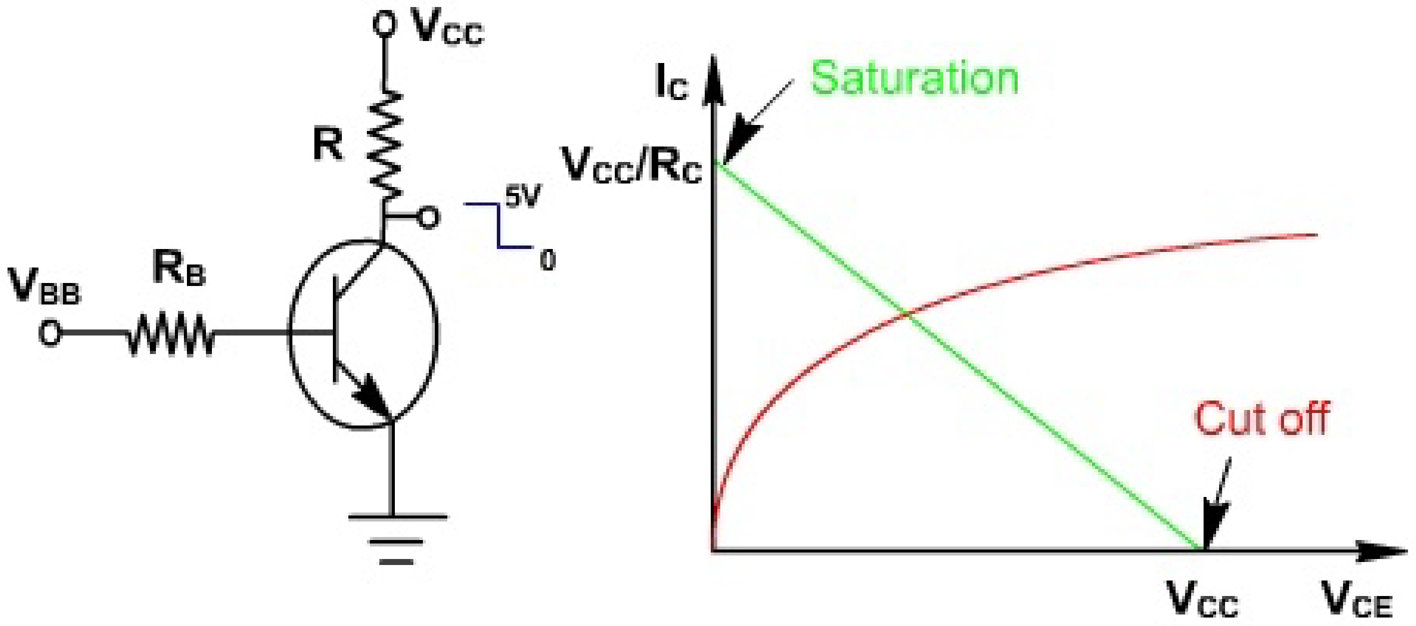
Transistor as a Switch

Prepared By
Noor Md Shahriar
Senior Lecturer
Department of EEE
University of Global Village (UGV), Barishal

Transistor as a Switch

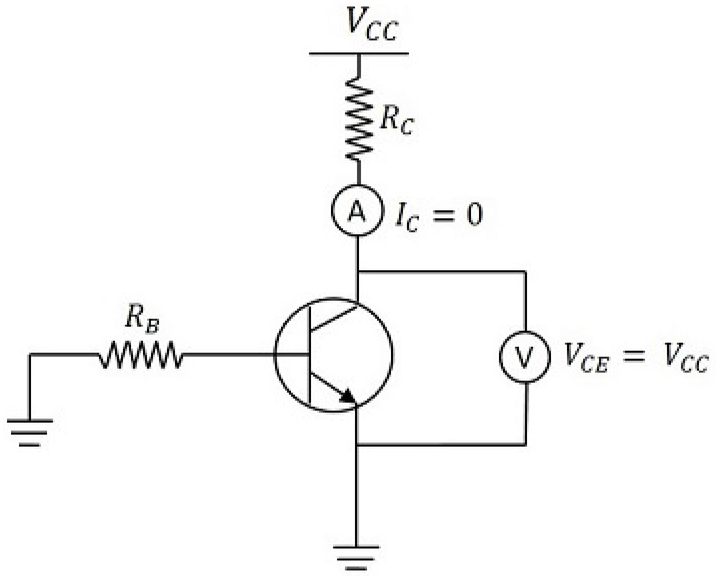
- A transistor is used as an electronic switch by driving it either in saturation or in cut off. The region between these two is the linear region. A transistor works as a linear amplifier in this region. The Saturation and Cut off states are important consideration in this regard.



