كلية مدينة العلم الجامعة
قسم هندسة الحاسوب

محاضرات المرحلة الاولى لمادة الهندسة الالكترونية

اعداد

د.سعيد سلمان كمون

Equivalent Circuit Models

المحاضرة الثانية

References

Text Books :

1-ELECTRONIC DEVICES AND CIRCUIT THEORY

Eleventh Edition By

Robert L. Boylestad and Louis Nashelsky

2-ELECTRONIC DEVICES

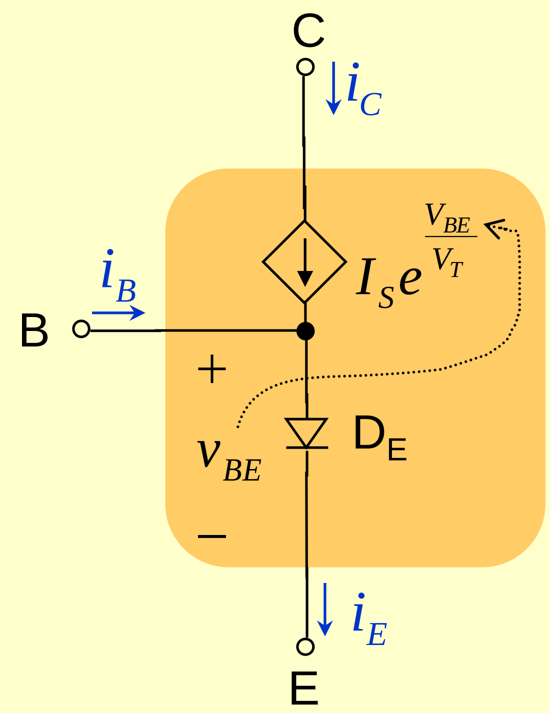
Ninth Edition By

Thomas L. Floyd

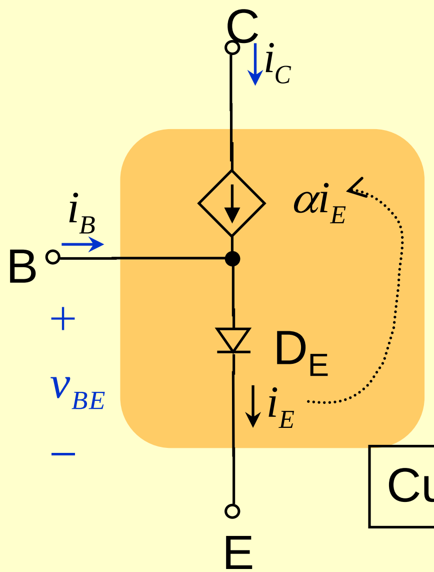
First Order Equivalent Circuit Models

Voltage Controlled Current Source Model

- The externally controlled signals for this model are the three currents shown ***outside*** the gray box.
- The voltage $V_{BE,}$ exists internally as a result of the currents and can be externally measured. We can force a current and measure a voltage.
- The diode in the model is designated as D_E since the current flowing through the diode is the same as the emitter current. The collector current is dependent on the base-emitter voltage V_{BE}.
- The model is a non-linear voltage controlled current source



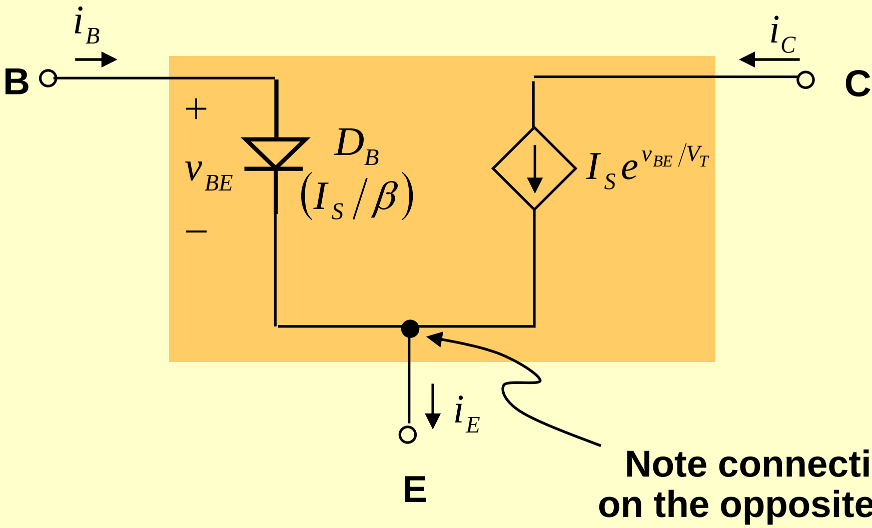
- The externally controlled signals for this model are two currents and the voltage V_{BE} shown ***outside*** the gray box.
- The current i_E exists internally as a result of the voltage V_{BE} and can be externally measured.
- The collector current is dependent on the emitter current i_E.

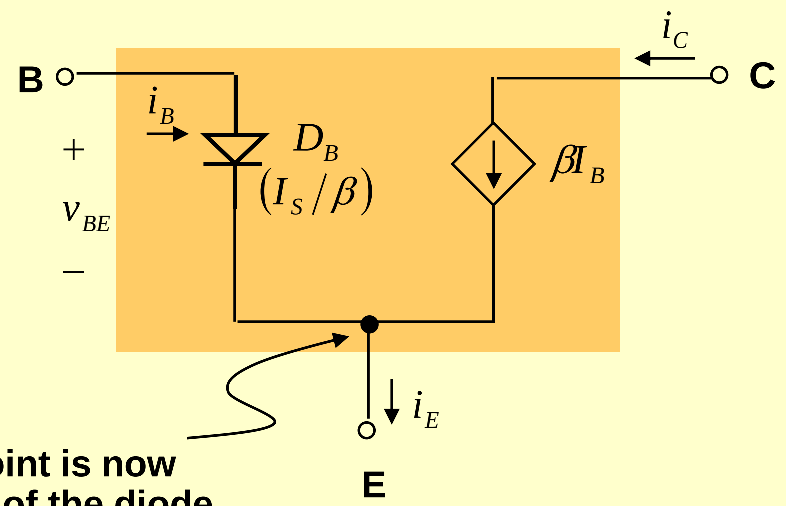


Current Controlled Current Source

Equivalent Circuit Models, cont'd

- **In this version of the model the diode conducts the BASE current which is beta times smaller.**
- **In one version the dependent current source is voltage controlled (v_{BE}), in the other version the dependent current source is current controlled (β).**



