Electronic Circuits
Chapter 2: BJT

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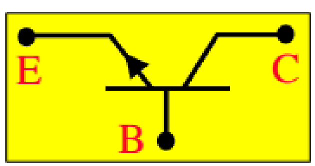
Content

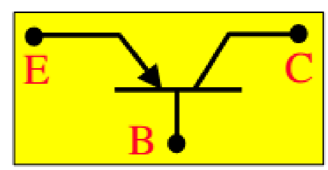
Bipolar Junction Transistor

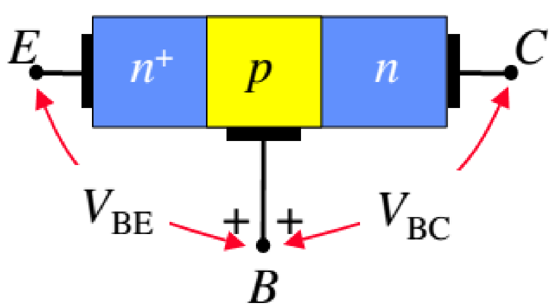
- First Introduced in 1948 (Bell labs), consists of 2 pn junctions.
- The choice in the design of both discrete and integrated circuit for 3 decades.
- the MOSFET was undoubtedly the most widely used electronic device, and CMOS technology the technology of choice in the design of integrated circuits.
- The BJT remains popular in discrete-circuit design.
- The BJT is still the preferred device in very demanding analog circuit applications.
- The BJT can be combined with MOSFETs to create innovative circuits.

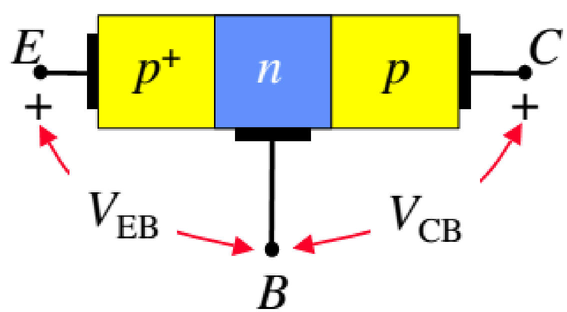
NPN - transistor



PNP - transistor



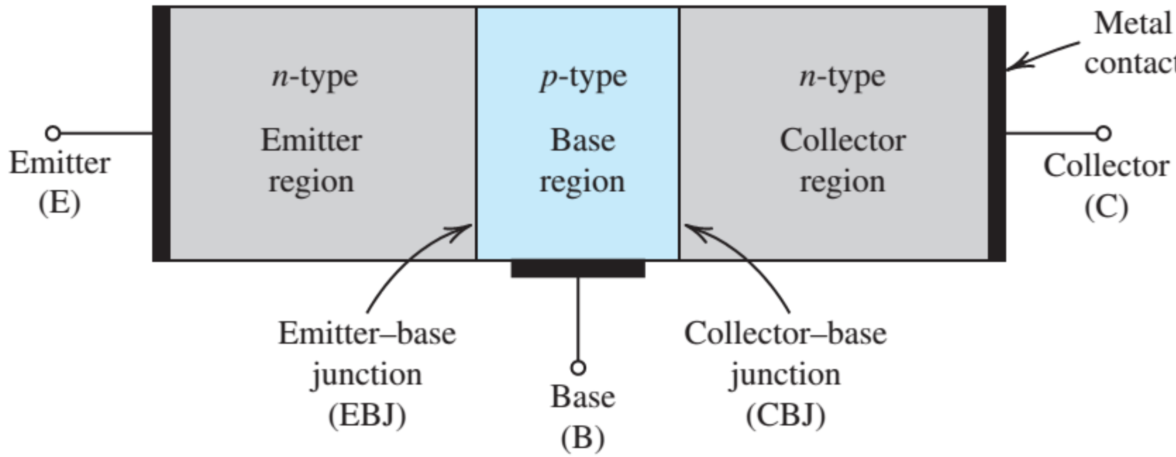




Bipolar Junction Transistor (BJT)

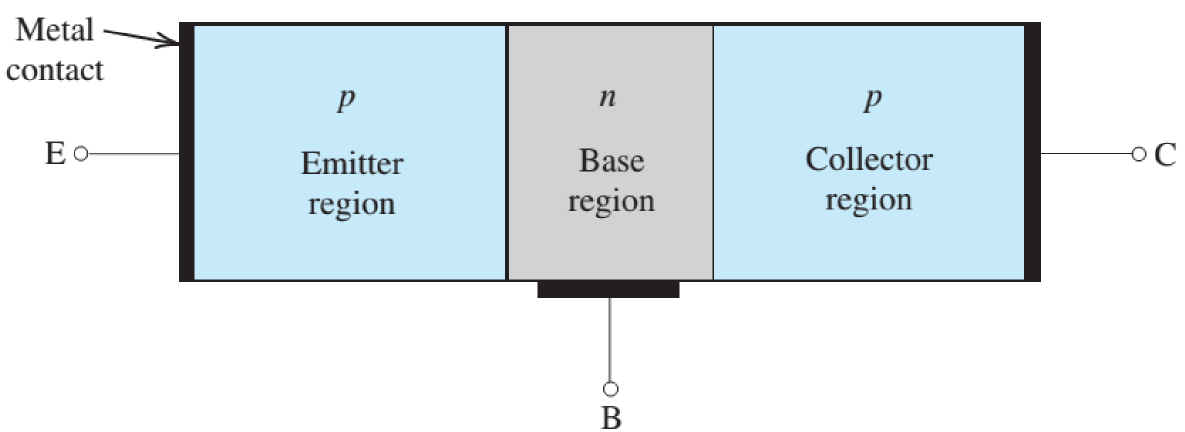
BJT consists of two pn junctions:

- emitter-base junction (EBJ)
- collector-base junction (CBJ)



A simplified structure of npn transistor

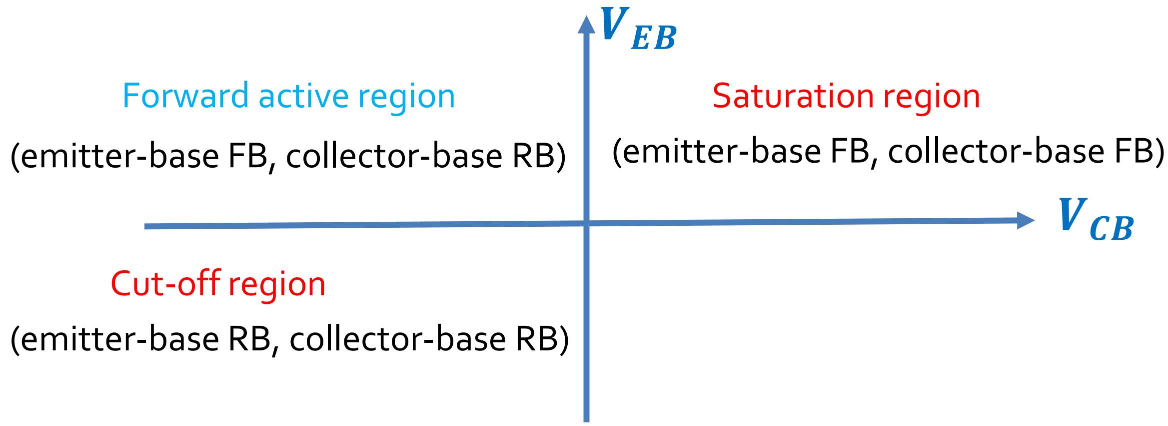
Depending on the bias condition (forward or reverse) of each of these junctions, differentmodes of operation of the BJT are obtained.



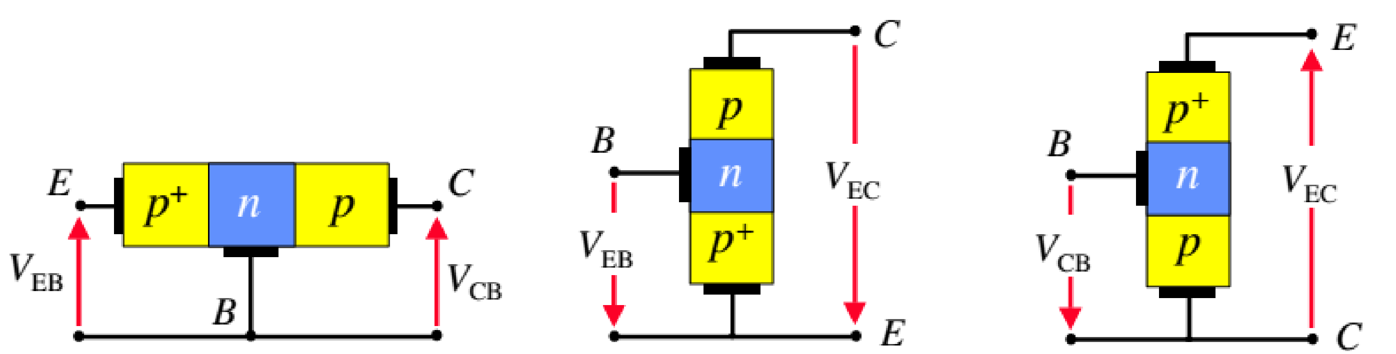
A simplified structure of pnp transistor

BJT Modes of Operation

Regions of operation of a BJT transistor (example for a pnp BJT):

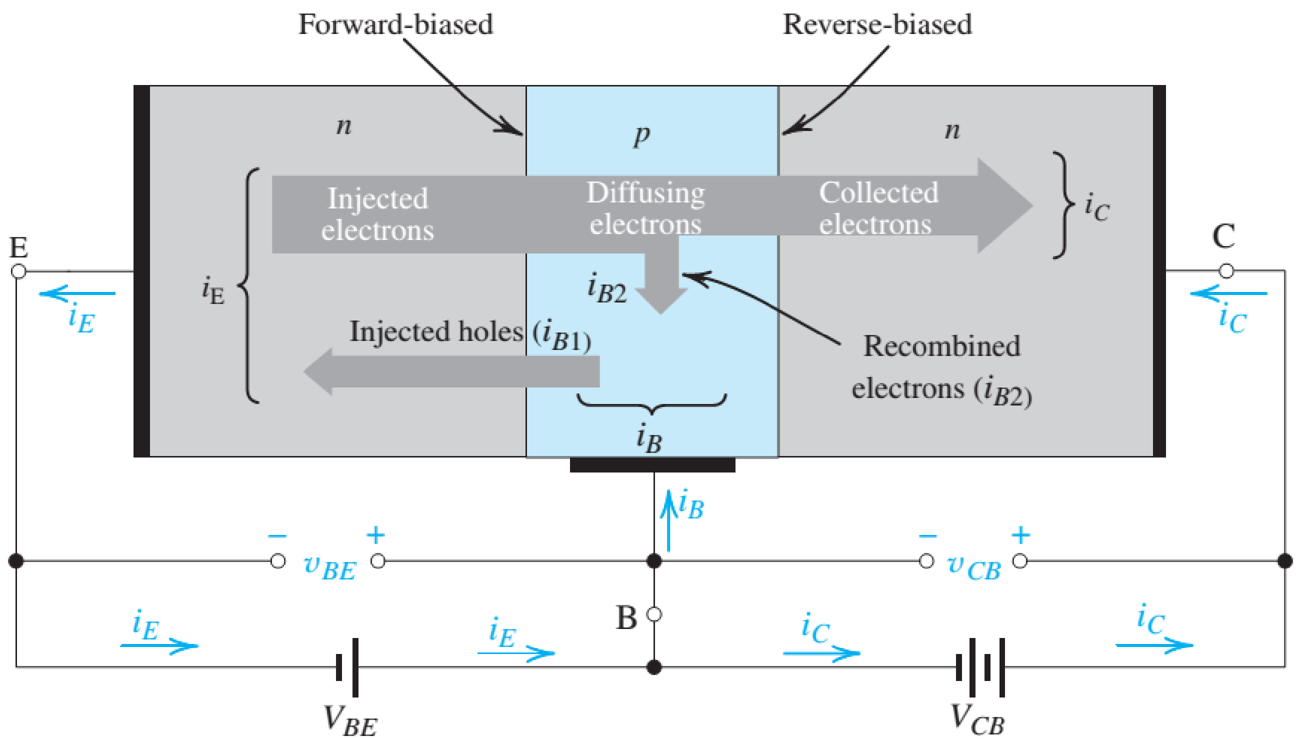


Since BJT has three terminals, there are three possible amplifier types:



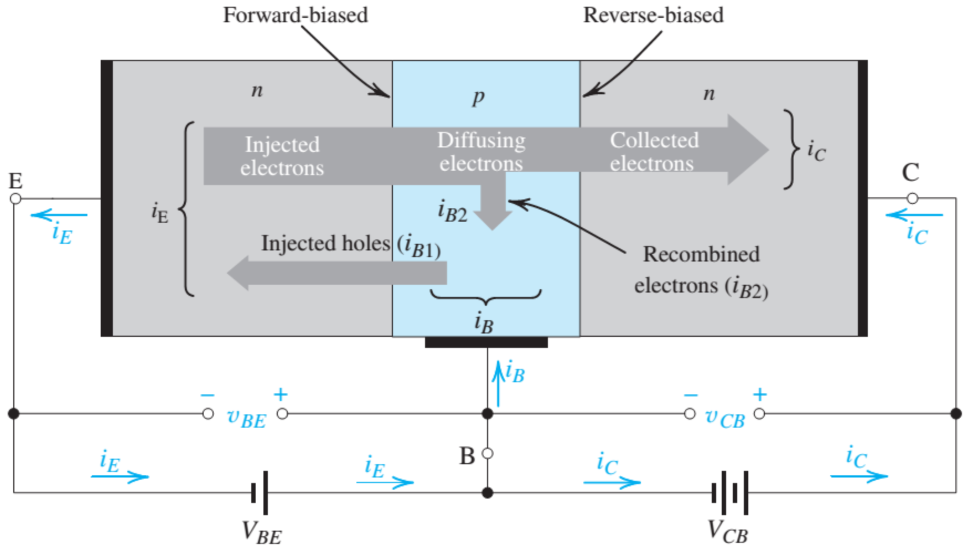
(a) Common-base (b) Common-emitter (c) Common-collector

Active mode (npn BJT)



Emitter-base junction is Forward Biased, collector-base junction is Reversed Biased

Active mode (npn BJT)



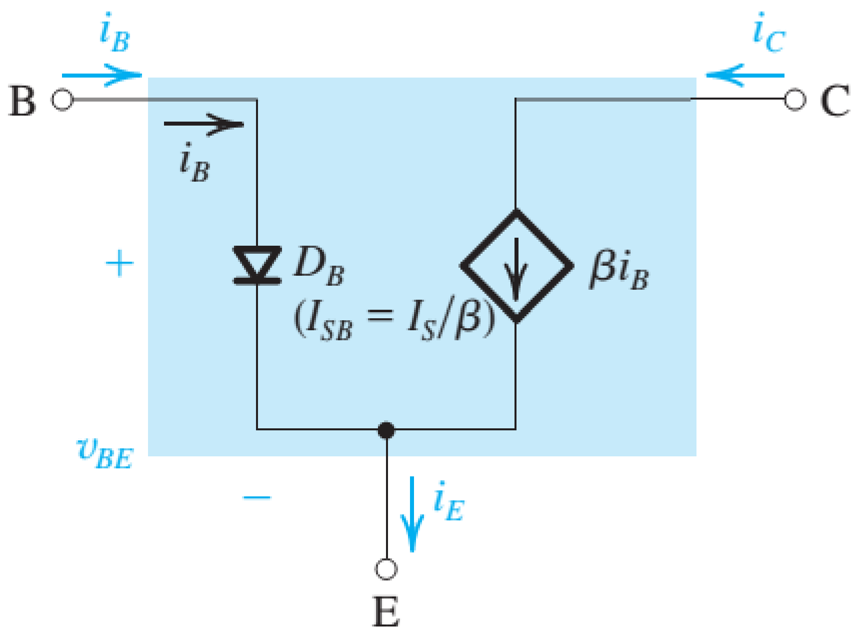
- Forward bias of EBJ causes electrons to diffuse from emitter into base.

- As base region is very thin, the majority of these electrons diffuse to the edge of the depletion region of CBJ, and then are swept to the collector by the electric field of the reverse-biased CBJ.

- A small fraction of these electrons recombine with the holes in base region.

- Holes are injected from base to emitter region.

Active mode (npn BJT)

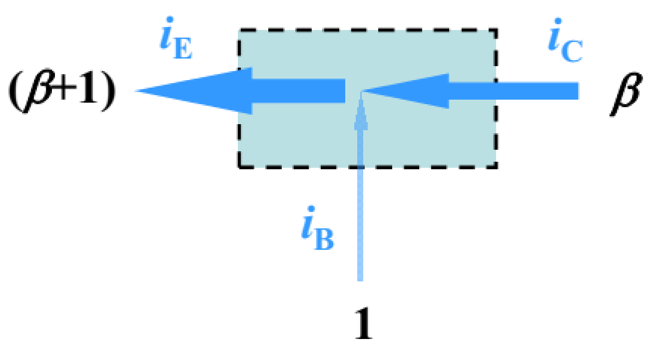


$$i_C = I_S\left(e^{v_{BE}/V_T} - 1\right) \approx I_S e^{v_{BE}/V_T}$$

I_S : saturation current $\quad I_S = \dfrac{A_E q D_n n_i^2}{N_A W}$

- A_E : Area of base-emitter junction
- W : Width of base region
- N_A : Doping concentration in base
- D_n : Electron diffusion constant
- n_i : Intrinsic carrier concentration

$$V_T = \frac{kT}{q} \approx 25mV \text{ @ } 25^0C$$

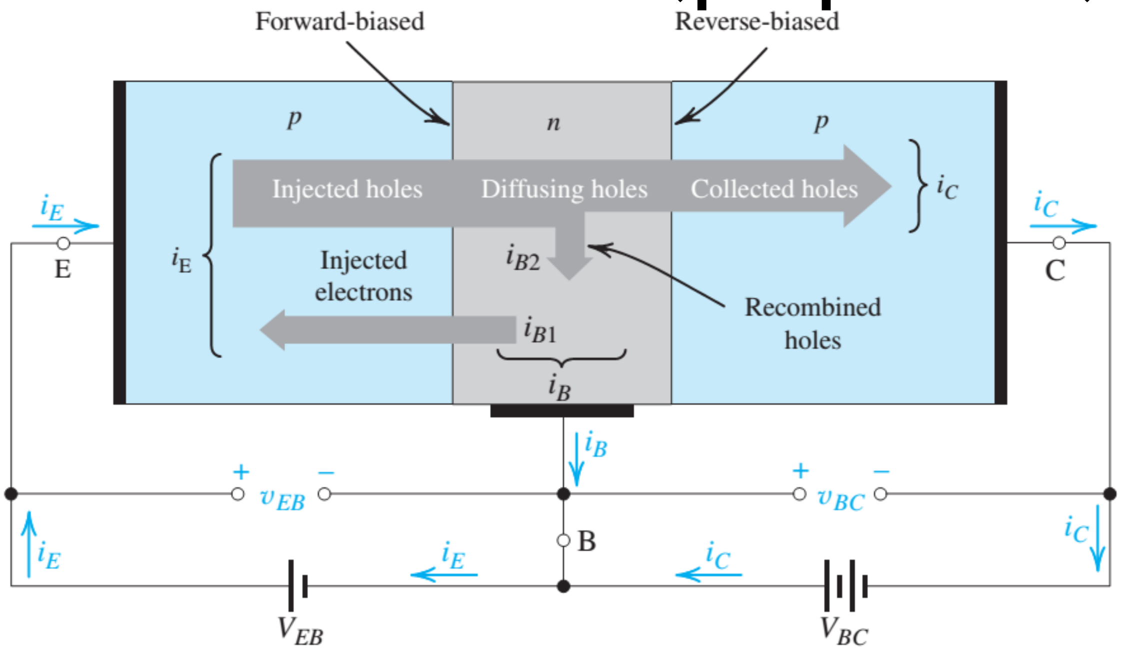


$$i_B = \frac{i_C}{\beta}$$

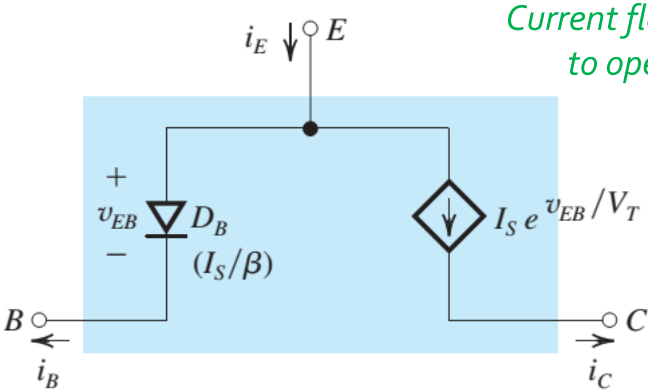
$$i_E = i_B + i_C = (\beta + 1)i_B$$

$$= \frac{\beta + 1}{\beta} i_C = \frac{i_C}{\alpha}$$

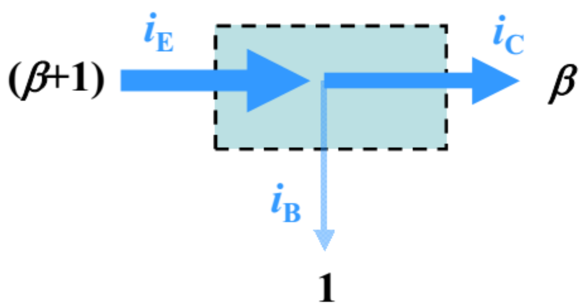
Active mode (pnp BJT)



Current flow in a pnp transistor biased to operate in the active mode.



Large signal model for the pnp transistor operating in the active mode

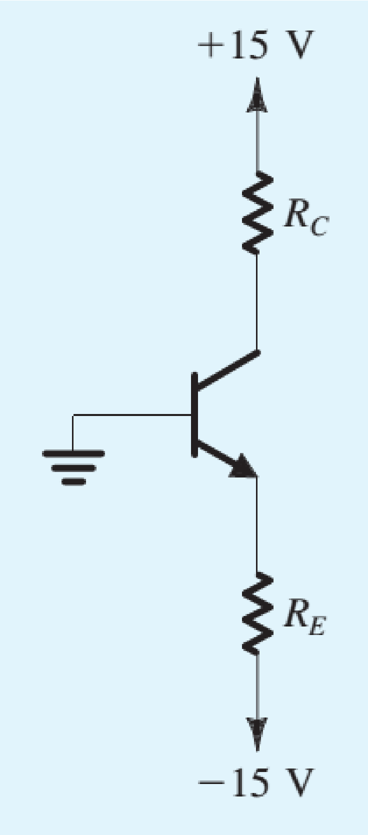


Current gain

Active mode (npn BJT)

For modern npntransistors, β is in the range 50 to 200, but it can be as high as 1000 for special devices.

Example 1:
The transistor in the following circuit having $\beta = 100$ and exhibits a v_{BE} of $0.7V$ at $i_C = 1\ mA$. Design the circuit so that a current of $2mA$ flows through the collector and a voltage of $+5\ V$ appears at the collector.



