ECE3110J Mid RC Part1

Yi ZHAO

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Contents

00 Basics | GND and VDD

In a circuit:

(1)Only **ONE** VDD

(2)Only **ONE** GND

Thus:

(1)All VDD are connected to the **SAME** power supply

(2)All GND are connected to the **SAME** ground

00 Basics | GND and VDD

Definition of Ground

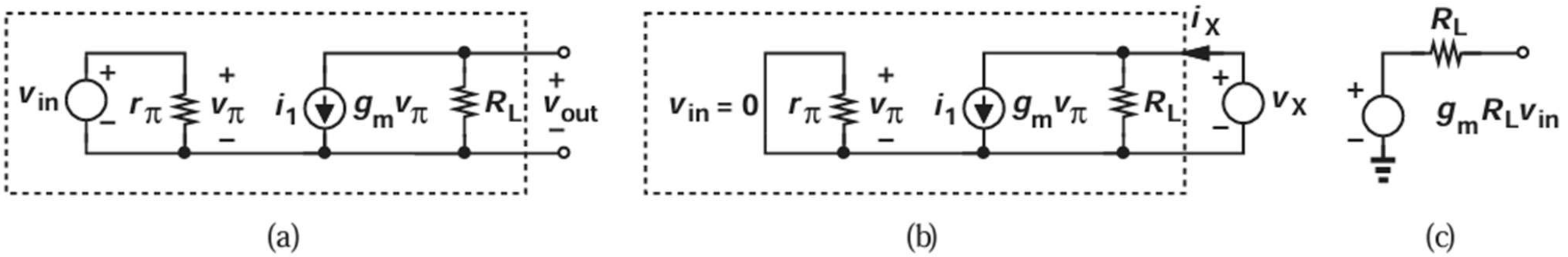
Ground serves as the reference point for all signals in an electrical circuit. While often associated with earth ground, it is not always connected to the physical ground; instead, it is **a conductive plane or return path within the system**.

Return Current Path

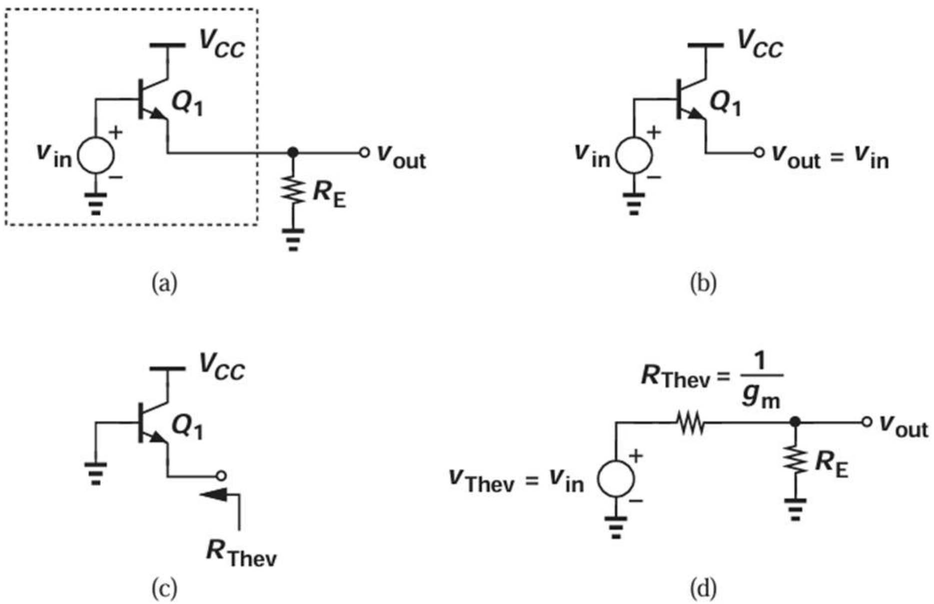
The behavior of the return current path depends on signal frequency:
•High-frequency signals: Return current seeks the path of least inductance, typically directly beneath the signal trace.
•Low-frequency signals: Return current follows the path of **least resistance.**

c.f. Proper Grounding in Electronics and PCB Design

00 Basics | Thévenin



2 Terminal



1 Terminal:
Other terminal
grounded

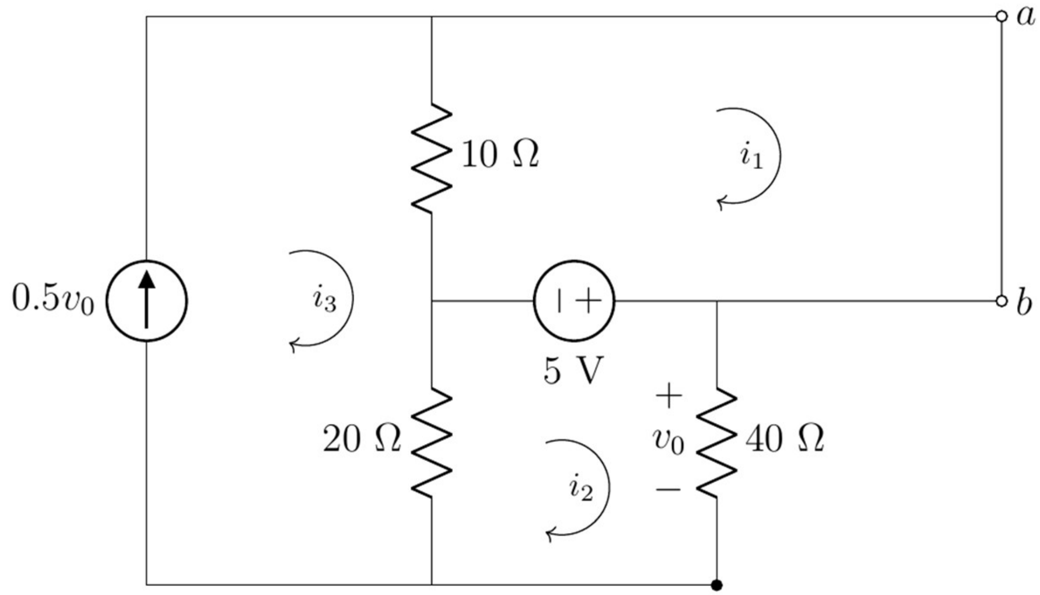
00 Basics | Thevenin

$$V_{\mathrm{Th}} = v_{oc}$$

$$I_N = i_{sc}$$

$$R_{\mathrm{Th}} = \frac{v_{oc}}{i_{sc}} = R_N$$

If it is unintuitive to calculate R_{Th}
Try to calculate Norton Equivalent



To get R_{th}, we need short circuit current between terminal a and b. By observing,

