ECE 121
Electronics (1)
Lec. 3: BJT Circuits & Troubleshooting

Instructor

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Outline

- Various BJT Circuits
- Troubleshooting Techniques

Various BJT Circuits

- MULTIPLE BJT NETWORKS
- CURRENT MIRRORS
- CURRENT SOURCE CIRCUITS
  - Bipolar Transistor Constant-Current Source
  - Transistor/Zener Constant-Current Source
- PNP TRANSISTORS
- TRANSISTOR SWITCHING NETWORKS

Multiple BJT Networks (1 of 6)

- R–C coupling

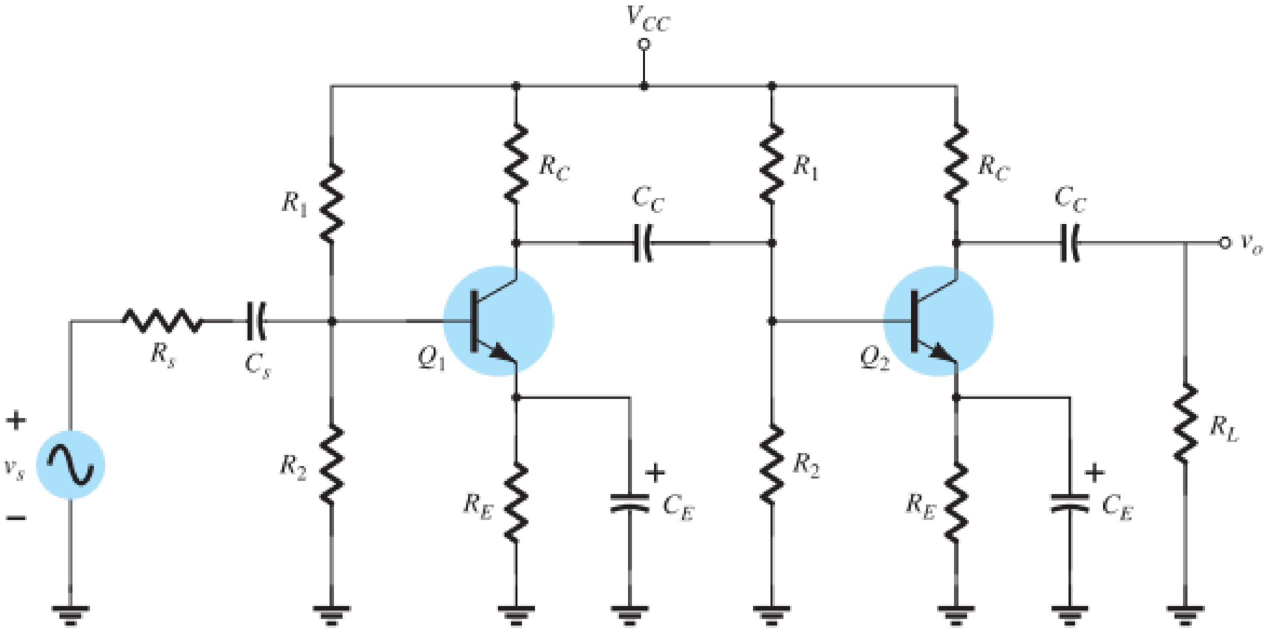


FIG. 4.64
R–C coupled BJT amplifiers.

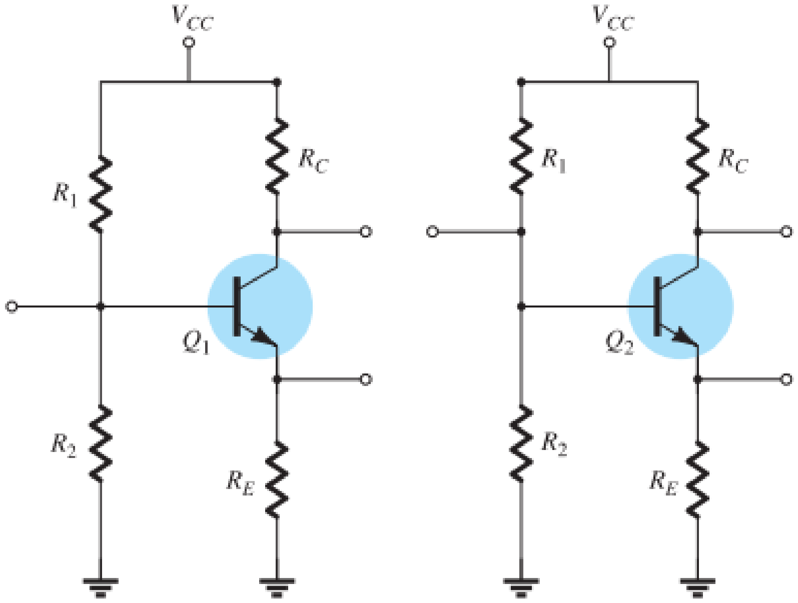


FIG. 4.65
DC equivalent of Fig. 4.64.

Multiple BJT Networks (2 of 6)

- Darlington configuration

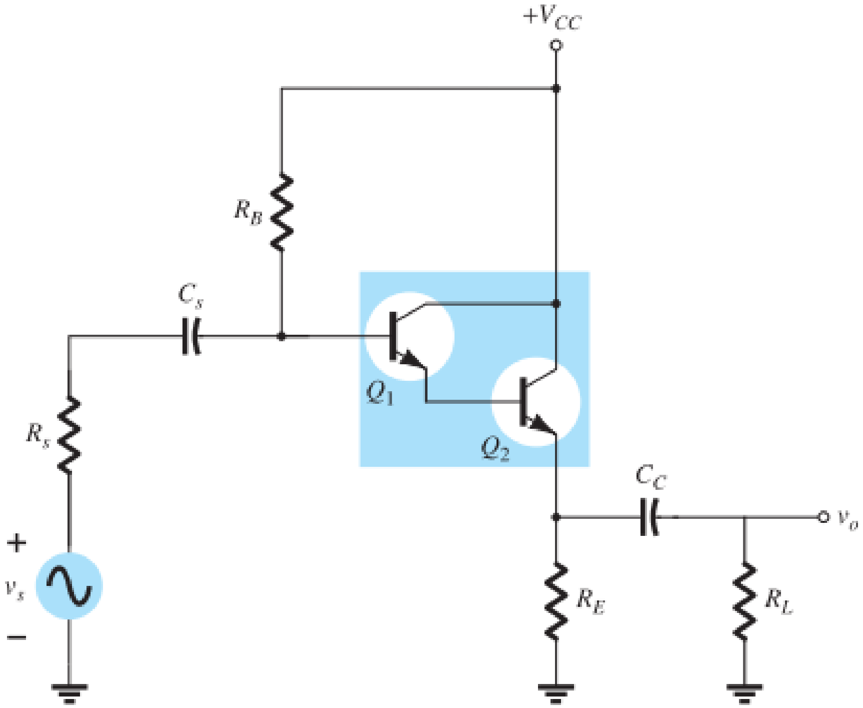


FIG. 4.66
Darlington amplifier.

