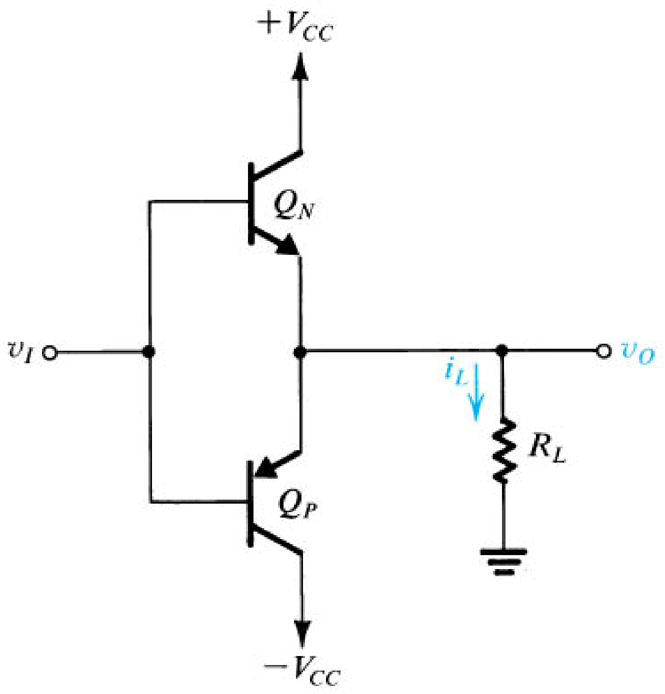
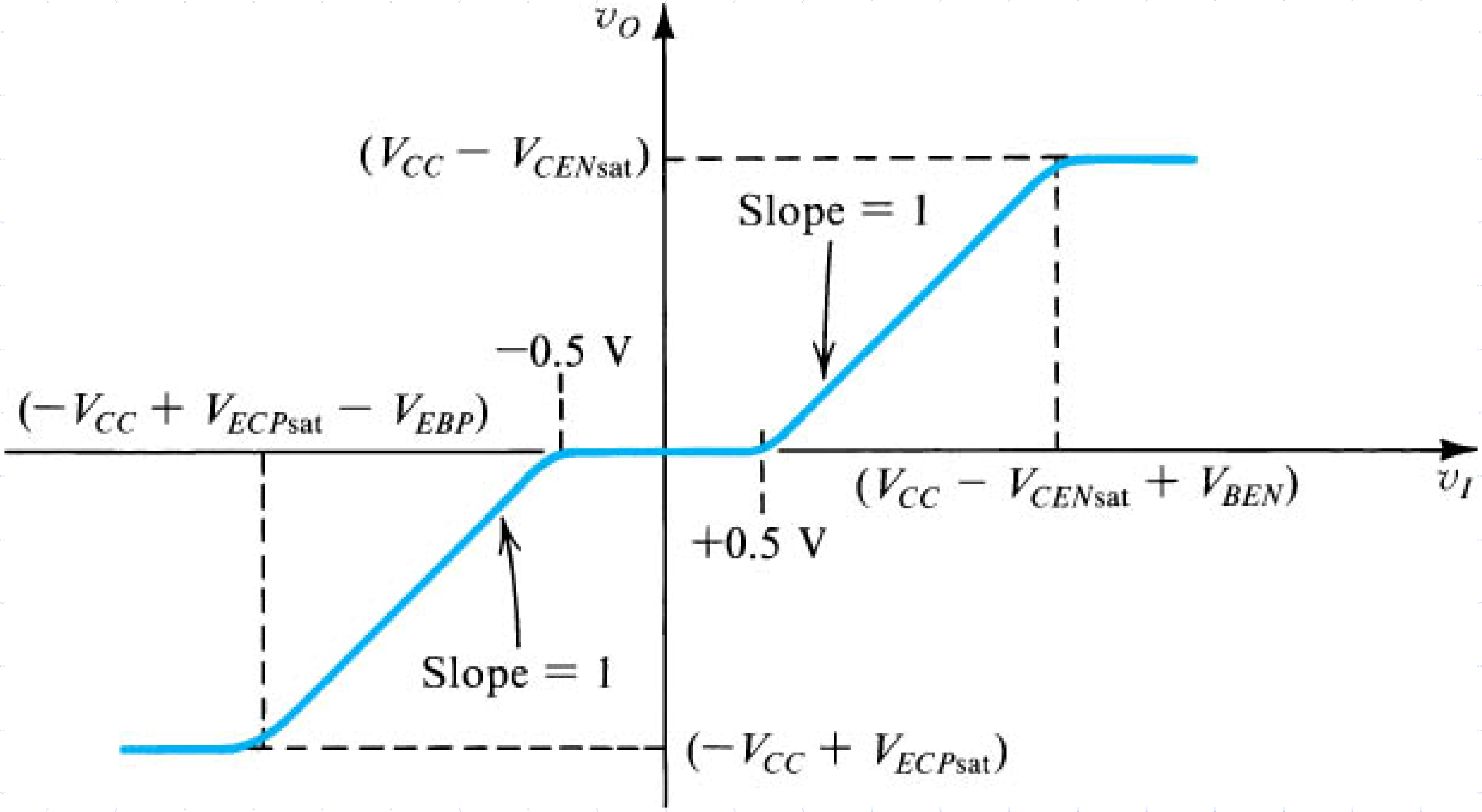
14.3.1 Circuit Operation