$$v_0 = 40i_2.$$

Thus,

$$i_3 = 0.5v_0 = 20i_2.$$

Apply KVL in loop 1 and 2,

$$5 + 10(i_1 - 20i_2) = 0$$
$$20(i_2 - 20i_2) - 5 + 40i_2 = 0$$

Thus,

$$i_N = i_1 = -\frac{34}{27}.A$$

As the result,

(2)
$$R_{th} = \frac{V_{th}}{i_N} = \frac{20}{3}\Omega.$$

$$V_0 = \frac{kT}{q} ln \frac{N_A N_D}{n_i^2}$$

Intrinsic: Silicon

P-type: Donor Ions (Boron) Nd

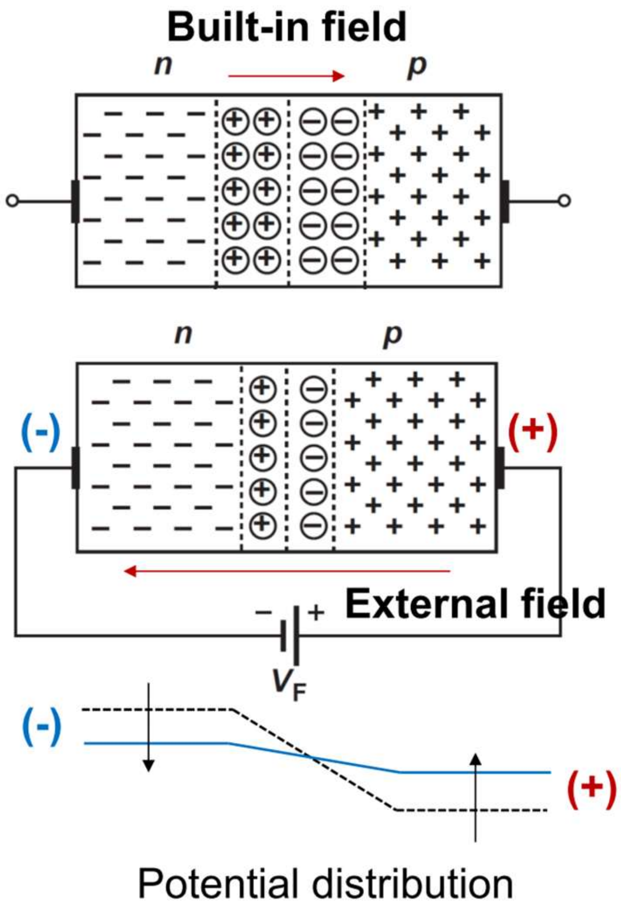
Main charge carrier: holes h+

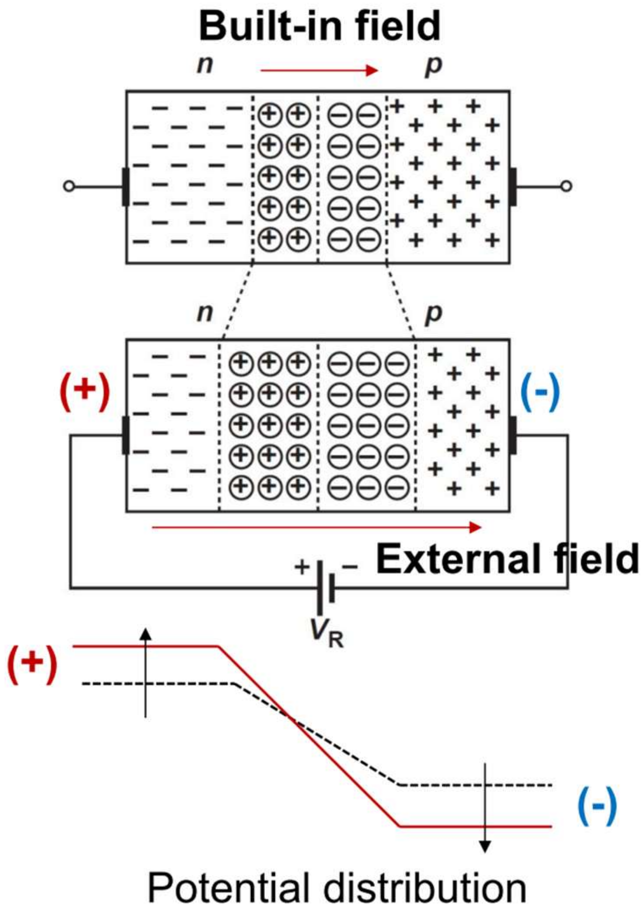
N-type: Acceptor Ions (Phosphorous) Na

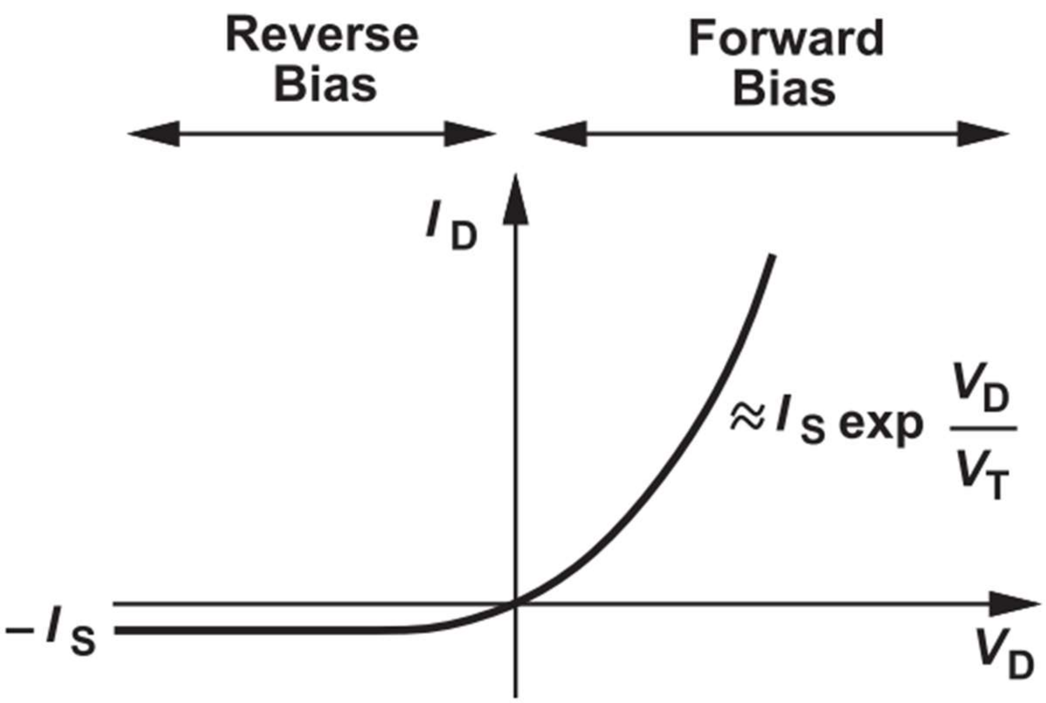
Main charge carrier: electrons e-

00 Basics

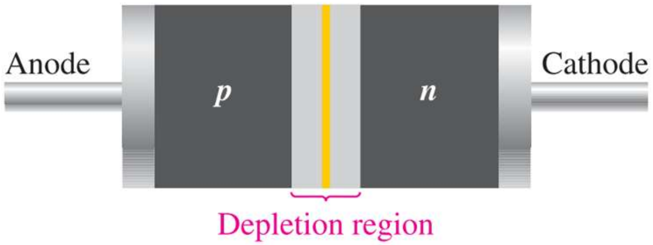
Semiconductor Basics






Reverse Bias
Forward Bias
I_D
$\approx I_S \exp \frac{V_D}{V_T}$
$-I_S$
V_D

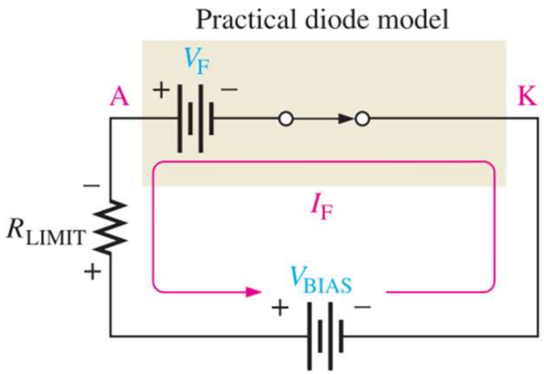
01 Diode | Diode Model



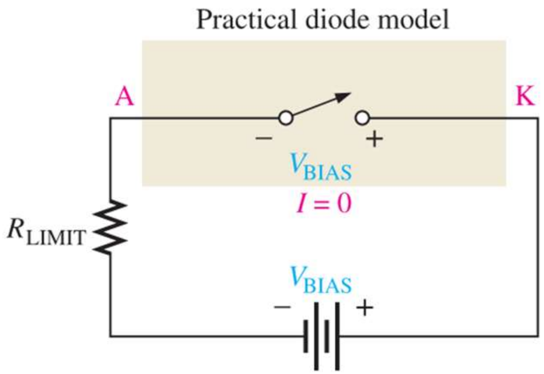
(a) Basic structure

(b) Symbol

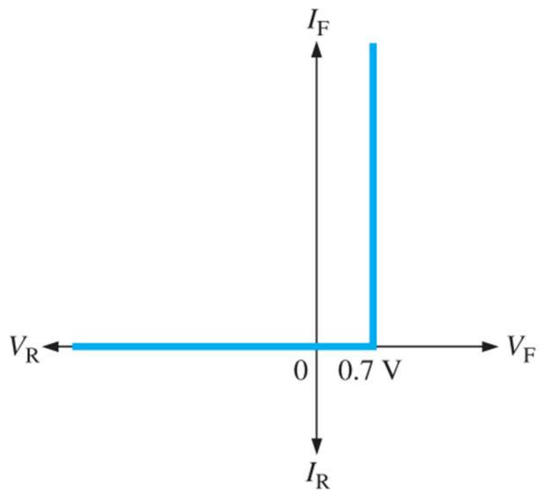
This equivalent voltage source represents the barrier potential that **must be exceeded** by the bias voltage before the diode will conduct and is **not an active source of voltage**. When conducting, a voltage drop of 0.7 V appears across the diode.



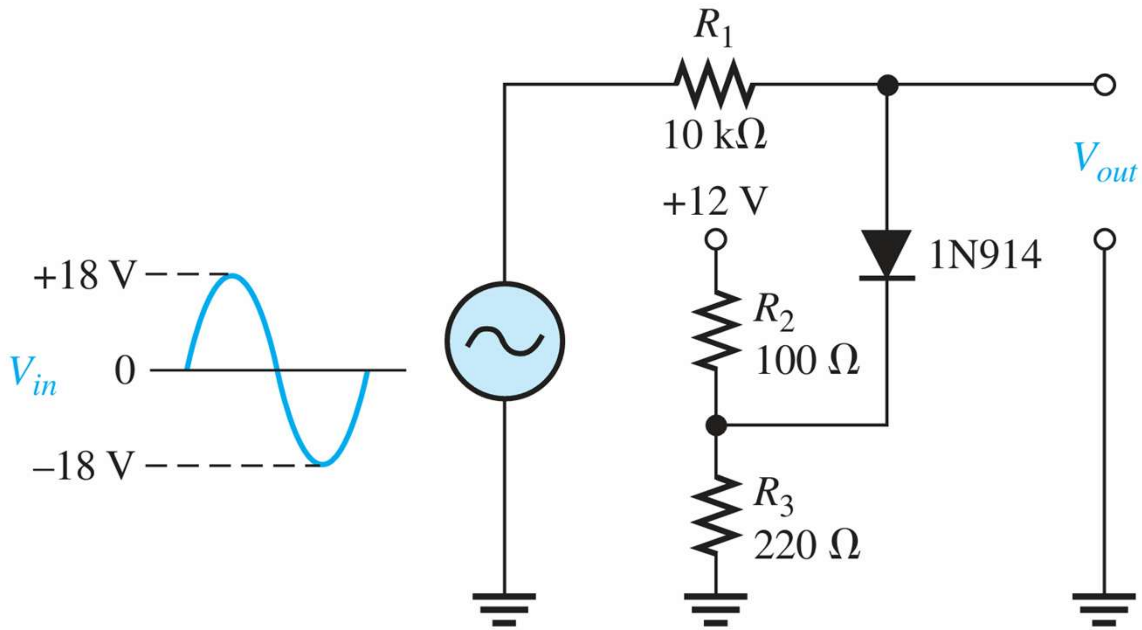
(a) Forward bias



(b) Reverse bias



(c) Characteristic curve (silicon)



Describe the output voltage waveform

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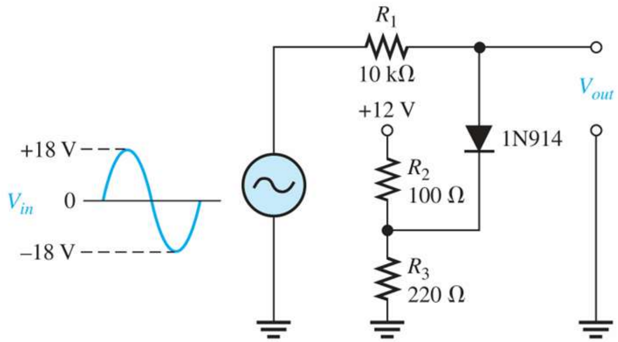
01 Diode | Diode Model



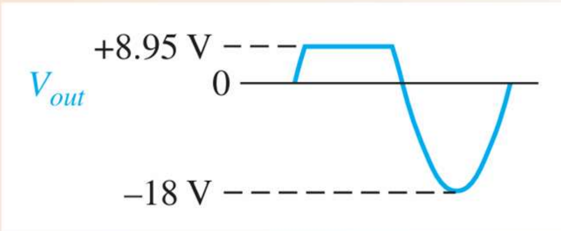
Describe the output voltage waveform

The circuit is a positive limiter. Use the voltage-divider formula to determine the bias voltage.

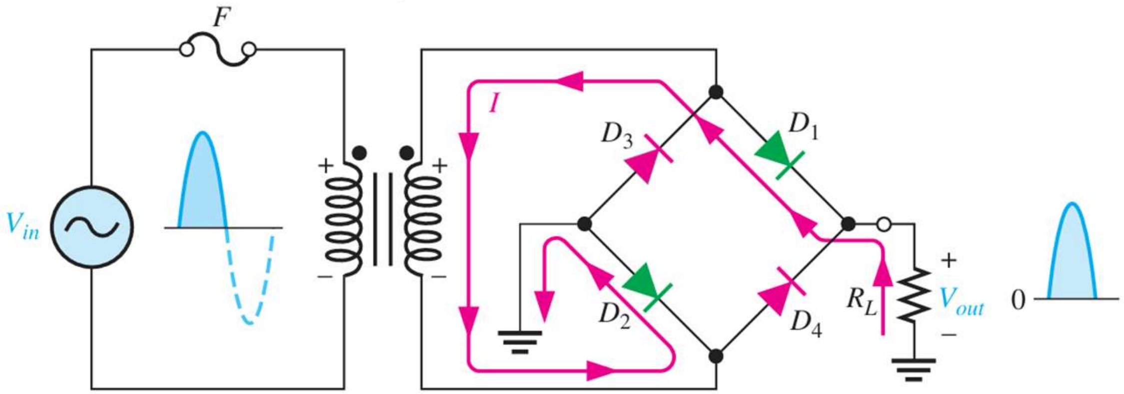
$$V_{\text{BIAS}} = \left(\frac{R_3}{R_2 + R_3}\right)V_{\text{SUPPLY}} = \left(\frac{220\ \Omega}{100\ \Omega + 220\ \Omega}\right)12\ \text{V} = 8.25\ \text{V}$$

The output voltage waveform is shown in Figure 2–62. The positive part of the output voltage waveform is limited to $V_{\text{BIAS}} + 0.7$ V.

