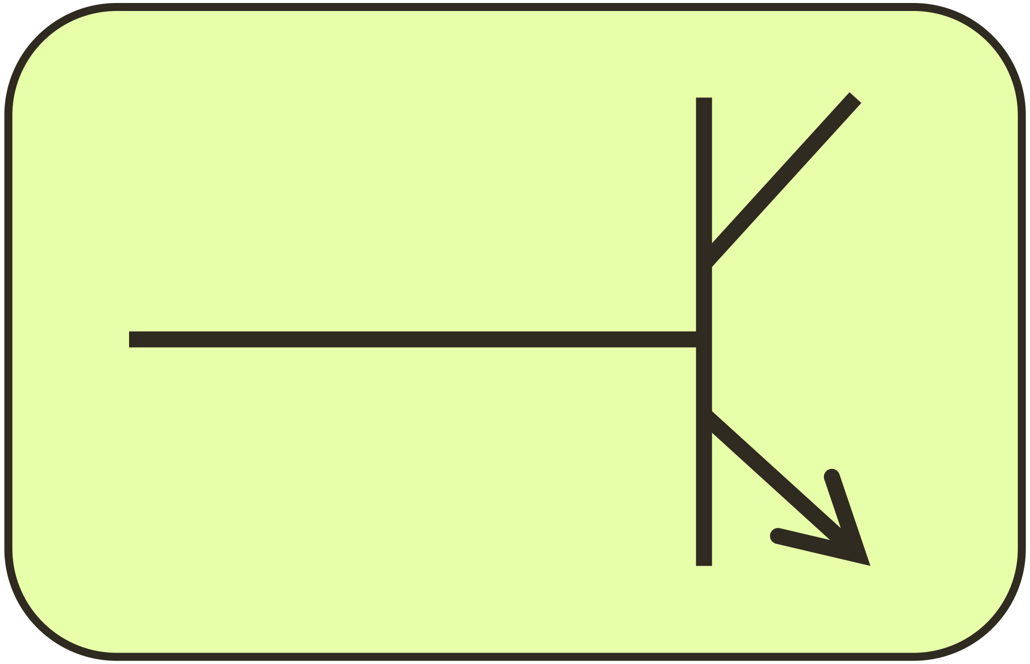
TRANSISTOR

LECTURE NO. - 24

Introducing Transistors

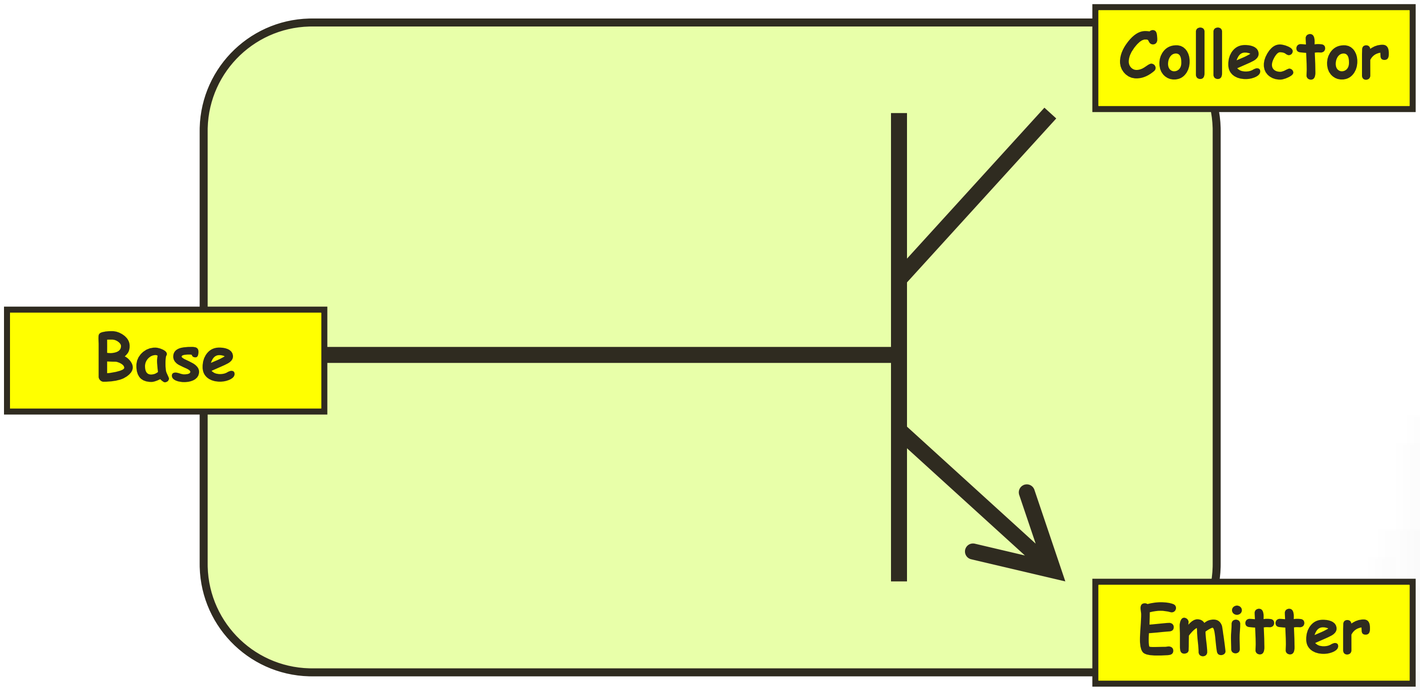
- Transistors are **process** devices.



- **This is the symbol for an NPN transistor.**[3]

Transistor Terminals

- Transistors have three terminals:



- It is a three layer (terminal)semiconductor device

- Two *n* and one *p* type or two *p* and one *n* type layers

- Two *n* and one *p* type is *npn transistor*
- Two *p* and one *n* type is *pnp transistor*

- *Two types-*

– *<u>Bipolar junction transistor(BJT)</u>*

Both electrons and holes participate in current flow

– *<u>Unipolar junction transistor(UJT)</u>*

Only one, either electrons or holes participate in current flow

Transistor family

- BJT FET (UJT)
- p-n-p n-p-n JFET MOSFET
- n-channel p-channel

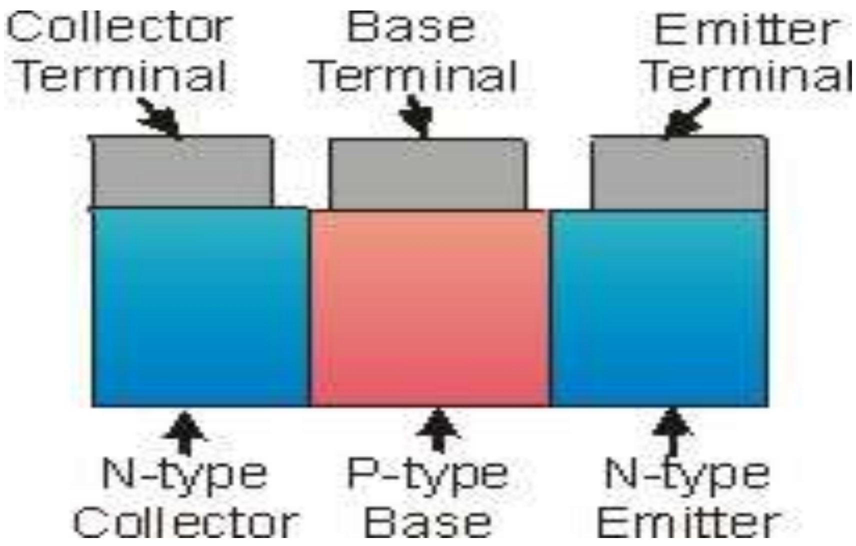
depletion enhancement

- Transistors are three-terminal semiconductor devices

LECTURE NO. - 25

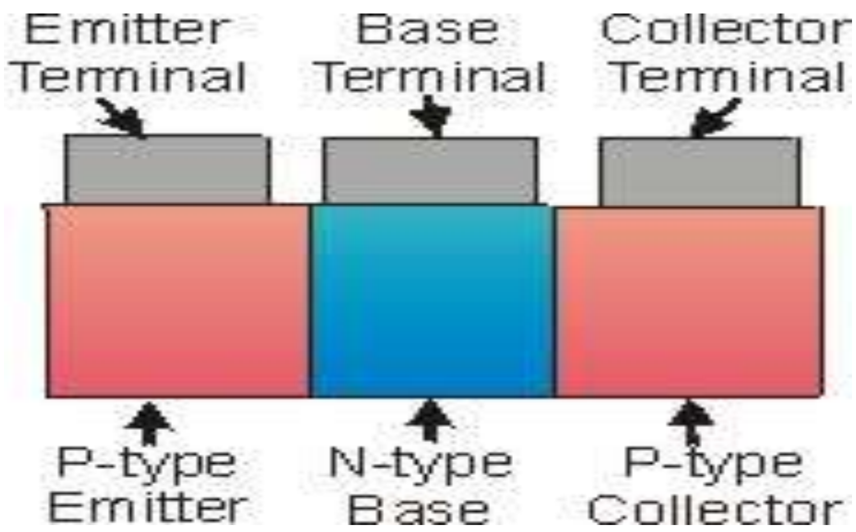
BJT Transistors:

NPN Transistor



Sandwiching a P-type layer between two n-type layers.

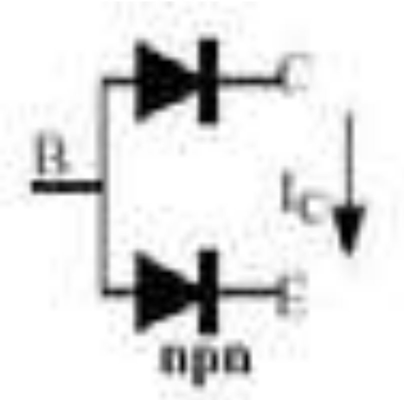
PNP Transistor

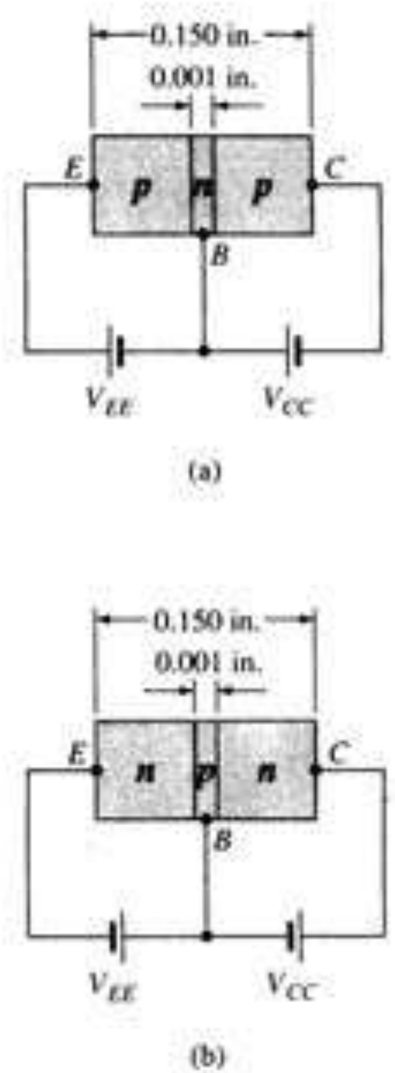


Sandwiching a N-type layer between two p-type layers.