Active mode (npn BJT)

Example 2: In the circuit shown in figure a, the voltage at the emitter was measured and found to be – $0.7\ V$. If $\beta = 50$, find I_E, I_B, I_C and V_C.

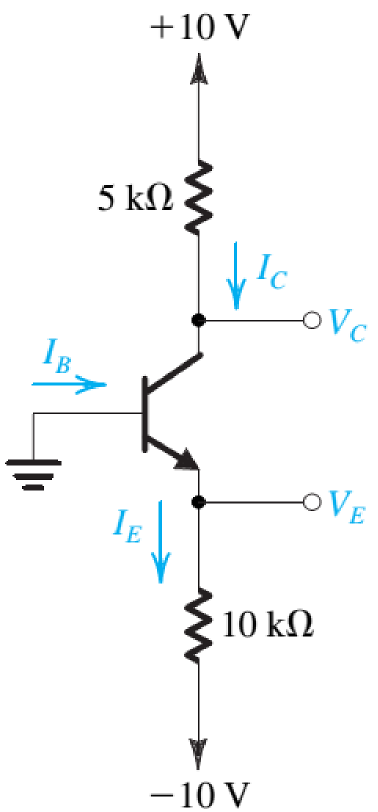


Figure a

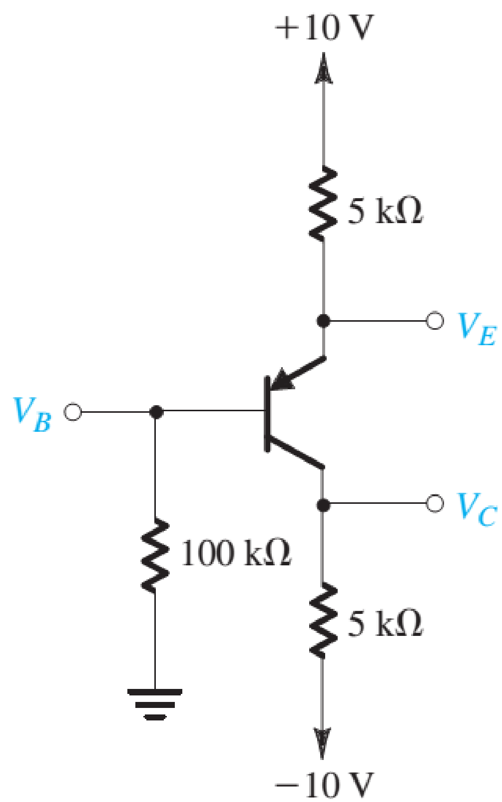
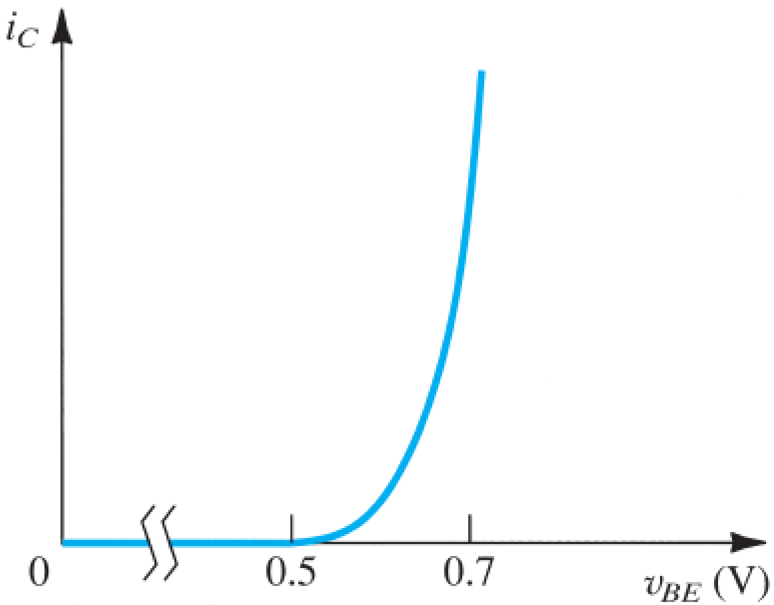


Figure b

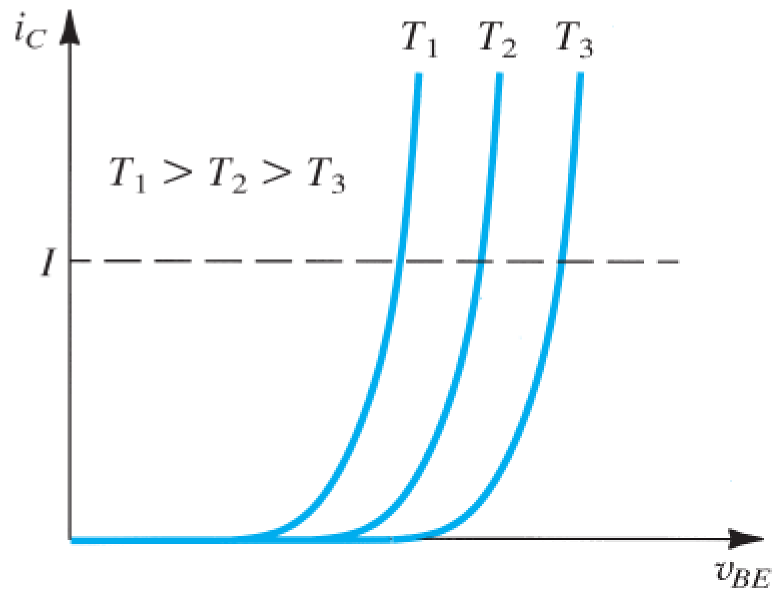
Example 3: In the circuit shown in figure b, measurement indicates V_B to be $+1.0V$ and V_E to be $+1.7V$. What are α and β for this transistor? What voltage V_C do we expect at the collector?

Transistor Characteristics

i_C - v_{BE} characteristic for an npn transistor.

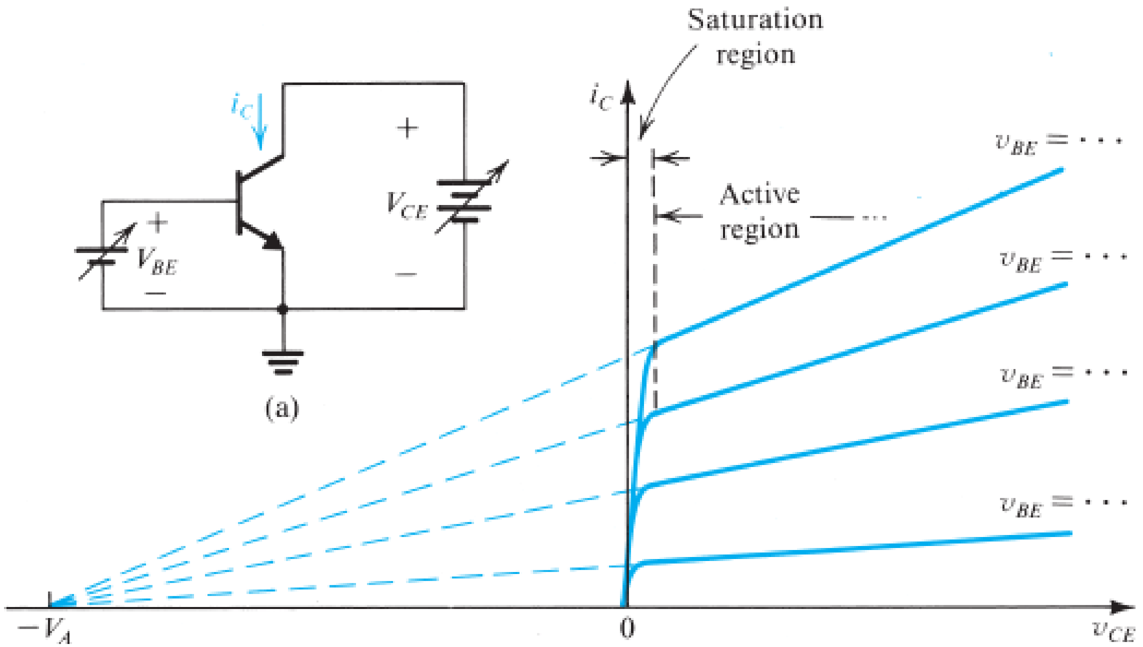


$$i_C = I_S e^{v_{BE}/V_T}$$



Transistor Characteristics – Early Effect

i_C - v_{CB} characteristic for an npn transistor.



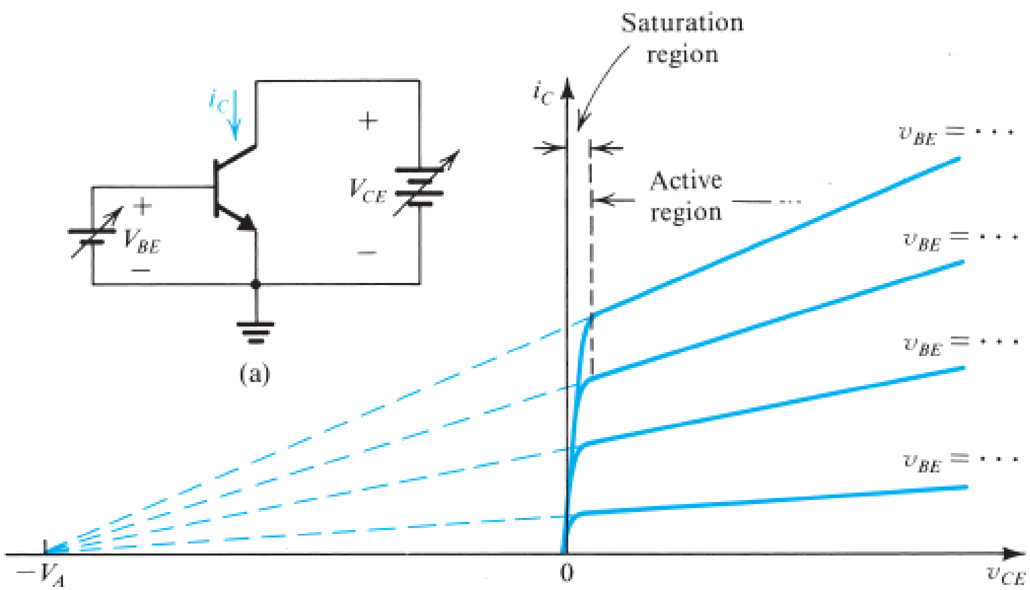
V_A: Early Voltage.

V_A ~ 10V – 100V.

Transistor Characteristics – Early Effect

In saturation region, it behaves as a closed switch with a small resistance R_{CEsat}.

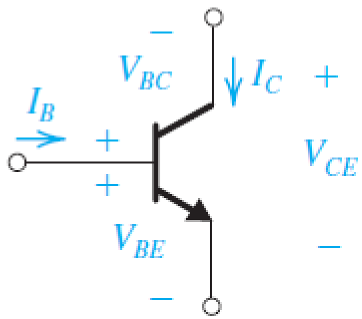
The saturation I-V curve can be approximated by a straight line intersecting the v_{CE} axis at V_{CEoff}.

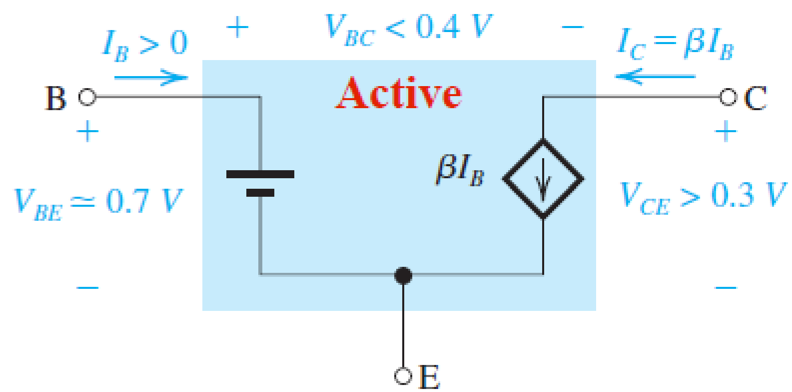


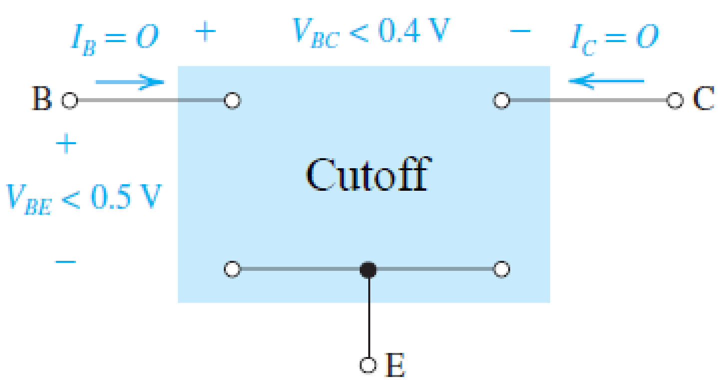
The **output resistance** looking into the collector is not infinite:

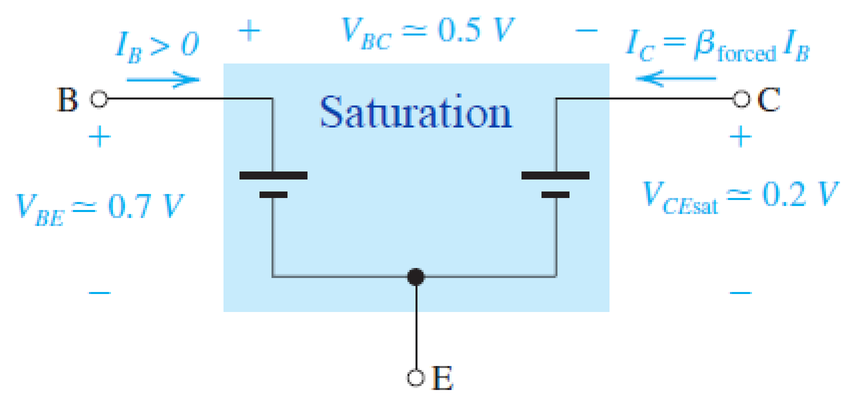
$$\boldsymbol{r_o = \frac{V_A + V_{CE}}{I_C}}$$

BJT Circuits at DC - npn





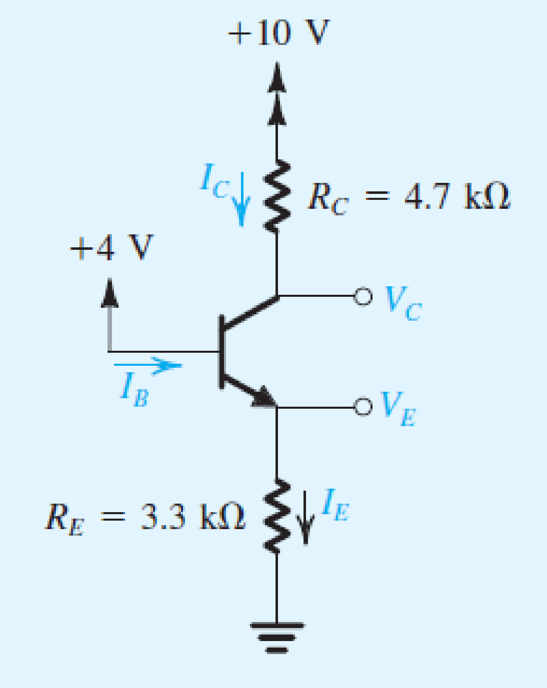


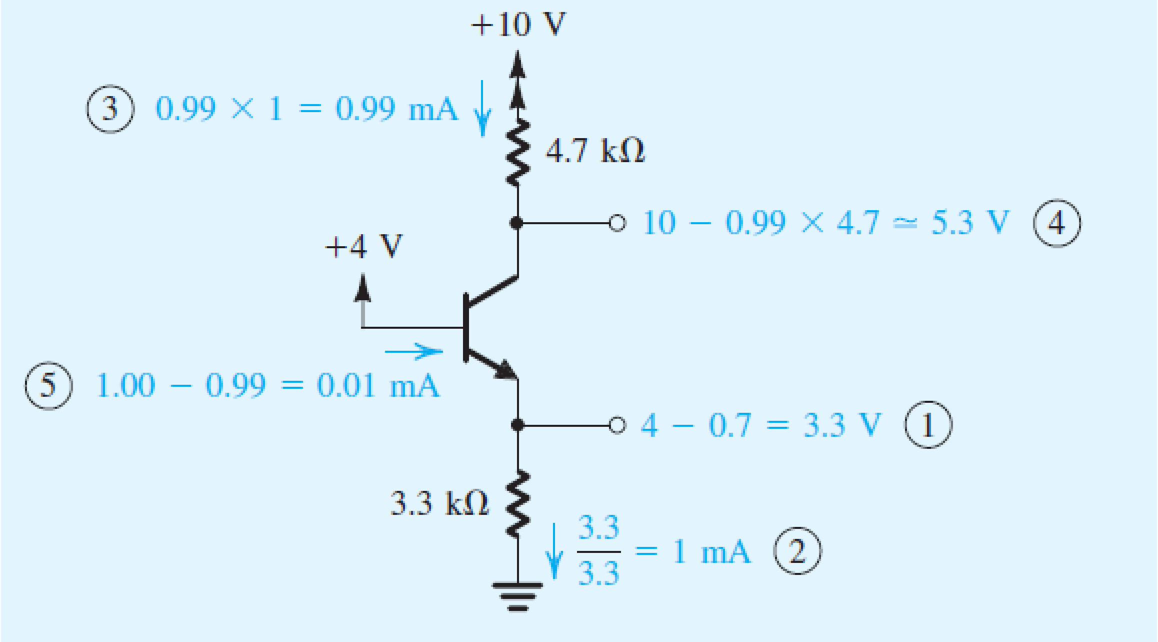


- Step 1: assume the operation mode.
- Step 2: use the conditions or model for circuit analysis.
- Step 3: verify the solution.
- Step 4: repeat the above steps with another assumption if necessary.

BJT Circuits at DC - npn

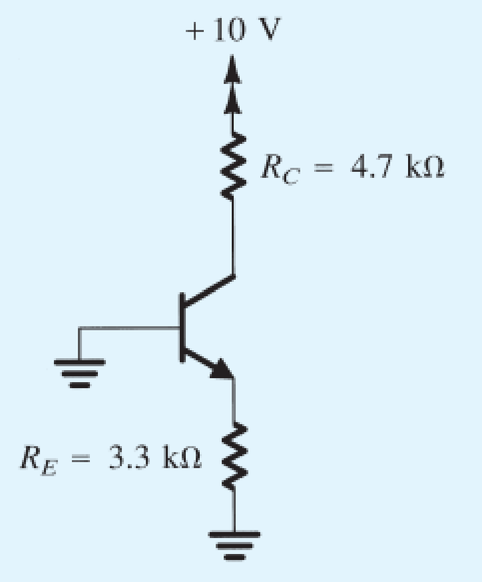
Example 4: Analyze the following circuit to determine all node voltages and branch currents. Assume that β is specified to be 100.

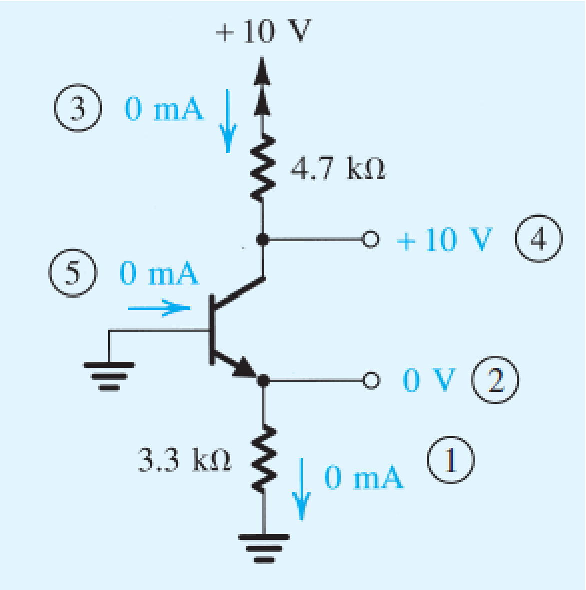




BJT Circuits at DC - npn

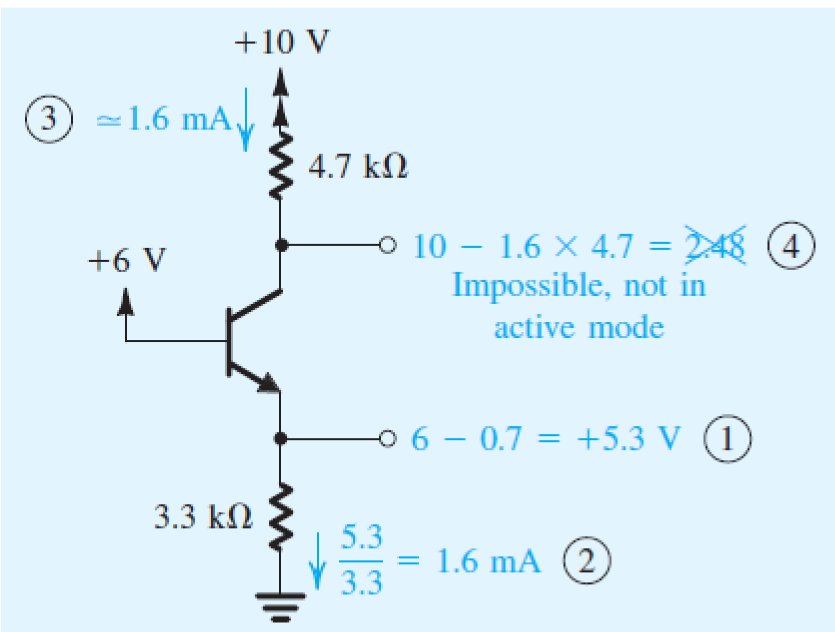
Example 5: Analyze the circuit in Example 1 to determine all node voltages and branch currents. *The voltage at the base is now +0V.*