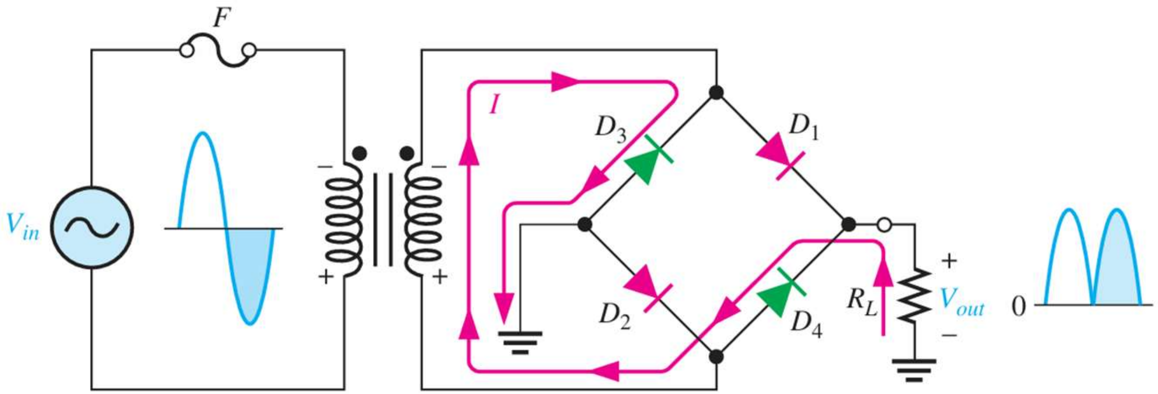
FIGURE 2–62



01 Diode | Rectifier

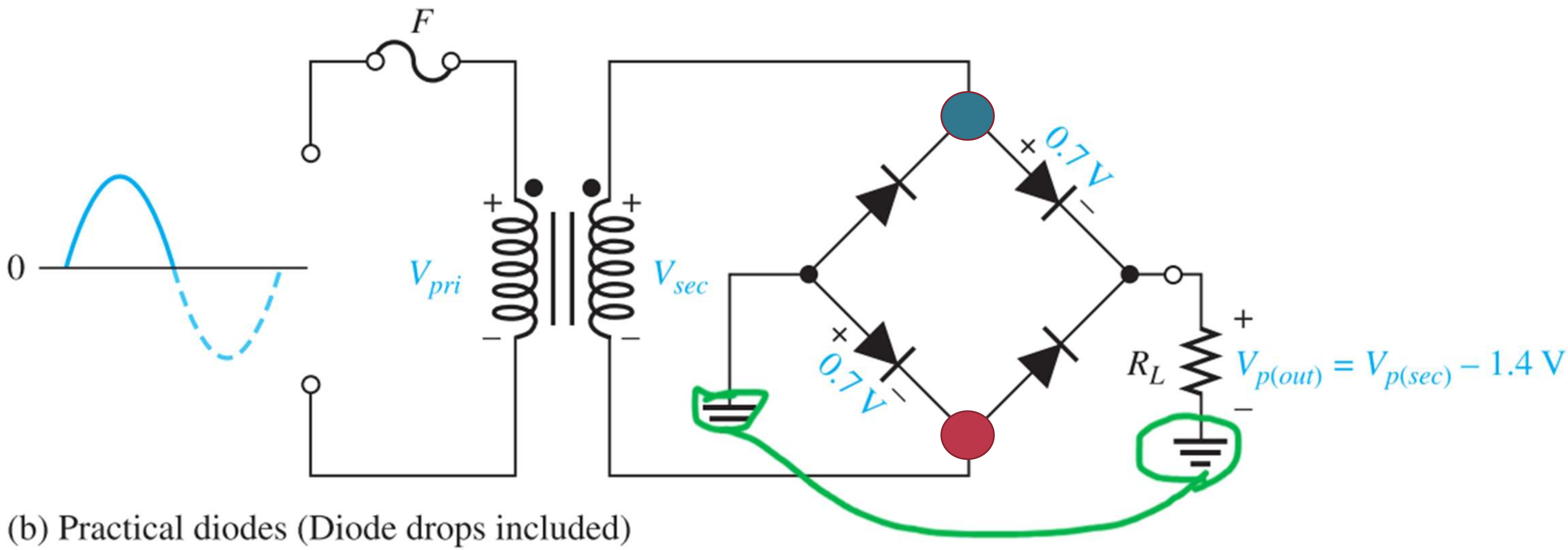


(a) During the positive half-cycle of the input, D_1 and D_2 are forward-biased and conduct current. D_3 and D_4 are reverse-biased.



(b) During the negative half-cycle of the input, D_3 and D_4 are forward-biased and conduct current. D_1 and D_2 are reverse-biased.

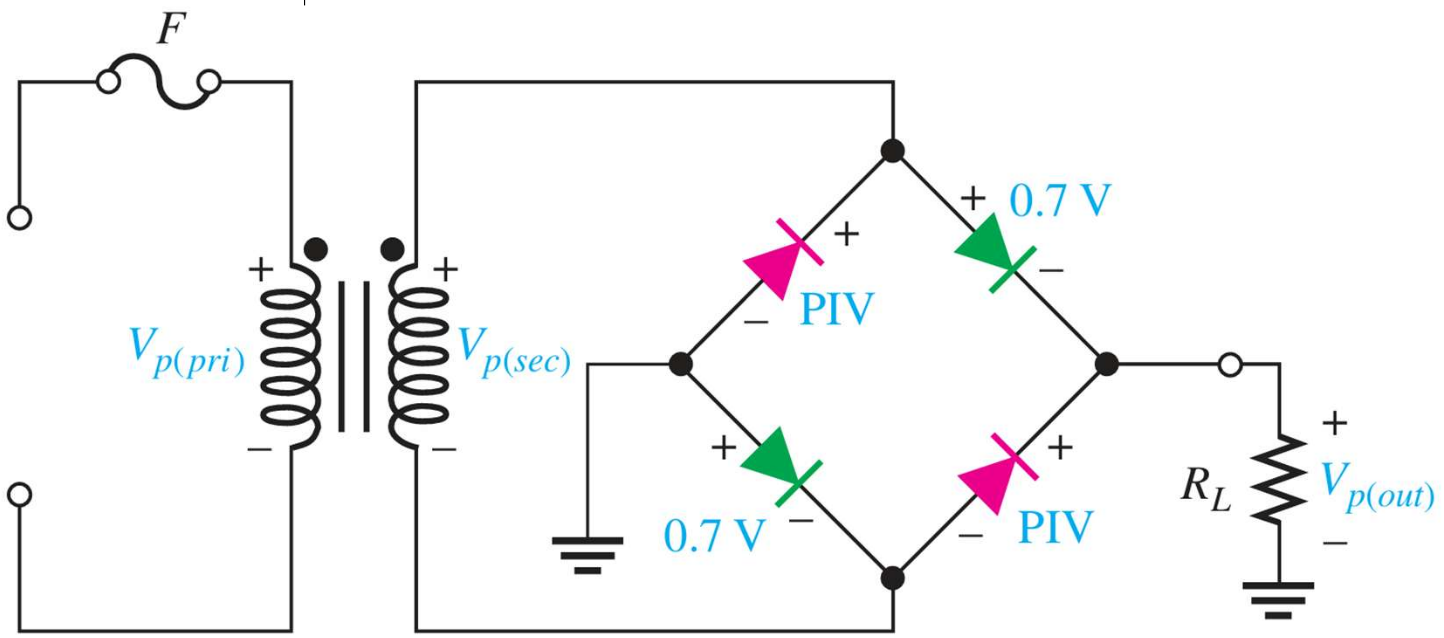
01 Diode | Rectifier



(b) Practical diodes (Diode drops included)

Take GND as V=0: V1=-0.7V, V2=4.3V

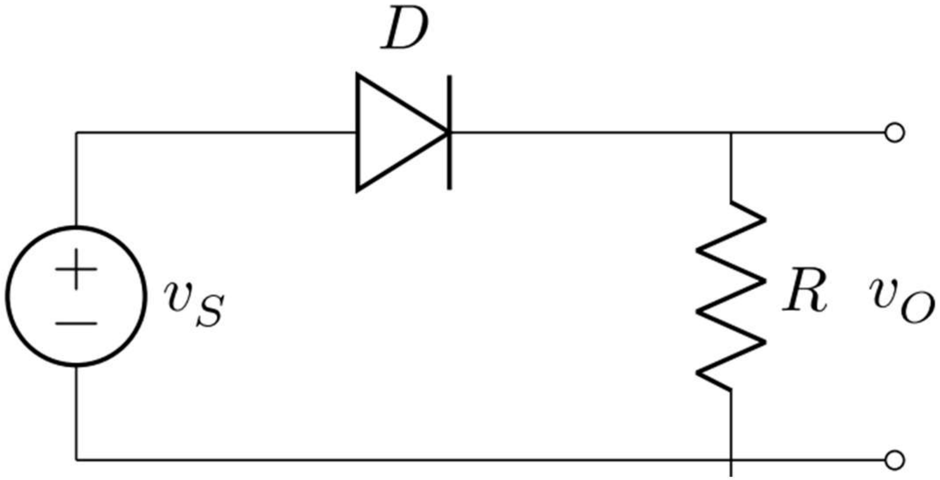
01 Diode | Rectifier

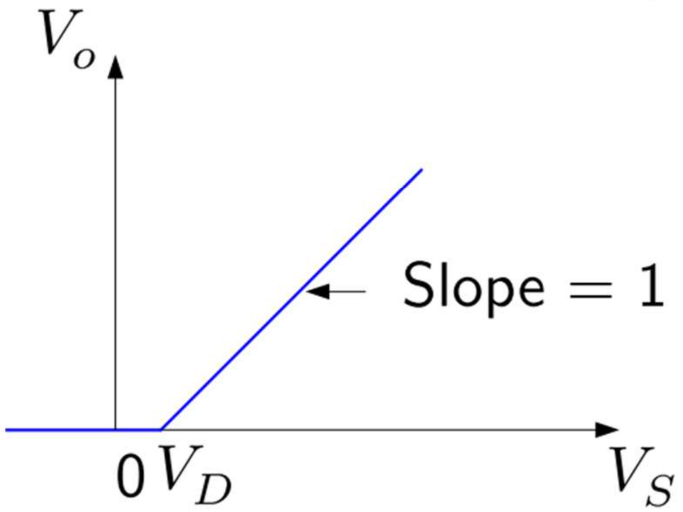


(b) For the practical diode model (forward-biased diodes D_1 and D_2 are shown in green), PIV = $V_{p(out)}$ + 0.7 V.

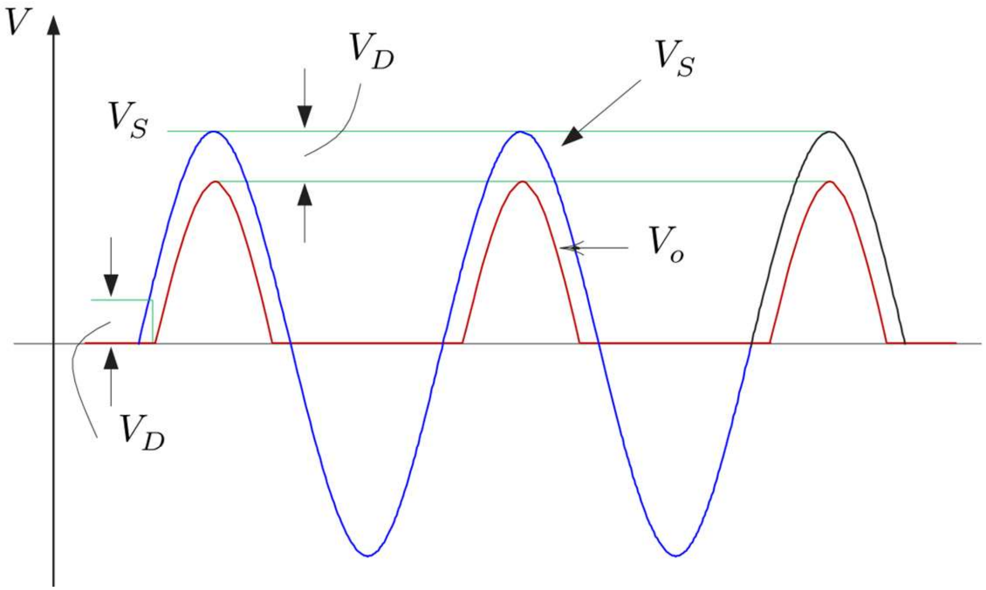
PIV: Diode Peak **Inverse** Voltage. **PIV=Vs-Von** for Full-Wave **Bridge** Rectifier

01 Diode | Rectifier Ripple





Half-Wave Rectifier with Resistive Load

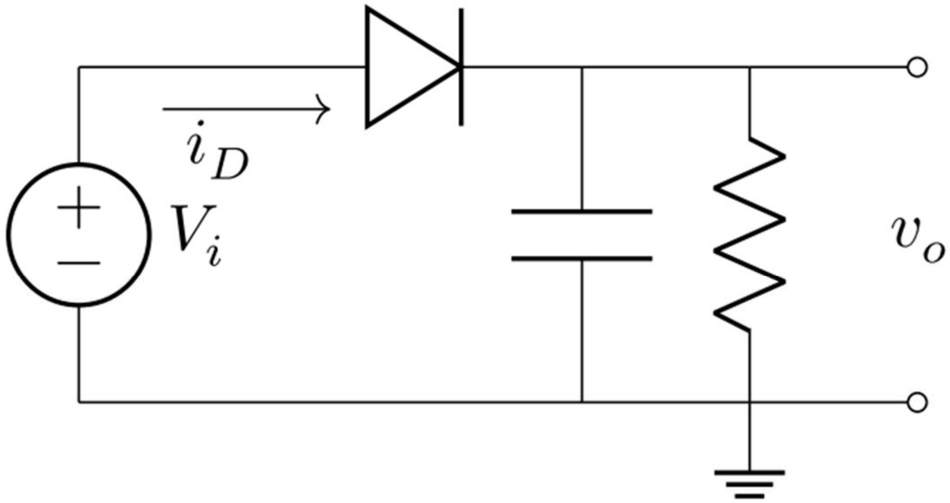


01 Diode | Rectifier Ripple

$$i_L = V_o/R \tag{22}$$

$$i_D = i_C + i_L = C\frac{dv_I}{dt} + i_L \tag{23}$$

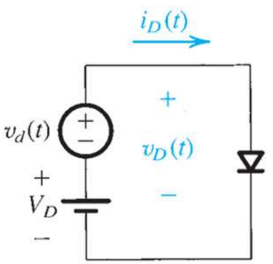
$$V_p - V_r \simeq V_p e^{-T/CR} \tag{24}$$