ON & OFF States of a Transistor

- There are two main regions in the operation of a transistor which we can consider as ON and OFF states. They are saturation and cut off states. Let us have a look at the behavior of a transistor in those two states.

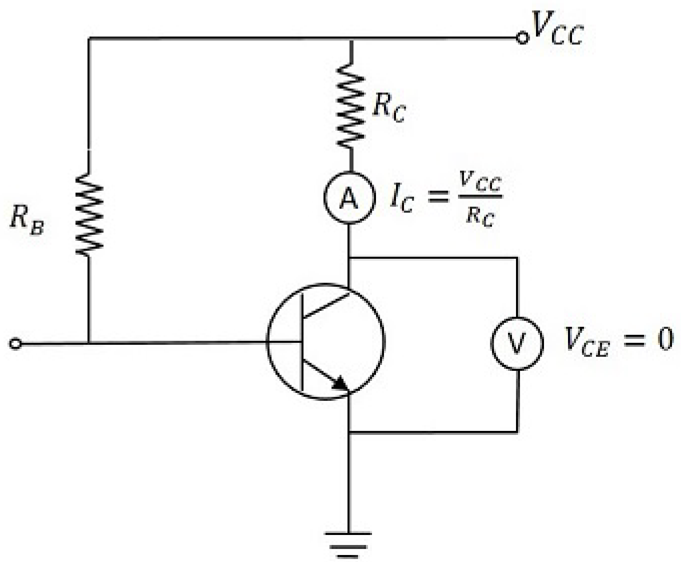
Operation in Cut-off condition



- When the base of the transistor is given negative, the transistor goes to cut off state. There is no collector current. Hence $I_C = 0$.
- The voltage VCC applied at the collector, appears across the collector resistor RC. Therefore,

$$V_{CE} = V_{CC}$$

Operation in Saturation region



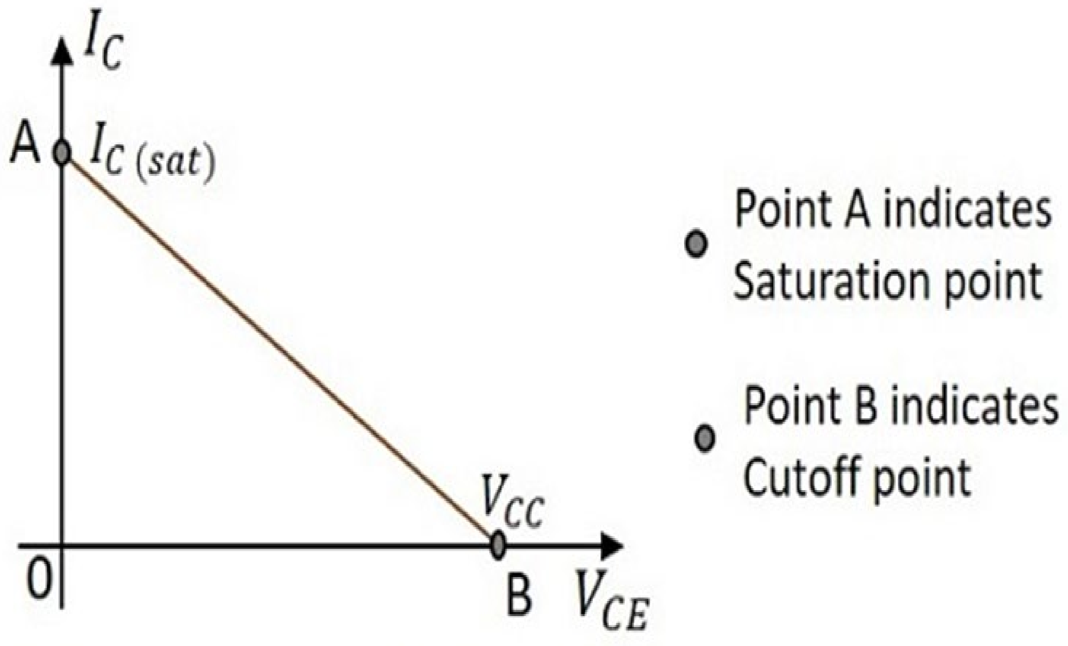
- When the base voltage is positive and transistor goes into saturation, I_C flows through R_C.
- Then V_{CC} drops across R_C. The output will be zero.