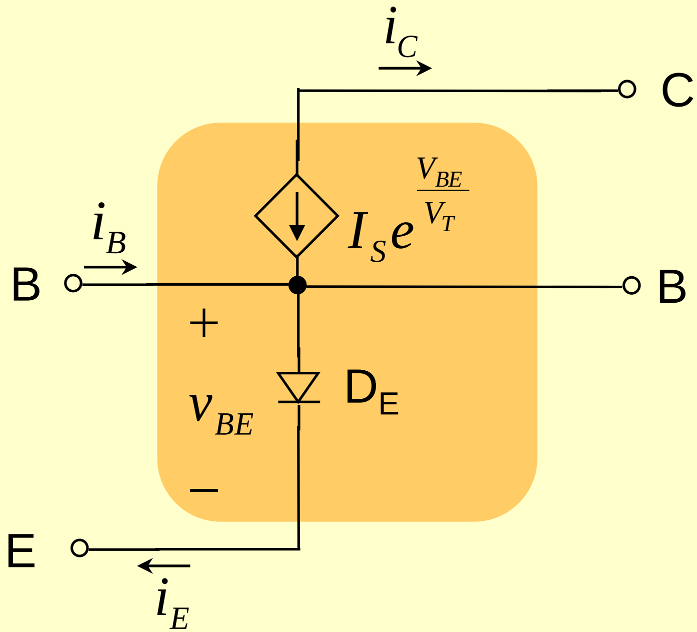


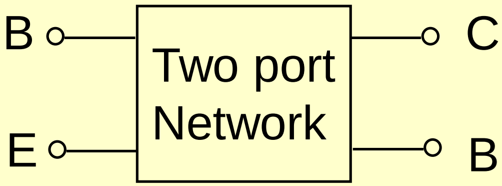
Note connection point is now on the opposite side of the diode

Voltage Controlled Current Source Model

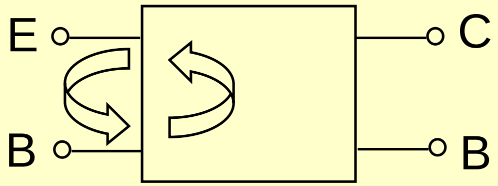
Current Controlled Current Source

Two Port Model of the Common-Base Configuration

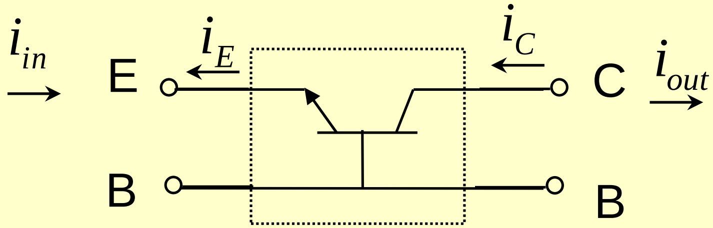




The base lead is common to both ports



If we switch the leads within the network
the common base aspect is more apparent



Two-Port representation of a BJT Transistor symbol in a common-base configuration

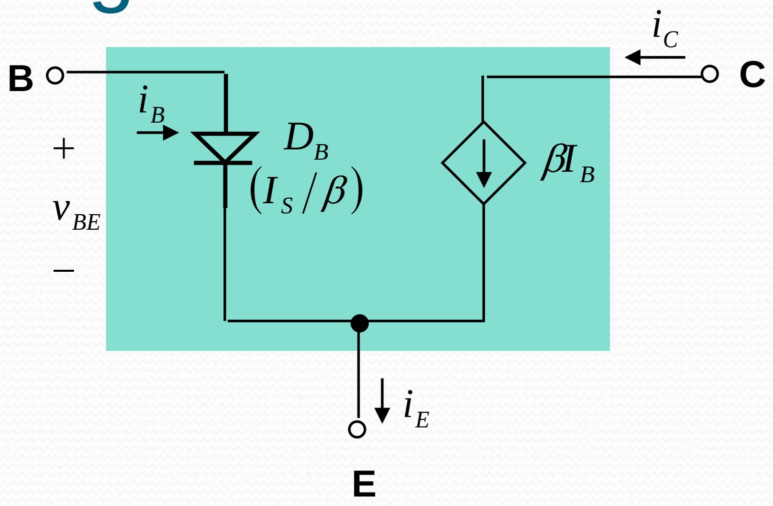
$$i_{in} = -i_E$$

$$i_{out} = -i_c$$

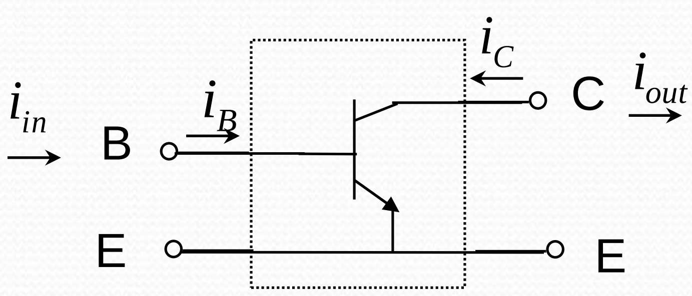
$$A_i = \frac{i_{out}}{i_{in}} = \frac{i_C}{i_E} = \alpha$$

The common-base current gain is α

Two Port Model of the Common-Emitter Configuration



The emitter lead is common to both ports



Two-Port representation of a BJT Transistor symbol in a common-emitter configuration

