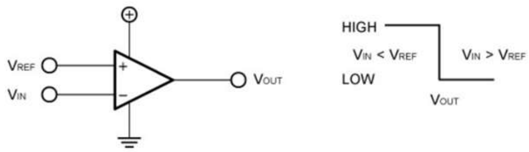
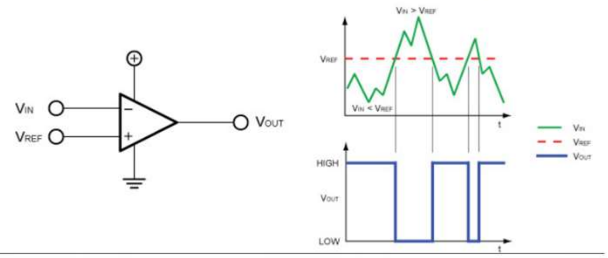
OPAMP in Open Loop as a Comparator

- Inverting Operation: When V_{IN} exceeds V_{REF}, the output V_{OUT} goes from HIGH to LOW.

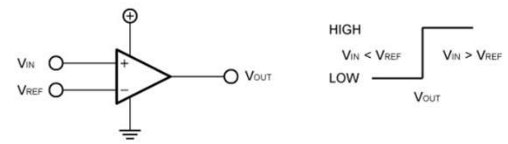


The inverting operation can be represented in another graphical form:

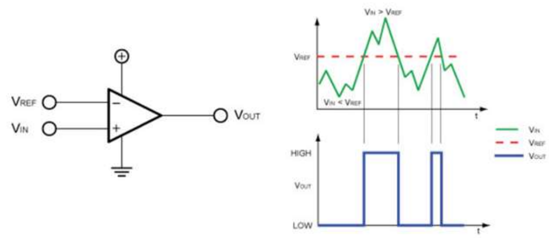


Inverting Comparator Operation

- Non-inverting Operation: When V_{IN} exceeds V_{REF}, the output V_{OUT} goes from LOW to HIGH.



The non- inverting operation can be represented in another graph:

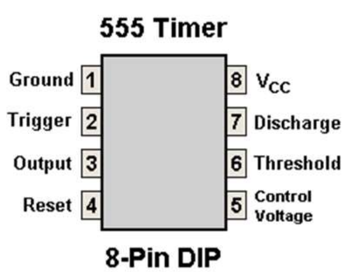


Non-inverting Comparator Operation

1

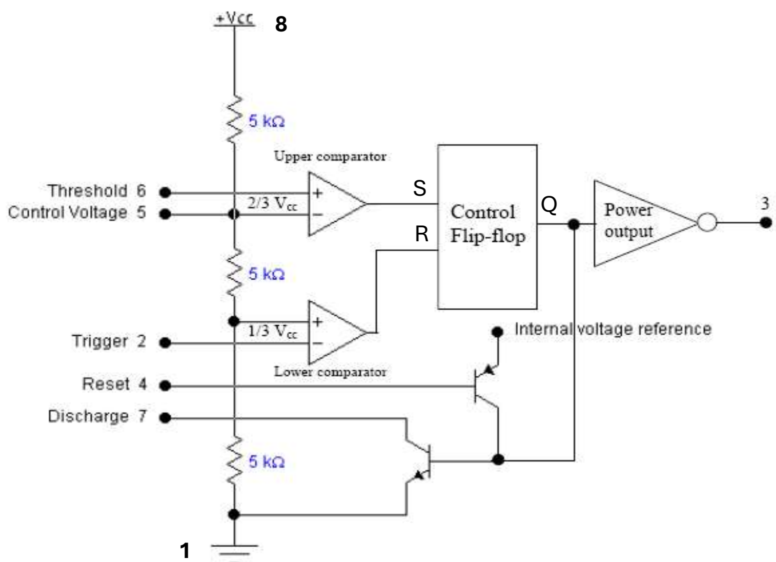
555 Timer IC

- For lowish frequencies (<1MHz), a cheap and reliable clock can be made with a 555 timer chip.