Transistors

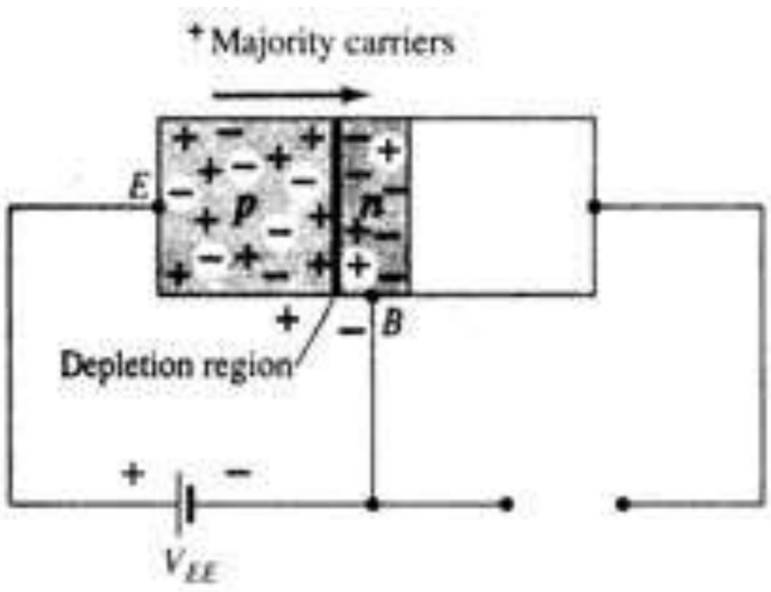
- Three terminals - Emitter, base, collector
- Middle layer or sandwich layer
- thin compare to outer layers
- lightly doped, less free carriers
- Can be looked as two diodes connected back
- to back but does not behave like a diode. In
- case of diode during reverse bias it behaves as
- a switch in off condition





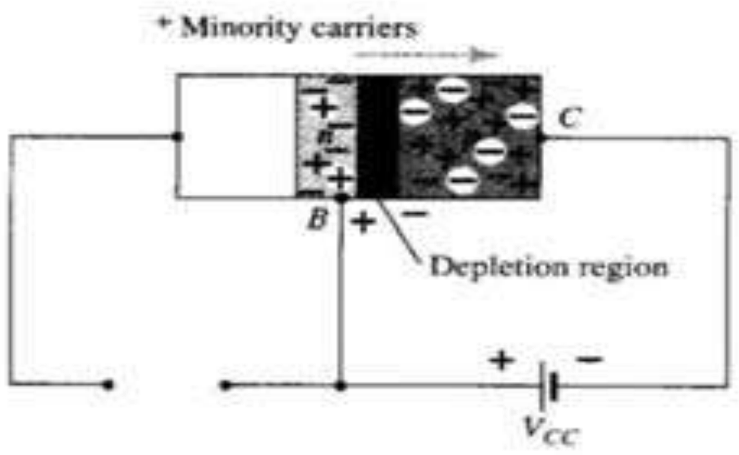
Transistor operation - *pnp*

- Forward biased diode - *pn* junction, emitter-base
- Base- collector is open circuit.
- Depletion layer is reduced and behave like a normal diode



Forward biased *pn* junction of a *pnp* transistor

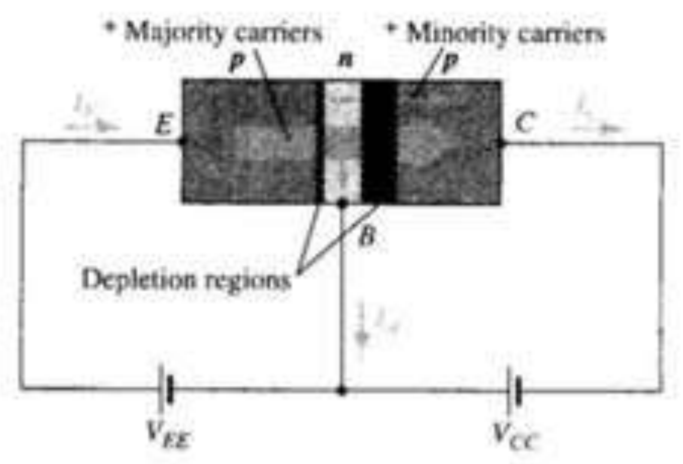
- Reverse biased diode - *np* junction, base collector
- Depletion layer is increased and behave like a reverse biased diode



Reverse biased *np* junction of a *pnp* transistor

Transistor operation - *pnp*

- Forward biased emitter-base, and reverse biased base collector Base is lightly doped, unable to handle large majority carriers. Diffuse to
- collector which is reverse bias, ready to accept the diffused holes.



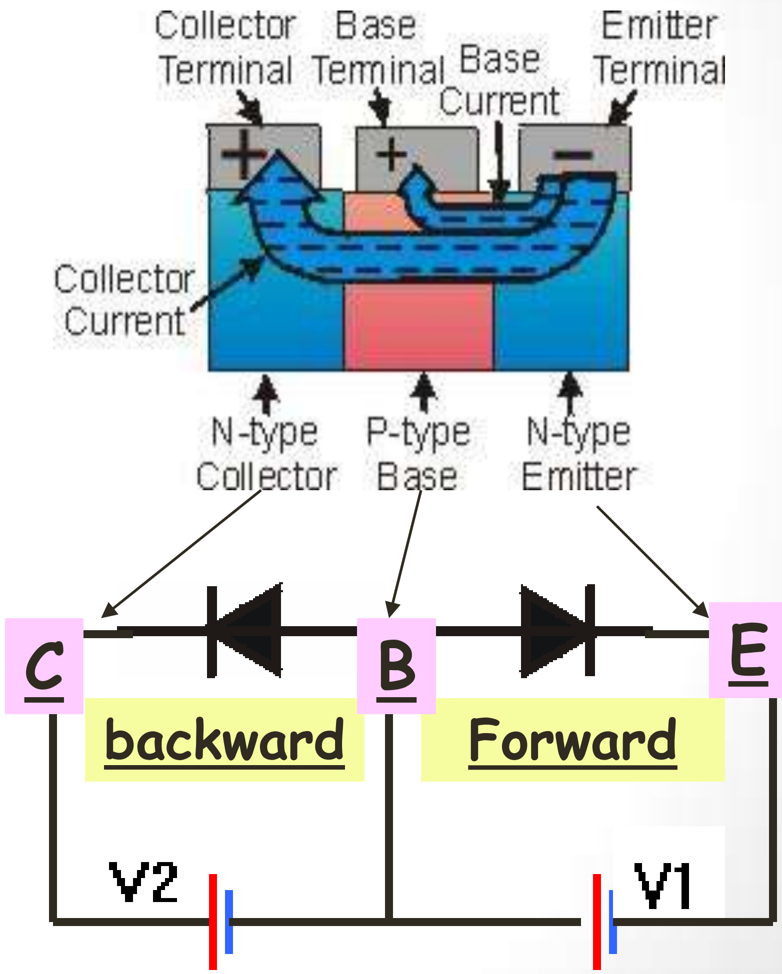
$I_E = I_B + I_C$

$I_C = I_C(\textbf{majority}) + I_{CO}(\text{min}\textbf{ority})$

IC(majority) – Generally it is milliamp.
IC(minority) – Current when emitter junction is open. Generally it is in microamperes and sensitive to temperature variation.

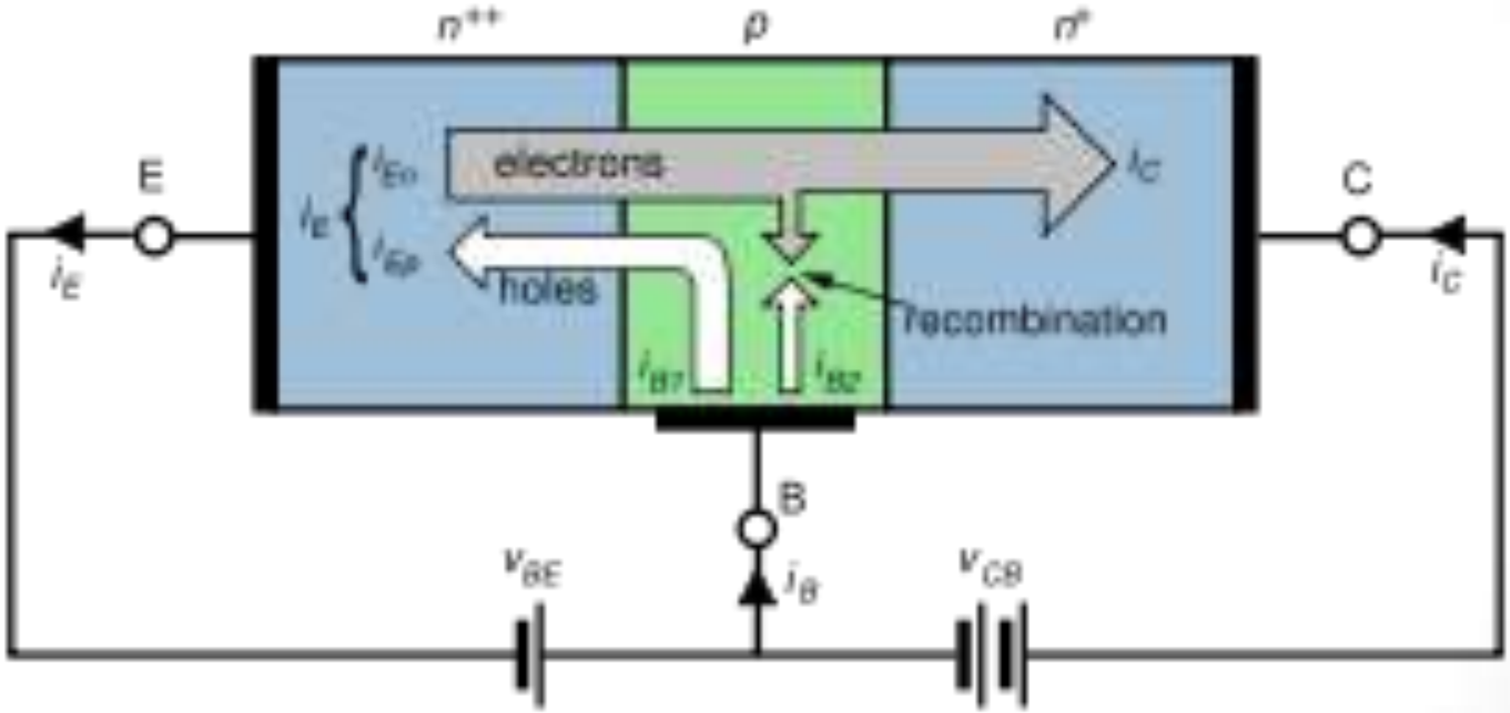
How a "NPN" Transistor works?

The base-emitter diode (forward) acts as a switch. when v1>0.7 it lets the electrons flow toward collector. so we can control our output current (Ic) with the input current (Ib) by using transistors.

