APPENDIX L

ANSWERS TO SELECTED PROBLEMS

CHAPTER 1

1.1 (a) 5 mA; (b) 5 kΩ; (c) 1 V; (d) 10 mA

1.3 (a) 5 V, 25 mW; (b) 5 kΩ, 5 mW; (c) 10 mA, 1 kΩ; (d) 10 V, 100 kΩ; (e) 31.6 mA, 31.6 V

1.5 990 kΩ, 190 kΩ, 90 kΩ, 10 kΩ; 9.9 kΩ (1% reduction), 9.09 kΩ (9.1% reduction), 5 kΩ (50% reduction)

1.7 2 V, 1.2 kΩ; 1.88 V to 2.12 V; 1.26 kΩ to 1.14 kΩ

1.9 4.80 V, Shunt the 10-kΩ resistor with 157 kΩ; Add a series resistance of 200 Ω.

1.11 10 kΩ, 5 kΩ

1.15 0.77 V, 12.31 kΩ, 0.05 mA

1.16 0.75 mA, 0.5 mA, 1.25 mA, 2.5 V

1.20 (a) 10^{-7} s, 10^7 Hz, 6.28×10^7 rad/s; (f) 10^3 rad/s, 1.59×10^2 Hz, 6.28×10^{-3} s

1.22 (a) $(1 - j\,1.59)$ kΩ; (b) $(247.3 - j\,1553)$ Ω; (c) $(71.72 - j\,45.04)$ kΩ; (d) $(100 + j\,628)$ Ω

1.24 60 mV, 1.2 μA, 50 kΩ

1.25 5 kΩ

1.29 (a) 165 V; (b) 24 V

1.32 14 kHz, 441 mV (peak); 312 mV; 693 mV, 71.4 μs

1.34 0, 110, 1011, 11100, 111011

1.36 (c) 12, 1.2 mV, 0.6 mV

1.38 7.056×10^5 bits/second.

1.40 11 V/V or 20.8 dB; 22 A/A or 26.8 dB; 242 W/W or 23.8 dB; 120 mW, 95.8 mW, 20.2%

1.43 (a) 82.6 V/V or 38.3 dB

1.46 0.69 V; 0.69 V/V or −3.2 dB; 8280 A/A or 78.4 dB; 5713 W/W or 37.6 dB.

1.48 S-A-B-L is preferred as it provides higher voltage gain.

1.51 (a) 400 V/V; (b) 40 kΩ, 2×10^4 A/A, 8×10^6 W/W; (c) 500 Ω; (d) 750 V/V; (e) 100 kΩ, 100 Ω, 484 V/V

1.56 38.1 V/V

1.59 Voltage amplifier, $R_i = 1 \times 10^5\ \Omega$, $R_o = 1 \times 10^2\ \Omega$, $A_{vo} = 121$ V/V

1.64 1025 V/V or 60.2 dB, 2500 A/A or 68 dB, 2.63×10^6 W/W or 64.2 dB

1.68 4 MHz

1.70 64 nF

1.73 $0.51/CR$

1.75 0.8 kΩ, 8.65 kΩ, connect 2 nF to node B.

1.78 159 kHz; 14.5 Hz; $\simeq$ 159 kHz

1.81 10 Hz, 10 kHz, 0.04 dB, 0.04 dB, 10 Hz, 10 kHz

CHAPTER 2

2.2 4004 V/V

2.5 40,000 V/V

2.7 0.1%

2.8 In all cases, −5 V/V, 20 kΩ

2.11 (a) −1 V/V; (c) −0.1 V/V; (e) −10 V/V

2.13 10 kΩ, 100 kΩ

2.15 Average = +5 V, highest = +10 V, lowest = 0 V

2.17 $\pm 2x\%$; −98 to −102 V/V

2.19 1.8 kΩ; 18 kΩ

2.21 ±2 mV

2.24 $1000\left(1+\frac{R_2}{R_1}\right)$, $100\left(1+\frac{R_2}{R_1}\right)$, $10\left(1+\frac{R_2}{R_1}\right)$; $1000\,R_1$, $100\,R_1$, $10\,R_1$

2.26 (b) 1 kΩ, 100 kΩ, 909 V/V

2.28 (a) 10.2 kΩ

2.32 (a) 0.1 mA, 0.1 mA, 10 mA, 10.1 mA, −1 V; (b) 1.19 kΩ; (c) −11.1 V to −2.01 V

2.34 (a) 1 kΩ; (b) 0, ∞; (c) −0.57 mA to +0.57 mA (d) 2.2 mA

2.36 $v_O = -(10\,v_1 + 5\,v_2)$; −5 V

2.43 12.8 kΩ

2.44 (a) ∞; 0; (b) 10 kΩ, 10 kΩ; (d) 10 kΩ, 990 kΩ

2.46 100 kΩ; no

2.50 $2\sin(2\pi \times 1000t)$

2.51 $1/x$; 1 to ∞; add 1-kΩ resistor between the left end of the pot and ground.

2.53 (a) 10 mV, 10 μA, 10 μA; (b) 10 V, 10 mA, 0; from the power supply of the op amp

2.58 (a) −0.83 V/V, 17%; (c) −0.98 V/V, 2%; (e) −9 V/V, 10%

2.60 20 V/V, 10 kΩ, 0.0095 V/V, 66.4 dB

2.64 $R_1 = R_3$, $R_2 = R_4$

2.65 0.02x V/V; 0.002 V/V, 54 dB; 0.02 V/V, 34 dB; 0.1 V/V, 20 dB

2.67 1 kΩ, 1 MΩ, 1 kΩ, 1 MΩ; 1% tolerances

2.69 $R = 1$ MΩ, $R_5 = 756$ Ω, $R_6 = 6.8$ kΩ

2.73 (a) −0.12 V to +0.12 V; (b) −12 V to +12 V

2.75 Ideal: 21 V/V, 0, ∞; ±1% resistors: $A_d = 21 \pm 4\%$, $|A_{cm}| = 0.02$, CMRR = 60.4 dB

2.77 (a) $v_B/v_A = 3$ V/V, $v_C/v_A = -3$ V/V; (b) 6 V/V; (c) 56 V pp, 19.8 V rms

2.79 (a) 1591 Hz; (b) leads by 90°; (c) increases by a factor of 10; (d) the same as in (b)

2.81 1 MHz; 0.159 μs

2.83 $R = 10$ kΩ, $C = 159$ pF; $R_F = 1$ MΩ, 1 kHz; (a) v_O decreases linearly to −6.3 V, (b) v_O decreases exponentially, $v_O(t) = -100(1 - e^{-t/159})$, reaching −6.1 V at the end of the pulse.