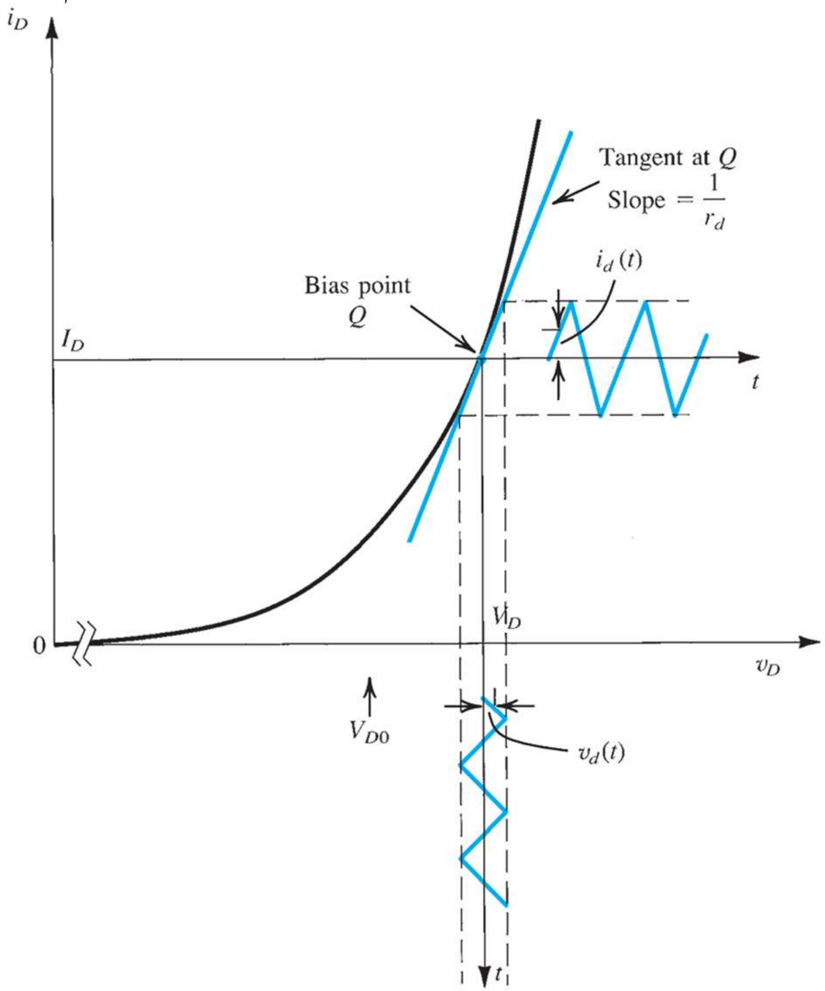
- A very large capacitor is required to reduce the ripple

Only Capacitor can hold charges. Resistor CANNOT
Ripple is a simple RC circuit without source in ECE2150J

Diode Small Signal Model



(a)



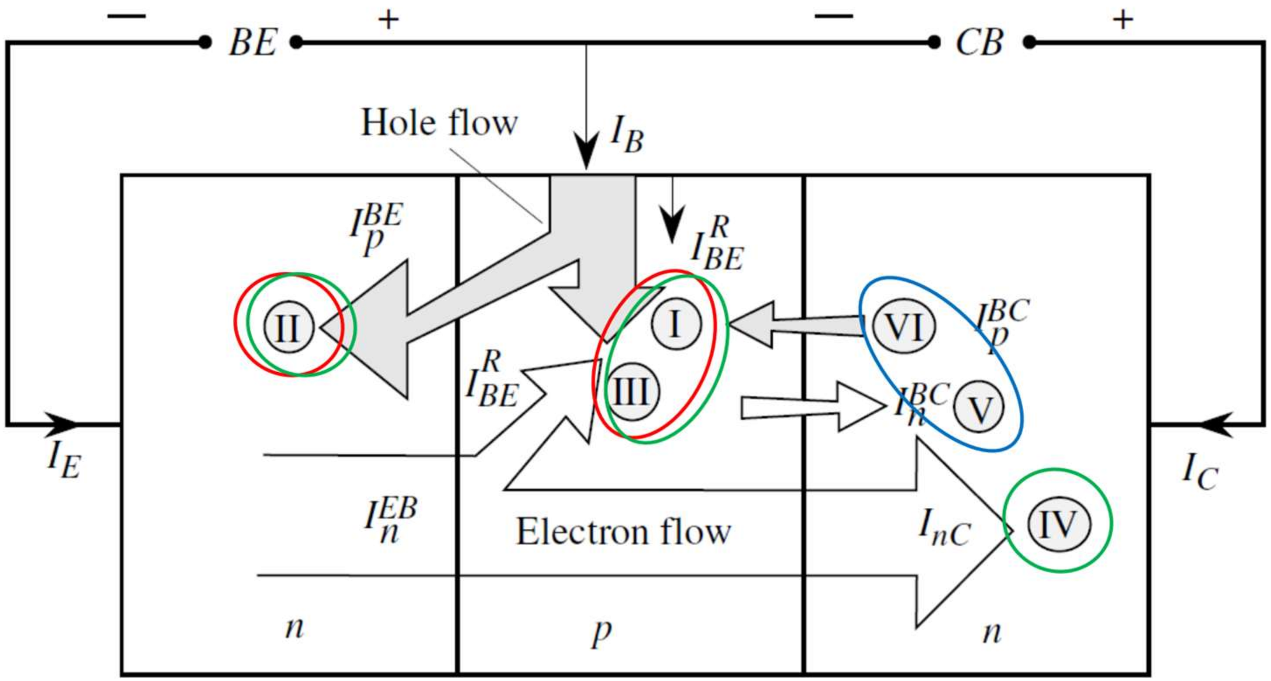
(b)

Small signal behavior of diode is linear.

