Basic Mechatronics Workshop

Module 2: Sensors

Lecture-4

Sensor Interface

(NPN and PNP Type)

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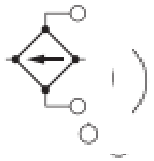
Lecture-4

Sensor Interface
(NPN and PNP Type)

Objectives

Upon completion of this chapter, Student should be able to

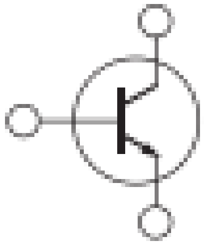
- ✓ List the sensor output configuration.
- ✓ Define the transistor function and its applications.
- ✓ Explain the main types of transistors.
- ✓ Describe Bipolar Junction Transistors.
- ✓ Explain the Metal Oxide Semiconductor Field Effect Transistors .
- ✓ Describe the Insulated Gate Bipolar Transistors .



sor output configuration

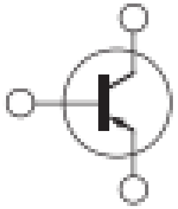
NPN transistor output

A general-use transistor can be directly connected to a Programmable Controller or Counter.



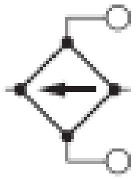
PNP transistor output

Primarily built into machines exported to Europe and other overseas destinations.



Non-polarity/non-contact output

A 2-wire AC output that can be used for both AC and DC Sensors. Eliminates the need to be concerned about reversing the polarity.



NO (normally open)

NO When there is an object in the sensing area, the output switching element is turned ON.

NC (normally closed)

When there is no object in the sensing area, the output switching element is turned ON.

NO/NC switchable

NO or NC operation can be selected for the output switching element by a switch or other means.

Transistors

A transistor can function in two ways:

1. as an ON/OFF switch,
2. as a proportional amplifier.

It is an electronic switch (solid-state switch) that can be opened or closed completely or partially. Another way of looking at a transistor is that it is a variable resistor where the resistor value is controlled by the gate current. It is an active element which is used to modulate (control) the flow of power from source to load.

The main types of transistors are:

1. Bipolar junction transistors (BJTs) are the most common transistors.

1. Metal oxide semiconductor field effect transistors (MOSFETs) require smaller gate current, have better efficiency, and have higher switching frequency.

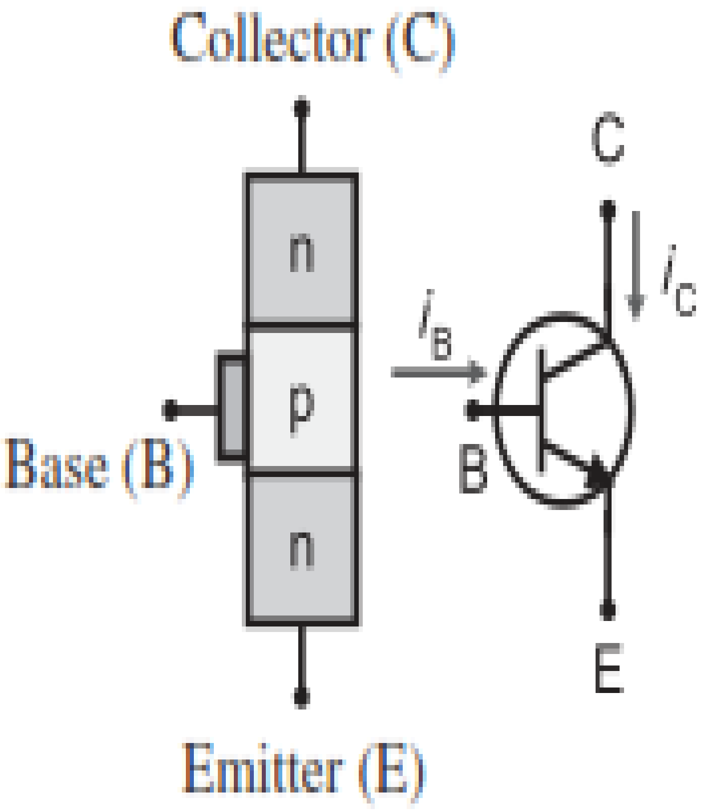
1. Insulated gate bipolar transistors (IGBTs) are a more recent transistor type which attempts to combine the advantages of BJTs and MOSFETs.