2.86 $R_1 = 10$ kΩ, $R_2 = 1$ MΩ, $C = 0.16$ nF; 100 kHz

2.88 15.9 kHz, $v_O = -5 \sin(10^6 t + 90°)$ V

2.90 Square wave of the same frequency, 8 V peak amplitude, average is 0 V; 30 kΩ

2.92 $R_1 = 1$ kΩ, $R_2 = 100$ kΩ, $C = 79$ nF; 20 Hz

2.94 4 mV

2.96 9 mV; 12 mV

2.98 (a) 0.53 μA, into the input terminals; (b) −3 mV; (c) −60 nA

2.100 $R_1 = 1.01$ kΩ, $R_2 = R_3 = 100$ kΩ, $C_1 = 1.58$ μF, $C_2 = 0.16$ μF

2.102 6 V; 3 V; 9 mV

2.104 (a) 0.2 V; (b) 0.4 V; (c) 10 kΩ, 20 mV; (d) 0.22 V

2.106 (a) 9.9 kΩ; (b) 0.222 V

2.108 80,000 V/V, 125 Hz, 10 MHz

2.111 19.61 kHz, 49.75 V/V, 4.975 V/V

2.113 (a) 5.1 MHz; (c) 10 MHz; (e) 10.1 MHz; (g) 2 MHz

2.116 36.6 MHz

2.118 500 MHz; 3; 7 MHz; 3.6 MHz

2.121 100 mV

2.125 1 MHz, 3.18 V

CHAPTER 3

3.1 $-55°C$: 2.68×10^6 cm^{-3}, one out of every 1.9×10^{16} silicon atoms; $+75°C$: 3.70×10^{11} cm^{-3}, $N/n_i = 1.4 \times 10^{11}$

3.3 5×10^{18} cm^{-3}; 45 cm^{-3};

3.5 At 27°C: $n_n = 10^{17}$/cm^3, $p_n = 2.25 \times 10^3$ cm^3;
At 125°C: $n_n = 10^{17}$/cm^3, $p_n = 2.23 \times 10^8$ cm^3

3.7 $v_{p-\text{drift}} = 1.44 \times 10^6$ cm/s, $v_{n-\text{drift}} = 4.05 \times 10^6$ cm/s

3.9 9.26×10^{17}/cm^3

3.12 778 mV; 0.2 μm, 0.1 μm, 0.1 μm; 1.6×10^{-14}C

3.14 1.6 pC

3.16 59.6 mV

3.20 7.85×10^{-17} A; 0.3 mA

3.22 3.6×10^{-16} A; 0.742 V

3.24 31.6 fF; 14.16 fF

3.27 0.5 pF; 129.5 ps

CHAPTER 4

4.2 (a) −3 V, 0.6 mA; (b) +3 V, 0 mA

4.3 (a) $V = 2$ V, $I = 2.5$ mA; (b) $I = 1$ mA, $V = 1$ V

4.6 $X = AB$; $Y = A + B$; X and Y are the same for $A = B$; X and Y are opposite if $A \# B$.

4.9 (a) $I = 0$, $V = 1$ V; (b) $I = 0.25$ mA, $V = 0$ V

4.11 $R \geq 4.2$ kΩ, 169.7 V

4.13 2.5 V; 1.25 V; 25 mA; 12.5 mA; 2.5 V

4.15 34 V; 8.3 Ω; 0.6 A; 29 V; 34 V, 8 Ω; 25%; 103 mA; 0.625 A; 29 V

4.17 At −55°C, $V_T = 18.8$ mV; At +55°C, $V_T = 28.3$ mV; $V_T = 25$ mV at 17° C.

4.19 0.335 μA

4.21 (a) 6.91×10^{-13} A, 0.64 V; (c) 5.11×10^{-17}A, 0.59 V

4.23 3.9 mA; −22 mV

4.26 $A_4 = 2A_3 = 4A_2 = 8A_1$; 1.5 mA

4.28 42 Ω

4.31 50°C; 6 W; 8.33°C/W

4.33 230 mV; independent of temperature

4.35 0.6635 V, 0.3365 mA

4.37 $R = 582\ \Omega$

4.41 (a) −2.3 V, 0.53 mA; (b) +3 V, 0 mA

4.43 (a) $I = 0$, $V = -1.23$ V; (b) $I = 0.133$ mA, $V = 0$ V

4.45 $R \geq 4.23$ kΩ, 169.7 V; essentially the same.

4.48 0.24 mV, 2.0 mV, 9.6 mV; 25 μA

4.53 $V_o/V_i = 1/(1 + j\omega C r_d)$; $-\tan^{-1}(\omega C\, V_T/I)$; 157 μA −84.3° to −5.71°

4.56 $R = 417\ \Omega$; 7.39 mA; 6.8 mV; −3.4 mV; −6.8 mV; −13.6 mV

4.59 (a) $r_z = 8\ \Omega$, 1.04 W; (b) $V_{Z0} = 8.8$ V, 188 mW

4.61 88.9 mV

4.63 167 Ω; 7.65 V; 7.35 V; 7.78 V; 707 Ω; 7.2 V

4.66 (a) 9.825 V; (b) 207 Ω; (c) 33 mV/V, ±1.65%; (d) −6.77 V/A, −1.35%; (e) 70.9 mA, 732 mW

4.69 0.324 V

4.71 13.44 V; 48.4%; 8.3 V; 8.3 mA

4.73 (a) 10.1:1; (b) 1.072:1

4.75 45 V

4.77 (a) 12.77 V, 13.37 V; (b) 7.1%, 2.24%; (c) 192 mA, 607 mA; (d) 371 mA; 1.2 A

4.80 (a) 9.7 V; (b) 542 μF; (c) 25.7 V, 38.5 V; (d) 739 mA; (e) 1.42 A

4.83 10.74 V; 23.5 μs; 4.913 A; 4.913 A

4.85 (a) +1 V, +2 V, +2.7 V; (b) +3 V, +6 V, +6.7 V; (c) 0 V, 0 V, 0 V, −13 V; (d) 0 V, 0 V, −13 V.

4.96 −7.07 V

CHAPTER 5

5.1 580 to 2900 μm^2; 24 to 54 μm

5.4 (a) 0.5; (b) 0.5; (c) 1.0; (d) 0.5

5.7 0.35 μm

5.9 0.5 V; 0.5 mA

5.11 (a) −1.1 V; (b) −0.4 V; (c) 0.05 mA; 0.5 mA

5.13 116.3 Ω, 116.3 mV; 50

5.17 2.8 V; 500 Ω, 100 Ω

5.19 5 mA/V^2; 0.6 V

5.21 0.5 V; 20; 145 μA; 1.5 V, 1.125 mA

5.23 2.5 kΩ to 125 Ω; (a) 5 kΩ to 250 Ω; (b) 1.25 kΩ to 62.5 Ω; (c) 2.5 kΩ to 125 Ω.

5.29 (a) 3%; (b) 5%

5.31 200 kΩ, 20 kΩ; 5%, 5%

5.33 104 μA; 4%; double L to 3 μm

5.35 Increases by a factor of 16.

5.38 350 μA; 750 μA; 864 μA; 880 μA; 960 μA

5.41 At 3.0 V, transistor is cut off; at 2.5 V, transistor enters saturation region; at 0.5 V, transistor enters triode region.