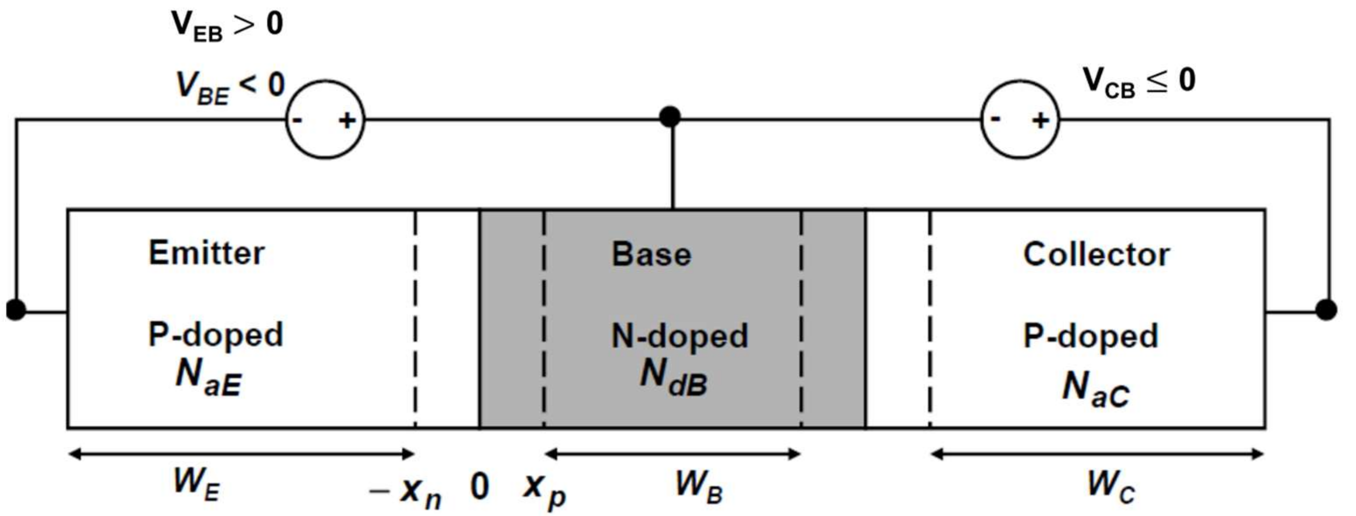
Linear=Ohmic=Resistor

$$r_d = 1 \Big/ \left[\frac{\partial i_D}{\partial v_D} \right]_{i_D = I_D}$$

BJT Fundamentals



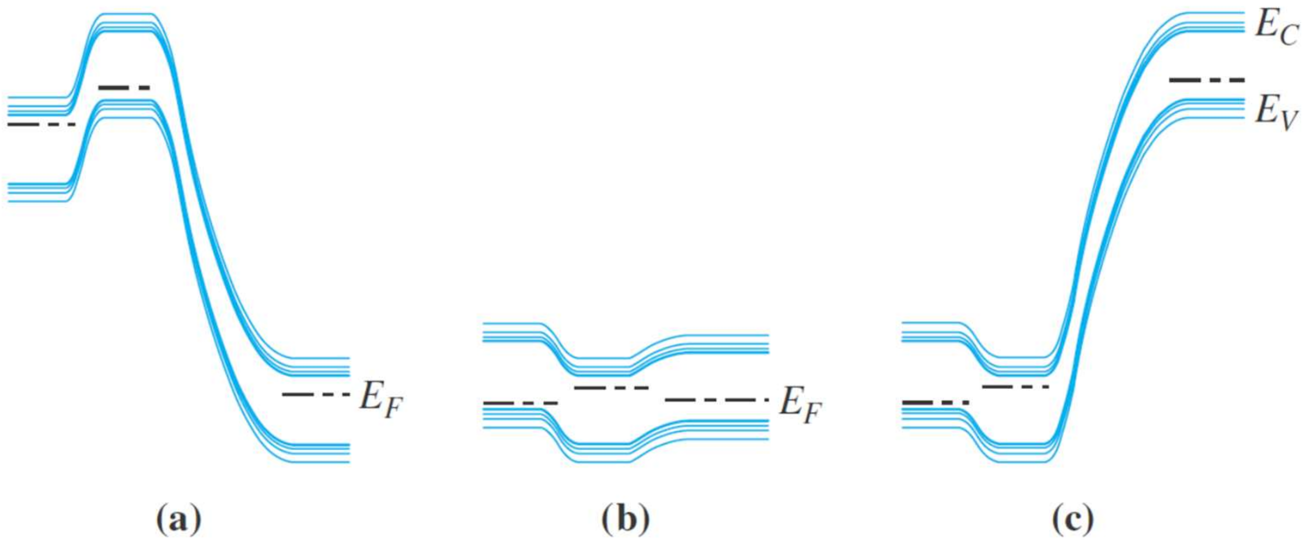
Forward Active Mode in PNP



The base-emitter junction is forward biased $\mathbf{V_{EB} > 0}$

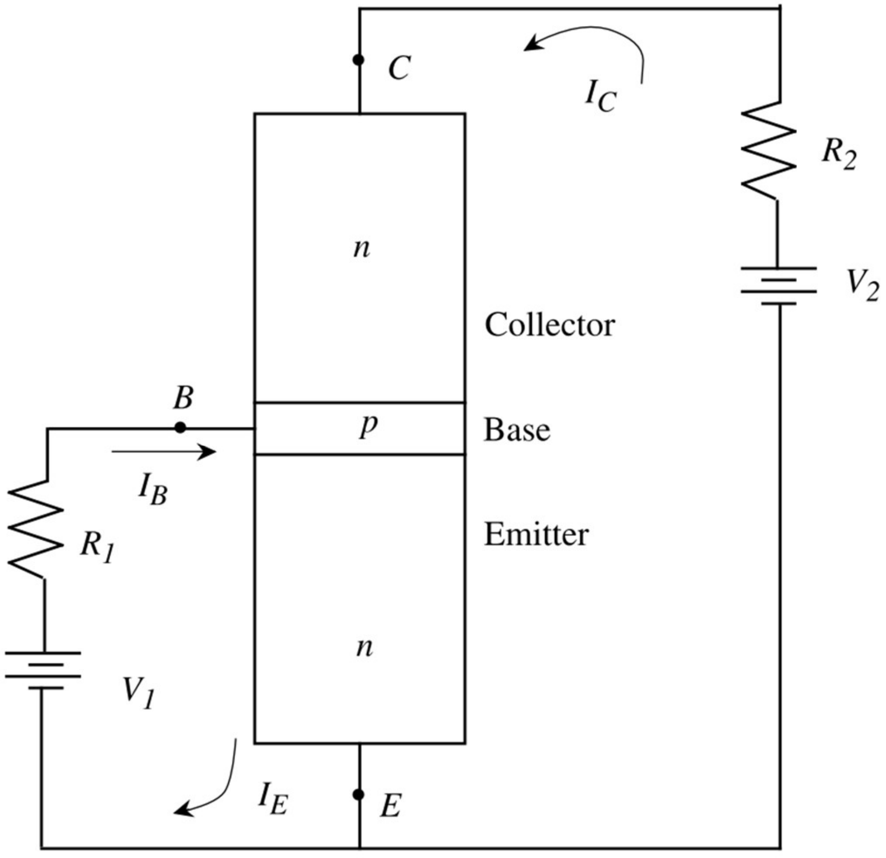
The base-collector junction is reverse biased $\mathbf{V_{CB} \leq 0}$

BJT Fundamentals

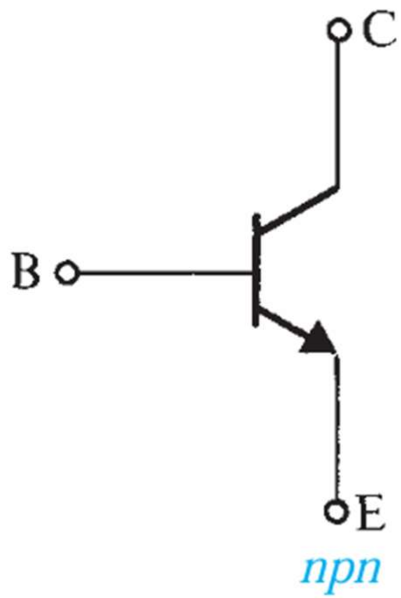


02 BJT

BJT Device

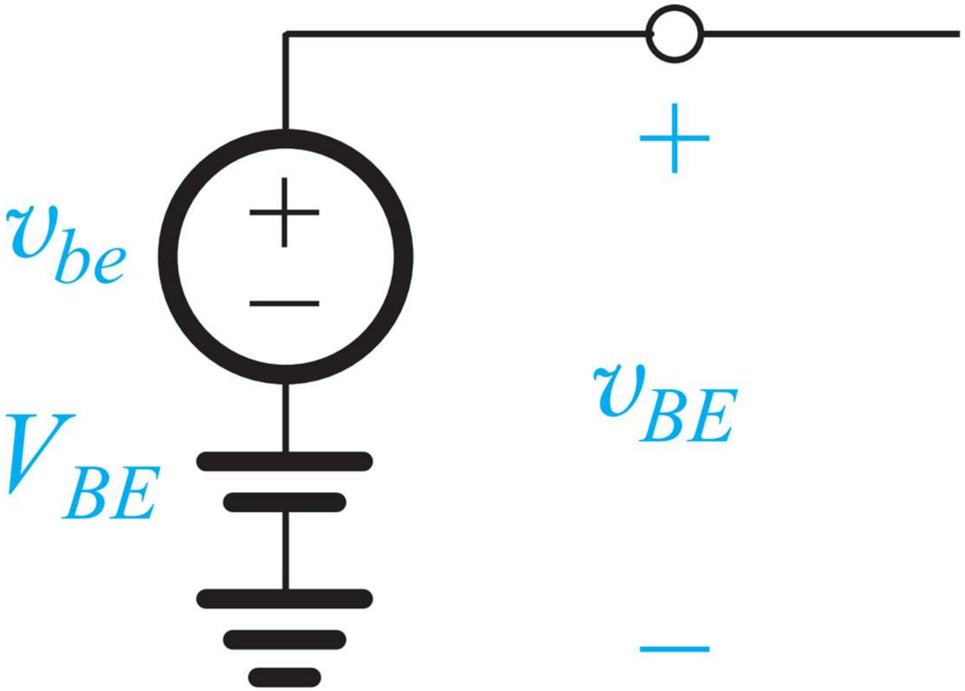


(a)

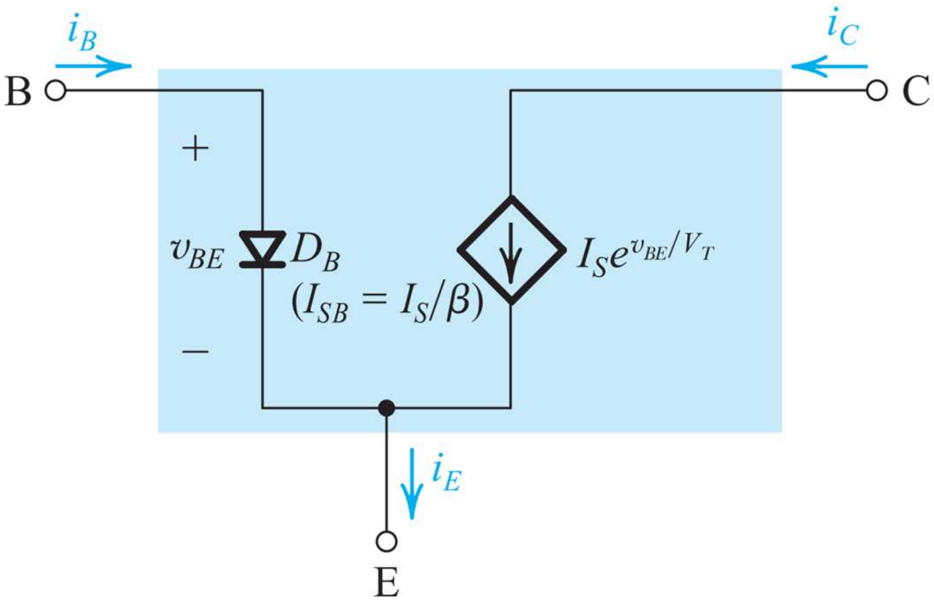


(a)

Signal Notation



02 BJT | Large Signal Pi Model



Forward Active

Large Signal Voltage Relation

Table 6.2 Summary of the BJT Current–Voltage Relationships in the Active Mode

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

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

$$i_C = \alpha i_E \qquad i_B = (1-\alpha) i_E = \frac{i_E}{\beta + 1}$$

$$i_C = \beta i_B \qquad i_E = (\beta + 1) i_B$$

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

$$V_T = \text{thermal voltage} = \frac{kT}{q} \simeq 25 \text{ mV} \text{ at room temperature}$$

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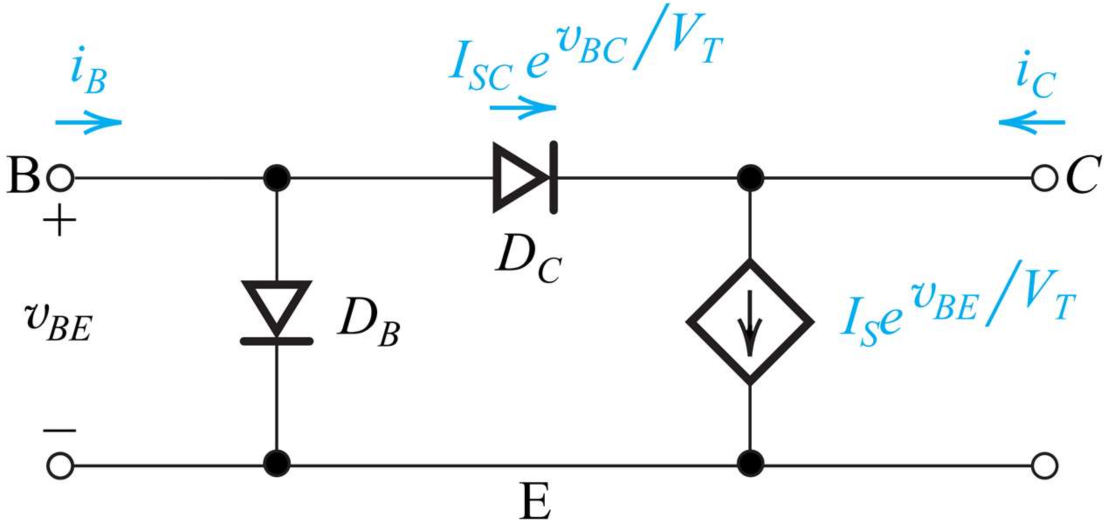
02 BJT