$$I_C = I_{C(sat)} = \frac{V_{CC}}{R_C} \; and \; V_{CE} = 0$$

Operation in Saturation region

- Actually, this is the ideal condition. Practically, some leakage current flows. Hence we can understand that a transistor works as a switch when driven into saturation and cut off regions by applying positive and negative voltages to the base.

Operation in Saturation region



Graph indicating DC Load line

- Observe the dc load line that connects the I_C and V_{CC}. If the transistor is driven into saturation, IC flows completely and $V_{CE} = 0$ which is indicated by the point A.
- If the transistor is driven into cut off, IC will be zero and $V_{CE} = V_{CC}$ which is indicated by the point B. the line joining the saturation point A and cut off B is called as Load line. As the voltage applied here is dc, it is called as DC Load line

Practical Considerations

Although the above-mentioned conditions are all convincing, there are a few practical limitations for such results to occur.

- During the Cut off state

An ideal transistor has $V_{CE} = V_{CC}$ and $I_C = 0$.

But in practice, a smaller leakage current flows through the collector.

Hence I_C will be a few µA.

This is called as Collector Leakage Current which is of course, negligible.

Practical Considerations

- During the Saturation State

An ideal transistor has $V_{CE} = 0$ and $I_C = I_{C(sat)}$.

But in practice, V_{CE} decreases to some value called knee voltage.

When V_{CE} decreases more than knee voltage, β decreases sharply.

As $I_C = \beta I_B$ this decreases the collector current.

Hence that maximum current I_C which maintains V_{CE} at knee voltage, is known as Saturation Collector Current.

$$\text{Saturation Collector Current} = I_{C(sat)} = \frac{V_{CC} - V_{knee}}{R_C}$$

Practical Considerations

- A Transistor which is fabricated only to make it work for switching purposes is called as Switching Transistor. This works either in Saturation or in Cut off region. While in saturation state, the collector saturation current flows through the load and while in cut off state, the collector leakage current flows through the load.

Switching Action of a Transistor

- A Transistor has three regions of operation. To understand the efficiency of operation, the practical losses are to be considered. So let us try to get an idea on how efficiently a transistor works as a switch.

During Cut off (OFF) state

- The Base current $I_B = 0$
- The Collector current $I_C \;=\; I_{CEO}$ (collector leakage current)
- Power Loss = Output Voltage × Output Current

$$= V_{CC} \times I_{CEO}$$

- As I_{CEO} is very small and V_{CC} is also low, the loss will be of very low value. Hence, a transistor works as an efficient switch in OFF state.