5.43 1 V, 0 V, 1 V, 0.25 V; 5 kΩ, 5 kΩ, 5 kΩ, 5 kΩ; 10 kΩ, 2 V; 10 kΩ, −1 V; 10 kΩ, 2 V; 10 kΩ, −0.75 V

5.45 0.08 mA; 10 kΩ, 5 kΩ; 17.5 kΩ

5.48 4 kΩ

5.50 4 μm, 11.1 μm; 1.4 kΩ

5.52 0.45 mA, +7.3 V; quite tolerant.

5.54 44.4; 1.25 kΩ

5.56 −1 V, −1.43 V, −2.8 V, 1 V, 2.8 V, +1 V, 2.8 V, −1 V

5.59 $I_1 = 405$ μA, $V_2 = 1.5$ V; $I_3 = 217$ μA, $V_4 = 1.232$ V; $V_5 = 1.5$ V, $I_6 = 405$ μA

5.61 (a) 0.5 V, 0.5 V, −0.983 V; (b) 0.1 V, 0.9 V, −1.01 V

5.63 −1.24 V

5.65 triode, 0.59 mA; triode, 5 mA; saturation, 9 mA; saturation, 9 mA

CHAPTER 6

6.2 4.7×10^{-17} A, 1.87×10^{-16}A; $A_2/A_1 = 4$

6.4 0.31 V

6.6 Old: 0.673 V; New: 0.846 V

6.8 80; 0.988

6.10 0.5; 0.67; 0.91; 0.95; 0.98; 0.99; 0.995; 0.998; 0.999

6.12 $I_C = 0.5$ mA → 3 mA; $I_E = 0.51$ mA → 3.01 mA; 30 mW

6.14 990 μA, 99, 0.99; 980 μA, 49, 0.98; 950 μA, 19, 0.95

6.17 −0.668 V; 1.04 V; 0.02 mA

6.19 EBJ: 0.691 V; CBJ: 0.576 V; EBJ: 0.49 μA; CBJ: 48.5 μA

6.23 0.758 V; 0.815 V

6.25 238 mA; 6×10^{-14} A; 87

6.28 (a) 2 mA, −0.7 V; (b) −2 V; (c) 2 V, 0.5 mA; (d) 1.6 mA, −4.5 V

6.30 8.3 kΩ; 20; 100; 200

6.32 $R_C = 4$ kΩ; $R_E = 3.64$ kΩ; $R_{C\max} = 5.86$ kΩ

6.34 $R_E = 3.66$ kΩ; $R_C = 5$ kΩ

6.36 10.24 μA

6.38 0.75 V; 0.55 V

6.40 3.35 μA; 3000

6.43 125 kΩ; 125 V; 12.5 kΩ

6.45 1 mA; 10 V; 50 V; 50 kΩ

6.47 $\beta = 100$; $\beta_{ac} = 80$; $\Delta i_C = 0.18$ mA, $i_C = 1.18$ mA

6.50 $\beta_{forced} = 11.2$; $V_C = 4.8$ V; $R_B = 45.7$ kΩ

6.52 2.05 V, 2.38 V

6.55 $R_1 = 18$ kΩ, $R_2 = 12$ kΩ; 0.46 mA, 2.54 V

6.58 +0.41 V, +1.11 V, −1.15 V; +1.2 V, +1.9 V, −1.9 V; 204

6.61 (a) −0.7 V, +1.2 V; (b) +1.2 V, 0.5 mA; (c) −0.7 V, 0 V, +1.2 V; (d) +1.45 V, −0.5 V; (e) +0.75 V, +1.45 V, −0.5 V

6.63 $R_E = 4$ kΩ, $R_B = 50$ kΩ, $R_C = 4$ kΩ, $I_C = 0.85$ mA to 0.98 mA, $V_C = -1.6$ V to −1.1 V

6.66 (a) 0 V, +0.7 V, −0.725 V, −1.425 V, +1.1 V; (b) +0.23 V +0.93 V, −1 V, −1.7 V, +1.47 V

6.68 0 V, 0 V; +1.8 V, +1.1 V; −2.2 V, −1.5 V; −3 V, −2.3 V

CHAPTER 7

7.2 A: (0.5 V, 5 V); B: (0.72 V, 0.22 V)

7.3 20 kΩ; (0.72 V, 0.22 V); −40 V/V; 0.78 V; 19.5 mV

7.6 0.4 V; 8.33

7.8 (a) 0.712 V; (b) −42.7 V/V, 11.7 mV; (c) 42.88 kΩ; 24.9

7.10 −160 V/V; 0.7 V; 4.4 mV

7.12 1.08 V; 0.78 V; −156.7 V/V

7.15 −60 V/V

7.18 3 mA; −120 V/V; +5 mV: exp. → −660 mV, linear → −600 mV; −5 mV: exp. → +540 mV, linear → +600 mV.

7.25 (a) 0.1 mA, 0.8 V; (b) 1 mA/V; (c) −10 V/V; (d) 100 kΩ, −9.1 V/V

7.26 0.5 mA/V; 0.067 mA, 0.27 V; 9.14; 0.67 V

7.29 16 μm; 0.75 V

7.31 −18.2 V/V; 1.207 V, −23.6 V/V

7.33 (b) 2 mA/V, 200 kΩ; (d) 3.33 MΩ, 0.94 V/V, −15.38 V/V, −14.5 V/V

7.35 2.5 V; 0.611 mA, 1.95 V; 5 mV; −0.55 V; −110 V/V; −100 V/V

7.37 40 mA/V; 25 Ω; 2.5 kΩ; 1 V

7.39 1.04 kΩ to 4.7 kΩ

7.42 (a) 1.000, ∞, 1.00 mA, 1.00 mA, 0 mA, 40 mA/V, 25 Ω, ∞ Ω; (c) 0.980, 50, 1.00 mA, 1.02 mA, 0.02 mA, 40 mA/V, 24.5 Ω, 1.25 kΩ; (e) 0.990, 100, 0.248 mA, 0.25 mA, 0.002 mA, 9.92 mA/V, 100 Ω, 10.1 kΩ

7.48 1 V; 125 Ω; 80 V/V

7.53 $R_{in} = 75\ \Omega$; $v_o/v_{sig} = 39.6$ V/V

7.55 −1000 V/V; −5000 V/V

7.57 8.6 kΩ, 7.7 kΩ; 77 V/V

7.59 79.4 V/V; 4762 A/A

7.64 −10 V/V

7.66 1 mA/V; 125 μA; −7.5 V/V

7.68 5 kΩ, 10 kΩ, −200 V/V; −100 V/V, −33.3 V/V; 15 mV, 0.5 V

7.70 (b) 1250 V/V

7.72 0.5 kΩ

7.74 30.3 kΩ, −40 V/V, 12 kΩ; −20 V/V, −15 V/V; 6.65 mV, 100 mV

7.76 80 V/V, 44.4 V/V to 109.1 V/V; $R_e = 275\ \Omega$, 25 V/V, 20 V/V to 27.3 V/V

7.78 2.5 mA/V; 0.2 V

7.80 $i_{sig}R_C$

7.82 0.357 kΩ; 1.6 mA; 1.13 V

7.84 1.25 mA; 1.5 mA, 1.0 mA; 0.5 V/V; 1 V

7.86 149 Ω, 0.87 V/V; 116 Ω to 246 Ω; 0.80 V/V to 0.90 V/V

7.89 −91 V/V

7.91 27.5 V/V, 41.2 V/V, 55.6 V/V, 57.1 V/V, 55.6 V/V; 0.325 mA

7.92 18 MΩ, 22 MΩ, 3 kΩ, 3 kΩ; 2 V

7.94 5.07 V, 1.27 mA to 2.48 mA; 620 Ω; 0.91 mA to 1.5 mA

7.96 2 V; 2.4 V; 1.2 mA

7.101 (a) 2.7 V, 2.2 V; (b) 3.05 V, 3.05 V

7.103 2.5 kΩ, 22 MΩ, 20 MΩ

7.105 (a) 230 kΩ; 0.5 mA to 1.5 mA; 1 V to 0 V (saturated transistor), design very intolerant of β variation.