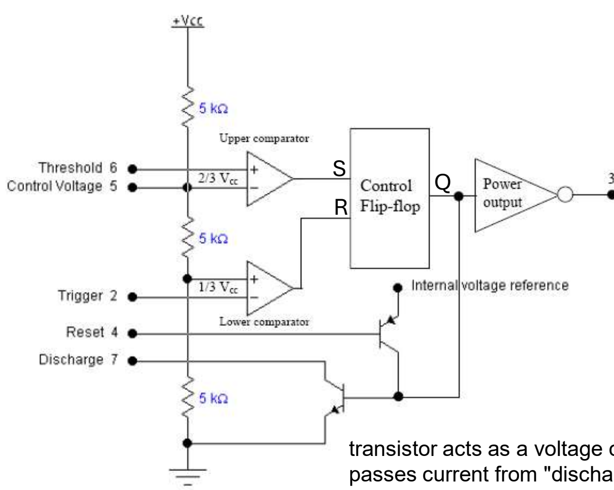
2

555 Timer: Block Diagram



3

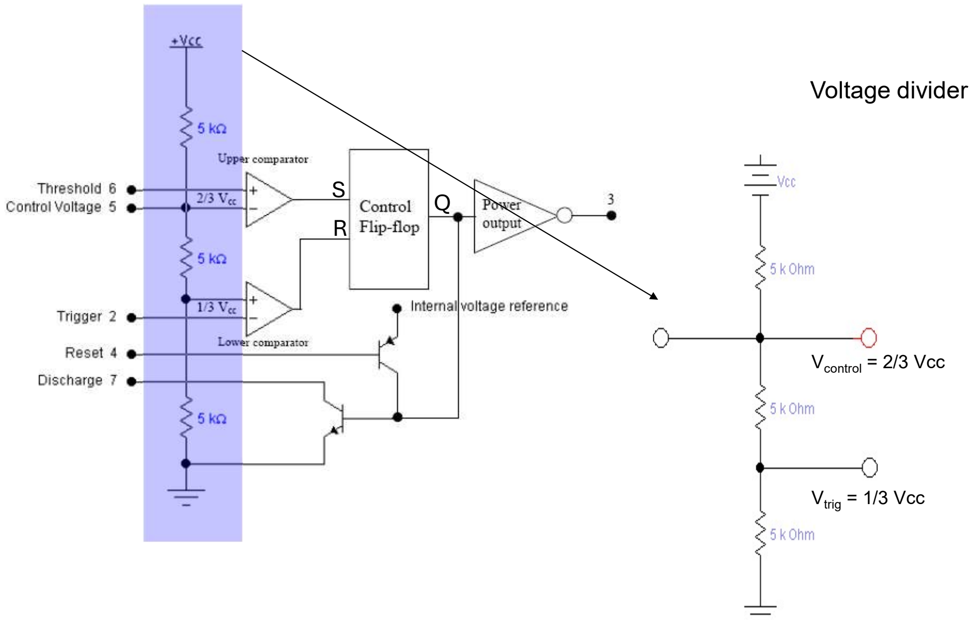
555 Timer



transistor acts as a voltage controlled switch that passes current from "discharge" input to ground when base voltage is HIGH

