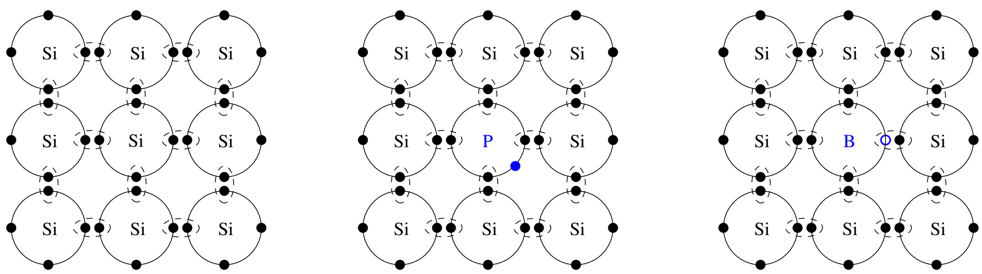
Electronics

Electronic circuits are corner stone of modern civilization. The semi-conductor materials were invented in late 1940's have they have evolved considerably over the past 6-7 decades. This section pertains itself with the fundamentals of semiconductor materials and basic circuits which lay foundation of complex and useful circuits. Although semi-conductors can be developed from several materials Silicon, Germanium, Galium Arsenide however Silicon is the most widely used material because of abundant availability and other desirable properties. Silicon is its purest form is non-conducting (insulating) material as there are no spare electrons to flow in the circuit. However, by adding some impurities this material can become conductive.

The process of adding impurities is called doping and Silicon can be doped with different types of materials e.g. adding little quantity of Phosphorous can make bonds with Silicon which have excess electrons, while adding Boron can make bonds with Silicon which are deficient in electrons. The Phosphorous doped silicon is called N-type material, while Boron doped material is called P-type material. It is commonly denoted that material with excess of electrons have electrons and material with lack of electrons has holes.

1 Diodes:

This is the basic building block of semi-conductor circuits. The junction is constructed by combining N-type and P-type material. As illustrated in the figures when P and N type materials are combined,



(a) Silicone Lattice. (b) with Phasporous Doping. (c) with Boron Doping.

Figure 1: Illustration of Silicon lattice, with Phosphorous and Boron doping.

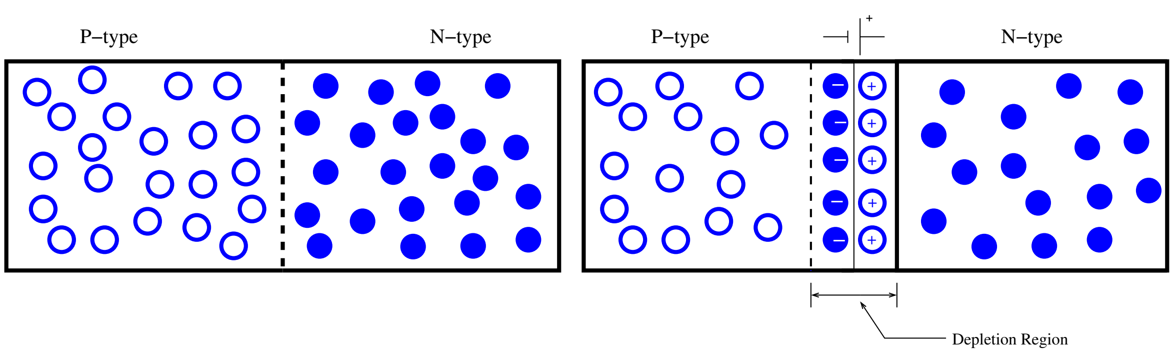
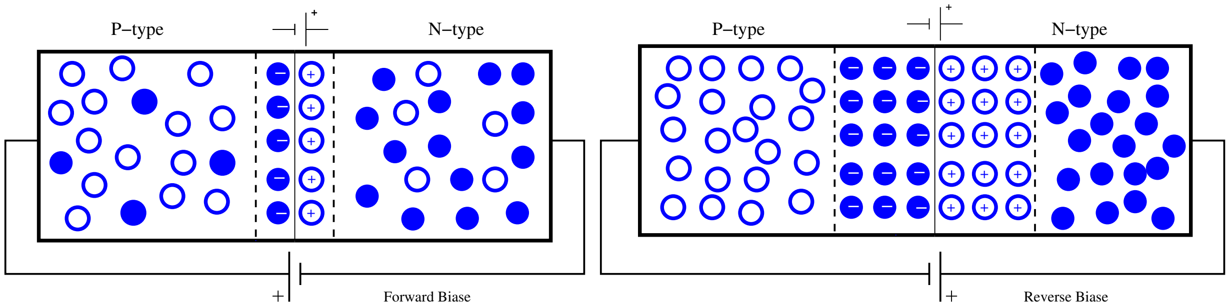
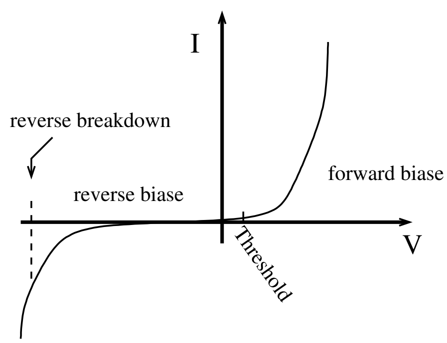


