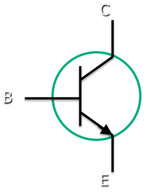
Electronics and Microelectronics AE4B34EM

5. lecture

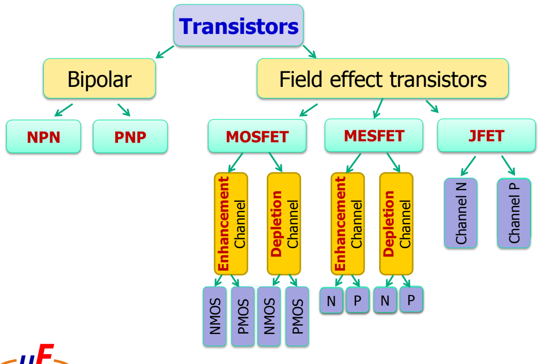
- Bipolar transistor
- Parameters
- Applications



Transistor

- Active components are needed in electronics and microelectronics circuits out of passive components (resistors, capacitors, inductors, ...)
- A transistor is a semiconductor device used to amplify and switch electronic signals
- Transistors are made of a solid piece of semiconductor material, with at least three terminals for connection to an external circuit
- The transistors are the fundamental building block of modern electronic devices.

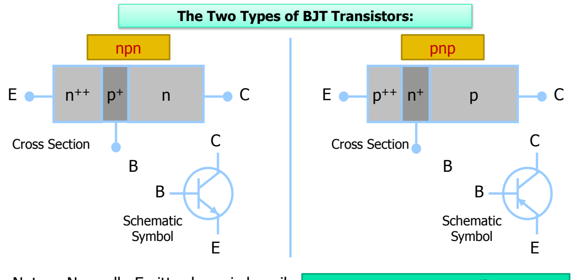
Transistors - types



Bipolar transistors

- Consists of 3 alternate layers of *n* and *p* type semiconductor called **emitter** (*E*), **base** (*B*) and **collector** (*C*).
- Majority of current enters collector, crosses base region and exits through emitter. A small current also enters base terminal, crosses base-emitter junction and exits through emitter.

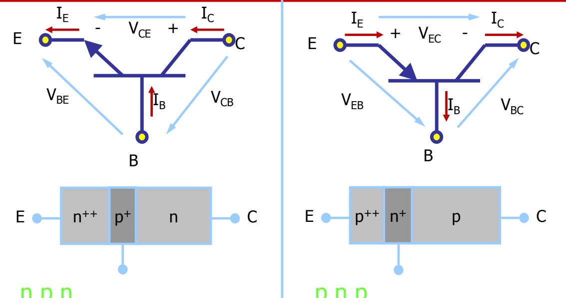
The BJT – Bipolar Junction Transistor



Note: Normally Emitter layer is heavily doped, Base layer is lightly doped and Collector layer has Moderate doping.

Collector doping is usually ~ 10^{15}
Base doping is slightly higher ~ (10^{16} – 10^{17})
Emitter doping is much higher ~ 10^{22}

BJT Current & Voltage - Equations



n p n

$I_E = I_B + I_C$

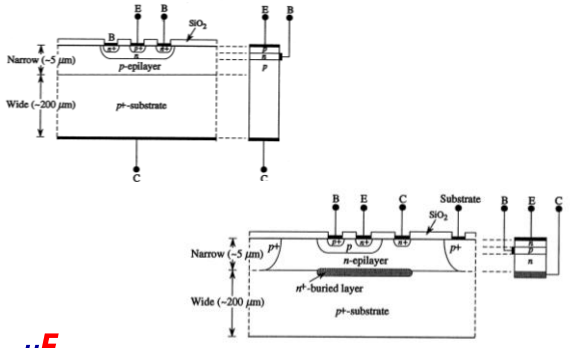
$V_{CE} = V_{CB} + V_{BE}$

p n p

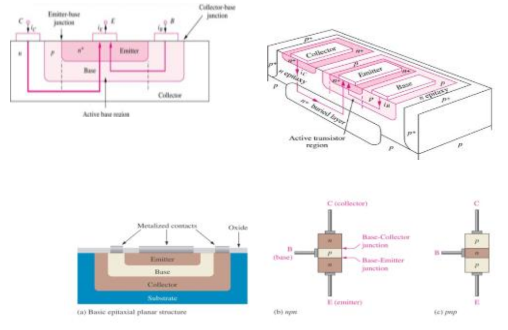
$I_E = I_B + I_C$

$V_{EC} = V_{EB} + V_{BC}$

Cross sections and simplified models of discrete and IC npn BJTs



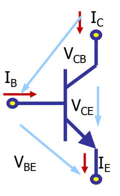
Physical Structure



Various Regions (Modes) of Operation of BJT

- There are four basic operation regions

Region	Polarization B-E	Polarization B-C
Cutoff	$V_{BE} < V_T$ reverse	$V_{BC} < 0$ reverse
Forward-active	$V_{BE} > V_T$ forward	$V_{BC} < 0$ reverse
Reverse	$V_{BE} < 0$ reverse	$V_{BC} > U_T$ forward
Saturation	$V_{BE} > 0$ forward	$V_{BC} > 0$ forward