4

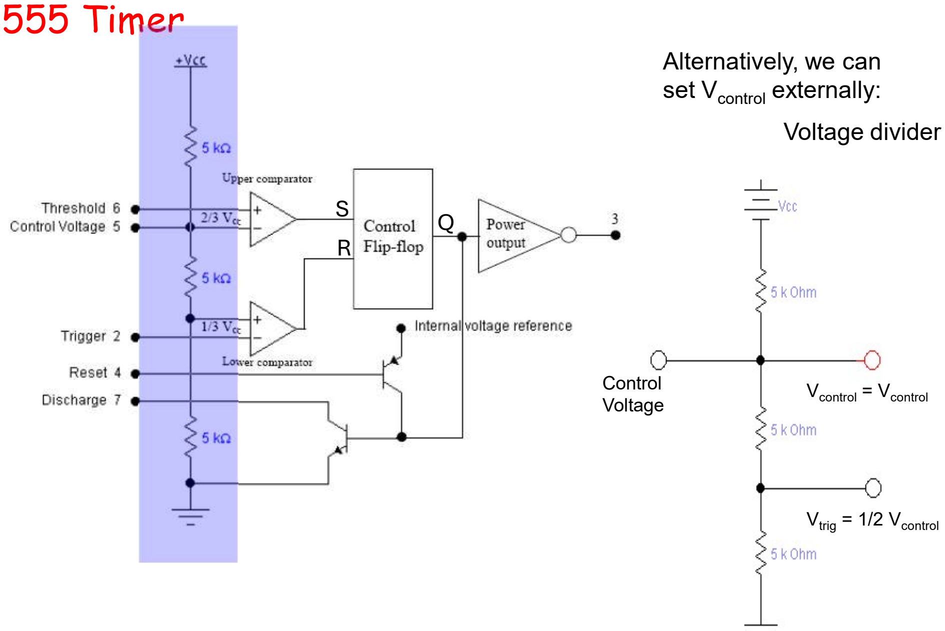
555 Timer



5

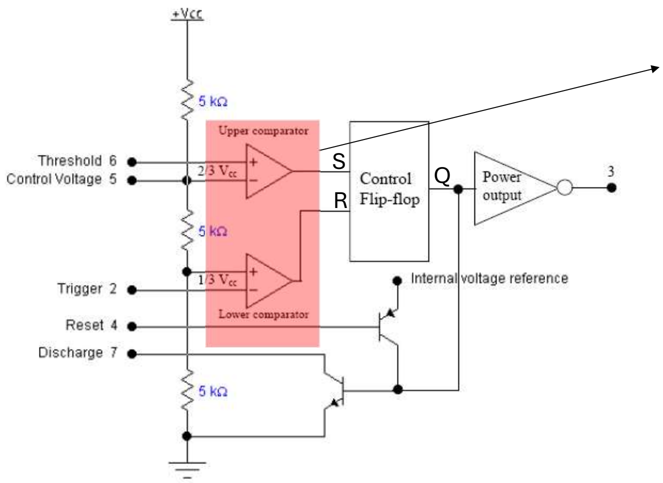
555 Timer

Alternatively, we can set $V_{control}$ externally:



6

555 Timer



Two Comparators:
Output a HIGH voltage level when the "+" input is greater than the "-" input.

Upper comparator: Threshold input is compared to $V_{control}$

Lower comparator: Trigger input is compared to V_{trig}.

Results are passed to a flipflop

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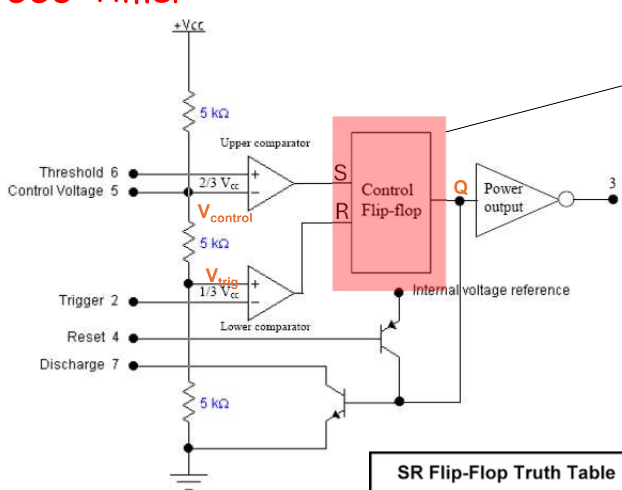
555 Timer



Flipflop:
Stores the information of which comparator last passed it a high voltage.

If Threshold>$V_{control}$;
S=1
Output state is HIGH.
Transistor is switched on

If Trigger< V_{trig};
R=1
Output state is LOW
Transistor is switched off.

SR Flip-Flop Truth Table

Inputs		Outputs	
S	**R**	**Q**	**$\overline{Q}$**
0	0	No Change	
0	1	0	1
1	0	1	0
1	1	Undefined	

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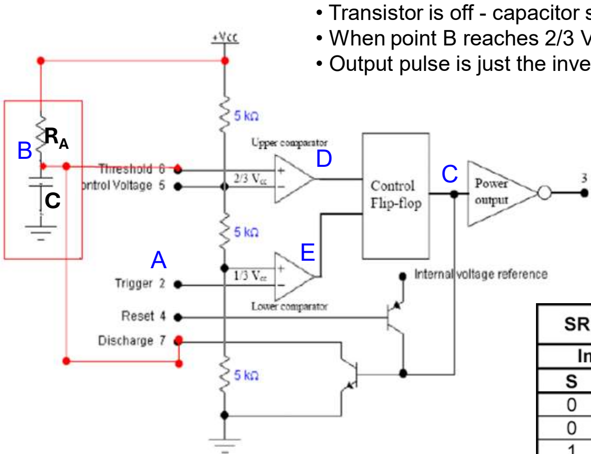
555 Timer: Monostable configuration

Single pulse in response to single input trigger signal

- Initial state: flipflop is "set". Point C is HIGH.
- Transistor is on - passing capacitor charge to ground.
- When trigger input at A goes LOW, bottom comparator triggers and E goes HIGH.
- Flipflop changes state: C goes LOW
- Transistor is off - capacitor starts charging (B) through R
- When point B reaches 2/3 Vcc, flipflop changes state, transistor is on, capacitor discharges rapidly.
- Output pulse is just the inverse of C