- When the input voltage v_i is zero,
  - both transistors are cut off – v_o is zero.
- When v_i exceeds about 0.5 V,
  - Q_N conducts and operates as an emitter follower.
  - v_o follows v_i ($v_o = v_i – 0.5V$), Q_P cut off.
- When v_i goes negative by more than 0.5 V,
  - Q_P conducts and operates as an emitter follower.
  - v_o follows v_i Q_N cut off.
- The circuit operates in a push-pull fashion.



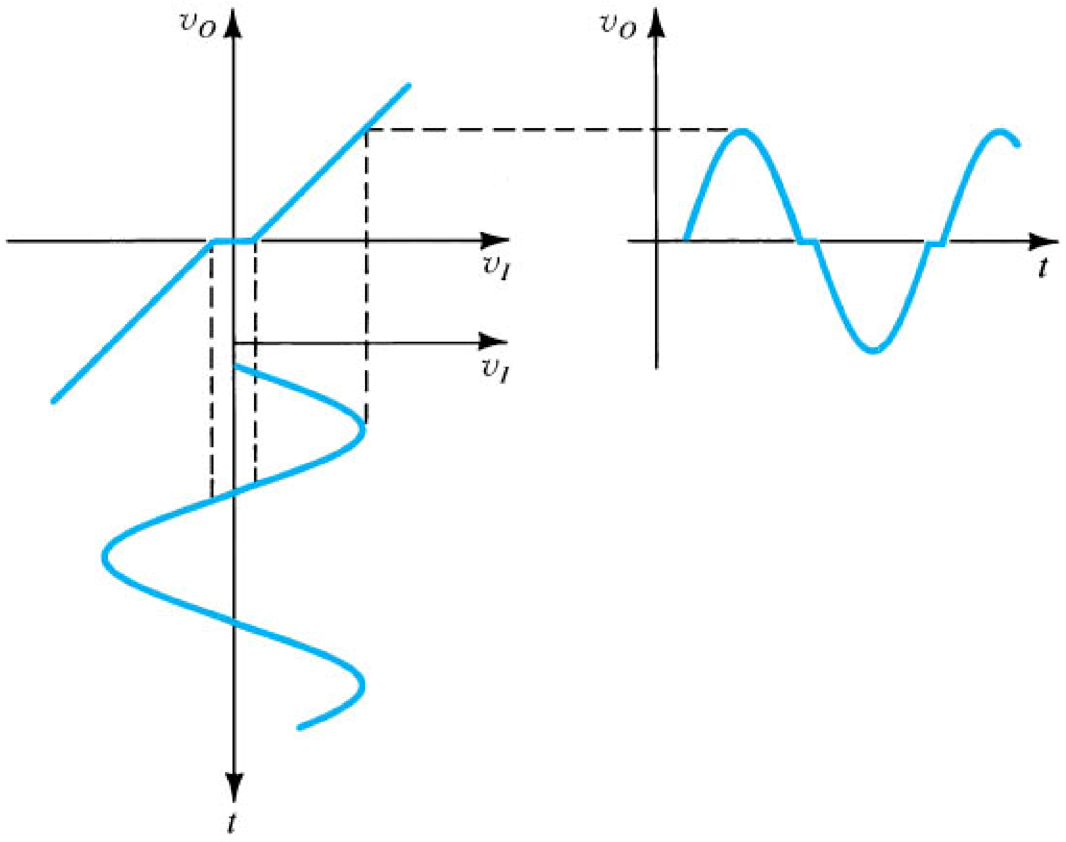
14.3.2 Transfer Characteristic

- The transfer characteristic of the class B stage



14.3.2 Transfer Characteristic (cont.)

- The dead band results in the crossover distortion.



14.3.3 Power-Conversion Efficiency

- The average load power will be,

$$P_L = \frac{1}{2}\frac{\hat{V}_o^{\,2}}{R_L}$$

- The average current drawn from each of the two power supplies will be,

$$P_{S+} = P_{S-} = \frac{1}{\pi}\frac{\hat{V}_o}{R_L}V_{CC}$$

- The total supply power will be,

$$P_S = \frac{2}{\pi}\frac{\hat{V}_o}{R_L}V_{CC}$$