7.108 (a) 5.73; (b) $V_{BB} = V_{BE} + 0.352\ V_{CC}$; (c) 38.8 kΩ, 37.5 kΩ, 3.33 kΩ; (d) 8.1 kΩ; 0.475 mA to 0.509 mA with a nominal value of 0.5 mA

7.110 5.75 kΩ, 6.2 kΩ; 10.8%

7.112 (a) $R_C = 1.5$ kΩ, $R_B = 80$ kΩ; (b) $R_C = 1.5$ kΩ, $R_B = 82$ kΩ; 1.52 V, 0.98 mA; (c) 0.7 V, 1.53 mA; (d) $R_{B1} = 40$ kΩ, $R_{B2} = 70$ kΩ, $R_C = 1.47$ kΩ, 1.1 V, 1.28 mA

7.116 8.6 kΩ, +0.4 V

7.118 (a) $V_D = 2.5$ V, $k_n = 11.1$ mA/V^2; (b) 120 kΩ, −4.1 V/V; (c) 0.264 V, 1.08 V; (d) 300 Ω, 1.08 V

7.120 20 mA/V; 0.1 mA; 5 mV; 10 kΩ

7.122 (a) 0.99 V/V, 99 Ω; (b) 99 Ω, 14.3 V/V; (c) 7.15 V/V

7.124 (a) 1.6 V, 0.1 mA, 82.4 kΩ; (b) 1 mA/V; (d) 1.95 V/V, 39.1 kΩ

7.126 $R_1 = 47$ kΩ, $R_2 = 24$ kΩ, $R_E = 2.2$ kΩ, R_C either 4.7 kΩ or 5.1 kΩ

7.128 $R_B = 91$ kΩ, $R_C = 22$ kΩ, $I = 0.2$ mA; −176 V/V; −29.7 V/V

7.130 (a) 1 mA, 8.2 V; (c) 2.32 kΩ, 0.32 V/V; (d) 2.32 kΩ, −69.2 V/V; (e) −61.8 V/V; (f) 1368.5 V/V

7.132 (a) 0.495 mA, 1.18 V; −71.9 V/V

7.134 $\beta = 50$: (a) 0.78 mA, 0.78 V, 1.48 V; (b) 21.3 kΩ; (c) 0.64 V/V; $\beta = 200$: (a) 1.54 mA, 1.54 V, 2.24 V; (b) 50.9 kΩ; (c) 0.81 V/V

7.136 (a) 1.73 mA, 68.4 mA/V, 14.5 Ω, 1.4645 kΩ; (b) 148.3 kΩ, 0.93 V/V; (c) 18.21 kΩ, 0.64 V/V

7.138 75 Ω; 25 Hz; 25 V/V

CHAPTER 8

8.1 12 kΩ; 0.2 V; 25 kΩ; 20 μA

8.3 50; 8.75 kΩ

8.6 5 μm, 25 μm, 10 μm, 2.5 μm, 5 μm; 15 kΩ; 25 kΩ, 31.25 kΩ

8.8 (a) 0.691 V to 0.863 V, 10 μA to 10 mA; (b) 9.62 μA, 0.098 mA, 0.98 mA, 9.62 mA

8.11 0.1 mA, 10%

8.14 Both cases: −0.7 V, +2 V, +0.7 V, −0.7 V, −1.7 V; (a) $I = 0.4$ mA; (b) $I = 0.04$ mA

8.17 700 Ω, 5 A/A, 10 kΩ.

8.19 $v_o = g_{m1} v_i\,(W_3/W_2)R_L$; $g_{m1}R_L\,(W_3/W_2)$; $1/g_{m2}$; $-g_{m1}/g_{m2}$

8.21 (a) 1.6 kΩ; (b) 250 Ω

8.25 $I = 10$ μA: 0.4 mA/V, 250 kΩ, 1 MΩ, 400 V/V; $I = 100$ μA: 4 mA/V, 25 kΩ, 100 kΩ, 400 V/V; $I = 1$ mA: 40 mA/V, 2.5 kΩ, 10 kΩ, 400 V/V

8.27 50 V/V; 0.2 mA; 12.5 μm

8.29 0.4 μm; 25; 0.2 mA

8.31 0.5 mA; 4 mA/V

8.33 1 mA/V; 15 kΩ; 15 V/V; 3.9 μm

8.35 0.144 mA

8.37 (a) 80 μA/V, 0.18 MΩ, 14.4 V/V; (b) 0.79 V, 0.253 mA/V, 18 kΩ, 4.55 V/V; (c) 0.8 mA/V, 18 kΩ, 14.4 V; (d) 0.08 V, 0.253 mA/V, 180 kΩ, 45.5 V/V; (e) lowest A_0: first design when operated at $I_D = 100$ μA, $A_0 = 4.55$ V/V, highest A_0: second design when operated at $I_D = 10$ μA, $A_0 = 45.5$ V/V; gain increases by a factor 10.

8.39 0.5 μm; 12.5

8.41 1.05 V; 2 μm; 8; 32

8.43 (a) 0.95 V, 0.475 μA, 2.375 V; (b) −86.5 V/V, 1.9 V, 22 mV; (c) 33.7 kΩ

8.45 0.913 V; 1.07 V

8.47 (a) 25 μA; (b) 0.33 V and 2.98 V; (c) −189.3 V/V; (d)−195.8 V/V; (e) −210.6 V/V

8.49 (a) 0.25 mA; (b) 120 kΩ, 120 kΩ, 60 kΩ; (c) 5 kΩ, 10 mA/V; (d) 5 kΩ, −600 V/V, 60 kΩ

8.51 980 Ω; 61 kΩ; 10.1 V/V

8.53 2 kΩ; 1.1 V

8.55 (a) 100 μA, 1.03 V; (b) 0.9 mA/V, 200 kΩ; (c) 2.2 kΩ; (d) 209 kΩ; (e) 90.9 V/V, 89 V/V; (f) 32 mV

