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APPENDIX

F

Answers to Selected Problems

Chapter 1

1.1 (a) (i) $1.9 \times 10^9\ \text{cm}^{-3}$, (ii) $8.71 \times 10^{10}\text{cm}^{-3}$
(b) (i) $1.34 \times 10^5\ \text{cm}^{-3}$, (ii) $1.63 \times 10^7\ \text{cm}^{-3}$

1.3 (a) n-type; $n_o = 5 \times 10^{15}\ \text{cm}^{-3}$, $p_o = 4.5 \times 10^4\,\text{cm}^{-3}$
(b) n-type; $n_o = 5 \times 10^{15}\,\text{cm}^{-3}$, $p_o = 6.48 \times 10^{-4}\,\text{cm}^{-3}$

1.6 (a) Add donors, $N_d = 7 \times 10^{15}\,\text{cm}^{-3}$,
(b) $T = 324\,\text{K}$

1.10 (a) $p_o = 10^{17}\,\text{cm}^{-3}$, $n_o = 3.24 \times 10^{-5}\,\text{cm}^{-3}$.
(b) $n = n_o + \delta n \cong 10^{15}\,\text{cm}^{-3}$; $p = p_o + \delta p = 1.01 \times 10^{17}\,\text{cm}^{-3}$

1.13 For $N_d = 10^{16}\,\text{cm}^{-3}$ and $N_a = 10^{15}\,\text{cm}^{-3}$, $V_{bi} = 0.637\,\text{V}$; For $N_d = 10^{16}\,\text{cm}^{-3}$ and $N_a = 10^{18}\,\text{cm}^{-3}$, $V_{bi} = 0.817\,\text{V}$

1.17 (a) $f_o = 8.38\,\text{MHz}$;
(b) $f_o = 13.2\,\text{MHz}$

1.20 (a) 0.430 V; (b) 0.549 V

1.23 2.83×10^3

1.25 (a) $I_D = 0.145\,\mu\text{A}$, $V_D = 0.046\,\text{V}$
(b) $I_D = -30\,\text{nA}$, $V_D = -1.2\,\text{V}$

1.27 $V_I = 1.81\,\text{V}$

1.29 (a) $I_D = 0.0267\,\text{mA}$, $V_D = 0.7\,\text{V}$
(b) $V_D = 0.45\,\text{V}$, $I_D = 0$

1.32 $I_{D1} = 0.65\,\text{mA}$, $I_{D2} = 1.30\,\text{mA}$, $R_1 = 2.35\,\text{k}\Omega$

1.35 (a) and (b) $v_d = 1.30\,\text{mV}$ (peak-to-peak)

1.37 0.599 V; 0.299 V

1.41 (a) $V_O = 5.685\,\text{V}$,
(b) $\Delta V_O = 0.039\,\text{V}$,
(c) $V_O = 5.658\,\text{V}$

1.43 (a) 6.921 V; (b) −0.13 V

Chapter 2

2.4 (a) 6.06, (b) 1.58; PIV = 25.7 V for (a), PIV = 100.7 V for (b)

2.8 $R = 1.19\,\Omega$, 32.25%, 18 W

2.11 3.04 V

2.13 (a) $I_L = 26.3\,\text{mA}$, $I_I = 45.0\,\text{mA}$, $I_Z = 18.8\,\text{mA}$
(b) $R_L = 2\,\text{k}\Omega$
(c) $R_L = 585\,\Omega$

2.15 (a) $\Delta V_O = 0.815\,\text{V}$, (b) 4.08%

2.18 $R_i = 18.2\,\Omega$, $C = 9900\,\mu\text{F}$

2.21 (a) $v_O = v_I$ for $0 \le v_I \le 5.7\,\text{V}$;
$v_O = \dfrac{v_I}{2.5} + 3.42$ for $5.7 \le v_I \le 15\,\text{V}$
(b) $i_D = 0$ for $0 \le v_I \le 5.7\,\text{V}$;
$i_D = \dfrac{0.6v_I - 3.42}{1\,\text{k}\Omega}$ for $5.7 \le v_I \le 15\,\text{V}$

2.33 (a) $I = I_{D1} = I_{D2} = 0$, $V_O = 10\,\text{V}$
(b) $I_{D1} = 0$, $I = I_{D2} = 0.94\,\text{mA}$, $V_O = 1.07\,\text{V}$

(c) $I_{D1} = 0$, $I = I_{D2} = 0.44\,\text{mA}$, $V_O = 5.82\,\text{V}$

(d) $I = 0.964\,\text{mA}$, $I_{D1} = I_{D2} = 0.482\,\text{mA}$, $V_O = 0.842\,\text{V}$

2.35 (a) $V_1 = 6.9\,\text{V}$, $V_2 = -0.6\,\text{V}$, $I_{D1} = 1.25\,\text{mA}$, $I_{D2} = 0$, $I_{D3} = 0.95\,\text{mA}$

(b) $V_1 = 4.4\,\text{V}$, $V_2 = -0.3\,\text{V}$, $I_{D1} = 0.833\,\text{mA}$, $I_{D2} = 0.107\,\text{mA}$, $I_{D3} = 0$

(c) $V_1 = 4.4\,\text{V}$, $V_2 = -0.6\,\text{V}$, $R_1 = 10\,\text{k}\Omega$, $R_2 = 5\,\text{k}\Omega$, $R_3 = 2.93\,\text{k}\Omega$

2.38 (a) $I_{D1} = 0.86\,\text{mA}$, $V_O = 0$;
(b) $I_D = 0$, $V_O = -3.57\,\text{V}$

2.40 (a) $I_D = 0$, $V_D = -2.5\,\text{V}$;
(b) $I_D = 0.19\,\text{mA}$, $V_D = 0.6\,\text{V}$

