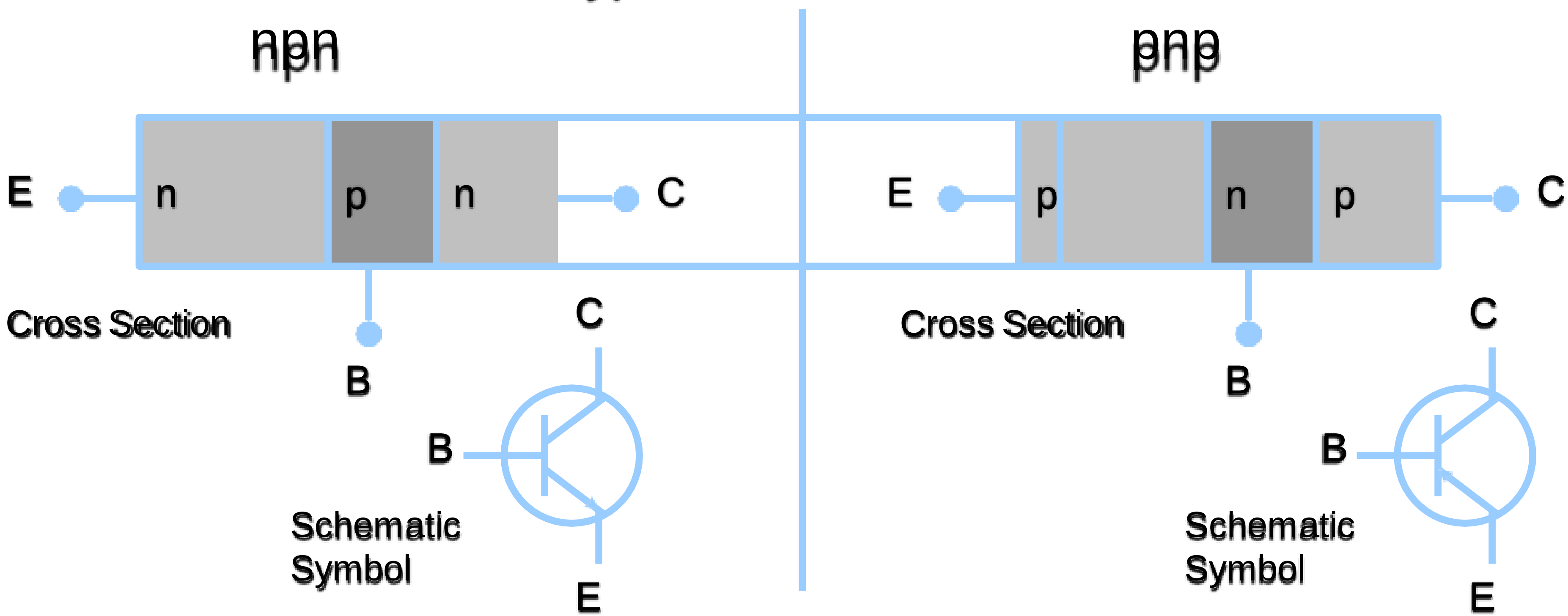
UNIT - V
BIPOLAR JUNCTION TRANSISTOR AND APPLICATIONS

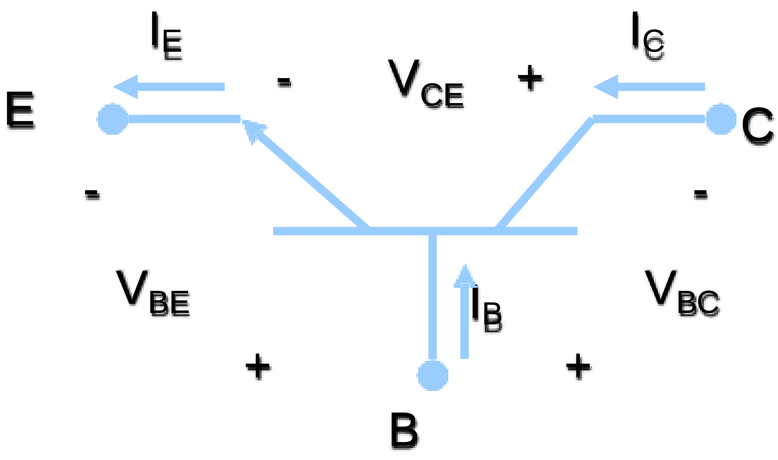
The BJT – Bipolar Junction Transistor

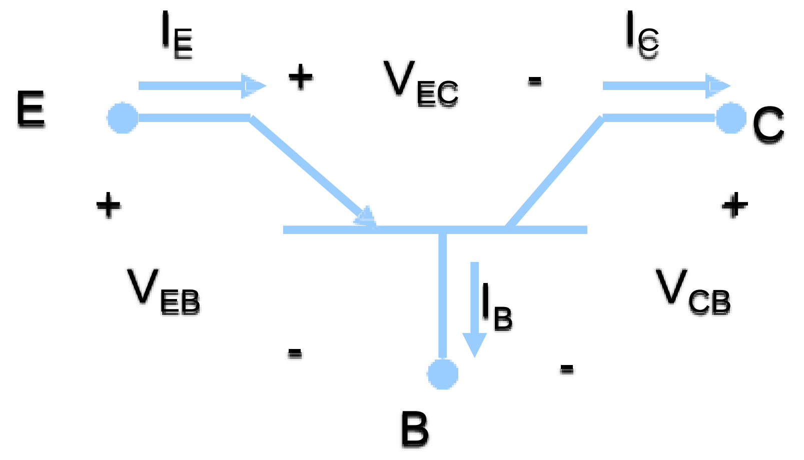
The Two Types of BJT Transistors:



- Collector doping is usually ~ 10^{6}
- Base doping is slightly higher ~ 10^{7} – 10^{8}
- Emitter doping is much higher ~ 10^{15}

BJT Relationships - Equations





npn

$$I_E = I_B + I_C$$

$$V_{CE} = -V_{BC} + V_{BE}$$

pnp

$$I_E = I_B + I_C$$

$$V_{EC} = V_{EB} - V_{CB}$$

Note: The equations seen above are for the transistor, not the circuit.

DC β and DC α

β = Common-emitter current gain

α = Common-base current gain

$$\beta = \frac{I_C}{I_B} \qquad \alpha = \frac{I_C}{I_E}$$

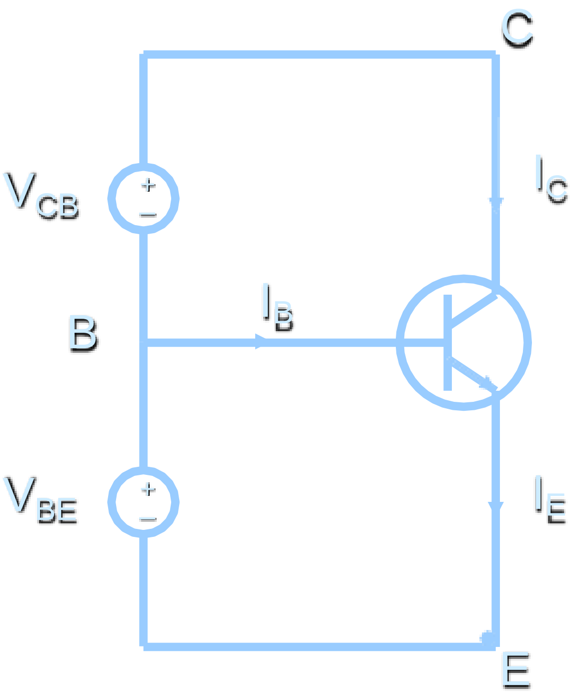
The relationships between the two parameters are:

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

Note: α and β are sometimes referred to as α_{dc} and β_{dc} because the relationships being dealt with in the BJT are DC.

BJT Example

Using Common-Base NPN Circuit Configuration



Given: $I_B = 50\ \mu A$, $I_C = 1\ mA$
Find: I_E , β , and α

Solution:

$I_E = I_B + I_C = 0.05\ mA + 1\ mA = 1.05\ mA$

$\beta = I_C / I_B = 1\ mA / 0.05\ mA = 20$

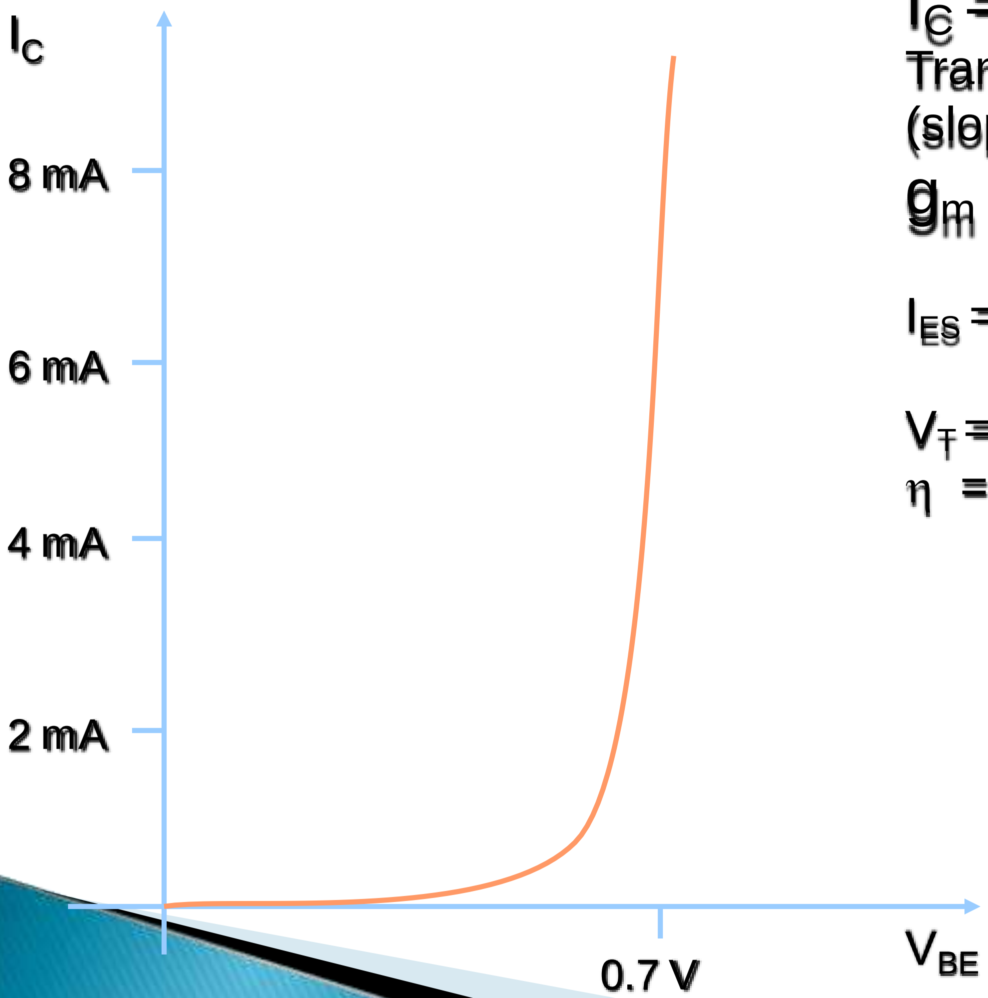
$\alpha = I_C / I_E = 1\ mA / 1.05\ mA = 0.95238$