8.57 r_o

8.59 0.99 (or more exactly, 0.975); 14.8 MΩ

8.61 (a) 208 Ω; (b) 500 Ω; (c) 4.8 kΩ; 101 with $R_e = \infty$

8.63 (a) 50, 1.6 MΩ; (b) 250, 320 kΩ

8.65 0.5 μm; 20; 1 V; 0.25 mA; 0.5 V

8.67 0.6 μm; 0.125 mA; $(W/L)_{1,2} = 10$; $(W/L)_{3,4} = 40$

8.69 $g_{m2}r_{o2}$

8.71 0.2 V; 0.5 V to 0.8 V

8.74 1.2 V; 1.0 V; 0.8 V; 100; 6.91 MΩ

8.76 1 MΩ

8.79 -10^5 V/V

8.81 (a) 1.41 mA/V, 822.3 kΩ, −1159 V/V; (b) 1.41 mA/V, 457 kΩ, −644 V/V

8.83 $(g_{m3}r_{o3})\ (g_{m2}r_{o2})r_{o1}$

8.85 (a) $I_{O1} = I_{O2} = \frac{1}{2} I_{REF}/(1+2/\beta^2)$; (b) Use $I_{REF} = 0.7$ mA and 3 transistors Q_3, Q_4 and Q_5 whose EBJ areas are in the ratio 1:2:4; currents realized are 0.0999 mA, 0.1999 mA and 0.3997 mA.

8.88 (a) 0.3 V, 0.8 V; (b) 8 μA, 172 μA; (c) 180 μA; (d) 1.1 V; (e) 12 MΩ; (f) 0.08 μA, 0.04%

8.90 (a) $R_E = 2.88$ kΩ; (b) 8.2 MΩ, 0.7 μA

8.92 (a) 58.5 kΩ; (b) 79.9 MΩ,

8.95 360 μA; 2.4 mA/V; 0.48 mA/V; 27.8 kΩ; 0.81 V/V; 339 Ω; 0.7 V/V

8.97 (b) $g_{m1} = 0.632$ mA/V, $g_{m2} = 40$ mA/V, $r_{\pi 2} = 5$ kΩ; (c) −19.5 V/V; (d) 487 kΩ, −9.6 V/V; (e) 10 MΩ, −18.6 V/V

8.99 50.2 V/V

CHAPTER 9

9.1 (a) 0.2 V, 0.6 V; (b) −0.6 V, 0.08 mA, 0.08 mA, +0.6 V, +0.6 V; (c) −0.2 V, 0.08 mA, 0.08 mA, +0.6 V, +0.6 V; (d) −0.7 V, 0.08 mA, 0.08 mA, +0.6 V, +0.6 V; (e) 1.0 V; (f) −0.8 V, −0.2 V

9.3 (a) 0 V, −0.6 V, 0.6 V, 0.6 V, 0 V; (b) 0.104 V, −0.541 V, 0.4 V, 0.8 V, 0.4 V; (c) 0.283 V, −0.4 V, +0.2 V, 1 V, 0.8 V; (d) −0.104 V, −0.645 V, +0.8 V, +0.4 V, −0.4 V; (e) −0.283 V, −0.683 V, +1 V, +0.2 V, −0.8 V

9.5 0.587 V; −0.587 V; 0.612 V; 0.025 V; 0.10 V, 4 V/V; −0.025 V

9.7 0.35 V; 16.3; 1.14 mA/V

9.9 0.212 V; 554.5 μA

9.11 (a) 0.1 V_{OV}; (b) 0, 0.338 V_{OV}, 0.05 V_{OV}, 0.005 V_{OV}, 1.072 V_{OV}

9.13 0.25 V; 0.5 mA; 5 kΩ; 40

9.15 0.5 mA; 3.6 kΩ; 38.6

9.17 $I = 2I_D$; $P_{diff} = 2P_{CS}$

9.19 (a) $g_{m1,2}\left[\frac{1}{g_{m3,4}} \| r_{o3,4} \| r_{o1,2}\right]$; (b) $\sqrt{[\mu_n (W/L)_{1,2}]/[\mu_p (W/L)_{3,4}]}$; (c) 25

9.23 8 kΩ; W/L, I_D (mA) and $|V_{GS}|$ (V) are: Q_1(50, 0.1, 0.7), Q_2(50, 0.1, 0.7), Q_3(100, 0.2, 0.7), Q_4(20, 0.1, 0.7), Q_5(20, 0.1, 0.7), Q_6(100, 0.2, 0.7), Q_7(40, 0.2, 0.7)

9.25 0.632 μm; 0.28 mA

9.27 $v_{B1} = +0.5$ V: −0.177 V, +0.52 V, 2.5 V; $v_{B1} = -0.5$ V: −0.677 V, +2.5 V, +0.52 V

9.30 (a) −0.574 V, 0.4 V, 0.4 V; (b) −0.326 V to 0.674 V; (c) 5 mV

9.32 (a) $V_{CC} - (I/2)R_C$; (b) 2 V; (c) 0.4 mA, 5 kΩ

9.34 $R_C = 5.05$ kΩ, +1.6 V

9.36 0.5 mA, 1.0 mA; 17.3 mV

9.38 8 mA/V; 40 kΩ

9.40 5 mV; 250 Ω; −40 V/V; 200 mV; 400 mV

9.42 Each emitter has a resistance $R_e = 450$ Ω, $R_C = 10$ kΩ; $I = 1$ mA; Possible value of $V_{CC} = 10$ V

9.49 12 V/V

9.51 16 V/V

9.53 25 V/V; 101 kΩ

9.55 7.7 V/V; 5×10^{-4} V/V; 1.54×10^{4} or 83.8 dB

9.57 (a) 2.332 V; (b) 5.06 kΩ; (c) 2.47 V; (d) −1.92 V/V; (e) 0.287 V

9.59 4 μm

9.61 (a) 20 V/V; (b) 0.23 V/V; (c) 86.5 or 38.7 dB; (d) $-0.023 \sin 2\pi \times 60t + 0.2 \sin 2\pi \times 1000t$, volts

9.63 (a) 100 V/V; (b) 50 kΩ; (c) 2.5×10^{-4} V/V; (d) 4×10^{5} or 112 dB; (e) 25 MΩ

9.65 (a) 50 V/V; (b) 2.5×10^{-3} V/V, 2×10^{4} or 86 dB; (c) 5×10^{-5} V/V, 10^{6} or 120 dB

9.67 (a) Two emitter resistances and a single bias-current source I; $R_e = 25$ Ω; $R_C = 10$ kΩ; $V_{CC} = +15$ V; $R_{EE} = 50$ kΩ; $V_A = 100$ V; 2.4 MΩ

9.69 2/3 in one transistor and 1/3 in the other; 0.008 V/V

9.72 11 mV; variability of V_t; 7.33%

9.74 2.5 mV

9.77 −0.25 mV

9.79 1.25 mV

9.81 (a) $x = 0.3$ kΩ; (b) $x = 0.225$ kΩ

9.83 $2\alpha I/3$ and $\alpha I/3$; $\alpha I R_C/3$; 18.75 mV; 17.3 mV

9.85 20 kΩ; 40 V/V

9.87 1.4 mA/V; 25 kΩ; 25 kΩ; 17.5 V/V

9.89 3 V

9.92 1 mA/V; 75 kΩ; 75 V/V; 75 kΩ

9.94 20 kΩ; 20 kΩ; 10 mA/V; 200 V/V; 100 V/V

9.96 $-2V_T/\beta_P^2$; $-20\ \mu$V

9.98 2.67×10^4 V/V

9.100 $\frac{I/2}{\beta+1} \Big/ \left(\frac{\beta}{2}\right)$, a reduction by a factor of $(\beta/2)$; R_{id} increases by a factor $(\beta/3)$