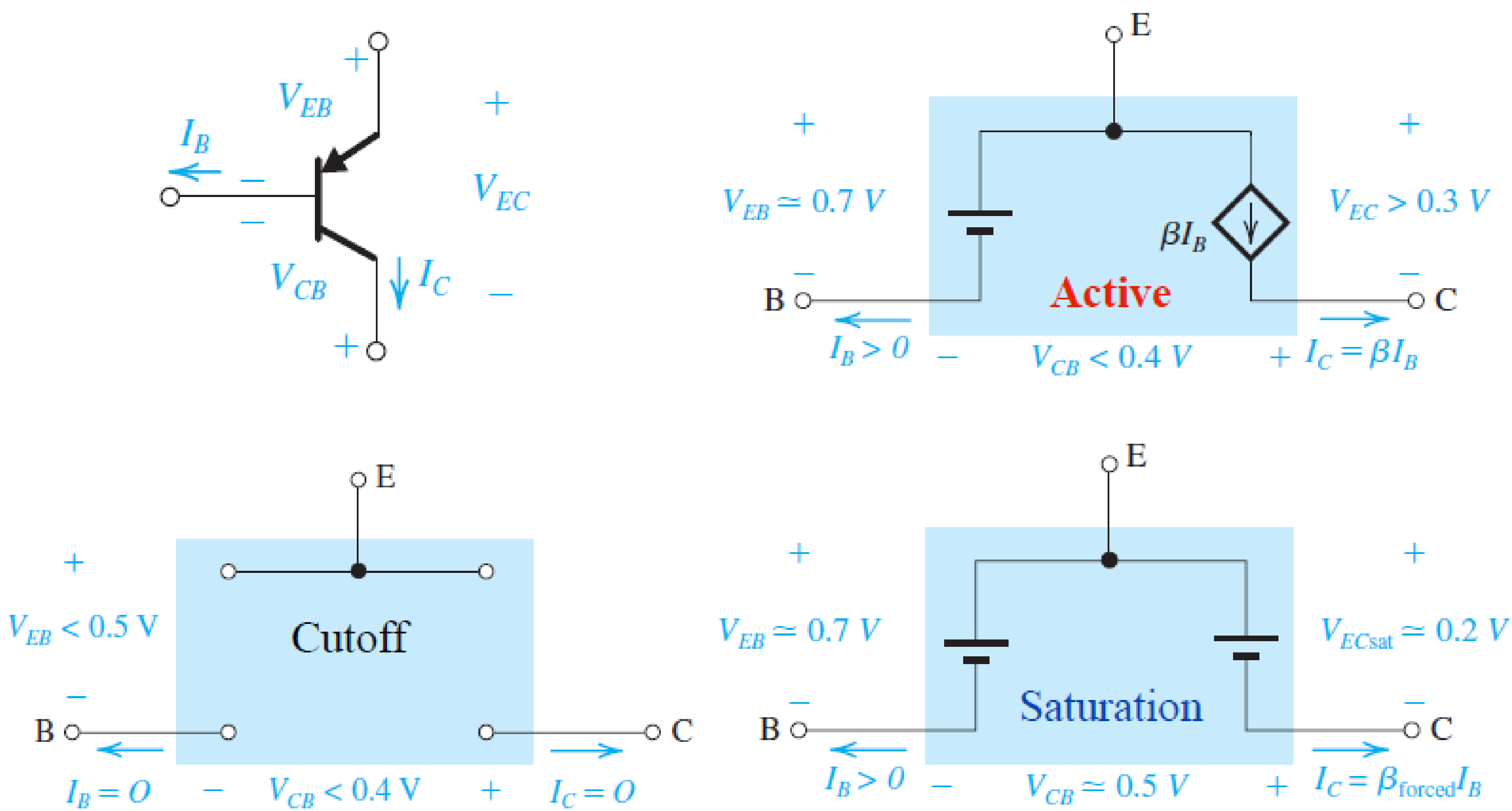


BJT Circuits at DC - npn

Example 6: Analyze the circuit in Example 1 to determine all node voltages and branch currents. *The voltage at the base is now +6V.*

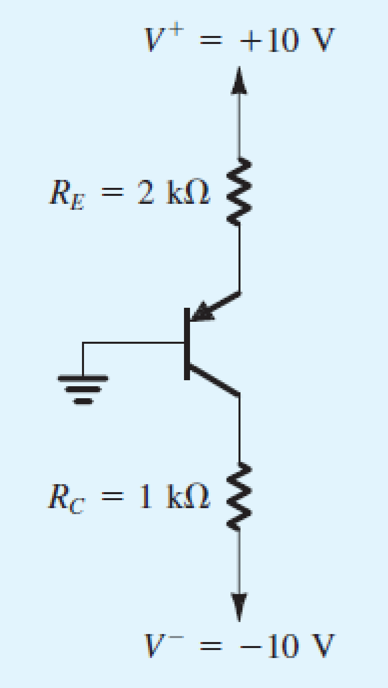


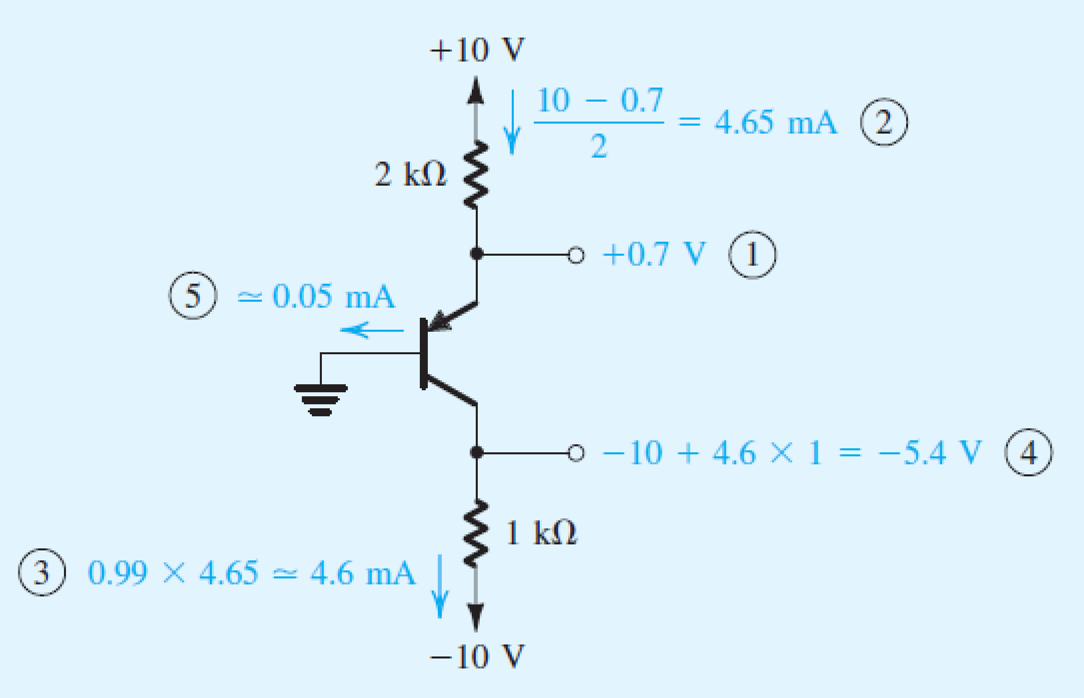
BJT Circuits at DC - pnp



BJT Circuits at DC

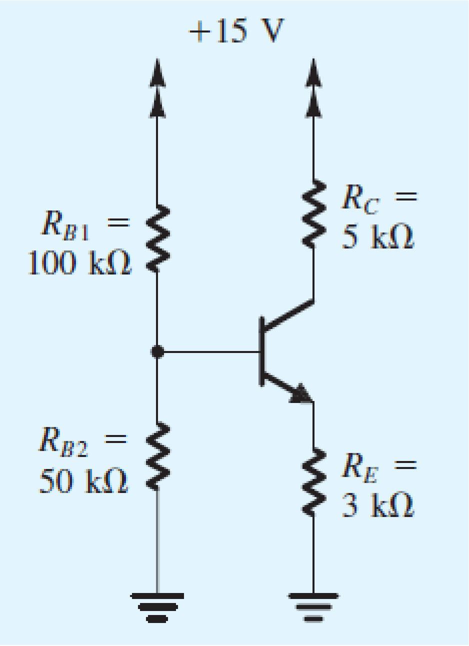
Example 7: **A**nalyze the following circuit to determine all node voltages and branch currents. Assume that β is specified to be 100.

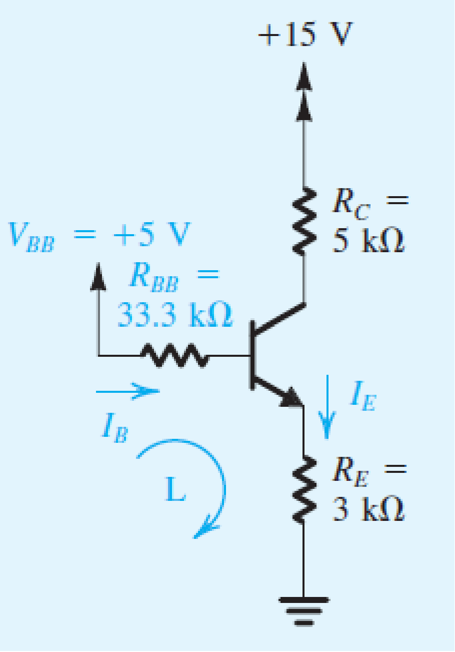


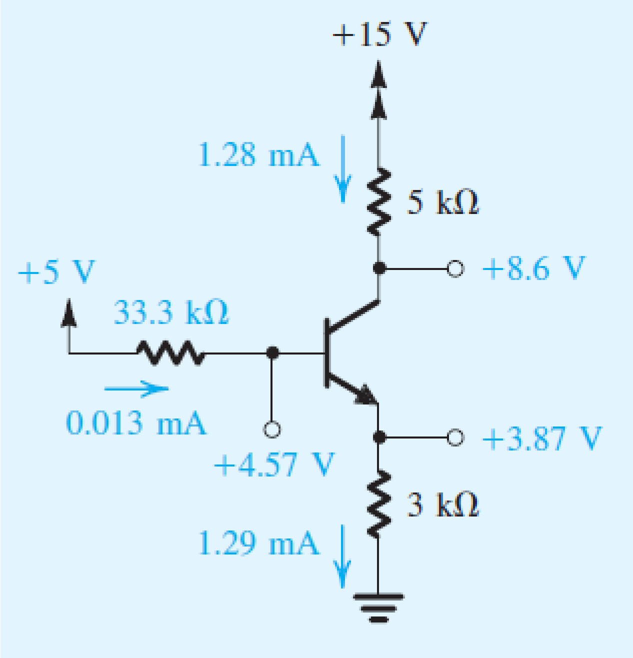


BJT Circuits at DC

Example 8: Analyze the following circuit to determine all node voltages and branch currents. Assume that β is specified to be 100.

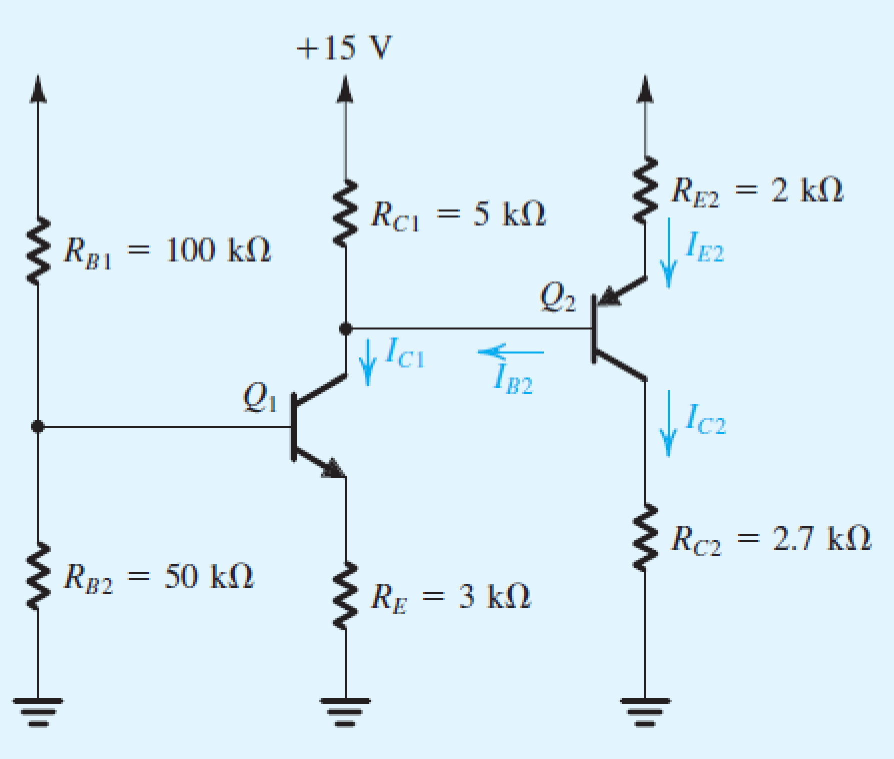


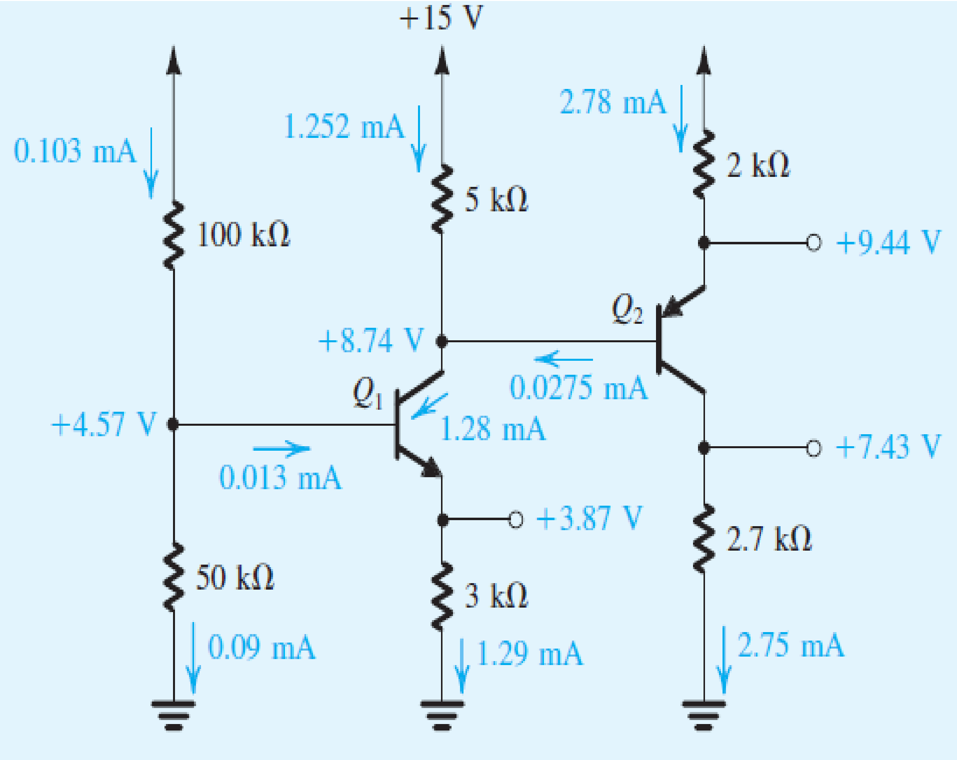




BJT Circuits at DC

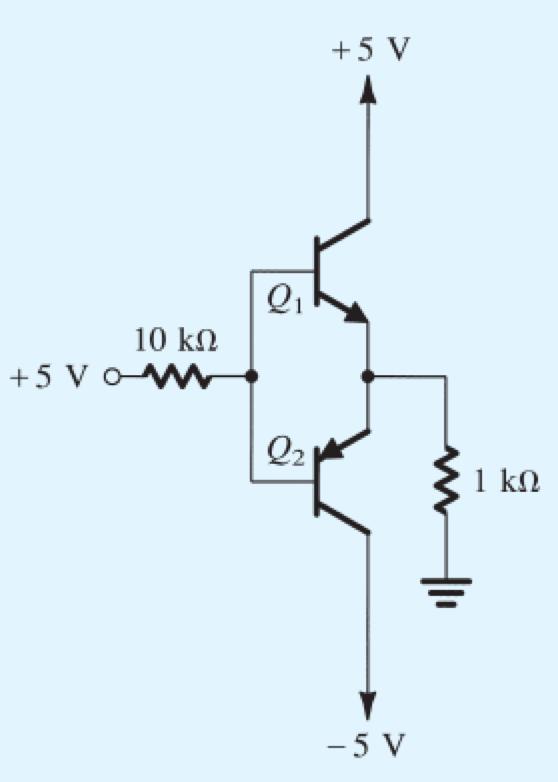
Example 9: Analyze the following circuit to determine all node voltages and branch currents.

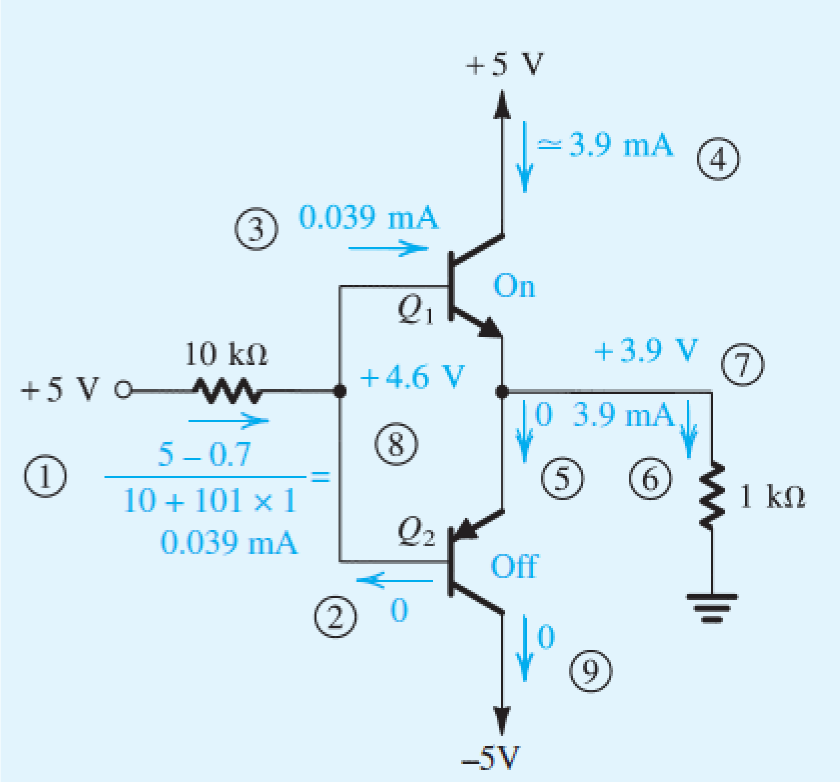




BJT Circuits at DC

Example 10: **A**nalyze the following circuit to determine all node voltages and branch currents. Assume that β is specified to be 100.

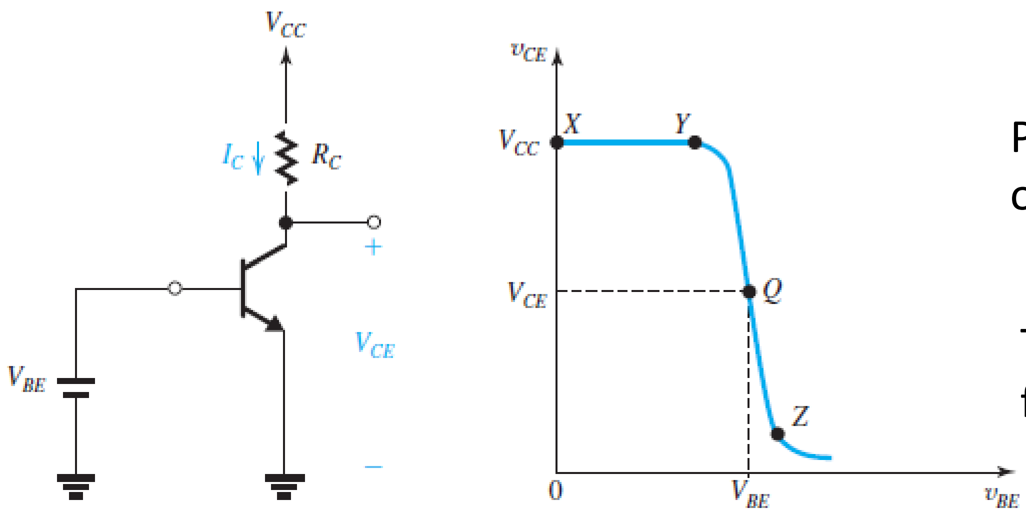




DC Bias for BJT amplifier

❖ The amplifiers are operating at a proper dc bias point.

❖ The DC bias circuit is to ensure the BJT in active mode with a proper collector current IC.



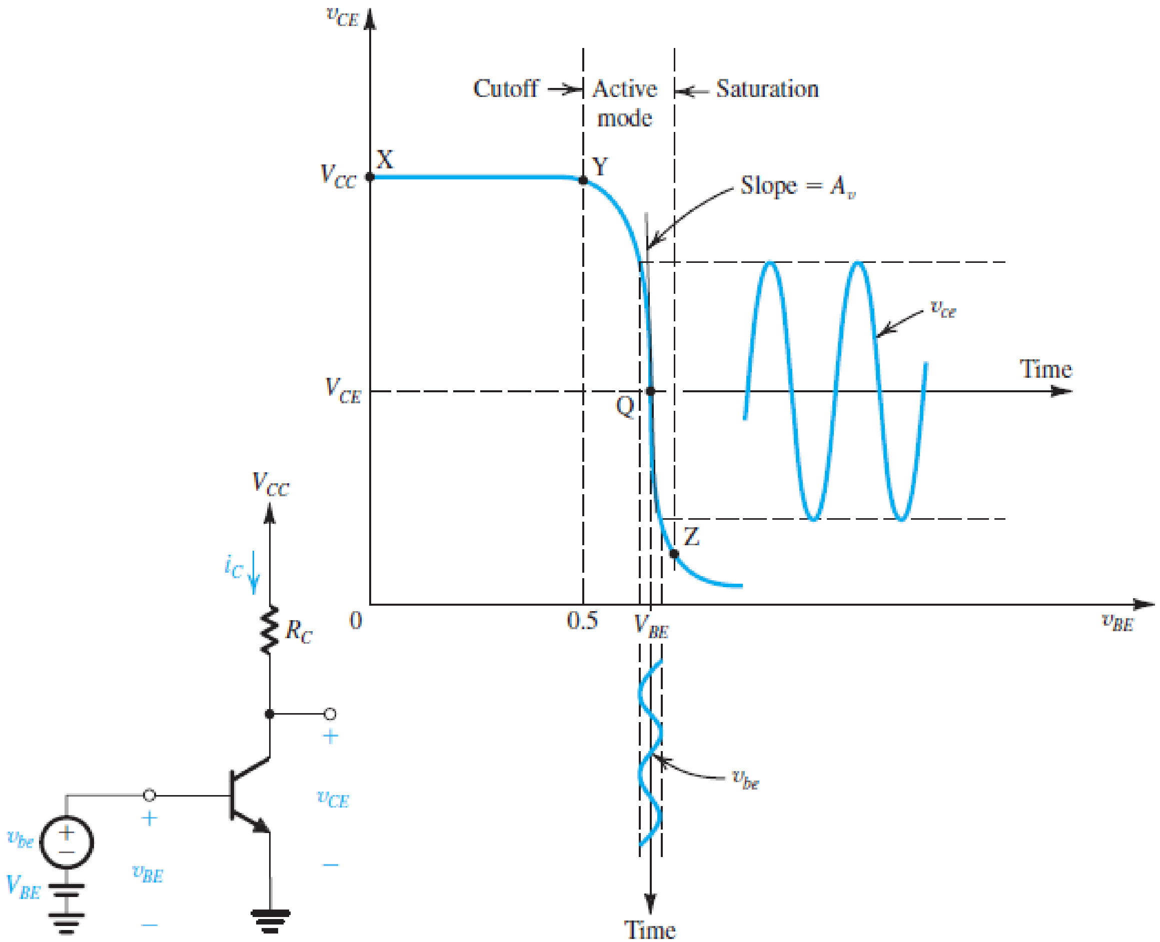
Point Q is known as the **bias point** or the **dc operating point**.