Figure 2: Illustration of PN junction.



(a) Operation of PN junction in forward and reverse bias mode.



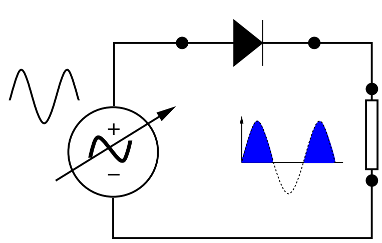
(b) Current Voltage Curve of PN Junction.

Figure 3: Illustration of Silicon lattice, with Phosphorous and Boron doping.

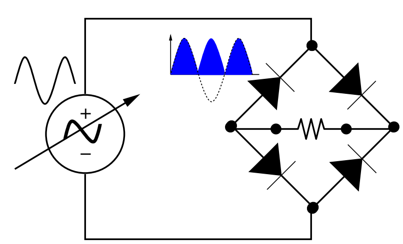
the excess electrons in N type material travel from N-type material and interact with holes on the other side of the junction. This causes the depletion region at the junction. This junction acts a voltage barrier.

1.1 Applications of Diodes

Diodes find applications in a wide range of applications. Circuit protection, rectification and signal detection are just to list a few. Full wave rectifiers are the most simple (and least efficient) way to convert AC waveform into DC waveform.
There exist a few types of diodes based on composition and characteristics. The well-known diodes include Schottkey Diode, Zener Diode and Light Emitting Diode.



(a) Half wave Rectifier.



(b) Full wave Rectifier.

Figure 4: Use of diode for rectification purpose.

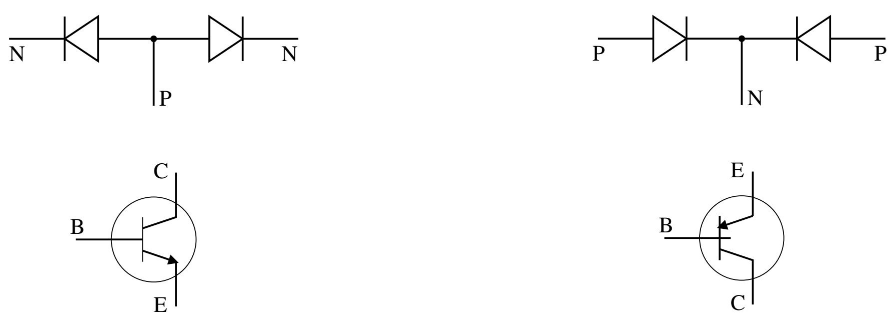
Transistors

Transistors are a true miracle of 20th century, the single most important device invented in the 20th century. Transistor come in a variety of configurations and a key building block to a host of applications. For the introductory session we concern ourselves with special type Bipolar Junction Transistors. The transistor configurations The construction of diode is usually described as a sandwich of two N and one P type materials or vice-versa. However, the actual design is illustrated in fig. 7. It is important to note that the base material is lightly doped, whereas collector and emitter terminals are respectively doped moderately and heavily. The operation of transistor on a micro-level is illustrated in fig.8. It apparent the applying a suitable potential on the base of the transistor activates the emitter-base junction into forward bias. Since all the electrons flowing from emitter can not emitter slightly doped base, they travel across the junction into collector, producing a much bigger current flow between emitter and collector. It is apparent from fig.8 that

$$I_E = I_B + I_C \tag{1}$$

The relation between emitter, collector and base currents are defined as key parameters of a transistor.

$$\alpha = \frac{I_C}{I_E} \approx 1 \qquad\qquad \beta = \frac{I_C}{I_B} \gg 1 \tag{2}$$



(a) NPN Configuration.