i_C is out of phase with i_B

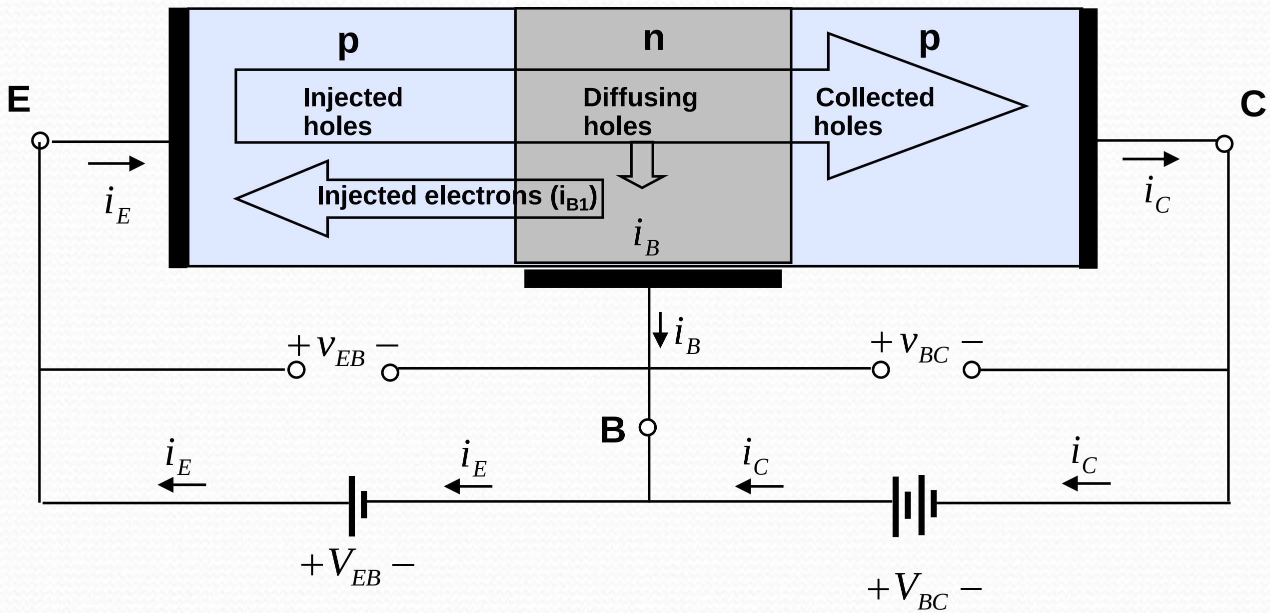
$$i_{in} = -i_B$$

$$i_{out} = -i_C$$

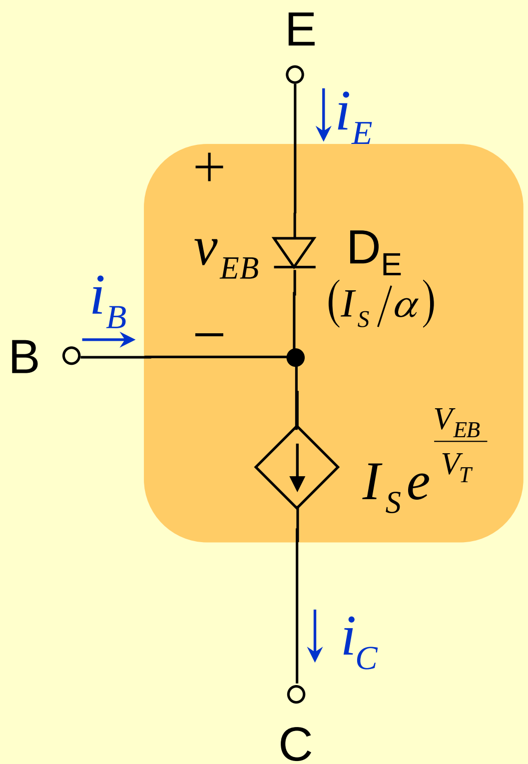
$$A_i = \frac{i_{out}}{i_{in}} = \frac{-i_C}{i_B} = -\beta$$

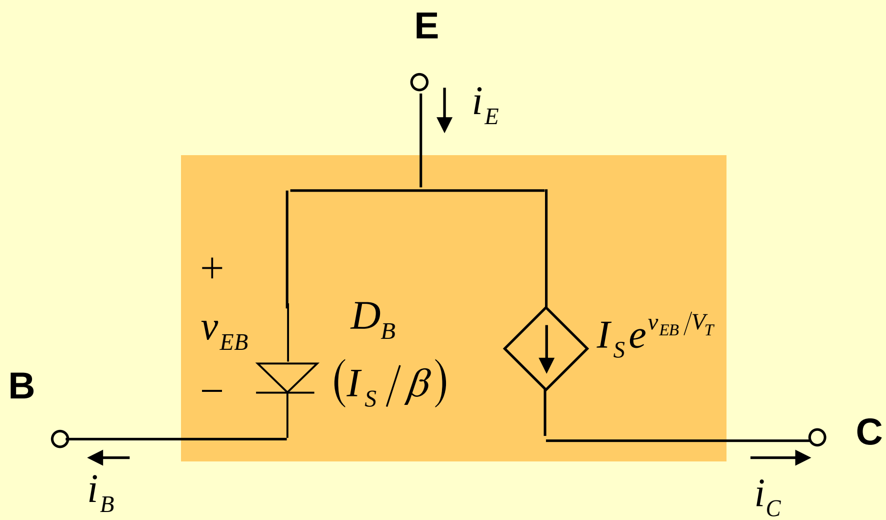
The common-emitter current gain is **α**