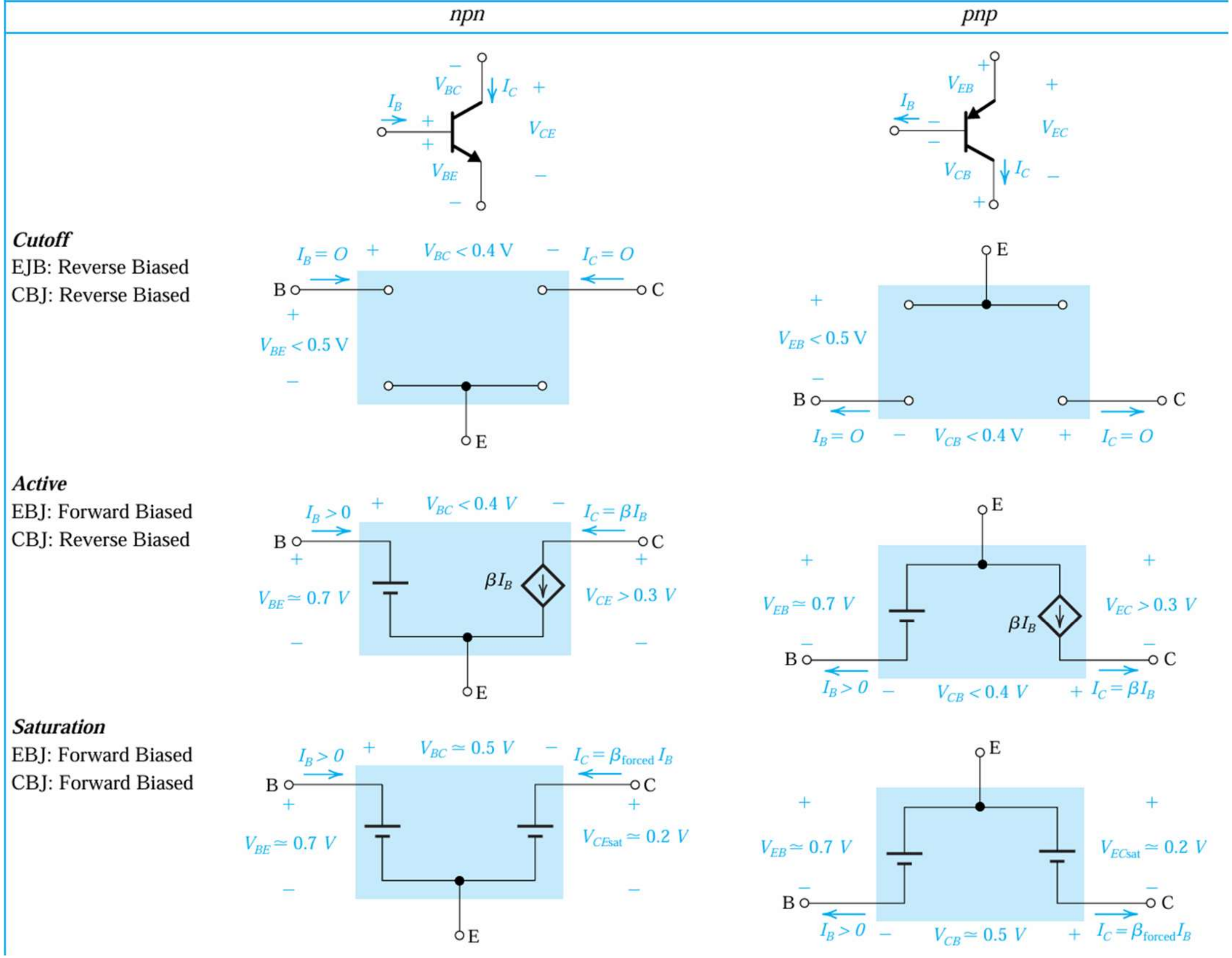
Large Signal Saturation Model



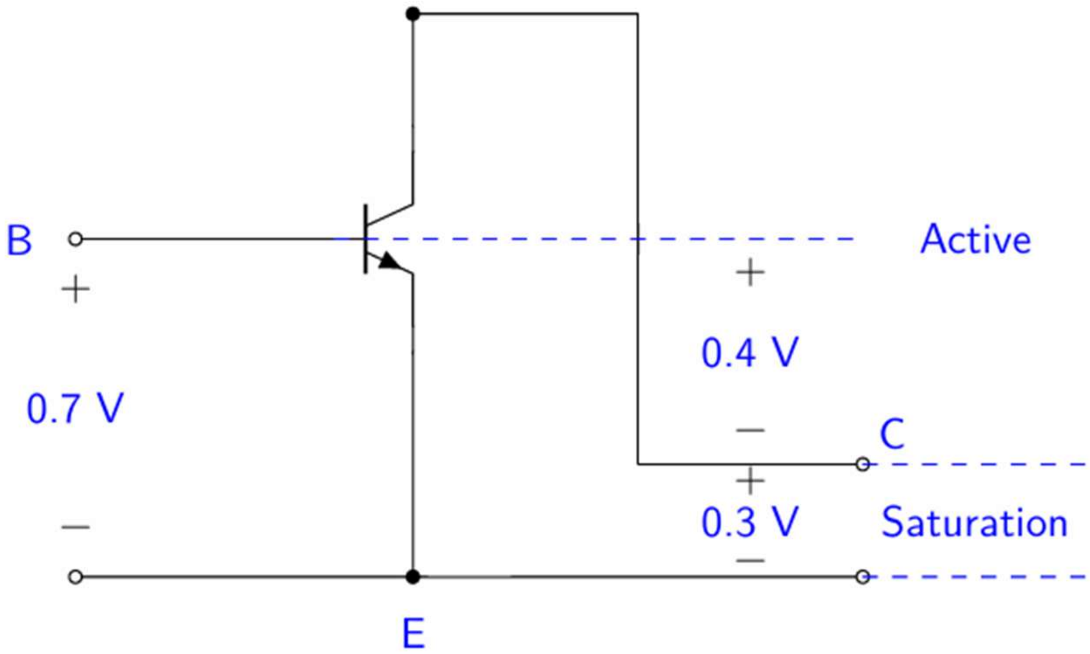
Saturation (Adding a Diode Dc)

Biasing Condition CTPP

Table 6.3 Conditions and Models for the Operation of the BJT in Various Modes



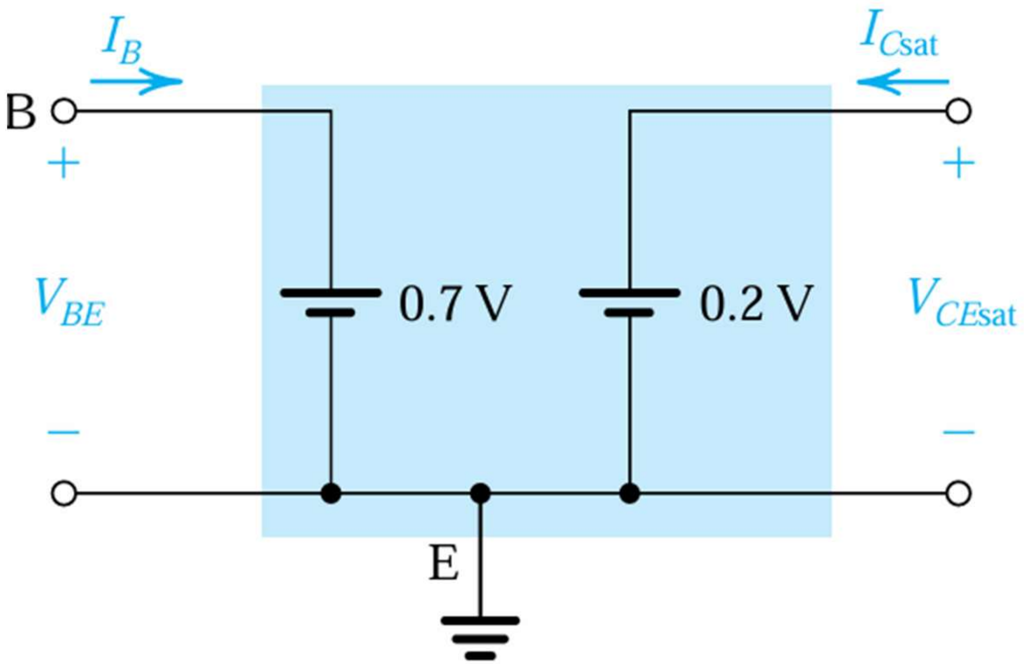
Bias Voltage Requirement



- Forward Active
- $V_{CB} \geq -0.4V$
- $V_{CE} \geq 0.3V$
- Otherwise get “Saturation”

V_{BE}	(ON)	0.7 V
V_{BC}	(ON)	0.5 V

02 BJT | Saturation



- Typically:

$$V_{BE}\ \text{(ON)} \quad 0.7\ \text{V}$$
$$V_{BC}\ \text{(ON)} \quad 0.5\ \text{V}$$

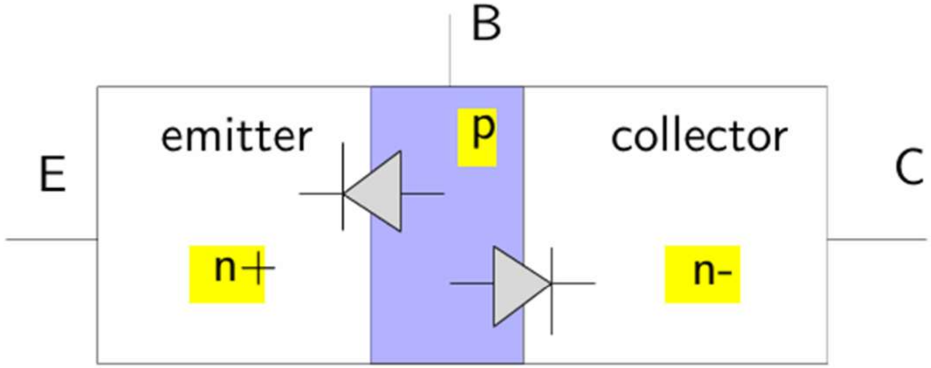
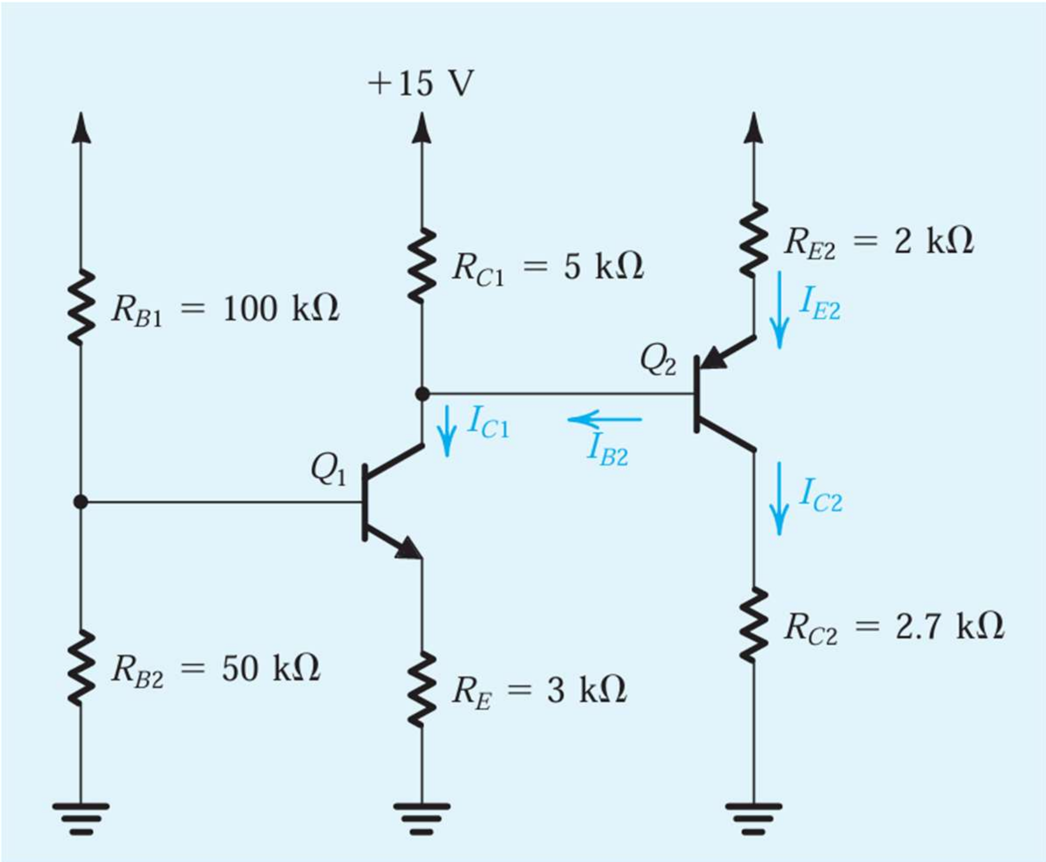


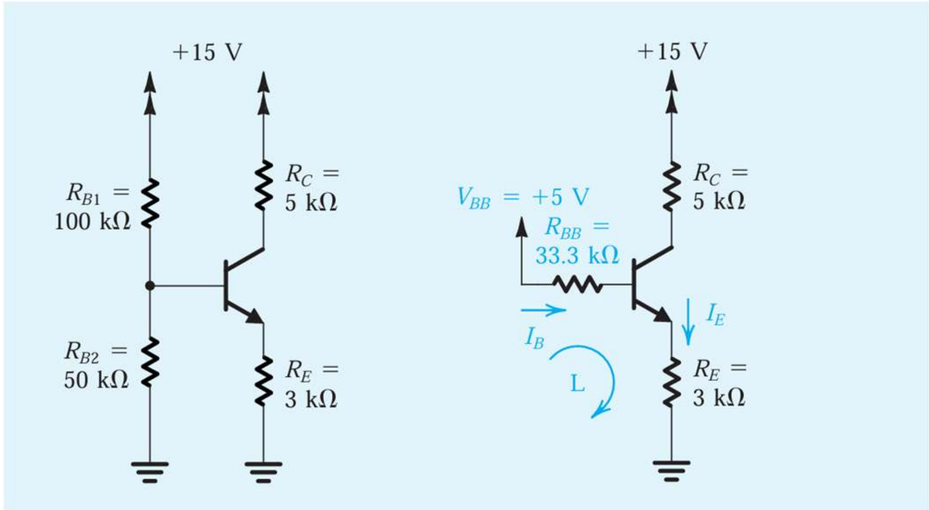
Figure 6.20 A simplified equivalent-circuit model of the saturated transistor.