Various Regions (Modes) of Operation of BJT

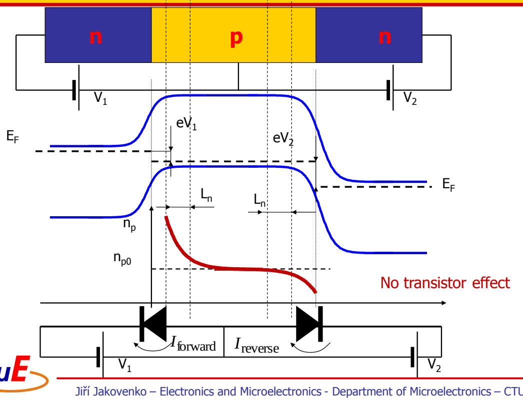
Cutoff: In cutoff, both junctions reverse biased. There is very little current flow, which corresponds to a logical "off", or an open switch.

Forward-active (or simply, **active**): The emitter-base junction is forward biased and the base-collector junction is reverse biased. Most bipolar transistors are designed to afford the greatest common-emitter current gain, β_f in forward-active mode. If this is the case, the collector-emitter current is approximately proportional to the base current, but many times larger, for small base current variations.

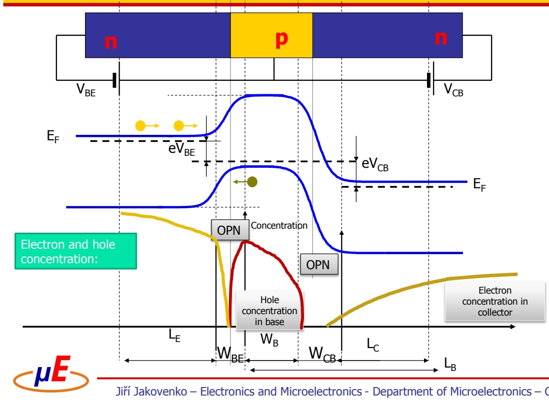
Reverse-active (or **inverse-active** or **inverted**): By reversing the biasing conditions of the forward-active region, a bipolar transistor goes into reverse-active mode. In this mode, the emitter and collector regions switch roles. Since most BJTs are designed to maximize current gain in forward-active mode, the β_f in inverted mode is several times smaller. This transistor mode is seldom used. The reverse bias breakdown voltage to the base may be an order of magnitude lower in this region.

Saturation: With both junctions forward-biased, a BJT is in saturation mode and facilitates current conduction from the emitter to the collector. This mode corresponds to a logical "on", or a closed switch.

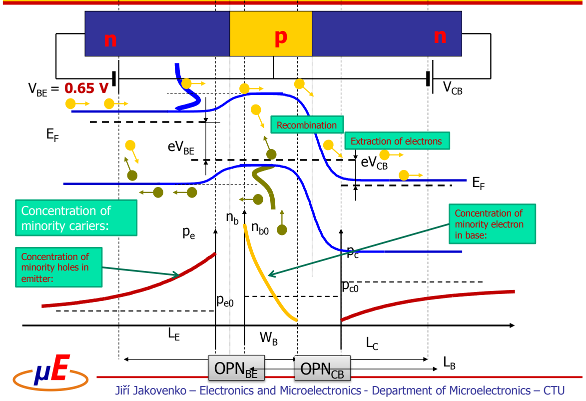
Two diodes in series



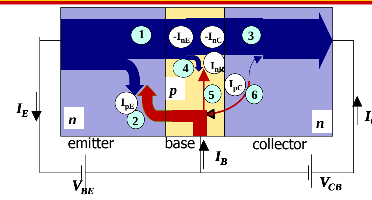
Cutoff region $W_B < L_n$



BJT $W_B<L_n$



Currents in the BJT (forward active mode)



Emiter: $I_E=I_{nE}+I_{pE}$ (1) (2)

$\gamma_E = \dfrac{I_{nE}}{I_{nE}+I_{pE}} = \dfrac{1}{1+I_{pE}/I_{nE}}$ Emitter injection efficiency