Bipolar junction transistors (BJTs)

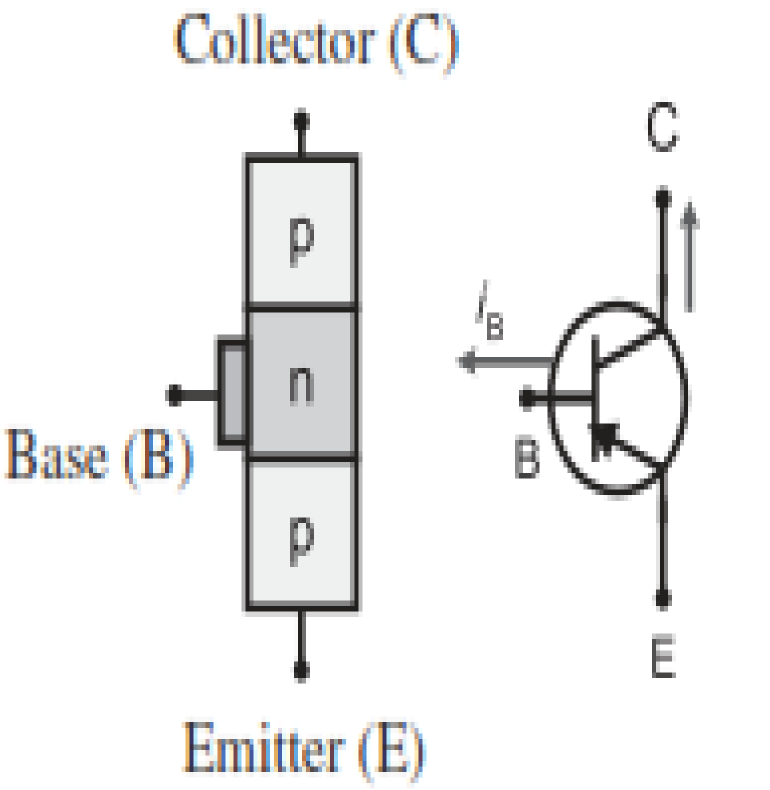
Transistors, How do they work ?

https://www.youtube.com/watch?v=7ukDKVHnac4

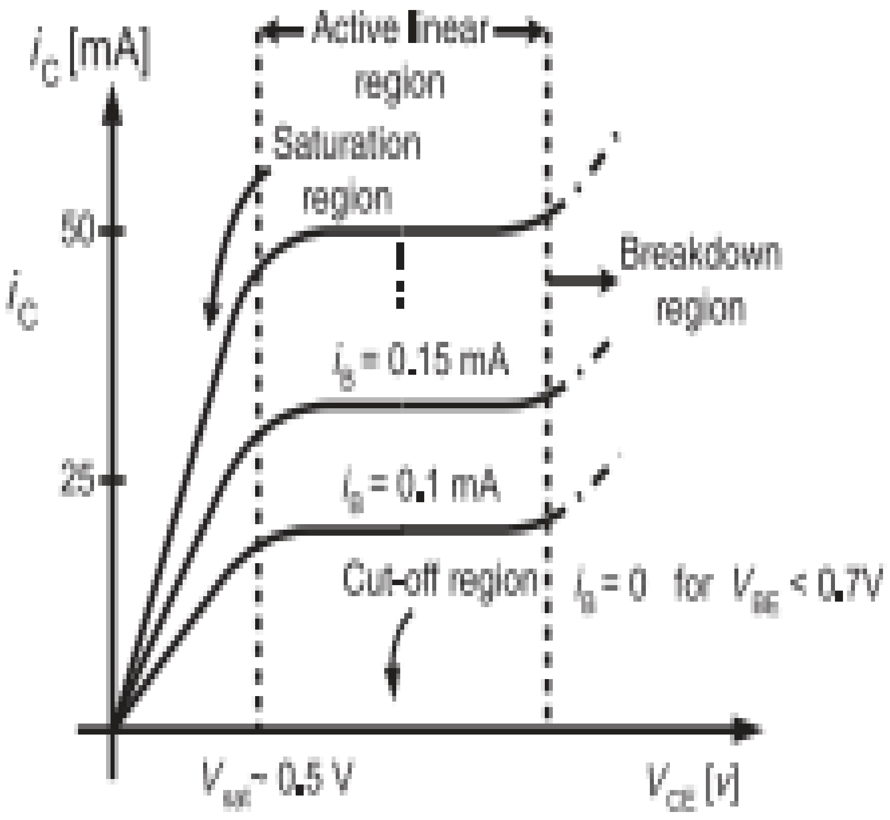
Bipolar junction transistors (BJTs)