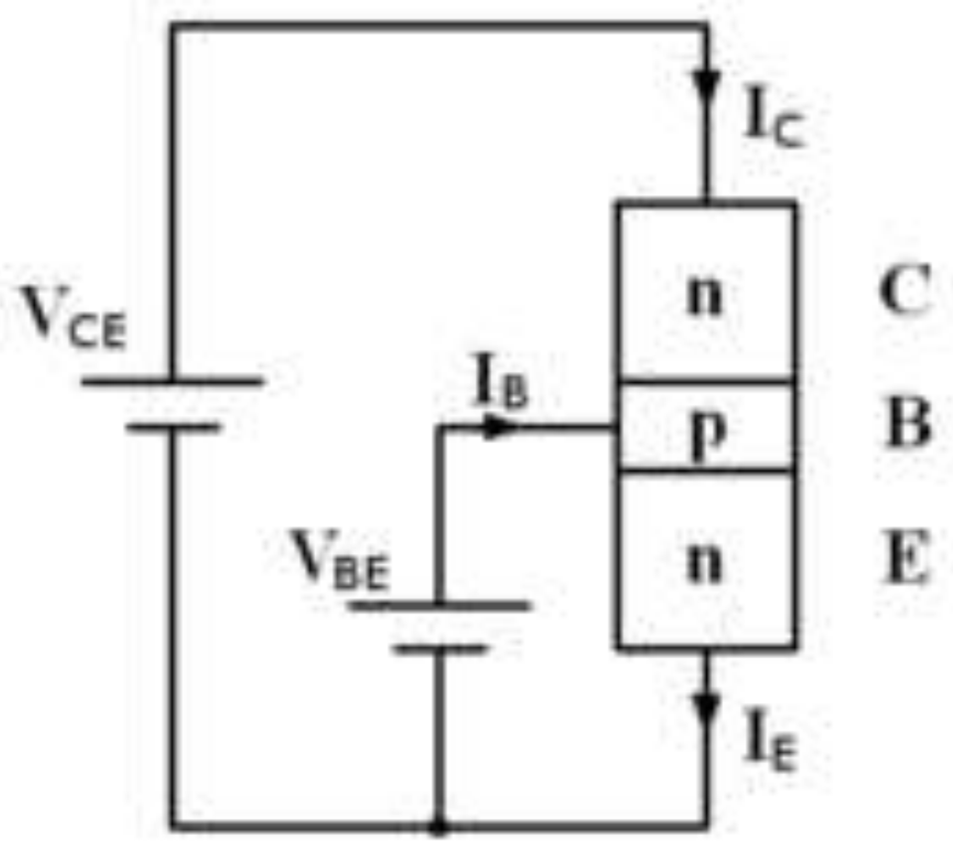


LECTURE NO. - 27

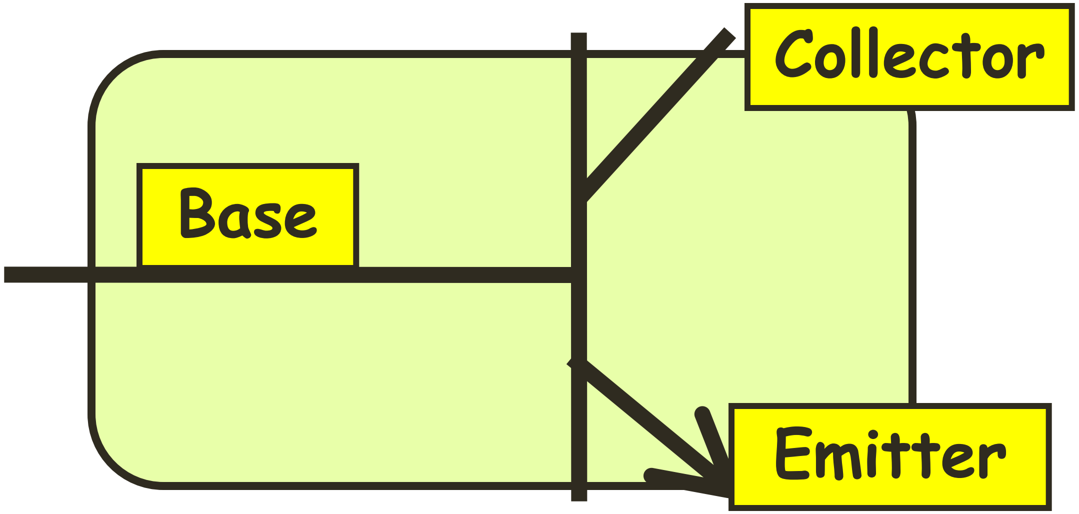
Transistor current component



Transistors in circuits



Transistors have three terminals:



Transistors work in 3 regions

Active: Always on

Ic=BIb

Saturation :Ic=Isaturation

On as a switch

Off :Ic=0

Off as a switch

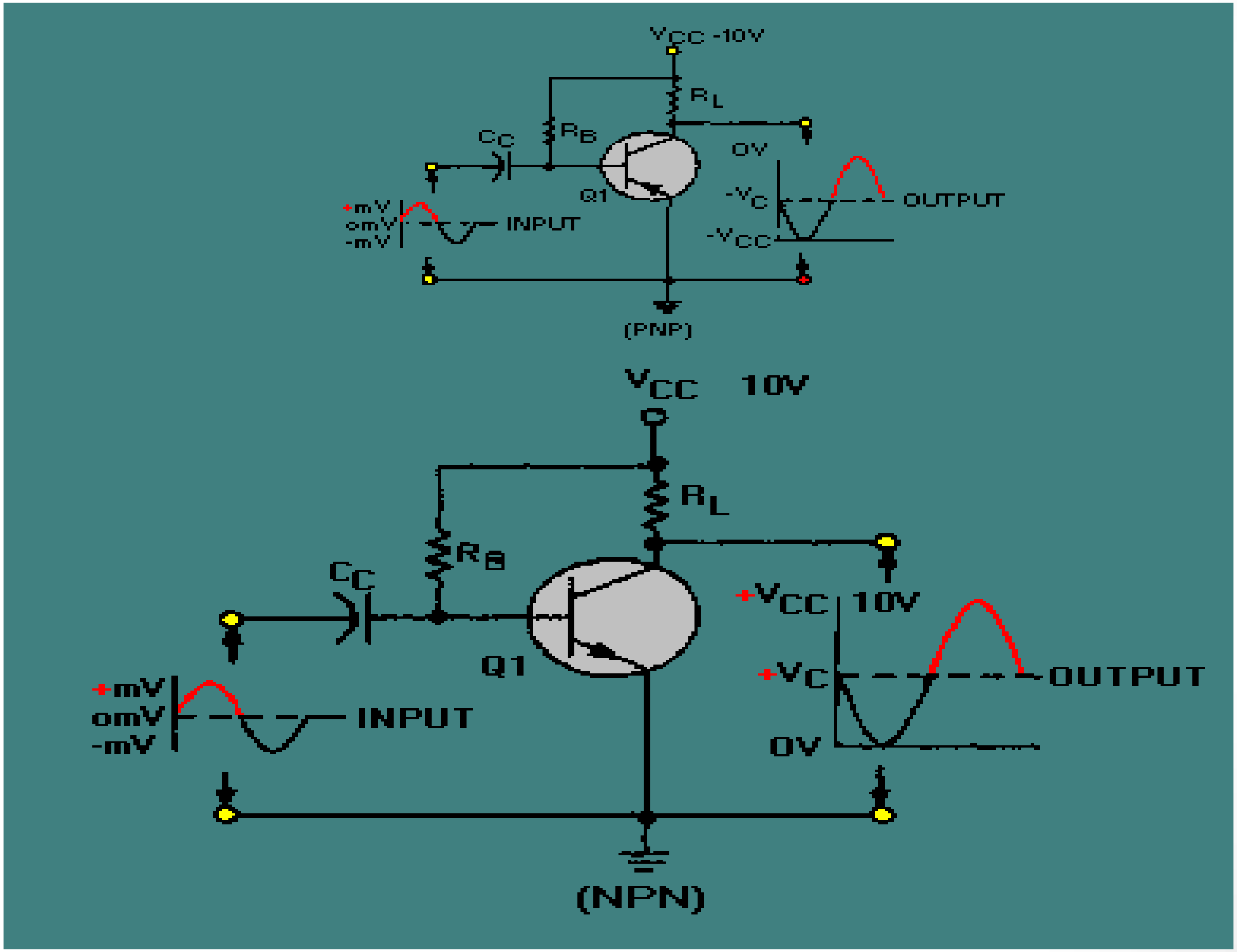
- Because of the electric field existing between base and collector (caused by V_{CE}), the majority of these electrons cross the upper p-n junction into the collector to form the collector current, I_C.
- The remainder of the electrons recombine with holes, the majority carriers in the base, making a current through the base connection to form the base current, I_B

- As shown in the diagram, the emitter current, *IE*, is the total transistor current which is the sum of the other terminal currents. That is:

$$I_E = I_B + I_C$$

LECTURE NO. - 28

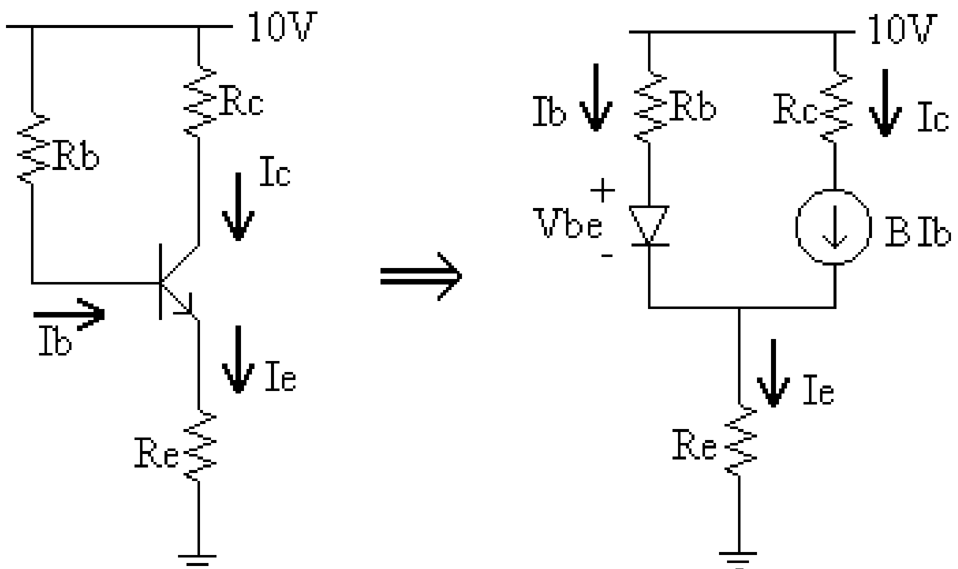
Transistor as an amplifier



Transistor as an amplifier:

Transistors are often used as amplifiers to increase input signal in radios, televisions and some other applications .The circuit may be designed to increase the current or voltage level.

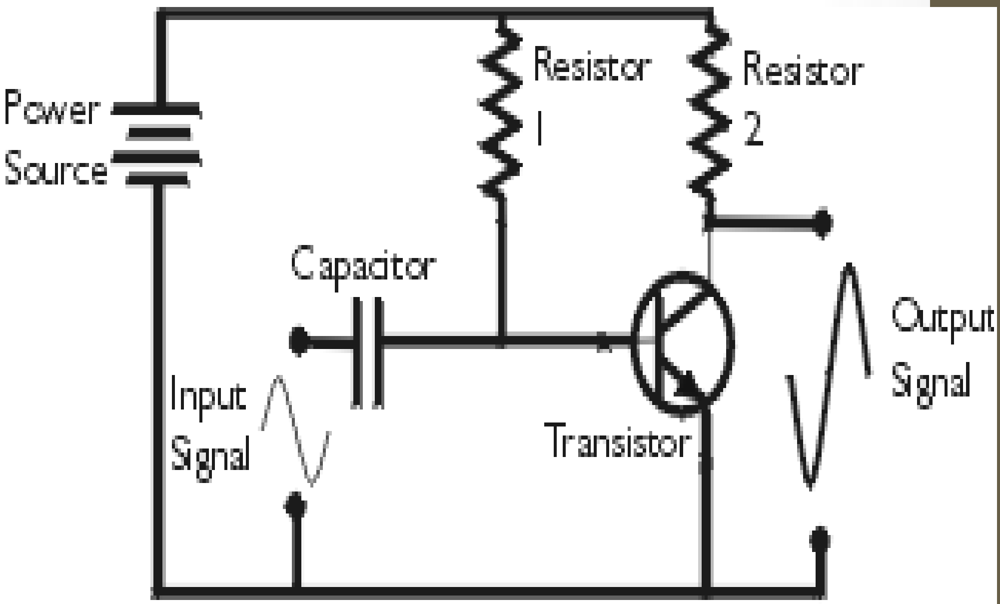
The power gain is the product of current gain and voltage gain (P=V*I).



Amplifier example:

As you see, the transistor is biased to be always on. The input signal is amplified by this circuit. The frequency of output is the same as its input, but the polarity of the signal is inverted.