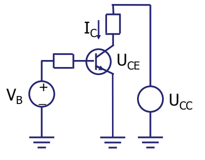
Base: $I_{nE}=I_{nC}+I_{nR}$ (1) (3) (4)

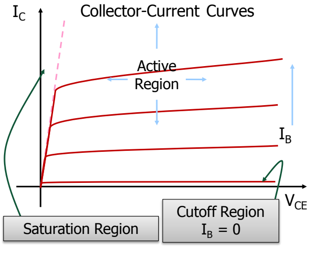
$\alpha_T = I_{nC}/I_{nE}$ -Base transport factor. $I_{nR} = I_{pR}$ (4) (5)

Colector: $I_{pc}+I_{nc}$ (6)

$I_E=I_{nE}+I_{pE}$
$I_C=I_{nC}+I_{pC}$
$I_B=I_{pE}-I_{pC}+I_{pR}$

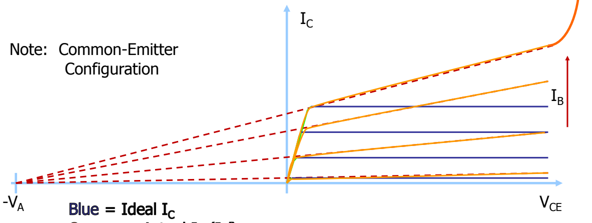
Output characteristics





The Early Effect (Early Voltage)

Note: Common-Emitter Configuration



Blue = Ideal I_C
Orange = Actual I_C (I_C')

$I_C' = I_C\left(\dfrac{V_{CE}+1}{V_A}\right)$

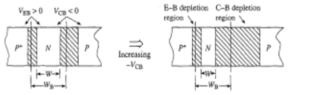
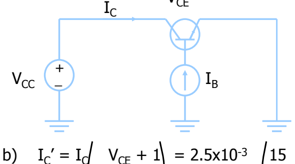


Figure 11.6 Base width modulation. Decrease in W resulting from an increase in the reverse bias applied across the C–B junction.

Early Effect Example

Given: The common-emitter circuit below with I_B = 25μA, V_{CC} = 15V, β = 100 and V_A = 80.
Find: a) The ideal collector current
b) The actual collector current

Circuit Diagram

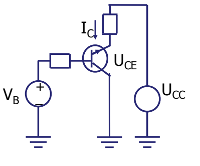


$\beta = 100 = I_C/I_B$
a)
$I_C = 100 * I_B = 100 * (25\times10^{-6}$ A)
I_C = 2.5 mA

b) $I_C' = I_C\left(\dfrac{V_{CE}+1}{V_A}\right) = 2.5\times10^{-3}\left(\dfrac{15\ +\ 1}{80}\right) = 2.96$ mA

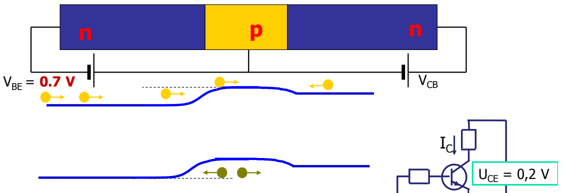
I_C' = 2.96 mA

Reverse-active mode

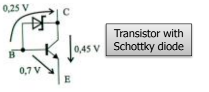


- Emitter and collector regions switch roles
- Since most BJTs are designed to maximize current gain in forward-active mode, the β*f* in inverted mode is several times smaller.
- This transistor mode is seldom used., example: NAND in TTL logic

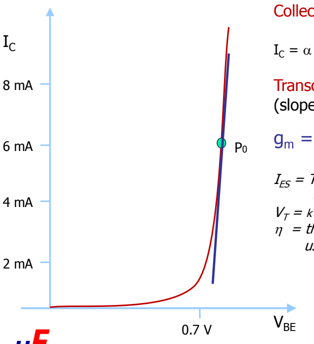
Saturation mode



- If base current is so large that electron injection causes flooding of BC junction, its polarization will change in a forward direction
- Transistor shows very little resistance
- Transistor is used as a switch
- Disadvantage - need to divert off a great charge from the base



Input characteristic



Collector Current:

$I_C = \alpha\, I_{ES}\, e^{V_{BE}/\eta V_T}$

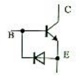
Transconductance:
(slope of the curve)

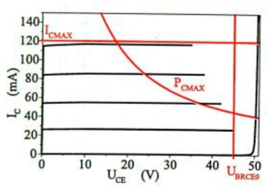
$g_m = \Delta I_C / \Delta V_{BE}$

I_{ES} = The reverse saturation current of the B-E Junction.
V_T = kT/q = 26 mV (@ T=300 K)
η = the emission coefficient and is usually ~1