Operation of the pnp Transistor in the Active Mode

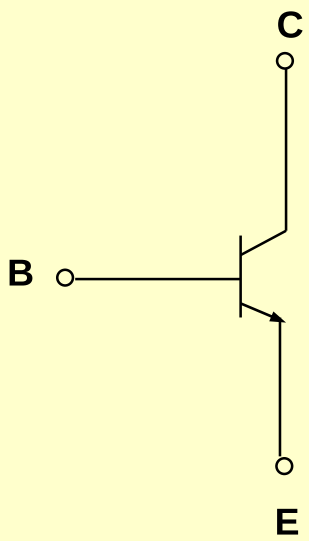


Equivalent pnp Circuit Models

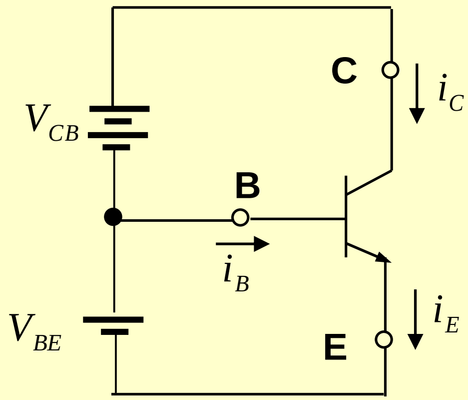




Circuit Symbols and Conventions - npn

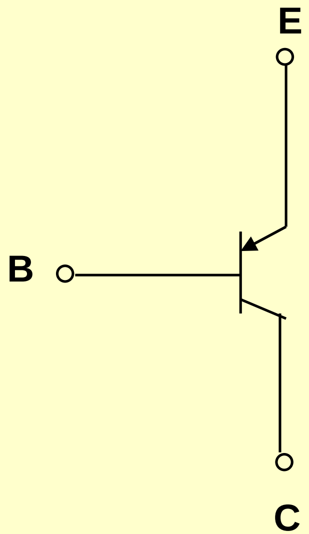


npn BJT

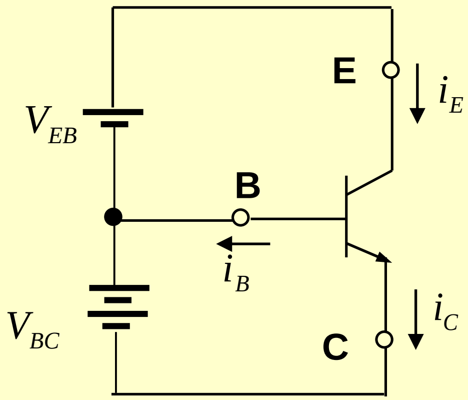


Voltage polarities and current flow in a transistor biased in the active mode.

Circuit Symbols and Conventions - pnp



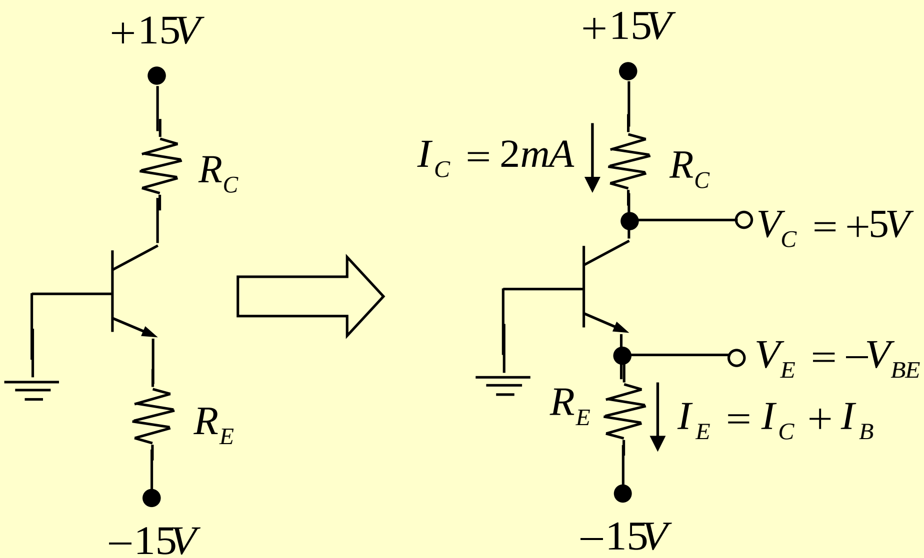
pnp BJT



Voltage polarities and current flow in a transistor biased in the active mode.

Example 4.1

- **The transistor in the circuit below has β = 100 and exhibits a v_{BE} of 0.7V at i_C = 1 mA. Design the circuit so that a current of 2 mA flows through the collector and a voltage of +5V appears at the collector.**



$$R_C = \frac{15V - 5V}{2mA} = \frac{10V}{2mA} = 5k$$

since $V_{BE} = 0.7V$ at $i_C = 1mA$,

$$V_{BE} = 0.7 + V_T \ln\left(\frac{2}{1}\right) = 0.717V$$

and $V_E = -V_{BE} = -0.717V$

for $\beta = 100$, $\alpha = 100/101 = 0.99$

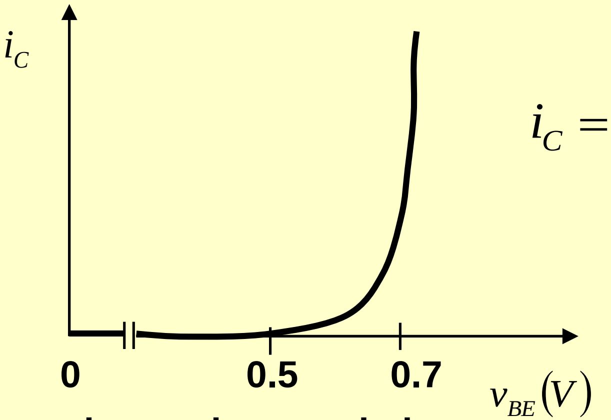
thus $I_E = \dfrac{I_C}{\alpha} = \dfrac{2}{0.99} = 2.02mA$

$$R_E = \frac{V_E - (-15)}{I_E}$$

$$= \frac{-.0717 + 15}{2.02} = 7.07k\Omega$$

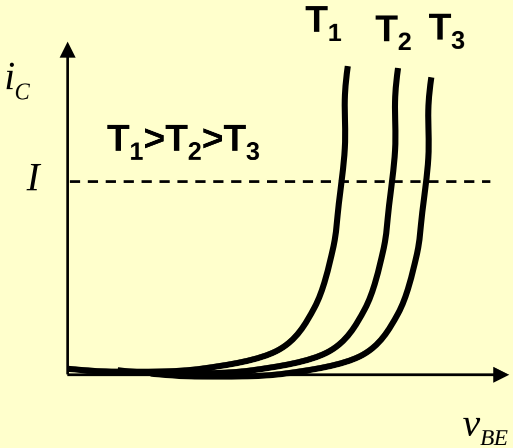
Graphical Representation of Transistor Characteristics

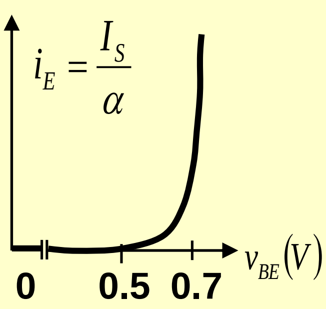
- Similar to diodes, except we talk about the voltage across one junction V_{BE} and the current through the other terminal i_C.
- For most of the conditions we will encounter in working with BJTs the ideality factor, n will be considered to be 1.