- Thus the PCE is given by

$$\eta = \frac{\pi}{4}\frac{\hat{V}_o}{V_{CC}}$$

14.3.3 Power-Conversion Efficiency (cont.)

- The maximum efficiency is obtained when $\hat{V}_o$ is maximum (=V_{CC}-V_{CESAT}≈V_{CC})
- At this value of peak output voltage, the PCE is

$$\eta_{\max} = \frac{\pi}{4} = 78.5\% \; (>> 25\% \; \textit{in the class A case})$$

- The maximum average power available from a class B output stage is,

$$P_L = \frac{1}{2}\frac{\hat{V}_o^{\,2}}{R_L} \rightarrow P_{L,\max} = \frac{1}{2}\frac{V_{CC}^2}{R_L}$$

14.3.4 Power Dissipation

- The quiescent power dissipation of the class B stage is zero.
- When an input signal is applied, the average power dissipated in the class B stage is given by

$$P_D = P_S - P_L$$

- Substituting for $P_S = \frac{2}{\pi}\frac{\hat{V}_o}{R_L}V_{CC}$ and for $P_L = \frac{1}{2}\frac{\hat{V}_o^{\,2}}{R_L}$ results in

$$P_D = \frac{2}{\pi}\frac{\hat{V}_o}{R_L}V_{CC} - \frac{1}{2}\frac{\hat{V}_o^{\,2}}{R_L}$$