n-p-n transistor



p-n-p transistor

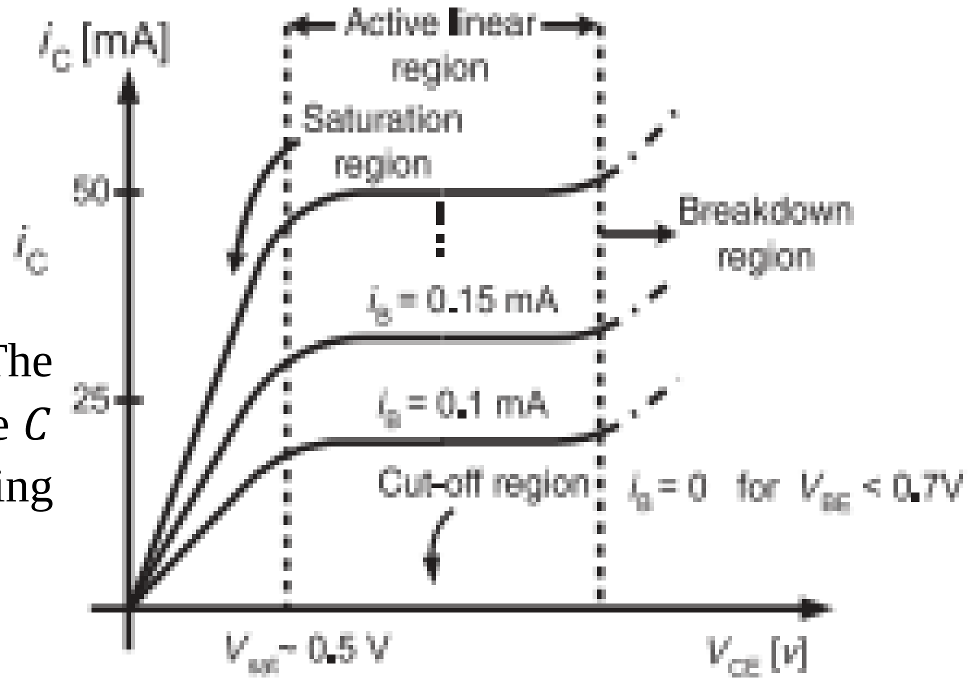


Bipolar junction transistors (BJTs)

Transistors as a Switch: Theory & Explanation

https://www.youtube.com/watch?v=UIEGKvCfDOA

Bipolar junction transistors (BJTs)



There are three main modes of operation of the BJT in steady-state,

1. ***Cut-off Region:*** $\boldsymbol{V_{BE} < V_{FB}, i_B = 0,}$ **hence,** $\boldsymbol{i_c = 0, V_{CE} < V_{Supply}}$. The transistor acts like an OFF-state switch. There is no current flow between the C and E. V_{FB} can vary between $0.6V\ to 0.8\ V$ as a result of manufacturing variations. In valve analogy, the valve is closed.