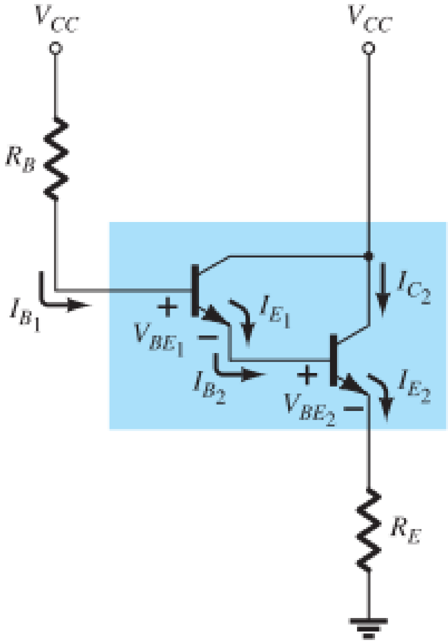


FIG. 4.67
DC equivalent of Fig. 4.66.

$$I_{B_1} = \frac{V_{CC} - V_{BE_1} - V_{BE_2}}{R_B + (\beta_D + 1)R_E}$$

$$\boxed{V_{BE_D} = V_{BE_1} + V_{BE_2}}$$

$$\boxed{I_{B_1} = \frac{V_{CC} - V_{BE_D}}{R_B + (\beta_D + 1)R_E}}$$

$$\boxed{I_{C_2} \cong I_{E_2} = \beta_D I_{B_1}}$$

$$\boxed{\beta_D = \beta_1\beta_2}$$

$$\boxed{V_{E_2} = I_{E_2}R_E}$$

$$\boxed{V_{C_2} = V_{CC}}$$

$$V_{CE_2} = V_{C_2} - V_{E_2}$$

$$\boxed{V_{CE_2} = V_{CC} - V_{E_2}}$$

Multiple BJT Networks (3 of 6)

- Cascode configuration

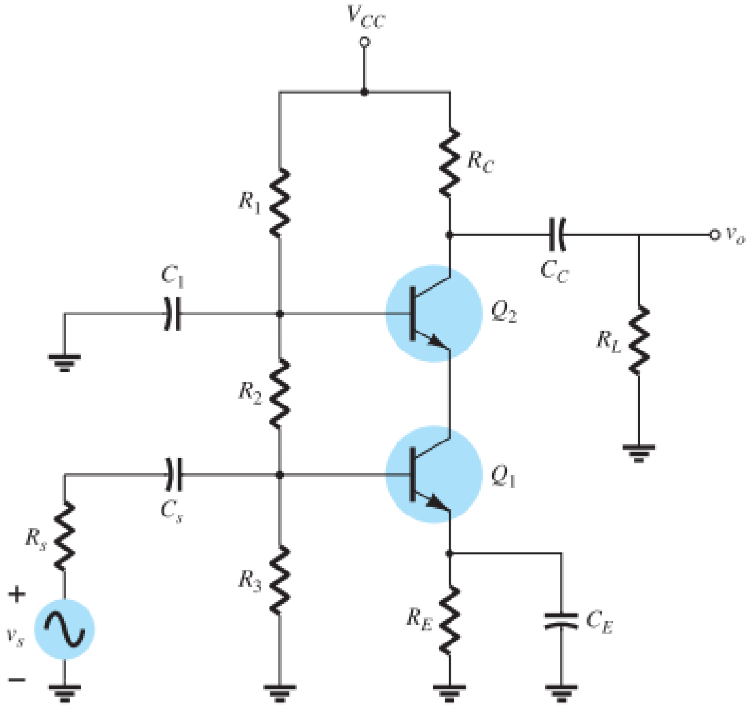


FIG. 4.68
Cascode amplifier.

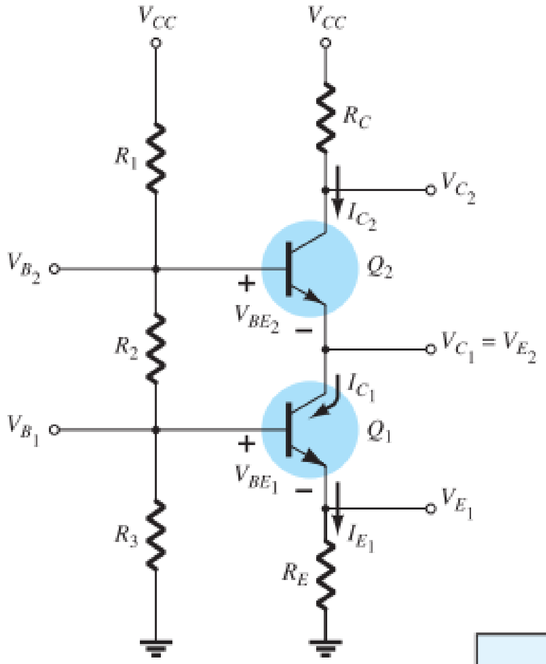


FIG. 4.69
DC equivalent of Fig. 4.68.

$$I_{R_1} \cong I_{R_2} \cong I_{R_3} \gg I_{B_1} \text{ or } I_{B_2}$$

$$\boxed{V_{B_1} = \frac{R_3}{R_1 + R_2 + R_3} V_{CC}}$$

$$\boxed{V_{B_2} = \frac{(R_2 + R_3)}{R_1 + R_2 + R_3} V_{CC}}$$

$$\boxed{V_{E_1} = V_{B_1} - V_{BE_1}}$$

$$\boxed{V_{E_2} = V_{B_2} - V_{BE_2}}$$

$$\boxed{I_{C_2} \cong I_{E_2} \cong I_{C_1} \cong I_{E_1} = \frac{V_{B_1} - V_{BE_1}}{\cancel{R_{E_1} + R_{E_2}}}}$$

R_E

$$\boxed{V_{C_1} = V_{B_2} - V_{BE_2}}$$

$$\boxed{V_{C_2} = V_{CC} - I_{C_2} R_C}$$

$$\boxed{I_{R_1} \cong I_{R_2} \cong I_{R_3} = \frac{V_{CC}}{R_1 + R_2 + R_3}}$$

$$\boxed{I_{B_2} = \frac{I_{C_2}}{\beta_2}}$$

$$\boxed{I_{B_1} = \frac{I_{C_1}}{\beta_1}}$$

Multiple BJT Networks (4 of 6)

- Feedback Pair

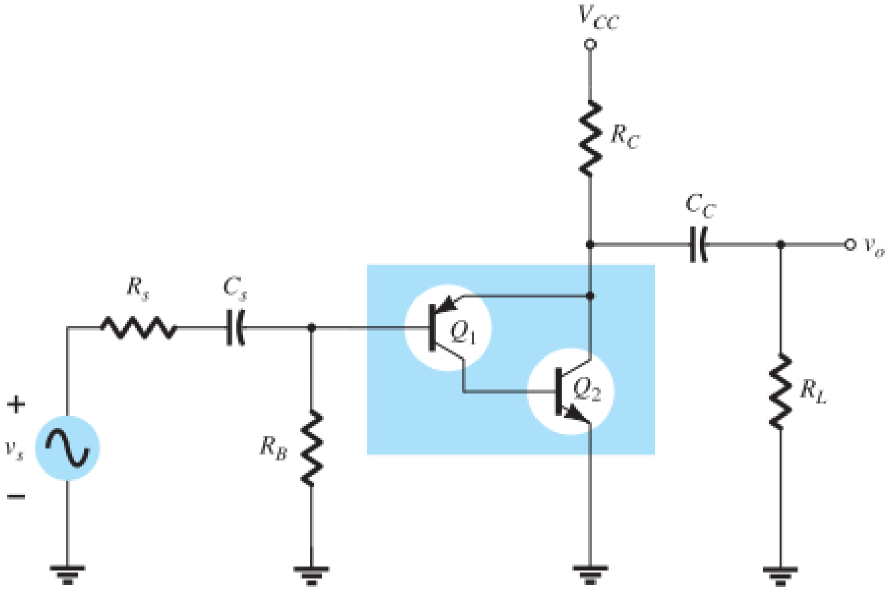


FIG. 4.70
Feedback Pair amplifier.