α could also be calculated using the value of β with the formula from the previous slide.

$$\alpha = \frac{\beta}{\beta + 1} = \frac{20}{21} = 0.95238$$

BJT Transconductance Curve

Typical NPN Transistor[1]



Collector Current:

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

Transconductance:
(slope of the curve)

$g_m \equiv \partial I_C / \partial V_{BE}$ V_{BE}

I_{ES} = The reverse saturation current of the B-E Junction.

$V_T = kT/q$ = 26 mV (@T=300K)

η = the emission coefficient and is usually ~1

Modes of Operation

Active:

- Most important mode of operation
- Central to amplifier operation
- The region where current curves are practically flat

Saturation:

- Barrier potential of the junctions cancel each other out causing a virtual short

Cutoff:

- Current reduced to zero
- Ideal transistor behaves like an open switch

* Note: There is also a mode of operation called inverse active, but it is rarely used.

Three Types of BJT Biasing

Biasing the transistor refers to applying voltage to get the transistor to achieve certain operating conditions.

Common-Base Biasing (CB) : input = V_{EB} & I_E
output = V_{CB} & I_C

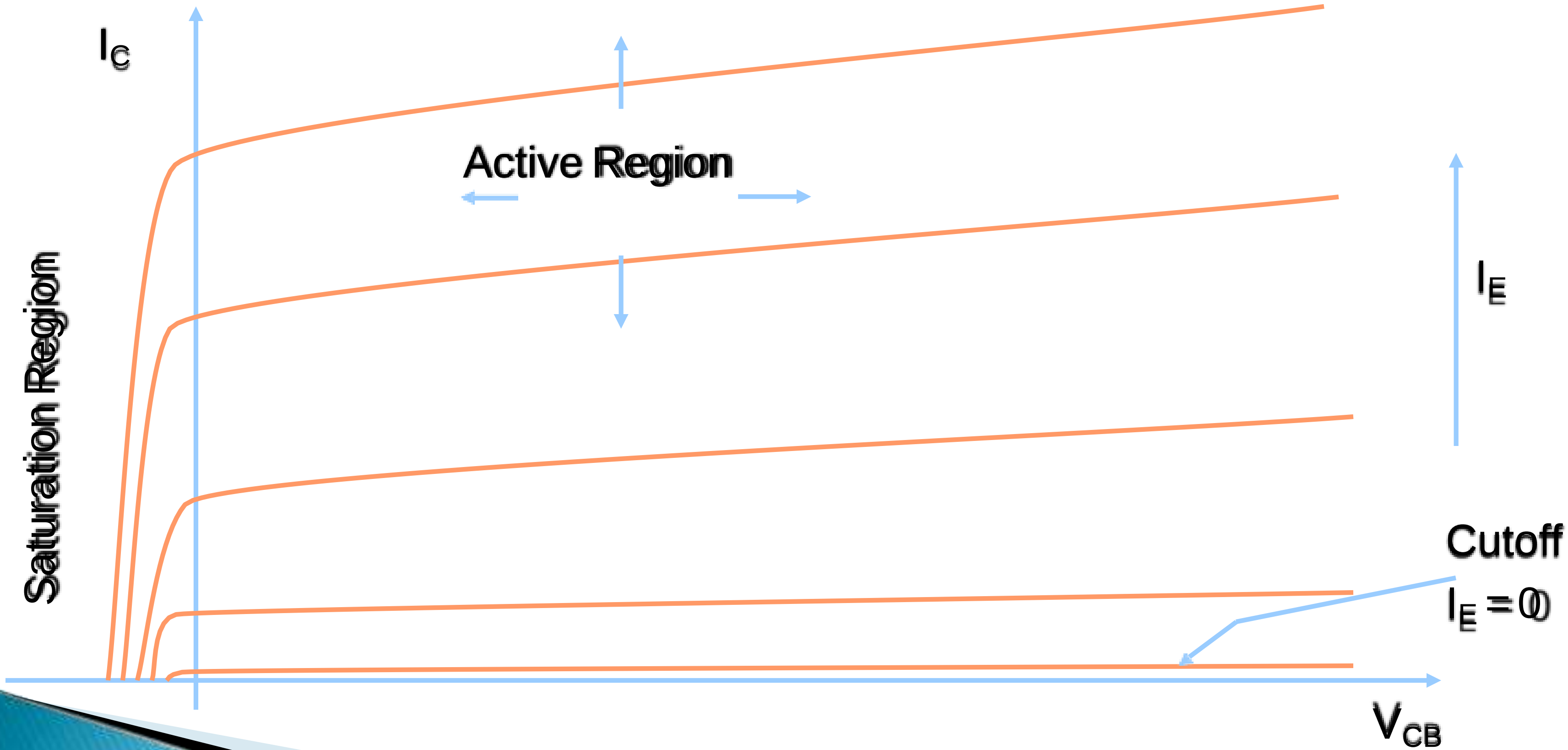
Common-Emitter Biasing (CE): input = V_{BE} & I_B
output = V_{CE} & I_C