2.43 (a) $V_{O1} = V_{O2} = 5\,\text{V}$;
(b) $V_{O1} = 0.6\,\text{V}$, $V_{O2} = 1.2\,\text{V}$;
(c) $V_{O1} = 0.6\,\text{V}$, $V_{O2} = 1.2\,\text{V}$

2.47 $V_{PS} = 2.6\,\text{V}$

Chapter 3

3.1 (a) $\beta_F = 85$, $\alpha_F = 0.9884$, $i_E = 516\,\mu\text{A}$

(b) $\beta_F = 53$, $\alpha_F + 0.9815$, $i_E = 2.70\,\text{mA}$

3.4 $i_C = 1.85\,\text{mA}$, $i_B = 0.0154\,\text{mA}$, $i_E = 1.865\,\text{mA}$

3.7 $I_{S1} = 1.69 \times 10^{-13}\,\text{A}$, $I_{S2} = 6.94 \times 10^{-15}\,\text{A}$, $I_{S1}/I_{S2} = 24.35$

3.10 60.6

3.14 $R_B = 120\,\text{k}\Omega$, $I_{CQ} = 1.05\,\text{mA}$, $R_C = 2.38\,\text{k}\Omega$

3.16 (a) $I_E = 0$, $V_C = 6\,\text{V}$,
(b) $I_E = 0.3\,\text{mA}$, $V_C = 3\,\text{V}$,
(c) $I_E = 1.3\,\text{mA}$, $V_C = 1.5\,\text{V}$

3.19 $V_B = 1.19\,\text{V}$, $I_E = 0.49\,\text{mA}$

3.22 $V_E = -0.7\,\text{V}$, $V_C = 2.84\,\text{V}$

3.25 $I_{E1} = I_{E2} = 0.5\,\text{mA}$, $V_{C1} = V_{C2} = 3\,\text{V}$

3.28 3.97 V

3.31 $R_1 = 338\,\text{k}\Omega$, $R_2 = 58.7\,\text{k}\Omega$, $R_C = 6.49\,\text{k}\Omega$

3.34 (a) $I_{BQ} = 0.0624\,\text{mA}$, $I_{CQ} = 4.68\,\text{mA}$, $V_{CEQ} = 5.22\,\text{V}$,

(b) $I_{BQ} = 0.0326\,\text{mA}$, $I_{CQ} = 4.89\,\text{mA}$, $V_{CEQ} = 4.41\,\text{V}$

3.37 $I_{CQ} = 4.41\,\text{mA}$, $V_{ECQ} = 6\,\text{V}$, $R_C = 1.26\,\text{k}\Omega$

3.40 $I_{CQ} = 2.73\,\text{mA}$, $V_{CEQ} = 6\,\text{V}$, $R_1 = 23.2\,\text{k}\Omega$, $R_2 = 2.83\,\text{k}\Omega$

3.43 (a) $I_{BQ} = 0.0214\,\text{mA}$, $I_{CQ} = 1.60\,\text{mA}$, $V_{ECQ} = 15.2\,\text{V}$,

(b) $I_{BQ} = 0.0161\,\text{mA}$, $I_{CQ} = 1.61\,\text{mA}$, $V_{ECQ} = 15.1\,\text{V}$

3.46 $R_E = 4.90\,\text{k}\Omega$, $R_1 = 72.4\,\text{k}\Omega$, $R_2 = 50.9\,\text{k}\Omega$, designed using $\beta = 60$.

3.49 (a) $R_{TH} = 6.67\,\text{k}\Omega$, $V_{TH} = 1.67\,\text{V}$,

(b) $I_{BQ} = 0.593\,\text{mA}$, $I_{CQ} = 3.56\,\text{mA}$, $V_E = 2.76\,\text{V}$, $V_C = -2.17\,\text{V}$

3.52 (a) $R_{TH} = 54.7\,\text{k}\Omega$, $V_{TH} = -3.03\,\text{V}$,
(b) $I_{CQ} = 0.227\,\text{mA}$, $V_{CEQ} = 7.51\,\text{V}$

3.55 $I_{E2} = 3.6\,\text{mA}$, $I_{B2} = 0.0444\,\text{mA}$, $I_{C2} = 3.56\,\text{mA}$, $I_{E1} = 0.259\,\text{mA}$, $I_{B1} = 0.0032\,\text{mA}$, $I_{C1} = 0.256\,\text{mA}$

Chapter 4

4.1 (a) $g_m = 76.9\,\text{mA/V}$, $r_\pi = 2.34\,\text{k}\Omega$, $r_o = 75\,\text{k}\Omega$,

(b) $g_m = 19.2\,\text{mA/V}$, $r_\pi = 9.36\,\text{k}\Omega$, $r_o = 300\,\text{k}\Omega$

4.4 $41.5 \le g_m \le 50.8\,\text{mA/V}$, $1.58 \le r_\pi \le 2.89\,\text{k}\Omega$

4.7 (a) $V_B = -0.0347\,\text{V}$, $V_E = -0.735\,\text{V}$,
(b) $R_C = 6.43\,\text{k}\Omega$, (c) $A_V = -83.7$,
(d) $A_V = -74.9$

4.10 (a) $I_{CQ} = 1.19\,\text{mA}$, $V_{ECQ} = 8.42\,\text{V}$,
(b) $A_V = -1.94$,
(c) $1.76 \le |A_V| \le 2.14$

4.13 (a) $R_E = 11.0\,\text{k}\Omega$, (b) $R_C = 3.71\,\text{k}\Omega$,
(c) $A_V = -43.9$, (d) $R_i = 4.81\,\text{k}\Omega$