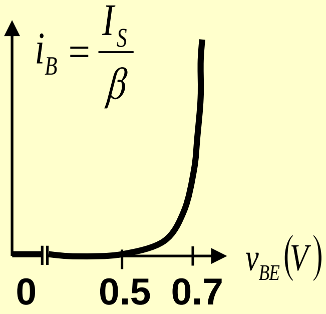


$$i_C = I_S e^{v_{BE}/V_T}$$

i_C-v_{BE} characteristics





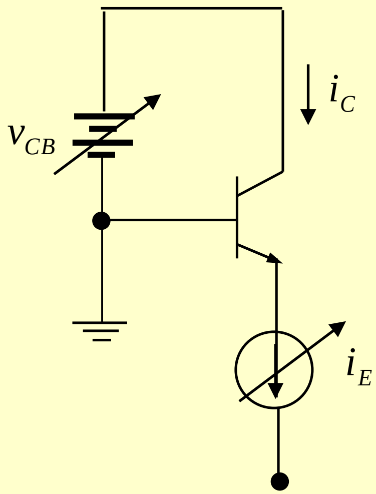


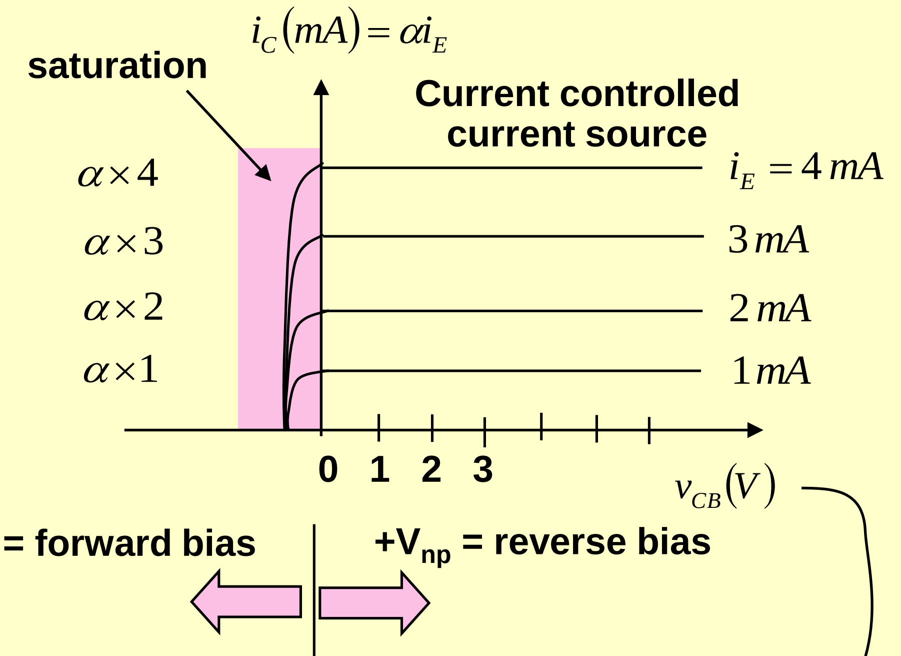
Effect of temperature on i_C-v_{BE} characteristic.
At a constant current, v_{BE} changes by –2mV/°C.

Bipolar Junction Transistors

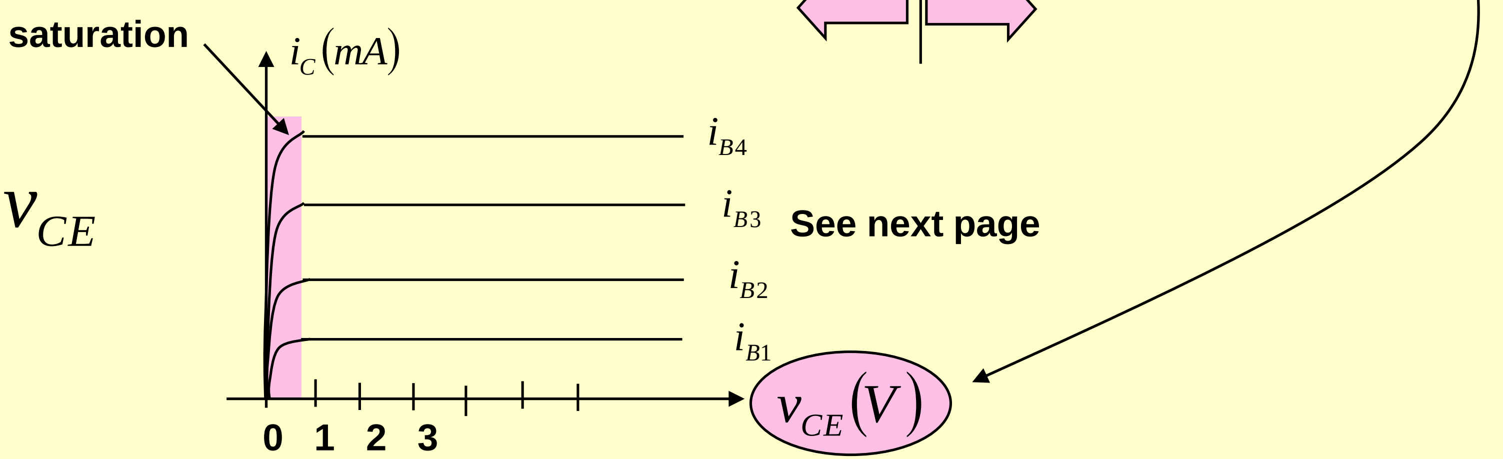
i_C versus v_{CB} Characteristics

- **npn transistor in active mode**





i_C vs v_{CE}



i_C=v_{CE} Characteristics

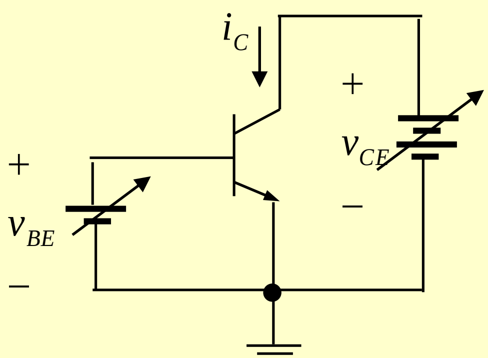
- The Early Voltage (typically 50 -100 Volts), also known as the Base-Width Modulation parameter.

