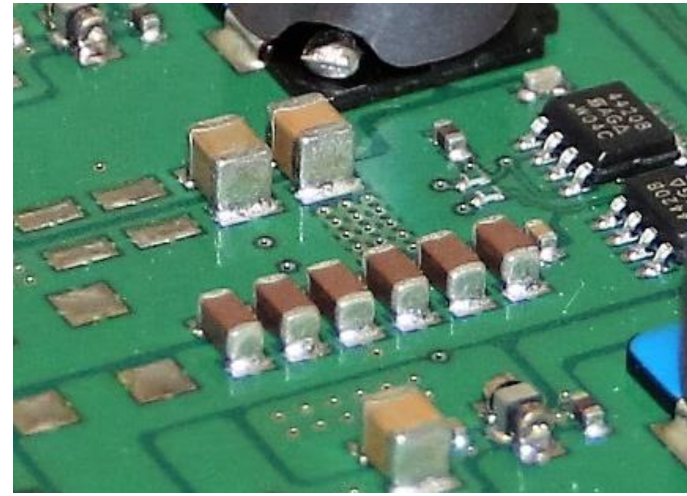
- BJT (Bipolar Junction Transistor) is a three terminal device.
  It has three pins: emitter, collector and base. There are two types of BJTs, either **P-N-P** or **N-P-N**.
- BJT is made of P and N material and is a 'sandwich style' construction.
- BJTs are current-driven devices.

