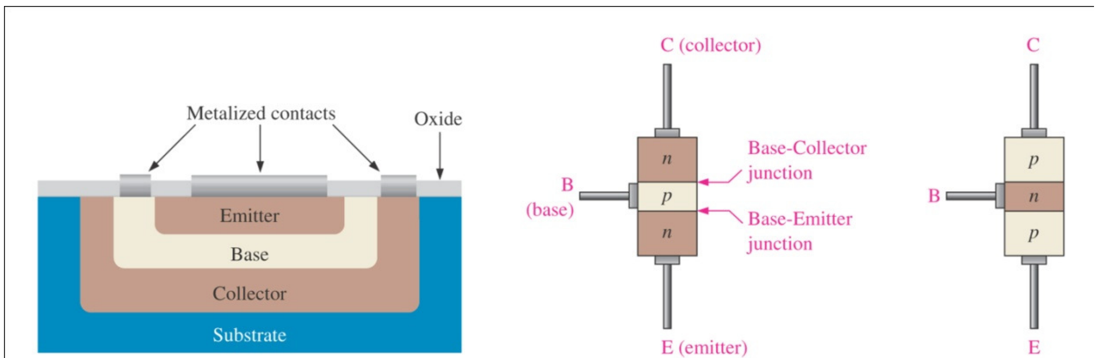
Chapter 17

Transistors and Applications

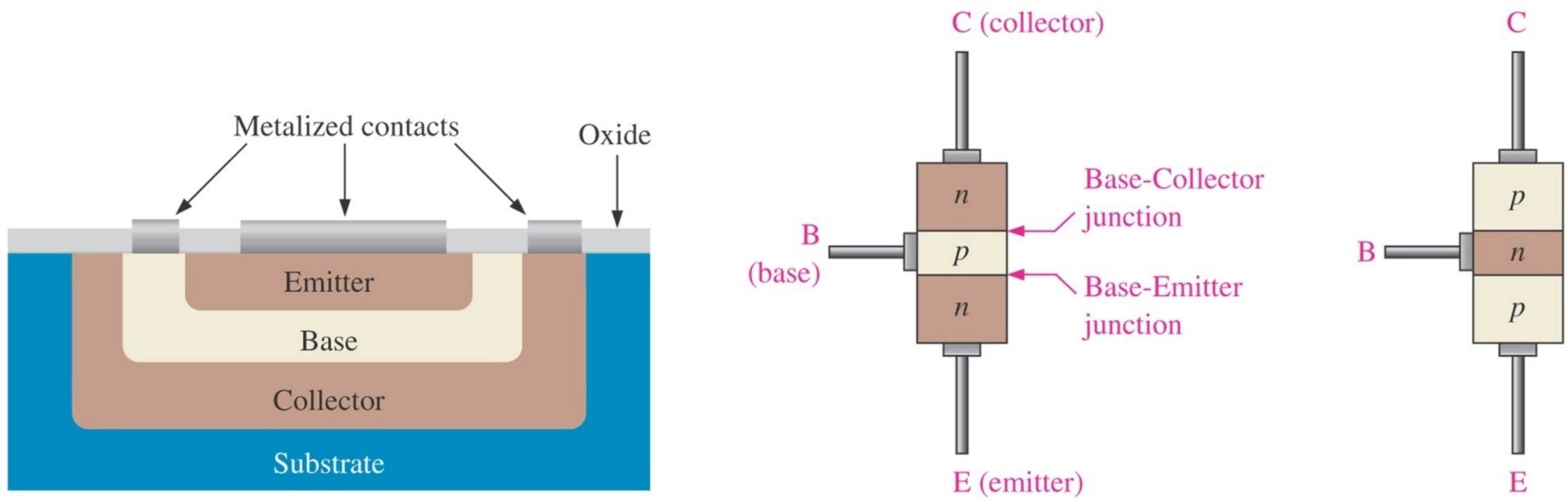
DC Operation of Bipolar Junction Transistors (BJTs)

- The bipolar junction transistor (BJT) is constructed with three doped semiconductor regions separated by two *pn* junctions
- Regions are called **emitter**, **base** and **collector**



(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

Basic construction of bipolar junction transistors.

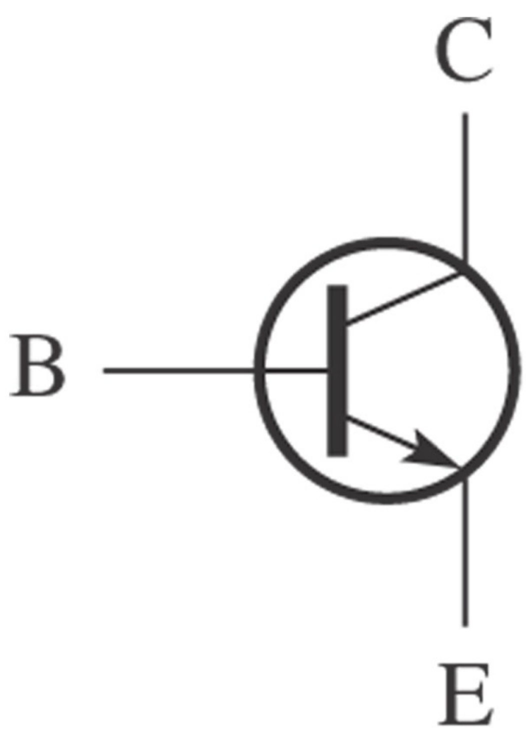


(a) Basic epitaxial planar structure (b) *npn* (c) *pnp*

Thomas L. Floyd

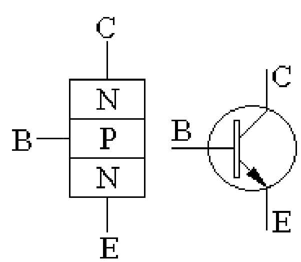
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

Transistor symbols.

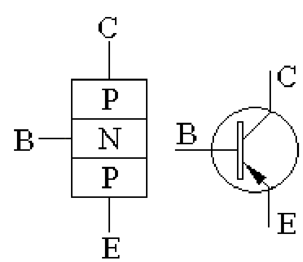


(a) *npn*

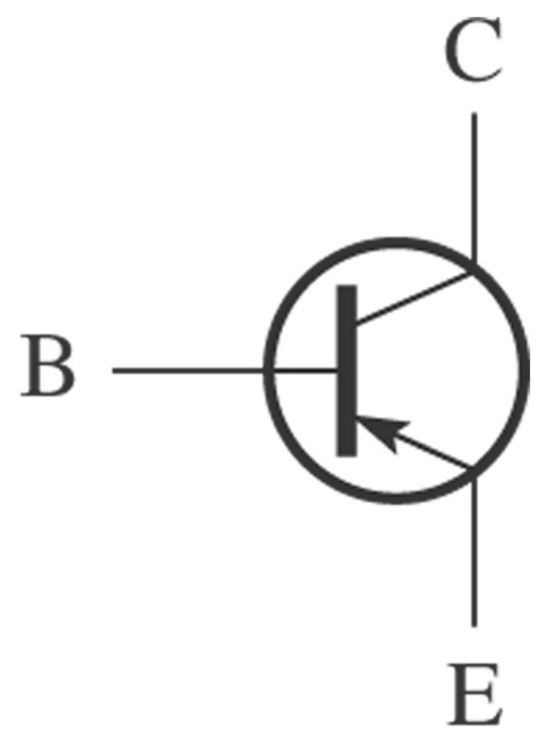
NPN – “Not Pointing In”