During Saturation (ON) state

$$I_{C(sat)} = \frac{V_{CC} - V_{knee}}{RC}$$

- The output voltage is V_{knee}.
- Power loss = Output Voltage × Output Current

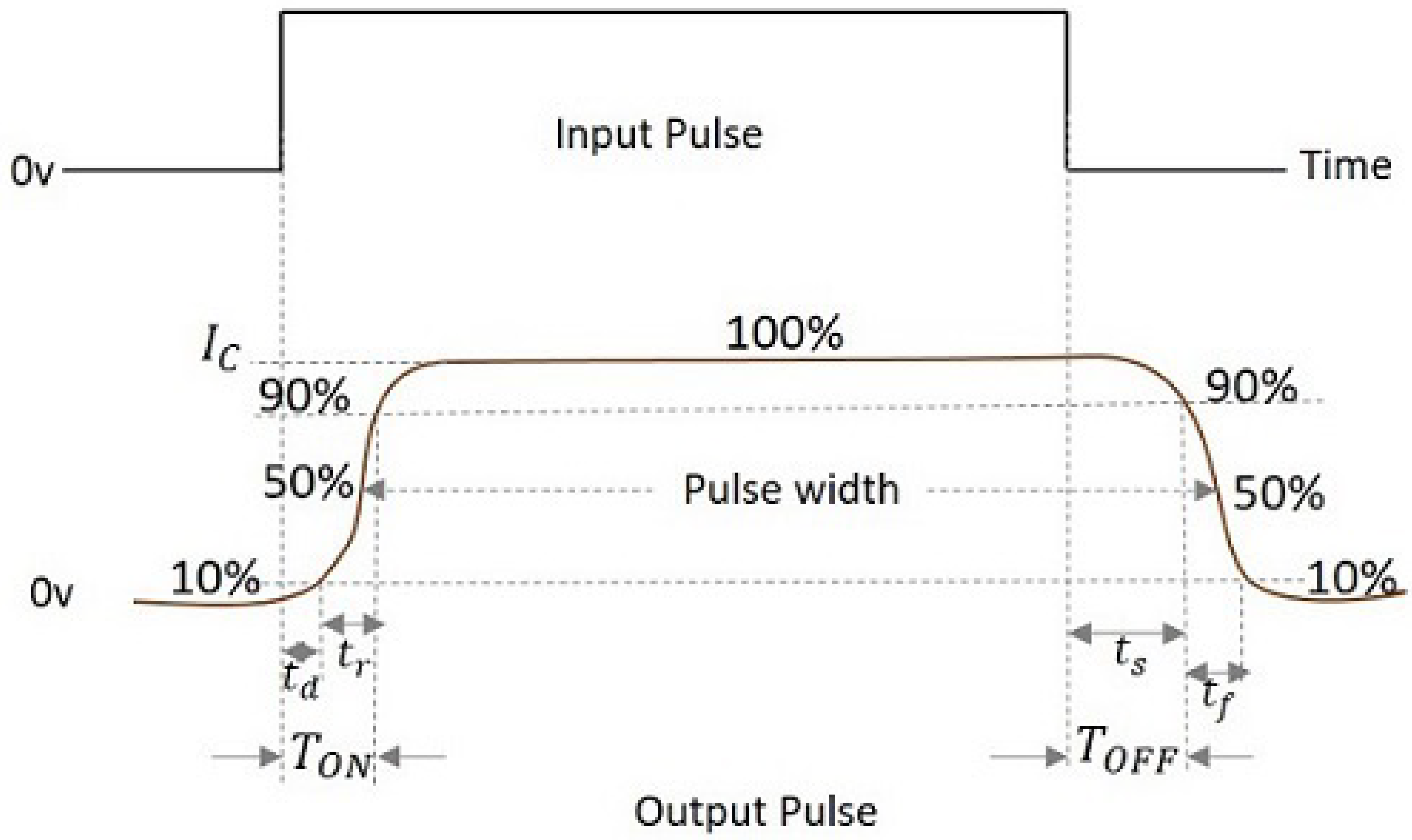
$$= V_{knee} \times I_{c(sat)}$$

- As V_{knee} will be of small value, the loss is low. Hence, a transistor works as an efficient switch in ON state.

Switching Times

- The Switching transistor has a pulse as an input and a pulse with few variations will be the output. There are a few terms that you should know regarding the timings of the switching output pulse. Let us go through them.
- Let the input pulse duration = T
- When the input pulse is applied the collector current takes some time to reach the steady state value, due to the stray capacitances. The following figure explains this concept.

Switching Times



Switching Times

- Time delay(t_d) – The time taken by the collector current to reach from its initial value to 10% of its final value is called as the Time Delay.
- Rise time(t_r) – The time taken for the collector current to reach from 10% of its initial value to 90% of its final value is called as the Rise Time.
- Turn-on time (T_{ON}) – The sum of time delay (t_d) and rise time (t_r) is called as Turn-on time.

$$T_{ON} = t_d + t_r$$

Switching Times

- Storage time (t_s) – The time interval between the trailing edge of the input pulse to the 90% of the maximum value of the output, is called as the Storage time.
- Fall time (t_f) – The time taken for the collector current to reach from 90% of its maximum value to 10% of its initial value is called as the Fall Time.
- Turn-off time (T_{OFF}) – The sum of storage time (t_s) and fall time (t_f) is defined as the Turn-off time.

$$T_{OFF} = t_s + t_f$$

- Pulse Width(W) – The time duration of the output pulse measured between two 50% levels of rising and falling waveform is defined as Pulse Width.