9.102 1.13 mA/V; 75 kΩ; 85 V/V

9.105 1 mA/V; 25 kΩ; 25 V/V; 25 kΩ, 0.02 mA/V; 0.98 kΩ; 0.98 A/A; 50 kΩ; 2600 kΩ; −0.0196 V/V; 1274 or 62.1 dB

9.107 0.1

9.110 8 mA/V; 100 kΩ; 800 V/V; 37.5 kΩ; 100 kΩ; −0.013 V/V; 60,000 or 96 dB; 444.4 V/V

9.112 (a) 83.3 kΩ; (b) 1200 V/V; (c) 21×10^6 or 146 dB

9.114 (a) W/L: 12.5, 12.5, 50, 50, 25, 100, 25, 25, 0 V; (b) −0.1 V to +0.7 V; (c) −0.7 V to +0.7 V; (d) 900 V/V

9.116 108 μA; 909 mV; 0.86 mV

9.118 (a) W/L: 32.9, 32.9, 178, 178, 65.8, 356, 65.8, 32.9; (b) 0.65 V to 1.05 V; (c) 0.15 V to 1.05 V; 144 V/V

9.120 25 V/V; 20 kΩ; 5000 A/A

9.122 R_5; 7.37 kΩ; reduced to about half its original value; change R_4 to 1.085 kΩ, this will slightly reduce A_2.

9.124 (a) 0.52 mA, 1.04 mA, 2.1 mA, 0 V; (b) 4 kΩ, 65.5 Ω; (e) 8770 V/V

CHAPTER 10

10.1 20 nf

10.3 10 μF; 88.4 Hz; 8.84 Hz

10.5 (a) 10 kΩ; (b) 3.53 μF; (c) 10 Hz; (d) 100 Hz; (e) dc gain = 2, makes perfect sense since C_S behaves as an open-circuit at dc.

10.7 5 μF; 0.5 μF; 0.5 μF; 92.2 Hz; 6 μF

10.10 141.4

10.13 $g_m = 1.3$ mA/V; $g_{mb} = 0.25$ mA/V; $r_o = 100$ kΩ; $C_{gs} = 61.6$ fF; $C_{gd} = 4.3$ fF; $C_{sb} = 12.8$ fF; $C_{db} = 9.4$ fF; $f_T = 3.1$ GHz

10.17 $L = L_{\min}$: 6.5 V/V, 113 GHz; $2L_{\min}$: 13 V/V, 28.3 GHz; $3L_{\min}$: 19.5 V/V, 12.6 GHz; $4L_{\min}$: 26 V/V, 7.1 GHz; $5L_{\min}$: 32.5 V/V, 4.5 GHz

10.19 265.3 MHz

10.21 500 MHz; 600 MHz; 252 ps; 0.43 pF

10.23 50 MHz; 10 MHz

10.25 5 pF; < 31.8 kΩ

10.28 200.2 pF; $-1000/[1 + sC_{in}R_{sig}]$; 795 kHz; 795 MHz

10.31 870 kHz; -6.1 V/V; $R_{in} = 33.3$ kΩ → 3.1 V/V; $R_L = 1.24$ kΩ → 1.6 V/V

10.33 -9.2 V/V; 525 kHz

10.35 61 pF; 522 kHz

10.37 -33 V/V; 873 kHz; 28.8 MHz; f_H increases by a factor of 1.16 and voltage gain decreases by the same factor while GB remains nearly constant. Power dissipation increases by a factor of 2.

10.39 -32.8 V/V; 572 kHz

10.41 (a) 1001 pF, 1.001 pF; (c) 20 pF, 20 pF; (e) -90 pF, 9 pF; $+90$ pF

10.44 (a) 0.54 mA; (b) 21.6, A/V, 4.63 kΩ; (c) -10.8 V/V; (d) 4 kΩ, 2.14 kΩ; (e) -7.4 V/V; (f) 14.37 pF; (g) 16.3 MHz

10.46 -80 V/V; 3.8 MHz; 6.4 GHz; 304 MHz

10.48 -81.4 V/V; 21.4 MHz; 11.2 GHz

10.50 (a) 99.2 MHz; (b) 227.6 MHz

10.53 (a) 4.26; (b) 49.3

10.55 5.67×10^7 rad/s

10.57 -40.6 V/V; $\tau_{gs} = 243.8$ ns; $\tau_{gd} = 3112.8$ ns; $\tau_{CL} = 300$ ns; 43.5 MHz

10.59 -80 V/V; 10.1 pF; 788 kHz; 652 kHz; the latter as it takes into account C_L.

10.61 41.6 fF

10.63 -138.9 V/V; 2.98 MHz; 2.28 MHz, the latter as it takes into account C_L.

10.66 8.3 V/V; 239 MHz; 7.23 MHz; 7.23 MHz

10.69 11.1 fF

10.71 -913 V/V; 6.28 MHz

10.73 0.2 V; 0.2 mA; 289.4 MHz; 57.9 kHz, -100 V/V (40 dB)

10.76 -26.5 V/V; 5.7 MHz

10.78 $-100,000$ V/V; 31.8 kHz, 31.8 kHz; 3.18 GHz

10.79 0.91 V/V; 200 Ω; 398 MHz; 33.4 MHz, 90.7 MHz; 31.6 MHz

10.82 $0.8/[s^2 + 8.886 \times 10^6\ s + 39.48 \times 10^{12}]$

10.84 0.96 V/V; 2 GHz; 676 MHz, 4.6 GHz; 676 MHz

10.86 1.59 MHz

10.88 4 MHz; decreases by a factor of 4 to 1 MHz

10.90 (b) −49.8 V/V; (c) 53.2 pF, 598 kHz, 29.8 MHz

10.92 50 V/V; 15.9 MHz; 1.59 GHz; 3.18 GHz

10.96 (a) −100 V/V, 603 kHz, 60.3 MHz; (b) −50 V/V, 1.02 MHz, 51.2 MHz

10.101 (a) 2.5 MΩ, −4000 V/V; (b) 107.6 kHz; two dominant capacitances: C_L (most significant) and $C_{\mu 2}$

10.103 66.7 V/V; 2 MHz

10.106 (a) 10,000 V/V; (b) 11.1 MHz

CHAPTER 11

11.1 4.9×10^{-3}; 169.5; −15.3%

11.3 1; 0.999 V/V; 60 dB; 0.999 V, 0.001 V; −0.011%

11.5 (b) (i) 1000; (ii) 100; (iii) 20

11.7 2500 V/V; 0.0196 V/V; 49; 50 V/V; 34 dB

11.10 99; 4

11.12 1000 V/V; 0.099 V/V

11.14 416.6 V/V; 9.33×10^{-3} V/V; 5016.8 V/V, 9.95×10^{-3} V/V; 41.66 V/V, 9.33×10^{-2} V/V; 501.68 V/V, 9.95×10^{-2} V/V