Common-Collector Biasing (CC): input = V_{BC} & I_B
output = V_{EC} & I_E

Common-Base

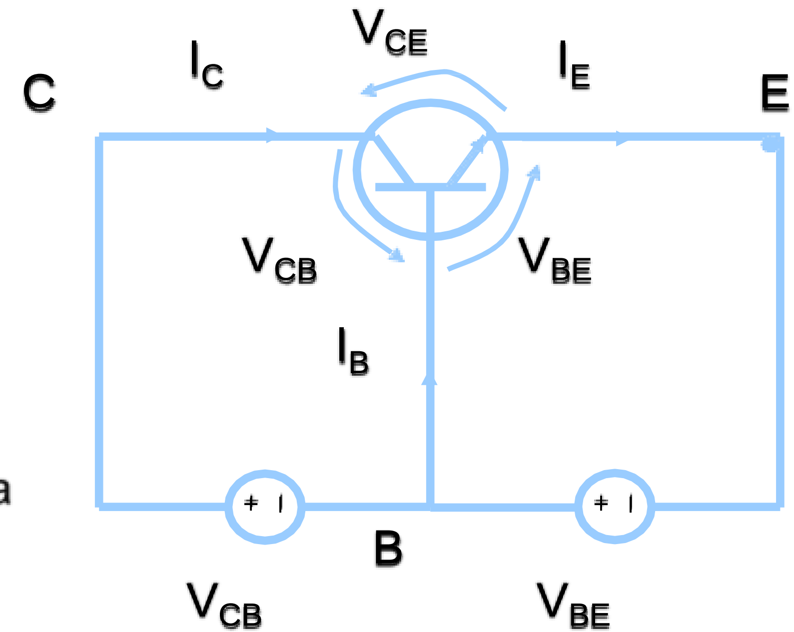
Although the Common-Base configuration is not the most common biasing type, it is often helpful in the understanding of how the BJT works.

Emitter-Current Curves



Common-Base

Circuit Diagram: NPN Transistor

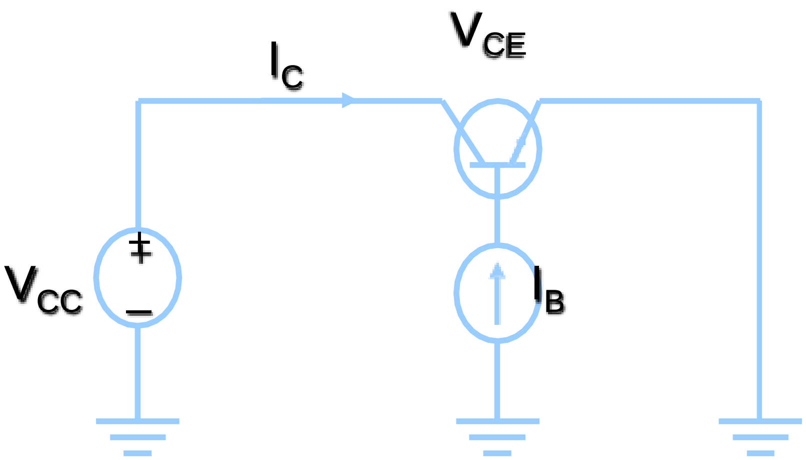


The Table Below lists assumptions that can be made for the attributes of the common-base biased circuit in the different regions of operation. Given for a Silicon NPN transistor.