The signal to be amplified v_{be} ,a function of time t.

$$\boxed{V_{CE} = V_{CC} - R_C I_S e^{V_{BE}/V_T}}$$

DC Bias for BJT amplifier

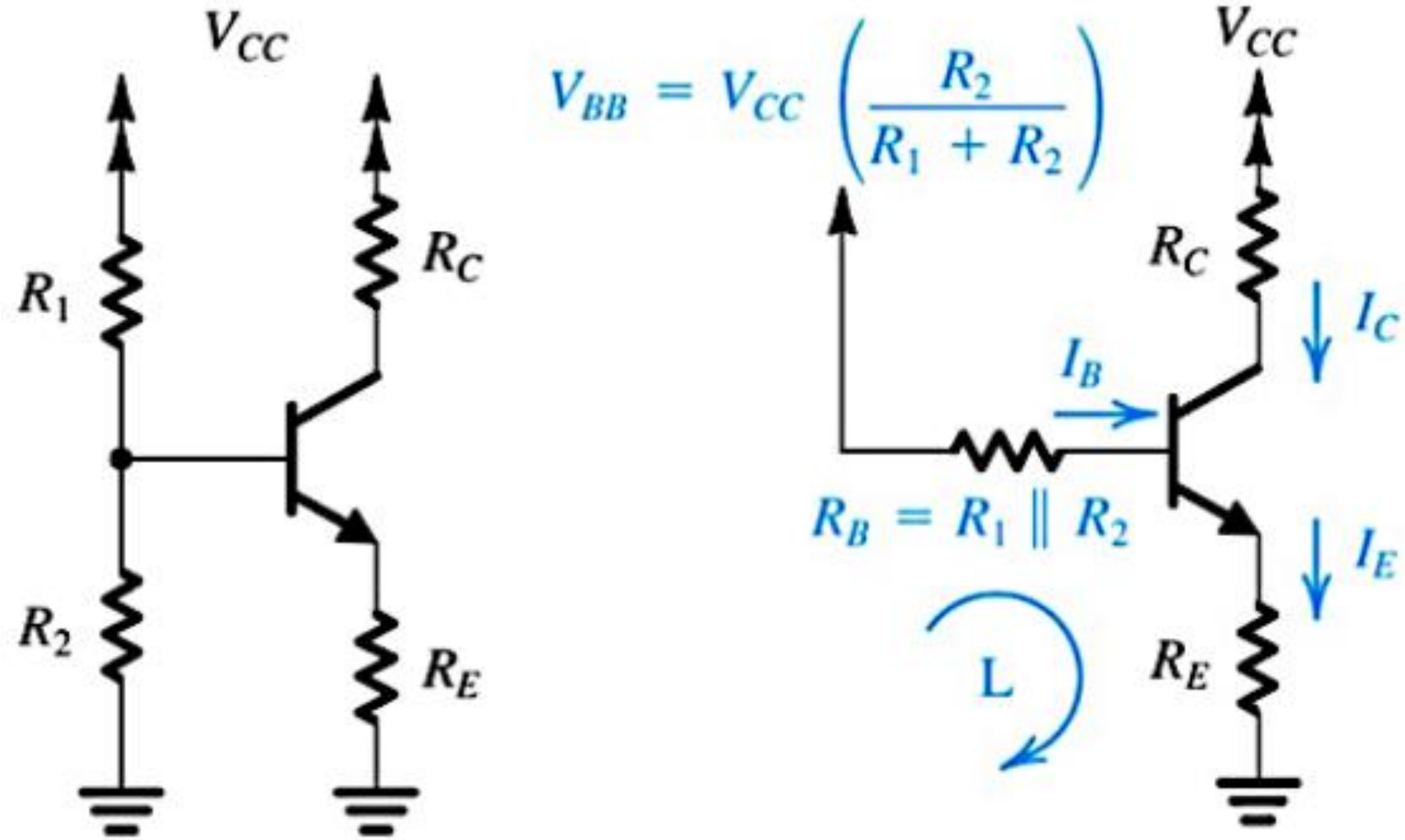
The signal to be amplified v_{be}, a function of time t: $\boldsymbol{v_{BE}(t) = V_{BE} + v_{be}(t)}$



DC Bias for BJT amplifier

❖ **The classical discrete-circuit bias arrangement:**

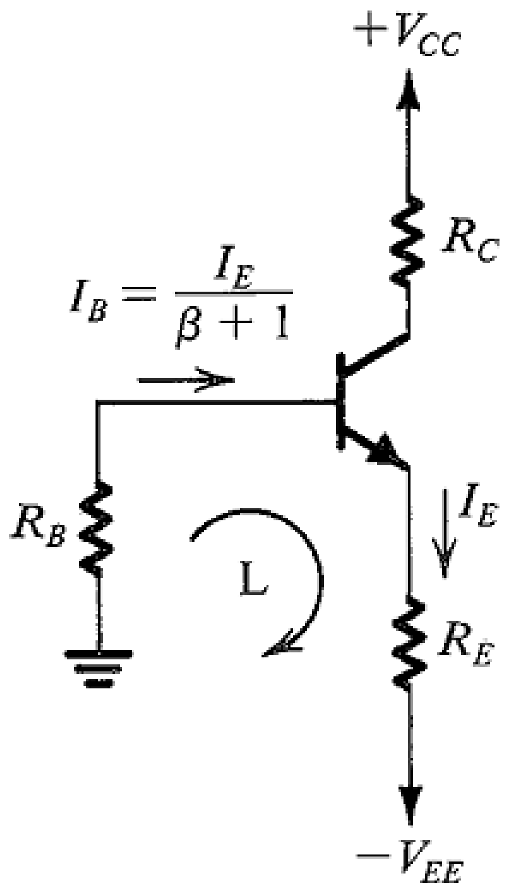
➢ A single power supply and resistors are needed.



DC Bias for BJT amplifier

❖ **The classical discrete-circuit bias arrangement:**

- The two-power-supply version.

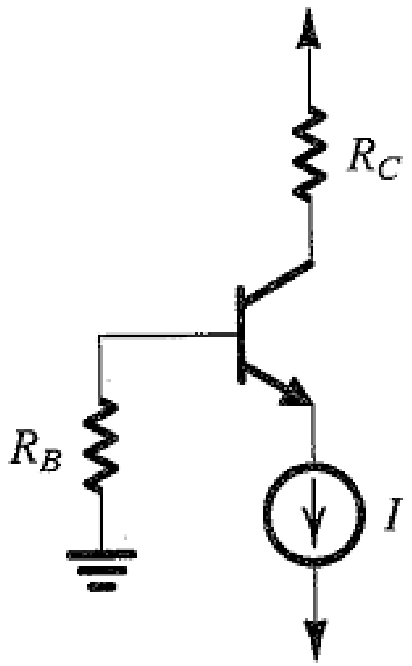


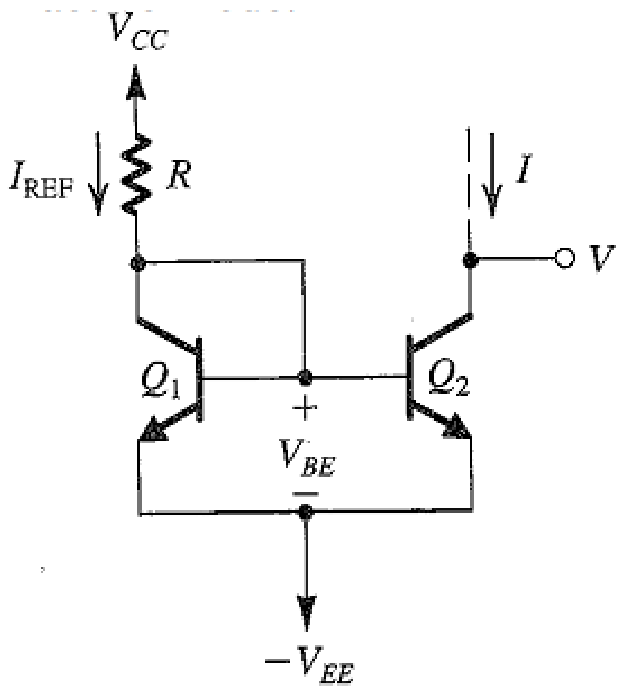
$$I_E = \frac{V_{EE} - V_{BE}}{R_E + R_B/(\beta + 1)}$$

DC Bias for BJT amplifier

❖ **Biasing using a constant-current source:**

- ➢ R_C is chosen to operate the BJT in active mode.
- ➢ The current source is typically implemented by a BJT current mirror.
  - ✓ Both BJT transistors Q1 and Q2 are in active mode.
  - ✓ Assume current gain β is very high.



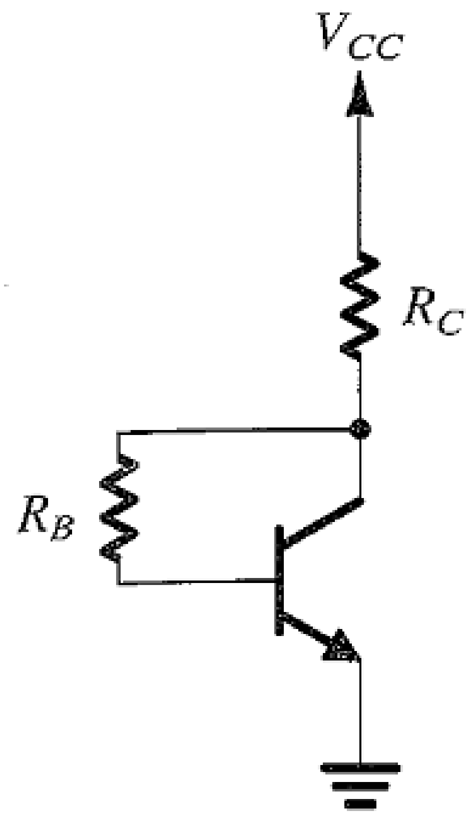


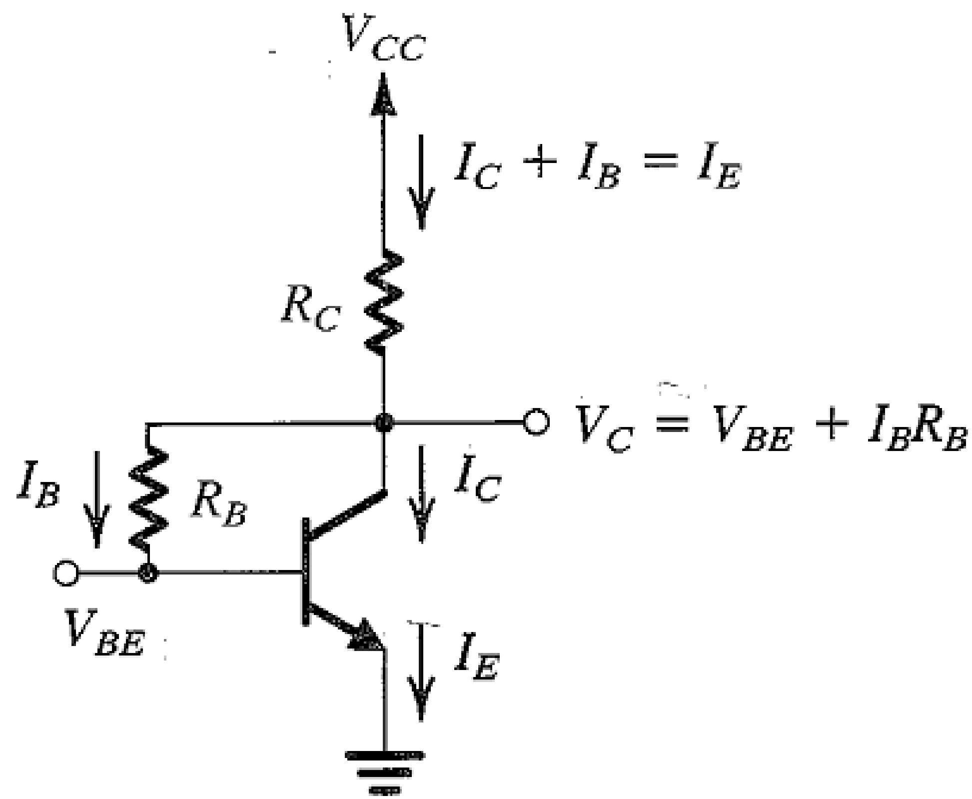
$$I_{REF} = \frac{V_{CC} + V_{EE} - V_{BE}}{R}$$

DC Bias for BJT amplifier

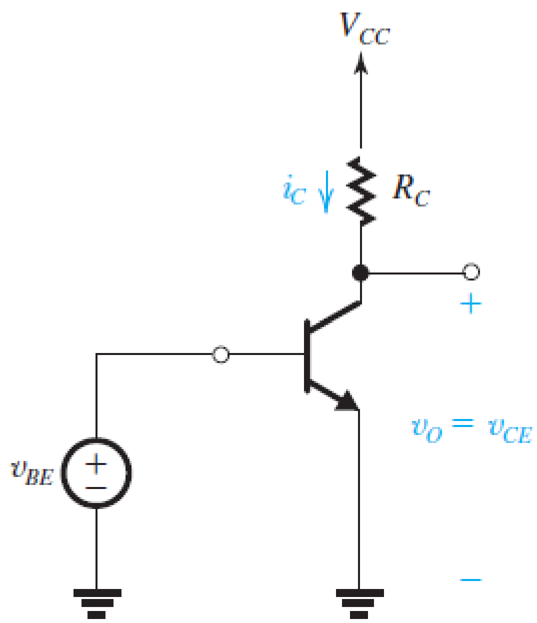
❖ **Biasing using a collector-to-base feedback resistor:**

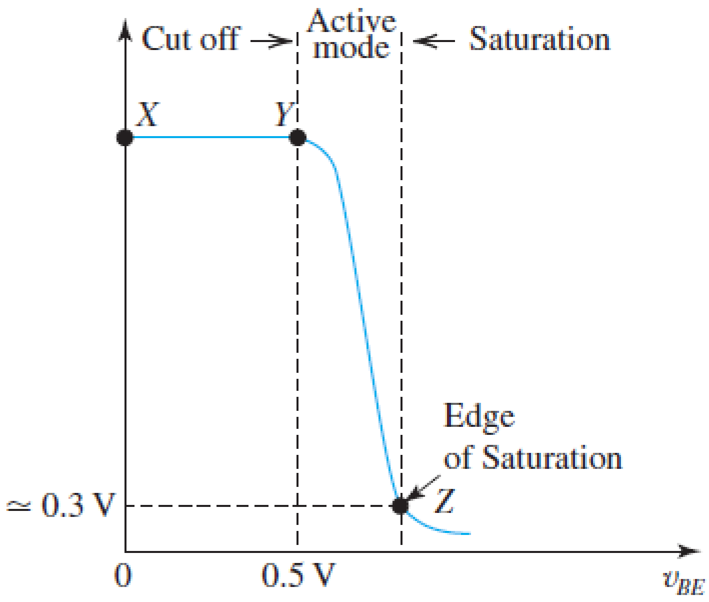
➢ R_B ensures the BJT in active ($V_{CE} > V_{BE} = 0.7V$)





Obtaining a Voltage Amplifier





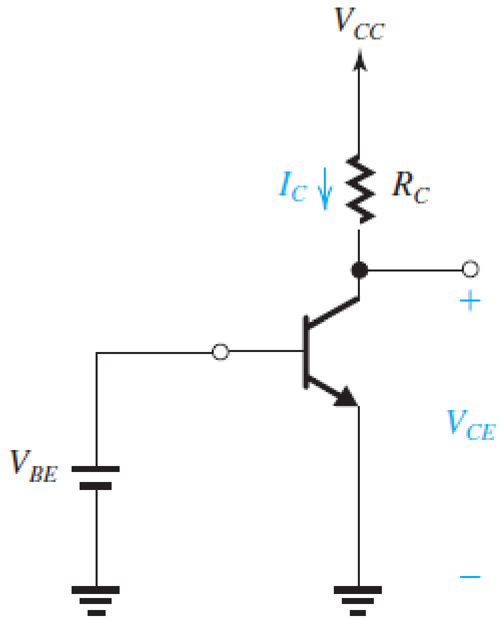
The output voltage v_{CE} is given by: $v_{CE} = V_{CC} - i_C R_C$

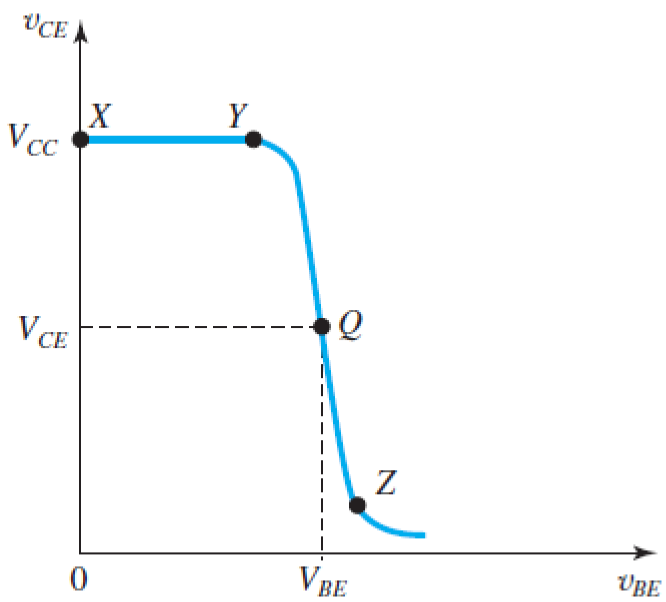
In active mode: $i_C = I_S e^{v_{BE}/V_T}$ (Neglect the Early effect)

The result is: $v_{CE} = V_{CC} - I_S e^{v_{BE}/V_T} R_C$

This is obviously a nonlinear relationship.

Biasing the BJT



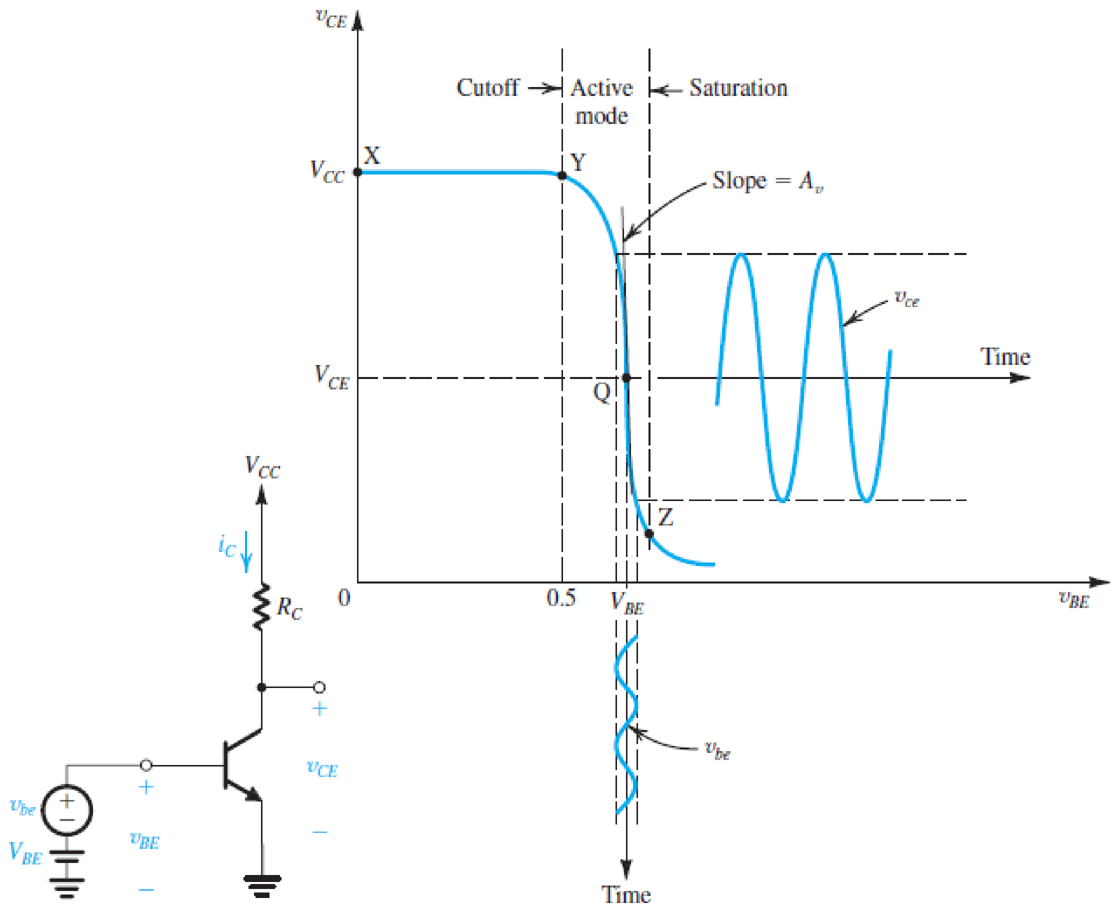


A dc voltage is selected to obtain operation at a point Q: $V_{CE} = V_{CC} - I_S e^{V_{BE}/V_T} R_C$

Point Q is known as the ***Bias point*** or the ***DC operating point***.