SR Flip-Flop Truth Table

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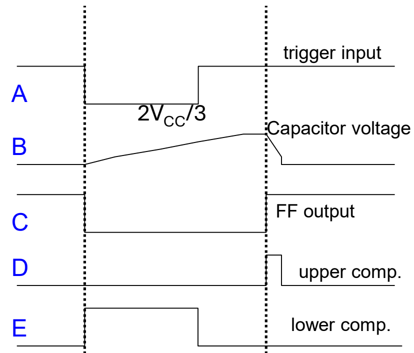

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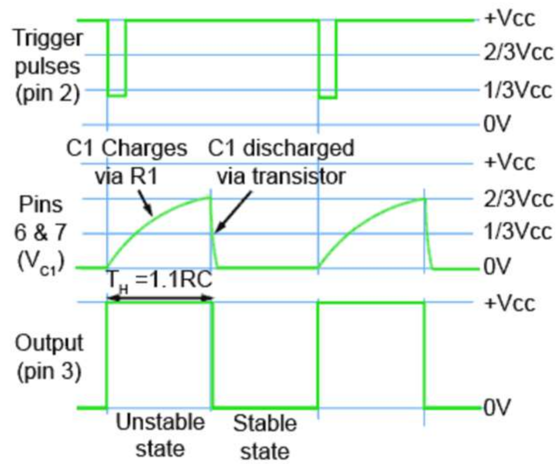
Time duration for which output remains High in Monostable Multivibrator / configuration:
T_H = The Time Required to charge Capacitor C with Voltage $v_c = 2V_{CC}/3$.

Capacitor Charging Equation $v_c = V_{CC}(1 - e^{-t/RC})$

At $v_c = 2V_{CC}/3$

$t = R_A C \ln(3) = 1.0986\, R_A C \approx 1.1\, R_A C$



The monostable circuit has only one stable state (output low).

Monostable 555 operation

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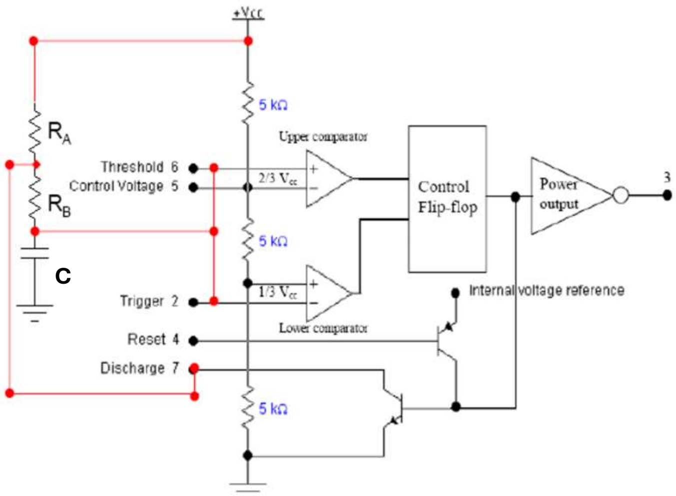
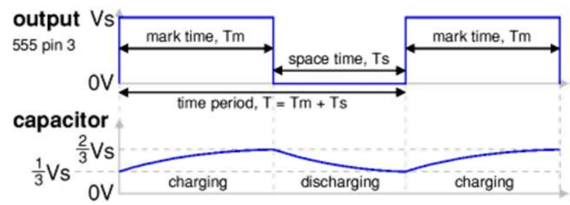
555 Timer: Astable configuration

- In this mode, connect both comparator inputs to the capacitor in order to generate a clock.
- Charge up through R_A+R_B, discharge through R_B
- Capacitor charging and discharging times can be controlled by resistor selection, in order to define the clock period and duty cycle



$\tau_c=(R_A+R_B)C$ $\quad T_H=(R_A+R_B)C\times\ln2$

$\tau_d=R_BC$ $\quad T_L=R_BC\times\ln2$



Time duration for which output remains High in Astable configuration:
T_H = The Time Required to charge Capacitor C from $V_{cc}/3$ to $2V_{CC}/3$ trough R_A and R_B

Gen. eq. of Capacitor Charging $v_c= V_{CC}(1- e^{-t/RC})$

Time required from 0 V to $V_{cc}/3= t_1$

=> $V_{cc}/3 = V_{CC}(1- e^{-t_1/(R_A+R_B)C})$ => $t_1= (R_A+R_B)C*\ln(3/2)$

Time required from 0 V to $2Vcc/3=t_2$

$2*V_{cc}/3 = V_{CC}(1- e^{-t_2/(R_A+R_B)C})$, => $t_2= (R_A+R_B)*C*\ln(3)$

Therefore, Time required to charge $V_{cc}/3$ to $2V_{cc}/3= t_2-t_1=T_H = (R_A+R_B)*C*\ln(2)= 0.693 (R_A+R_B)*C$