The measure of amplification is the gain of transistor.



Transistor Amplifier

Example:
Input Amplitude =0.2v
Output amplitude=10v
Gain=10/0.2=50

- With Q1 properly biased, direct current flows continuously, with or without an input signal, throughout the entire circuit
- It is introduced into the circuit by the coupling capacitor and is applied between the base and emitter.

- As the input signal goes positive, the voltage across the emitter-base junction becomes more positive.

- This in effect increases forward bias, which causes base current to increase at the same rate as that of the input sine wave.

Modes of transistor operation

- Modes of transistor operation
- Common - base
- Common - emitter
- Common - collector
- Particular terminal is common to both input and output

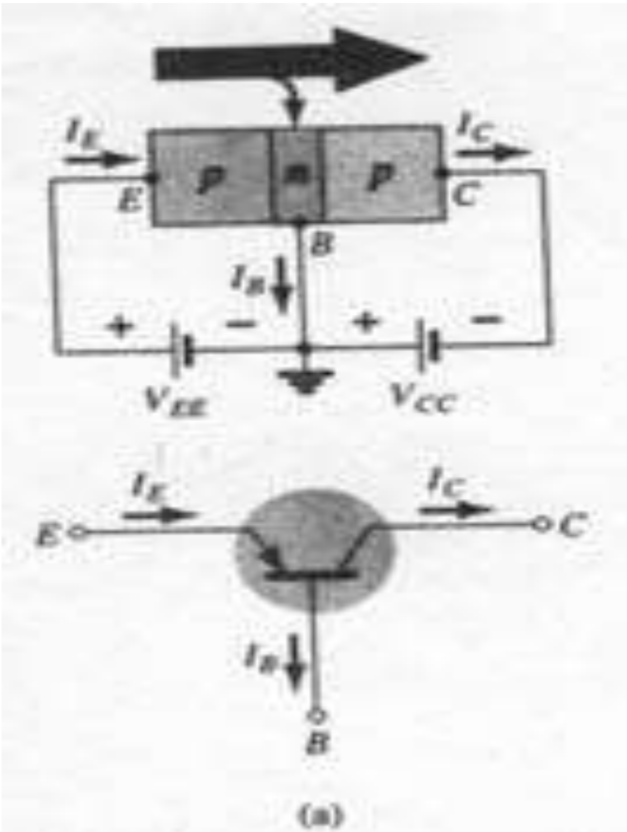
BJT Transistors

- The arrow on the emitter lead shows the direction of emitter current flow,when emitter-base junction is forward biased, it is always from *p to n*

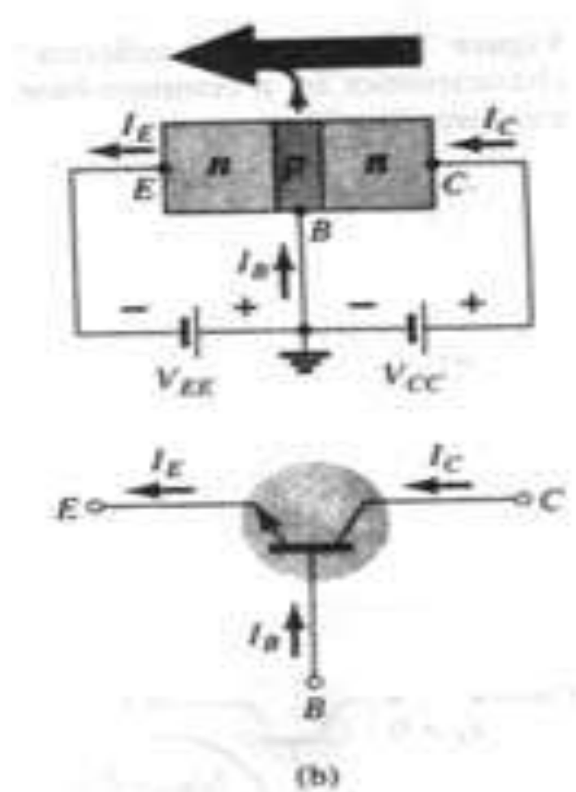
- For a *pnp* transistor it will be inward and for *npn* transistor it will be outward. To understand transistor behavior fully two sets of characteristics:
- Driving point or input parameters and the other for output side. Driving point will relate input voltage vs input current and similarly output side will relate output current and output voltage

LECTURE NO. - 30

Common - base



pnp transistor

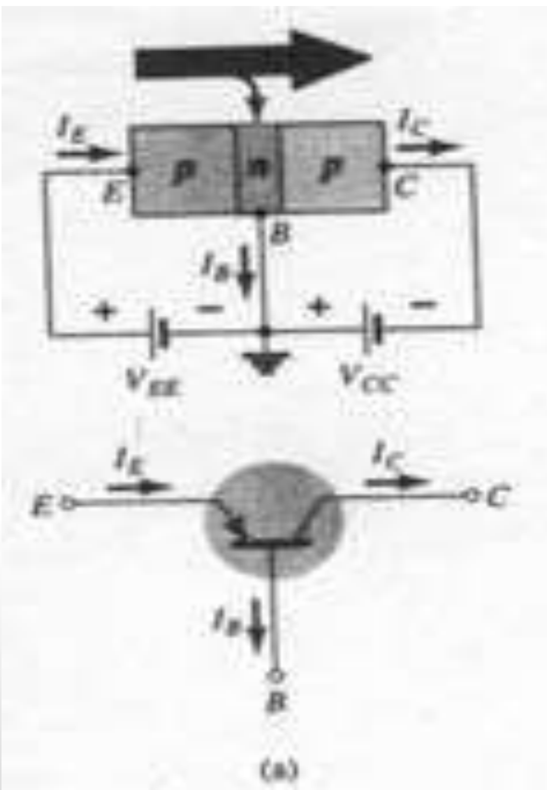


npn transistor

Current direction changes in the above two configuration

Common - base

- Base is common to input and output
- Emitter-base junction is forward biased. Collector-base junction is reverse biased
- Biasing remains same irrespective of *npn* or *pnp*



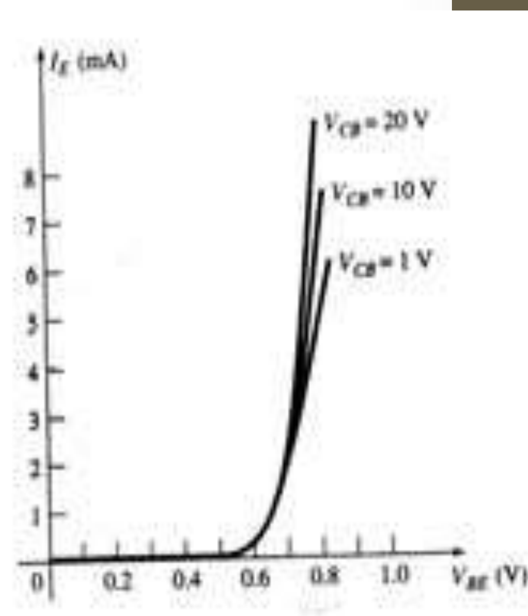
put characteristics for a

mmon base silicon transistor

e a *pn* junction

CB not having major

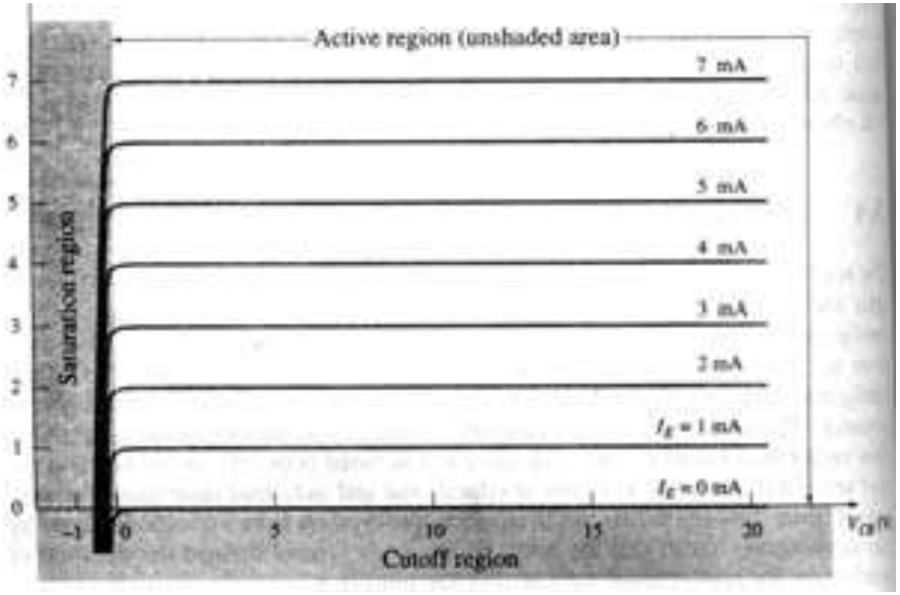
fluence



Common - base

- Active region - base-emitter forward biased and collector-base is reverse biased
- **Ic** ≈ IE

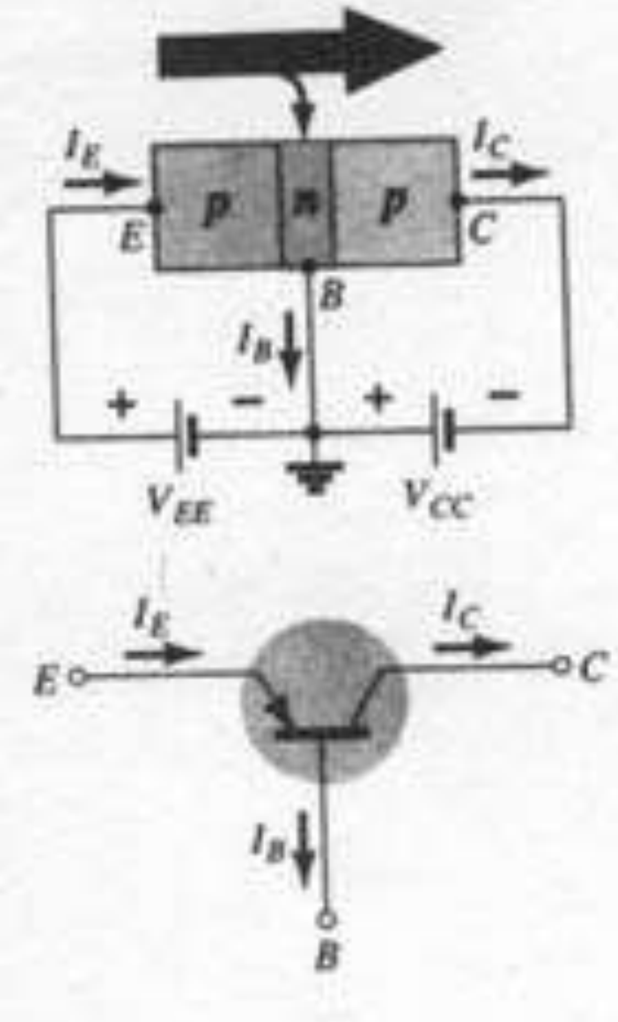
IC (mA)