4.16 (a) $39.0 \le |A_V| \le 43.2$,

(b) $1.64 \le R_i \le 2.13\,\text{k}\Omega$,
(c) $3.70 \le R_o \le 3.85\,\text{k}\Omega$

4.19 $r_e = r_\pi \left\| \left(\frac{1}{g_m}\right) \right\| r_o$

4.25 3.24 V peak-to-peak

4.28 0.342 mA peak-to-peak

4.31 Δi_C (peak-to-peak) = 1.29 mA,
Δv_{CE} (peak-to-peak) = 2.58 V

4.33 (a) $I_{CQ} = 2.09\,\text{mA}$, $V_{CEQ} = 3.69\,\text{V}$,
(c) $A_V = 0.988$,
(d) $R_{ib} = 122\,\text{k}\Omega$, $R_o = 12.2\,\Omega$

4.37 (a) $I_{CQ} = 0.650\,\text{mA}$, $V_{ECQ} = 3.01\,\text{V}$,
(c) $A_V = 0.977$, $A_i = 4.61$,
(d) $R_{ib} = 88.2\,\text{k}\Omega$, $R_o = 38.7\,\Omega$,
(e) $4.21 \le A_i \le 5.05$

4.40 (a) $V_B = 0.0617\,\text{V}$, $V_E = 0.762\,\text{V}$;
(b) $g_m = 19\,\text{mA/V}$, $r_\pi = 4.21\,\text{k}\Omega$,
$r_o = 304\,\text{k}\Omega$;
(c) $A_v = 0.906$,
$A_i = 14.8$; (d) $A_v = 0.728$,
$A_i = 14.8$

4.44 (a) $I_{CQ} = 1.46\,\text{mA}$, $V_{CEQ} = 7.75\,\text{V}$;
(b) $R_m = 1.93\,\text{k}\Omega$; (c) $A_v = 26.0$

4.47 (a) $V_E = 0.5\,\text{V}$, $V_B = 1.20\,\text{V}$,
$V_C = 1.70\,\text{V}$,
(b) $A_V = 9.36$, (c) $R_i = 49.5\,\Omega$

4.50 (a) $g_{m1} = 42.7\,\text{mA/V}$, $r_{\pi 1} = 2.34\,\text{k}\Omega$,
$g_{m2} = 48.5\,\text{mA/V}$, $r_{\pi 2} = 2.06\,\text{k}\Omega$,
$r_{o1} = r_{o2} = \infty$,
(b) $A_{V1} = -85.4$, $A_{V2} = -97$,
(c) $A_V = 3890$

4.53 (a) $I_{C1} = 12.8\,\mu\text{A}$, $V_{CE1} = 5.11\,\text{V}$,
$I_{C2} = 1.29\,\text{mA}$, $V_{CE2} = 5.81\,\text{V}$,
(b) $A_V = -55.2$,
(c) $R_{is} = 74.4\,\text{k}\Omega$, $R_o = 2.2\,\text{k}\Omega$

4.56 (a) $P_{RE} = 1.66\,\text{mW}$, $P_{RC} = 13.0\,\text{mW}$,
$P_Q = 7.0\,\text{mW}$,
(b) $\overline{P}_{RL} = 1.44\,\text{mW}$

4.59 (a) $P_{RC} = 7.02\,\text{mW}$, $P_Q = 2.65\,\text{mW}$,
(b) $\overline{P}_{RL} = 0.290\,\text{mW}$,
$\overline{P}_{RC} = 0.0289\,\text{mW}$, $\overline{P}_Q = 2.33\,\text{mW}$

Chapter 5

5.1 (a) 3.06 mA, (b) 2.81 mA

5.4 W/L = 9.375

5.7 7.21 μm

5.10 (a) $V_{SD}(\text{sat}) = 1\,\text{V}$, $I_D = 0.12\,\text{mA}$
(b) $V_{SD}(\text{sat}) = 2\,\text{V}$, $I_D = 0.48\,\text{mA}$
(c) $V_{SD}(\text{sat}) = 3\,\text{V}$, $I_D = 1.08\,\text{mA}$

5.13 781 kΩ, 63.7 kΩ, 100 V

5.16 $1.24\,\text{V}^{1/2}$

5.19 $V_{GS} = 2.05\,\text{V}$, $I_D = 0.775\,\text{mA}$,
$V_{DS} = 5.35\,\text{V}$

5.22 $V_S = 2.21\,\text{V}$, $V_{SD} = 5.21\,\text{V}$

5.25 For example, let W/L = 10, then
$V_{SG} = 4\,\text{V}$, $R_S = 5\,\text{k}\Omega$, $R_D = 7.5\,\text{k}\Omega$,
$R_1 = 100\,\text{k}\Omega$, $R_2 = 150\,\text{k}\Omega$

5.28 $R_D = 5\,\text{k}\Omega$, $R_S = 2.36\,\text{k}\Omega$

5.31 $R_D = 4\,\text{k}\Omega$. Let W/L = 10, then
$R_S = 3.94\,\text{k}\Omega$

5.34 $(W/L)_1 = 3.23$

5.37 20.3

5.40 $I_D = 0.49\,\text{mA}$, W/L = 0.731

5.43 $V_{DS} > V_{DS}(\text{sat}) = -V_P$, $I_D = I_{DSS}$

5.46 $V_{DD} \le -2.5\,\text{V}$, $V_S = -1.06\,\text{V}$

5.49 $V_{GSQ} = -1.17\,\text{V}$, $I_{DQ} = 5.85\,\text{mA}$,
$V_{DSQ} = 7.13\,\text{V}$

5.52 $R_D = 0.9\,\text{k}\Omega$, $R_1 = 8.6\,\text{k}\Omega$,
$R_2 = 91.4\,\text{k}\Omega$