Time duration for which output remains LOW in Astable configuration:
Similarly, the discharging equation from 2Vcc/3 at any instant t, is given by $v_c=2vcc/3 *e^{-t/R_BC}$

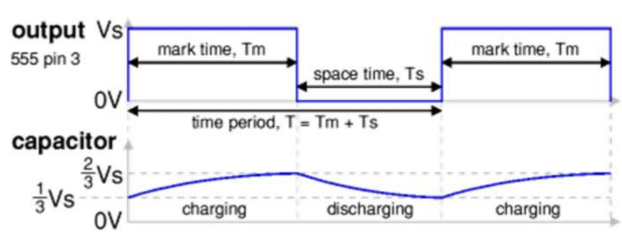
If Time of discharging from 2Vcc/3 to Vcc/3 = T_L

$Vcc/3=2V_{CC}/3 *e^{-T_L/R_BC}$ => $T_L= R_BC*\ln(2)=0.693\ R_BC$

$V_S=V_{CC}$

Overall, period of the square wave T= $T_H+ T_L= 0.693(R_A+2R_B)C$

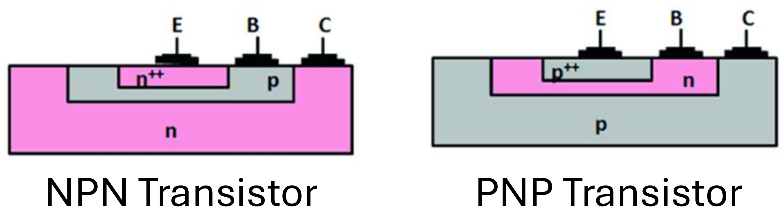
Duty cycle=$T_H/(T_H+T_L)=(R_B+R_A)/(2R_B+R_A)$



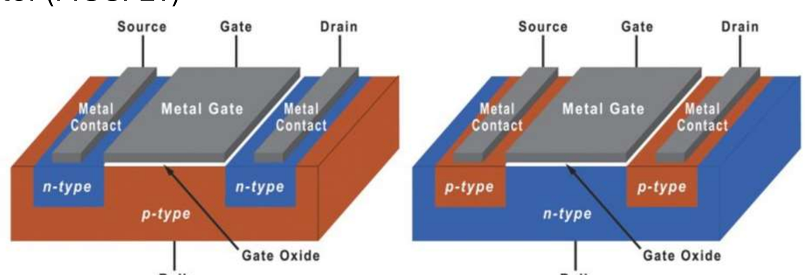
Basics of Transistors

Transistor Technologies (Review)

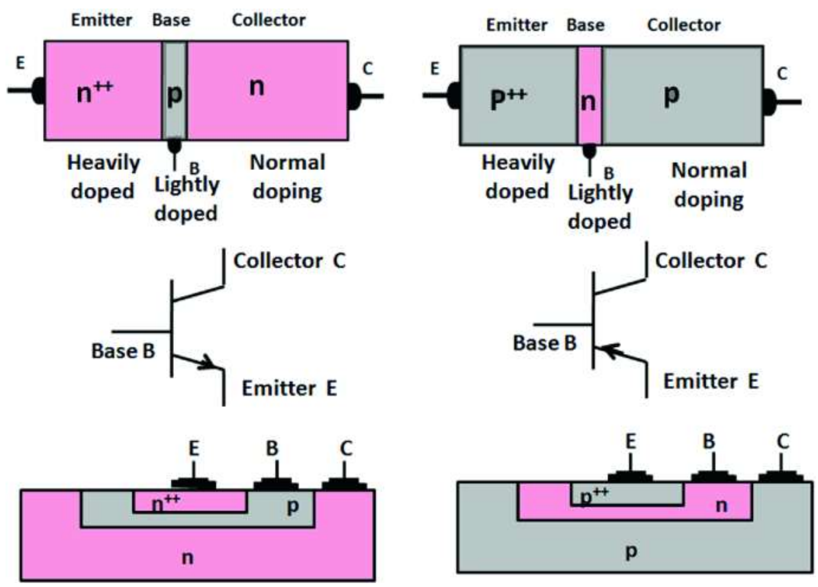
Bipolar Junction Transistor



Metal-Oxide-Field Effect Transistor (MOSFET)