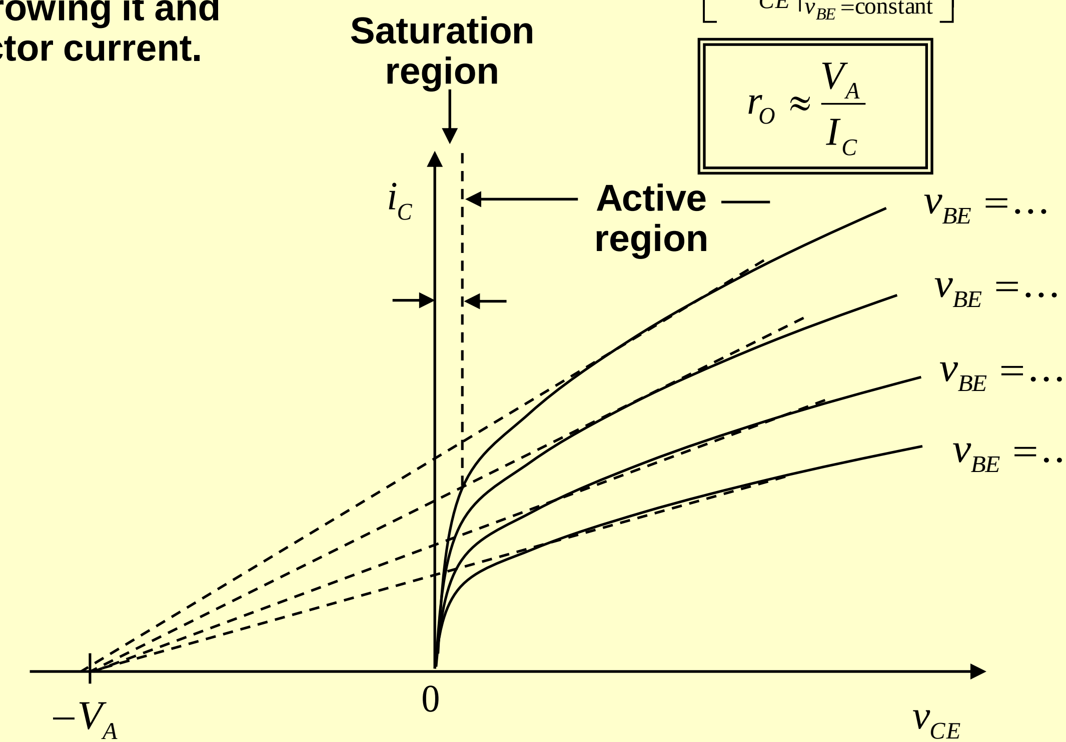
- As the base-collector junction reverse bias is increased the depletion layer expands and consumes some of the base narrowing it and causing an increase in the collector current.

$$r_O = \left[\left. \frac{\partial i_C}{\partial v_{CE}} \right|_{v_{BE}=\text{constant}} \right]^{-1}$$

$$r_O \approx \frac{V_A}{I_C}$$

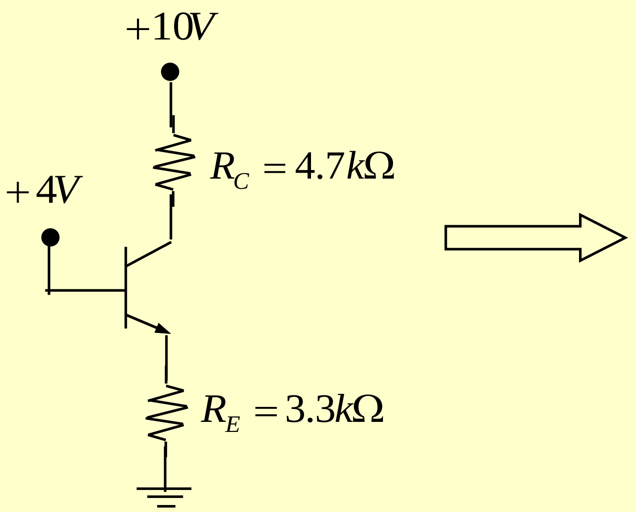
$$i_C = I_S e^{v_{BE}/V_T}\left(1+\frac{v_{CE}}{V_A}\right)$$

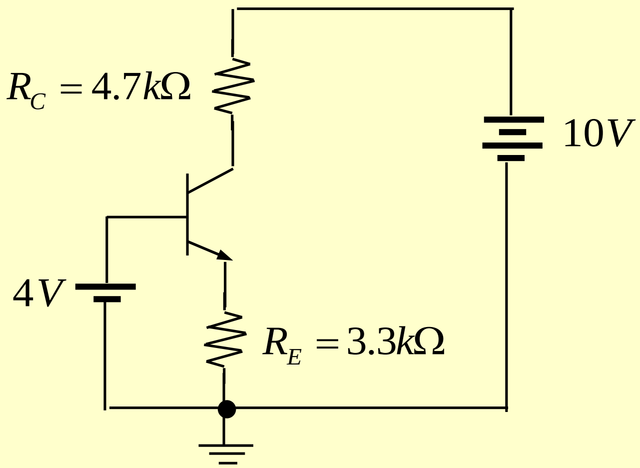




Example 4.2

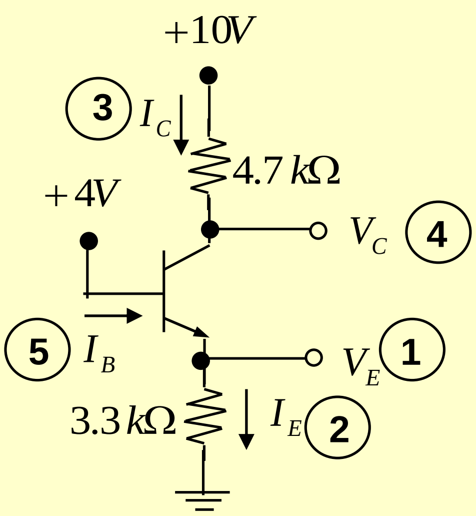
- We wish to analyze this circuit to determine all node voltages and branch currents. We will assume that β is specified to be 100.