5.55 $R_D = 1.75\,\text{k}\Omega$, $I_D = I_{DSS} = 4\,\text{mA}$

5.58 $128\,\mu\text{A/V}^2$

Chapter 6

6.1 (a) 12.5, (b) 2.21 V

6.4 0.833 mA

6.6 (a) $R_D = 8\,k\Omega$, W/L = 11.6,
(b) $g_m = 0.835\,mA/V$, $r_o = 133\,k\Omega$,
(c) -6.3

6.10 2.1 mA/V

6.13 (b) -2.88, (c) 2.76 V peak-to-peak

6.16 (a) $R_S = 0.5\,k\Omega$, $I_{DQ} = 1.0\,mA$,
(b) -1.33

6.19 $K_n = 0.202\,mA/V^2$, $V_{TN} = -2.65\,V$,
$R_D = 1.23\,k\Omega$, $R_S = 0.10\,k\Omega$,
$R_1 = 529\,k\Omega$, $R_2 = 123\,k\Omega$

6.23 (No load) $A_V = 0.995$, $R_o = 0.249\,k\Omega$;
(With load) $A_V = 0.905$, $R_o = 0.226\,k\Omega$

6.26 (a) 47.0, (b) 3.13 mA

6.30 (a) $100\,\Omega$, (b) $100\,\Omega$

6.33 (a) $I_{DQ} = 0.365\,mA$, $V_{DSQ} = 4.53\,V$,
(b) $g_m = 2.09\,mA/V$, $r_o = \infty$,
(c) $A_V = 4.64$

6.36 (a) $R_S = 2.26\,k\Omega$, $R_D = 1.07\,k\Omega$,
(b) $A_V = 4.74$

6.39 $0.936\,k\Omega$

6.42 (a) 0.731, (b) $0.40\,k\Omega$

6.45 (a) $R_1 = 545\,k\Omega$, $R_2 = 1.50\,M\Omega$,
(b) $I_{DQ1} = 0.269\,mA$, $I_{DQ2} = 0.5\,mA$,
$V_{DSQ1} = 4.62\,V$,
(c) $A_V = 0.714$, $R_o = 1.25\,k\Omega$

6.48 (a) $R_1 = 38.8\,k\Omega$, $R_2 = 35\,k\Omega$,
$R_3 = 26.2\,k\Omega$, $R_D = 0.6\,k\Omega$,
(b) $A_V = -5.36$

6.53 (a) $I_{DQ} = 1.42\,mA$, $V_{SDQ} = 2.9\,V$,
(b) $A_V = 0.844$, $A_i = 4.18$,
(c) 5.8 V peak-to-peak

Chapter 7

7.1 (c) $v_o(t) = 1 - e^{-t/R_1C_1}$

7.5 (a) $\tau_S = (R_i + R_P)C_S = 0.40\,s$,
$\tau_P = (R_i \| R_P)C_P = 0.375\,\mu s$
(b) $f_L = 0.398\,Hz$, $f_H = 424\,kHz$,
$|T|_{max} = 7.5\,k\Omega$

7.8 (a) $|A_V| = 159$;
(b) τ_S (open circuit) = 5.31 ms, τ_P (short circuit) = $0.332\,\mu s$;
(c) $C_C = 0.932\,\mu F$, $C_L = 55.3\,pF$

7.11 (a) 959 Hz, (b) $|A_V| = 6.70$

7.13 (a) $R_S = 2.59\,k\Omega$, $R_D = 4.41\,k\Omega$,
(c) $1.89\,\mu F$

7.16 (a) $I_{DQ} = 1.8\,mA$, $V_{SDQ} = 5.68\,V$,
$g_m = 2.68\,mA/V$, $r_o = \infty$
(b) For C_{C1}, $\tau_{S1} = 2.28\,ms$; For C_{C2}, $\tau_{S2} = 51.2\,ms$
(c) C_{C2} dominates; $f_{3\text{-}dB} = 3.1\,Hz$

7.19 $C_C = 456\,\mu F$

7.22 (a) $C_E = 57.2\,\mu F$,
(b) $f_B \approx 199.7\,Hz$, $f_A = 0.556\,Hz$

7.25 $C_L = 121\,pF$

7.31 $f_T = 511\,MHz$, $f_\beta = 4.26\,MHz$

7.33 (a) $f_\beta = 13.3\,MHz$, (b) $f = 199\,MHz$

7.37 $f_L = 540\,Hz$, $f_H = 344\,kHz$

7.41 (a) $r_S = 198\,\Omega$, (b) 12%

7.44 (a) $C_\pi = 2.21\,pF$, $C_M = 27.7\,pF$,
(b) $f_H = 3.06\,MHz$, $A_V = -19.5$

7.47 (a) $f_H = 10.4\,MHz$, (b) $C_M = 18.2\,pF$,
(c) $A_V = -4.66$

7.50 $f_{P\mu} = 17.9\,MHz$, $A_V = 0.863$

Chapter 8

8.2 (a) $R_L = 7.2\,\Omega$, $R_B = 1.12\,k\Omega$,
(b) $V_P = 26\,mV$

8.5 (b) 9.38, 30, 39.4, 10.8, 7.16 W,
(c) Yes

8.9 $T_{dev} = 136\,°C$, $T_{case} = 101\,°C$, $T_{snk} = 85\,°C$

8.11 $P_D = 10\,W$

8.13 (a) $I_Q = 9.8\,mA$, $R = 949\,\Omega$,
$i_{E1}(max) = 19.6\,mA$,
$i_{E1}(min) = 0$, $i_L(max) = 9.8\,mA$,
$i_L(min) = -9.8\,mA$,
(b) 16.3%