Bipolar Junction Transistor



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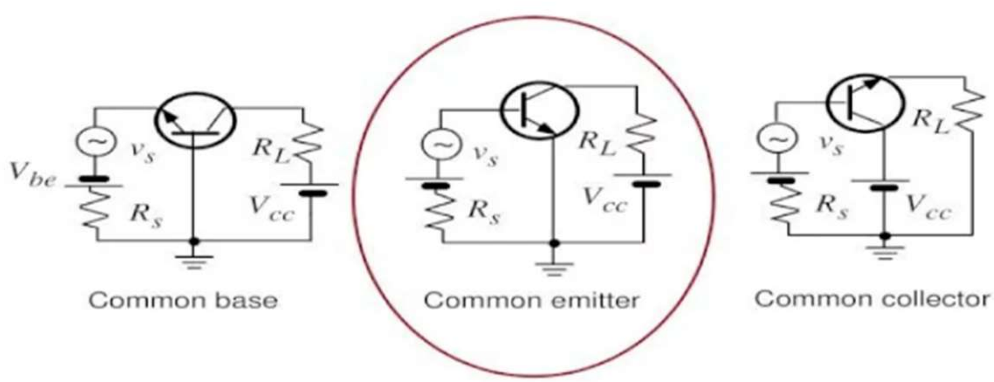
Three Fundamental BJT Amplifier/biasing Configurations



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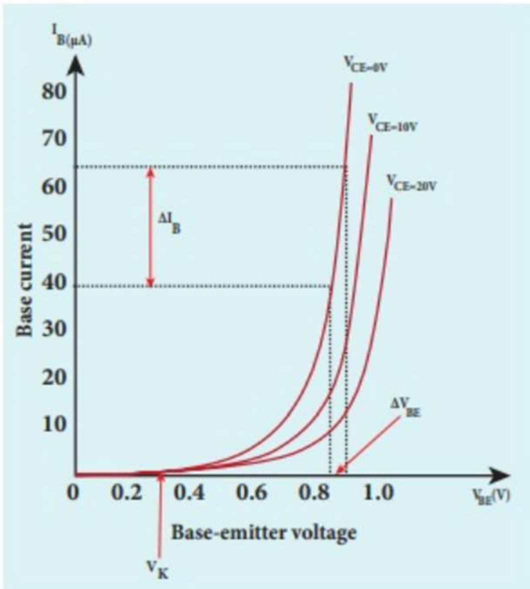
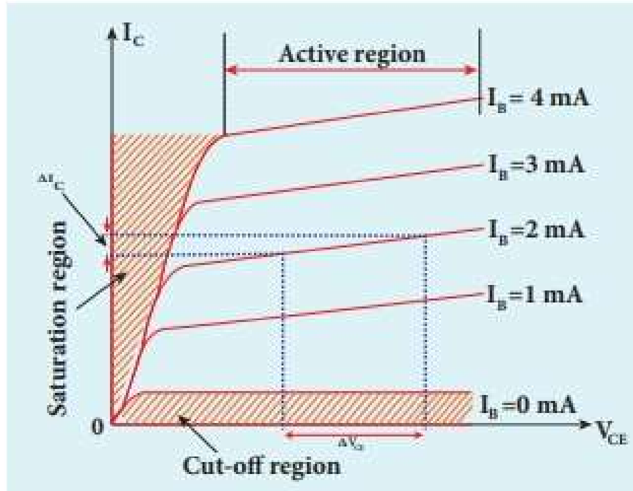
Common Emitter I-V characteristics





I_C - V_{CE} Output Characteristics

I_B - V_{BE} Input

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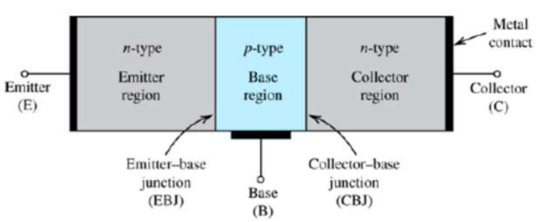
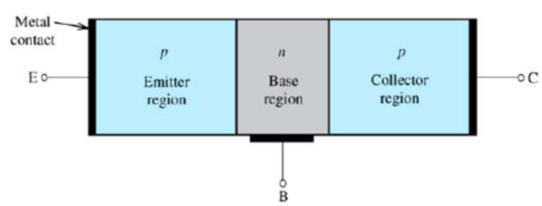
Physical structure of bipolar junction transistor (BJT)

- ❑ Both electrons and holes participate in the conduction process for bipolar devices
- ❑ BJT consists of two *pn* junctions constructed in a special way and connected in series, back to back
- ❑ The transistor is a three-terminal device with **emitter**, **base** and **collector** terminals
- ❑ From the physical structure, BJTs can be divided into two groups: ***npn*** and ***pnp*** transistors