BJT Problem1

Calculate all the Biasing Voltage and Current



Step 1. Input Thevenin



02 BJT | BJT Problem1

Calculate all the Biasing Voltage and Current

What is the correct order of the Solution??

A:

$$I_C = I_{C1} + I_{B2}$$
$$I_{C1} = \frac{15 - V_{C1}}{5\ \text{K}} = \frac{15 - V_{B2}}{5\ \text{K}}$$
$$V_{B2} = 8.78\ \text{V}$$

B:

$$I_{E_2} = \frac{15 - V_{E2}}{2\ \text{K}}$$
$$V_{E2} = V_{B2} + 0.7$$
$$I_{B2} = \frac{15.7 - V_{B2}}{2\ \text{K}} \cdot \frac{1}{\beta + 1}$$

C:

$$V_{B_1} = 5 - I_{B_1} R_{BB}$$
$$I_{B_1} = \frac{1}{\beta} I_C \quad (\text{NOT } \text{I}_{\text{C}_1})$$
$$V_{B_1} = 0.7 + V_{E2}$$
$$V_{E2} = I_E R_{EE} = \frac{\beta + 1}{\beta} I_C$$

D:

$$5 - \frac{1}{100} I_C (33.3\text{k}) = V_B = 0.7 + \frac{101}{100} I_C \cdot 3\ \text{K} = 0.7 + V_E$$
$$I_C = 1.279 \times 10^{-3}\ \text{A}$$

E. $I_C \Rightarrow I_{B_2}, I_{E_1} \Rightarrow V_{B_1} \Rightarrow V_{E_1}$

F. $V_{B2} \Rightarrow V_{E2} \Rightarrow I_{E2} \Rightarrow I_{C2} \cdot I_{B2} \Rightarrow V_{C2}$

02 BJT

BJT Problem 2

We desire to evaluate the voltages at all nodes and the currents through all branches in the circuit of Fig. 6.30(a). Assume $\beta = 100$.

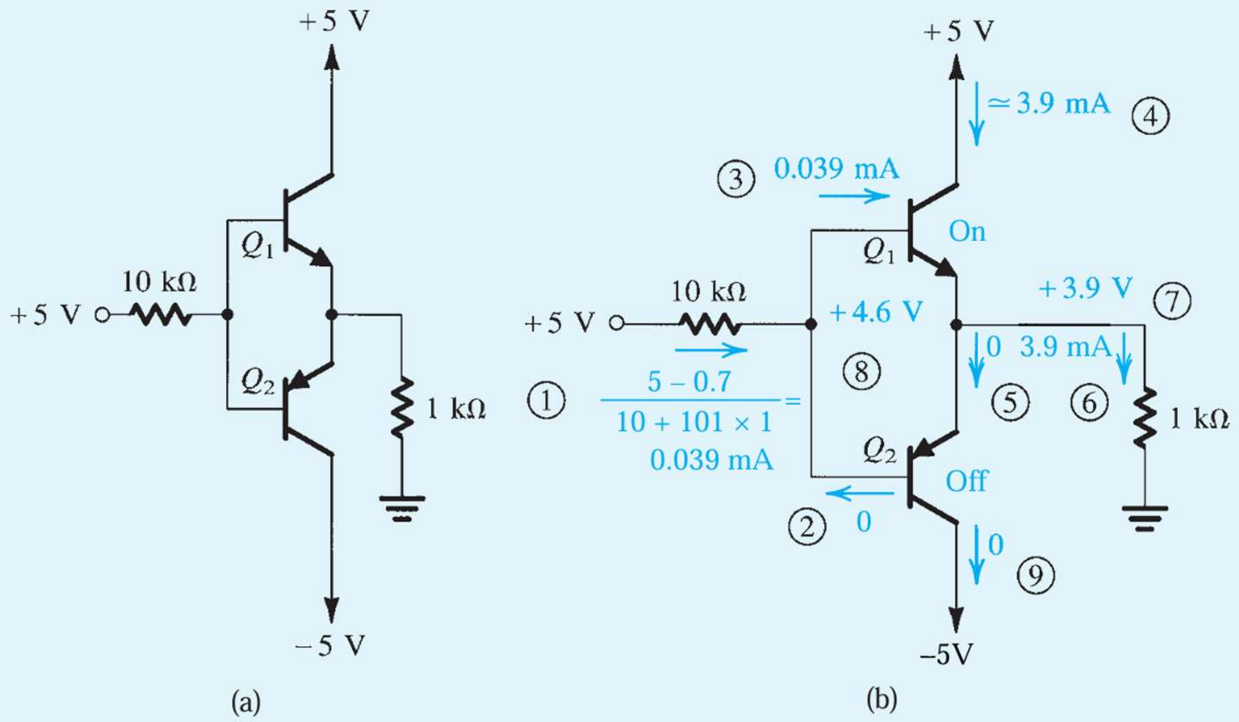


Figure 6.30 Example 6.12: **(a)** circuit; **(b)** analysis with the steps numbered.

BJT Problem 2

Solution

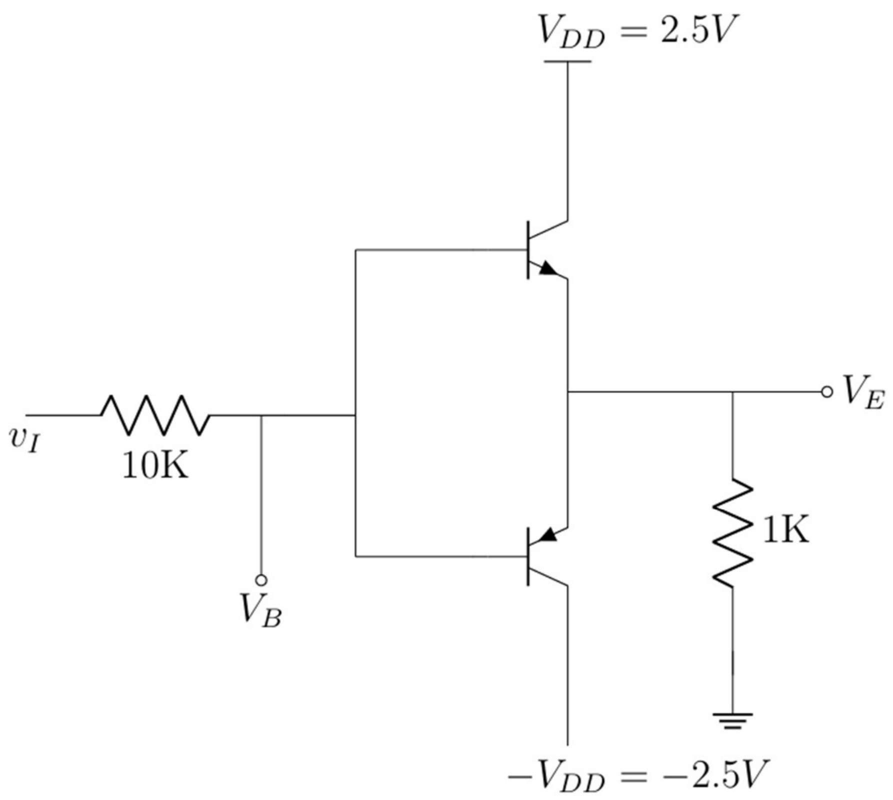
By examining the circuit, we conclude that the two transistors Q_1 and Q_2 cannot be simultaneously conducting. Thus if Q_1 is on, Q_2 will be off, and vice versa. Assume that Q_2 is on. It follows that current will flow from ground through the 1-kΩ resistor into the emitter of Q_2. Thus the base of Q_2 will be at a negative voltage, and base current will be flowing out of the base through the 10-kΩ resistor and into the +5-V supply. This is impossible, since if the base is negative, current in the 10-kΩ resistor will have to flow into the base. Thus we conclude that our original assumption—that Q_2 is on—is incorrect. It follows that Q_2 will be off and Q_1 will be on.

The question now is whether Q_1 is active or saturated. The answer in this case is obvious: Since the base is fed with a +5-V supply and since base current flows into the base of Q_1, it follows that the base of Q_1 will be at a voltage lower than +5 V. Thus the collector–base junction of Q_1 is reverse biased and Q_1 is in the active mode. It remains only to determine the currents and voltages using techniques already described in detail. The results are given in Fig. 6.30(b).

02 BJT

BJT Problem 2.5

For the circuit in Fig 2, find V_B and V_E for $v_I = 0\text{V}$, $+2\text{V}$,-2.5V, and -5V. The BJTs have β=50.



02 BJT

BJT Problem 2.5

For the circuit in Fig 2, find V_B and V_E for $v_I = 0$V, +2V, –2.5V, and –5V. The BJTs have β=50.

① $V_I = +2V$

Assume npn FAR, pnp cut-off

$$\frac{V_I - V_B}{10K} = I_B, \quad \frac{V_E}{1K} = I_E \Rightarrow \frac{V_I - V_B}{10K} \cdot (\beta+1) = \frac{V_B - 0.7}{1K} \Rightarrow \begin{cases} V_B = 1.79V < V_C \\ V_E = 1.09V \end{cases}$$

② $V_I = 0V$

if npn on, $V_E = I_E \cdot 1K > 0$ $\Rightarrow V_B < V_E$ off

however $V_B = V_I - I_B \cdot 10K < V_I = 0$

if pnp FAR: $V_E = I_E \cdot 1k$, $V_B = V_I + I_B \cdot 10k$

$$\Rightarrow V_E = 0.7 + V_B = 0.7 + \frac{I_E}{\beta+1} 10K = I_E \cdot 1K \Rightarrow \begin{cases} I_E = 5.85 \times 10^{-4} A \\ V_E = 0.585V > 0 \end{cases}$$

which is impossible

both cutoff $\Rightarrow V_E = V_B = 0$

02 BJT

BJT Problem 2.5

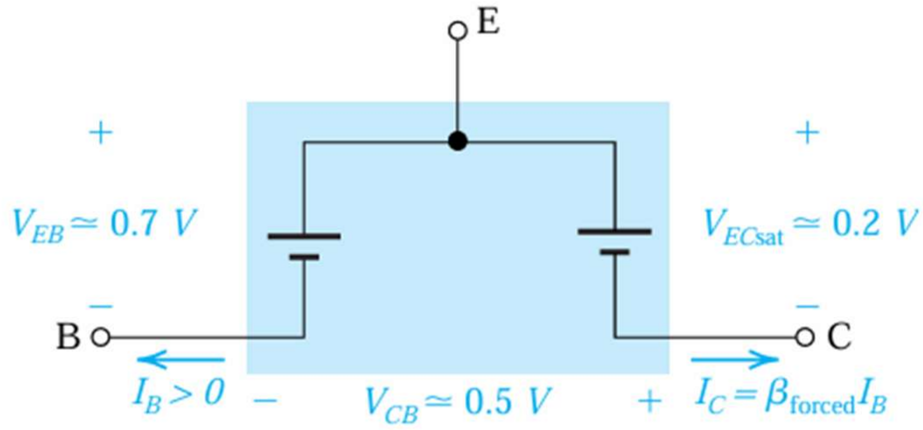
Forward Active

$V_{CB} \geq -0.4V$

$V_{CE} \geq 0.3V$

Otherwise get "Saturation"

V_{BE}	(ON)	0.7 V
V_{BC}	(ON)	0.5 V



This is for NPN.
PNP need to
reverse the sign

02 BJT

BJT Problem 2.5

both cut off $\Rightarrow V_E = V_B = 0$ $= 0V$, $+2V$, $-2.5V$, and $-5V$. The BJTs have $\beta = 50$.

③ $V_I = -2.5V$

Suppose: pnp FAR, npn cut-off

$I_E \cdot 1k = V_E = 0.7 + V_B = 0.7 + (-2.5) + \frac{-I_E}{51} \cdot 10k \Rightarrow \begin{cases} I_E = -1.5 \times 10^{-3} A \\ V_E = -1.5 V \\ V_B = -2.2V > V_C \end{cases}$

Indeed FAR.