1. ***Active Linear Region:*** $\boldsymbol{V_{BE} = V_{FB}, i_B \neq 0;\ i_c = \beta i_B\ ,\ V_{SAT} < V_{CE} < V_{Supply}}$. The typical value of $V_{SAT} \approx 0.2$Vto 0.5 V. Transistor acts like a current amplifier. The output current, i_c, is proportional to the base current, i_B, where the proportionality constant (gain) is a design parameter of the transistor, which is typically around 100 and can range from $50\ to\ 200$. Good circuit designs should not rely on this open-loop transistor gain for it can vary significantly from one copy to another of the same transistor as well as being a function of temperature. The current i_c is also function of the V_{CE} slightly. Under constant base current conditions, the collector current increases slightly as the collector to emitter voltage increases. In valve analogy, valve is partially open.

2. ***Saturation Region:*** $\boldsymbol{V_{BE} = V_{FB}, i_B > \frac{i_{c,max}}{\beta},;\ V_{CE} \leq V_{SAT} \approx 0.2 - 0 \cdot 5}$. In this mode the transistor operates like a closed (ON) switch between C and E terminals. The actual value of i_c is determined by the circuit preceding the collector, which is analogous to a completely open valve where the flow rate is determined by the supply and load pressures.

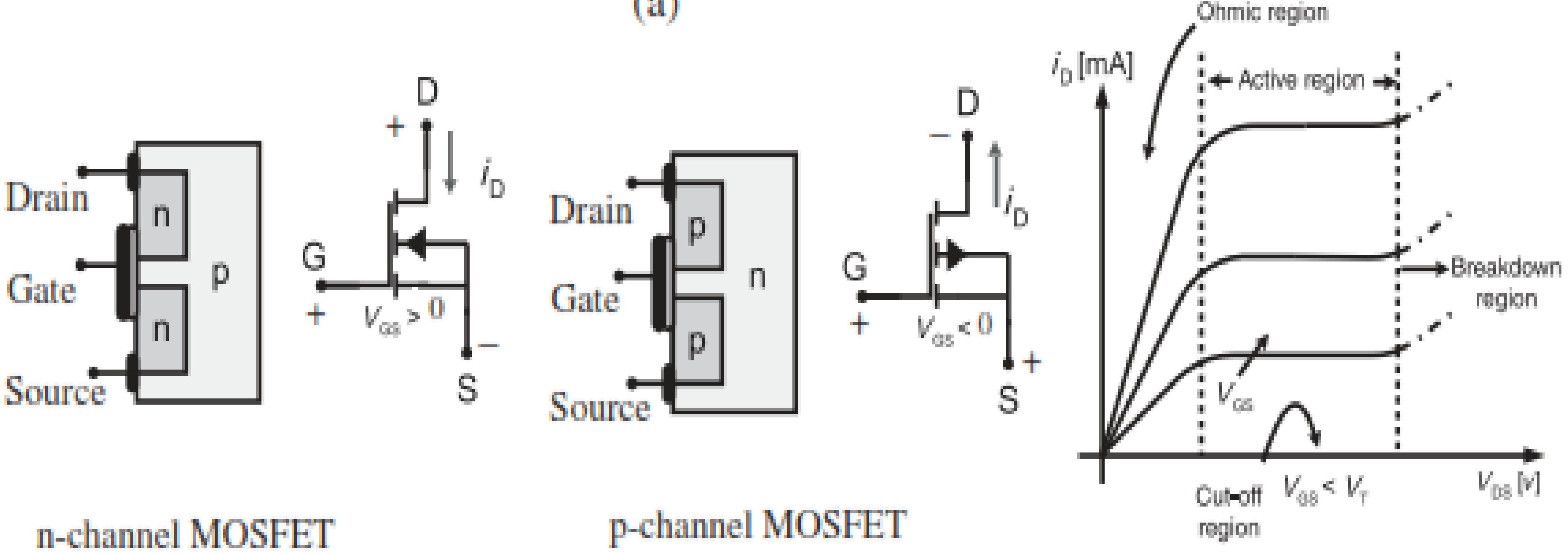
Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