Since at Q no signal component is present, it is also known as the ***Quiescent point.***

Biasing the BJT



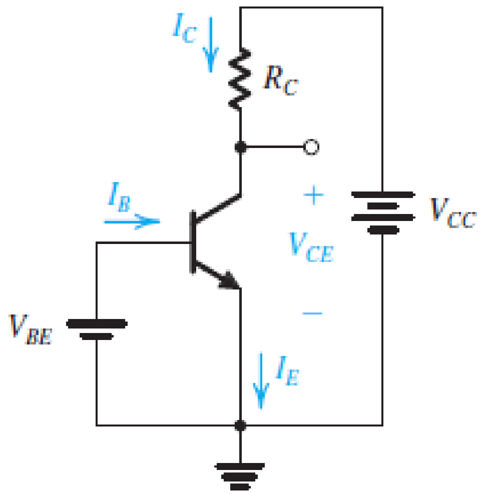
The signal v_{be} to be amplified a function of time t is superimposed on the bias voltage V_{BE}:

$$v_{BE}(t) = V_{BE} + v_{be}(t)$$

The resulting $v_{CE}(t)$ can be obtained by substituting this expression for $v_{BE}(t)$ into:

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

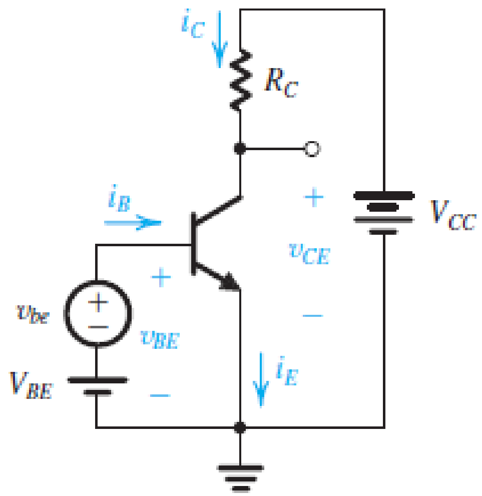
Small-Signal Operation and Models



We consider the **DC** bias conditions by setting $v_{be} = 0$. Then:

$$I_C = I_S e^{V_{BE}/V_T} \qquad I_B = I_C/\beta$$

$$I_E = I_C/\alpha \qquad V_{CE} = V_{CC} - I_C R_C$$



When $v_{be} \neq 0$, the total instantaneous base-emitter voltage v_{BE} becomes: $v_{BE} = V_{BE} + v_{be}$

The collector current becomes:

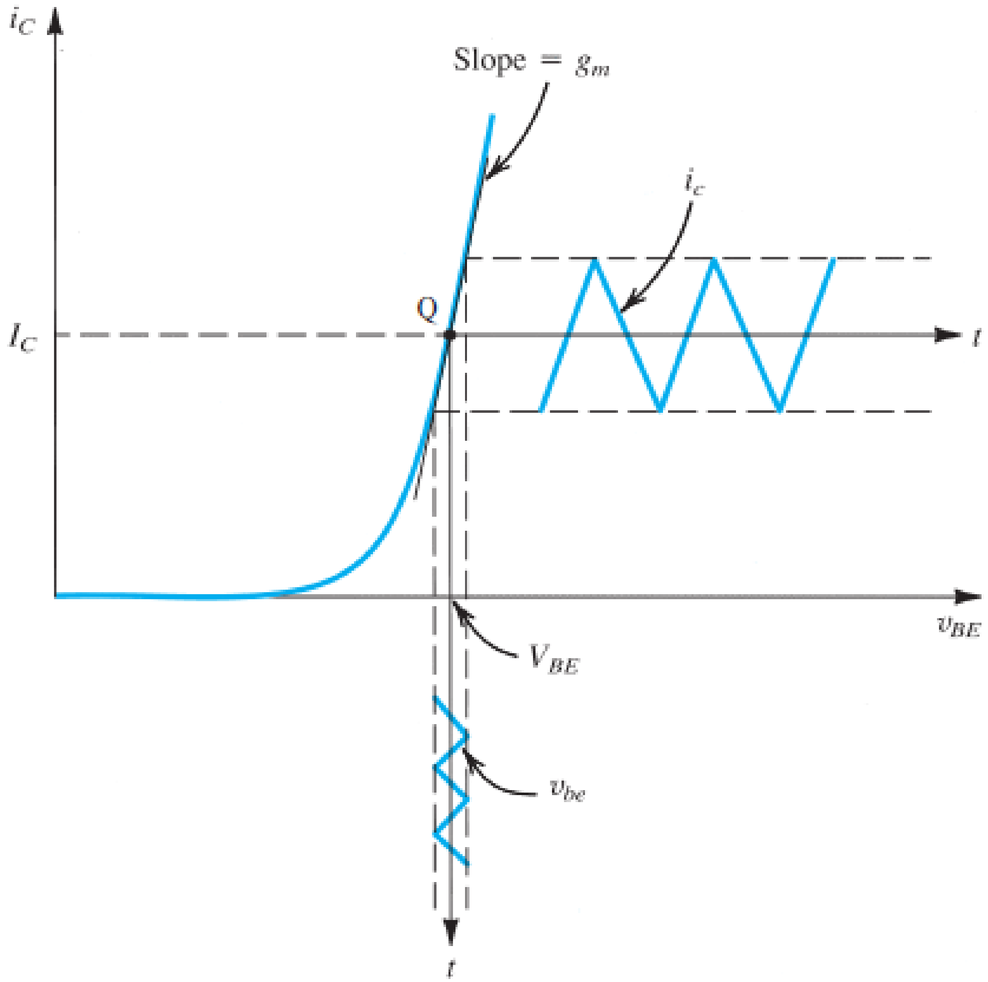
$$i_C = I_S e^{v_{BE}/V_T} = \left(I_S e^{V_{BE}/V_T}\right) e^{v_{be}/V_T} = I_C e^{v_{be}/V_T}$$

Small signal operation: $v_{be} \ll V_T$

$$i_C = I_C + i_c \approx I_C\left(1 + \frac{v_{be}}{V_T}\right) = I_C + \frac{I_C}{V_T} v_{be}$$

$$g_m = \frac{\partial i_C}{\partial v_{BE}}\Big|_{i_C = I_C} = \frac{I_C}{V_T}$$

Small-Signal Operation and Models



g_m is called the **trans-conductance**:

$$g_m = \frac{\partial i_C}{\partial v_{BE}}\Big|_{i_C = I_C} = \frac{I_C}{V_T}$$

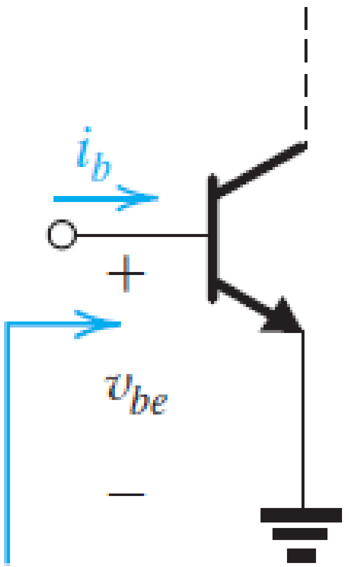
Small-Signal Operation and Models

- The base current and the input resistance at the base:
  - Base current:

$$i_B = \frac{i_C}{\beta} = \frac{I_S}{\beta} e^{v_{BE}/V_T} = I_B e^{v_{be}/V_T}$$

  - Small-signal approximation: $v_{be} \ll VT$

$$i_B = I_B + i_b \approx I_B\left(1 + \frac{v_{be}}{V_T}\right) = I_B + \frac{I_B}{V_T} v_{be}$$



$$r_\pi \equiv \frac{v_{be}}{i_b}$$

$$r_\pi = \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{V_T}{I_B}$$

The small-signal input resistance between base and emitter (looking into the base)

Small-Signal Operation and Models

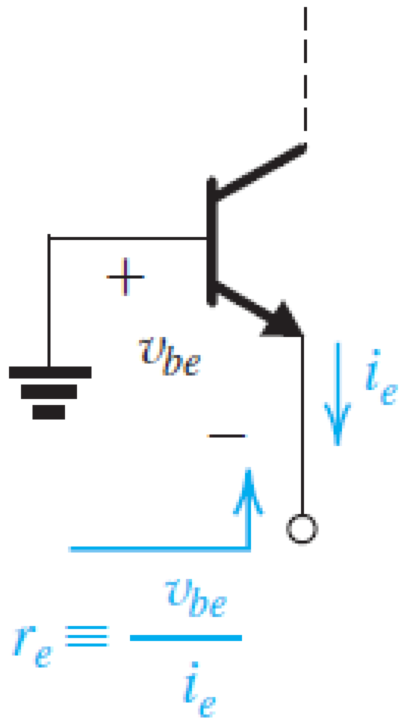
- The emitter current and the input resistance at the emitter:
  - Emitter current:

$$i_E = I_E + i_e = \frac{i_C}{\alpha} = \frac{I_C}{\alpha} + \frac{i_c}{\alpha}$$

  - Small-signal approximation: $v_{be} << VT$

$$i_e = \frac{i_c}{\alpha} = \frac{g_m}{\alpha} v_{be} = \frac{I_E}{V_T} v_{be}$$

$$r_e \equiv \frac{v_{be}}{i_e} = \frac{V_T}{I_E} = \frac{\alpha}{g_m} \approx \frac{1}{g_m}$$



$$r_\pi = (1+\beta) r_e$$

The relation between resistance at base and resistance at emitter

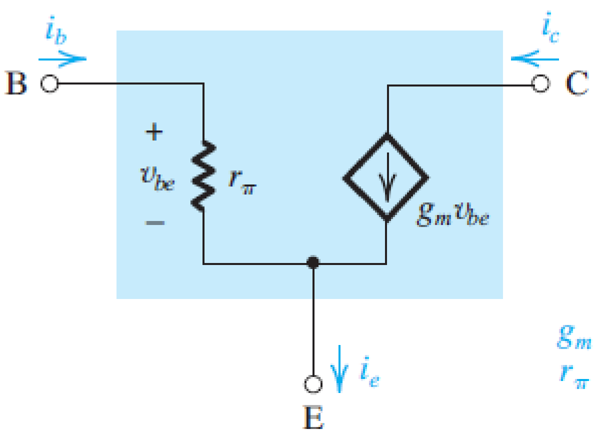
Small-Signal Operation and Models

There are **two type** of equivalent circuit model of and BJT in small-signal operation:

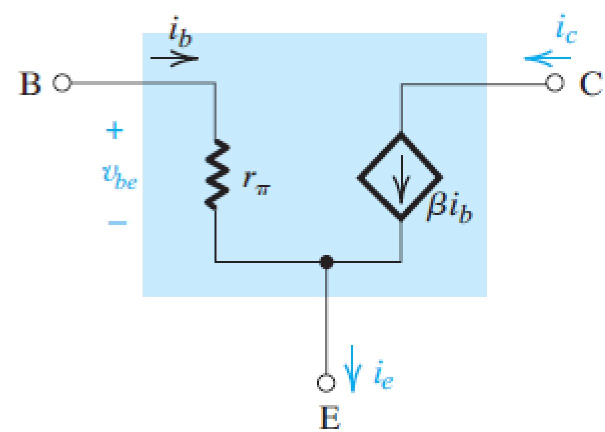
- The Hybrid-Pi model.
- The T model.

Two models are **exchangeable** and does not affect the analysis result.

The hybrid-π model: typically used as the emitter is grounded.

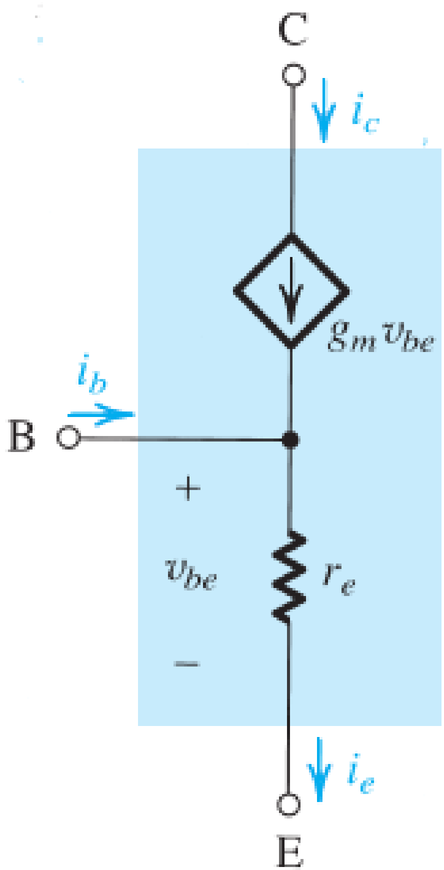


$g_m = I_C / V_T$
$r_\pi = \beta / g_m$



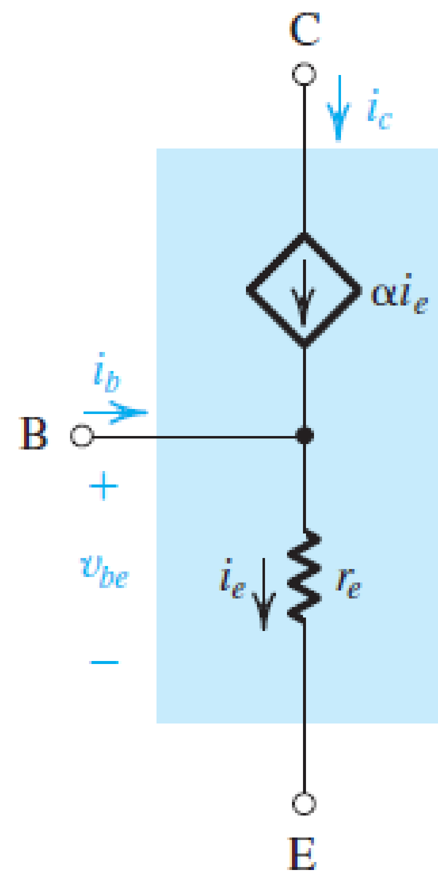
Small-Signal Operation and Models

The T model: typically used as the emitter is not grounded.



$$g_m = I_C / V_T$$

$$r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m}$$



Small-Signal Operation and Models

The analysis above indicates that every current and voltage in the amplifier circuit is composed of **two components**: a dc component and a small-signal component.

- **DC analysis:**
  - Remove all ac sources (short for voltage source and open for current source).
  - All capacitors are considered open-circuit.
  - DC analysis of BJT circuits for all nodal voltages and branch currents.
  - Find the dc current I_C and make sure the BJT is in active mode.

- **AC analysis:**
  - Remove all dc sources (short for voltage source and open for current source).
  - All large capacitors are considered short-circuit.
  - Replace the BJT with its small-signal model for ac analysis.
  - The circuit parameters in the small-signal model are obtained based on the value of I_C.

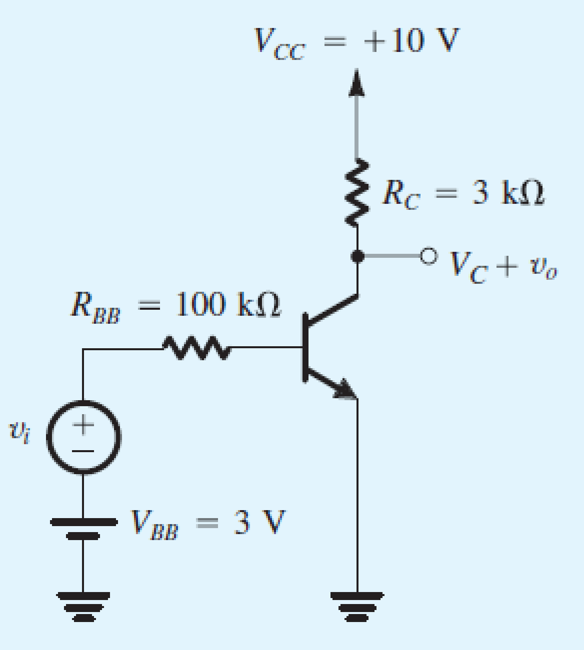
Small-Signal Operation and Models

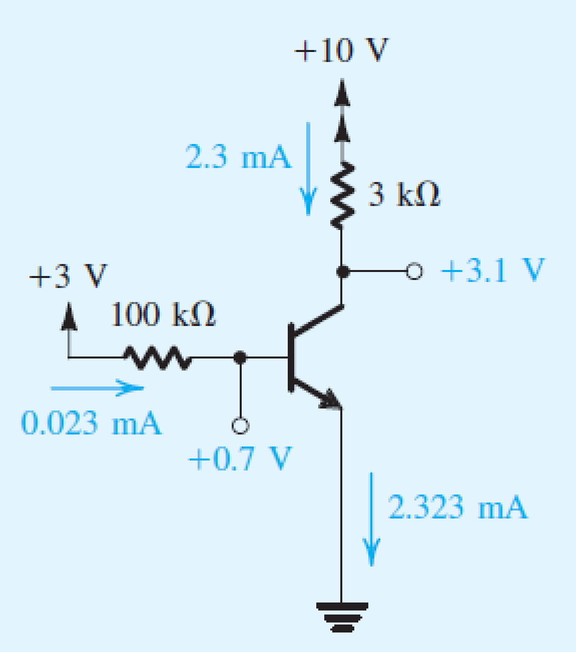
Example 12:

a. Analyze the following transistor amplifier to determine its voltage gain ${}^{v_o}/_{v_i}$. Assume β = 100.

b. Assume that v_i has a triangular waveform. Determine the maximum amplitude that v_i is allowed to have.

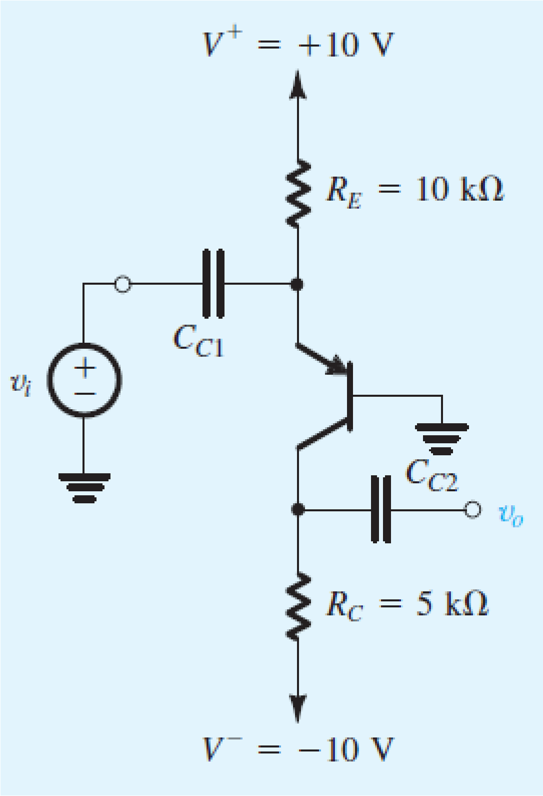
c. Set amplitude of v_i to this value, give the waveforms of the total quantities $i_B(t)$, $v_{BE}(t)$, $i_C(t)$, and $v_C(t)$.

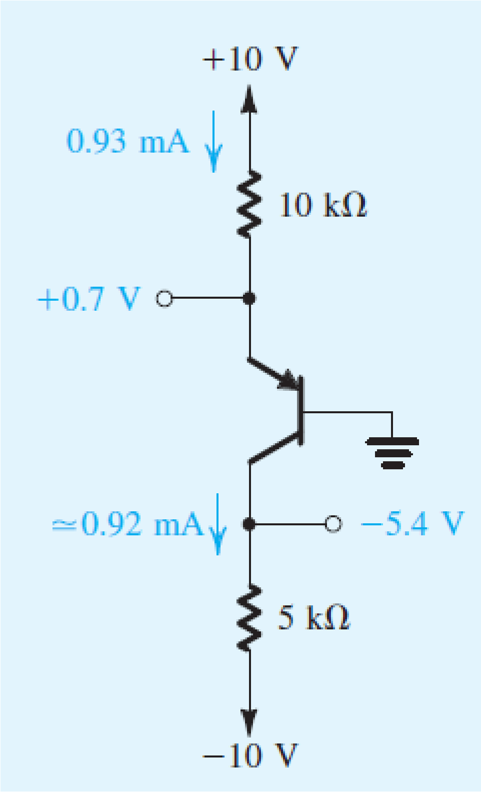




Small-Signal Operation and Models

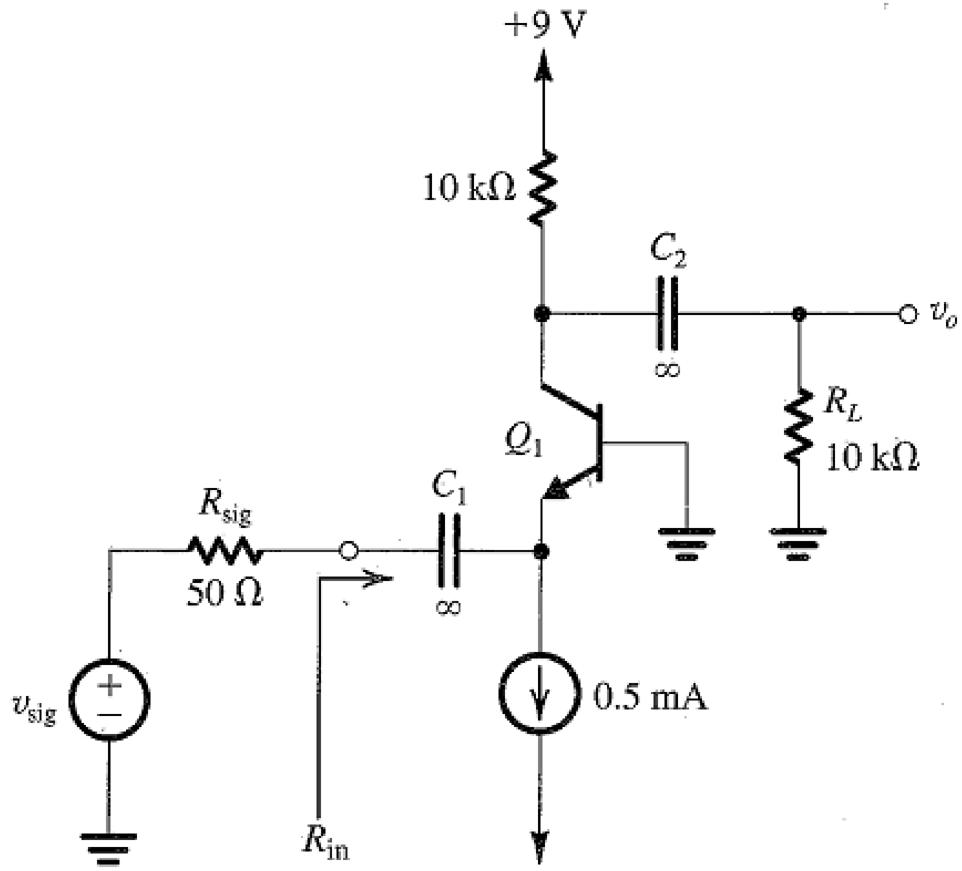
Example 13: Analyze the following transistor amplifier to determine its voltage gain v_o/v_i. Assume β = 100.





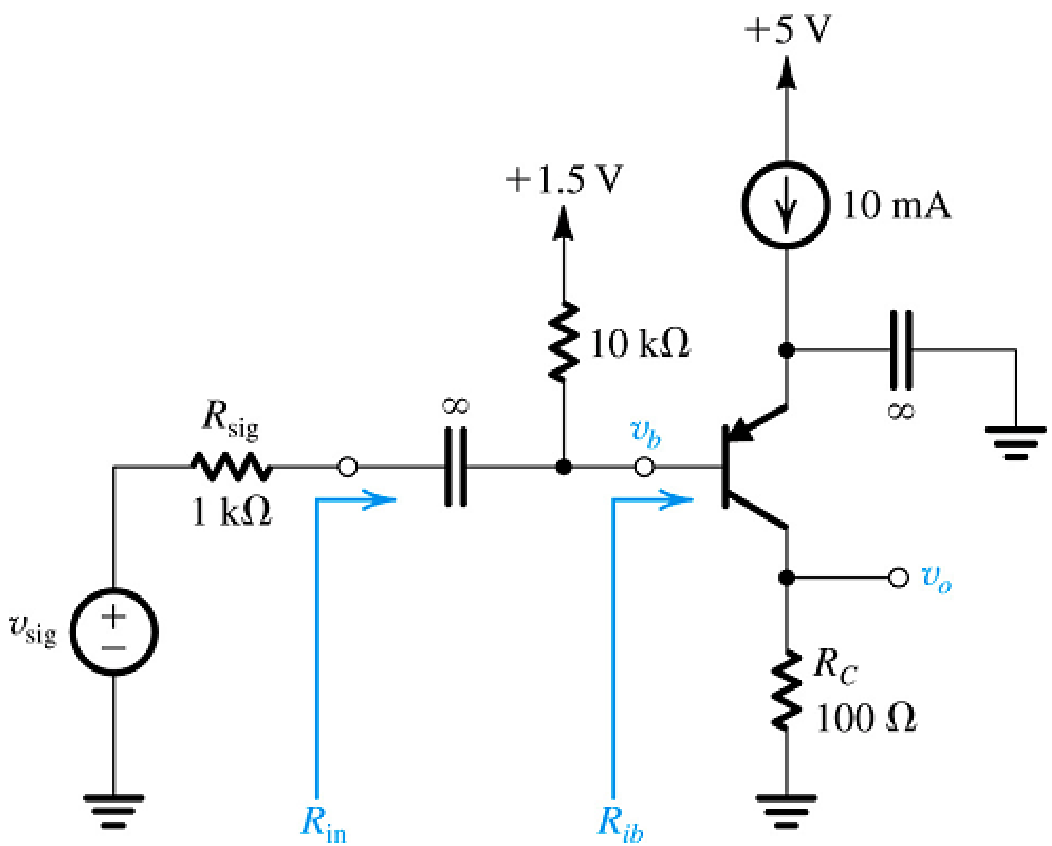
Small-Signal Operation and Models

Example 14: Calculate the overall voltage gain (v_o/v_{sig}) of the following circuit. What is the input resistance R_{in}. Assume $\beta = 200$.