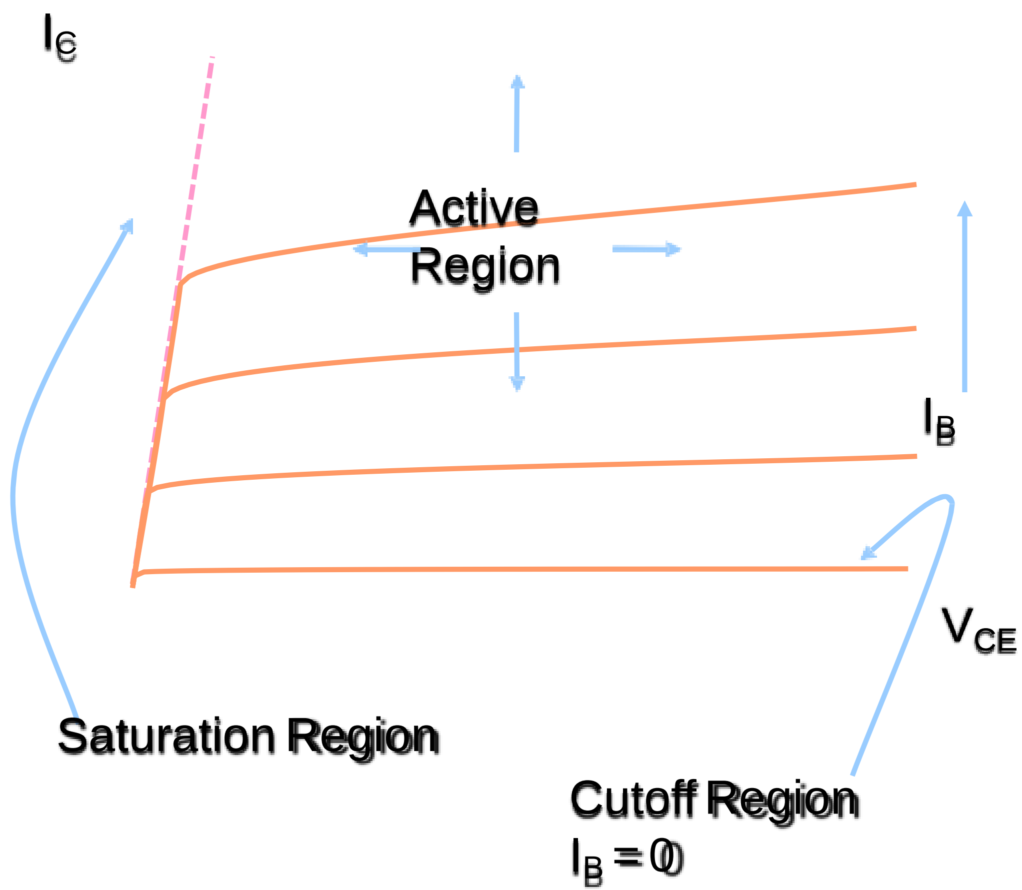
Region of Operation	I_C	V_{CE}	V_{BE}	V_{CB}	C-B Bias	E-B Bias
Active	βI_B	$=V_{BE}+V_{CE}$	~0.7V	○ 0V	Rev.	Fwd.
Saturation	Max	~0V	~0.7V	$-0.7V<V_{CE}<0$	Fwd.	Fwd.
Cutoff	~0	$=V_{BE}+V_{CE}$	☯ 0V	○ 0V	Rev.	None /Rev.