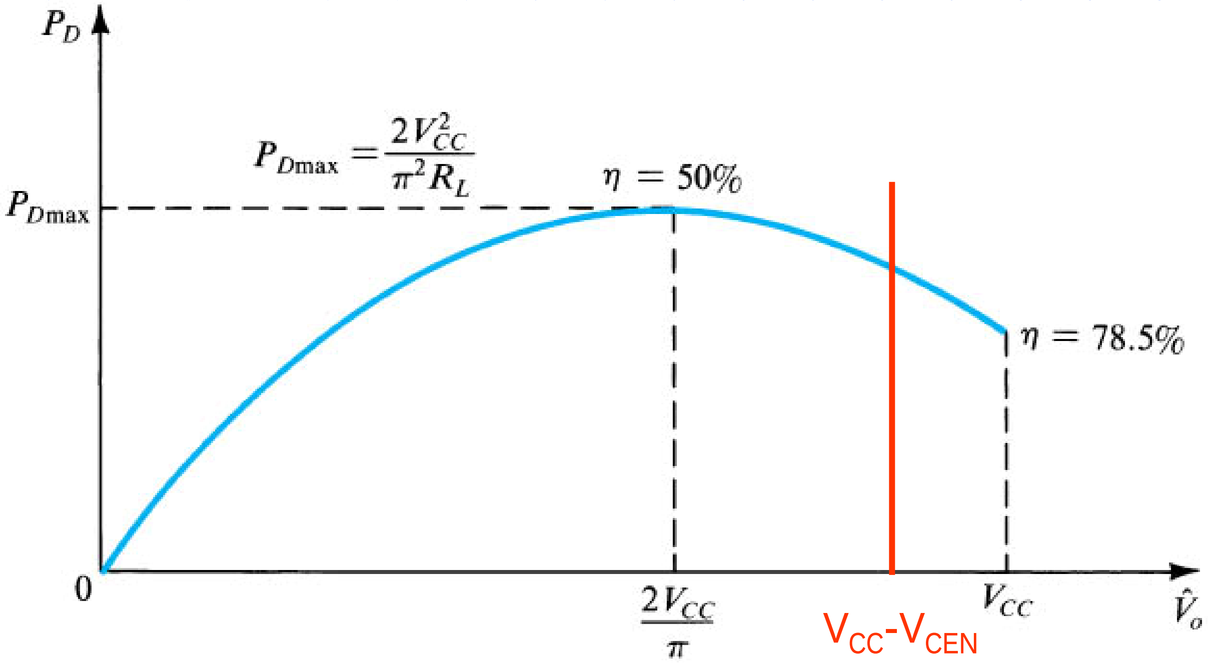
- The maximum average power dissipation is (given by differentiating above eqn.)

$$\left.\hat{V}_o\right|_{P_{D\max}} = \frac{2}{\pi}V_{CC} \longrightarrow P_{D\max} = \frac{2V_{CC}^{\;2}}{\pi^2 R_L}$$

14.3.4 Power Dissipation (cont.)

- The maximum average power dissipation

$$P_{DP\max} = P_{DN\max} = \frac{2V_{CC}^{\;2}}{\pi^2 R_L}$$



Overdrive till Vcc → better efficiency but nonlinear distortion (entering Vsat)

14.3.6 Single-Supply Operation

- Class B operation from a single power supply

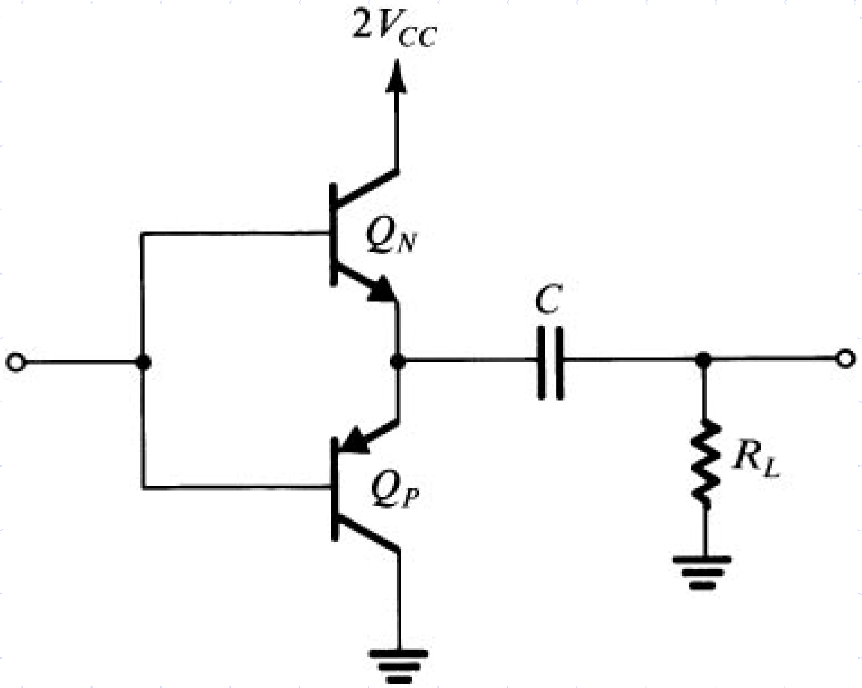


Figure 14.10 Class B output stage operated with a single power supply.