Modes of operation

- ❑ The two junctions of BJT can be either forward or reverse-biased
- ❑ The BJT can operate in different modes depending on the junction bias
- ❑ The BJT operates in active mode for amplifier circuits
- ❑ Switching applications utilize both the cutoff and saturation modes

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

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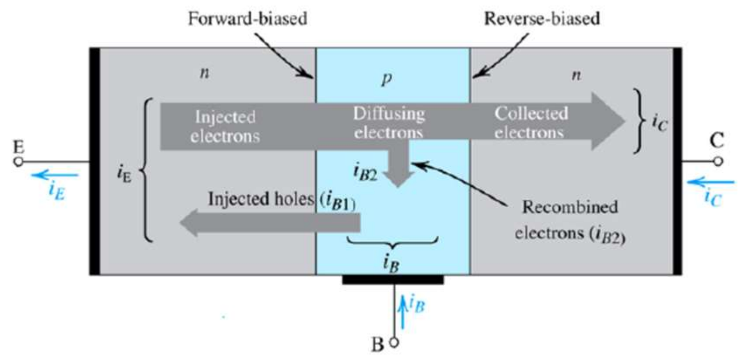
Operation of the *npn* transistor in the active mode

- Terminal currents of BJT in active mode:
  i_E(emitter current) = i_{En}(electron injection from E to B) + i_{Ep}(hole injection from B to E)
  i_C(collector current) = i_{Cn}(electron drift) + i_{CBO}(CBJ reverse saturation current with emitter open)
  i_B(base current) = i_{B_1}(hole injection from B to E) + i_{B_2}(recombination in base region)



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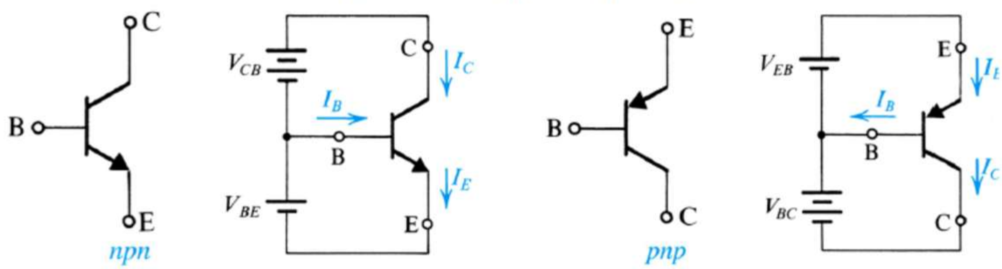
Circuit symbols, voltage polarities and current flow

- Terminal currents are defined in the direction as current flow in active mode
- Negative values of current or voltage mean in opposite polarity (direction)



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Summary of the BJT current-voltage relationships in the active mode

- ❑ The terminal currents for a BJT in active mode solely depend on the junction voltage of EBJ
- ❑ The ratios of the terminal currents for a BJT in active mode are constant
- ❑ The current directions for *npn* and *pnp* transistors are opposite

npn transistor	*pnp* transistor	
$i_C = I_S e^{v_{BE}/V_T}$ $i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T}$ $i_E = \frac{i_C}{\alpha} = \frac{I_S}{\alpha} e^{v_{BE}/V_T}$	$i_C = I_S e^{v_{EB}/V_T}$ $i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{EB}/V_T}$ $i_E = \frac{i_C}{\alpha} = \frac{I_S}{\alpha} e^{v_{EB}/V_T}$	$i_E = i_C + i_B$ $\alpha = \frac{\beta}{\beta+1}$ $\beta = \frac{\alpha}{1-\alpha}$

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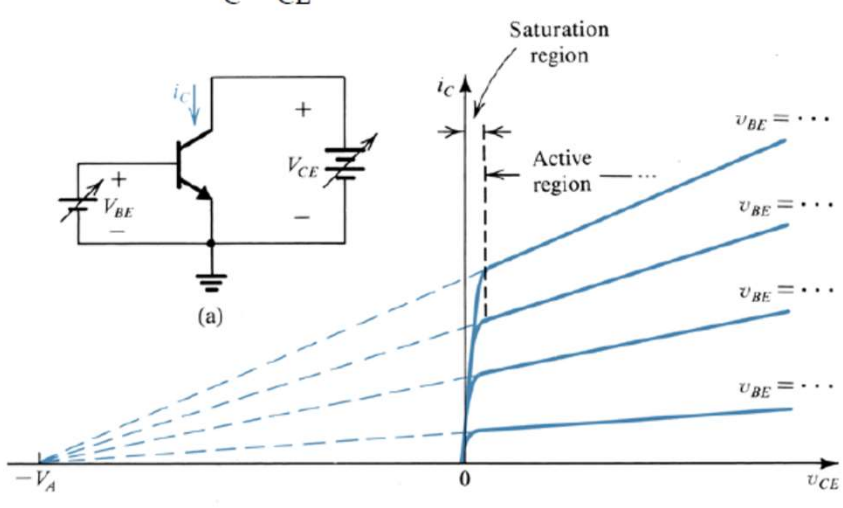
Current-voltage characteristics of BJT