Common - base

- IE = IB + IC
- Current in base is negligible.
- Current in emitter and collector
- is almost same.
- Current gain less than unity
- α = IC/IE (0.90 - 0.998)
- Current IE can be changed by VBE

  and this will change the IC

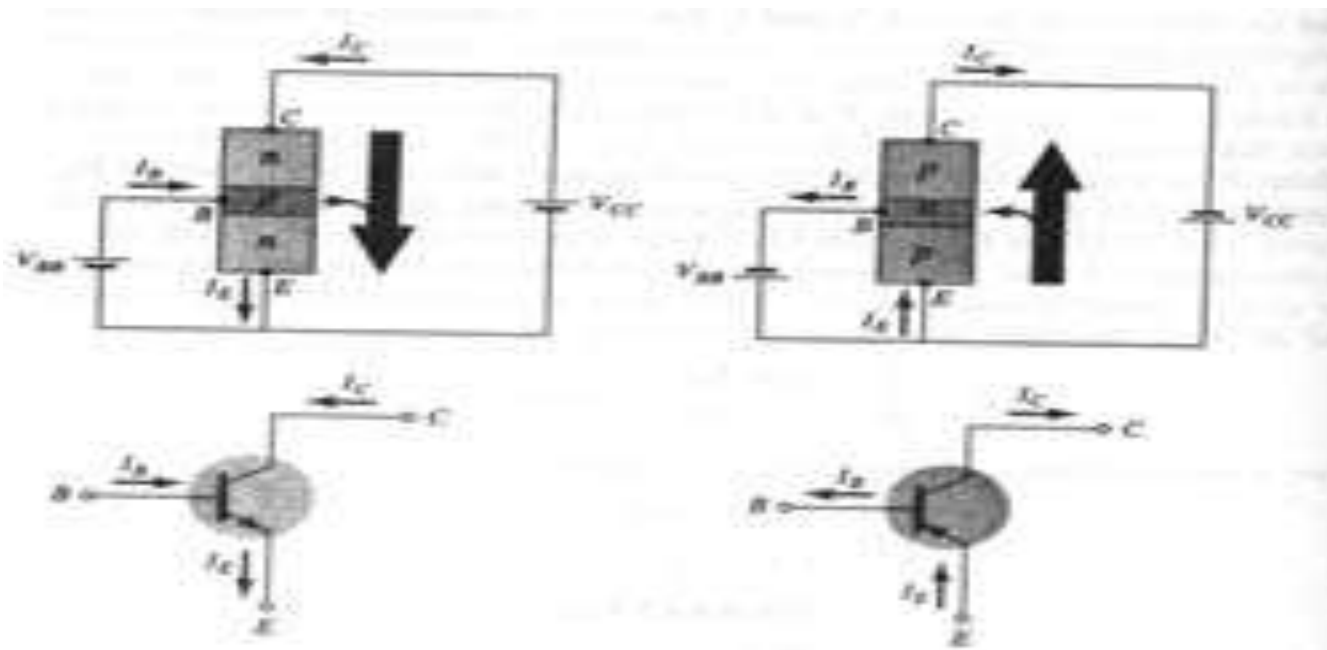


(a)

LECTURE NO. - 29

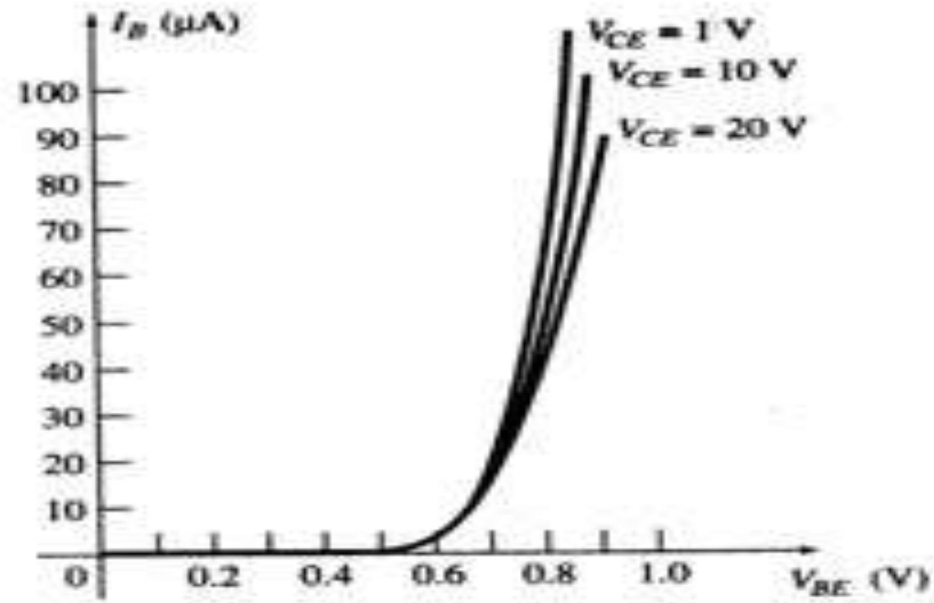
Common - emitter

- Emitter is common to input and output
- Base-emitter junction is forward biased. Collector-emitter junction is reverse biased
- Biasing remains same irrespective of *npn* or *pnp*



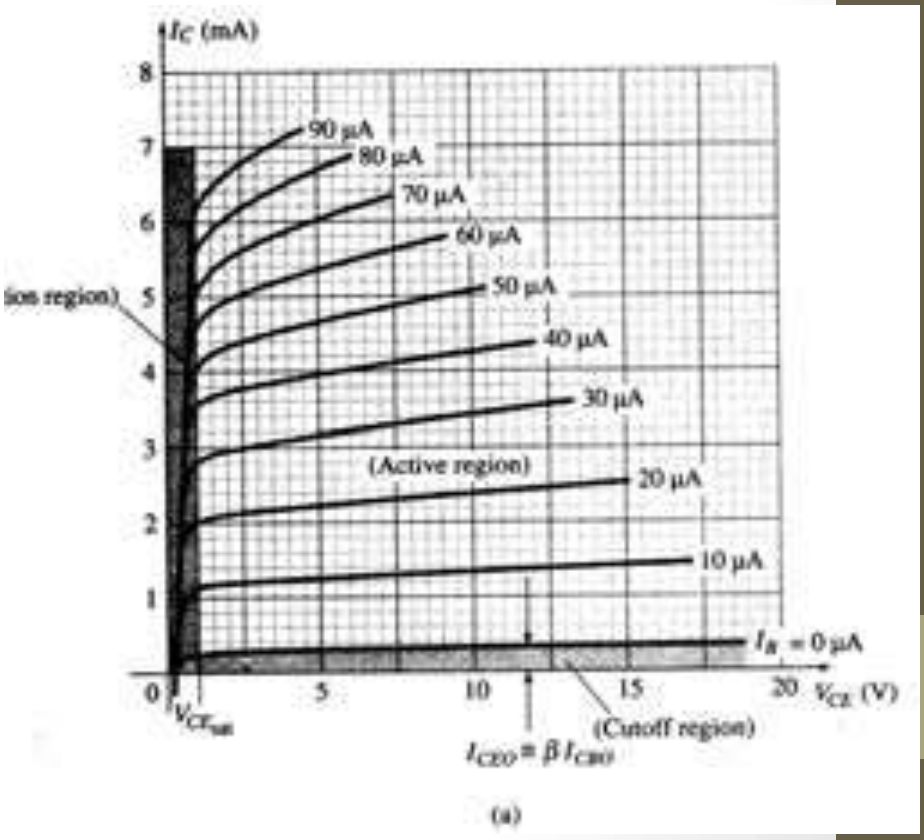
Common - emitter

- Base-emitter *pn* junction, forward biased
- Base current is in micro ampere
- VCE does not have major influence on IB



Common - emitter

- Base-emitter *pn* junction, forward biased & base collector is reverse biased.
- Base current is in micro ampere,
- collector current in mili ampere
- High current gain
- Cutoff region below IB = 0



Transistor Configuration Comparison Chart

AMPLIFIER TYPE	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
Input/Output Phase Relationship	0°	180°	0°
Voltage Gain	High	Medium	Low
Current Gain	Low(a)	Medium(b)	High(g)
Power Gain	Low	High	Medium
Input Resistance	Low	Medium	High
Output Resistance	High	Medium	Low

LECTURE NO. - 33

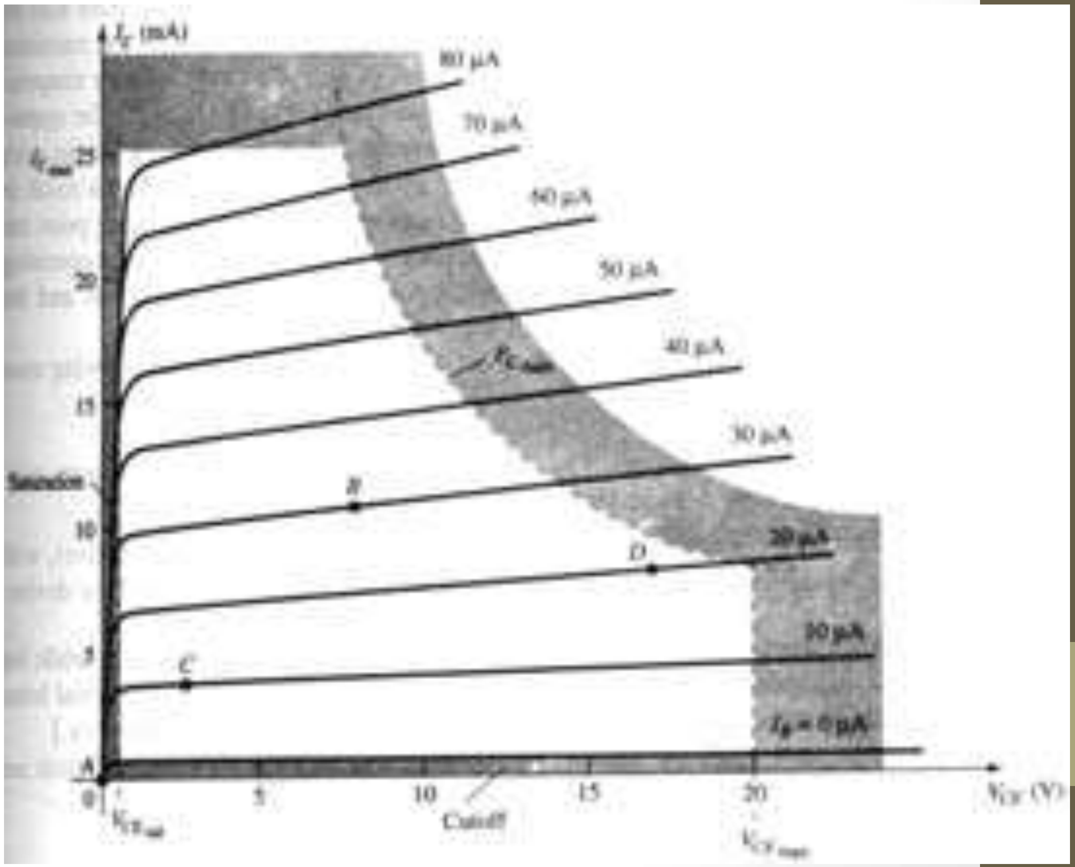
DC Biasing - BJT

- Biasing - shifting the mean operating point. To avoid operation in
- Non-linear region
- Saturation region
- Cut-off region
- Max. power consumption

<u>Linear region operation</u>
- *Base-emitter forward bias*
- *Base-collector reverse bias*

<u>Cutoff region</u>
- *Base-emitter reverse bias*

<u>*Saturation region*</u>
- *Base-emitter forward bias*
- *Base-collector forward bias*



Transistor Bias Stabilization

- **Used to compensate for temperature effects which affects semiconductor operation. As temperature increases, free electrons gain energy and leave their lattice structures which causes current to increase.**

Transistor biasing :

Requirements upon biasing circuit :

The operating point of a device, also known as bias point or quiescent point (or simply Q-point), is the DC voltage and/or current which, when applied to a device, causes it to operate in a certain desired fashion.

1. For analog circuit operation, the Q-point is placed so the transistor stays in **active mode** (does not shift to operation in the saturation region or cut-off region) when input is applied. For digital operation, the Q-point is placed so the transistor does the contrary - switches from "on" to "off" state. Often, Q-point is established near the center of active region of transistor characteristic to allow similar signal swings in positive and negative directions.