8.16 (a) $v_o(\max) = 8\,\text{V}$, $i_L = 1.6\,\text{mA}$, $v_I = 10\,\text{V}$,
(b) 62.7%

8.19 (a) $V_{BB} = 5\,\text{V}$, $P = 5\,\text{mW}$,
(b) $v_o(\max) = 8\,\text{V}$, $i_L = i_{Dn} = 8\,\text{mA}$, $i_{Dp} = 0$, $v_I = 9.5\,\text{V}$, $P_L = 64\,\text{mW}$, $P_{Mn} = 16\,\text{mW}$, $P_{Mp} = 0$

8.21 (a) $200\,\mu\text{A/V}^2$

8.24 $\overline{P}_L(\max) = 112.5\,\text{mW}$, $R_1 = 40.4\,\text{k}\Omega$, $R_2 = 13.3\,\text{k}\Omega$

8.29 (a) Set $V_e = 0.9V_{CC} = aV_P$, then $a = 2.86$;
(b) $P_Q = 4.95\,\text{W}$

8.33 $R_i = 46.4\,\text{k}\Omega$

Chapter 9

9.2 (a) $A_v = -10$, $R_i = 10\,\text{k}\Omega$;
(b) $A_v = -5$, $R_i = 10\,\text{k}\Omega$;
(c) $A_v = -20$, $R_i = 5\,\text{k}\Omega$

9.5 $R_2 = 1\,\text{M}\Omega$, $R_1 = 33.3\,\text{k}\Omega$

9.7 (a) $v_O = -150\sin\omega t\,(\text{mV})$;
(b) $i_2 = 10\sin\omega t\,(\mu\text{A})$, $i_L = -37.5\sin\omega t\,(\mu\text{A})$, $i_O = -47.5\sin\omega t\,(\mu\text{A})$

9.11 (a) $450\,\text{k}\Omega$, (b) $4.95\,\text{M}\Omega$

9.15 (a) $-1.996\,\text{V}$, (b) $+1.996\,\text{V}$

9.19 (a) $v_O = -2.667\,\text{V}$,
(b) $v_{I3} = 0.525\,\text{V}$

9.20 $R_1 = 20\,\text{k}\Omega$, $R_2 = 160\,\text{k}\Omega$, $R_F = 80\,\text{k}\Omega$

9.24 (a) $R_F = 10\,\text{k}\Omega$,
(b) $v_O = 0.3125\,\text{V}, 4.6875\,\text{V}$

9.27 $R_1 = 8\,\text{k}\Omega$, $R_2 = 72\,\text{k}\Omega$

9.31 $A_v = 5$

9.34 $v_{O1} = -v_{O2} = \left(1 + \dfrac{R_2}{R_1}\right) \cdot v_I$

9.37 (b) $R_S \geq 1.1\,\text{k}\Omega$

9.40 $R_2 = R_3 = 1\,\text{k}\Omega$, Set $R_1 = R_F = 1\,\text{k}\Omega$

9.43 $v_{I2} = 2.5\,\text{V}$

9.47 $R_{if} = 1.52\,\text{k}\Omega$, Potentiometer $\approx 300\,\text{k}\Omega$

9.50 (a) $f = 31.8\,\text{Hz}$, Phase $= -90°$,
(b) $f = 15.9\,\text{Hz}, 159\,\text{Hz}$

9.53 (a) $A_v = -\dfrac{R_2}{R_1} \cdot \dfrac{j\omega R_1 C_1}{1 + j\omega R_1 C_1}$,
(b) $A_v = -\dfrac{R_2}{R_1}$, (c) $f = \dfrac{1}{2\pi R_1 C_1}$

Chapter 10

10.2 $I_{C1} = I_{C2} = 962\,\mu\text{A}$, $I_{B1} = I_{B2} = 19.2\,\mu\text{A}$

10.5 $I_{REF} = 0.54\,\text{mA}$, $R_1 = 7.96\,\text{k}\Omega$

10.7 (a) $R_1 = 9.3\,\text{k}\Omega$, (b) $I_O = 2\,\text{mA}$,
(c) $R_{C2} = 4.65\,\text{k}\Omega$

10.11 (a) $I_2 = 1.0\,\text{mA}$, $I_3 = 1.5\,\text{mA}$;
(b) $I_1 = 0.25\,\text{mA}$, $I_3 = 0.75\,\text{mA}$;
(c) $I_1 = 0.167\,\text{mA}$, $I_2 = 0.333\,\text{mA}$

10.14 $I_{REF} = 0.500392\,\text{mA}$, $R_1 = 17.19\,\text{k}\Omega$

10.17 $I_{REF} = 1.00053\,\text{mA}$, $R_1 = 9.295\,\text{k}\Omega$

10.20 (a) $0.466\,\text{mA}$, (b) $400\,\Omega$

10.23 $R_O = 12.8\,\text{M}\Omega$, 0.936%

10.25 $V_{BE1} = 0.681\,\text{V}$, $I_{REF} = 0.482\,\text{mA}$, $I_O = 8.7\,\mu\text{A}$, $V_{BE2} = 0.577\,\text{V}$

10.29 $R_{E2} = 10.17\,\text{k}\Omega$, $R_{E3} = 2.44\,\text{k}\Omega$, $R_1 = 18.6\,\text{k}\Omega$, $V_{BE2} = 0.598\,\text{V}$, $V_{BE3} = 0.6268\,\text{V}$

10.32 (a) $I_{O1} = 4.64\,\text{mA}$, $I_{O2} = 2.32\,\text{mA}$, $I_{O3} = 6.96\,\text{mA}$,
(b) $R_{C1} \simeq 2\,\text{k}\Omega$, $R_{C2} \simeq 4\,\text{k}\Omega$, $R_{C3} \simeq 1.34\,\text{k}\Omega$