(b) PNP Configuration.

Figure 5: The equivalent circuit diagram and symbols of transistors.

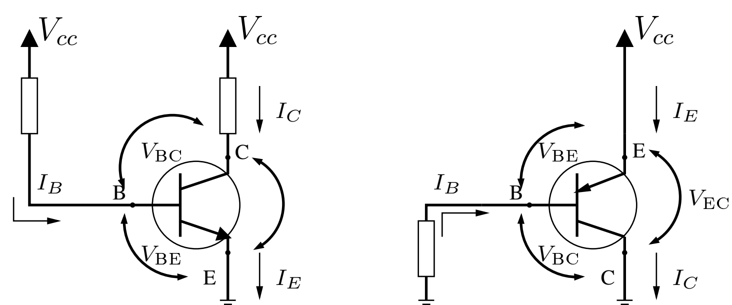


Figure 6: The equivalent circuit diagram and symbols of transistors.

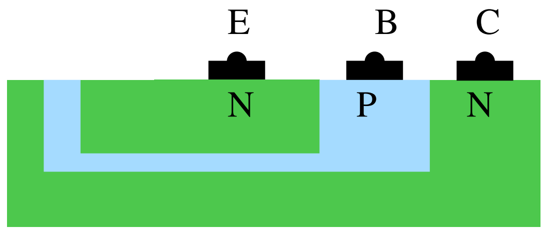


Figure 7: The physical construction of a transistor.

here β is known as the current gain of the transistor typical value of β is between 20 and 200. The *beta* and α are related as follows

$$\frac{I_E}{I_C} = \frac{I_B}{I_C} + \frac{I_C}{I_C}$$

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1$$

inserting the definition of α and β from 2

$$\alpha = \frac{\beta}{1+\beta}$$

likewise we can express β in terms of α

$$\beta = \frac{\alpha}{1-\alpha}$$

The operation of a transistor is divided into 4 regions as illustrated in the fig.9. as illustrated in fig.9.

Active Region

One junction of the transistor is in forward bias while the other is in reverse bias. The base current I_B can be used to control the amount of collector current I_C. Therefore, active region is used for amplification of signal, the input is applied in the form of I_B

$$I_C = \beta I_B$$

This is called the linear region between cut-off and saturation region as illustrated in fig.9.

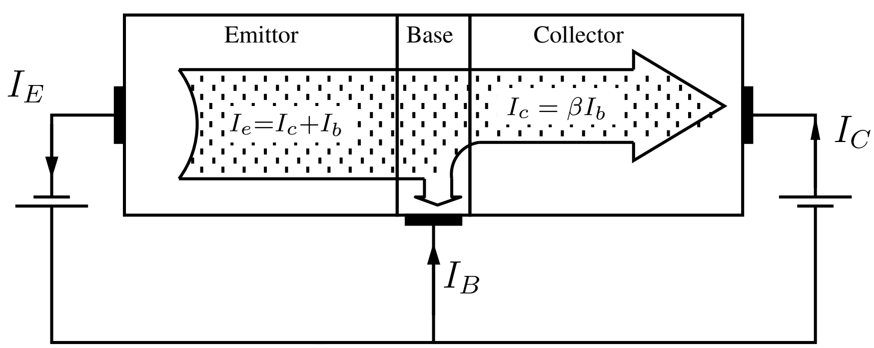


Figure 8: The flow of electrons of in an NPN transistor.

Saturation Region

In saturation region, both junctions are in forward bias. This region is suitable for On-state for a switch.

$$I_C = I_{\text{sat}}$$

where I_{sat} is the maximum amount of current flowing between emitter and collector terminals.

Cut-off Region

Both junctions of the transistor are in the reverse bias. BJT will be in off state of the switch.

$$I_C = 0$$

Breakdown Region

is the region where the collector voltage, V_{cc}, is so large that the collector-base diode breaks down, causing a large, undesired collector current to flow.

When the collector-base voltage is too large, the collector-base diode breaks down, so that the collector conducts electricity. So even though the base of the transistor doesn't receive any current, the transistor still conducts across the collector. This is called the breakdown region.