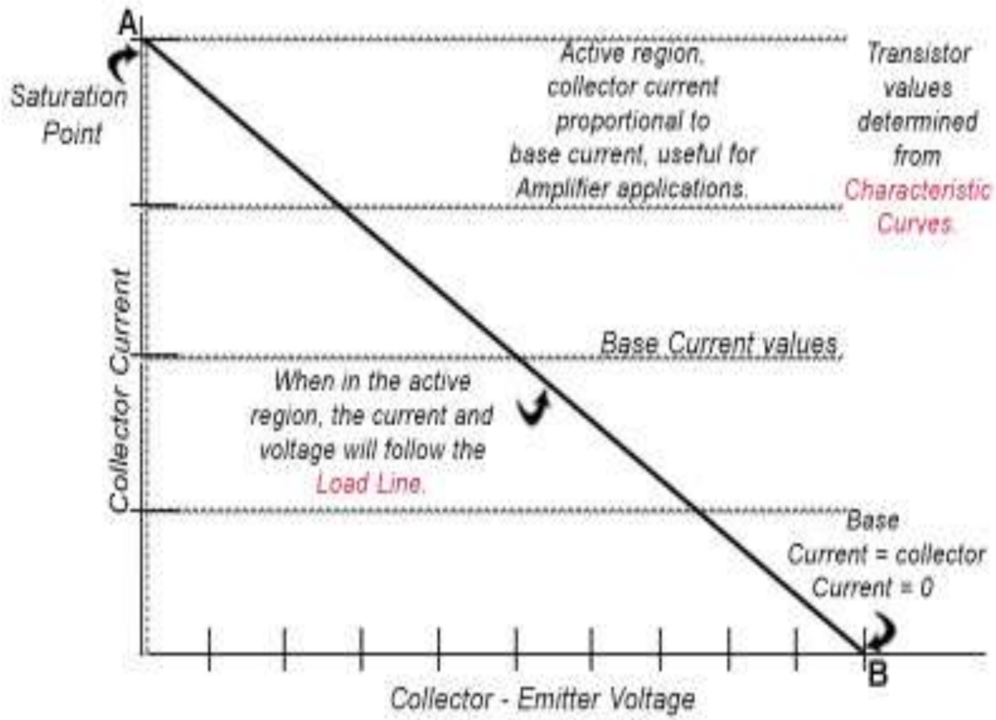
- Q-point should be stable. In particular, it should be insensitive to variations in transistor parameters (for example, should not shift if transistor is replaced by another of the same type), variations in temperature, variations in power supply voltage and so forth.
- The circuit must be practical: easily implemented and cost-effective.

Q-POINT

- The Q-point or operating point is established by the DC analysis which establishes the DC load line. The AC load line has a different slope then the DC load line and the two load lines intersect at the Q-point. In the common emitter amplifier, as you increase the frequency,the gain to go down and the phase shift to move away from -180 degrees. The Q-point remains unchanged.

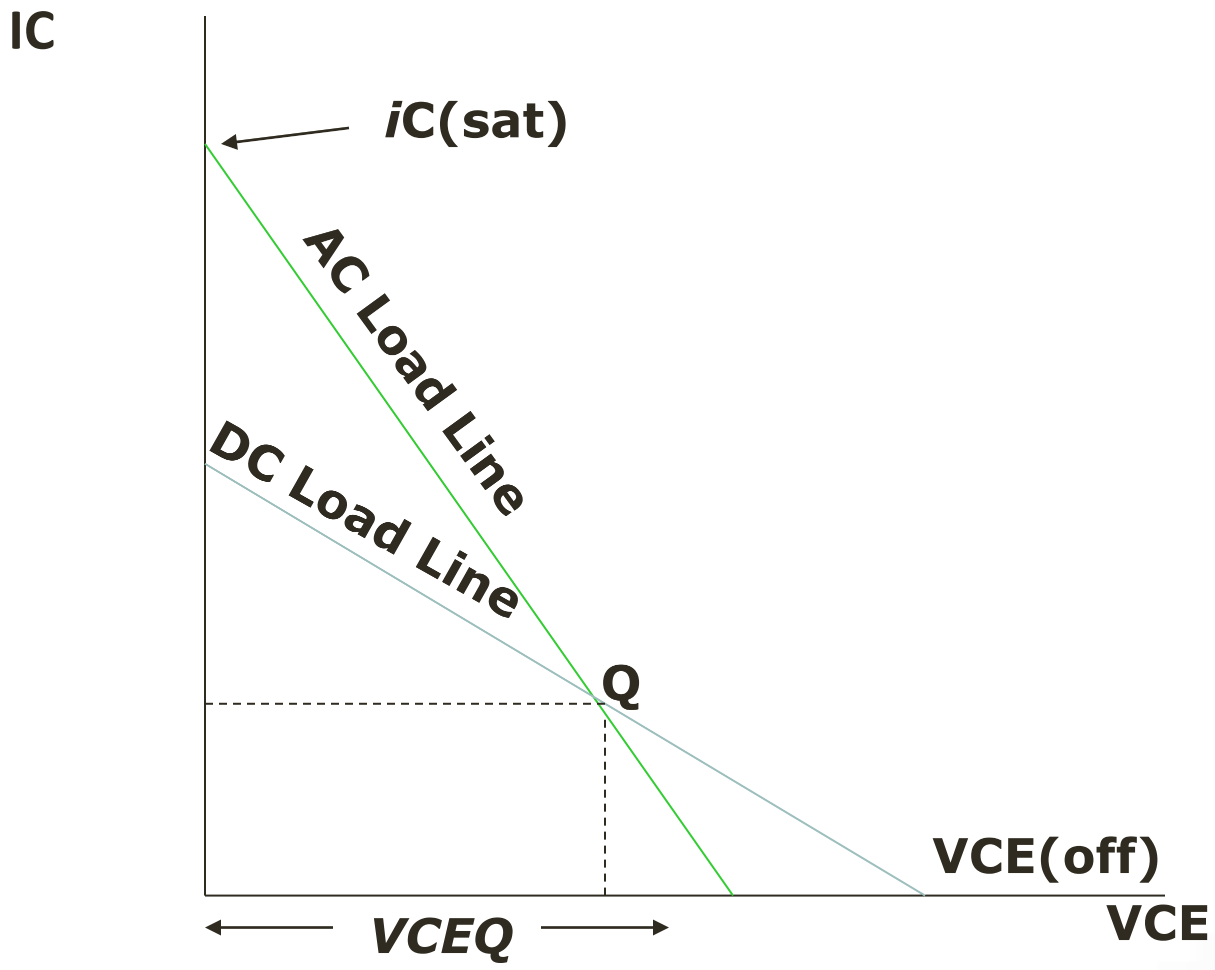
DC & AC load line Analysis

- ***Load Lines***



- Every amplifier has two loads: a dc Load and an ac load.
- The dc load line represents all possible combinations of I_c and V_{CE}
- ***The ac load line*** represents all possible ***ac*** combinations of and i_c & V_{CE}.
- The dc load line will not follow the path of the ac load line as shown to the left. This is because the ac signal "sees" the ac equivalent circuit that includes r_C
- Note that the Q point is shared by both lines.

•


IC
iC(sat)
AC Load Line
DC Load Line
Q
VCE(off)
VCE
VCEQ

- ***The ac Load Line***
- The ac load line uses $R_C || R_L$ in its determination, and consequently, the ac load line will be than the dc load line.
- The ends of the ac load line are found using the formulas:

$$i_c(sat) = I_{CQ} + \frac{V_{CEQ}}{r_c}$$

$$v_{ce}(off) = V_{CEQ} + \frac{I_{CQ}}{r_C}$$

- Note that the Q point is in the centre of the dc loadline but not in the centre of the ac load line.
- The ac load line tells us what the maximum output voltage swing will be for the given amplifier.

LECTURE NO. – 34

Bias stability

One of the basic problems with transistor amplifiers is establishing and maintaining the proper values of quiescent current and voltage in the circuit.

This is accomplished by selecting the proper circuit-biasing conditions and ensuring these conditions are maintained despite variations in ambient (surrounding) temperature, which cause changes in amplification and even distortion (an unwanted change in a signal).

- Thus a need arises for a method to properly bias the transistor amplifier and at the same time stabilize its dc operating point (the no signal values of collector voltage and collector current).

Stabilty factor

- The Stabilty factor may be defined as the rate of change of collector current with respect to the revere saturation current keeping the CE current gain and base current as constant ,

$S = dI_c$

dI_{co}

$= \Delta I_c$

ΔI_{co}

- In defination of s,β, & V_{BE} are assumed to be constant while they vary with temp.

Hence we define two other stabilty constant : S_β & Sv

1. $S_\beta = \frac{dI_c}{d\beta} = \frac{\Delta I_c}{\Delta \beta}$

2. $Sv = \frac{dI_c}{dV_{BE}} = \frac{\Delta I_c}{\Delta V_{BE}}$

Types of bias circuit

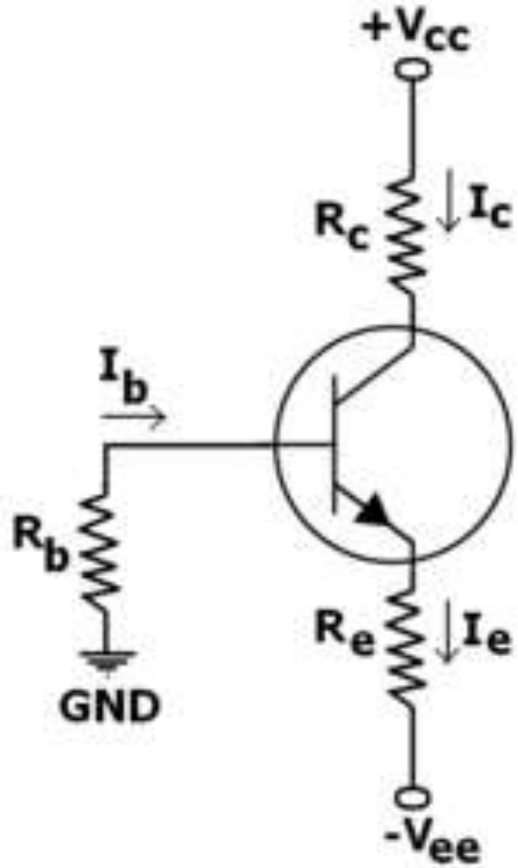
- The following discussion treats four common biasing circuits used with bipolar transistors:
- Fixed bias
- Collector-to-base bias
- Voltage divider bias
- Emitter bias

Types of Bias Stabilization

- ***Self Bias***: A portion of the output is fed back to the input 180o out of phase. **This negative feedback will reduce overall amplifier gain.**
- ***Fixed Bias***: Uses resistor in parallel with Transistor emitter-base junction.
- ***Combination Bias***: This form of bias stabilization uses a combination of the emitter resistor form and a voltage divider. It is designed to compensate for both temperature effects as well as minor fluctuations in supply (bias) voltage.
- ***Emitter Resister Bias***: As temperature increases, current flow will increase. This will result in an increased voltage drop across the emitter resistor which opposes the potential on the emitter of the transistor.