Small-Signal Operation and Models

Example 15: Find the input resistance R_{ib} and R_{in} and the overall voltage gain (v_o/v_{sig}). Assume $\beta = 200$.

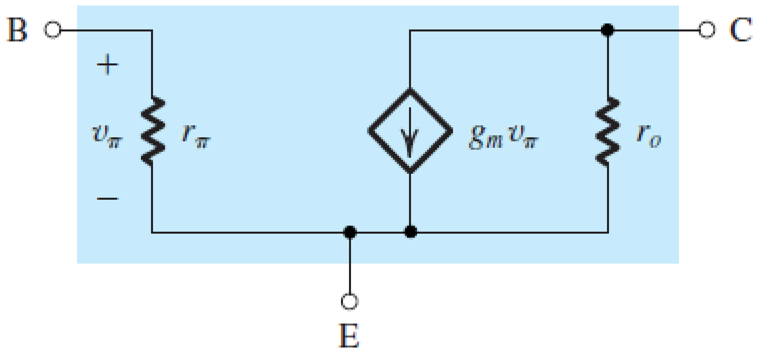


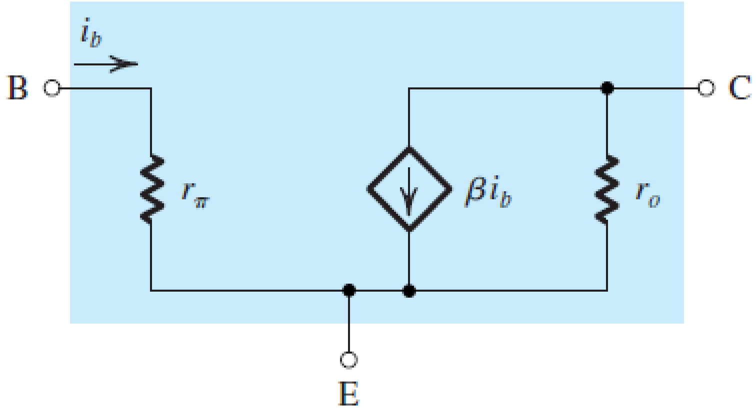
Small-Signal Analysis – Early Effect

Early effect: The collector current depends not only on v_{BE} but also on v_{CE}.

The dependence on v_{CE} can be modeled by assigning a finite output resistance:

$$r_o = (V_A + V_{CE})/I_C \approx V_A/I_C$$ (V_A : the Early voltage).





Small-Signal Analysis – Early Effect

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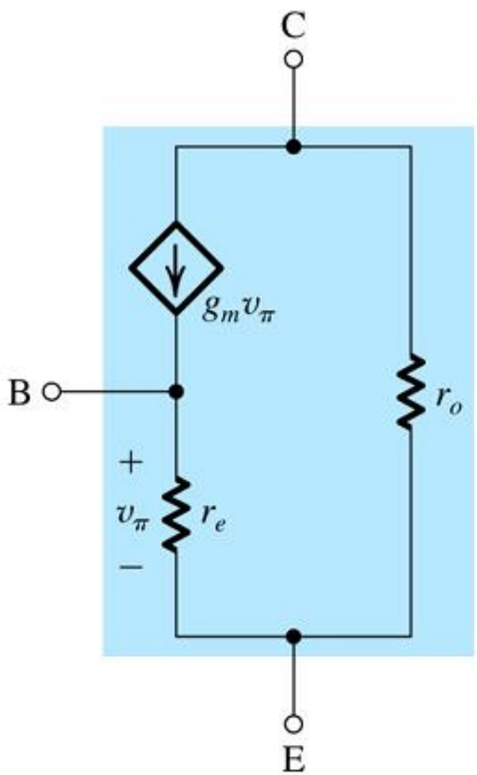
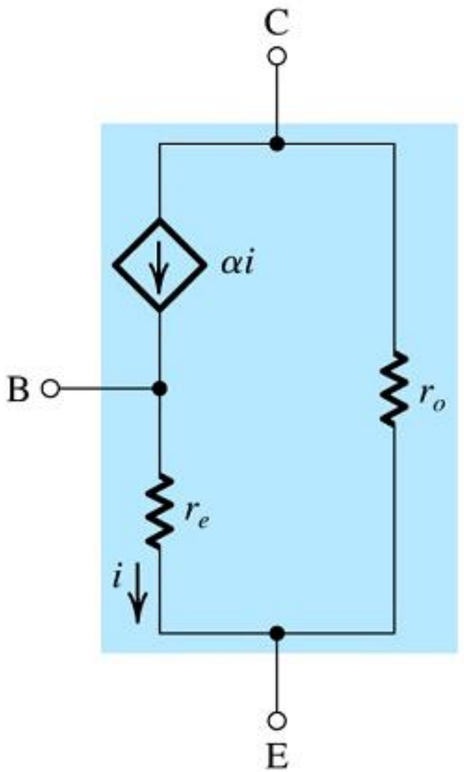




Small-Signal Analysis – Summary

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

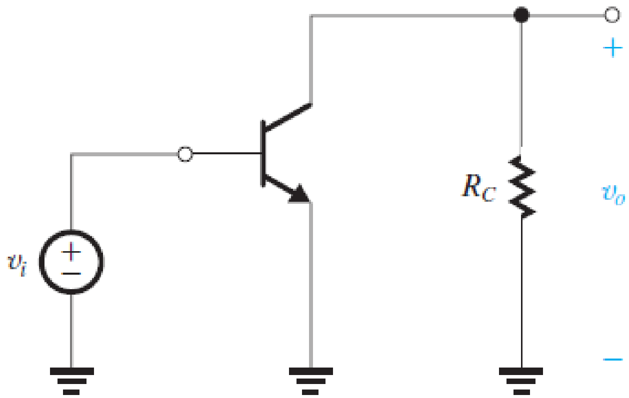
$$g_m = \frac{\alpha}{r_e} \qquad r_\pi = (\beta+1)r_e \qquad g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$$

Relationships between α and β

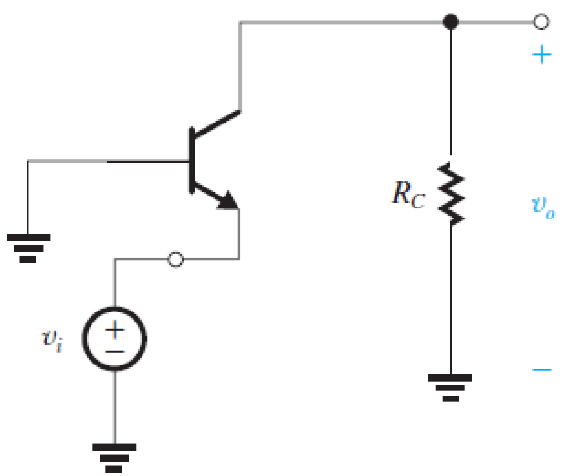
$$\beta = \frac{\alpha}{1-\alpha} \qquad \alpha = \frac{\beta}{\beta+1} \qquad \beta+1 = \frac{1}{1-\alpha}$$

Basic BJT Amplifier Configurations

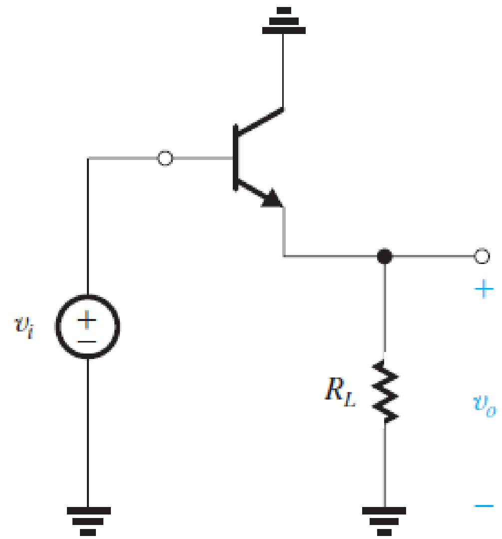
- Three basic configurations



(a) Common-Emitter (CE)



(b) Common-Base (CB)



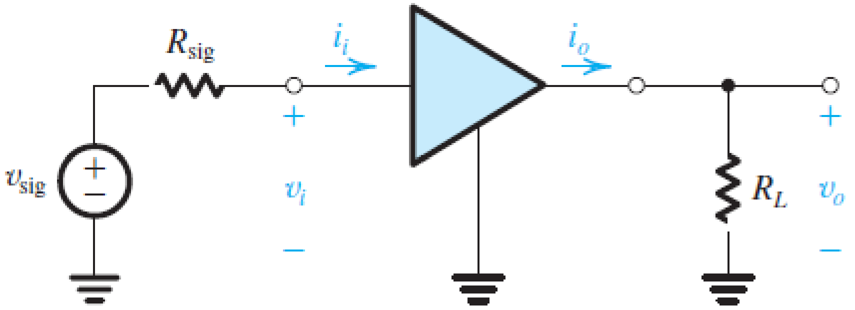
(c) Common-Collector (CC)
or Emitter Follower

Basic BJT Amplifier Configurations

Characterizing amplifiers:

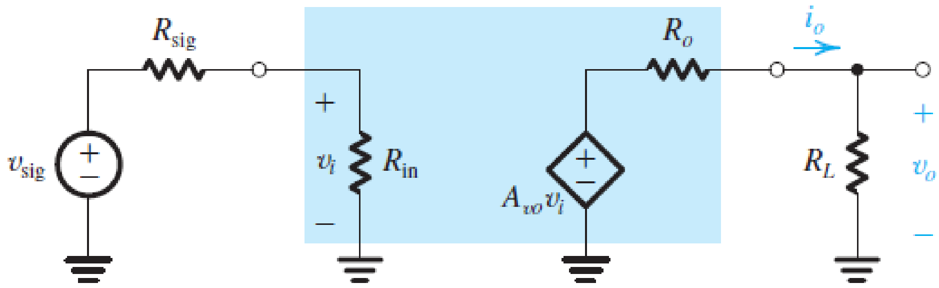
- Input resistance: $\boldsymbol{R_{in} = \frac{v_i}{i_i}}$. Together with the resistance $\boldsymbol{R_{sig}}$ forms a voltage divider that reduces $\boldsymbol{v_{sig}}$.

$$v_i = v_{sig}\frac{R_{in}}{R_{in} + R_{sig}}$$



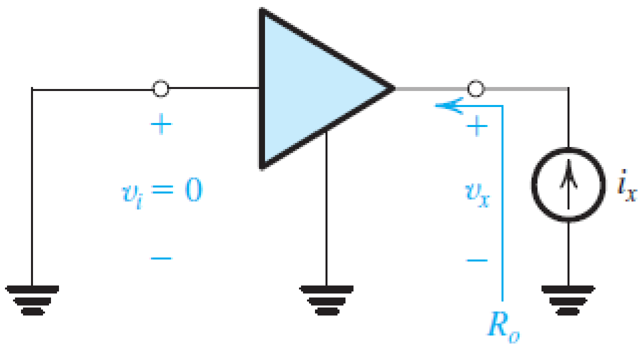
- Open circuit voltage gain:

$$\boldsymbol{A_{v0} = \frac{v_o}{v_i}\bigg|_{R_L=\infty}}$$



Basic BJT Amplifier Configurations

- Output resistance: $R_0 = \frac{v_x}{i_x}$

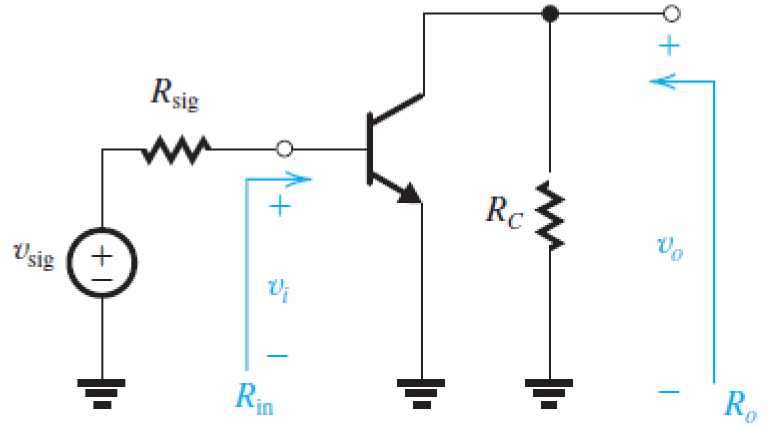


The output voltage can be found from: $v_0 = \frac{R_L}{R_L + R_o} A_{vo} v_i$

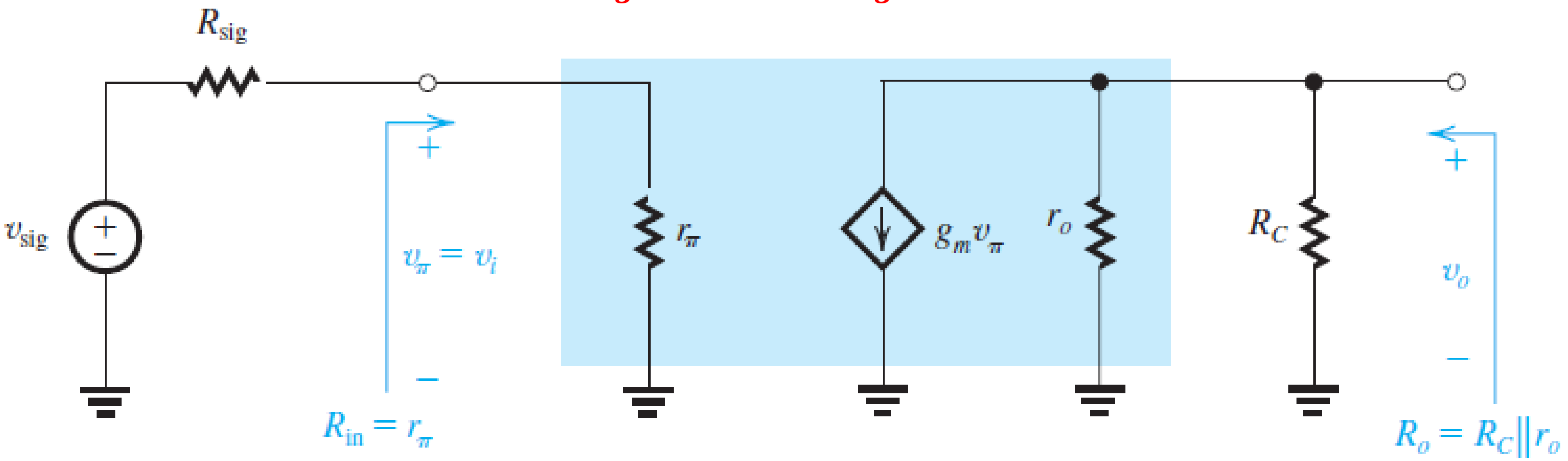
The overall voltage gain G_v: $G_v \equiv \frac{v_o}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} A_{vo} \frac{R_L}{R_L + R_o}$

Basic BJT Amplifiers - CE Amplifier

- Input resistance: $R_{in} = r_\pi$
- OC voltage gain: $A_{vo} = -g_m(R_C \parallel r_o)$
- Output resistance: $R_o = R_C \parallel r_o$



- Overall voltage gain: $G_v = \frac{v_o}{v_{sig}} = -\frac{r_\pi}{r_\pi + R_{sig}} g_m(R_C \parallel R_L \parallel r_o)$



Basic BJT Amplifiers - CE Amplifier

Alternative Gain expression:

- Voltage gain:

$$A_v = -g_m(R_L \parallel R_C \parallel r_o) = -\alpha \frac{(R_L \parallel R_C \parallel r_o)}{r_e} = -\alpha \frac{total\ resistance\ in\ collector}{total\ resistance\ in\ emitter}$$

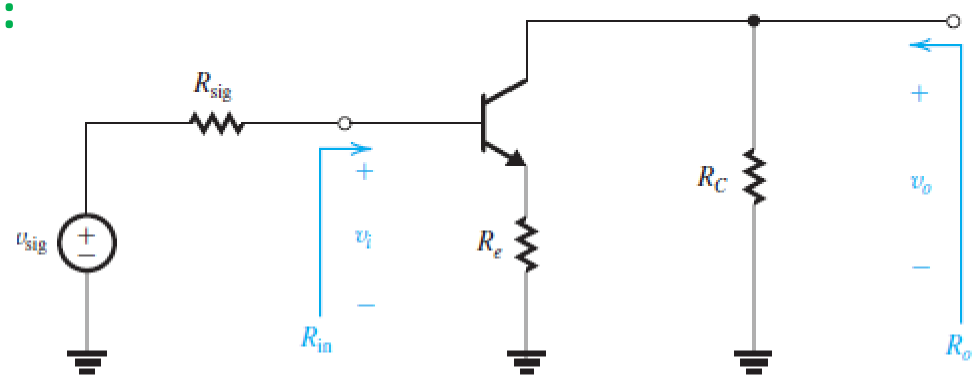
- Overall voltage gain:

$$G_v = -\frac{r_\pi}{r_\pi + R_{sig}} g_m(R_L \parallel R_C \parallel r_o) = -\beta \frac{(R_L \parallel R_C \parallel r_o)}{R_{sig} + r_\pi} = -\beta \frac{total\ resistance\ in\ collector}{total\ resistance\ in\ base}$$

Example 16: A CE amplifier utilizes a BJT with $\beta = 100$ and $V_A = 100V$, is biased at $I_C = 1\text{mA}$ and has a collector resistance $R_C = 5k\Omega$. Find R_{in}, R_o and A_{vo} . If the amplifier is fed with a signal source having a resistance of $5k\Omega$ and a load resistance $R_L = 5k\Omega$ is connected to the output terminal, find the resulting A_v and G_v If $\hat{v}_\pi$ is to be limited to 5 mV, what are the corresponding $\hat{v}_{sig}$ and $\hat{v}_o$ with the load connected?

Basic BJT Amplifiers - CE Amplifier

CE Amplifier with Emitter Resistance:



- Input resistance:

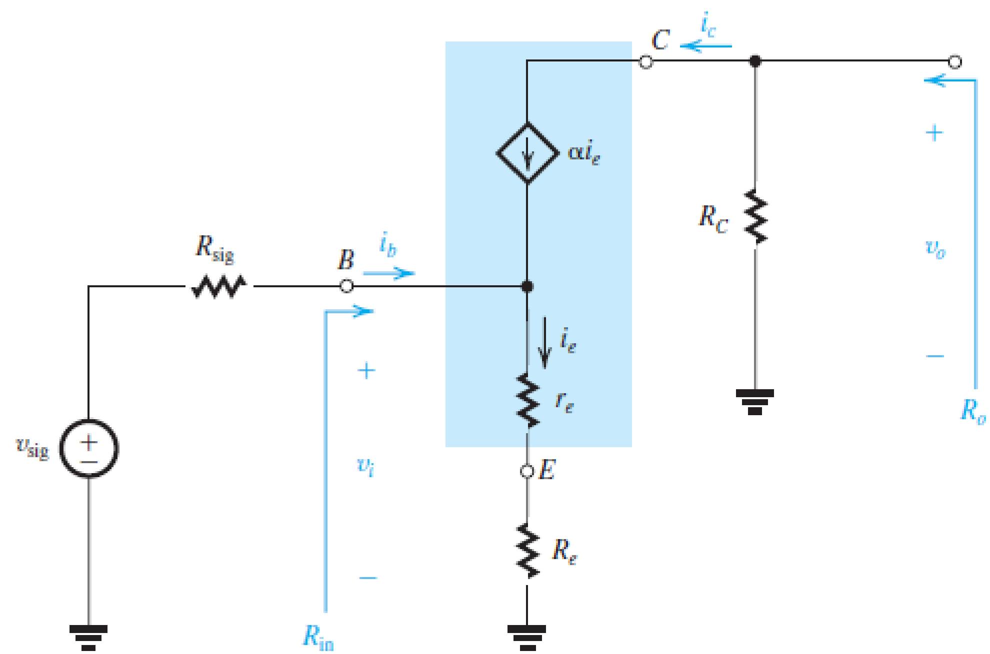
$$R_{in} = (\beta + 1)(r_e + R_e)$$

- OC voltage gain:

$$A_{vo} = -\alpha \frac{R_C}{r_e + R_e}$$

- Overall voltage gain:

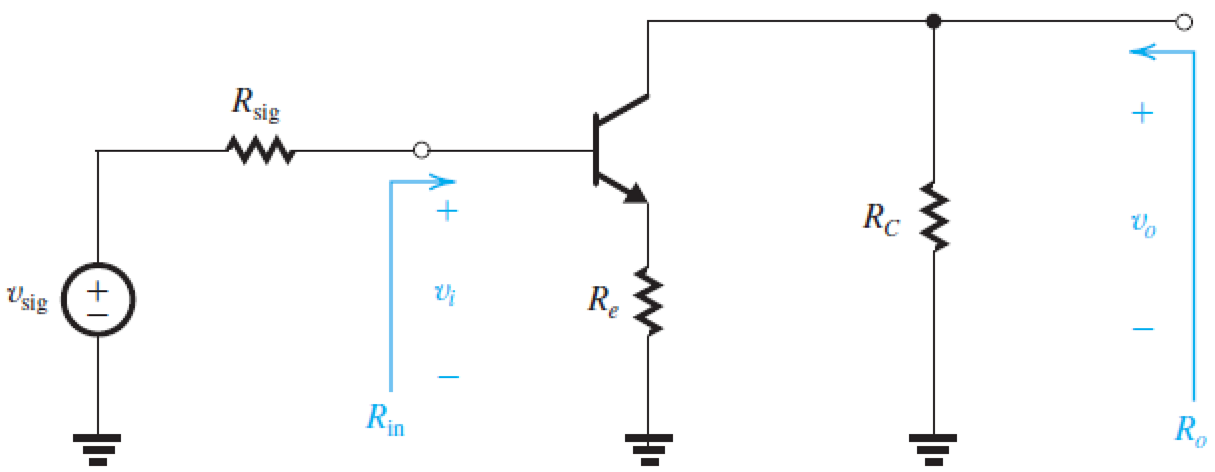
$$G_v = -\frac{R_{in}}{R_{in} + R_{sig}} \alpha \frac{R_C \parallel R_L}{r_e + R_e}$$