The breakdown region should always be avoided in transistor circuits. This is achieved by not placing too much bias voltage on the collector.

The voltages at different ports of transistor are provided in the table below.

The key parameters of operation are in the base input current I_B, the collector emitter voltage V_{CE} and the corresponding collector current I_C. The graph illustrates that the output collector current I_C depends on the I_B and V_{CE}.

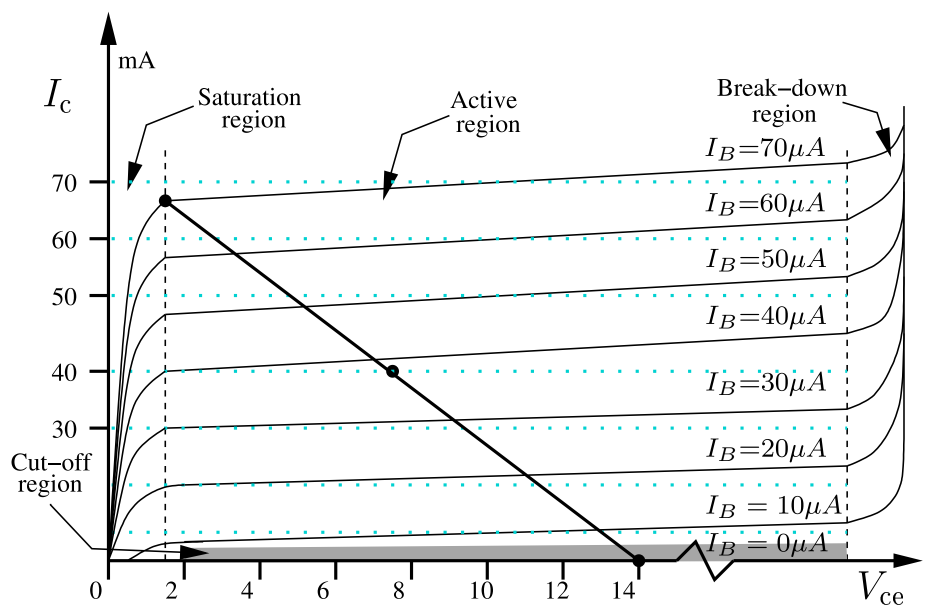


Figure 9: The operating regions of an NPN transistor.

Region	Voltage Condition
Cut-off region	$V_E > V_B$ & $V_C > V_B$
Saturation region	$V_E < V_B$ & $V_C < V_B$
Active region	$V_E < V_B < V_C$
Break Down region	

1.2 Analysis of transistor operation

Consider the circuit in fig. 10 . There are three transistor currents and three voltages I_B, I_C, I_E, V_{BE}, V_{CB} and V_{CE}. The source V_{BB} forward biases the base-emitter junction and V_{cc} reverse biases

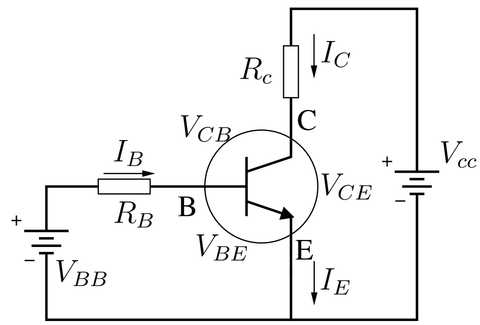


Figure 10: Analysis of an NPN transistor.

the base-collector junction. When the silicon base-emitter junction is forward biased, like a diode has a forward voltage drop of 0.7V.

$$V_{BE} \approx 0.7V$$

The voltage across R_B is

$$V_{R_B} = V_{BB} - V_{BE}$$

where as,

$$V_{R_B} = I_B R_B$$

consequently,

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

From (1) and (2) we know that

$$I_E = \frac{I_C}{\alpha}$$

$$I_C = \beta I_B$$

The voltage drop across R_C is

$$V_{R_C} = I_C R_C$$

voltage at collector w.r.t emitter,

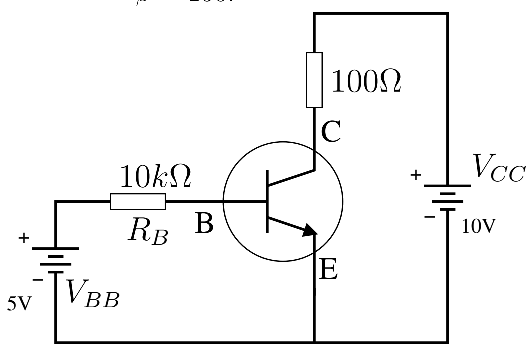
$$V_{CE} = V_{CC} - I_C R_C$$

voltage between the base and collector is,

$$V_{CB} = V_{CE} - V_{BC}$$

Example:

Determine the I_B, I_C, I_E, V_{CE} and V_{CB} when $\beta = 150$.