Common-Emitter

Circuit Diagram



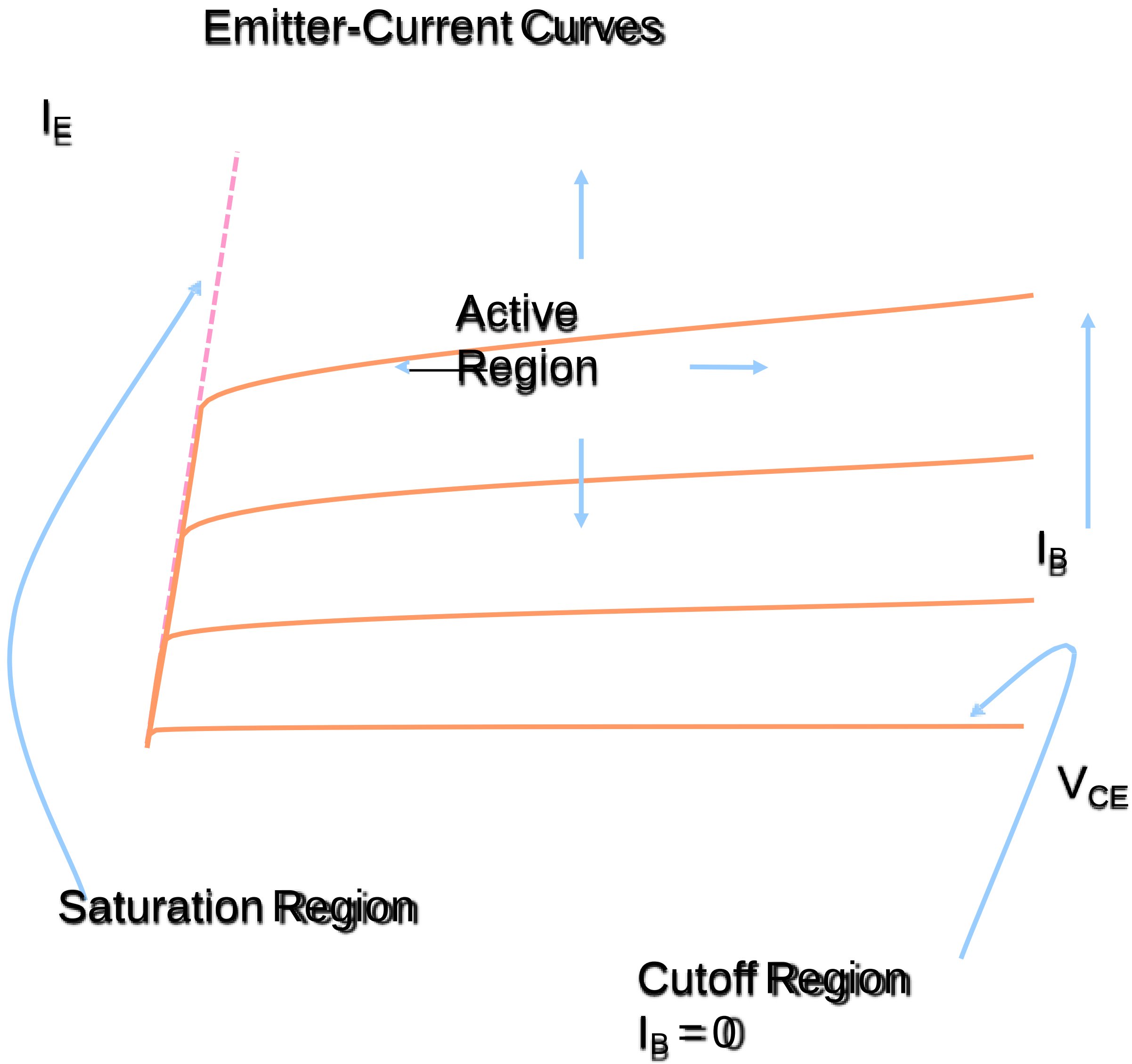
Collector-Current Curves



Region of Operation	Description
Active	Small base current controls a large collector current
Saturation	$V_{CE(sat)} \sim 0.2V$, V_{CE} increases with I_C
Cutoff	Achieved by reducing I_B to 0, Ideally, I_C will also equal 0.

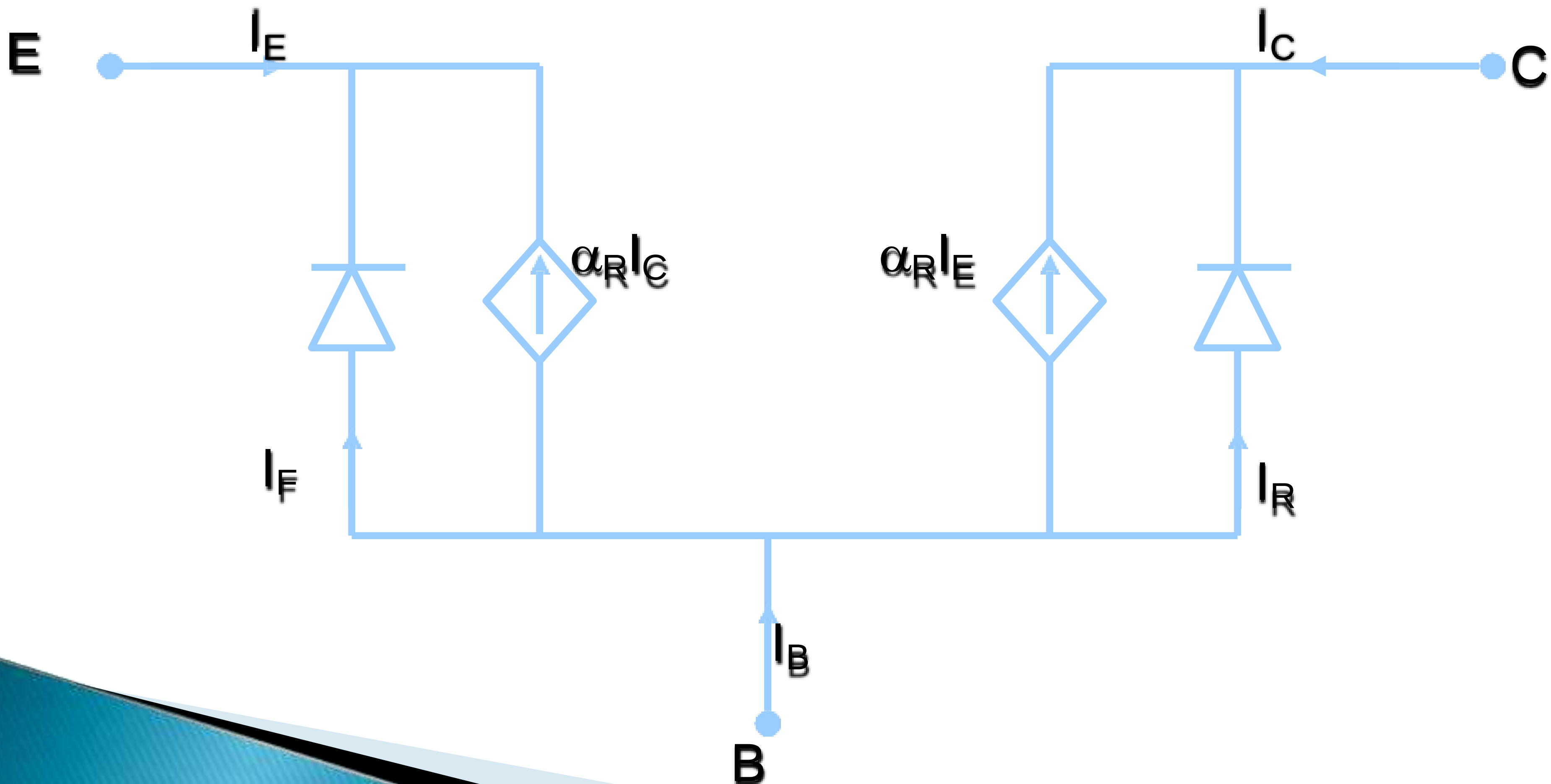
Common-Collector

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 $\alpha \approx 1$, and $\alpha = I_C/I_E$ that means $I_C \approx I_E$