11.16 500 V/V; 0.098 V/V; 653.4 V/V

11.19 1 MHz, 1 Hz

11.21 Three stages; each with a closed-loop gain of 10 V/V, an amount of feedback of 100, and $\beta = 0.099$ V/V.

11.23 50 V/V; 0.008 V/V; 16 Hz

11.25 0.089; for $|v_S| \leq 0.9$ V, $v_O/v_S = 11.1$ V/V, for $0.9 \text{ V} \leq |v_S| \leq 1.4$ V, $v_O/v_S =$ 10.1 V/V, and for $|v_S| \geq 1.4$ V, $v_O = \pm 15$ V

11.27 (a) 90 kΩ; (b) 43.11, 9.77 V/V; (c) 2.343

11.29 (a) $1 + \dfrac{R_2}{R_1} = 11$ V/V; (b) 0.1 mA, 0.3 mA, +7.7 V; (c) 23.2; (d) 10.5 V/V

11.31 (a) 0.9 kΩ; (b) 31.33, 9.7 V/V, −3%, change R_F to 933 Ω

11.33 (a) 47.62 β, 47.62 V/V; (b) 821 kΩ, 179 kΩ

11.35 Lower; 199; 20 kΩ

11.37 100 V/V; 1.001 MΩ

11.39 (a) $1 + (R_2/R_1) = 11$ V/V; (b) 0.1 mA, 0.3 mA, +7.7 V; (c) 255.3 V/V, 0.359 kΩ, 0.917 kΩ; (d) 1/11; (e) 10.5 V/V, 8.59 kΩ, 39.4 Ω, 4.5%

11.41 (b) 10 V/V; (c) 0.2 V, 1.1 V, 0.2 V, 0.9 V; (d) −35.3 V/V, −50 V/V, 0.935 V/V, 1650 V/V; (e) 0.1 V/V; (f) 9.94 V/V, −0.6%; (g) 5.6 Ω

11.44 (c) 1.2 kΩ; (d) 1.42 kΩ, 628 Ω; (e) 23.8 V/V; (f) 145 kΩ, 0.53 Ω

11.46 100 Ω; 9.94 mA/V

11.48 (c) −0.999 kΩ

11.50 (a) 0.135 V/V; (b) 7.4 V/V; (c) 0.14 Ω

11.53 (a) 200 Ω; (b) 1418.4 mA/V; (c) 283.7, 284.7; (d) 4.982 mA/V, very close; (e) 28.2 kΩ, 8 MΩ

11.56 9.56 mA/V; 503.4 kΩ

11.58 (a) 0 V, +0.6 V, +0.6 V; (b) 0.1 mA/V; (c) 0.099 mA/V; (d) 203 MΩ; (e) 0.99 V/V; 1.25 Ω

11.60 −9.88 kΩ, 11.1 Ω, 1.1 Ω compared to −9.99 kΩ, 1.11 Ω, 0.11 Ω.

11.62 3.23; −0.1 mA/V; −32.3 kΩ; −7.63 kΩ; due to the approximation used in the systematic analysis method.

11.64 (a) $-R_F/R_s$, 20 kΩ; (b) −9.88 V/V, 21.7 Ω, 22.1 Ω; (c) 82.18 kHz

11.66 159, larger by about 2.5%, a result of the approximations involved in the general method. The more accurate value is the one obtained here.

11.68 10 kΩ; −9.52 kΩ; 11.9 Ω; 244 Ω

11.70 (b) −98.8 V/V; 7.2 Ω; 10.3 Ω

11.72 0.53 kΩ; 10.5 Ω; 526 Ω

11.74 (d) −99.8 A/A, −0.1 A/A, 9.98, −9.1 A/A, 0.2 kΩ, 18.2 Ω; (e) 328.4 kΩ

11.76 970.9, −9709 A/A, −9.99 A/A; $A\beta$ and A differ slightly from the results in Example 11.10; however, A_f is identical.

11.81 $I_{C1} = 0.1$ mA, $I_{C2} = 10$ mA; $V_o/V_s = 3.62$ V/V; $R_{in} = 176.7\ \Omega$

11.83 20 krad/s; 4×10^{-3} V/V; 250 V/V

11.85 8×10^{-4}

11.87 10 V/V; 10^5 Hz; 1 MHz; by the amount-of-feedback $\simeq 10^4$.

11.89 (a) 2.025×10^{-4}, 5.5×10^4 Hz; (b) 3306 V/V, 1653 V/V; (c) 0.5; (d) $(-5.5 \pm j\,13.25) \times 10^4$ Hz, 1.325

11.91 0.1; 0.686; 2.1

11.93 2; 173.2 kHz

11.95 3.085×10^3 Hz; 18.15°; 10^{-3}

11.97 3.16×10^{-4}; 2.4×10^3 V/V or 67.6 dB.

11.99 2.4×10^4 V/V or 87.6 dB; 9.09×10^3 V/V or 79.2 dB.

11.101 2 kHz; 500

11.104 10 Hz; 15.9 nF

11.106 (b) 3.16×10^4 Hz, 1.8°; (c) zero: -10^3 rad/s, poles: $(-0.505 \pm j\,31.62) \times 10^3$ rad/s, the response is very peaky with a peak of 1000 at 31.62 krad/s.

CHAPTER 12

12.1 −9.3 V to +9.7 V; −8.6 V to +10.4 V; −4.65 V to +9.7 V; −3.95 V to +10.4 V; −9.7 V to +9.7 V; −9 V to +10.4 V

12.3 2.7 kΩ; 24 mW

12.6 $V_{CC}I$ (in all cases)

12.8 $\hat{V}$; $\hat{V}/R_L$; 25%

12.11 4.5 V; 6.4%; 625 Ω

12.13 10 V; 6.37 V; 6.85 Ω, 7.3 W; 9.62 Ω, 1.3 W

12.17 1.266 V; 12.5 Ω; 0.889 V/V; 0.998 V/V

12.19 2.15 mA

12.22 1 mA; −1.06 V; +4 V; −6 V

12.24 0.98 mA; +5.1 V; −10 V; 99; 1.96 mA; 1.92 mA

12.28 20.7 mA; 788 mW; 7.9°C; I_Q becomes 37.6 mA, etc., etc.

12.30 (a) 1.365 kΩ, 1.365 kΩ, 1.365 V; (b) 1.420; (c) 1.512 V; (d) 1.641 V

12.32 (a) For $R_L = \infty$: at $v_I = 0$, $I_1 = 0$; at $v_I = +10$ V, $I_1 = 20$ μA, at $v_I = -10$ V, $I_1 = -20$ μA; (b) $R_L = 100$ Ω; at $v_I = 0$, $I_1 = 0$, at $v_I = +10$ V, $I_1 = 22.5$ μA, at $v_I = -10$ V, $I_1 = -22.5$ μA.