14.4 Class AB Output Stage

- Crossover distortion can be virtually eliminated by biasing the complementary output transistors at a small nonzero current.

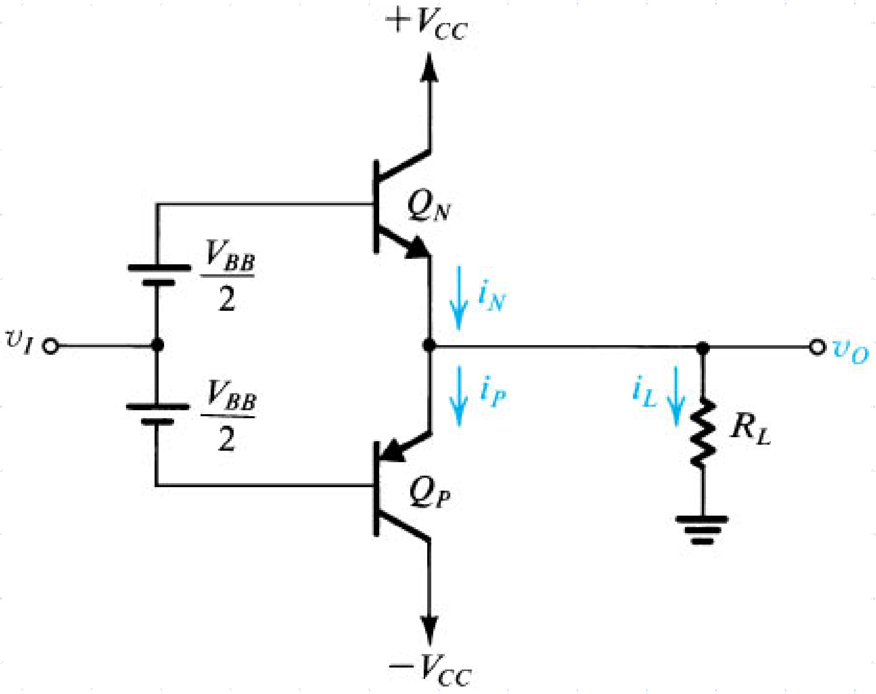


Figure 14.11 Class AB output stage. A bias voltage V_{BB} is applied between the bases of Q_N and Q_P, giving rise to a bias current I_Q given by Eq. (14.23). Thus, for small v_I, both transistors conduct and crossover distortion is almost completely eliminated.

14.4.1 Circuit Operation

- When v_I goes positive, the output becomes positive at almost equal value,

$$v_O = v_I + \frac{V_{BB}}{2} - v_{BEN}$$

- v_O causes a current i_L to flow through R_L, and i_N must increase and i_P must decrease

$$i_N = i_P + i_L$$

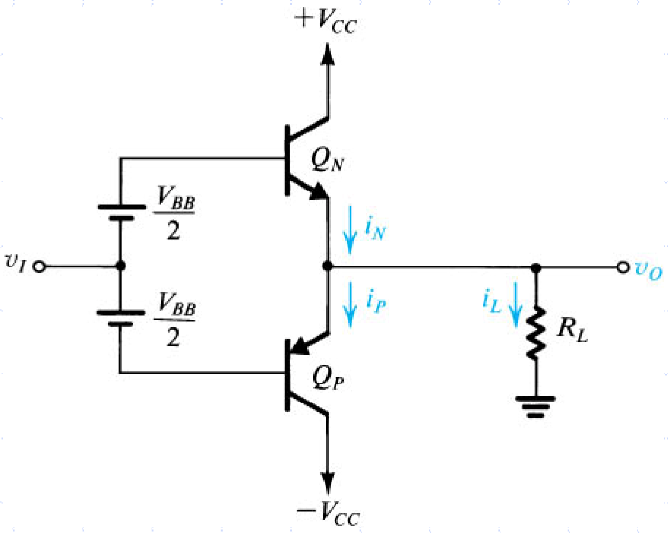
- Since the V_{BB} voltage remains constant, the increase in v_{BEN} will result in an equal decrease in v_{EBP} and in i_P. The relationship between i_N and i_P is,