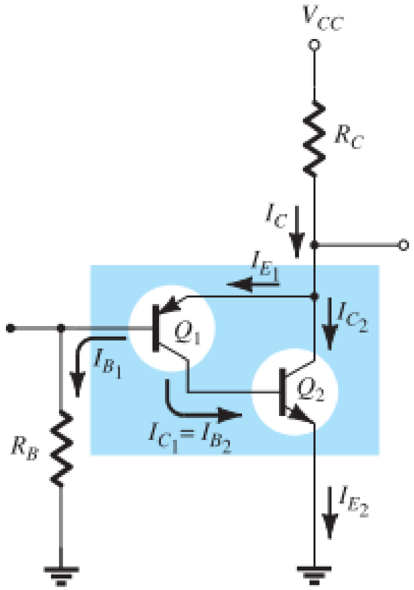


FIG. 4.71
DC equivalent of Fig. 4.70.

$$I_{B_2} = I_{C_1} = \beta_1 I_{B_1}$$

$$I_{C_2} = \beta_2 I_{B_2}$$

$$\boxed{I_{C_2} \cong I_{E_2} = \beta_1 \beta_2 I_{B_1}}$$

$$\begin{aligned} I_C &= I_{E_1} + I_{E_2} \\ &\cong \beta_1 I_{B_1} + \beta_1 \beta_2 I_{B_1} \\ &= \beta_1 (1 + \beta_2) I_{B_1} \end{aligned}$$

$$\boxed{I_C \cong \beta_1 \beta_2 I_{B_1}}$$

$$V_{CC} - I_C R_C - V_{EB_1} - I_{B_1} R_B = 0$$

$$V_{CC} - V_{EB_1} - \beta_1 \beta_2 I_{B_1} R_C - I_{B_1} R_B = 0$$

$$\boxed{I_{B_1} = \frac{V_{CC} - V_{EB_1}}{R_B + \beta_1 \beta_2 R_C}}$$

$$\boxed{V_{B_1} = I_{B_1} R_B}$$

$$\boxed{V_{B_2} = V_{BE_2}}$$

$$\boxed{V_{C_2} = V_{CC} - I_C R_C}$$

$$\boxed{V_{C_1} = V_{BE_2}}$$

$$\boxed{V_{CE_2} = V_{C_2}}$$

$$V_{EC_1} = V_{E_1} - V_{C_1}$$

$$\boxed{V_{EC_1} = V_{C_2} - V_{BE_2}}$$

Multiple BJT Networks (5 of 6)

- Direct Coupled

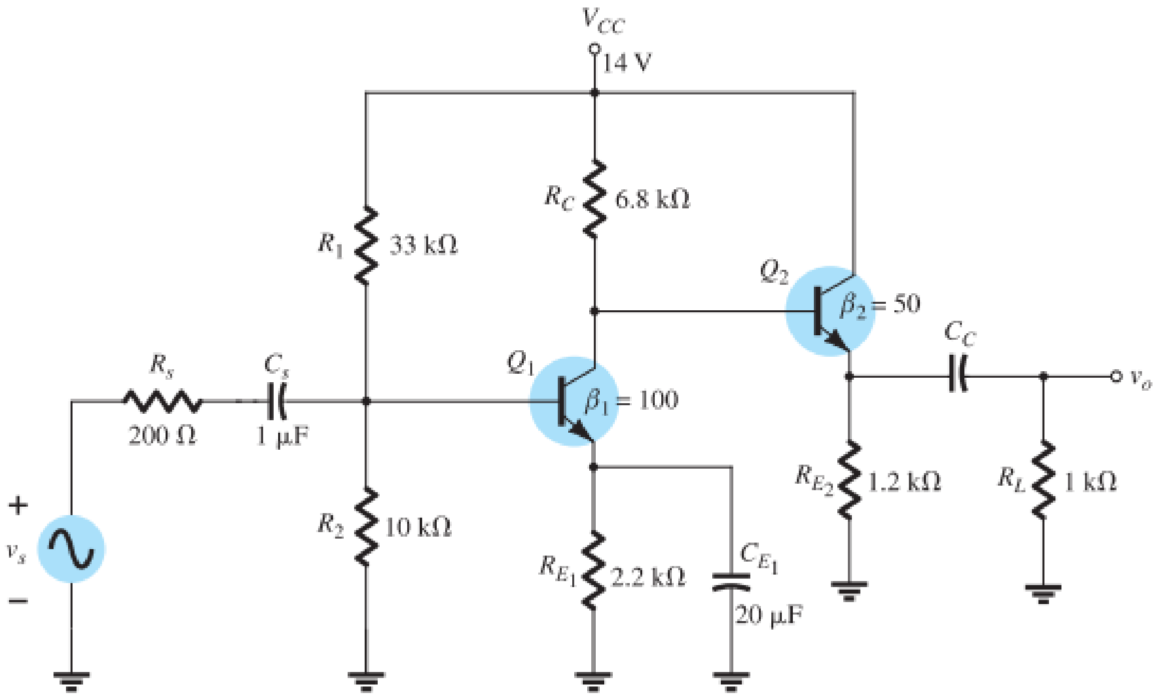


FIG. 4.72
Direct-coupled amplifier.

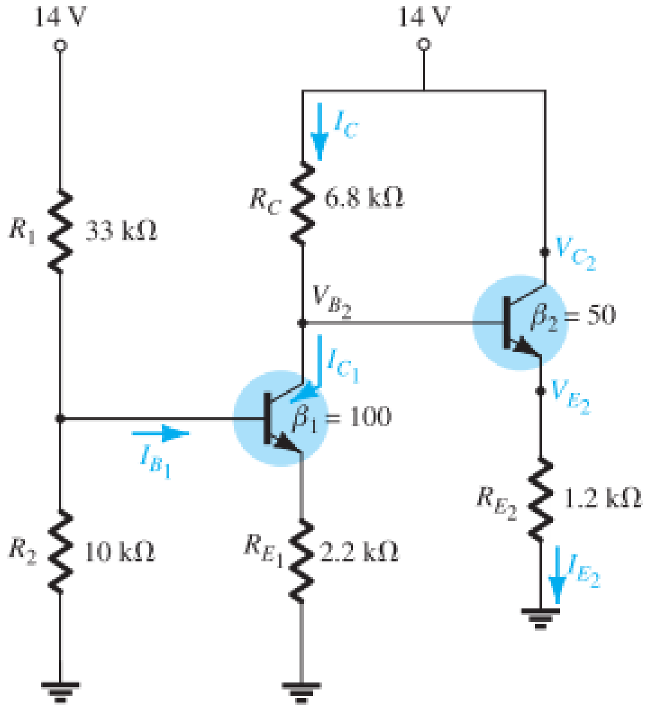


FIG. 4.73
DC equivalent of Fig. 4.72.