Working of Transistors | MOSFET

https://www.youtube.com/watch?v=stM8dgcY1CA&list=PLuUdFsbOK_8o1BzPcXHwILC7UN0MmTo5-&index=2

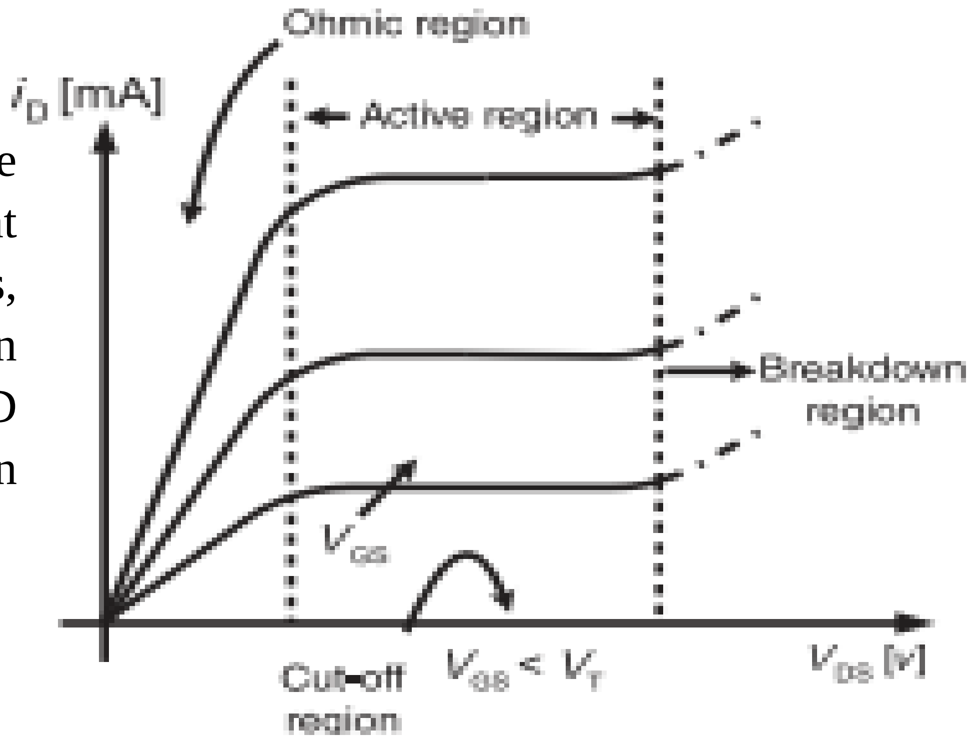
Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

(a)



Metal Oxide Semiconductor Field Effect Transistors (MOSFETs)

There are three regions of operation of a MOSFET,



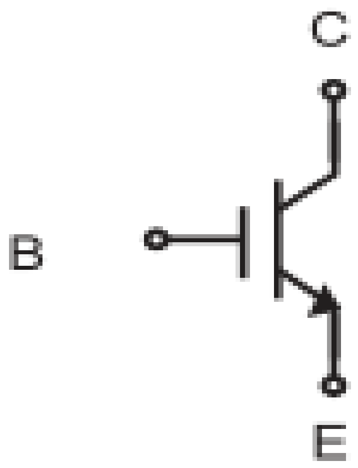
1. ***Cutoff Region:*** $\boldsymbol{V_{GS} < V_T}$ **and** $\boldsymbol{i_G = 0}$**, hence,** $\boldsymbol{i_D = 0}$**,** where V is the gate-source threshold voltage. The threshold voltage takes on different values for different types of FETs (i.e., $V_T \approx -4\,V$ for junction FETs, $V_T \approx -5\,V$ for MOSFETs in depletion mode, $V_T \approx 4\,V$ for MOSFETs in enhancement mode). There is negligible current flow through the D terminal and the connection between D and S terminals is in an open switch state.