Eber-Moll BJT Model

The Eber-Moll Model for BJTs is fairly complex, but it is valid in all regions of BJT operation. The circuit diagram below shows all the components of the Eber-Moll Model:



Eber-Moll BJT Model

α_R = Common-base current gain (in forward active mode)
α_F = Common-base current gain (in inverse active mode)
I_{ES} = Reverse-Saturation Current of B-E Junction
I_{CS} = Reverse-Saturation Current of B-C Junction

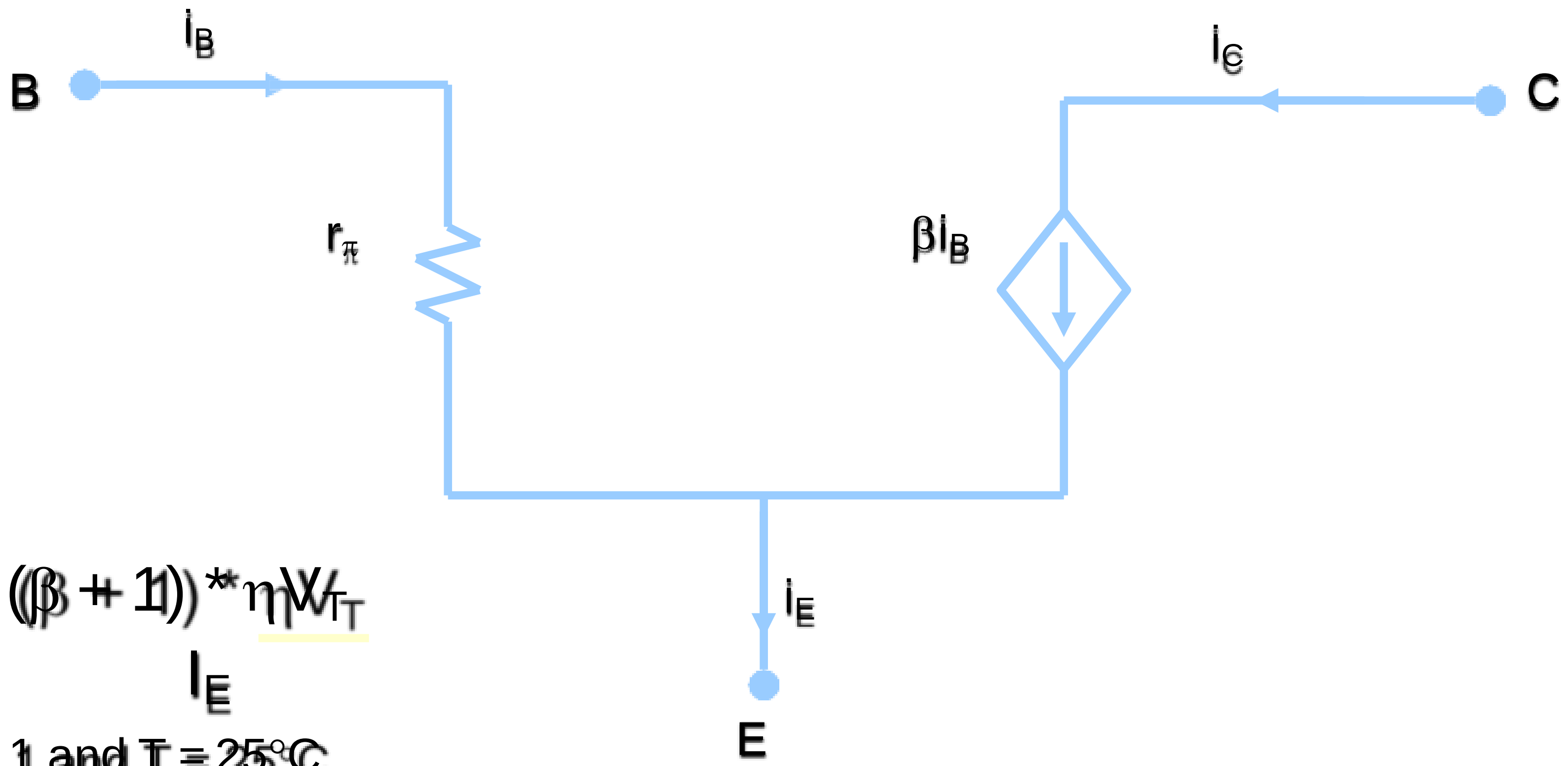
$I_C = \alpha_F I_F - I_R$ $\quad$ $I_B = I_E - I_C$
$I_E = I_F - \alpha_R I_R$

$I_F = I_{ES}\,[\exp(qV_{BE}/kT) - 1]$ $\quad$ $I_R = I_C\,[\exp(qV_{BC}/kT) - 1]$

- If I_{ES} & I_{CS} are not given, they can be determined using various BJT parameters.