$$I_{B_1} = \frac{E_{\text{Th}} - V_{BE}}{R_{\text{Th}} + (\beta + 1)R_{E_1}}$$

$$R_{\text{Th}} = R_1 \| R_2$$

$$E_{\text{Th}} = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$\boxed{V_{B_2} = V_{CC} - I_C R_C}$$

$$V_{E_2} = V_{B_2} - V_{BE_2}$$

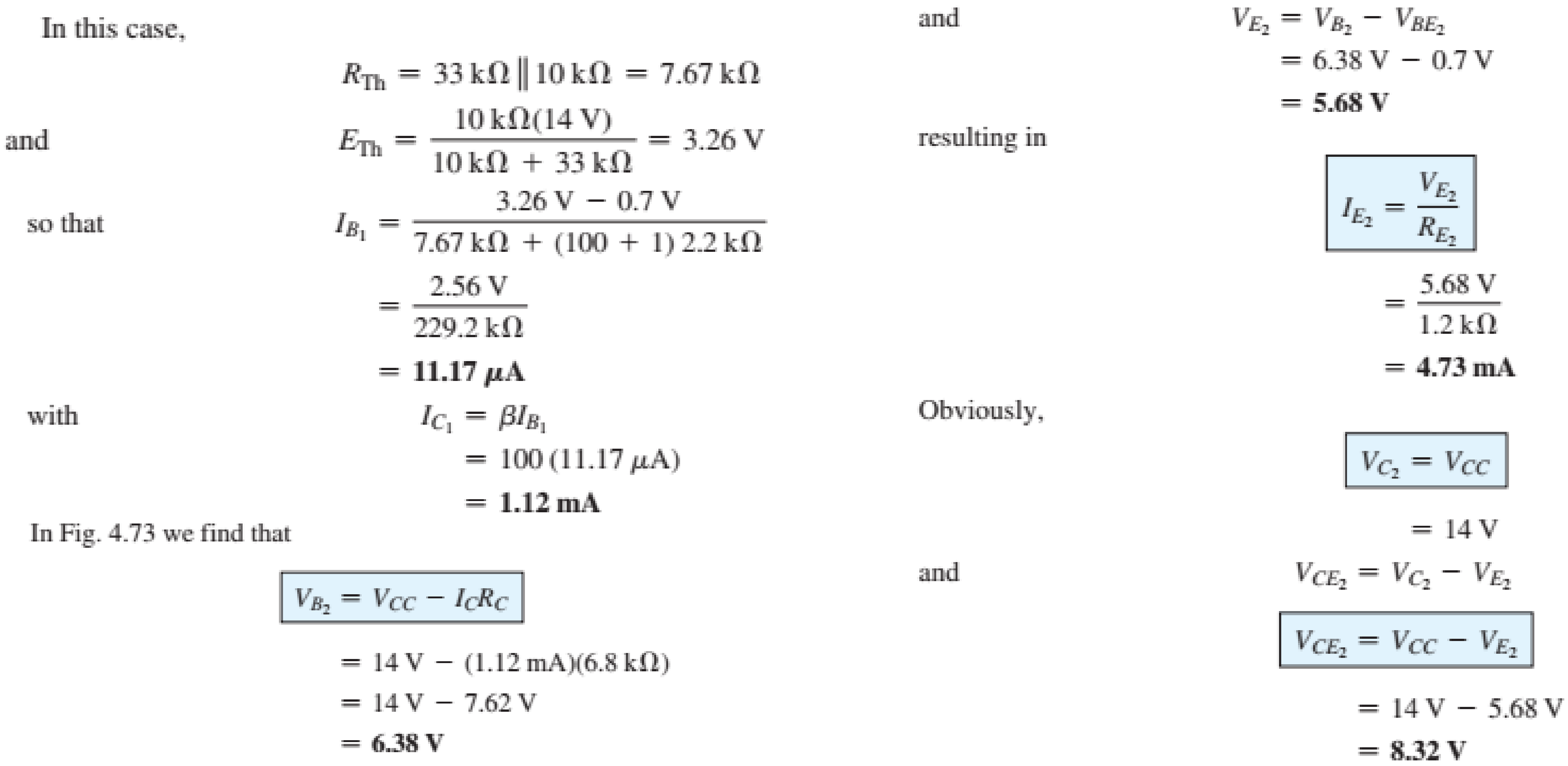
$$\boxed{I_{E_2} = \frac{V_{E_2}}{R_{E_2}}}$$

$$\boxed{V_{C_2} = V_{CC}}$$

$$V_{CE_2} = V_{C_2} - V_{E_2}$$

$$\boxed{V_{CE_2} = V_{CC} - V_{E_2}}$$

Multiple BJT Networks (6 of 6)



In this case,

$$R_{\text{Th}} = 33\text{ k}\Omega \parallel 10\text{ k}\Omega = 7.67\text{ k}\Omega$$

and

$$E_{\text{Th}} = \frac{10\text{ k}\Omega(14\text{ V})}{10\text{ k}\Omega + 33\text{ k}\Omega} = 3.26\text{ V}$$

so that

$$I_{B_1} = \frac{3.26\text{ V} - 0.7\text{ V}}{7.67\text{ k}\Omega + (100 + 1)\,2.2\text{ k}\Omega} = \frac{2.56\text{ V}}{229.2\text{ k}\Omega} = \mathbf{11.17\ \mu A}$$

with

$$I_{C_1} = \beta I_{B_1} = 100\,(11.17\ \mu\text{A}) = \mathbf{1.12\ mA}$$

In Fig. 4.73 we find that

$$\boxed{V_{B_2} = V_{CC} - I_C R_C}$$

$$= 14\text{ V} - (1.12\text{ mA})(6.8\text{ k}\Omega) = 14\text{ V} - 7.62\text{ V} = \mathbf{6.38\ V}$$

and

$$V_{E_2} = V_{B_2} - V_{BE_2} = 6.38\text{ V} - 0.7\text{ V} = \mathbf{5.68\ V}$$

resulting in

$$\boxed{I_{E_2} = \frac{V_{E_2}}{R_{E_2}}}$$

$$= \frac{5.68\text{ V}}{1.2\text{ k}\Omega} = \mathbf{4.73\ mA}$$

Obviously,

$$\boxed{V_{C_2} = V_{CC}}$$

$$= 14\text{ V}$$

and

$$V_{CE_2} = V_{C_2} - V_{E_2}$$

$$\boxed{V_{CE_2} = V_{CC} - V_{E_2}}$$

$$= 14\text{ V} - 5.68\text{ V} = \mathbf{8.32\ V}$$

Current Mirrors (1 of 2)

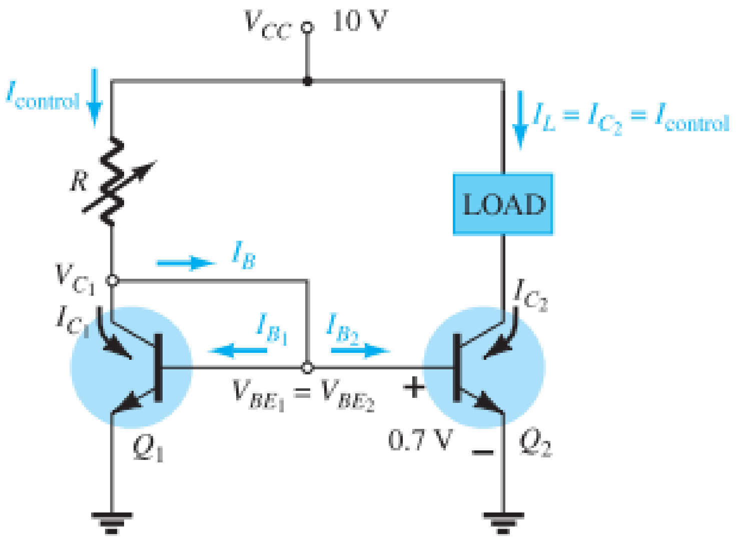


FIG. 4.74
Current mirror using back-to-back BJTs.