$$v_{BEN} + v_{EBP} = V_{BB}$$

$$V_T \ln\left(\frac{i_N}{I_S}\right) + V_T \ln\left(\frac{i_P}{I_S}\right) = 2V_T \ln\left(\frac{I_Q}{I_S}\right)$$

$$i_N i_P = I_Q{}^2$$

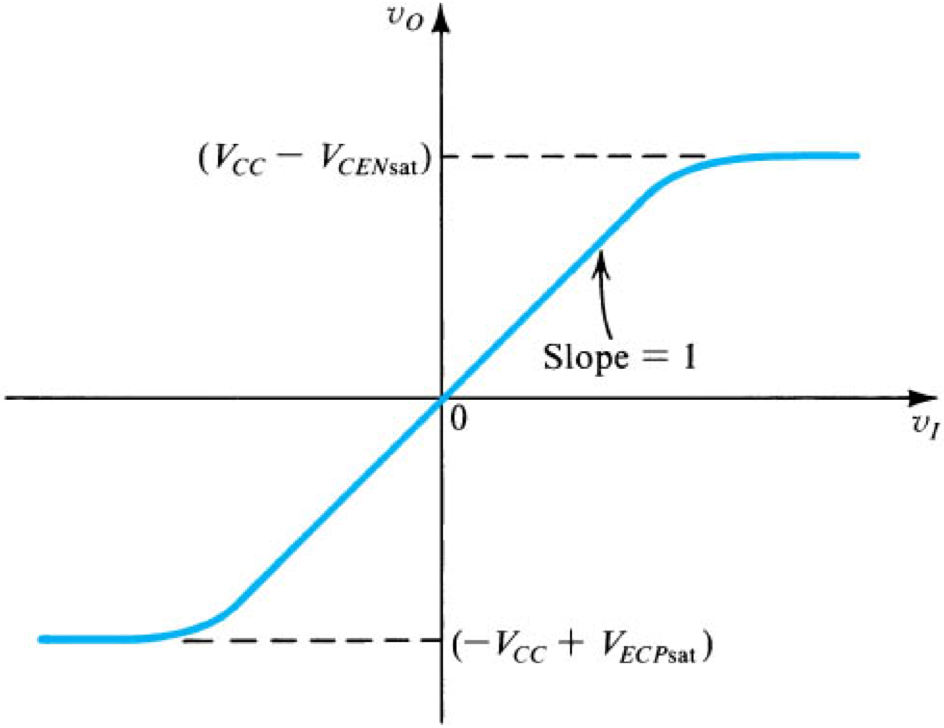
$$\therefore i_N{}^2 - i_L i_N - I_Q{}^2 = 0$$



Starts with i_N & i_P, but i_N takes over as $v_i \uparrow$

14.4.1 Circuit Operation (cont.)

- Transfer characteristic of the class AB stage
  - For small v_I, both transistors conduct, and as v_I is increased or decreased, one of the two transistors takes over the operation → crossover distortion is eliminated



