Chapter 4
Bipolar Junction Transistors

Section 4-1 Bipolar Junction Transistor (BJT) Structure

1. Majority carriers in the base region of an *npn* transistor are **holes.**

2. Because of the narrow base region, the minority carriers invading the base region find a limited number of partners for recombination and, therefore, move across the junction into the collector region rather than out of the base lead.

Section 4-2 Basic BJT Operation

3. The base is narrow and lightly doped so that a small recombination (base) current is generated compared to the collector current.

4. $I_B = 0.02I_E = 0.02(30\text{ mA}) = 0.6\text{ mA}$
$I_C = I_E - I_B = 30\text{ mA} - 0.6\text{ mA} = \mathbf{29.4\text{ mA}}$

5. The base must be negative with respect to the collector and positive with respect to the emitter.

6. $I_C = I_E - I_B = 5.34\text{ mA} - 475\ \mu\text{A} = \mathbf{4.87\text{ mA}}$

Section 4-3 BJT Characteristics and Parameters

7. $\alpha_{DC} = \dfrac{I_C}{I_E} = \dfrac{8.23\text{ mA}}{8.69\text{ mA}} = \mathbf{0.947}$

8. $\beta_{DC} = \dfrac{I_C}{I_B} = \dfrac{25\text{ mA}}{200\ \mu\text{A}} = \mathbf{125}$

9. $I_B = I_E - I_C = 20.5\text{ mA} - 20.3\text{ mA} = 0.2\text{ mA} = 200\ \mu\text{A}$
$\beta_{DC} = \dfrac{I_C}{I_B} = \dfrac{20.3\text{ mA}}{200\ \mu\text{A}} = \mathbf{101.5}$

10. $I_E = I_C + I_B = 5.35\text{ mA} + 50\ \mu\text{A} = 5.40\text{ mA}$
$\alpha_{DC} = \dfrac{I_C}{I_E} = \dfrac{5.35\text{ mA}}{5.40\text{ mA}} = \mathbf{0.99}$

11. $I_C = \alpha_{DC}I_E = 0.96(9.35\text{ mA}) = \mathbf{8.98\text{ mA}}$

12. $I_C = \frac{V_{R_C}}{R_C} = \frac{5\text{ V}}{1.0\text{ k}\Omega} = 5\text{ mA}$

$\beta_{DC} = \frac{I_C}{I_B} = \frac{5\text{ mA}}{50\ \mu\text{A}} = \mathbf{100}$

13. $\alpha_{DC} = \frac{\beta_{DC}}{\beta_{DC}+1} = \frac{100}{101} = \mathbf{0.99}$

14. $I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3\text{ V} - 0.7\text{ V}}{100\text{ k}\Omega} = \mathbf{23\ \mu A}$

$I_C = \beta_{DC} I_B = 200(23\ \mu\text{A}) = \mathbf{4.6\text{ mA}}$

$I_E = I_C + I_B = 4.6\text{ mA} + 23\ \mu\text{A} = \mathbf{4.62\text{ mA}}$

$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (4.6\text{ mA})(1.0\text{ k}\Omega) = \mathbf{5.4\text{ V}}$

15. I_C = does not change.

For $V_{CC} = 10$ V:

$V_{CE} = V_{CC} = I_C R_C = 10\text{ V} - (4.6\text{ mA})(1.0\text{ k}\Omega) = 5.4\text{ V}$

For $V_{CC} = 15$ V:

$V_{CE} = 15\text{ V} - (4.6\text{ mA})(1.0\text{ k}\Omega) = 10.7\text{ V}$

$\Delta V_{CE} = 10.7\text{ V} - 5.4\text{ V} = \mathbf{5.3\text{ V}}$ increase

16. $I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4\text{ V} - 0.7\text{ V}}{4.7\text{ k}\Omega} = \frac{3.3\text{ V}}{4.7\text{ k}\Omega} = \mathbf{702\ \mu A}$

$I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{24\text{ V} - 8\text{ V}}{470\ \Omega} = \mathbf{34\text{ mA}}$

$I_E = I_C + I_B = 34\text{ mA} + 702\ \mu\text{A} = \mathbf{34.7\text{ mA}}$

$\beta_{DC} = \frac{I_C}{I_B} = \frac{34\text{ mA}}{702\ \mu\text{A}} = \mathbf{48.4}$

17. (a) $V_{BE} = \mathbf{0.7\text{ V}}$

$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{4.3\text{ V}}{3.9\text{ k}\Omega} = 1.1\text{ mA}$