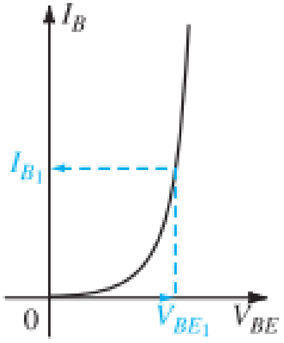


FIG. 4.75
Base characteristics for transistor Q_1 (and Q_2).

$$\boxed{I_{\text{control}} = \frac{V_{CC} - V_{BE}}{R}}$$

$$I_{\text{control}} = I_{C_1} + I_B = I_{C_1} + 2I_{B_1}$$

$$I_{C_1} = \beta_1 I_{B_1}$$

$$I_{\text{control}} = \beta_1 I_{B_1} + 2I_{B_1} = (\beta_1 + 2)I_{B_1}$$

β_1 is typically $\gg 2$, $I_{\text{control}} \cong \beta_1 I_{B_1}$

$$\boxed{I_{B_1} = \frac{I_{\text{control}}}{\beta_1}}$$

$$I_L = I_{C_2} = \beta I_{B_2}$$

$$I_L \uparrow I_{C_2} \uparrow I_{B_2} \uparrow V_{BE_2} \uparrow V_{CE_1} \uparrow, I_R \downarrow, I_B \downarrow, I_{B_2} \downarrow I_{C_2} \downarrow I_L \downarrow$$

Note

Current Mirrors (2 of 2)

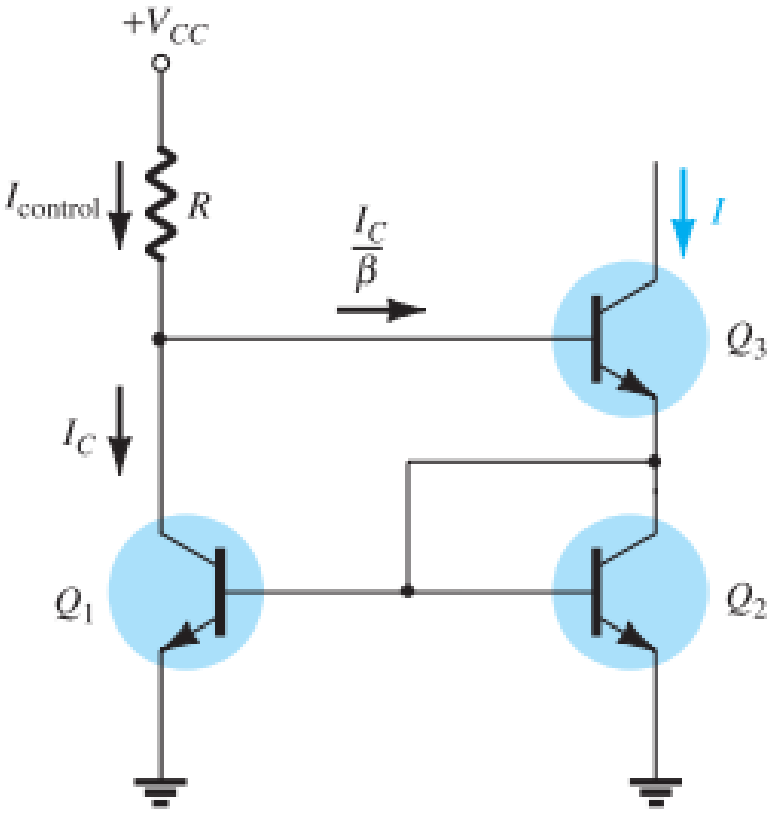
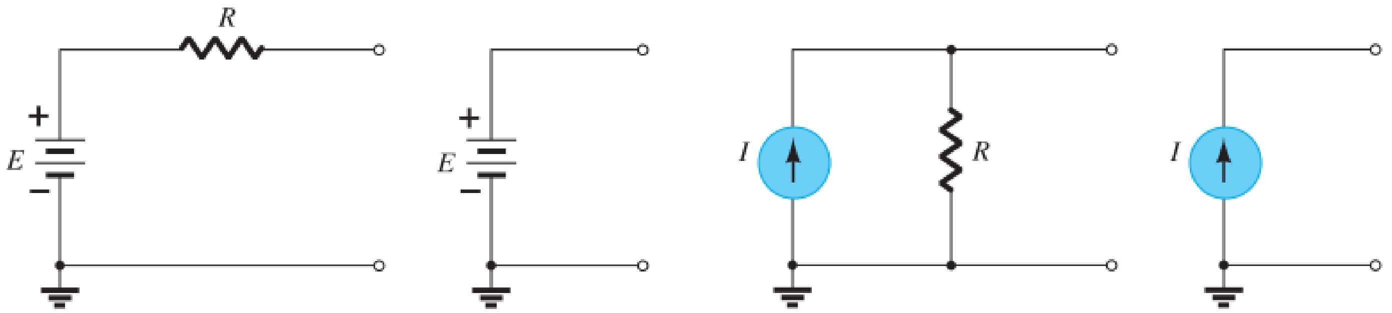


FIG. 4.78
Current mirror circuit with higher output impedance.

$$I_{control} = \frac{V_{CC} - 2V_{BE}}{R} \approx I_C + \frac{I_C}{\beta} = \frac{\beta + 1}{\beta} I_C \approx I_C$$

$$I \approx I_C = I_{control}$$

Current Source Circuits (1 of 2)



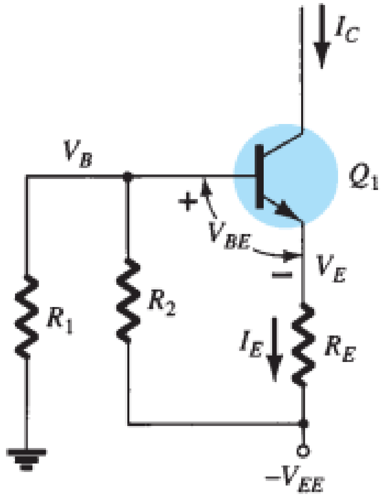
Practical voltage source

Ideal voltage source

Practical current source

Ideal current source

Bipolar Transistor Constant-Current Source



$$V_B = \frac{R_1}{R_1 + R_2}(-V_{EE})$$

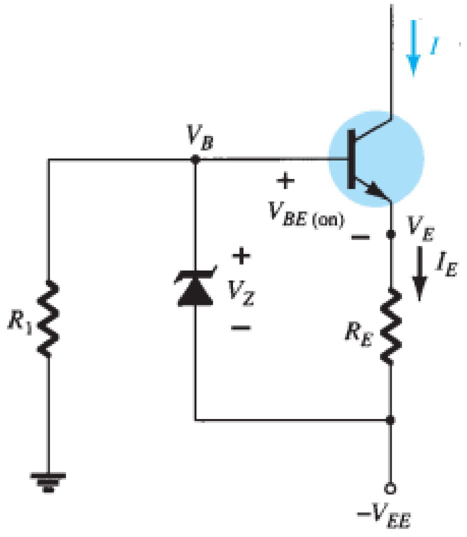
$$V_E = V_B - 0.7\text{ V}$$

$$I_E = \frac{V_E - (-V_{EE})}{R_E} \approx I_C$$

FIG. 4.81

Discrete constant-current source.