NPN Transistor



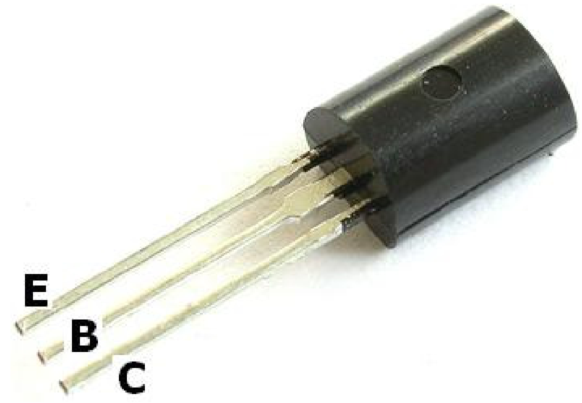
PNP Transistor

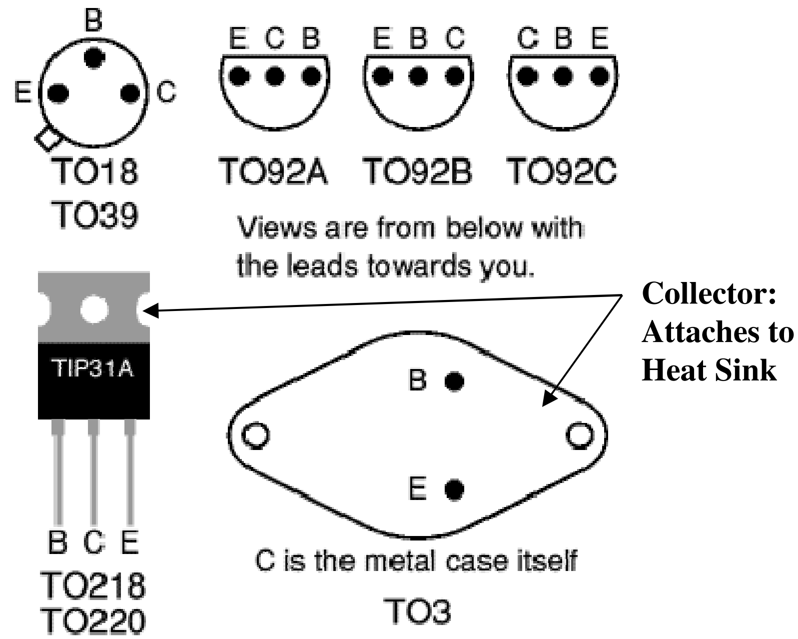


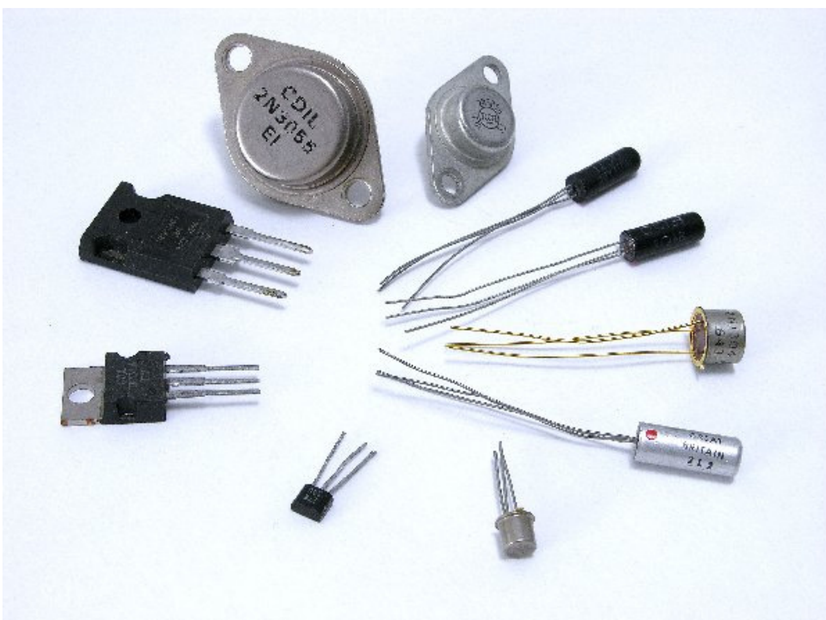
(b) *pnp*

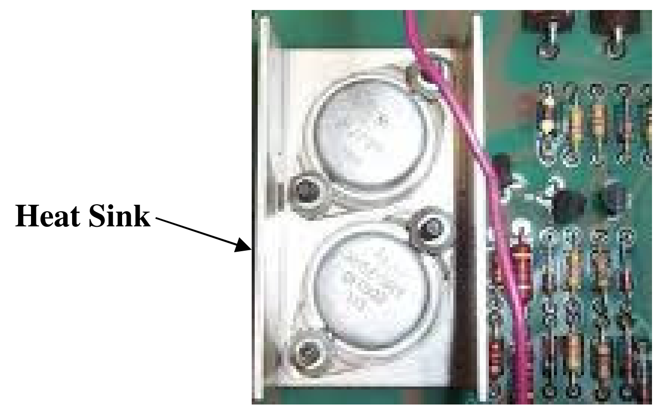
NPN – “Pointing In Please”

Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e







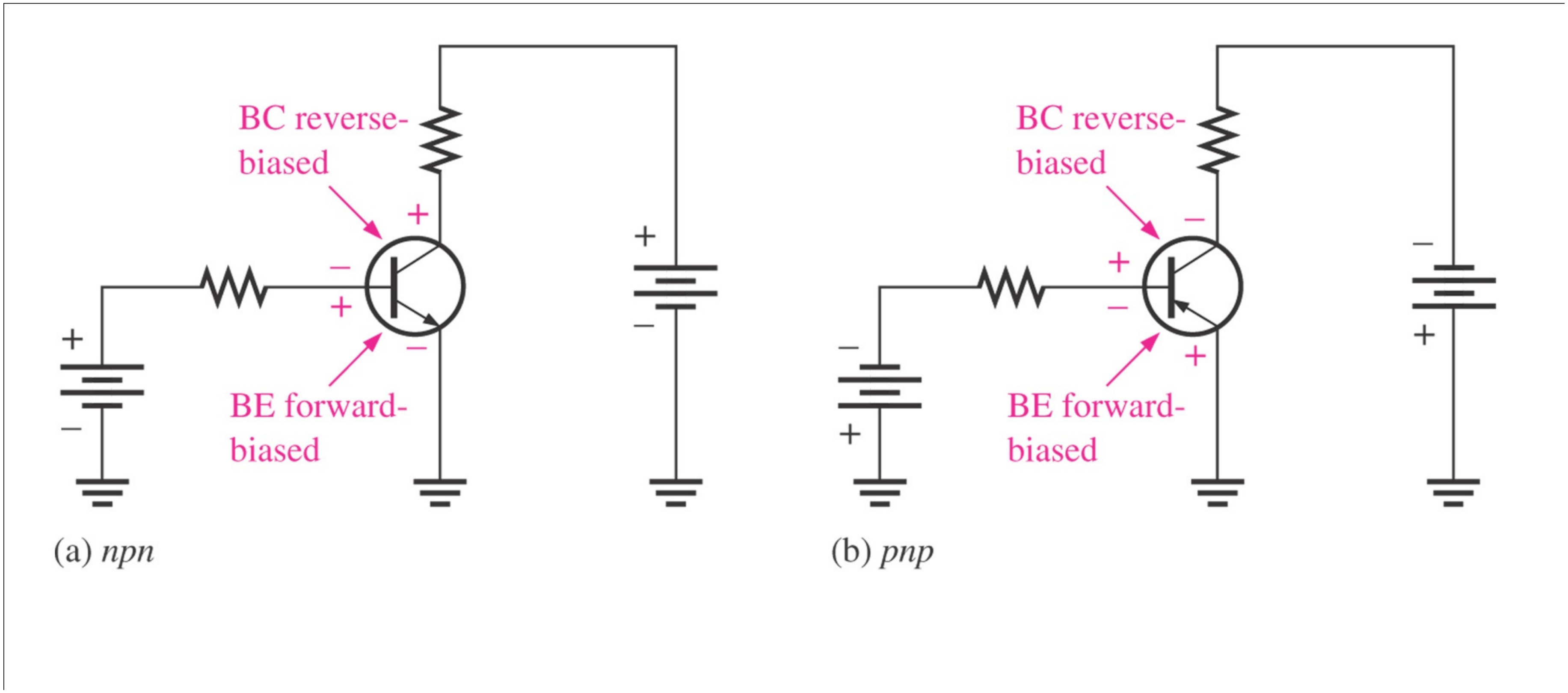


Collector Gives off Most Heat

DC Operation of Bipolar Junction Transistors (BJTs)

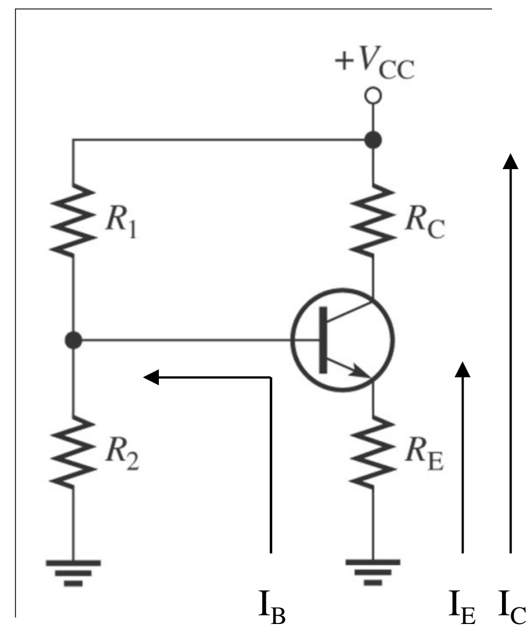
- There are two types of BJTs, the *npn* and *pnp*
- The two junctions are termed the *base-emitter* junction and the *base-collector* junction
- In order for the transistor to operate properly, the two junctions must have the correct dc bias voltages
  - the base-emitter (BE) junction is forward biased
  - the base-collector (BC) junction is reverse biased