10.35 (a) $0.475 \leq I_O \leq 0.525\,\text{mA}$,
(b) $0.451 \leq I_O \leq 0.551\,\text{mA}$

10.38 $(W/L)_2 = 3.125$, $(W/L)_1 = 1.25$, $(W/L)_3 = 0.2$

10.41 $(W/L)_2 = 20$, $(W/L)_1 = 60$, $(W/L)_3 = 0.986$

10.44 $I_{REF} = I_O = 0.74\,\text{mA}$, $V_{DS2}(\text{sat}) = 0.86\,\text{V}$

10.47 (a) $I_{REF} = 80\,\mu\text{A}$, $I_O \cong 80\,\mu\text{A}$;
(b) From a PSpice analysis, $\Delta I_O = 0.052\,\mu\text{A}$

10.50 $I_{REF} = 89.5\,\mu A$, $I_1 = 17.9\,\mu A$, $I_2 = 112\,\mu A$, $I_3 = 71.6\,\mu A$, $I_4 = 358\,\mu A$

10.52 (a) $i_D = 2.5\,mA$, (b) $i_D = 3\,mA$, (c) $i_D = 3.5\,mA$

10.56 (a) $V_{BE} = 0.5208\,V$, (b) $R_1 = 8.96\,k\Omega$, (c) $V_I = 4.462\,V$, (d) $A_v = -1846$

10.60 $A_v = -4447$

Chapter 11

11.1 (a) $R_E = 2\,k\Omega$, $R_c = 4\,k\Omega$; (c) $v_{CM}(max) = 4\,V$, $v_{CM}(min) = -8\,V$

11.5 (a) (i) 0 V, (ii) −0.1 V (b) (i) 0.768 V, (ii) 0.758 V

11.8 (a) $R_E = 62\,k\Omega$, (b) $A_d = 71.0$, $A_{cm} = -0.398$, $CMMR_{dB} = 45\,dB$ (c) $R_{id} = 70.4\,k\Omega$, $R_{icm} = 6.28\,M\Omega$

11.18 (a) $R_{id} = 46.8\,k\Omega$, (b) $R_{icm} = 43.1\,M\Omega$

11.22 (a) $R_D = 47.5\,k\Omega$, $R_1 = 73.75\,k\Omega$, $I_Q = I_1 = 240\,\mu A$ (b) $\Delta I_Q \cong 13\,\mu A$

11.25 (a) $v_d = 1\,V$, (b) $v_{d,max} = 1.58\,V$

11.30 $v_{cm}(max) = 6\,V$

11.36 (a) $I_Q = 1\,mA$, $R_D = 6\,k\Omega$, (b) $g_f(max) = 0.25\,mA/V$, (c) $A_d = 1.5$

11.41 (a) $A_d = 2307$, (b) $R_L = 150\,k\Omega$

11.44 (a) $I_O = 2\,\mu A$, (b) $A_d = 1923$, (c) $A_d = 641$

11.48 (a) $V_{DS3} = V_{DS4} = 2\,V$, $V_{DS1} = V_{DS2} = 10\,V$, (b) $A_d = 80$, (c) $R_o = 400\,k\Omega$

11.56 (a) $A_d = 88.9$

11.62 $R_i \cong 1.05\,M\Omega$, $R_o = 0.472\,k\Omega$, $A_v = -438$

11.66 (a) $R_{C1} = 80\,k\Omega$, $R_{C2} = 20\,k\Omega$; (b) $A_{d1} = -69.6$, $A_d = -5352$

Chapter 12

12.1 (a) 1.249×10^{-2}, (b) −0.016%, 79.987, (c) $\beta = 1.15 \times 10^{-2}$, −1.6%, 78.72

12.4 $A = 4999$

12.6 (a) $f_H = 8\,kHz$, (b) $f_H = 40\,kHz$

12.8 1000

12.11 (a) $R_i(max) = 10^5\,k\Omega$, $R_i(min) = 1\,\Omega$ (b) $R_o(max) = 10^4\,k\Omega$, $R_o(min) = 0.1\,\Omega$

12.14 $R_{if} \cong 500\,M\Omega$, $R_{of} = 0.0219\,\Omega$

12.18 $R_{if} = 10^6\,k\Omega$, $R_{of} = 5.04\,M\Omega$

12.22 (a) $I_{C1} = I_{C2} = 0.5\,mA$, $I_{C3} = 2\,mA$, $v_O = 0$; (b) $A_{vf} = 5.68$

12.26 $A_{vf} = 45.4$

12.30 (a) $r_{\pi1} = 15.8\,k\Omega$, $g_{m1} = 7.62\,mA/V$, $r_{\pi2} = 2.28\,k\Omega$, $g_{m2} = 52.7\,mA/V$ (b) $A_{if} = 8.63$; (c) $R_{if} = 45.1\,\Omega$

12.34 $A_{if} = 5.33$

12.38 $A_{gf} = 98.06\,mA/V$

12.41 (a) $A_v = -3.41$, (b) $A_{zf} = -85.0\,V/mA$, (c) $R_{if} = 14.9\,k\Omega$, (d) $R_{of} = 4.88\,k\Omega$

12.45 $R_F = 27.2\,k\Omega$

12.49 $T = 84.45$

12.51 (a) $f_{180} \cong 1.05 \times 10^4\,Hz$, (b) $\beta = 4.42 \times 10^{-4}$

12.55 (c) For $\beta = 0.005$, system is stable. Phase margin = 14°; For $\beta = 0.05$, system is unstable.