2. ***Active Region:*** $\boldsymbol{V_{GS} > V_T}$ **, hence,** $\boldsymbol{i_D \propto (V_{GS} - V_T)^2}$**,** $\boldsymbol{(V_{DS} > (V_{GS} - V_T)}$. The transistor functions as a voltage controlled current amplifier, where the output current is proportional to the square of the net GS voltage. Notice that for the MOSFET to operate in this region, V_{DS} must be above a certain threshold. Otherwise, the MOSFET operates in the ohmic region.

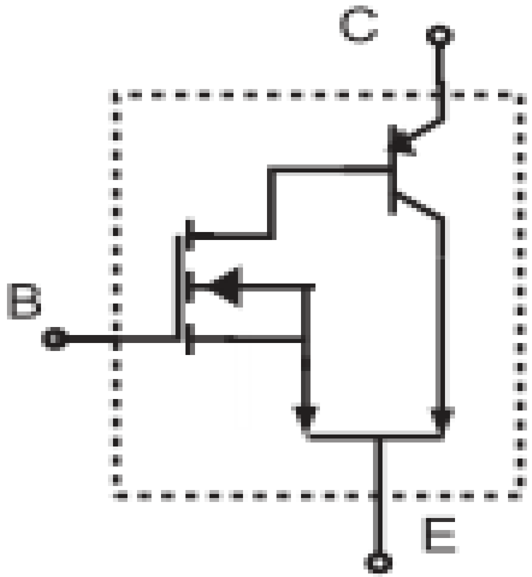
3. ***Ohmic Region:*** When V_{GS} is large enough $\boldsymbol{(V_{GS} > V_T)}$ **and** $\boldsymbol{(V_{DS} < (V_{GS} - V_T)}$ is determined by the source circuit connected to the D terminal and the transistor behaves like a closed switch between D and S terminals. $V_{GS} \gg V_T$ then and $i_D = V_{DS}/R_{ON}(V_{GS})$. The MOSFET acts like a nonlinear resistor where the value of the resistance is nonlinear function of the gate voltage.

Insulated Gate Bipolar Transistors (IGBT)

IGBTs are the new alternative to BJTs in high voltage (>500 V) applications where they combine the advantages of BJTs and MOSFETs. IGBT is a four-layer device with three terminals similar to BJTs. IGBTs are widely used in motor drive applications and operate in PWM mode for high efficiency.