Example 4.2, cont'd

- We don't know whether the transistor is in the active mode or not.
- A simple approach would be to assume that the device is in the active mode, and then check our results at the end



(1) $$V_E = 4 - V_{BE} \approx 4 - 0.7 = 3.3\,V$$

(2) $$I_E = \frac{V_E - 0}{R_E} = \frac{3.3}{3.3} = 1\,mA$$

(3) $$I_C = \alpha I_E,\ \alpha = \frac{\beta}{\beta+1} = \frac{100}{101} \approx 0.99$$

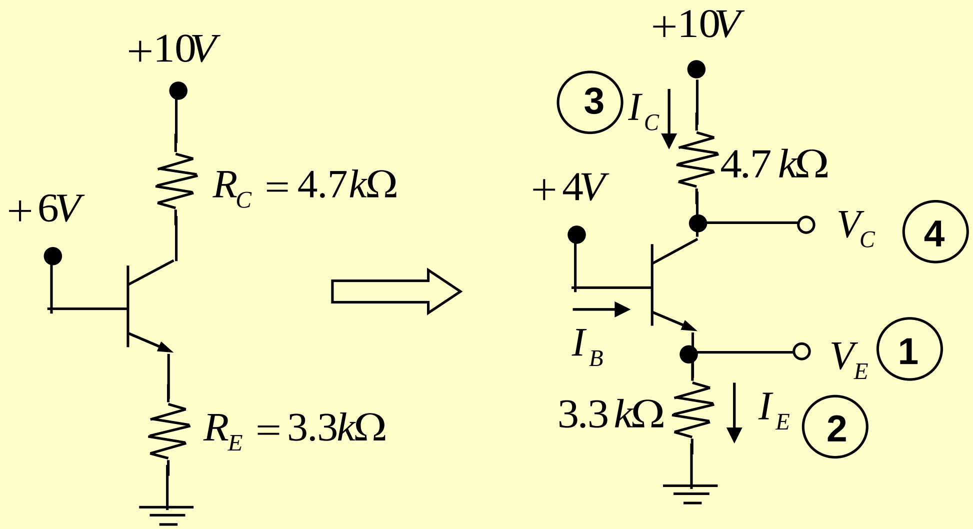
$$I_C = 0.99 \times 1 = 0.99\,mA$$

(4) $$V_C = 10 - I_C R_C = 10 - 0.99 \times 4.7 = +5.3\,V$$

(5) $$I_B = \frac{I_E}{\beta+1} = \frac{1}{101} \approx 0.01\,mA$$

Example 4.3

- **We wish to analyze the circuit shown below to determine the voltages at all nodes and the currents through all branches. Note that this circuit is identical to the previous circuit except that the voltage at the base is now +6 V.**



Assuming active-mode:

$$V_E = 5.6 - V_{BE} \approx 6 - 0.7 = 5.3V$$

$$I_E = \frac{5.3}{3.3} = 1.6\,mA$$

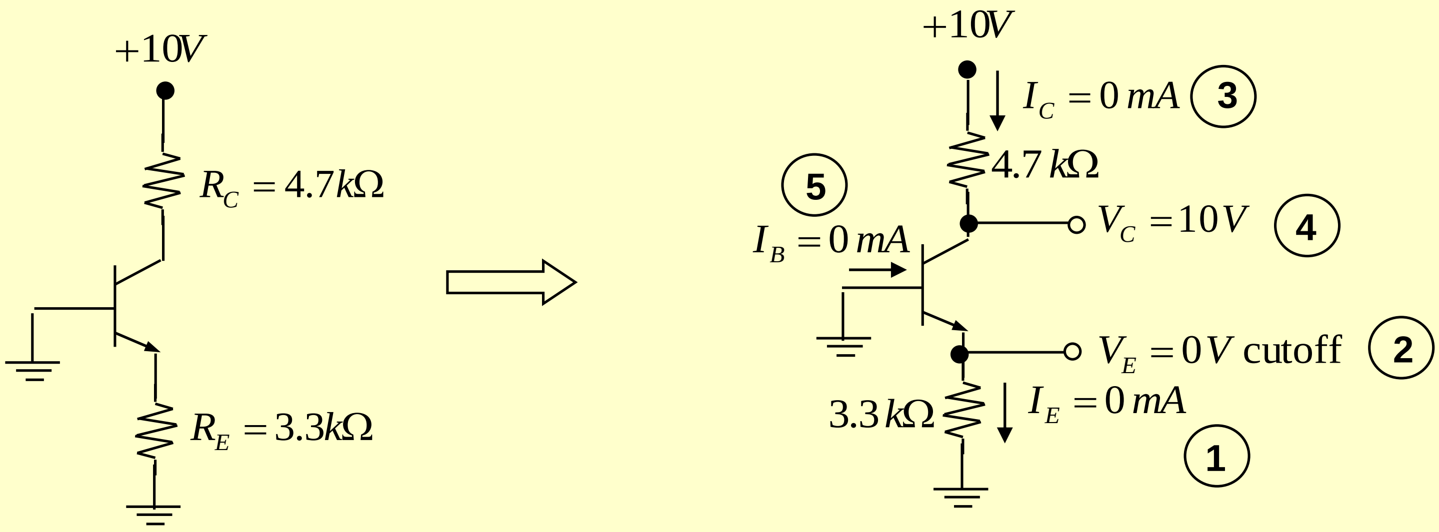
$$I_C = \alpha I_C \approx 1.6\,mA$$

$$V_C = 10 - 4.7 \times I_C \approx 10 - 7.52 = 2.48V$$

Collector voltage > base voltage saturation mode, not active mode

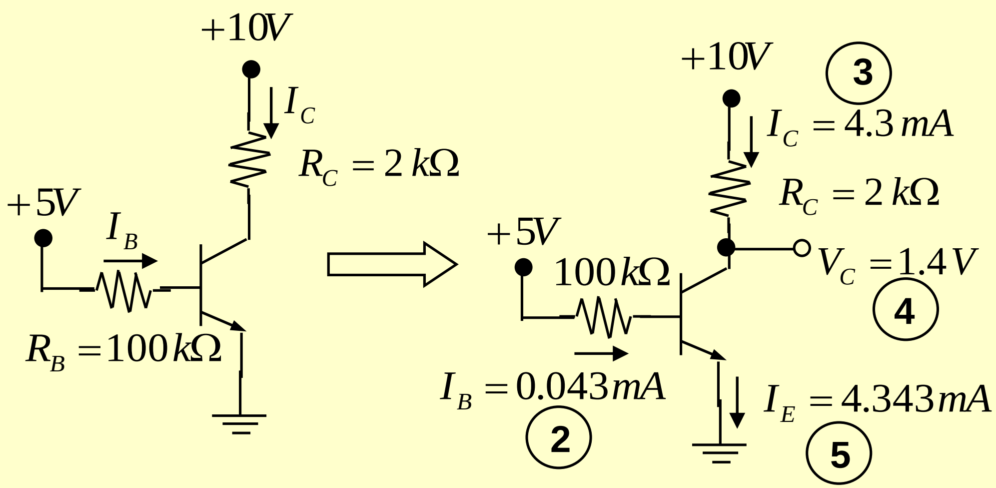
Example 4.4

- We wish to analyze the circuit below to determine the voltages at all nodes and the currents through all branches. This circuit is identical to that considered in the previous two examples except that now the base voltage is zero.