12.60 $\beta = 0.01428$

12.65 $f_{PD} = 555\,Hz$

Chapter 13

13.5 56.4 V

13.9 $I_{C2} = 10.28\,\mu A$, $I_{C9} = 17.13\,\mu A$, $I_{B9} = 1.713\,\mu A$, $I_{B4} = 0.9345\,\mu A$, $I_{C4} = 9.345\,\mu A$

13.12 $I_{C14} = 21.8\,mA$, $I_{C15} = 0.071\,mA$

13.14 $R_1 = 30.32\,k\Omega$, $R_2 = 33.96\,k\Omega$

13.18 $R_{id} = 2.095\,M\Omega$

13.22 (a) $I_{REF} = I_Q = I_{D7} = 89.2\,\mu A$,
(b) $A_d = 141$, $A_{v2} = 141$, $A_v = 19{,}881$

13.26 $R_o = 1.26\,M\Omega$

13.38 $-15 \le v_{CM} \le 11.6\,V$

13.41 $A_d = 10.38$, $|A_{v2}| = 1917$, $|A| = 19{,}895$

13.43 $I_{DSS} = 0.8\,mA$

Chapter 14

14.1 (a) $A_{CL} = -4.52$, $R_{if} = 90.8\,\Omega$
(b) $A_{CL} = -4.92$, $R_{if} = 98.9\,\Omega$
(c) $A_{CL} = -4.965$, $R_{if} = 99.8\,\Omega$

14.5 (a) $A_v \approx 1$, (b) $R_{of} = 0.02\,\Omega$

14.8 (a) $R_{if} = 99.1\,\Omega$, (b) $R_{of} = 18.4\,\Omega$, (c) $A_{CL} = 0.65$, (d) 0.65

14.11 $f_{3\text{-dB}} = 40\,Hz$, $f_T = 2\,MHz$

14.14 $f_{max} = 159\,kHz$

14.18 6.37 V

14.22 10^3 s

14.26 $i_{C1}/i_{C2} = 1.0155$

14.31 (a) $v_{O1} = v_{O2} = 0.5\,V$, $v_{O3} = -0.3\,V$,
(b) $R_A = 8.33\,k\Omega$, $R_B = 10\,k\Omega$,
(c) $v_{O1} = v_{O2} = 0.1\,V$, $v_{O3} = -0.14\,V$

14.34 (a) $R_2 = 22.48\,M\Omega$, (b) $R_1 = 6\,k\Omega$

14.37 For (a) $v_O = 9\,mV$,
for (b) $v_O = -1.0815\,V$

14.40 (a) Circuit a: $v_O = 0$, Circuit b: $v_O = -0.975\,V$
(b) Circuit a: $v_O = -0.010\,V$, Circuit b: $v_O = -1.18\,V$
(c) Circuit a: $I_B \rightarrow v_O = 0$, $I_{OS} \rightarrow v_O = 0.0125\,V$
Circuit b: $I_B \rightarrow v_O = -1.365\,V$, $I_{OS} \rightarrow v_O = -1.62\,V$

14.42 $CMRR_{dB} = 37.5\,dB$

Chapter 15

15.6 $N = 5$

15.10 (b) $|A_v|_{max} = 28.3$, $f_o = 5.305\,kHz$, $f_1 = 5.315\,kHz$, $f_2 = 5.296\,kHz$

15.13 (b) $R_2 = 524\,k\Omega$, $C_1 = 0.0732\,\mu F$, $C_2 = 66.3\,pF$

15.15 (a) $10\,M\Omega$, (b) $1\,M\Omega$, (c) $333\,k\Omega$

15.18 (a) $\tau = 60\,\mu s$, (b) $\Delta v_O = 0.167\,V$, (c) $N = 78$

15.21 $R = 8.12\,k\Omega$, $R_2 = 236\,k\Omega$

15.25 (a) $f_o = \dfrac{1}{2\pi\sqrt{R_A R_B C_A C_B}}$,
(b) $\dfrac{R_2}{R_1} = \dfrac{R_A}{R_B} + \dfrac{C_B}{C_A}$

15.29 $f_o = \dfrac{1}{2\pi}\sqrt{\dfrac{C_1 + C_2}{C_1 C_2 L}}$, $\dfrac{C_1}{C_2} = g_m R_L$

15.34 $V_{REF} = -5\,V$, $R_F = 10\,k\Omega$, $R_{VAR} = 40\,k\Omega$

15.36 (a) $V_{TH} = 2\,V$, $V_{TL} = -2\,V$

15.40 (b) $R_2 = 190\,k\Omega$, $V_{REF} = 1.579\,V$

15.42 (a) $R_2 = 12.6\,k\Omega$, (b) $R = 3.02\,k\Omega$

15.47 (b) Duty cycle = 50%, $f_o = 257\,Hz$

15.52 $T = 3.80\,ms$, recovery time $\approx 2\,ms$

15.56 $627\,Hz \le f \le 4.81\,kHz$, $52.2 \le d.c. \le 66.7\%$

15.60 $\dfrac{R_2}{R_1} = 14$, $\dfrac{R_4}{R_3} = 15$, Bias voltage = $\pm 12\,V$, $I_P = 2\,A$,
Peak output voltage = $\pm 10\,V$

Chapter 16

16.1 (a) $V_{SB} = 1\text{ V} \Rightarrow \Delta V_{TN} = 0.315\text{ V}$, $V_{SB} = 2\text{ V} \Rightarrow \Delta V_{TN} = 0.544\text{ V}$
(b) $I_D = 0.578, 0.384, 0.267\text{ mA}$