Transistor/Zener Constant-Current Source



$$I \approx I_E = \frac{V_Z - V_{BE}}{R_E}$$

FIG. 4.83

Constant-current circuit using Zener diode.

Current Source Circuits (2 of 2)

EXAMPLE 4.30 Calculate the constant current I in the circuit of Fig. 4.84.

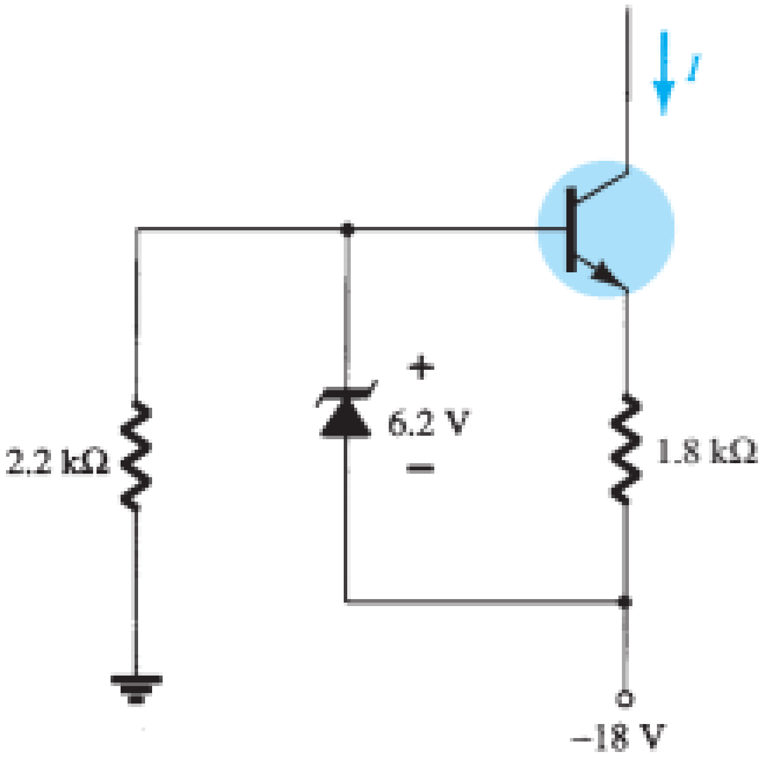


FIG. 4.84

Constant-current circuit for Example 4.30.

Solution:

Eq. (4.83): $$I = \frac{V_Z - V_{BE}}{R_E} = \frac{6.2\text{ V} - 0.7\text{ V}}{1.8\text{ k}\Omega} = 3.06\text{ mA} \approx \mathbf{3\text{ mA}}$$

PNP Transistors (1 of 2)

- The analysis thus far has been limited totally to *npn* transistors.
- Fortunately, the analysis of *pnp* transistors follows the same pattern established for *npn* transistors.
- In fact, the only difference between the resulting equations for a network in which an *npn* transistor has been replaced by a *pnp* transistor is the sign associated with particular quantities.

$$-I_E R_E + V_{BE} - I_B R_B + V_{CC} = 0$$

$$\boxed{I_B = \frac{V_{CC} + V_{BE}}{R_B + (\beta + 1)R_E}}$$

$$-I_E R_E + V_{CE} - I_C R_C + V_{CC} = 0$$

$$\boxed{V_{CE} = -V_{CC} + I_C(R_C + R_E)}$$

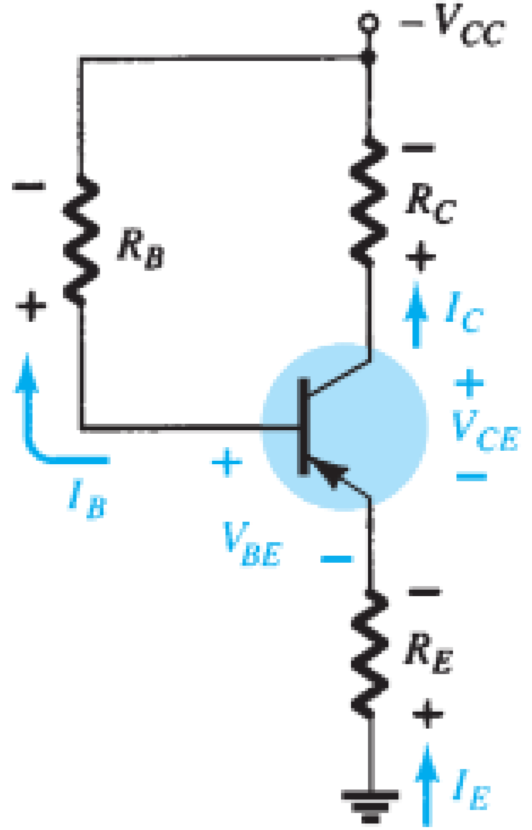


FIG. 4.85

pnp transistor in an emitter-stabilized configuration.

PNP Transistors (2 of 2)

EXAMPLE 4.31 Determine V_{CE} for the voltage-divider bias configuration of Fig. 4.86.