$I_C = \beta_{DC} I_B = 50(1.1\text{ mA}) = 55\text{ mA}$

$V_{CE} = V_{CC} - I_C R_C = 15\text{ V} - (55\text{ mA})(180\ \Omega) = \mathbf{5.10\text{ V}}$

$V_{CB} = V_{CE} - V_{BE} = 5.10\text{ V} - 0.7\text{ V} = \mathbf{4.40\text{ V}}$

(b) $V_{BE} = \mathbf{-0.7\text{ V}}$

$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{-3\text{ V} - (-0.7\text{ V})}{27\text{ k}\Omega} = \frac{-2.3\text{ V}}{27\text{ k}\Omega} = -85.2\ \mu\text{A}$

$I_C = \beta_{DC} I_B = 125(-85.2\ \mu\text{A}) = -10.7\text{ mA}$

$V_{CE} = V_{CC} - I_C R_C = -8\text{ V} - (-10.7\text{ mA})(390\ \Omega) = \mathbf{-3.83\text{ V}}$

$V_{CB} = V_{CE} - V_{BE} = -3.83\text{ V} - (-0.7\text{ V}) = \mathbf{-3.13\text{ V}}$

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18. (a) $I_{C(sat)} = \dfrac{V_{CC}}{R_C} = \dfrac{15\text{ V}}{180\ \Omega} = 83.3\text{ mA}$

$I_B = \dfrac{V_{BB} - V_{BE}}{R_B} = \dfrac{5\text{ V} - 0.7\text{ V}}{3.9\text{ k}\Omega} = 1.1\text{ mA}$

$I_C = \beta_{DC} I_B = 50(1.1\text{ mA}) = 55\text{ mA}$

$I_C < I_{C(sat)}$

Therefore, the transistor is **not saturated**.

(b) $I_{C(sat)} = \dfrac{V_{CC}}{R_C} = \dfrac{8\text{ V}}{390\ \Omega} = 20.5\text{ mA}$

$I_B = \dfrac{V_{BB} - V_{BE}}{R_B} = \dfrac{3\text{ V} - 0.7\text{ V}}{27\text{ k}\Omega} = 85.2\ \mu\text{A}$

$I_C = \beta_{DC} I_B = 125(85.2\ \mu\text{A}) = 10.7\text{ mA}$

$I_C < I_{C(sat)}$

Therefore, the transistor is **not saturated**.

19. $V_B = 2\text{ V}$

$V_E = V_B - V_{BE} = 2\text{ V} - 0.7\text{ V} = 1.3\text{ V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{1.3\text{ V}}{1.0\text{ k}\Omega} = \mathbf{1.3\text{ mA}}$

$I_C = \alpha_{DC} I_E = (0.98)(1.3\text{ mA}) = \mathbf{1.27\text{ mA}}$

$\beta_{DC} = \dfrac{\alpha_{DC}}{1 - \alpha_{DC}} = \dfrac{0.98}{1 - 0.98} = 49$

$I_B = I_E - I_C = 1.3\text{ mA} - 1.27\text{ mA} = \mathbf{30\ \mu A}$

20. (a) $V_B = V_{BB} = \mathbf{10\text{ V}}$

$V_C = V_{CC} = \mathbf{20\text{ V}}$

$V_E = V_B - V_{BE} = 10\text{ V} - 0.7\text{ V} = \mathbf{9.3\text{ V}}$

$V_{CE} = V_C - V_E = 20\text{ V} - 9.3\text{ V} = \mathbf{10.7\text{ V}}$

$V_{BE} = \mathbf{0.7\text{ V}}$

$V_{CB} = V_C - V_B = 20\text{ V} - 10\text{ V} = \mathbf{10\text{ V}}$

(b) $V_B = V_{BB} = \mathbf{-4\text{ V}}$

$V_C = V_{CC} = \mathbf{-12\text{ V}}$

$V_E = V_B - V_{BE} = -4\text{ V} - (-0.7\text{ V}) = \mathbf{-3.3\text{ V}}$

$V_{CE} = V_C - V_E = -12\text{ V} - (-3.3)\text{ V} = \mathbf{-8.7\text{ V}}$

$V_{BE} = \mathbf{-0.7\text{ V}}$

$V_{CB} = V_C - V_B = -12\text{ V} - (-4\text{ V}) = \mathbf{-8\text{ V}}$

21. For $\beta_{DC} = 100$:

$I_E = \dfrac{V_B - V_{BE}}{R_E} = \dfrac{10\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = 930\ \mu\text{A}$