1. R_{in} is increased by $1 + g_m R_e$
2. A_v is decreased by $1 + g_m R_e$

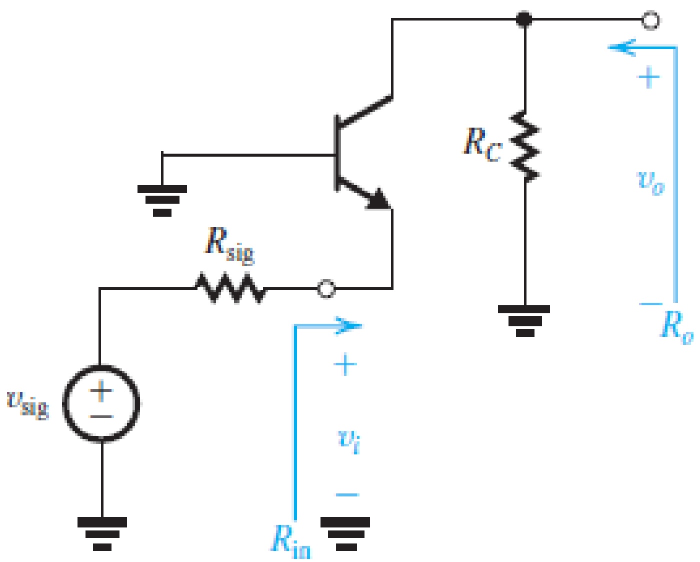
Basic BJT Amplifiers - CE Amplifier

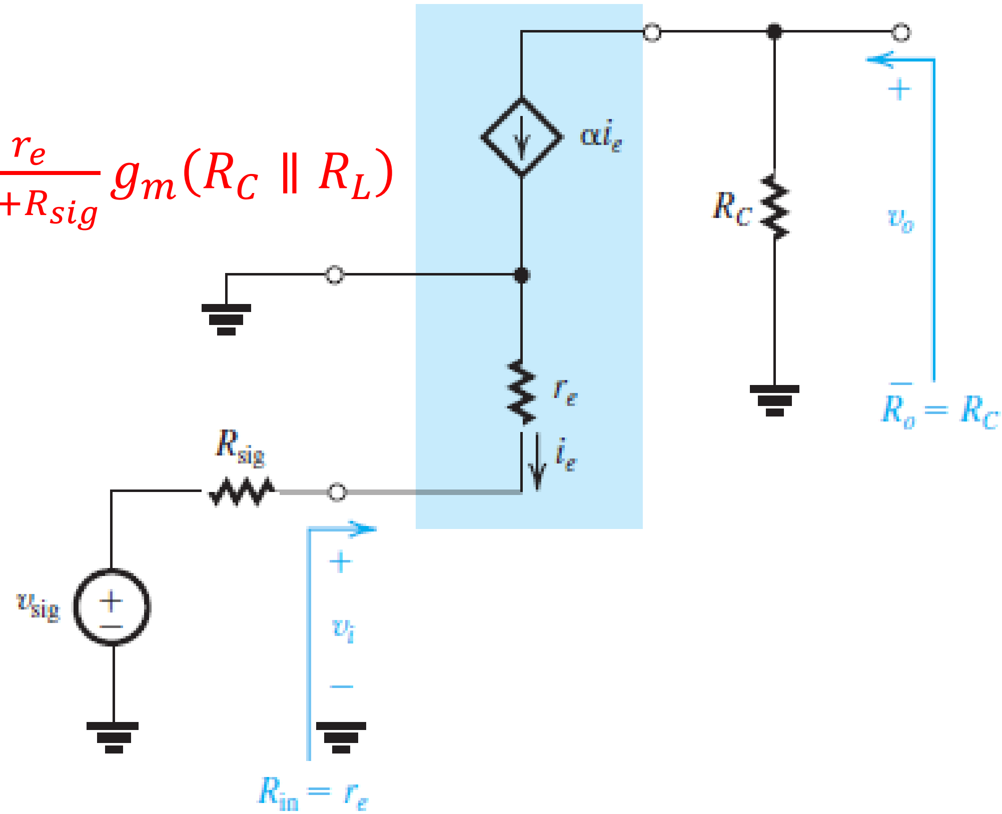
Example 17: For the CE amplifier specified in Example 16, what value of R_e is needed to raise R_{in} to a value four times that of R_{sig} ? With included R_e, find A_{vo} , R_o and A_v and G_v . Also, if $\hat{v}_\pi$ is limited to 5 mV, what are the corresponding values of $\hat{v}_{sig}$ and $\hat{v}_o$?



Basic BJT Amplifiers - CB Amplifier

- Input resistance: $R_{in} = r_e$
- OC voltage gain: $A_{vo} = g_m R_C$
- Output resistance: $R_o = R_C$
- Overall voltage gain: $G_v = \frac{v_o}{v_{sig}} = \frac{r_e}{r_e + R_{sig}} g_m (R_C \parallel R_L)$

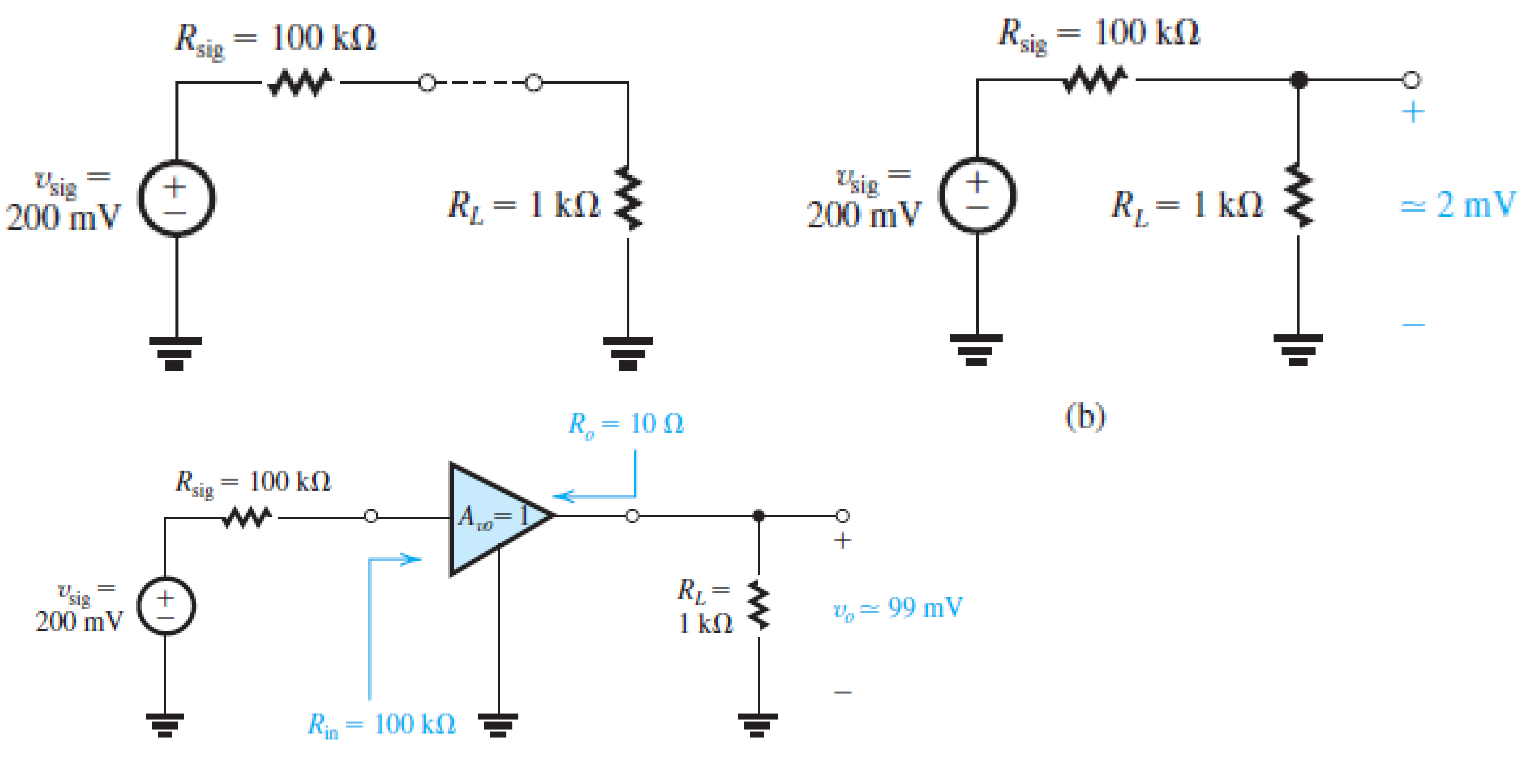




Basic BJT Amplifiers - CC Amplifier

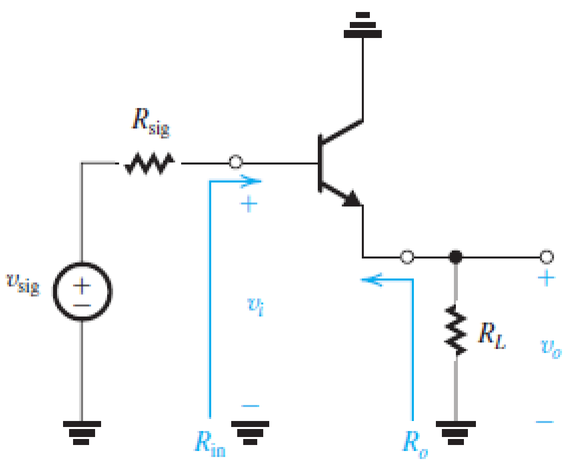
The need for voltage buffers: the amplifier has

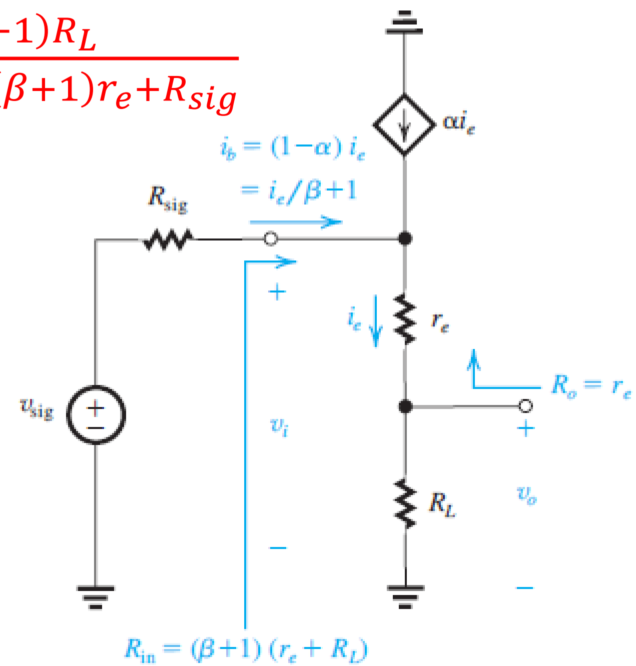
- **High input resistance.**
- **Low output resistance.**



Basic BJT Amplifiers - CC Amplifier

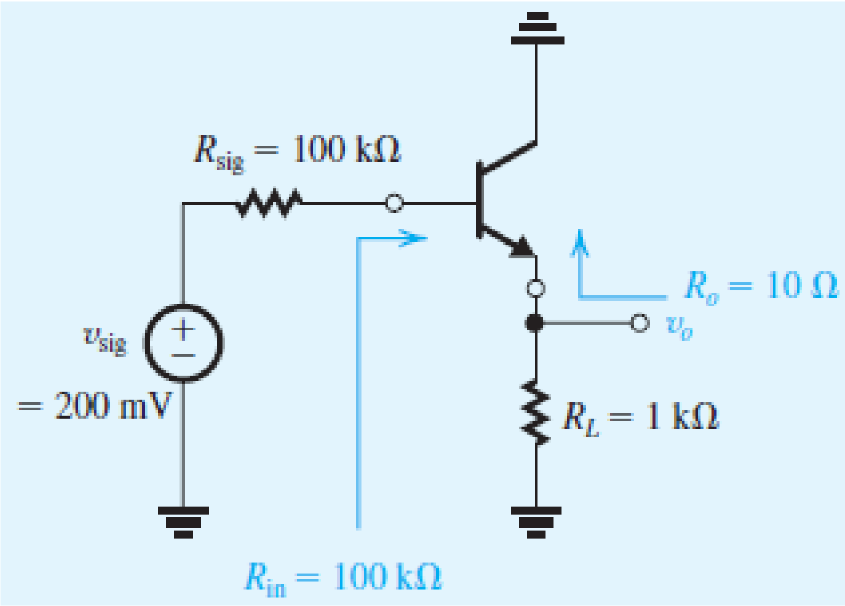
- Input resistance: $R_{in} = (\beta + 1)(r_e + R_L)$
- Voltage gain: $A_v = \frac{R_L}{R_L + r_e} \approx 1$
- Output resistance: $R_o = r_e$
- Overall voltage gain: $G_v = \frac{v_o}{v_{sig}} = \frac{(\beta+1)R_L}{(\beta+1)R_L + (\beta+1)r_e + R_{sig}}$





Basic BJT Amplifiers - CC Amplifier

Example 18: It is required to design an emitter follower to implement the buffer amplifier of following figure. Specify the required bias current I_E and the minimum value β the transistor must have. Determine the maximum allowed value of v_{sig} if v_{π} is to be limited to $5mV$ in order to obtain reasonably linear operation. With $v_{sig} = 200mV$, determine the signal voltage at the output if R_L is changed to $2k\Omega$ and to $0.5k\Omega$.

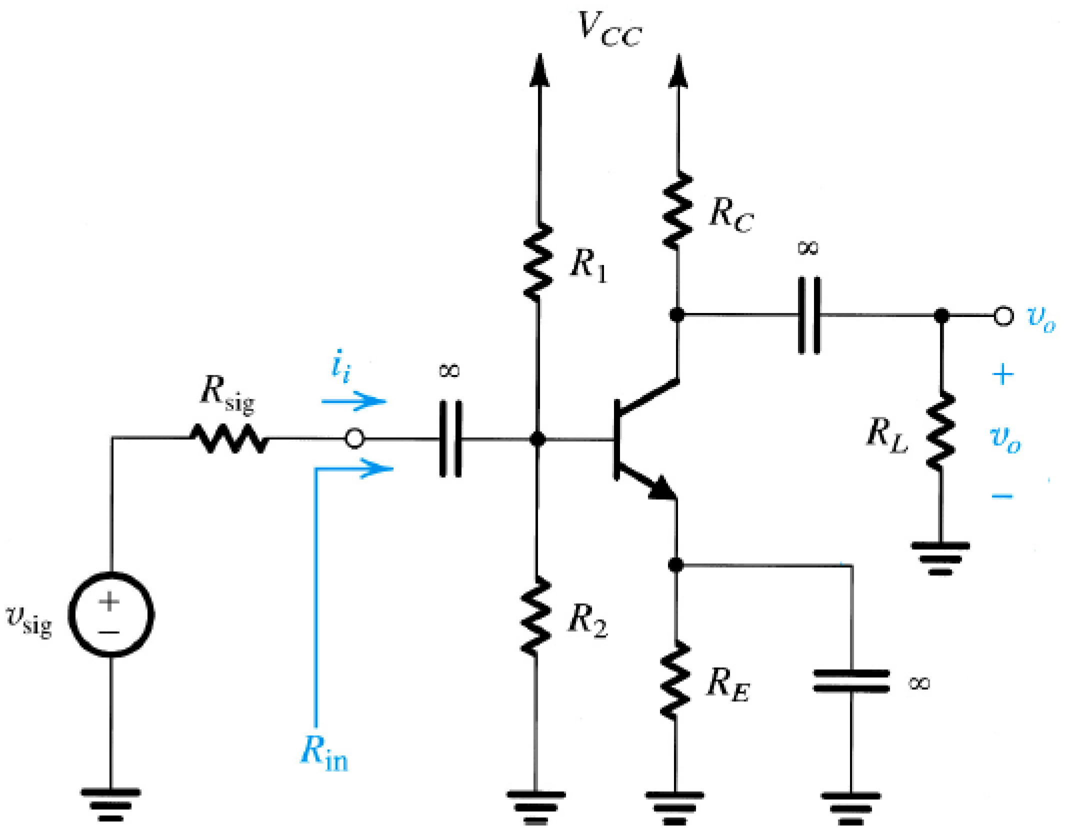


Basic BJT Amplifiers - Summary

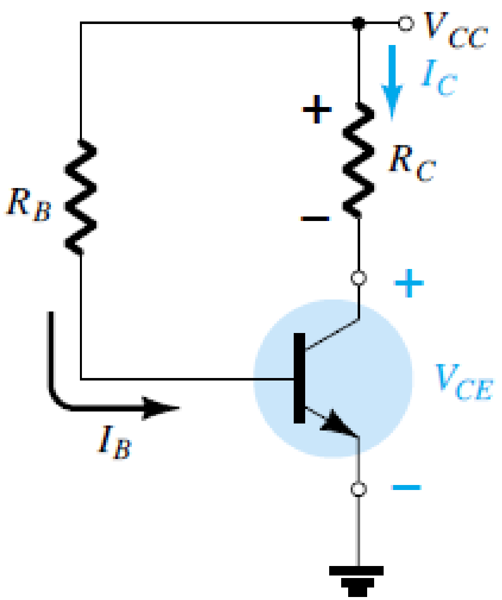
	R_{in}	A_{vo}	R_o	A_v	G_v
Common emitter (Fig. 6.50)	$(\beta+1)r_e$	$-g_m R_C$	R_C	$-g_m(R_C \parallel R_L)$ $-\alpha \frac{R_C \parallel R_L}{r_e}$	$-\beta \frac{R_C \parallel R_L}{R_{sig}+(\beta+1)r_e}$
Common emitter with R_e (Fig. 6.52)	$(\beta+1)(r_e+R_e)$	$-\frac{g_m R_C}{1+g_m R_e}$	R_C	$\frac{-g_m(R_C \parallel R_L)}{1+g_m R_e}$ $-\alpha \frac{R_C \parallel R_L}{r_e+R_e}$	$-\beta \frac{R_C \parallel R_L}{R_{sig}+(\beta+1)(r_e+R_e)}$
Common base (Fig. 6.53)	r_e	$g_m R_C$	R_C	$g_m(R_C \parallel R_L)$ $\alpha \frac{R_C \parallel R_L}{r_e}$	$\alpha \frac{R_C \parallel R_L}{R_{sig}+r_e}$
Emitter follower (Fig. 6.55)	$(\beta+1)(r_e+R_L)$	1	r_e	$\frac{R_L}{R_L+r_e}$	$\frac{R_L}{R_L+r_e+R_{sig}/(\beta+1)}$ $G_{vo}=1$ $R_{out}=r_e+\frac{R_{sig}}{\beta+1}$

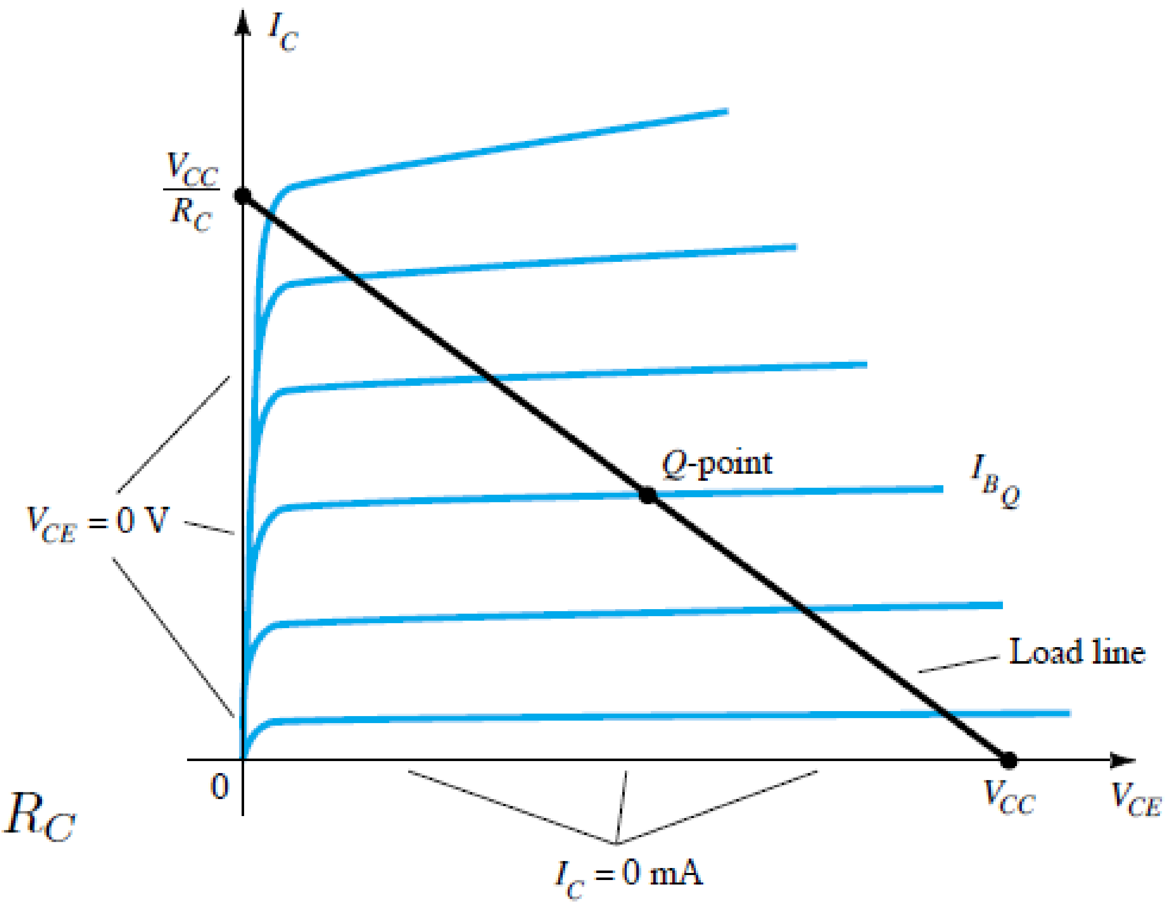
Basic BJT Amplifiers

Example 19: For the following circuit, let $V_{CC} = 9\text{V}$, $R_1 = 27k\Omega$, $R_2 = 15k\Omega$, $R_E = 1.2k\Omega$, and $R_C = 2.2k\Omega$. The transistor has $\beta = 100$. Calculate the DC bias current I_E. If the amplifier operates between a source for which $R_{sig} = 10k\Omega$ and a load of $2k\Omega$. Find the value of R_{in}, the voltage gain v_o/v_{sig}.