Forward-reverse bias of a BJT



DC Operation of Bipolar Junction Transistors (BJTs)

- Voltage divider base biasing is widely used
- The voltage at the base controls the base current
- The base current controls the emitter/collector current



$I_C = I_B + I_E$
$I_C \approx I_E$

DC Gain

- **beta** (β_{DC})

$$I_C = \beta_{DC} I_B$$

- **alpha** (α_{DC})

$$\alpha_{DC} = I_C/I_E \approx 1$$

  - β_{DC} typically has a value between 20 and 200
  - Is determined by construction of the transistor

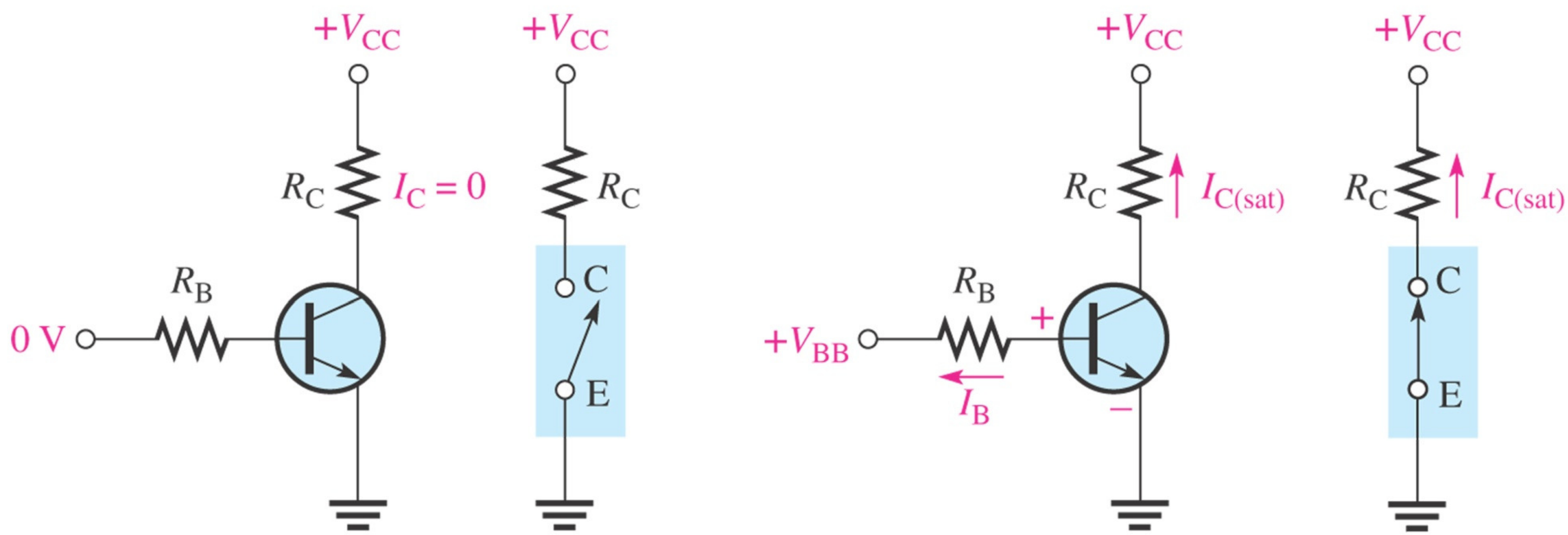
DC Operation (Biasing) of Bipolar Junction Transistors (BJTs)

- The base voltage is aproximately: $V_B \approx \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$
- Emitter voltage and Current
  - $V_E = V_B$ - .07v
  - $I_E = V_E/R_E$ ***or*** $I_E = (I_B)(B_{DC})$
  - $I_C \approx I_E$
  - $I_B = I_C/B_{DC}$
- Collector voltage: $V_C = V_{CC} - I_C R_C$
- $VCE = V_C - V_E$

The BJT as a Switch

- When used as an electronic switch, a transistor normally is operated alternately in cutoff and saturation
  - A transistor is in cutoff when the base-emitter junction is not forward-biased. V_{CE} is approximately equal to V_{CC}
  - When the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated

Ideal switching action of a transistor



(a) Cutoff — open switch

(b) Saturation — closed switch

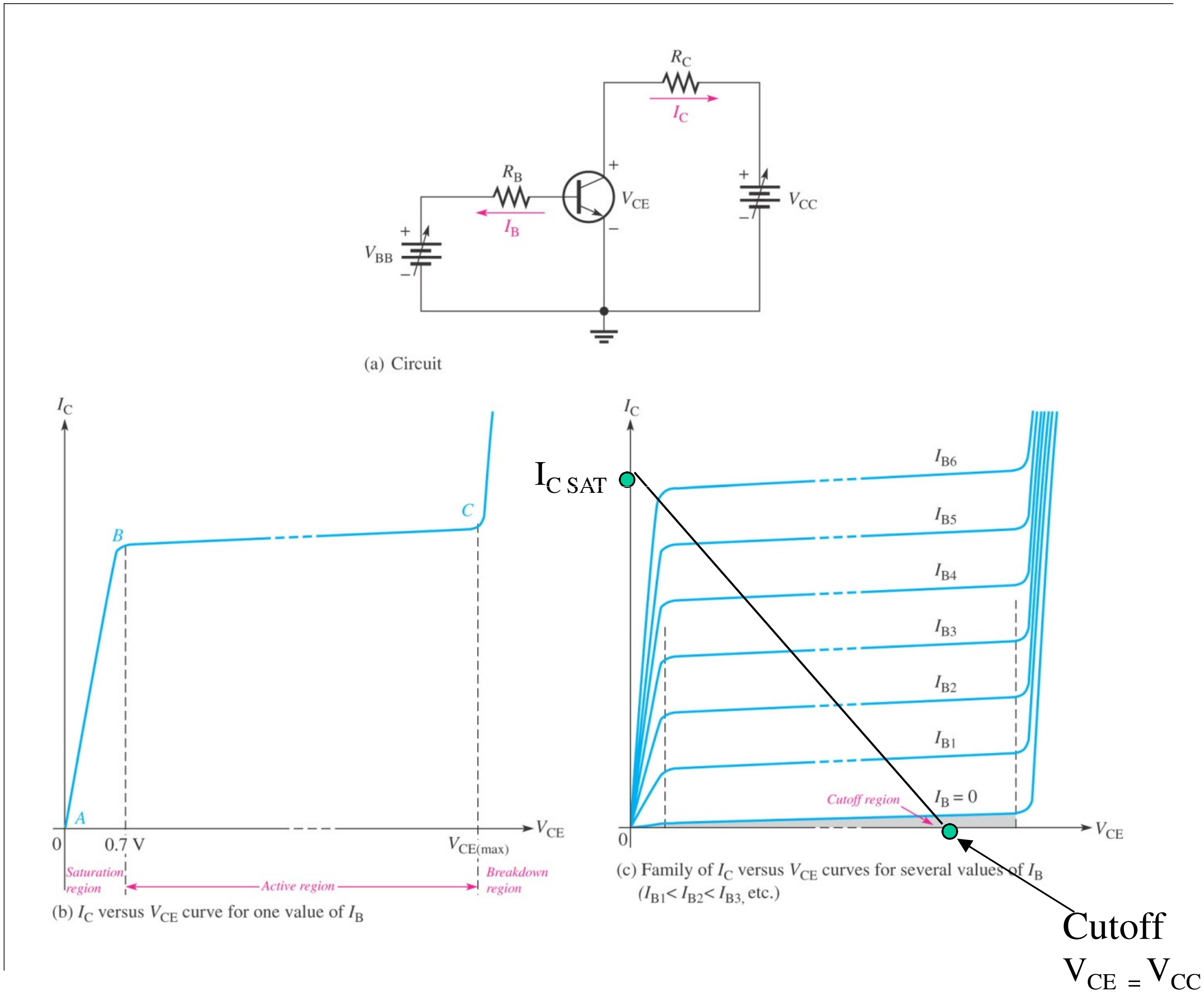
$V_{CE} = V_{CC}$
$I_C = 0$

$V_{CE} = 0V$
$I_C = V_{CC}/R_C$

BJT Class A Signal Amplifiers

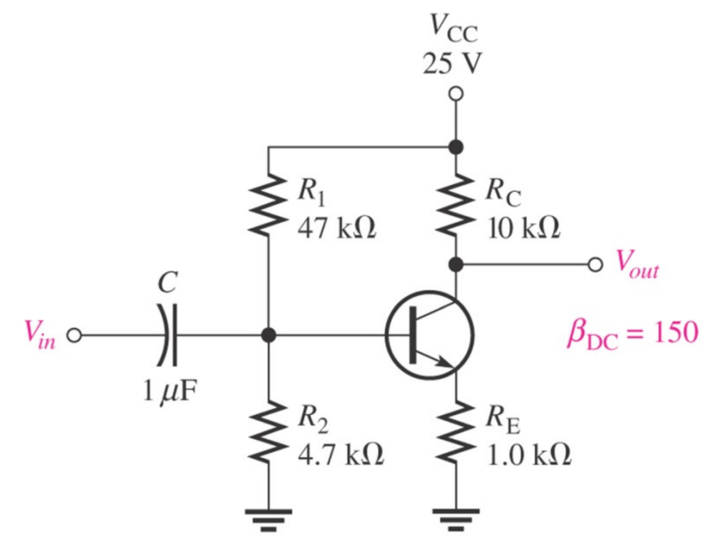
- In a class A amplifier, the transistor conducts for the full cycle of the input signal (360°)
  - used in low-power applications
- The transistor is operated in the active region, between saturation and cutoff
- The *load line* is drawn on the collector curves between saturation and cutoff

Collector characteristic curves



Signal Operation of Bipolar Junction Transistors (BJTs)

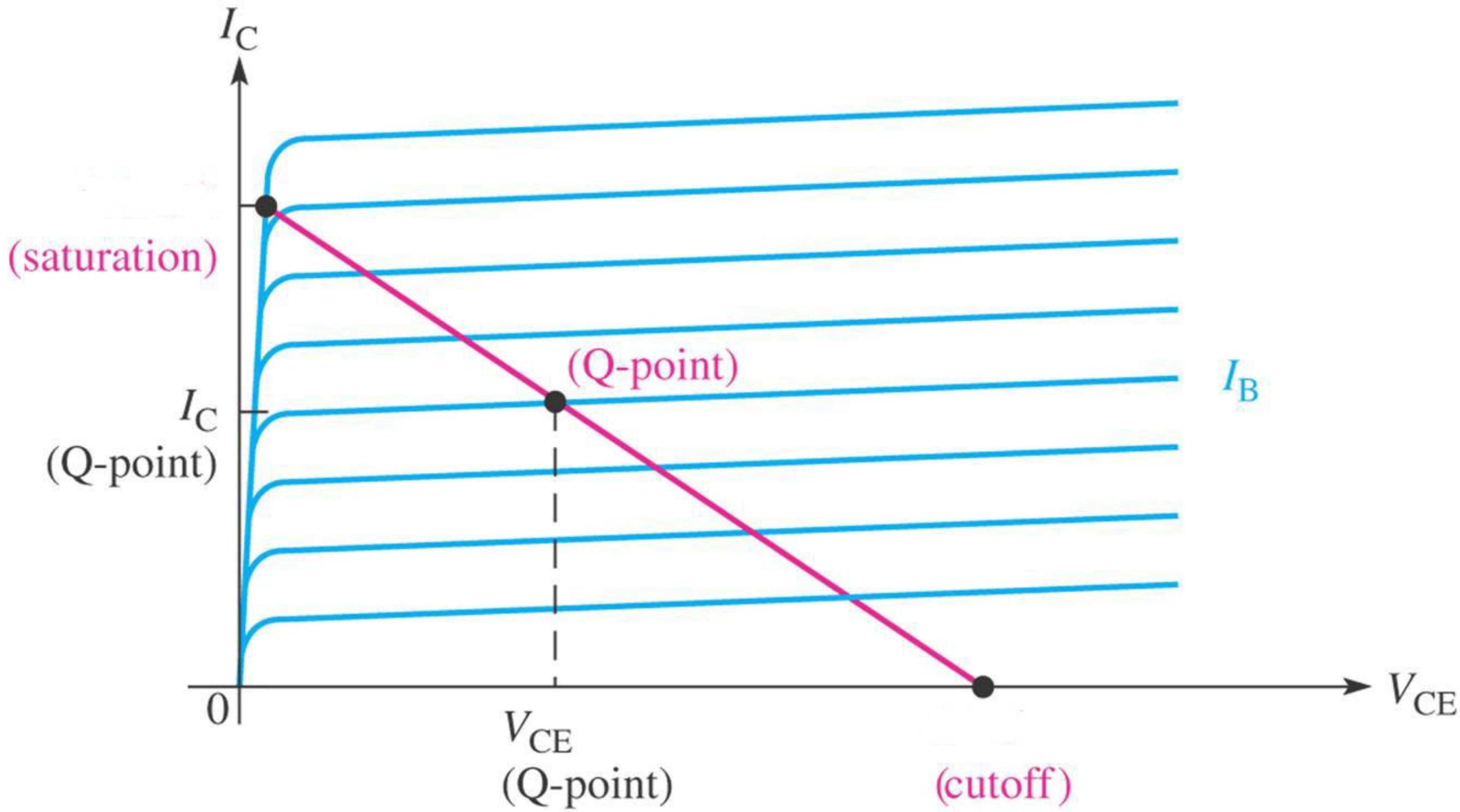
- A **common-emitter** (CE) amplifier
  - capacitors are used for coupling ac without disturbing dc levels



Signal Voltage Gain (A_V):

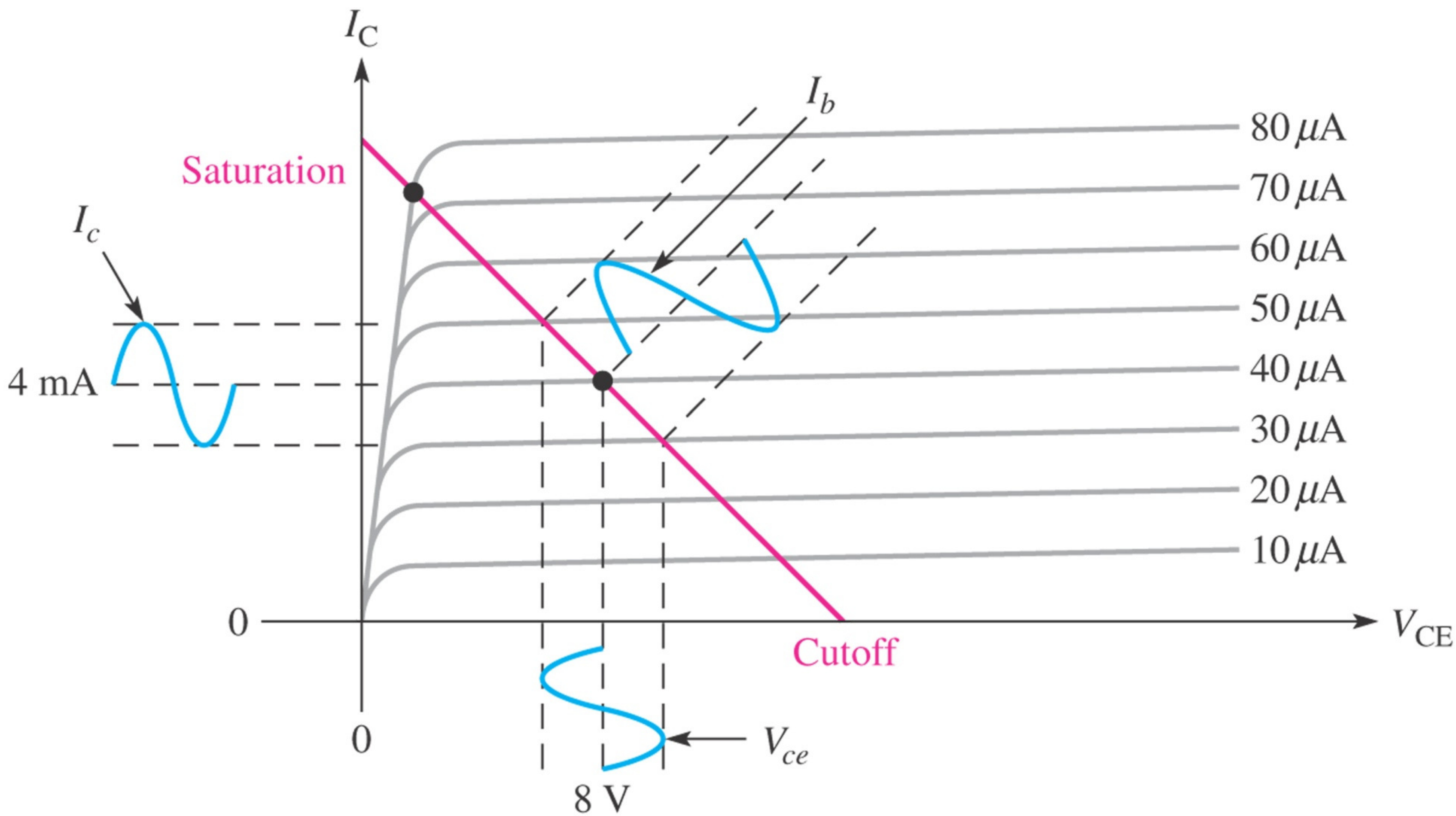
$$\frac{V_{out}}{V_{in}} \approx \frac{V_C}{V_E} \approx \frac{R_C}{R_E}$$