LECTURE NO. - 35

Emitter bias



- When a split supply (dual power supply) is available, this biasing circuit is the most effective. The negative supply VEE is used to forward-bias the emitter junction through RE.
- The positive supply VCC is used to reverse-bias the collector junction. Only three resistors are necessary

- We know that,

  $V_B - V_E = V_{be}$

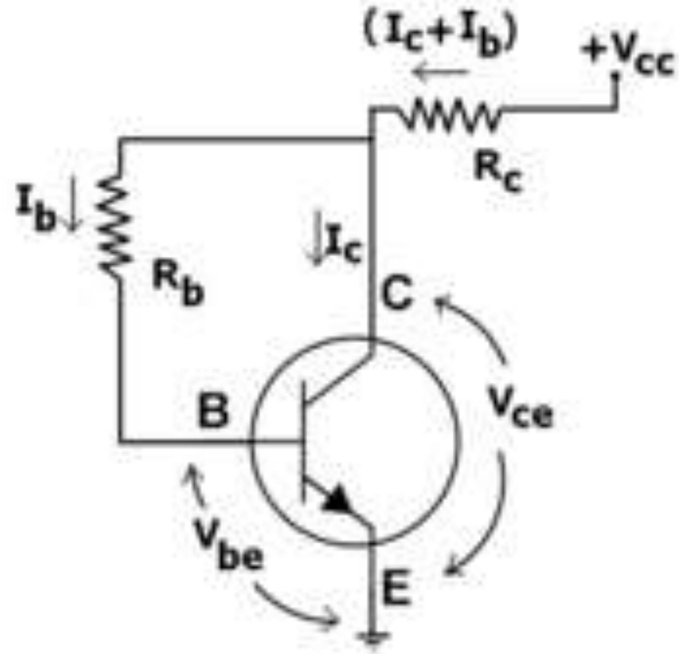
- If RB is small enough, base voltage will be approximately zero. Therefore emitter current is,

  $I_E = (V_{EE} - V_{be})/R_E$

The operating point is independent of β if RE >> RB/β

- **Merit:**
- Good stability of operating point similar to voltage divider bias.
- **Demerit:**
- This type can only be used when a split (dual) power supply is available.

bias



- In this form of biasing, the base resistor RB is connected to the collector instead of connecting it to the battery VCC.
- That means this circuit employs negative feedback to stabilize the operating point.

- From Kirchhoff's voltage law, the voltage across the base resistor is

$$V_{Rb} = V_{CC} - (I_C + I_b)R_C - V_{be}.$$

From Ohm's law, the base current is

$$I_b = V_{Rb} / R_b.$$

- For the given circuit,

$$I_B = (V_{CC} - V_{be}) / (R_B+\beta R_C).$$

- **Merits:**
- Circuit stabilizes the operating point against variations in temperature and β (ie. replacement of transistor)
- **Demerits:**
- In this circuit, to keep IC independent of β the following condition must be met:

$$I_C = \beta I_B = \frac{\beta(V_{CC} - V_{be})}{R_B + \beta R_C} \approx \frac{(V_{CC} - V_{be})}{R_C}$$

which is approximately the case if
β RC >> RB.

- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping RC fairly large, or making RB very low.
- If RC is of large value, high VCC is necessary. This increases cost as well as precautions necessary while handling.
- If RB is low, the reverse bias of the collector-base is small, which limits the range of collector voltage swing that leaves the transistor in active mode.

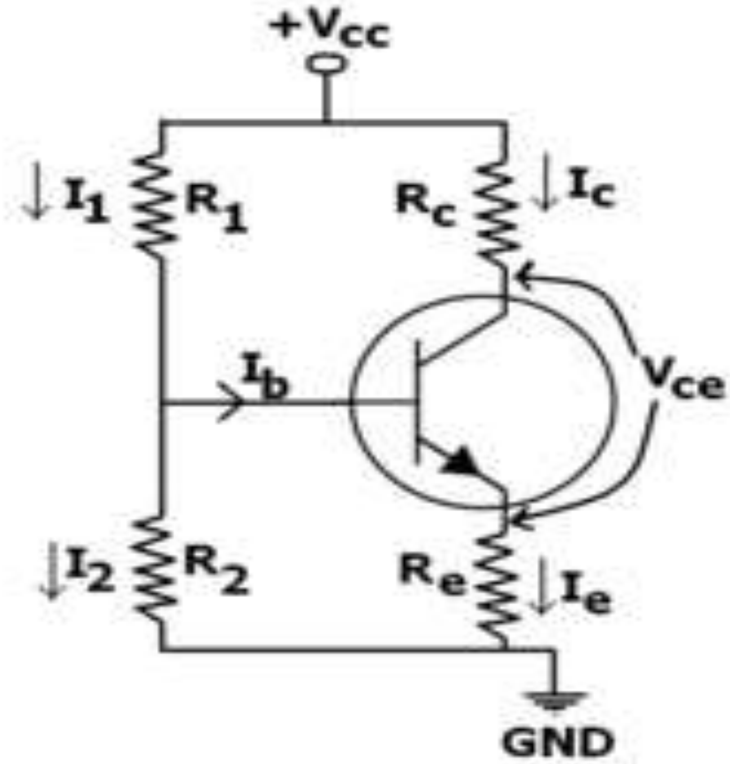
- As β-value is fixed for a given transistor, this relation can be satisfied either by keeping RC fairly large, or making RB very low.
- If RC is of large value, high VCC is necessary. This increases cost as well as precautions necessary while handling.
- If RB is low, the reverse bias of the collector-base is small, which limits the range of collector voltage swing that leaves the transistor in active mode.

- The resistor RB causes an ac feedback, reducing the voltage gain of the amplifier. This undesirable effect is a trade-off for greater Q-point stability.

- **Usage:** The feedback also decreases the input impedance of the amplifier as seen from the base, which can be advantageous. Due to the gain reduction from feedback, this biasing form is used only when the trade-off for stability is warranted.

LECTURE NO. - 36

Voltage divider bias



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- That means this circuit employs negative feedback to stabilize the operating point.

- From Kirchhoff's voltage law, the voltage across the base resistor is

  $V_{Rb} = V_{CC} - (I_C + I_b)R_C - V_{be}$.

- From Ohm's law, the base current is

  $I_b = V_{Rb} / R_b$.

- For the given circuit,

  $I_B = (V_{CC} - V_{be}) / (R_B + \beta R_C)$.

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- **Demerits:**
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$$I_C = \beta I_B = \frac{\beta(V_{CC} - V_{be})}{R_B + \beta R_C} \approx \frac{(V_{CC} - V_{be})}{R_C}$$

which is approximately the case if

$$\beta R_C >> R_B.$$

As β-value is fixed for a given transistor, this relation can be satisfied either by keeping RC fairly large, or making RB very low.

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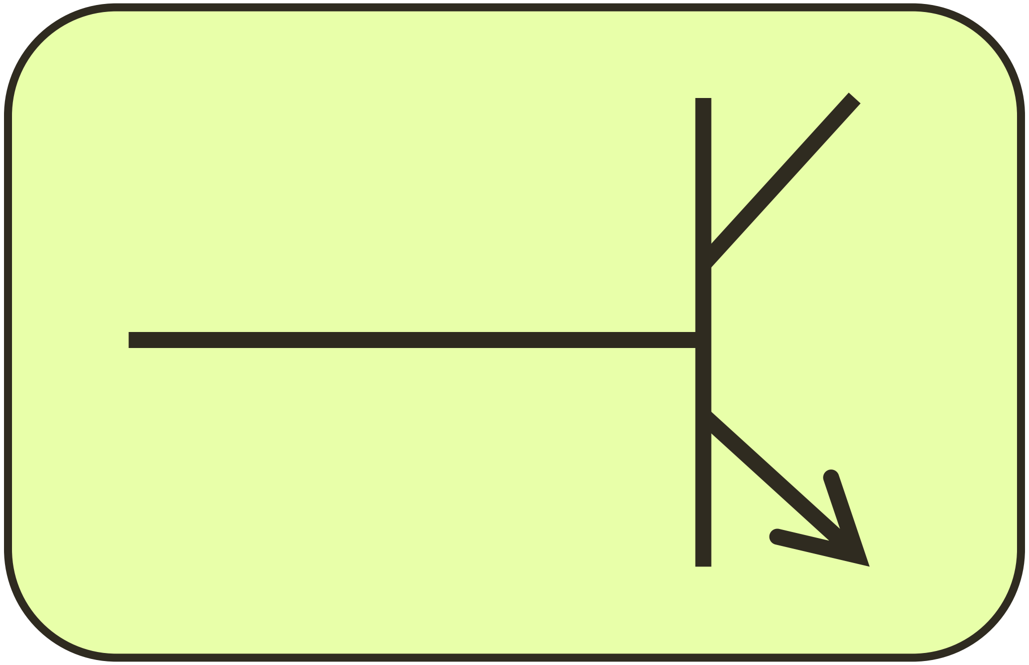
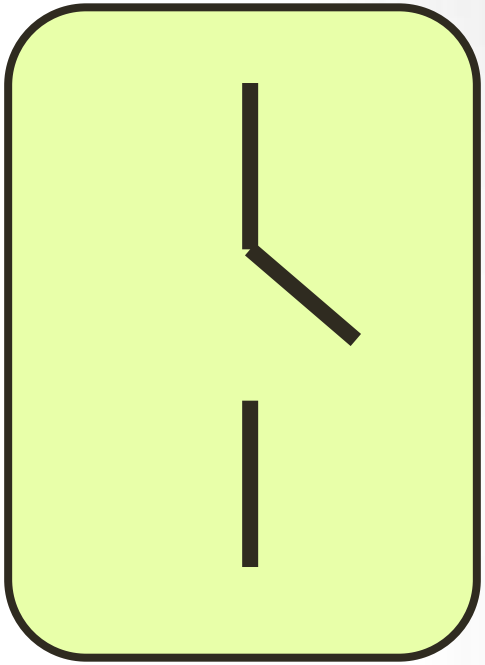
LECTURE NO. - 37

Transistor as a Switch

- Transistors can be used as switches.[1]



Transistor

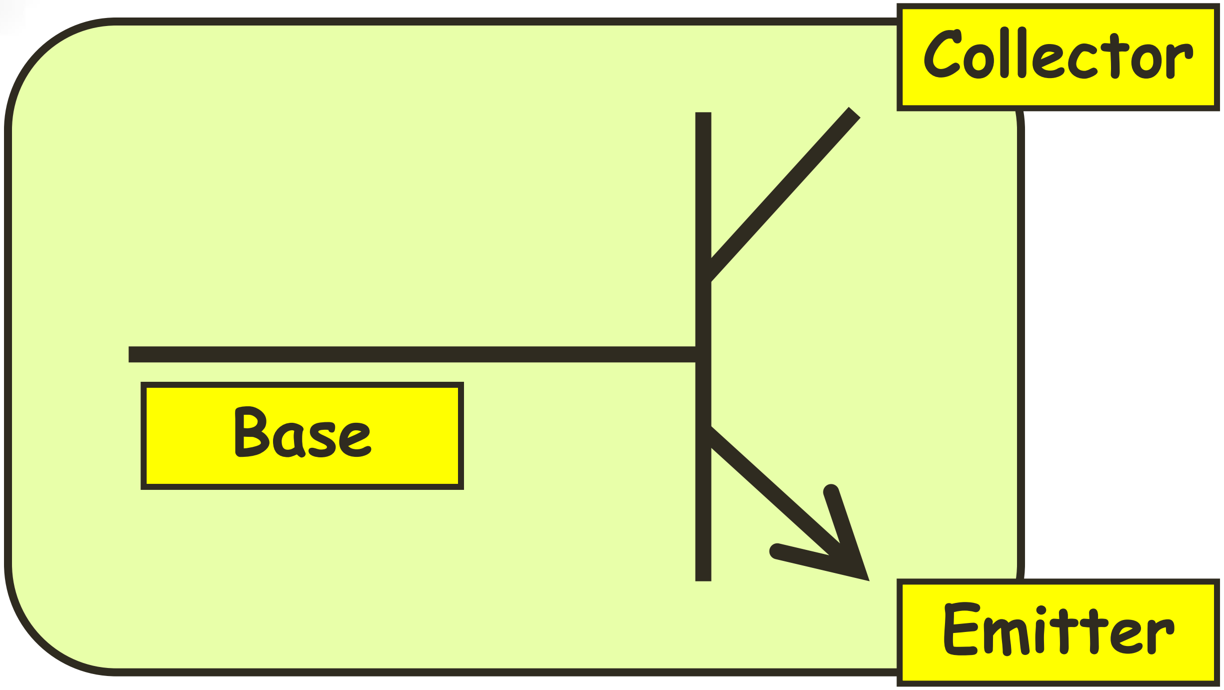


Switch

- Transistors can either conduct *or* not conduct current.[2]