Boundary parameters

- Max. voltage $\mathbf{V_{CE}}$
- Max. voltage $\mathbf{V_{BE}}$
- Max. current $\mathbf{I_C}$
- Max. power dissipation $\mathbf{P_{CMAX} = V_{CE} . I_C}$
- Max. input current $\mathbf{I_B}$

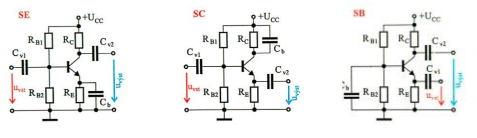




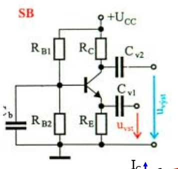
Basic BJT ciruits

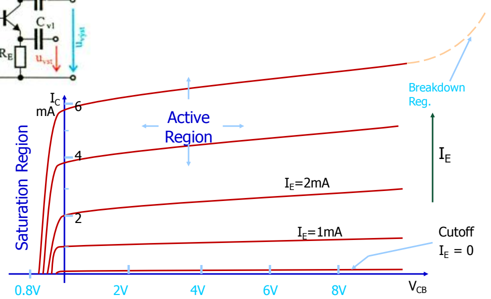
Biasing the transistor refers to applying voltages to the transistor to achieve certain operating conditions:

1. Common-Base Configuration (CB) : input = V_{EB} & I_E
   output = V_{CB} & I_C
2. Common-Emitter Configuration (CE): input = V_{BE} & I_B
   output= V_{CE} & I_C
3. Common-Collector Configuration (CC): input = V_{BC} & I_B
   (Also known as Emitter follower) output = V_{EC} & I_E



Common-Base (CB) Characteristics





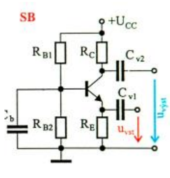
Common-Base (CB) Characteristics

- *α = Common-base current gain*
  - *(0.9-0.999; typical 0.99)*

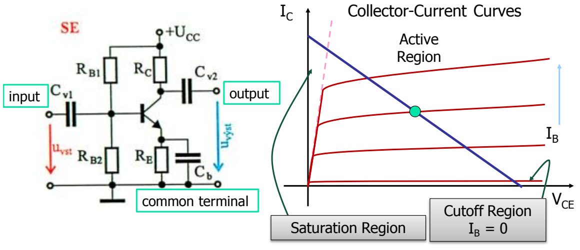
$$\alpha = \frac{i_C}{i_E}$$

$$i_C = I_S\, e^{U_{BE}/U_T}$$

$$i_E = \frac{I_S}{\alpha}\, e^{U_{BE}/U_T}$$



Common-Emitter Configuration (CE)



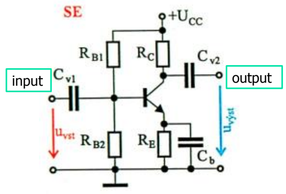
Common-Emitter Configuration (CE)

- β = *Common-emitter current gain (10-1000; typical 50-200)*

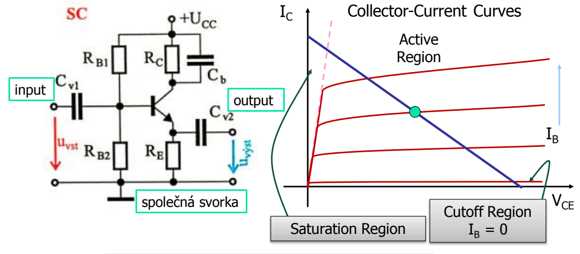
$$\beta = \frac{i_C}{i_B}$$

$$i_C = I_S \, e^{U_{BE}/U_T}$$

$$i_B = \frac{I_S}{\beta} \, e^{U_{BE}/U_T}$$



Common-Collector Configuration



The Common-Collector biasing circuit is basically equivalent to the common-emitter biased circuit except instead of looking at I_C as a function of V_{CE} and I_B we are looking at I_E.
Also, since $\alpha \sim 1$, and $\alpha = I_C/I_E$ that means $I_C \sim I_E$

Relation between α and β

- α = *Common-base current gain*
  - *(0.9-0.999; typical 0.99)*
- β = *Common-emitter current gain*
  - *(10-1000; typical 50-200)*

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

Example:
α = 0.98, β = 49
α = 0.99, β = 99
α = 0.995, β =199