DC load line (red)



Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

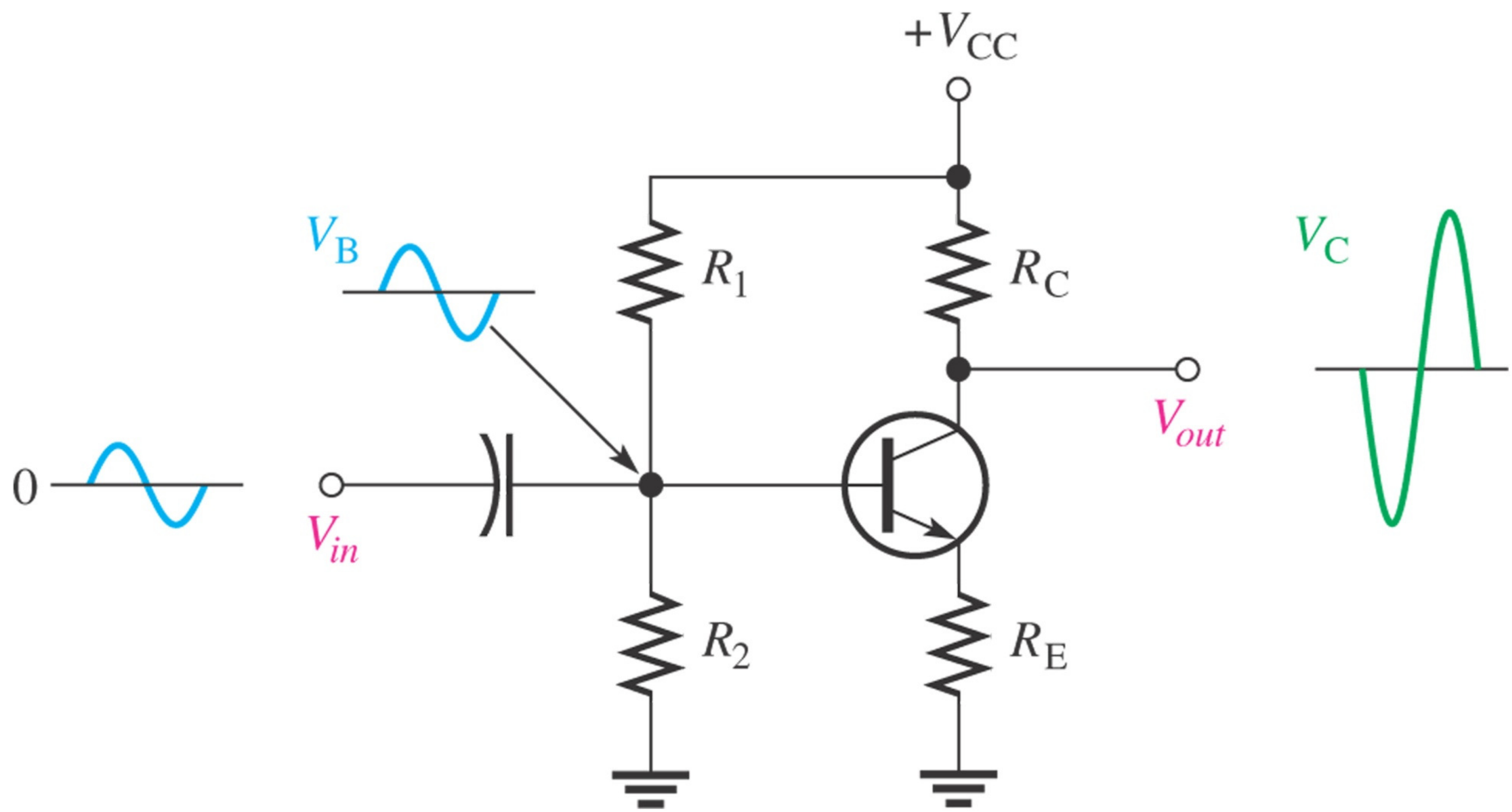
Signal operation on the load line



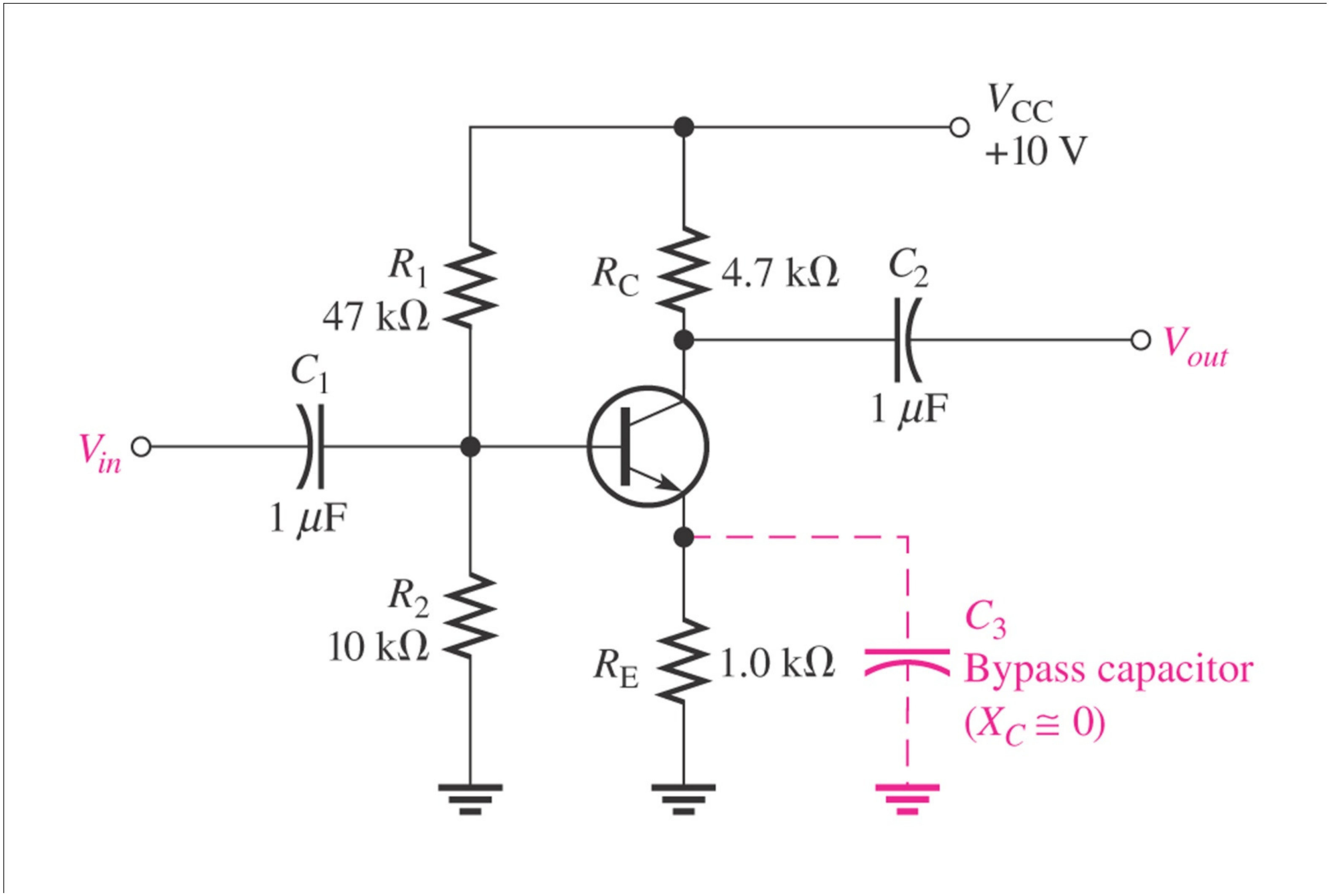
Thomas L. Floyd

Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

Signal Voltage amplification

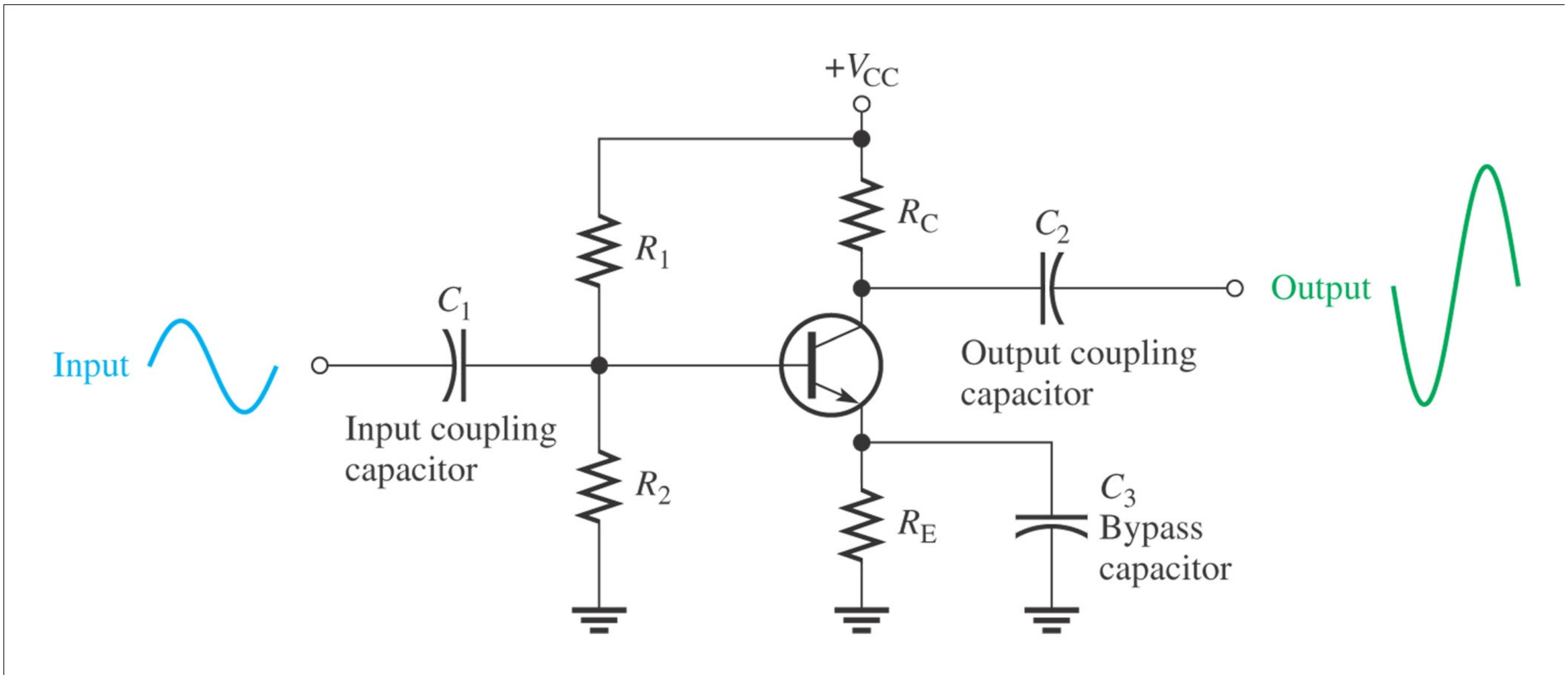


Typical common-emitter (CE) amplifier with bypass capacitor



Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