Small Signal BJT Equivalent Circuit

The small-signal model can be used when the BJT is in the active region. The small-signal active-region model for a CB circuit is shown below:



$$r_\pi = (\beta + 1) * \frac{\eta V_T}{I_E}$$

@ $\eta = 1$ and $T = 25°C$

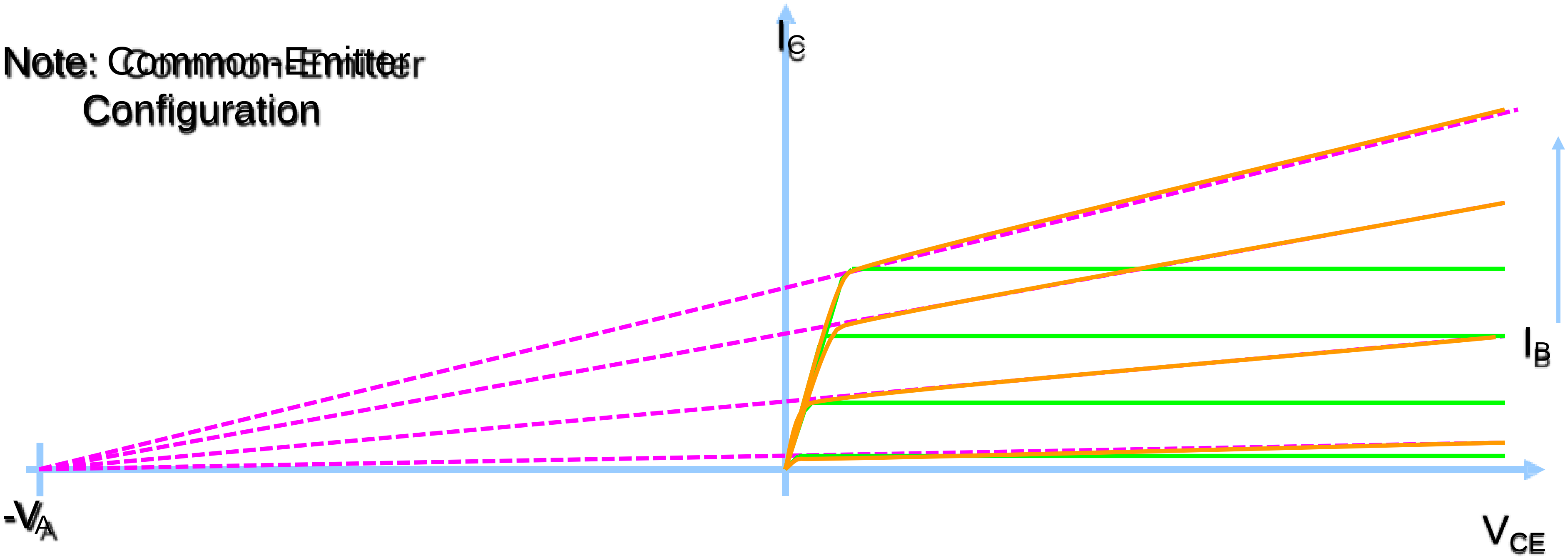
$$r_\pi = (\beta + 1) * \frac{0.026}{I_E}$$

Recall:

$\beta = I_C / I_B$

The Early Effect (Early Voltage)

Note: Common-Emitter Configuration



Green = Ideal I_C

Orange = Actual I_C (I_C')

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

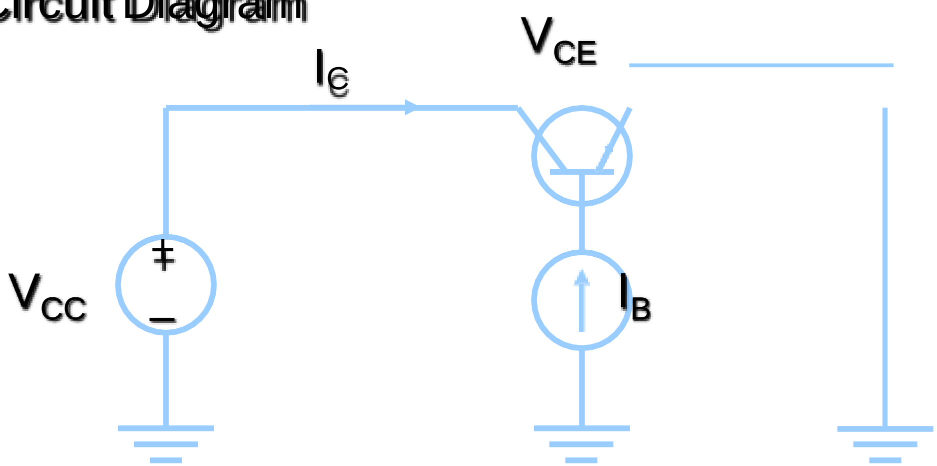
Early Effect Example

Given: The common-emitter circuit below with $I_B = 25\mu A$, $V_{CC} = 15V$, $\beta = 100$ and $V_A = 80$.

Find: a) The ideal collector current

b) The actual collector current

Circuit Diagram



$\beta = 100 = I_C/I_B$

a)

$I_C = 100 * I_B = 100 * (25x10^{-6} A)$

$I_C = 2.5 mA$

b) $I_C' = I_C \left(\frac{V_{CE}}{V_A} + 1\right) = 2.5x10^{-3} \left(\frac{15}{80} + 1\right) = 2.96 mA$

$I_C' = 2.96 mA$