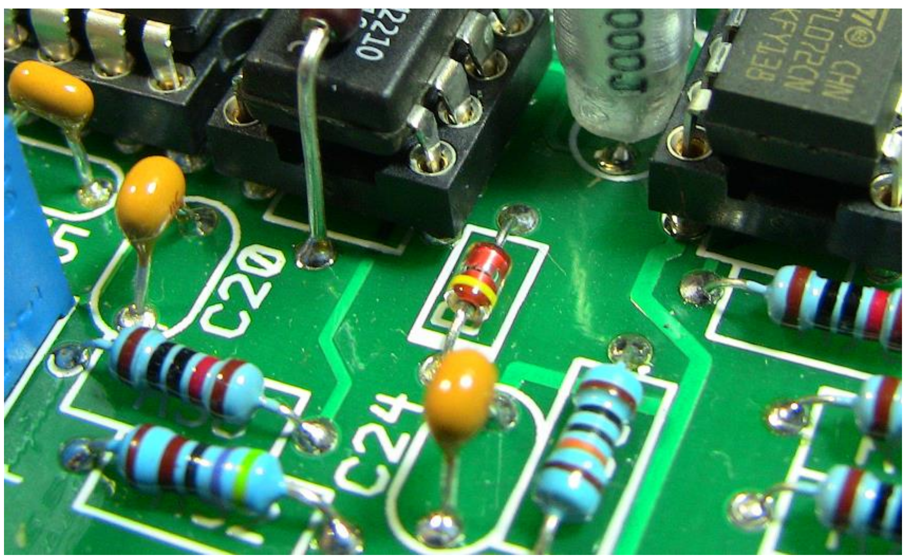




Printed Circuit Board examples

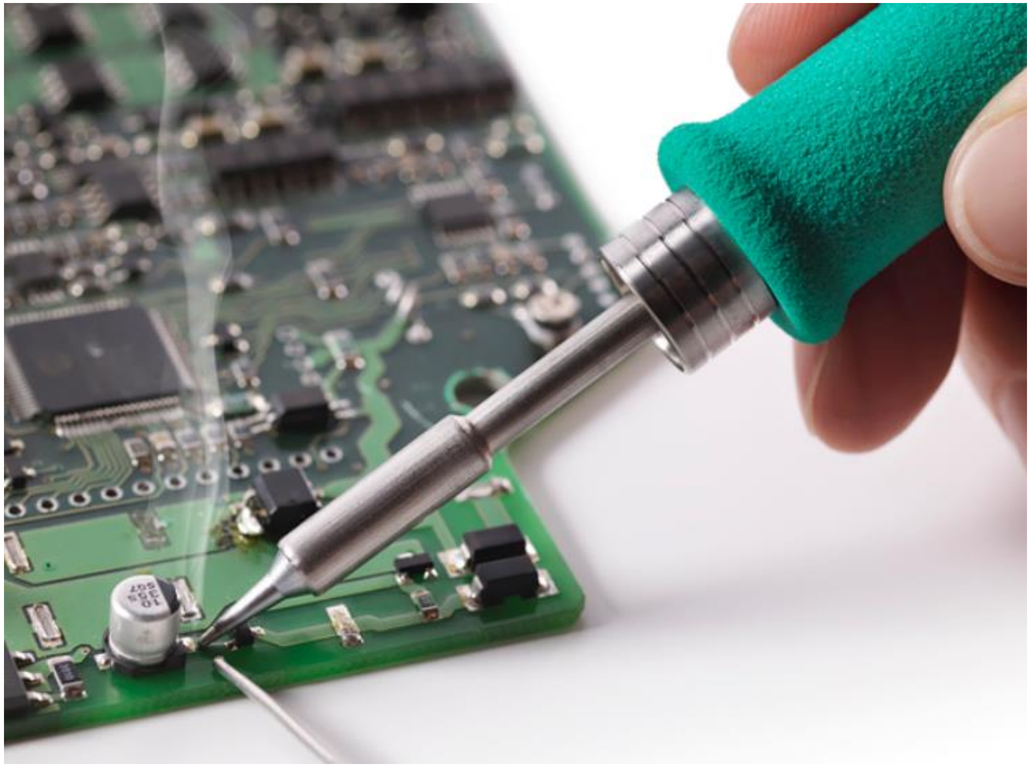




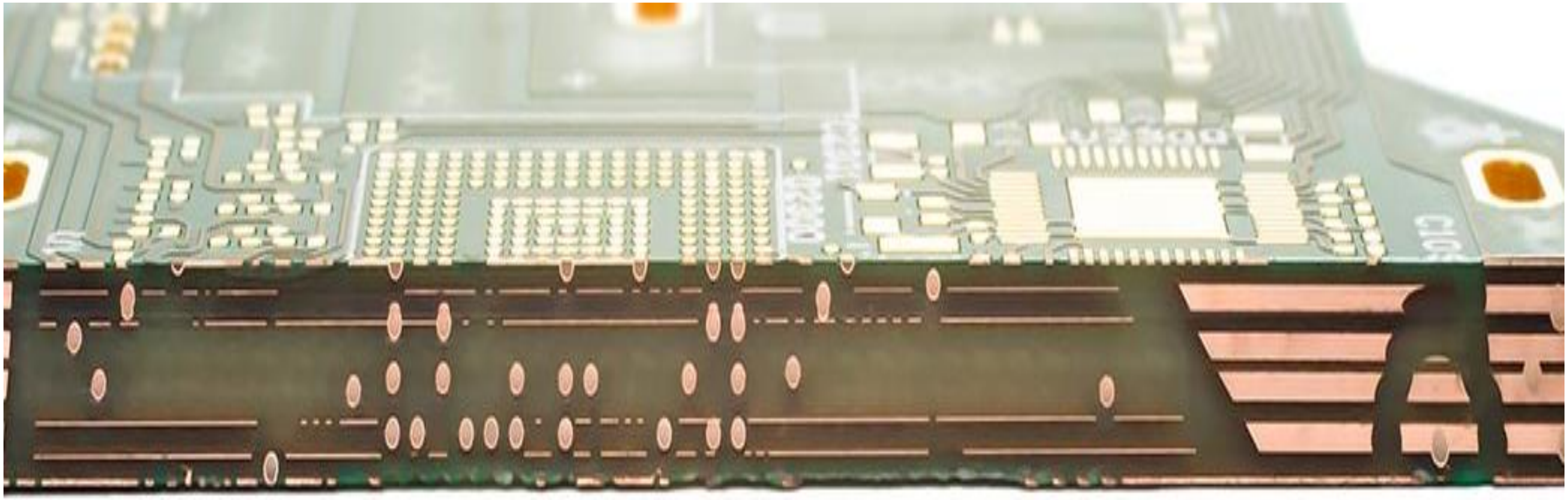


Electronics components are connected using conductive tracks etc by means of a printed circuit board (PCB).

Soldering - Example



Multi-Layer PCB



Multilayer PCB is a Printed Circuit Board with more than 2 layers.