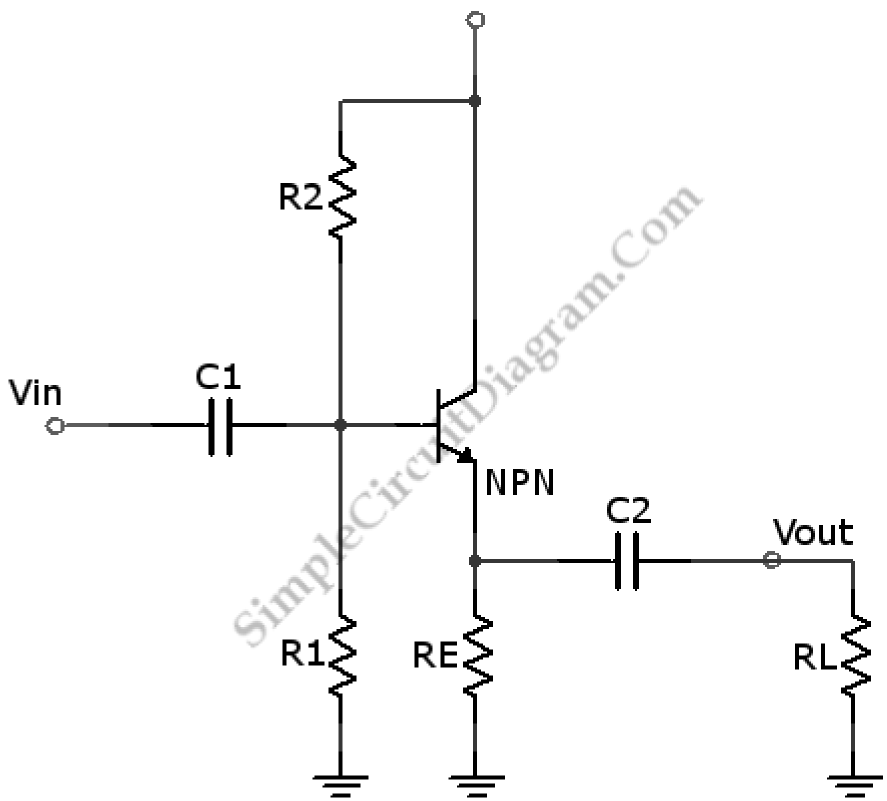
Adding an Emitter Bypass Capacitor



- A bypass capacitor in the emitter circuit passes the signal to ground.
- This increases gain by lowering the base-emitter impedance and stabilizing the emitter voltage

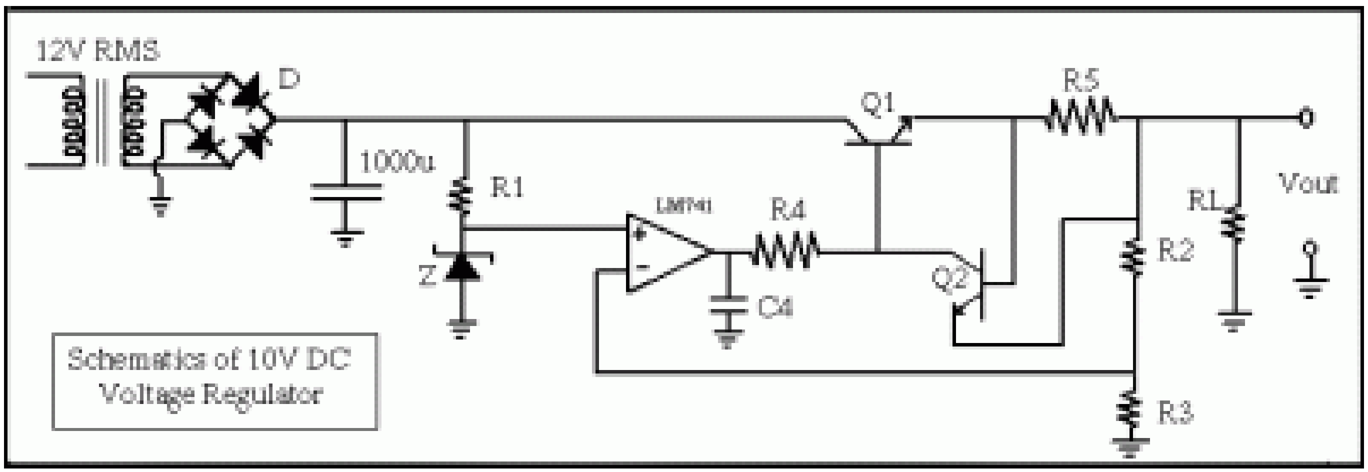
Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

Common Collector Configuration



- Signal Voltage Gain of Approximately 1
- No Phase Inversion
- Used as a Buffer between Circuits or Current Amplifier