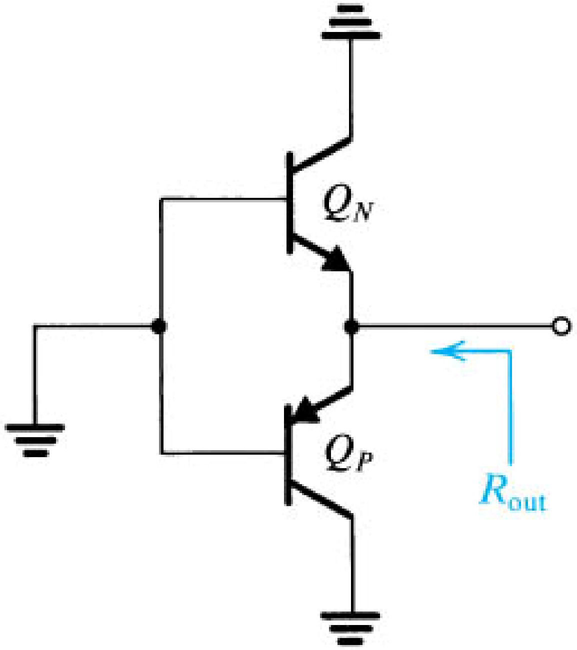
14.4.2 Output Resistance

- The output resistance of the class AB can be derived as follows

$$R_{out} = r_{eN} \parallel r_{eP}$$

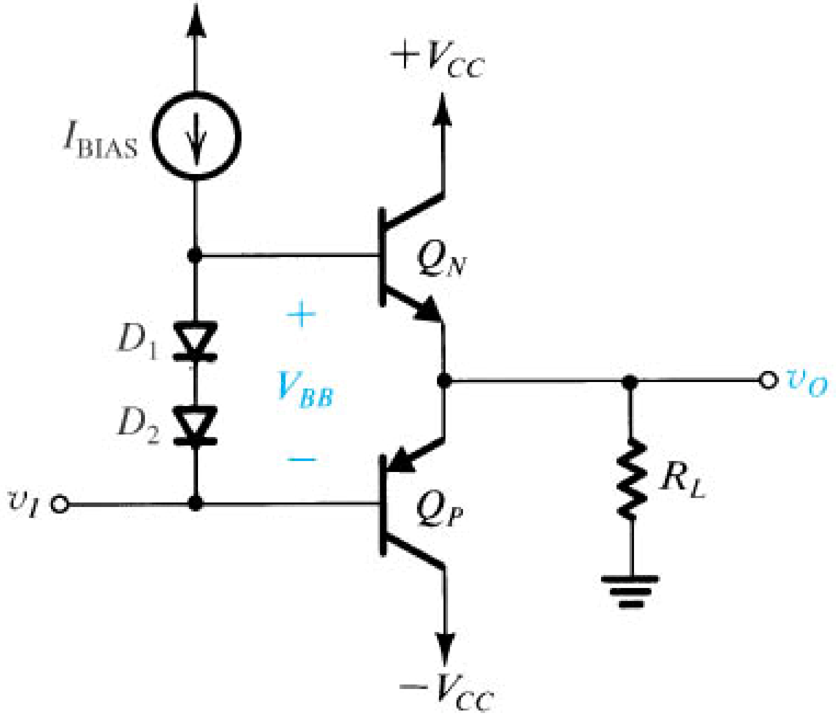
$$r_{eN} = \frac{V_T}{i_N}, \quad r_{eP} = \frac{V_T}{i_P}$$

$$\therefore \; R_{out} = \frac{V_T}{i_N} \parallel \frac{V_T}{i_P} = \frac{V_T}{i_P + i_N}$$



- The output resistance remains approximately constant in the region around v_I=0.
- At larger load currents, R_{out} decreases as the load current increases.

14.5.1 Biasing Using Diodes



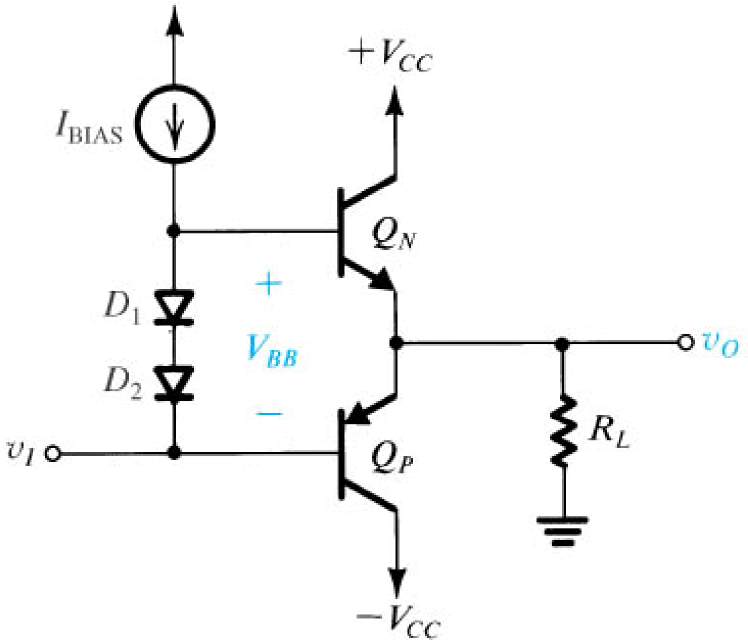
- The quiescent current I_Q, has the following relationship with I_{BIAS}.