Example 4.6

- **We will analyze the following circuit to determine the voltages at all nodes and currents through all branches. Assume β=100.**



$V_B = V_{BE} \approx 0.7\,V$ (1)

$I_B = \dfrac{5 - V_{BE}}{R_B} \approx \dfrac{5 - 0.7}{100} = 0.043\,mA$ (2)

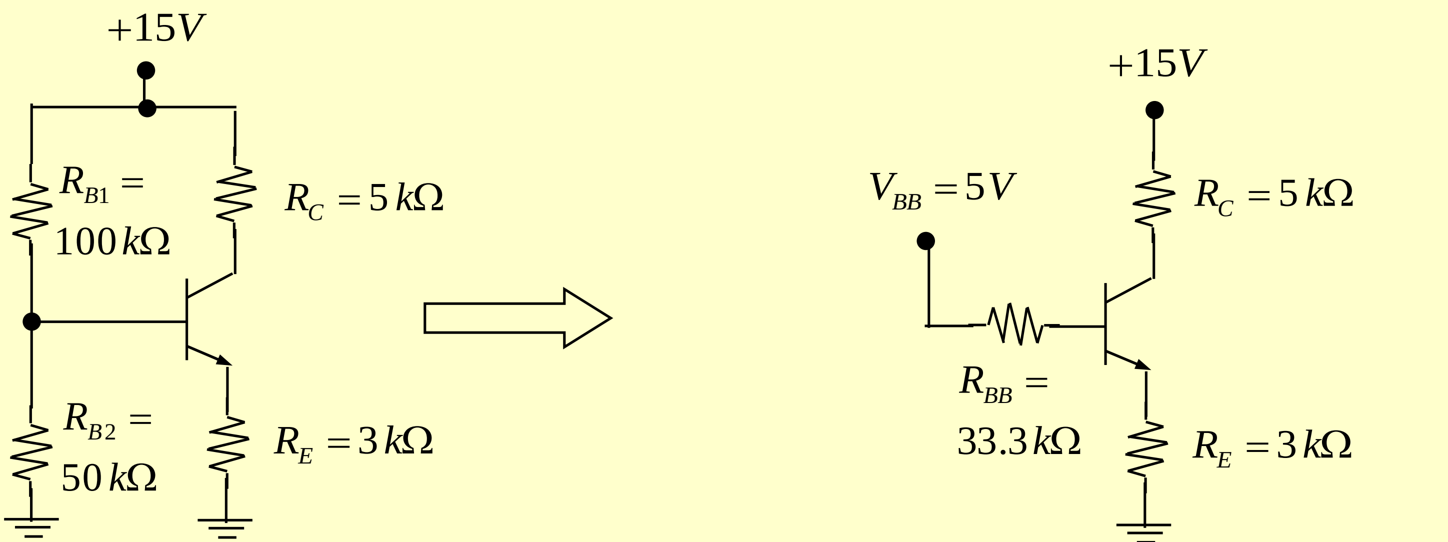
$I_C = \beta I_B = 100 \times 0.043 = 4.3\,mA$ (3)

$V_C = 10 - I_C R_C = 10 - 4.3 \times 2 = 1.4\,V$ (4)

$I_E = (\beta + 1) I_B = 101 \times 0.043 \approx 4.3\,mA$ (5)

Example 4.7

- We want to analyze the circuit shown below to determine the voltages at all nodes and currents through all branches. Assume β=100.



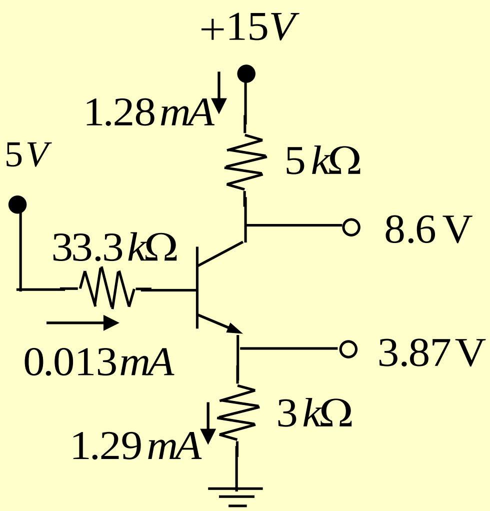
$$V_{BB} = 15\frac{R_{B2}}{R_{B1} + R_{B2}} = 15\frac{50}{100+50} = 5V$$

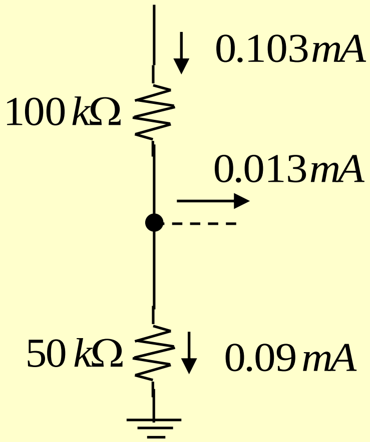
$$R_{BB} = \left(R_{B1} // R_{B2}\right) = \left(100 // 50\right) = 33.3\,k\Omega$$

$$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$$

$$I_B = \frac{I_E}{\beta + 1}$$

Example 4.7, cont'd





$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \left[R_{BB} / (\beta + 1)\right]}$$

$$I_B = \frac{1.29}{101} = 0.0128\,mA$$

$$V_B = V_{BE} + I_E R_E$$
$$= 0.7 + 1.29 \times 3 = 4.57\,V$$

assuming active-mode operation,

$$I_C = \alpha I_E = 0.99 \times 1.29 = 1.28\,mA$$

$$V_C = 15 - I_C R_C = 15 - 1.28 \times 5 = 8.6\,V$$