④ $V_I = -5V$

Suppose pnp FAR, npn cut-off

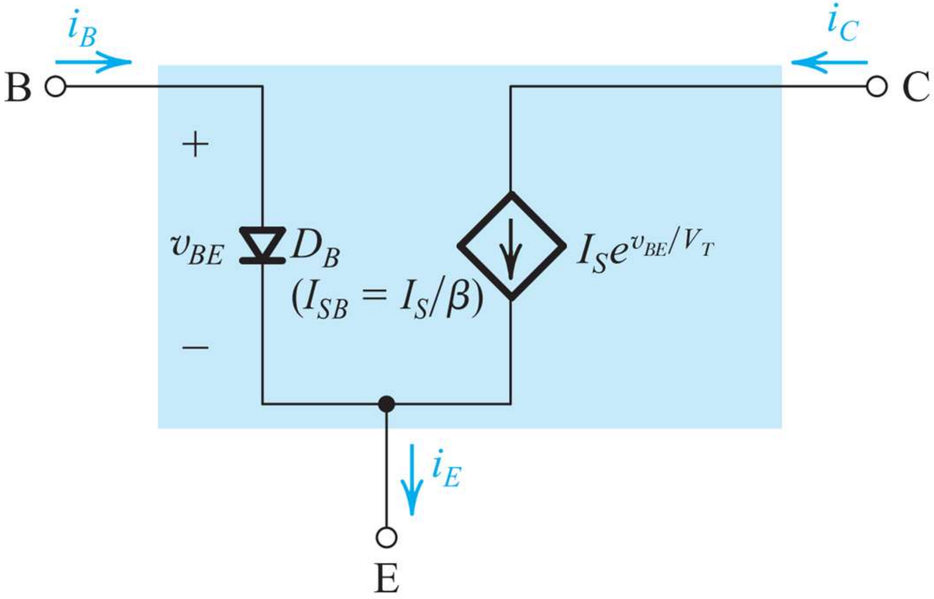
$I_E \cdot 1k = 0.7 - 5 + \frac{-I_E}{51} \cdot 10k$

$\Rightarrow I_E = -3.6 \times 10^{-3} A \Rightarrow V_E = -3.6V$, $V_B = -4.3V$

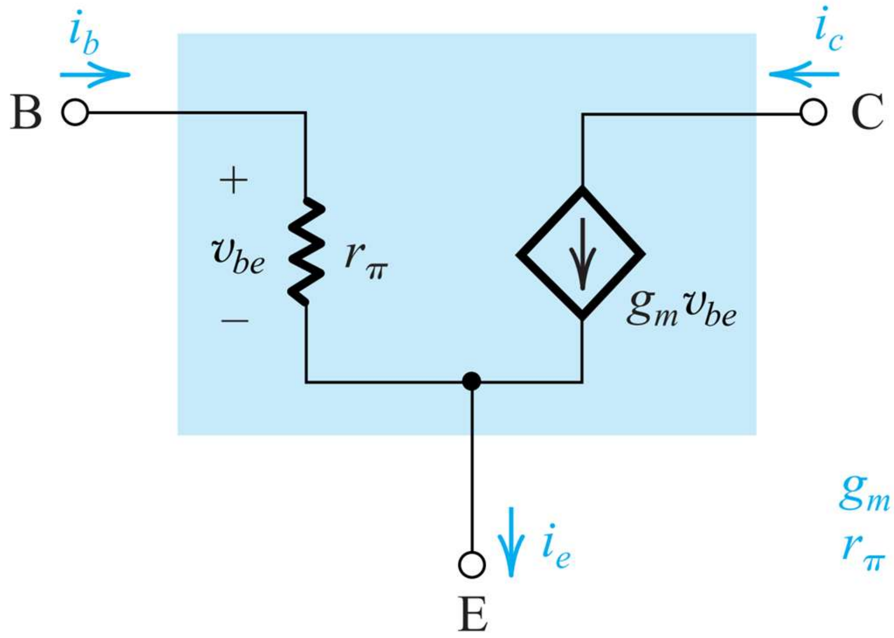
$V_{BC} = -1.8V < -0.4V \Leftrightarrow V_{CB} = 1.8V > 0.4V$

Diode D_C is on, saturation $\Rightarrow \begin{cases} V_{EB} = 0.7V \\ V_{CB} = 0.5V \\ V_{EC} = 0.2V \\ V_C = -2.5V \end{cases} \Rightarrow \begin{cases} V_B = -3V \\ V_E = -2.3V \end{cases}$

Small Signal Pi Model



Large Signal



$g_m = I_C/V_T$
$r_\pi = \beta/g_m$

Small Signal: Differentiate w.r.t. v_{BE} at $i\_c = I\_C$

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Small Signal Model

Model Parameters in Terms of DC Bias Currents

$$g_m = \frac{I_C}{V_T} \qquad r_e = \frac{V_T}{I_E} = \alpha \frac{V_T}{I_C} \qquad r_\pi = \frac{V_T}{I_B} = \beta \frac{V_T}{I_C} \qquad r_o = \frac{|V_A|}{I_C}$$

In Terms of g_m

$$r_e = \frac{\alpha}{g_m} \qquad r_\pi = \frac{\beta}{g_m}$$

In Terms of r_e

$$g_m = \frac{\alpha}{r_e} \qquad r_\pi = (\beta + 1) r_e \qquad g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$$

Relationships between α and β

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

Small Signal Model

Model Parameters in Terms of DC Bias Currents

$$g_m = \frac{I_C}{V_T} \qquad r_e = \frac{V_T}{I_E} = \alpha\frac{V_T}{I_C} \qquad r_\pi = \frac{V_T}{I_B} = \beta\frac{V_T}{I_C} \qquad r_o = \frac{|V_A|}{I_C}$$

In Terms of g_m

$$r_e = \frac{\alpha}{g_m} \qquad r_\pi = \frac{\beta}{g_m}$$

In Terms of r_e

$$g_m = \frac{\alpha}{r_e} \qquad r_\pi = (\beta+1)r_e \qquad g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$$

Relationships between α and β

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

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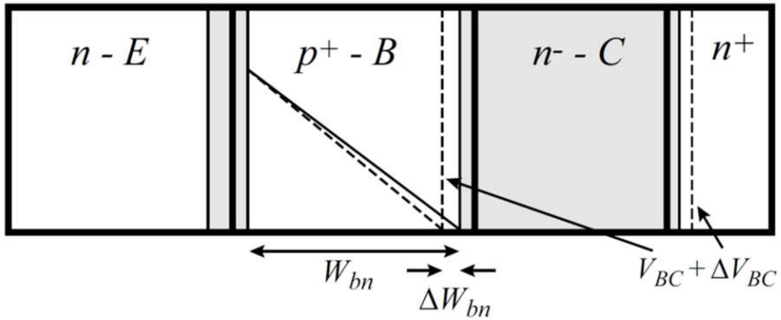
Secondary Order Effect

(2) Base Width Modulation: The Early Effect

The Early effect is **the variation in the effective width** of the base in a bipolar junction transistor due to a variation in the applied base-to-collector voltage.
(Early does not have a physical meaning - named after its discoverer James M. Early)

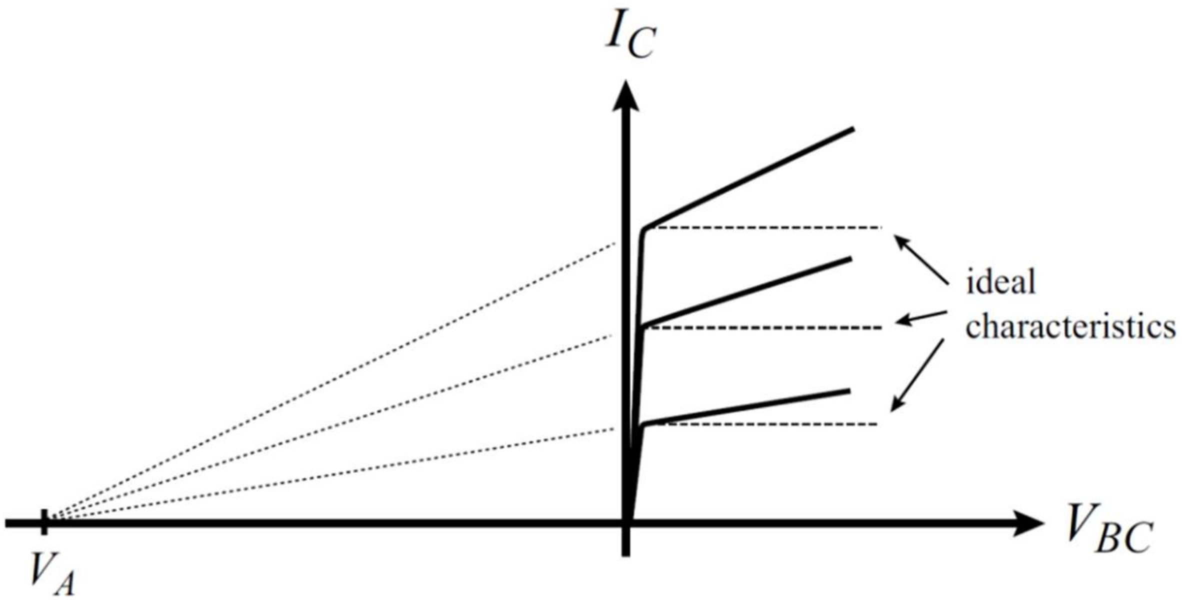


Reverse Bias (V_{BC}) ↑

- Base-Collector depletion width ↑
- Subsequently, W_{bn} ↓
- The slope of the minority carrier profile in the base ↑
- Results in collector current I_C ↑

$$I_C = \frac{eAD_b n_{b0}}{L_b \sinh\left(\frac{W_{bn}}{L_b}\right)} \left[\exp\left(\frac{eV_{BE}}{k_B T}\right) - 1\right]$$

Secondary Order Effect



Early Voltage

Early Effect results in a finite output resistance of the transistor $R_o = \frac{V_A}{I_C}$

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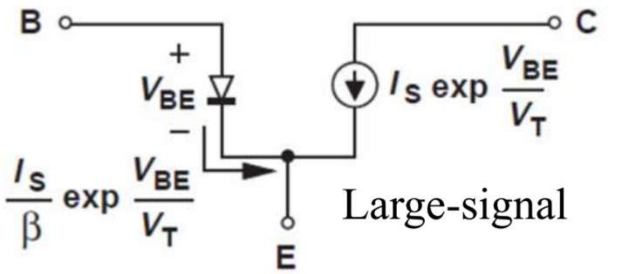
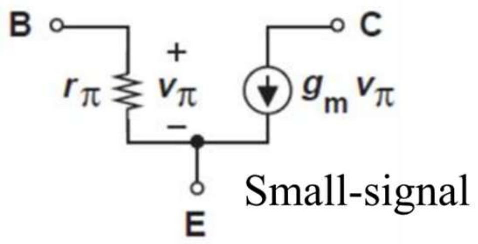
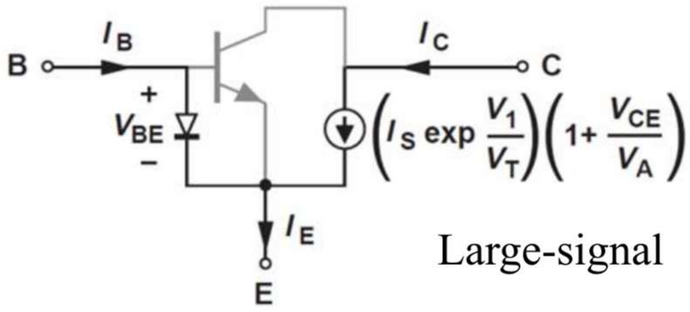
Secondary Order Effect

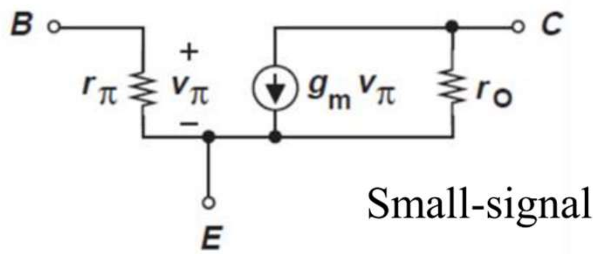


Without Early Effect





With Early Effect



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Good Luck!