  (n denotes the ratio of the emitter-junction area of Q to the junction area of D.)

$$I_Q = nI_{BIAS}$$

- $I_{BIAS} = I_{QN}+I_D$, $I_{BIAS} = I_Q/n$ →
  - ***n*** shouldn't be a large number because I_{BIAS} needs to supply the base of Q_N when its driving a load → Disadvantage
  - As vo increases, I_D and V_{BB} decreases

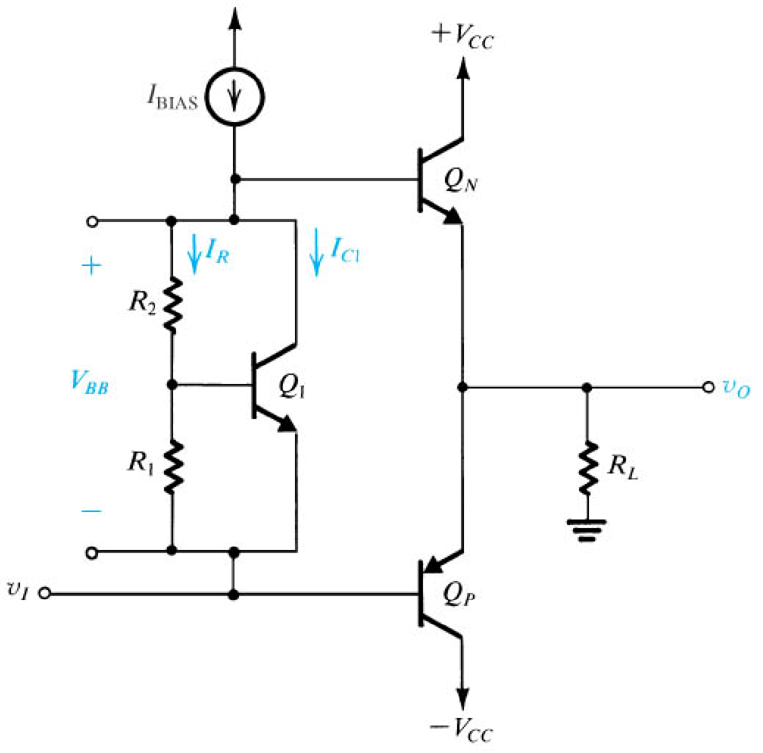
14.5.1 Biasing Using Diodes (cont.)



- Advantage
  - Protection against thermal runaway
- Disadvantage
  - Strong dependence of V_{BB} on I_{BIAS}

(Thermal runaway: a phenomenon that occurs when the power dissipation of the output stage brings temperature rise to the surroundings. The rise in temperature will accommodate more current through BJTs thus forms a positive loop in increasing the quiescent current. It will eventually destroy the BJTs.)

14.5.2 Biasing Using the V_{BE} Multiplier



- (Neglecting base current) R_1 and R_2 will carry the same current I_R, given by

$$I_R = \frac{V_{BE1}}{R_1}$$

- So, the voltage V_{BB} will be

$$V_{BB} = V_{BE1}\left(1+\frac{R_2}{R_1}\right)$$ → **V_{BE} multiplier**

where

$$I_{C1} = I_{BIAS} - I_R$$

$$V_{BE1} = V_T \ln \frac{I_{C1}}{I_{S1}}$$

Reduction of effective I_{BIAS} is mostly absorbed by I_{C1} (exp(I_R)) → I_R can be kept constant →V_{BB} kept constant