- ie, transistors can either be on *or* off.[2]

How Transistors Work

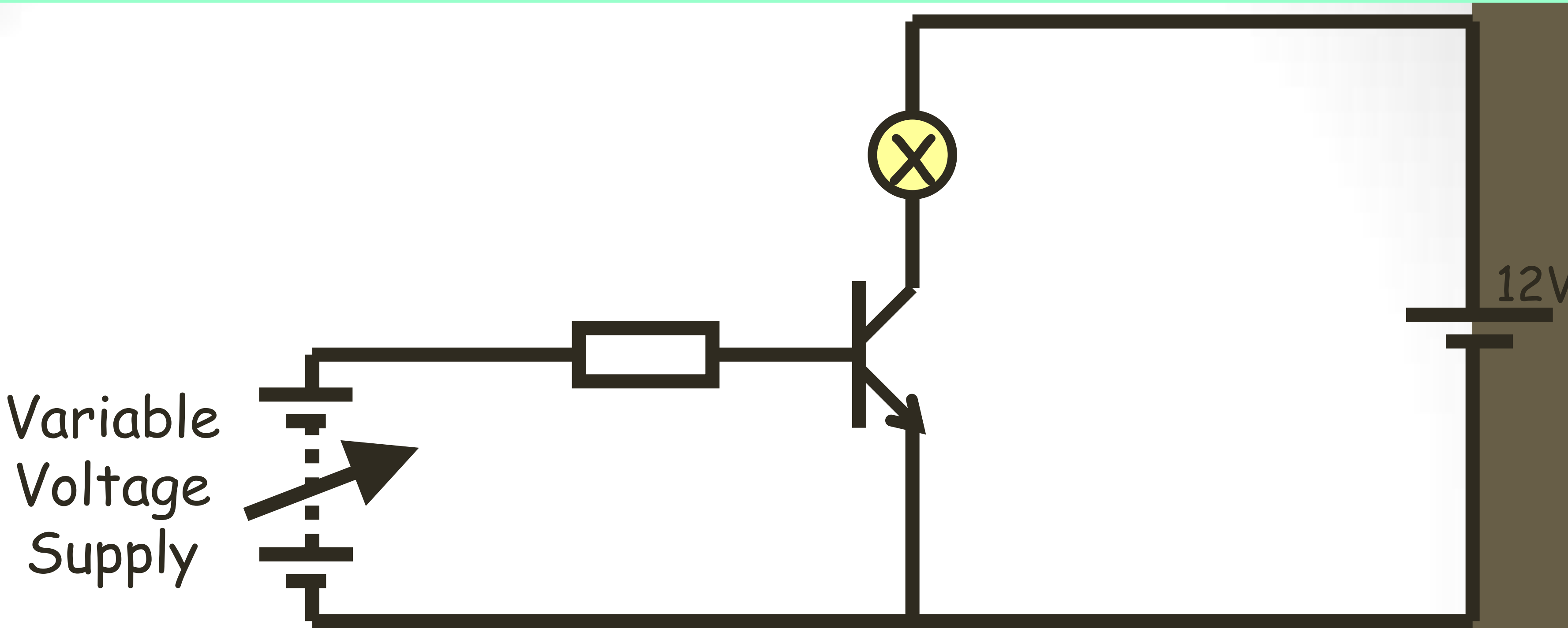


- Switching is controlled by the **voltage** between the **Base** and the **Emitter**.

- When V_{BE} < 0.7V the **transistor switches off** and **no current flows** between the Collector and the Emitter.

- When $V_{BE} \geq$ 0.7V the **transistor switches on** and **current flows** between the Collector and the Emitter.

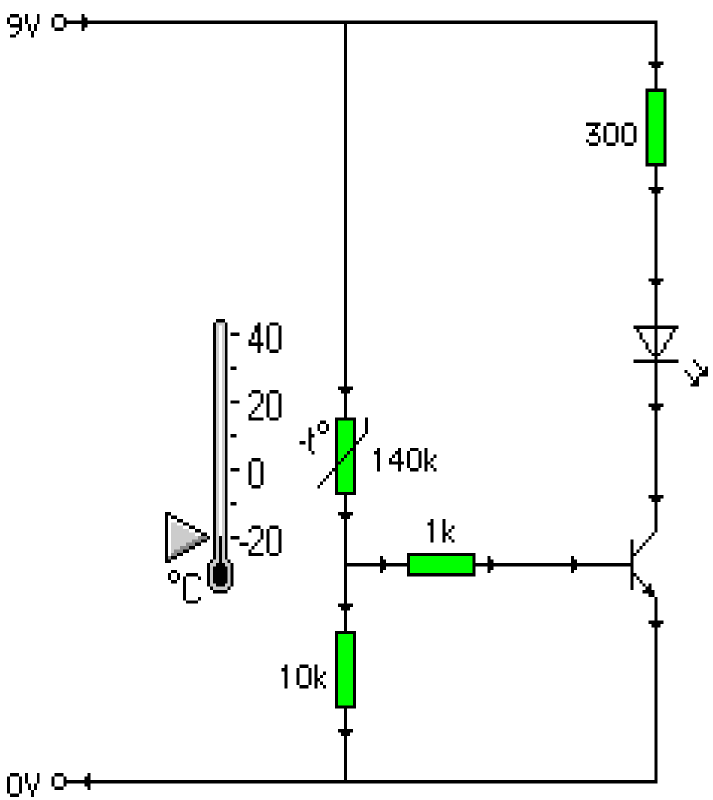
Transistor Switching Example[15]



- When V_{BE} is less than 0.7V the **transistor is off** and the **lamp does not light**.

- When V_{BE} is greater than 0.7V the **transistor is on** and the **lamp lights**.

Transistor Circuit #1: Temperature-Controlled Circuit

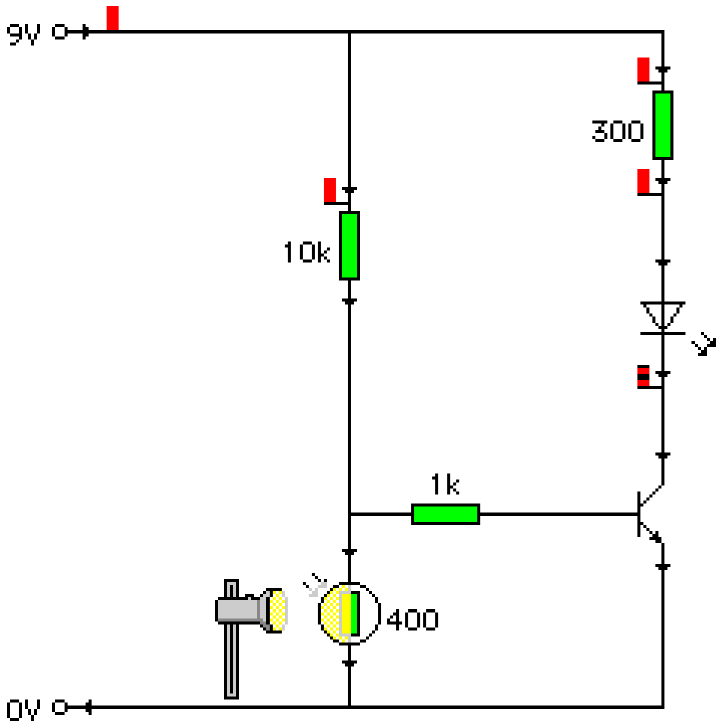


- This transistor circuit contains a **Thermistor**.
- Because of the thermistor, this circuit is dependent on **temperature**.
- The purpose of this circuit is to turn on the LED when the temperature reaches . . .

1) LED = Off.
2) Heat the Thermistor.
3) $R_{Thermistor}$ ↓.
4) $V_{Thermistor}$ ↓.
5) Voltage across 10kΩ resistor ↑.
6) Transistor switches on.
7) LED = On.

Input = Voltage Divider
Process = Transistor
Output = LED

Transistor Circuit #2: Light-Controlled Circuit



- This transistor circuit contains a **Light-Dependent Resistor**.

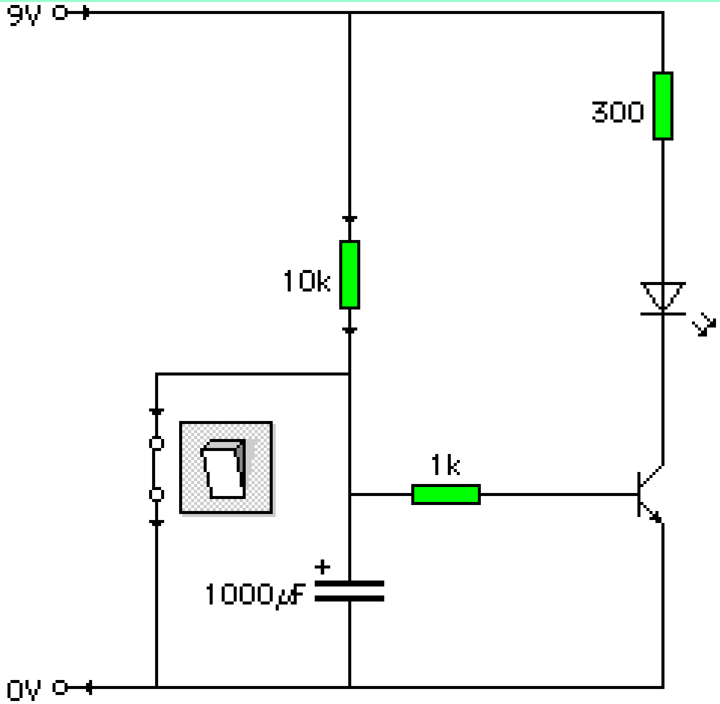
- Because of the LDR, this circuit is dependent on **light**.

- The purpose of this circuit is to turn on the LED when the light reaches a certain intensity.

1) LED = Off.
2) Cover LDR.
3) R_{LDR} ↑.
4) V_{LDR} ↑.
5) Transistor switches on.
6) LED = On.

Input = Voltage Divider
Process = Transistor
Output = LED

Transistor Circuit #3: Time-Controlled Circuit



- This transistor circuit contains a **Capacitor**.
- Because of the capacitor, this circuit is dependent on **the time taken to charge and discharge of the capacitor**.
- The purpose of this circuit is to turn on the LED a short time after the switch is opened.
- Where would this circuit be found in a car?

Input = Voltage Divider
Process = Transistor
Output = LED

1) Switch closed.
2) V_C = 0V.
3) Transistor switches off.
4) LED = Off.
5) Open Switch.
6) $V_C \uparrow$.
7) Transistor switches on after a short delay.
8) LED = On.

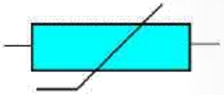
Summary of Transistor Switching Circuits

- **You are expected to know the purpose of a transistor switching circuit: the last three pages should help.**[4]

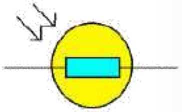
- In each of the three circuits the **input device** is:

- A **Voltage Divider** using a

Thermistor

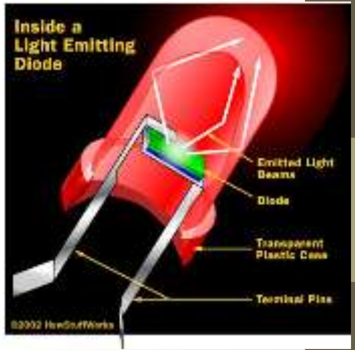


LDR



Capacitor

- In each of the three circuits the **output device** is: an **LED**



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