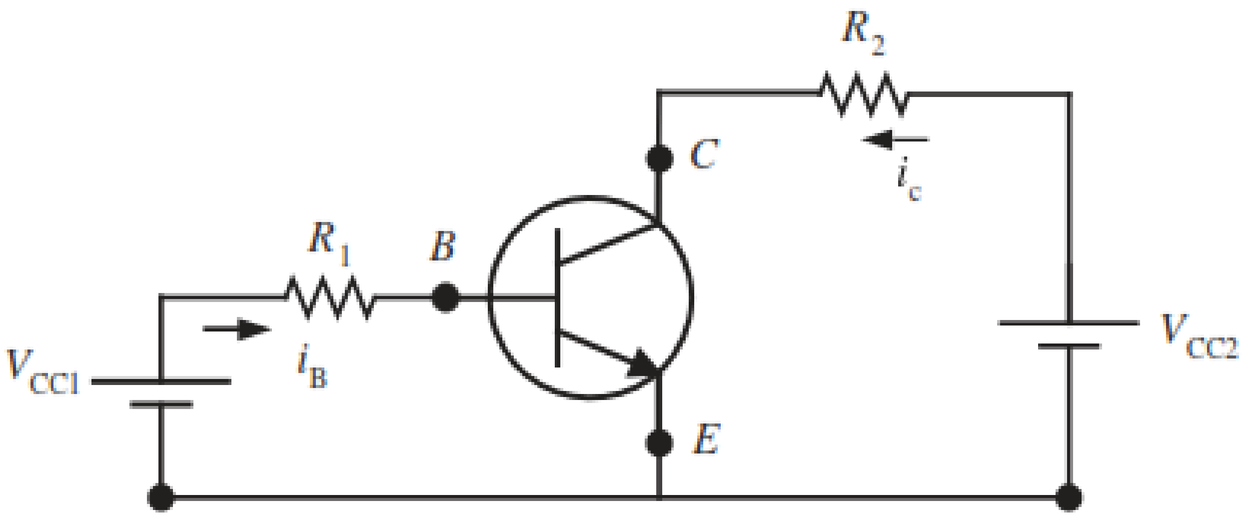
Schematic symbol



Equivalent circuit

Example In order to illustrate the fact that a transistor can be operated like a switch (ON or OFF) as well as a proportional amplifier, let us consider the following cases of input voltage in the same Figure 5.17. Furthermore, let us more accurately assume that = 0.7 V, and the minimum voltage drop across the collector and emitter is V_{BE} the maximum voltage drop across the base and emitter is V_{CE}= 0.2V.

1. Case 1: $V_{CC1} = 0.0\,V$. Then $i_B = 0$, hence, $i_C = 0$. Therefore, the voltage measured between the collector and the emitter (let us call it the output voltage, V_{out}) is $V_{out} = V_{CC2} = 25$ VDC .We can call this the OFF state of the transistor.



Common emitter configuration and voltage amplifier usage of a transistor.

Example

2. ***Case 2:*** $V_{\mathrm{CC1}} = 30.7\,V$ (more precisely, the input voltage at the gate is large enough to generate a large base current that will saturate the transistor output circuit). Then $i_B = (30.7 - 0.7)\,/\,100\,K = 0.3\,mA$, hence, $i_{\mathrm{C}} = \beta i_B = 30\,mA$. Therefore, the voltage measured between the collector and the emitter (let us call it the output voltage, V_{out}) is $V_{\mathrm{out}} = V_{\mathrm{CC2}} - R_2 \cdot i_{\mathrm{C}} = 25 - 1000 \cdot 30\,mA = -5\,V$. Since the output voltage at the collector cannot be less than the emitter voltage plus the $0.2\,V$ minimum voltage drops across the collector and emitter, it must be, $V_{\mathrm{out}} = 0.2\,V$. Hence the actual collector current saturates at $i_{\mathrm{C}} = \frac{V_{\mathrm{CC2}} - V_{\mathrm{CE}}}{R_2} = (25 - 0.2)/1000 = 24.8 mA$ and the output voltage at the collector is $V_{\mathrm{out}} = 0.2\,V$. We can call this the ON state of the transistor.

Example

3. Case 3: When the input voltage is above cutoff voltage ($V_{\mathrm{BE}} = 0.7\ V$) but below the saturation voltage, the transistor operates as a proportional voltage amplifier. The saturation voltage can be calculated as follows. The minimum voltage drops across C and E when the transistor is saturated is

$$V_{CE} = 0.2; when\ saturated$$

At this point, the current is

$$i_C = \frac{V_{\mathrm{CC2}} - V_{\mathrm{CE}}}{R_2} = \frac{25 - 0.2}{1000} = 24.8mA$$

The base current must be

$$i_\beta = \frac{1}{\beta} i_C = \frac{1}{100} i_C = \frac{V_{\mathrm{in\_sat}} - V_{\mathrm{BE}}}{R_1}$$

$$V_{\mathrm{in\_sat}} = 0.248mA \times 100K\Omega - 0.7 = 24.1V$$

Base voltage value larger than that operates the transistor in the saturation region.

$$V_{\mathrm{in}} < V_{\mathrm{BE}};\ transistor\ is\ in\ fully\ OFF\ state$$

$$V_{\mathrm{BE}} < V_{\mathrm{in}} < V_{\mathrm{in\_sat}};\ linear\ region$$

$$V_{\mathrm{in}} < V_{\mathrm{in\_sat}};\ saturated\ region\ (fully\ ON\ state)$$

Example

Case 1 and case 2 are shown as a mechanical switch analogy in Figure 5.18. Figure 5.18a shows the so-called sinking connection and Figure 5.18b shows the so-called sourcing connection of the transistor to the load. The names sinking and sourcing are given from the point of view of the transistor in that it either sinks the current from the load or sources current to the load.