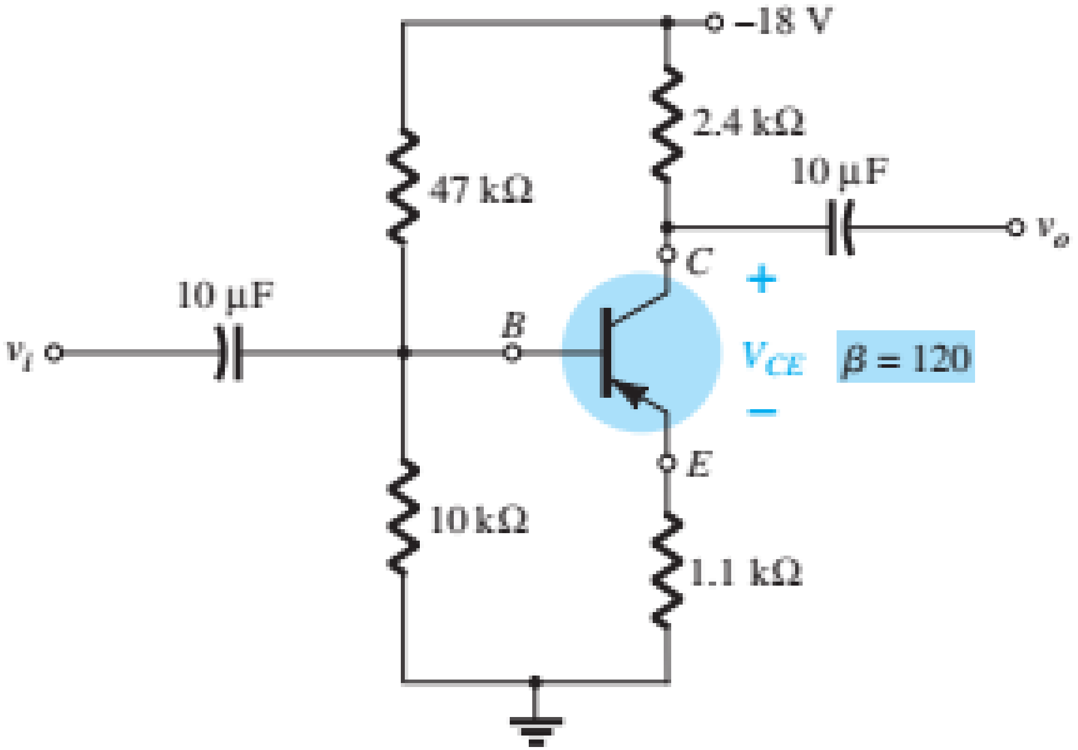
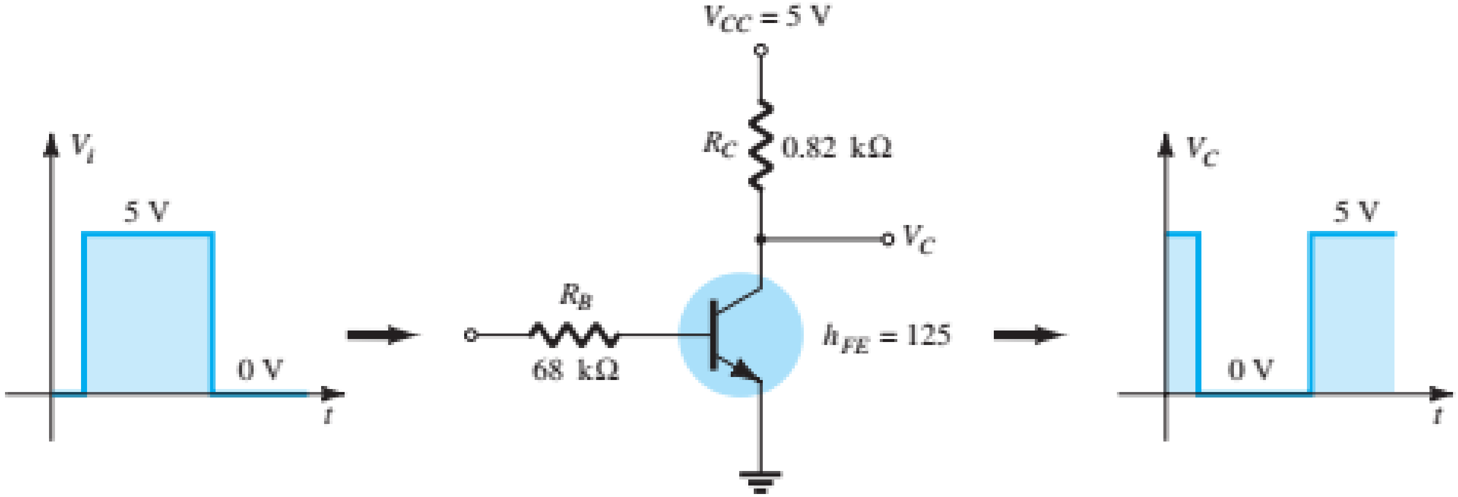


FIG. 4.86

pnp transistor in a voltage-divider bias configuration.

Write the equations of solution

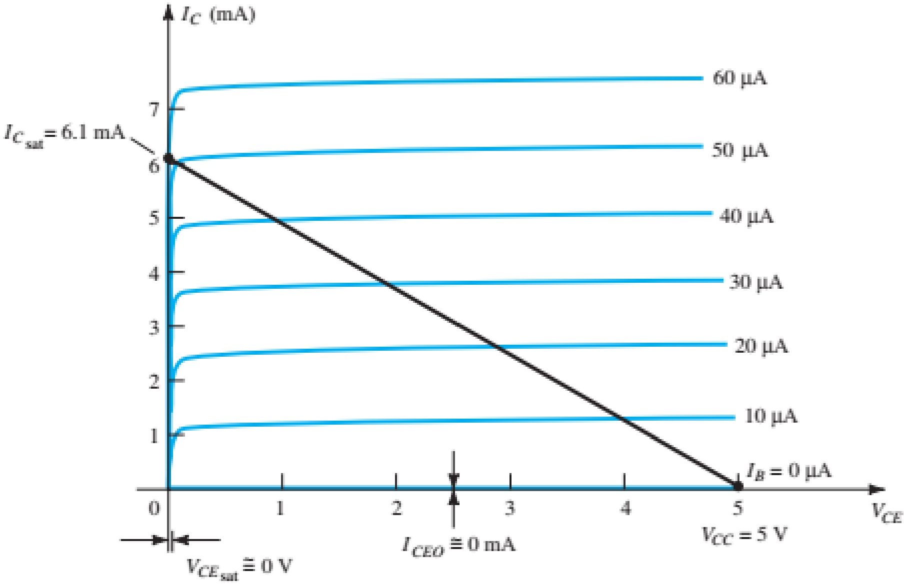
Transistor Switching Networks (1 of 3)



$$\boxed{I_{C_{\text{sat}}} = \frac{V_{CC}}{R_C}}$$

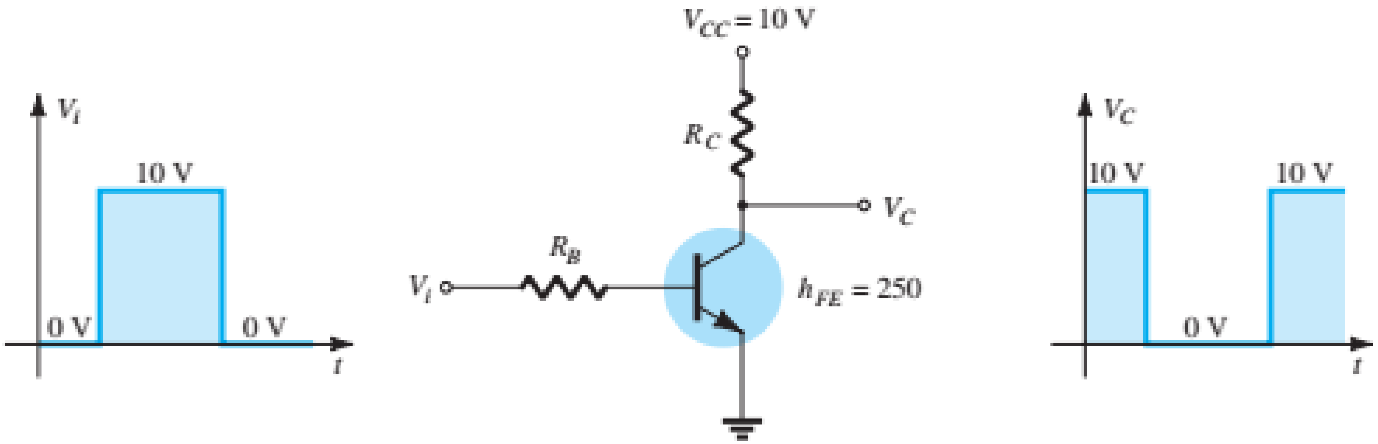
$$I_{B_{\max}} \cong \frac{I_{C_{\text{sat}}}}{\beta_{\text{dc}}}$$

$$\boxed{I_B > \frac{I_{C_{\text{sat}}}}{\beta_{\text{dc}}}}$$



Transistor Switching Networks (2 of 3)

EXAMPLE 4.32 Determine R_B and R_C for the transistor inverter of Fig. 4.90 if $I_{C_{sat}} = 10\text{ mA}$.