$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5 - 0.7}{10k\Omega} = 430\mu A$$

$$I_C = \beta I_B = (150)430\mu A = 64.5mA$$

$$\alpha = \frac{\beta}{1+\beta} = \frac{150}{151} = 0.993$$

$$I_E = \frac{I_E}{0.993} = 64.95mA$$

$$V_{CE} = V_{CC} - I_C R_C = 10 - (64.5)(100\Omega)$$

$$10 - 6.45 = 3.55V$$

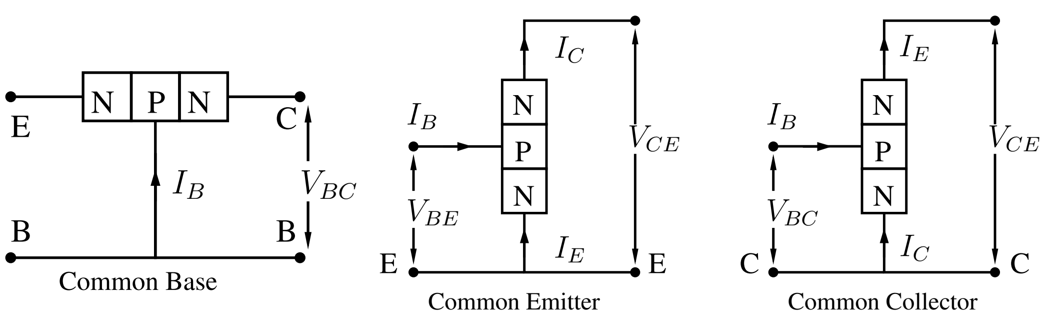
$$V_{CB} = V_{CE} - V_{BE} = 3.55 - 0.7 = 2.85V$$

Transistor Configurations

Based on how the input and output pins of a BJT transistor are connected the functionality of transistor can be vary considerably.

Fundamentally speaking at BJT transistor can be classified into three categories (i) Common Base (ii) Common Emitter and (iii) Common Collector Configurations. The basic circuit diagrams are illustrated in fig. 11 Each of the above listed configurations has a specific feature / properties which may be suitable for a certain applications.

Configuration	Voltage Gain	Current Gain	Power Gain	Phase Shift
Common Emitter	Medium	Medium	Very High	180°
Common Collector	Low	High	Medium	0°
Common Base	High	Low	Low	0°

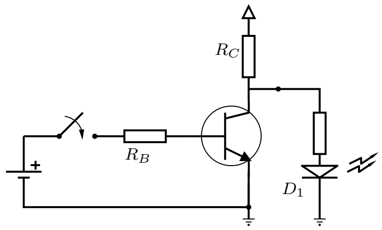


(a) Common Base. (b) Common Emitter. (c) Common Collector.

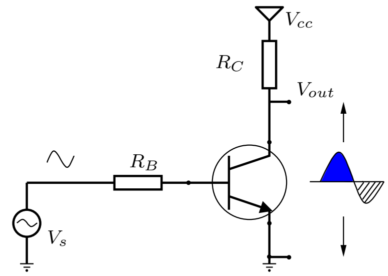
Figure 11: The BJT transistor Configuration.

Application

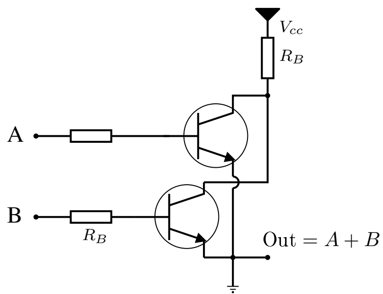
We can draw some parallels between electric and magnetic fields, however there are some stark differences as well.