Graphical analysis

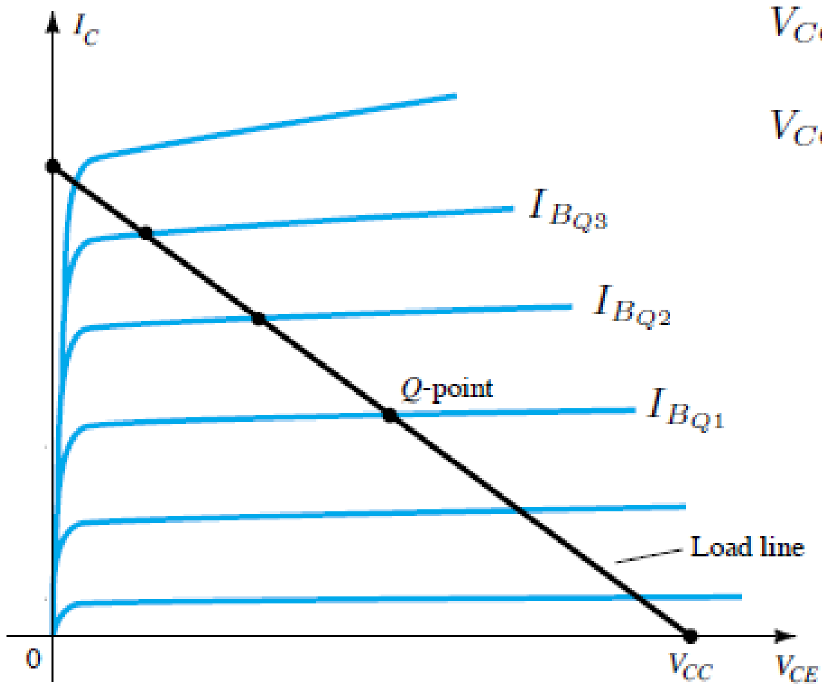


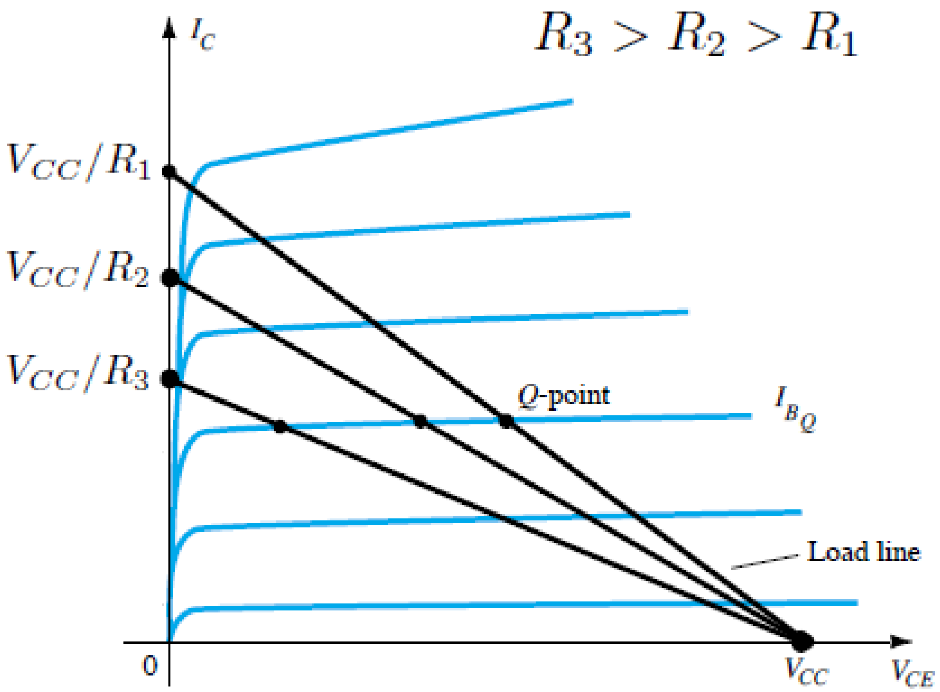


DC load line

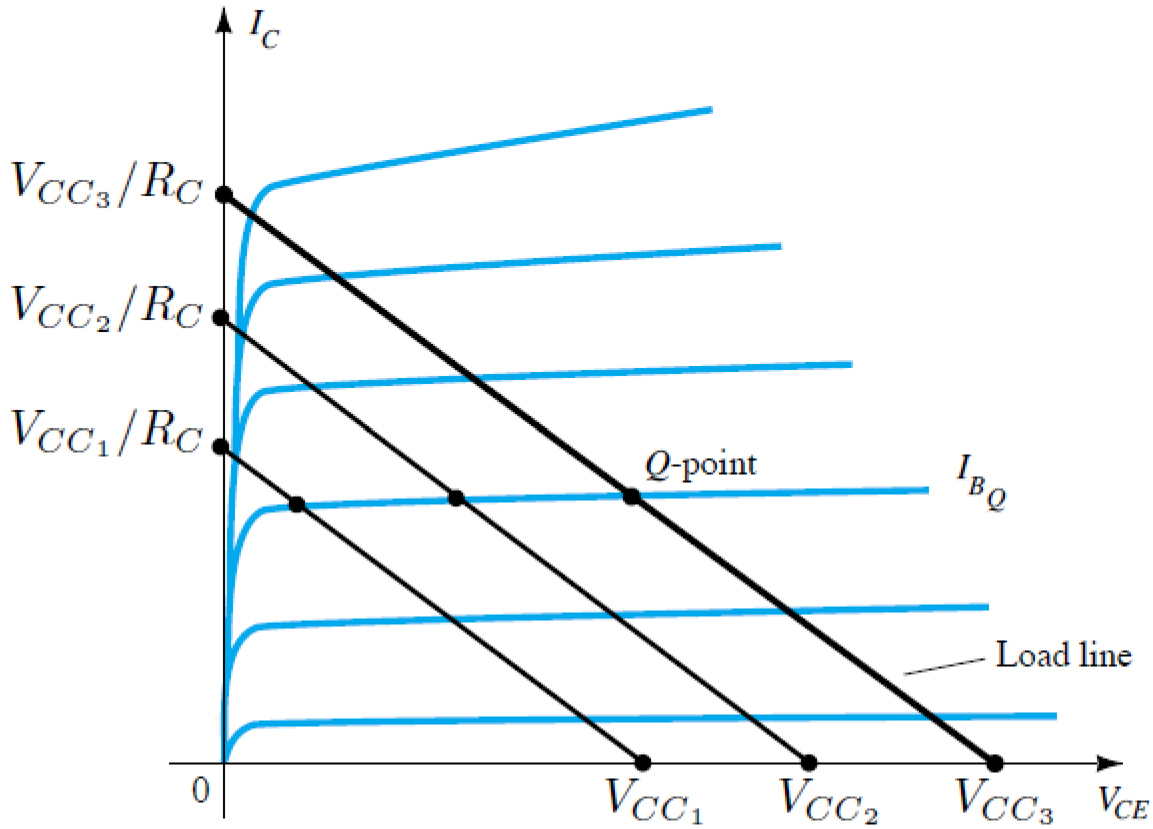
$$V_{CE} = V_{CC} - I_C R_C$$

DC Load Line


I_C
I_{BQ3}
I_{BQ2}
Q-point
I_{BQ1}
Load line
0
V_{CC}
V_{CE}

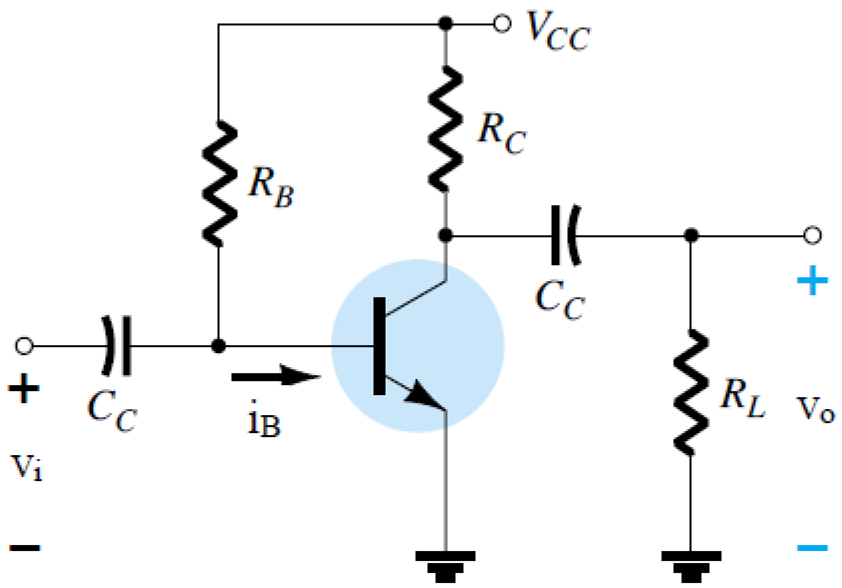

I_C
$R_3 > R_2 > R_1$
V_{CC}/R_1
V_{CC}/R_2
V_{CC}/R_3
Q-point
I_{BQ}
Load line
0
V_{CC}
V_{CE}

DC Load Line

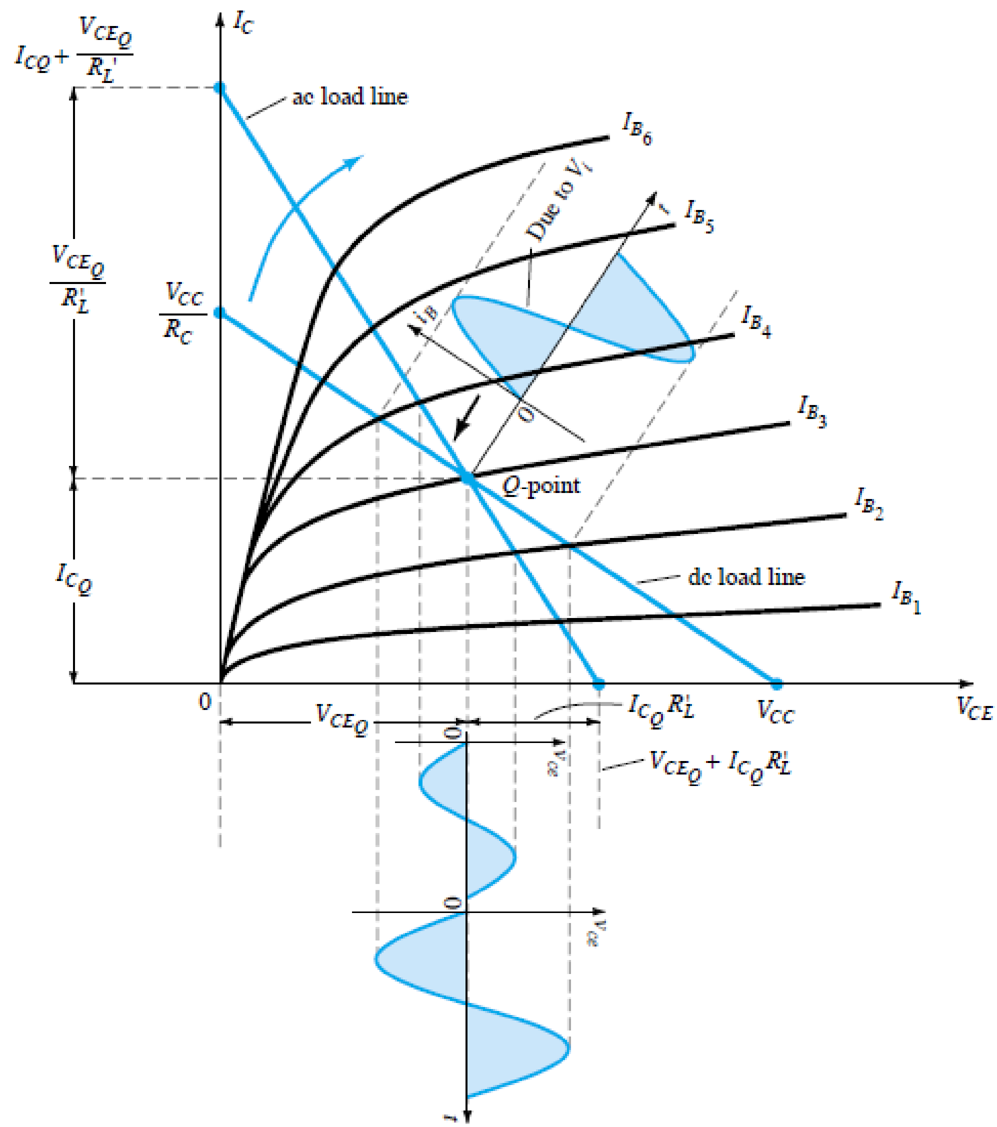


I_C
V_{CC_3}/R_C
V_{CC_2}/R_C
V_{CC_1}/R_C
Q-point
I_{B_Q}
Load line
0
V_{CC_1}
V_{CC_2}
V_{CC_3}
V_{CE}

AC Load Line



AC Load Line



- Max swing condition:

$$\boxed{I_{CQ} = \frac{V_{CC}}{R_{DC} + R_{ac}}}$$

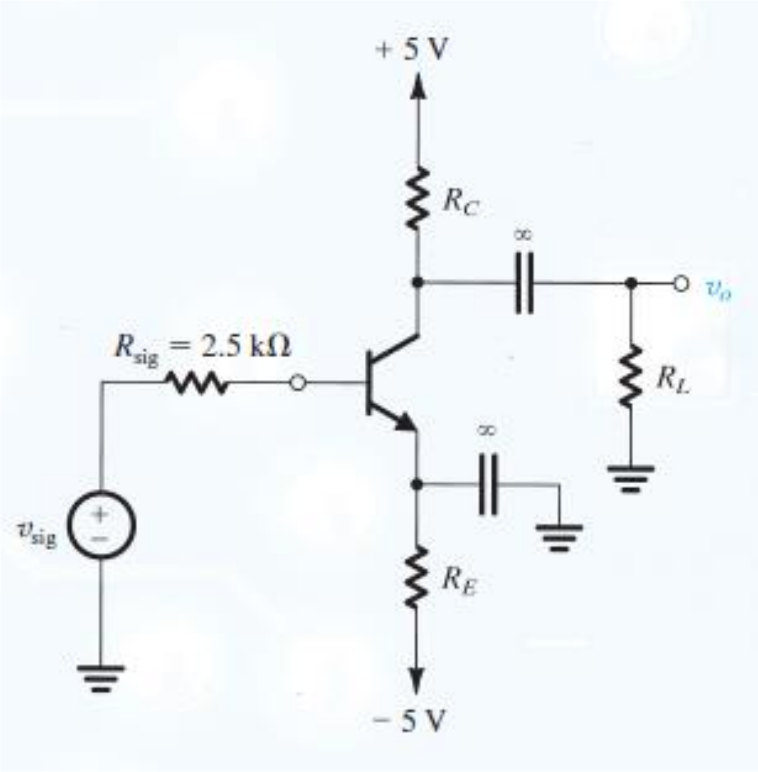
Exercises

Exercise 1: In the following circuit, v_{sig} is a small sine wave signal with zero average. The transistor β is 100.

a. Find the value of R_E to establish a dc emitter current of about 0.5 mA.

b. Find R_C to establish a dc collector voltage of about +5 V.

c. For $R_L = 10\ k\Omega$ and $r_o = 200k\Omega$, draw the small-signal equivalent circuit of the amplifier and determine its overall voltage gain.

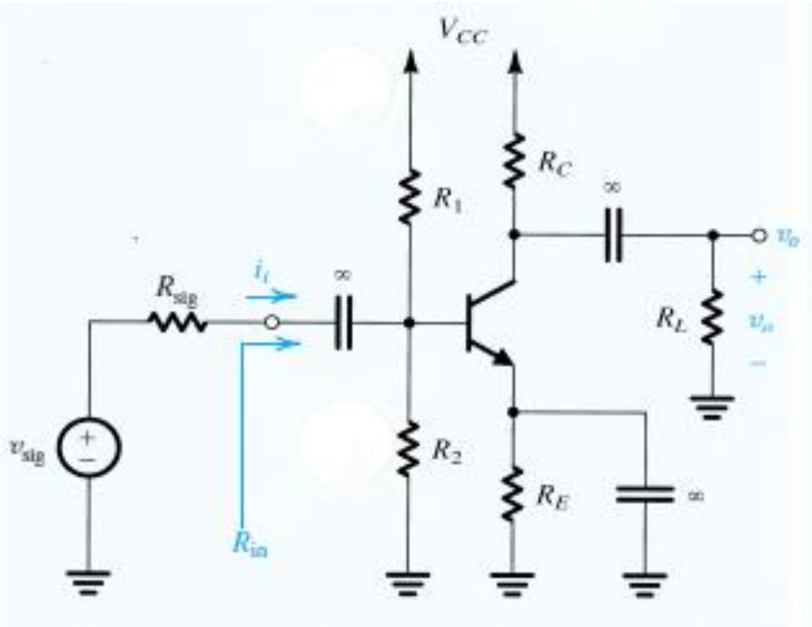


Exercises

Exercise 2: Using the topology of following circuit, design an amplifier to operate between a $10k\Omega$ source and a $2k\Omega$ load with a gain of $-8V/V$. The power supply available is $9V$. Use an emitter current of approximately $2mA$ and a current of about one-tenth of that in the voltage divider that feeds the base, with the dc voltage at the base about one-third of the supply. The transistor available has $\beta = 100$ and $V_A = 100V$. Use standard 5% resistor.

Table H.1 Standard Resistance Values

	1% Resistor Values (kΩ)			
5% Resistor Values (kΩ)	100–174	178–309	316–549	562–976
10	100	178	316	562
11	102	182	324	576
12	105	187	332	590
13	107	191	340	604
15	110	196	348	619
16	113	200	357	634
18	115	205	365	649
20	118	210	374	665
22	121	215	383	681
24	124	221	392	698
27	127	226	402	715
30	130	232	412	732
33	133	237	422	750
36	137	243	432	768
39	140	249	442	787
43	143	255	453	806
47	147	261	464	825
51	150	267	475	845
56	154	274	487	866
62	158	280	499	887
68	162	287	511	909
75	165	294	523	931
82	169	301	536	953
91	174	309	549	976



Exercises

Exercise 3: The following amplifier consists of two identical common-emitter amplifiers connected in cascade. Observe that the input resistance of the second stage, R_{in2}, constitutes the load resistance of the first stage.

a. For $V_{CC} = 15V$, $R_1 = 100k\Omega$, $R_2 = 47k\Omega$, $R_E = 3.9k\Omega$, $R_C = 6.8k\Omega$, and $\beta = 100$, determine the DC collector current and voltage of each transistor.

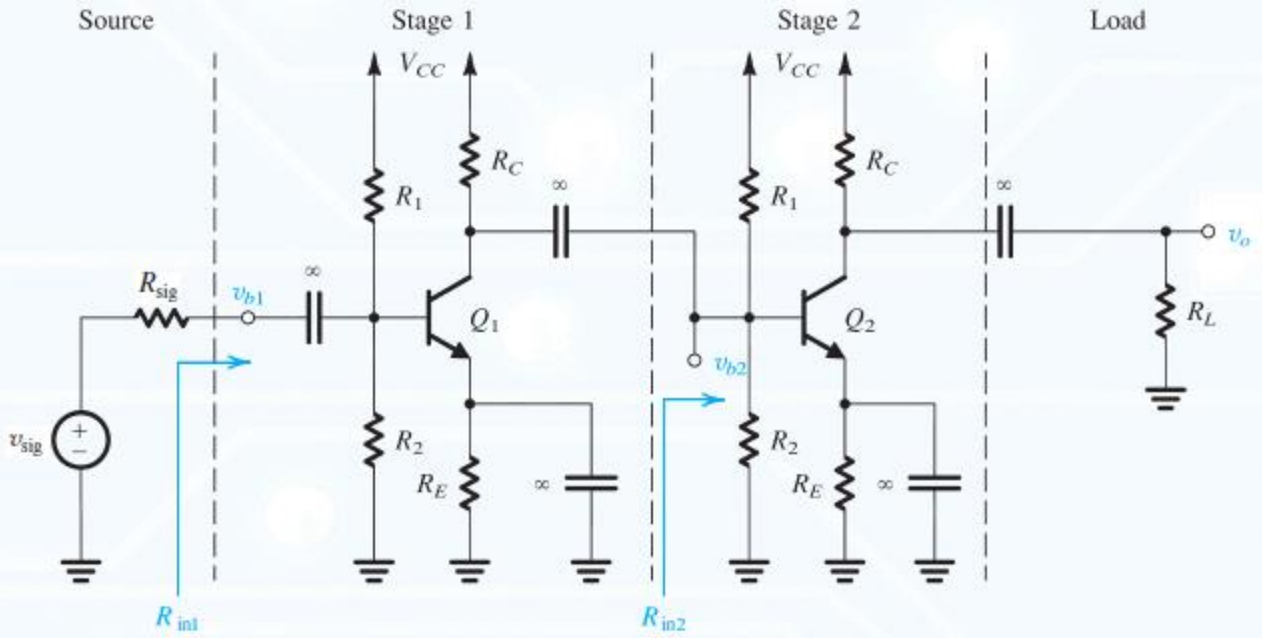
b. Draw the small-signal equivalent circuit of the entire amplifier and give the values of all its components.

c. Find R_{in1} and v_{b1}/v_{sig} for $R_{sig} = 5k\Omega$.

d. Find R_{in2} and v_{b2}/v_{b1}

e. For $R_L = 2\ k\Omega$, find v_o/v_{b2}

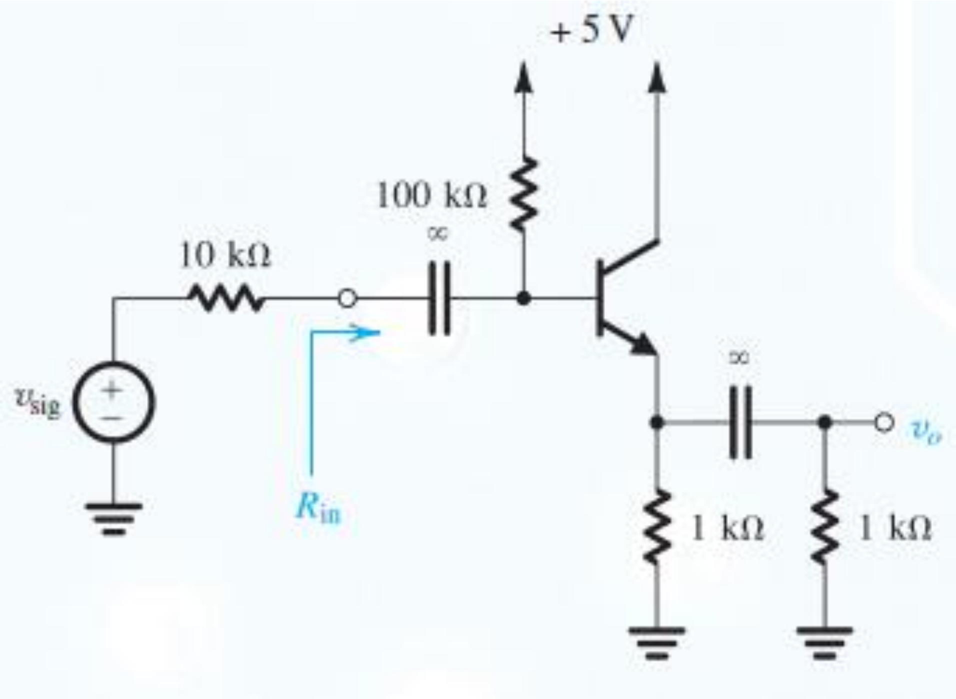
f. Find the overall voltage gain v_o/v_{sig}



Exercises

Exercise 4: For the following emitter-follower circuit, the BJT used is specified to have β values in the range of 40 to 200 (a distressing situation for the circuit designer). For the two extreme values of β (β = 40 and β = 200), find:

a. I_E, V_E, and V_B.
b. The input resistance R_{in}.
c. The voltage gain v_o/v_{sig}.



Q&A