Solution: At saturation,

$$I_{C_{sat}} = \frac{V_{CC}}{R_C}$$

and

$$10\text{ mA} = \frac{10\text{ V}}{R_C}$$

so that

$$R_C = \frac{10\text{ V}}{10\text{ mA}} = 1\text{ k}\Omega$$

At saturation,

$$I_B \cong \frac{I_{C_{sat}}}{\beta_{dc}} = \frac{10\text{ mA}}{250} = 40\ \mu\text{A}$$

Choosing $I_B = 60\ \mu\text{A}$ to ensure saturation and using

$$I_B = \frac{V_i - 0.7\text{ V}}{R_B}$$

we obtain

$$R_B = \frac{V_i - 0.7\text{ V}}{I_B} = \frac{10\text{ V} - 0.7\text{ V}}{60\ \mu\text{A}} = 155\text{ k}\Omega$$

Choose $R_B = 150\text{ k}\Omega$, which is a standard value. Then

$$I_B = \frac{V_i - 0.7\text{ V}}{R_B} = \frac{10\text{ V} - 0.7\text{ V}}{150\text{ k}\Omega} = 62\ \mu\text{A}$$

and

$$I_B = 62\ \mu\text{A} > \frac{I_{C_{sat}}}{\beta_{dc}} = 40\ \mu\text{A}$$

Therefore, use $R_B = \mathbf{150\text{ k}\Omega}$ and $R_C = \mathbf{1\text{ k}\Omega}$.

Transistor Switching Networks (3 of 3)

$$R_{\text{sat}} = \frac{V_{CE_{\text{sat}}}}{I_{C_{\text{sat}}}}$$

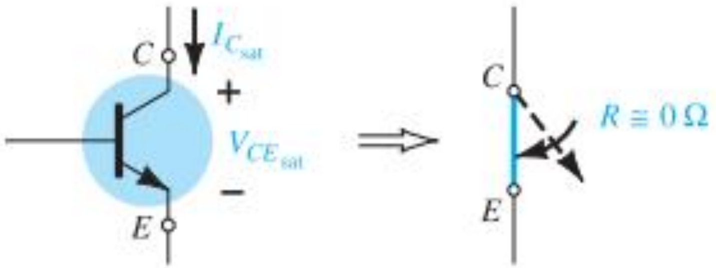


FIG. 4.88

Saturation conditions and the resulting terminal resistance.

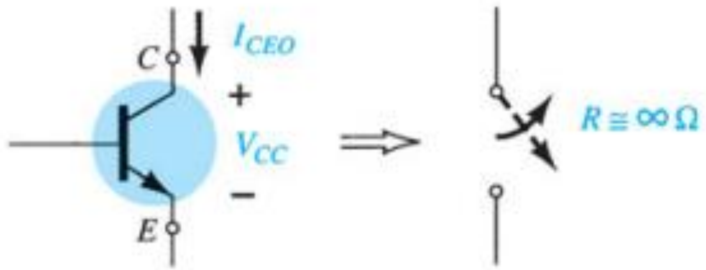


FIG. 4.89

Cutoff conditions and the resulting terminal resistance.

Using a typical average value of $V_{CE_{\text{sat}}}$ such as 0.15 V gives

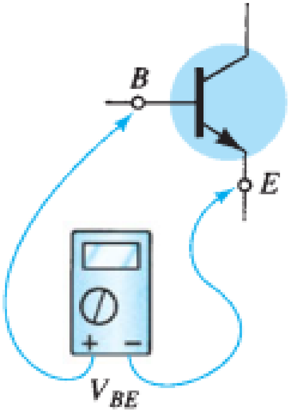
$$R_{\text{sat}} = \frac{V_{CE_{\text{sat}}}}{I_{C_{\text{sat}}}} = \frac{0.15\text{ V}}{6.1\text{ mA}} = 24.6\ \Omega$$

$$R_{\text{cutoff}} = \frac{V_{CC}}{I_{CEO}} = \frac{5\text{ V}}{0\text{ mA}} = \boldsymbol{\infty\ \Omega}$$

$$R_{\text{cutoff}} = \frac{V_{CC}}{I_{CEO}} = \frac{5\text{ V}}{10\ \mu\text{A}} = \mathbf{500\ k\Omega}$$

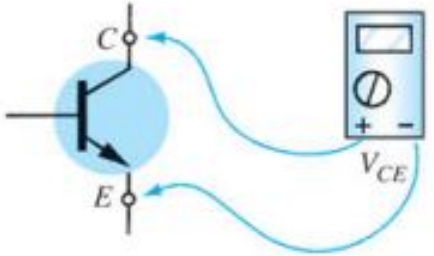
Troubleshooting Techniques

- For an “on” transistor, the voltage V_{BE} should be in the neighborhood of 0.7 V.
- For the typical transistor amplifier in the active region, V_{CE} is usually about 25% to 75% of V_{CC} .



≅ 0.7 V Si
≅ 0.3 V Ge
≅ 1.2 V GaAs

FIG. 4.92
Checking the dc level of V_{BE}.



0.3 V = saturation
0 V = short-circuit state or poor connection
Normally a few volts or more

FIG. 4.93
Checking the dc level of V_{CE}.

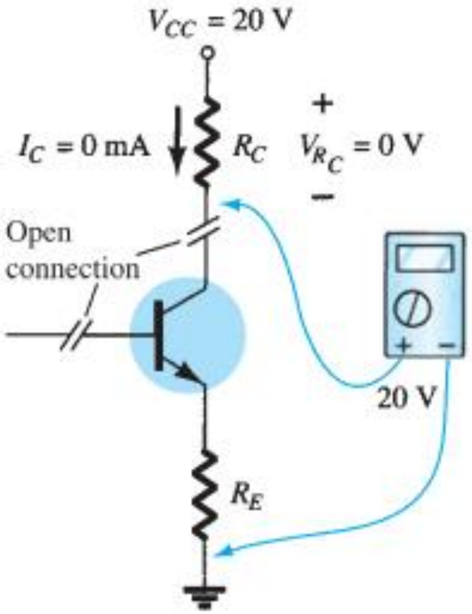


FIG. 4.94
Effect of a poor connection or damaged device.

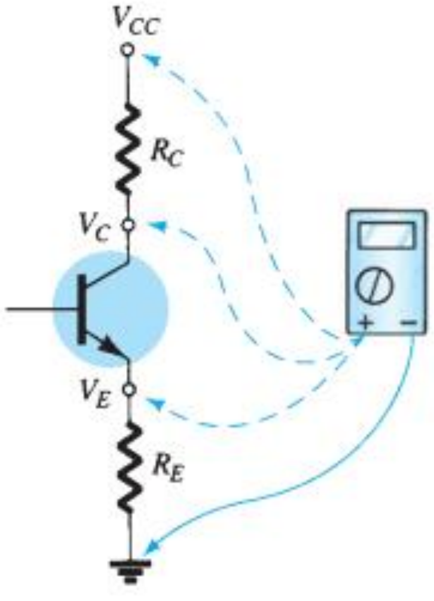


FIG. 4.95
Checking voltage levels with respect to ground.


Thank You!