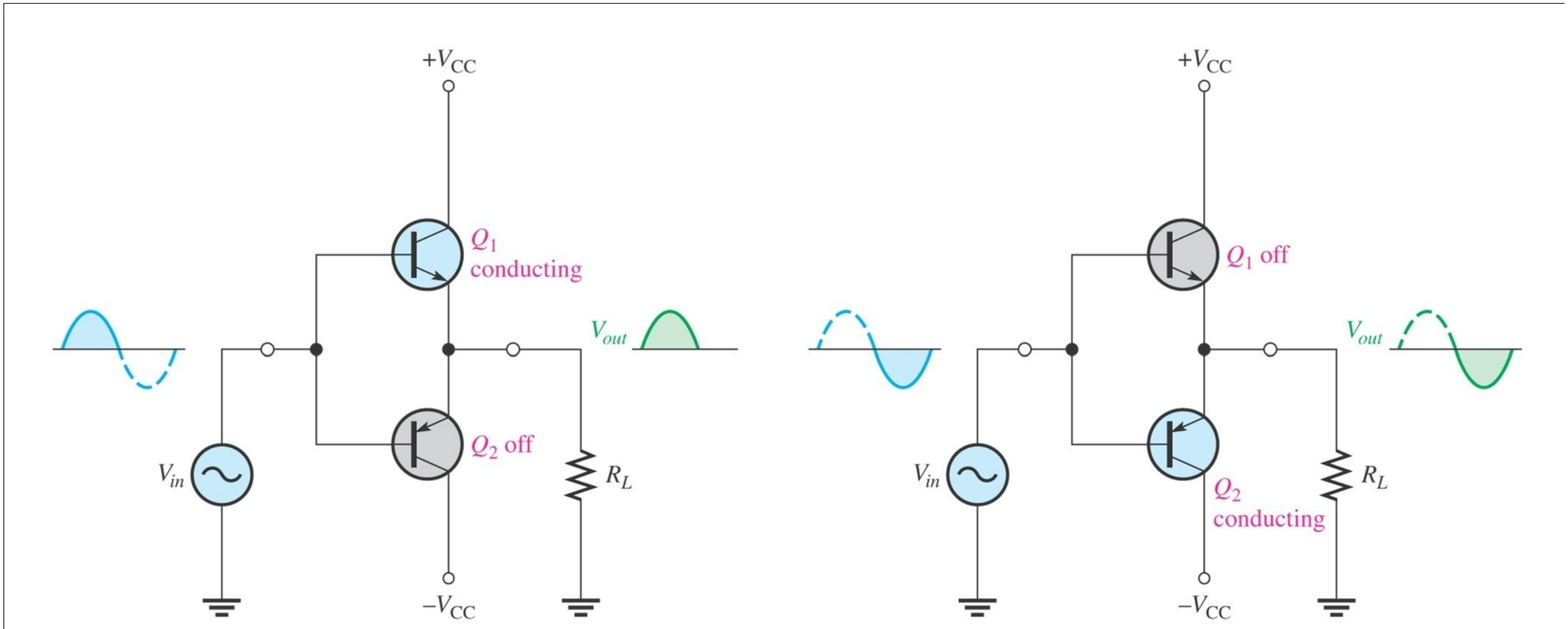
Common Base (Q1) Voltage Regulator Configuration



BJT Class B Amplifiers

- When an amplifier is biased such that it operates in the linear region for 180° of the input cycle and is in cutoff for 180°, it is a class B amplifier
  – A class B amplifier is more efficient than a class A
- In order to get a linear reproduction of the input waveform, the class B amplifier is configured in a push-pull arrangement
  – The transistors in a class B amplifier must be biased above cutoff to eliminate crossover distortion