16.5 $v_{it} = 4.67\text{ V}$, $v_{Ot} = 2.67\text{ V}$, $v_O = 1.09\text{ V}$

16.8 5.79

16.11 $V_{TNL} = -2.88\text{ V}$

16.14 (a) (i) 0, (ii) 1.16 mW;
(b) (i) 0, (ii) 825 µW;
(c) (i) 0, (ii) 200 µW

16.17 (a) (i) 4.2 V, (ii) 3.4 V

16.20 (a) 1.82;
(b) $(W/L)_L = 0.444$, $(W/L)_D = 0.808$;
(c) 0.0369 V

16.24 $\overline{(B \cdot C) + A}$

16.28 (a) $V_{It} = 2.5\text{ V}$, $V_{ONt} = 1.7\text{ V}$, $V_{OPt} = 3.3\text{ V}$;
(c) 4.64 V, 0.356 V

16.33 (a) 144.5 µA, (b) 99.4 µA

16.37 $V_{IL} = 4.125\text{ V}$, $V_{OHU} = 9.125\text{ V}$, $V_{IH} = 5.875\text{ V}$, $V_{OLU} = 0.875\text{ V}$
$NM_L = 3.25\text{ V}$, $NM_H = 3.25\text{ V}$

16.39 (a) 2.5 V, (b) $\left(\frac{W}{L}\right)_n = 4.5\left(\frac{W}{L}\right)_p$,
(c) 1.65 V

16.43 $\overline{(A \text{ OR } B) \text{ AND } C}$

16.46 (b) $v_{O2} = (v_A \text{ OR } v_B) \text{ AND } v_C$

16.50 6.25 ms

16.55 Exclusive-OR function

16.67 (a) $(W/L) = 0.329$;
(b) 32.8 mA, 65.6 mW

Chapter 17

17.1 (a) $i_E = 0.56\text{ mA}$, $v_{O1} = 3.5\text{ V}$, $v_{O2} = 2.38\text{ V}$
(b) $i_E = 0.76\text{ mA}$, $v_{O2} = 3.5\text{ V}$
(e) For $v_{O1} = 2.38\text{ V}$, $R_{C1} = 1.47\text{ k}\Omega$

17.4 $R_5 = 2.8\text{ k}\Omega$, $R_E = 2.1\text{ k}\Omega$, $R_2 = 2.1\text{ k}\Omega$, $R_1 = 0.5\text{ k}\Omega$, $R_3 = 1.1\text{ k}\Omega$, $R_4 = 0.767\text{ k}\Omega$, $R_{C2} = 1\text{ k}\Omega$, $R_{C1} = 0.808\text{ k}\Omega$

17.8 (a) AND logic function;
(b) Logic 0 = 0 V, Logic 1 = 1.8 V;
(c) $i_{E1} = 1.65\text{ mA}$, $i_{C3} = 0$, $i_{C2} = i_{E3} = 3\text{ mA}$, $V_2 = 0$
(f) $i_{E1} = 0.962\text{ mA}$, $i_{C2} = 0$, $i_{C3} = i_{E2} = 2.25\text{ mA}$, $V_2 = 1.8\text{ V}$

17.10 (a) Logic 1 = +0.2 V, Logic 0 = −0.2 V,
(b) $R_E = 3\text{ k}\Omega$, (c) $R_1 = 1\text{ k}\Omega$,
(d) $i_{R2} = 0.4\text{ mA}$, $i_{D2} = 0.467\text{ mA}$,
(e) 10.98 mW

17.13 (a) Logic 1 = 0 V, Logic 0 = −0.4 V,
(b) $v_{O1} : A + B$, $v_{O2} : C + D$, $v_{O3} : (A + B) \cdot (C + D)$

17.15 (a) (i) $v^I = 0.8\text{ V}$, $i_1 = 0.525\text{ mA}$, $i_3 = i_4 = 0$, $v_O = 5\text{ V}$
(ii) $v^I = 2.2\text{ V}$, $i_1 = 0.35\text{ mA}$, $i_3 = 2.04\text{ mA}$, $i_4 = 0.297\text{ mA}$
(b) 7, (c) 5

17.18 (a) (i) $i_1 = 0.683\text{ mA}$, $i_{B2} = i_2 = i_4 = i_{B3} = i_3 = 0$,
(ii) $i_1 = i_{B2} = 0.45\text{ mA}$, $i_2 = 2.05\text{ mA}$, $i_4 = 0.533\text{ mA}$, $i_{B3} = 1.97\text{ mA}$, $i_3 = 2.23\text{ mA}$

17.22 (a) $i_{B1} = 1.05\text{ mA}$, other currents = 0,
(b) $i_{B1} = 0.926\text{ mA}$, $i_{B2} = 1.59\text{ mA}$, $i_{C2} = 2.05\text{ mA}$, $i_{B3} = 2.64\text{ mA}$, $i_{C3} = 7.29\text{ mA}$

17.26 (a) $v_{B1} = 1.1\text{ V}$, $i_{B1} = 1.39\text{ mA}$, $v_{B2} = 0.8\text{ V}$, $i_{B4} = 0.0394\text{ mA}$, $i_{C4} = 1.18\text{ mA}$, $v_{B4} = 4.97\text{ V}$, all other currents = 0
(b) $v_{B1} = 1.7\text{ V}$, $v_{B2} = 1.4\text{ V}$, $v_{BO} = 0.7\text{ V}$, $v_{C2} = 1.1\text{ V}$
$i_{B1} = 1.18\text{ mA}$, $i_{B2} = 1.42\text{ mA}$, $i_{B4} = 0.00369\text{ mA}$, $i_{C2} = 5.13\text{ mA}$, $i_{BO} = 6.55\text{ mA}$

17.29 (a) $i_{E1} = 0.0975\text{ mA}$, $P = 0.4875\text{ mW}$;
(b) $P = 1.98\text{ mW}$;
(c) $i_{Sc} \cong 78\text{ mA}$

I N D E X

A

B

C

D

E

F

G

H

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

Z