$\alpha_{DC} = \dfrac{\beta_{DC}}{1 + \beta_{DC}} = \dfrac{100}{101} = 0.990$

$I_C = \alpha_{DC} I_E = (0.990)(930\ \mu\text{A}) = 921\ \mu\text{A}$

For $\beta_{DC} = 150$:
$I_E = 930\ \mu A$
$$\alpha_{DC} = \frac{\beta_{DC}}{1+\beta_{DC}} = \frac{150}{151} = 0.993$$
$I_C = \alpha_{DC} I_E = (0.993)(930\ \mu A) = 924\ \mu A$
$\Delta I_C = 924\ \mu A - 0.921\ \mu A = \mathbf{3\ \mu A}$

22. $P_{D(max)} = V_{CE} I_C$
$$V_{CE(max)} = \frac{P_{D(max)}}{I_C} = \frac{1.2\ W}{50\ mA} = \mathbf{24\ V}$$

23. $P_{D(max)} = 0.5\ W - (75°C)(1\ mW/°C) = 0.5\ W - 75\ mW = \mathbf{425\ mW}$

Section 4-4 The BJT as an Amplifier

24. $V_{out} = A_v V_{in} = 50(100\ mV) = \mathbf{5\ V}$

25. $$A_v = \frac{V_{out}}{V_{in}} = \frac{10\ V}{300\ mV} = \mathbf{33.3}$$

26. $$A_v = \frac{R_C}{r_e'} = \frac{560\ \Omega}{10\ \Omega} = 56$$
$V_c = V_{out} = A_v V_{in} = 56(50\ mV) = \mathbf{2.8\ V}$

27. $$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{2.5\ V - 0.7\ V}{100\ k\Omega} = 18\ \mu A$$
$I_C = \beta_{DC} I_B = 250(18\ \mu A) = 4.5\ mA$
$$R_C = \frac{V_{CC} - V_{CE}}{I_C} = \frac{9\ V - 4\ V}{4.5\ mA} = \mathbf{1.1\ k\Omega}$$

28. (a) DC current gain = β_{DC} = **50**
(b) DC current gain = β_{DC} = **125**

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Section 4-5 The BJT as a Switch

29. $I_{C(sat)} = \dfrac{V_{CC}}{R_C} = \dfrac{5\text{ V}}{10\text{ k}\Omega} = \mathbf{500\ \mu A}$

$I_{B(min)} = \dfrac{I_{C(sat)}}{\beta_{DC}} = \dfrac{500\ \mu\text{A}}{150} = \mathbf{3.33\ \mu A}$

$I_{B(min)} = \dfrac{V_{IN(min)} - 0.7\text{ V}}{R_B}$

$R_B I_{B(min)} = V_{IN(min)} - 0.7\text{ V}$

$V_{IN(min)} = R_B I_{B(min)} + 0.7\text{ V} = (3.33\ \mu\text{A})(1.0\text{ M}\Omega) + 0.7\text{ V} = \mathbf{4.03\ V}$

30. $I_{C(sat)} = \dfrac{15\text{ V}}{1.2\text{ k}\Omega} = 12.5\text{ mA}$

$I_{B(min)} = \dfrac{I_{C(sat)}}{\beta_{DC}} = \dfrac{12.5\text{ mA}}{50} = 250\ \mu\text{A}$

$R_{B(min)} = \dfrac{V_{IN} - 0.7\text{ V}}{I_{B(min)}} = \dfrac{4.3\text{ V}}{250\ \mu\text{A}} = \mathbf{17.2\ k\Omega}$

$V_{IN(cutoff)} = \mathbf{0\ V}$

Section 4-6 The Phototransistor

31. $I_C = \beta_{DC} I_\lambda = (200)(100\ \mu\text{A}) = \mathbf{20\ mA}$

32. $I_\lambda = (50\text{ lm/m}^2)(1\ \mu\text{A/lm/m}^2) = 50\ \mu\text{A}$

$I_E = \beta_{DC} I_\lambda = (100)(50\ \mu\text{A}) = \mathbf{5\ mA}$

33. $I_{out} = (0.30)(100\text{ mA}) = \mathbf{30\ mA}$

34. $\dfrac{I_{OUT}}{I_{IN}} = 0.6$

$I_{IN} = \dfrac{I_{OUT}}{0.6} = \dfrac{10\text{ mA}}{0.6} = \mathbf{16.7\ mA}$

Section 4-7 Transistor Categories and Packaging

35. See Figure 4-1.

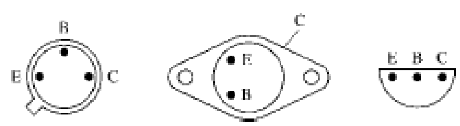

Figure 4-1

36. (a) Small-signal
(b) Power
(c) Power
(d) Small-signal
(e) RF