Class B push-pull operation

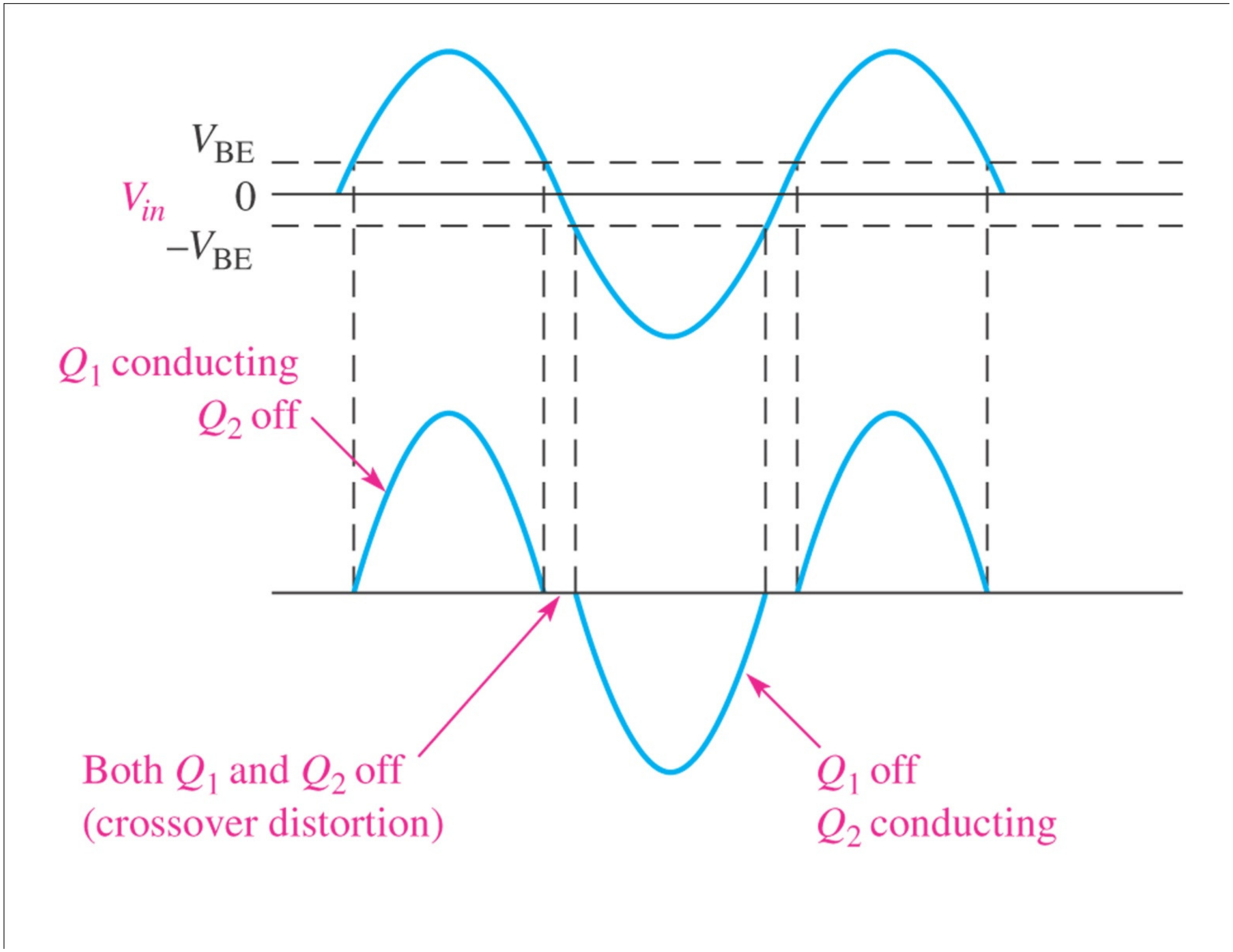


(a) Positive half-cycle (b) Negative half-cycle

Push-Pull Class B Amplifiers

Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

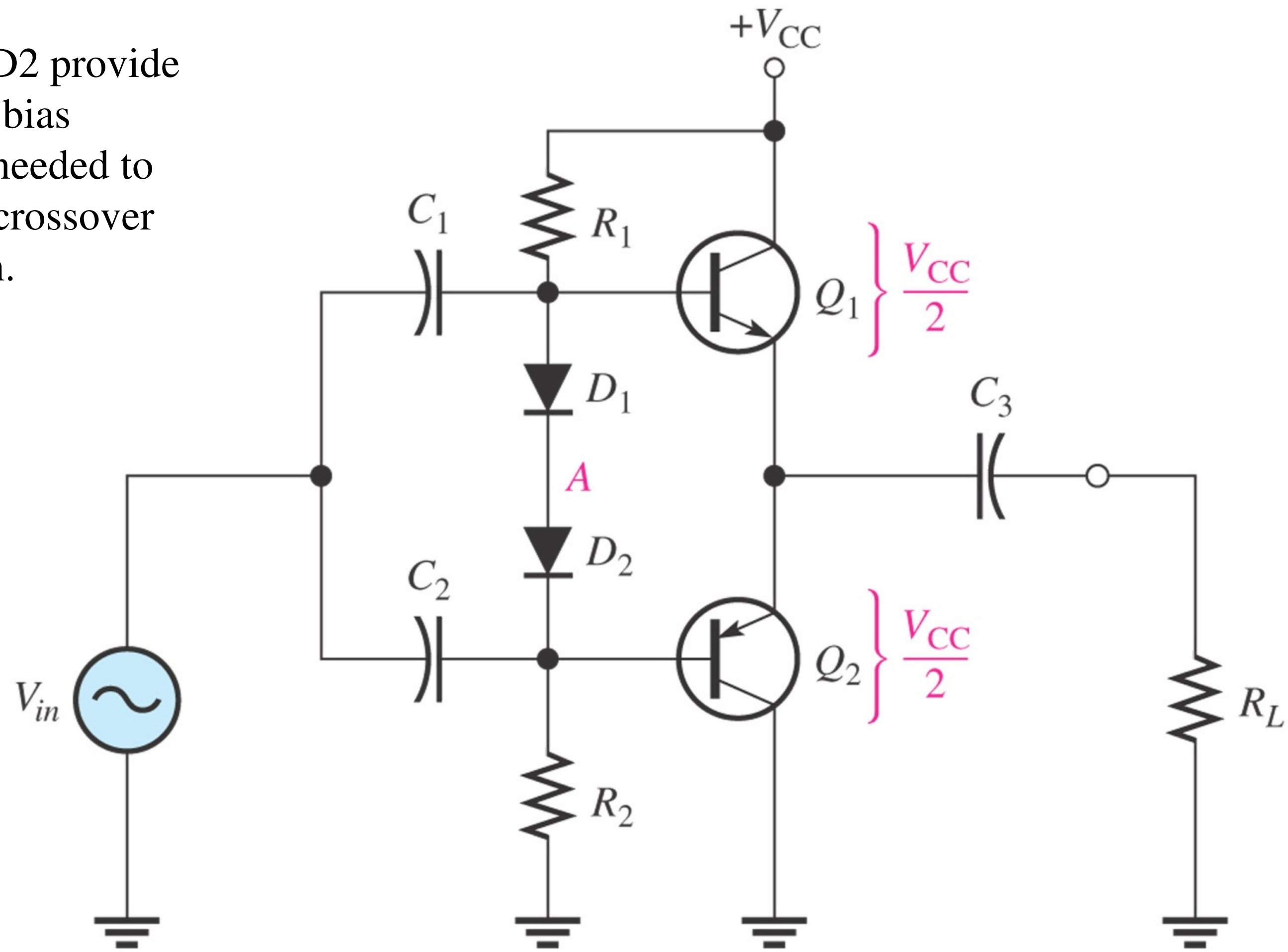
Illustration of crossover distortion in a class B push-pull amplifier



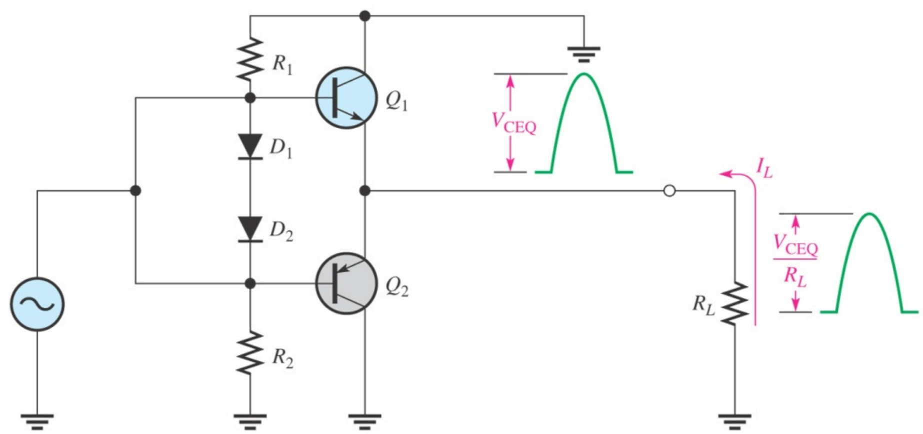
Biasing the push-pull amplifier to eliminate crossover distortion

Push-Pull Class B Amplifiers

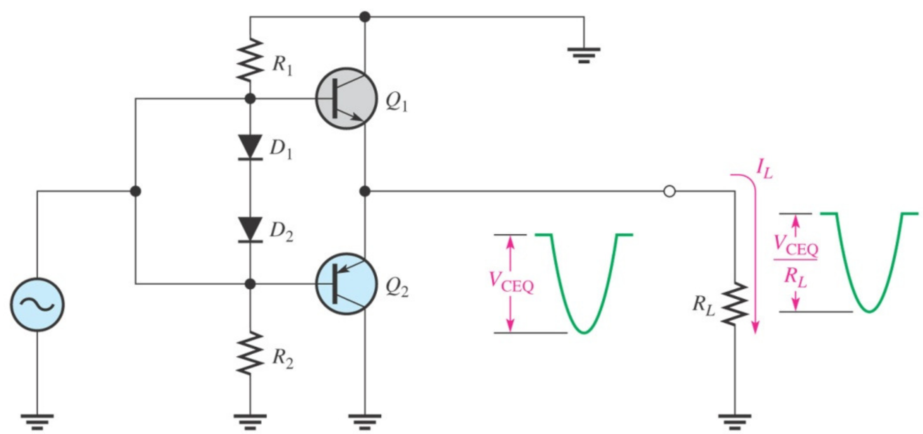
D1 and D2 provide the base bias voltage needed to prevent crossover disortion.



Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e



(a) Q_1 conducting with maximum signal output

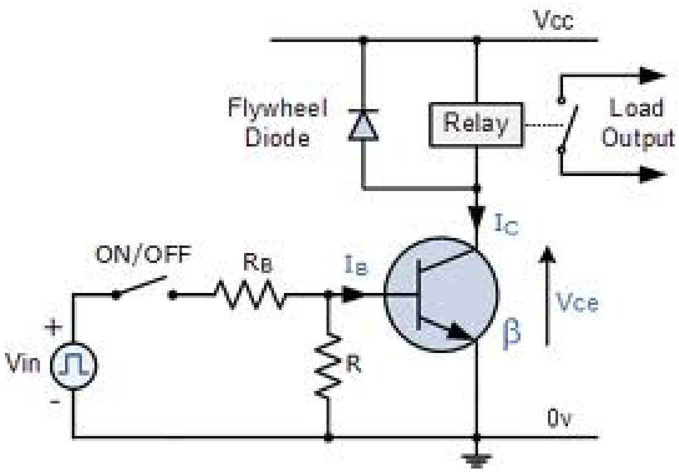


(b) Q_2 conducting with maximum signal output

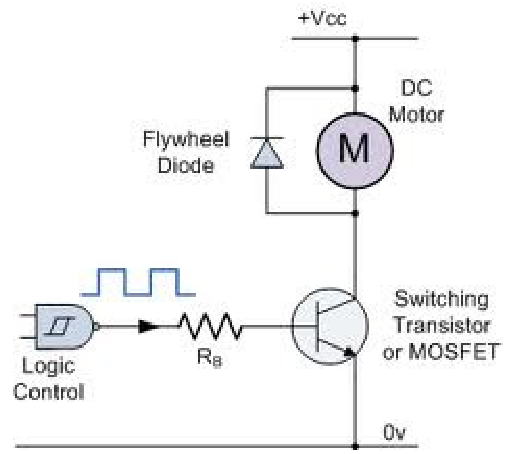
Thomas L. Floyd
Electronics Fundamentals, 6e
Electric Circuit Fundamentals, 6e

Transistor Operating as a Switch

Low Power Circuit (0V-05V Digital) Controlling a High Power Circuit (30V – 240V)



Switch Controlling a Relay



Switch Controlling a DC Motor

Flywheel Diode

A flywheel diode is often required with an inductive load. This is because when the current through the inductive load is suddenly broken when the transistor turns off, a back EMF will build up as the magnetic field breaks down (The voltage across the coil quickly increases or spikes trying to keep the current in the coil flowing in the same direction).

If there is no path for the current, a high voltage builds up (this voltage spike can reach hundreds or thousands of volts). The high voltage can damage the transistor or cause arcing in a relay switch.

The flywheel diode is connected in reverse bias across the load under normal operation, but becomes forward biased at turn off to provide a path for the current so the magnetic field and current can safely decline.