The i_C-v_{CE} characteristics



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BJT operation modes

- The BJT operation mode depends on the voltages at EBJ and BCJ
- The I-V characteristics are strongly nonlinear
- Simplified models and classifications are needed to speed up the hand-calculation analysis

***npn* transistor** (axes: v_{BE} horizontal, v_{BC} vertical)

Inverse Mode $v_{BE} < 0$, $v_{BC} > 0$	Saturation Mode $v_{BE} > 0$, $v_{BC} > 0$
Cutoff Mode $v_{BE} < 0$, $v_{BC} < 0$	Active Mode $v_{BE} > 0$, $v_{BC} < 0$

***pnp* transistor** (axes: v_{EB} horizontal, v_{CB} vertical)

Inverse Mode $v_{EB} < 0$, $v_{CB} > 0$	Saturation Mode $v_{EB} > 0$, $v_{CB} > 0$
Cutoff Mode $v_{EB} < 0$, $v_{CB} < 0$	Active Mode $v_{EB} > 0$, $v_{CB} < 0$

Applications: as a switch and as an Amplifier

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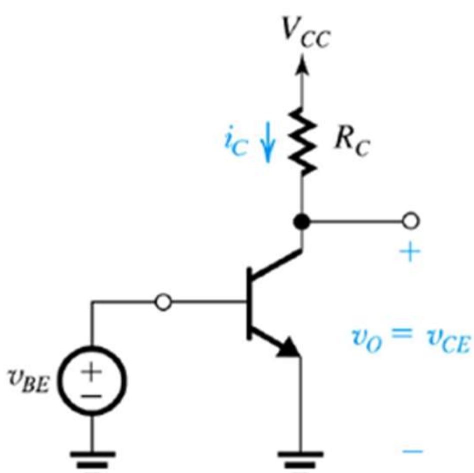
BJT voltage amplifier

- A BJT circuit with a collector resistor R_C can be used as a simple voltage amplifier
- Base terminal is used the amplifier input and the collector is considered the amplifier output
- The voltage transfer characteristic (VTC) is obtained by solving the circuit from low to high v_{BE}



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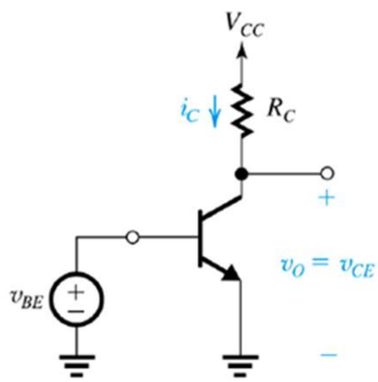
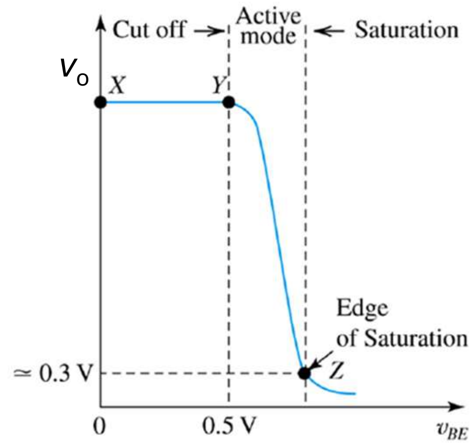
Voltage Transfer Characteristics

- Cutoff mode:
  - ➔ $0\ \text{V} \le v_{BE} < 0.5\ \text{V}$ and $i_C = 0$
  - ➔ $v_O = v_{CE} = V_{CC}$
- Active mode:
  - ➔ $v_{BE} > 0.5\ \text{V}$ and $i_C = I_S \exp(v_{BE}/V_T)$
  - ➔ $v_O = V_{CC} - i_C R_C = V_{CC} - R_C I_S \exp(v_{BE}/V_T)$
- Saturation:
  - ➔ v_{BE} further increases
  - ➔ $v_{CE} = v_{CEsat} = 0.2\ \text{V}$
  - ➔ $v_O = 0.2\ \text{V}$





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Thanks

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