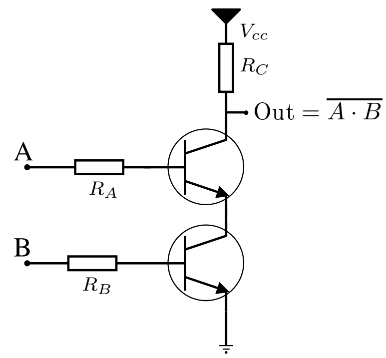
(a) Transistor as a Switch.



(b) Transistor as an Amplifier.

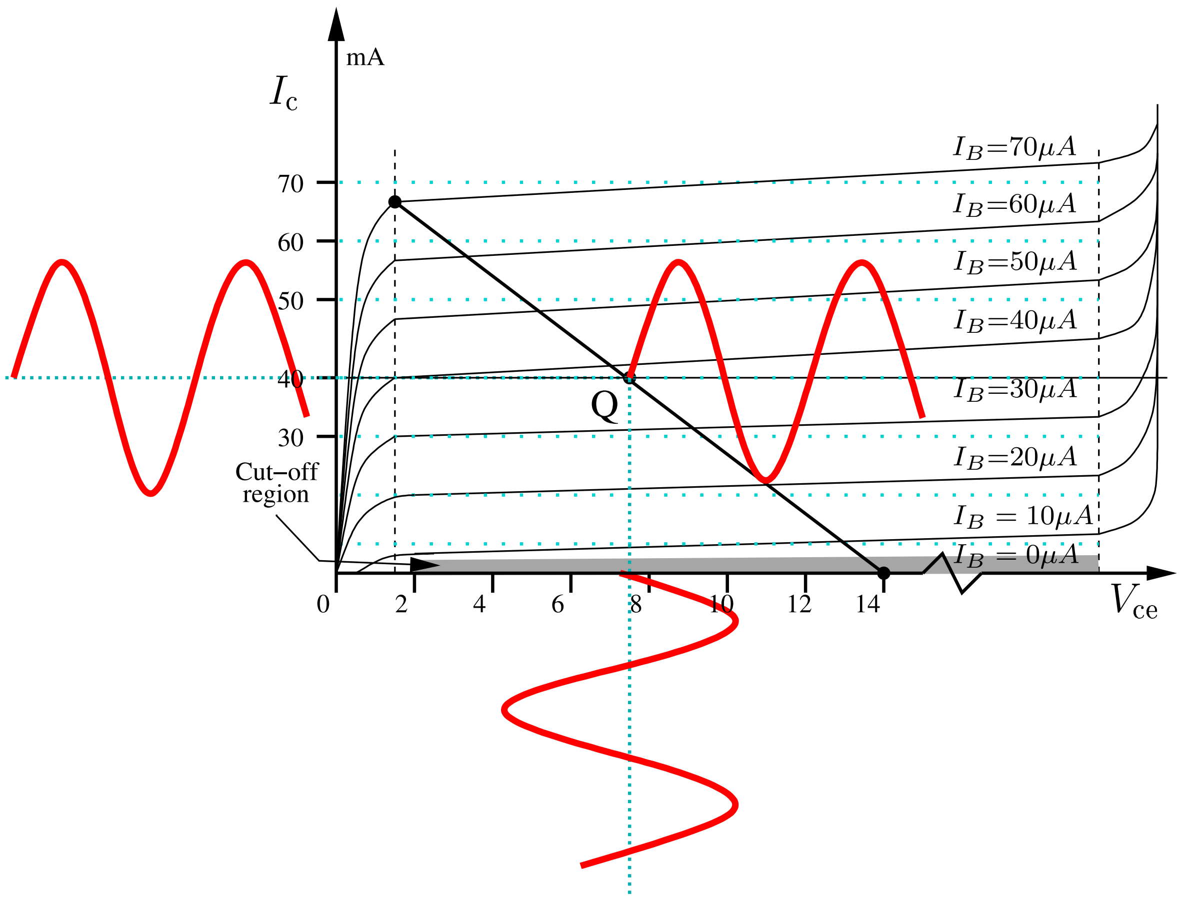


(c) Transistor as Or gate.



(d) Transistor as And gate.

Figure 12: Application of transistor for Various Applications.



mA
I_c
70
60
50
40
30
Cut−off region
I_B=70μA
I_B=60μA
I_B=50μA
I_B=40μA
I_B=30μA
I_B=20μA
$I_B = 10\mu A$
$I_B = 0\mu A$
Q
0
2
4
6
8
10
12
14
V_{ce}