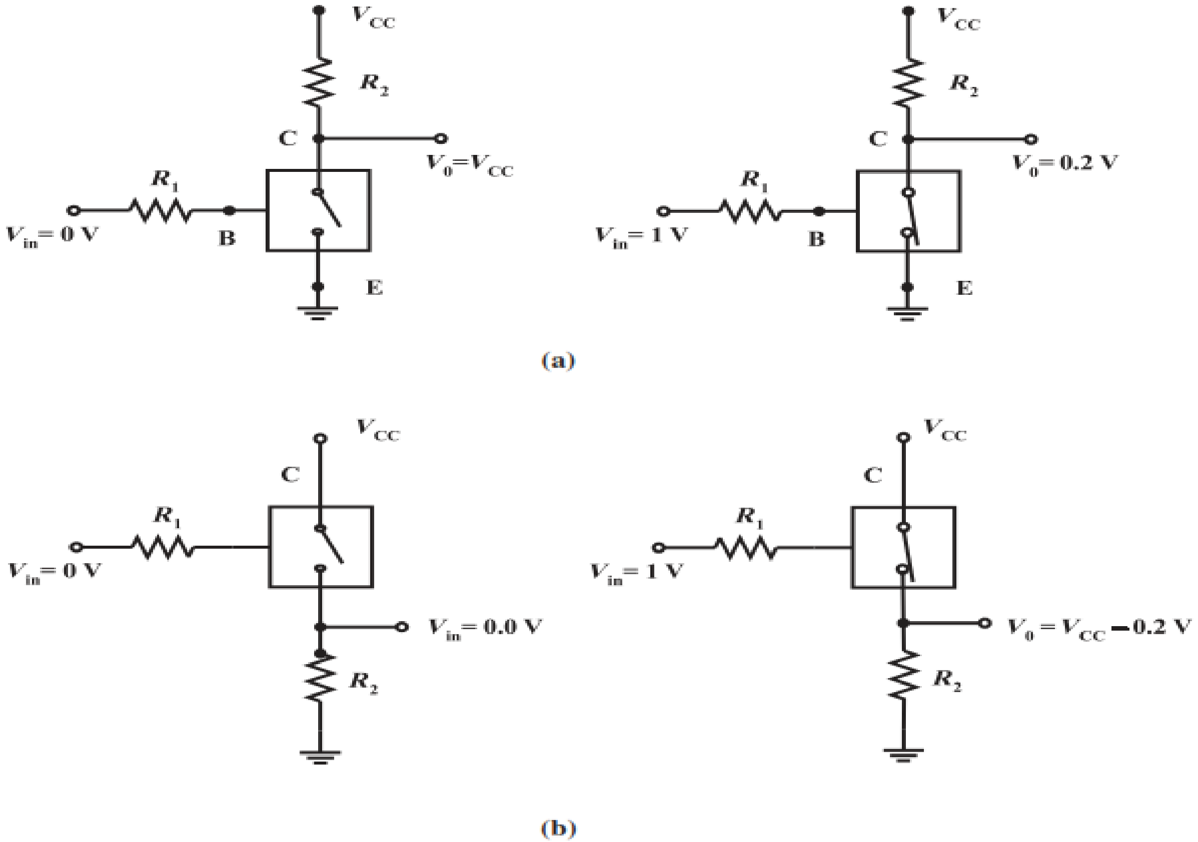


FIGURE: Mechanical switch analogy for a transistor:

(a) Current sinking connection (sinking current from the load). Also called a low-side (output) switch.

(b) Current sourcing connection (sourcing current to the load). Also called a high side (output) switch.