12.34 215 Ω, 215 Ω, 0.75 Ω, 0.75 Ω; 0.7 Ω; 0.704 V

12.37 (a) 0.0164 mA, 1.64 mA; (b) 32.8 v_i, −66.2 V/V; (c) 27.2 kΩ

12.39 $R_1 = 300$ kΩ, $R_2 = 632$ kΩ; 9.484 V and −10.644 V

12.41 3.84 Ω; 384 mV; 0.94 μA

12.43 6.5 Ω; 487.5 mV; 2.9 μA

12.45 (b) 1.25 V, 1.56 mA

12.47 (a) Q_1 : 35.6, Q_2 : 88.9, Q_N : 356, Q_P : 889; (b) −0.6 V; (c) 1.38 V

12.49 ±2.05 V

12.51 (b) 0.15 V

12.53 (a) 533.3, 1333.3; (b) 10 V/V; (c) −5%; (d) 1.85 V and −1.85 V; (e) 0.3 V and −0.3 V; (f) −1.77 V to +1.77 V

12.55 R_2 and R_3; R_3; R_2; $R_2 = 33.3$ kΩ and $R_3 = 1.33$ kΩ

12.57 16 V; 2.7 W; 13 V $p-p$

12.59 30 kΩ, 40 kΩ

12.62 +3 V; −3 V

12.64 (c) 8 Ω, 5 A, 50 W; (d) 6 Ω, 5 A, 37.5 W; (e) 3 Ω, 5A, 18.75 W

12.66 12.5°C/W; 8 W; 112.5°C

12.68 (a) 37.5°C/W; (b) 1.33 W; (c) 62.5°C

12.70 72°C; 1.5°C/W; 4 cm

CHAPTER 13

13.1 −0.8 V to +1.2 V; −0.8 V to +0.8 V

13.3 0.15 V

13.5 0.45 μm; 2000 V/V

13.7 (a) 10,000 V/V; (b) 10^8 rad/s and 10^7 rad/s; (c) 10^9 rad/s, 4 pF, 25×10^3 rad/s, 5×10^8 rad/s

13.9 (a) 1.59 pF; (b) $f_{P1} = f_t/A_0$, $f_{P2} = 318$ MHz, $f_Z = 200$ MHz; (c) 46°; (d) 500 Ω, 72.5°; (e) 722 Ω

13.11 125.6 V/μs; 0.8 pF

13.13 (a) 2 pF; (b) 1.51 pF

13.15 (a) 0.16 V; (b) 2 pF; (c) 78.1

13.17 (b) 0.45 μm

13.19 250 μA; 400 μA; 200 μA; 50 μA

13.21 25, 25, 25, 25, 6.25, 6.25, 6.25, 6.25, 125, 125, 50

13.23 100 μA; 150 μA; 15.92 MHz; 54.7°; 6.58 MHz; $C_L = 24.2$ pF; 4.13 V/μs

13.25 0.12 V; $I_B = I = 150$ μA; 15 V/μs; W/L : 26, 26, 65, 65, 26, 26, 26, 26, 130, 130, 52

13.28 (a) −0.25 V to +1.3 V; (b) −1.3 V to +0.25 V; (c) −0.25 V to +0.25 V; (d) −1.3 V to +1.3 V

13.30 $C_p = 0.176\, C_L$

13.33 $V_{EB} = 625$ mV; A device: 7.3 mA/V, 137 Ω, 6.85 kΩ, 278 kΩ; B device: 21.9 mA/V, 46 Ω, 2.28 kΩ, 90.9 kΩ

13.35 $I_3 = I_1 \left\{ \left[\frac{1}{\sqrt{k_1}} + \frac{1}{\sqrt{k_2}} \right] \Big/ \left[\frac{1}{\sqrt{k_3}} + \frac{1}{\sqrt{k_4}} \right] \right\}^2$; 0.1 mA

13.37 603 mV; 518 mV; 8.5 kΩ

13.39 4.75 μA; $R_4 = 1.94$ kΩ

13.41 14 μA

13.43 53.3 nA; 20.1 nA

13.45 −3 V to +4.8 V

13.47 6.4 kΩ; 270 μA

13.49 1.68 mA; 50.4 mW

13.51 4.63 kΩ

13.53 10 mV

13.55 0.691 μA; 3.6 mV

13.57 $R = 18.2$ kΩ; 15.55 MΩ

13.60 3.1 MΩ, 9.38 mA/V

13.62 −3.6 V to +4.2 V

13.64 14.4 Ω

13.66 20.2 mA; double the value of R_7

13.68 5.67 MHz

13.70 180 Hz; 0.7 pF

13.73 159.2 kHz; 10^8 rad/s or 15.9 MHz

13.75 (a) 0.05 mA, 0.05 mA, 0.05 mA, 0.05 mA, 1 mA, 1 mA, 1 mA; (b) 100 kΩ; (c) 5×10^4 V/V or 94 dB; (d) 63.7 pF

13.77 $Q_5 : Q_1 = 1$; $Q_6 : Q_1 = 4$; 3.47 kΩ; 3 MΩ and 7 MΩ

13.79 (a) 0.1 V to 2.2 V; (b) 0.8 V to 2.9 V

13.81 12.5 kΩ; 0.8 V to 3.35 V; 100 kΩ; 10 μA, 50 kΩ

13.83 $36.9/I$; 1240 V/V; $1240(IR_L)/(IR_L + 36.9)$; 5.1 μA, 11.8 μA

13.85 (a) 0.1 V to 2.9 V; (b) 20 kΩ; (c) 0.2 Ω; (d) 12.3 mA, 0.3 mA, 1.6 kΩ; (e) 0.3 mA, 12.3 mA, 2.4 kΩ

13.88 10.6 μA; 0.3 mA

CHAPTER 14

14.1 (a) 2.18 kΩ; (b) 5.40 kΩ; (c) 3.71

14.2 (a) 6; (b) 1.67 kΩ

14.16 0.6 V; 0.7 V

14.18 $NM_H = 0.2\ V_{DD}$; $NM_L = 0.3\ V_{DD}$; $0.2\ V_{DD}$; 2 V

14.20 (a) 0.12 V, 2.5 V, 1.5 V, 0.68 V; (b) $V_{OH} = 2.5 - 0.4N$, $NM_H = 1.5 - 0.4N$, $N = 2$; (c) (i) 3 mW, (ii) 1 mW

14.22 $V_{IL} = 0.776$ V, $V_{IH} = 0.816$ V; $NM_H = 1.184$ V; $NM_L = 0.776$ V; -50 V/V

14.24 $V_{DD} = 1.2$ V, $R_D = 38.3$ kΩ, $W/L = 1.5$; 0 W, 36 μW

14.26 $V_{DD} = 1.2$ V, $R_D = 23$ kΩ, $W/L = 2.5$; 0.435 V, 0.6 V, 0.7 V, 0.385 V, 0.5 V

14.29 6.84

14.31 (a) 244 nm, 22,181 nm^2; (b) 1 V, 0 V, 0.5375 V, 0.4625 V, 0.4625 V, 0.4625 V (c) both equal; 2.18 kΩ

14.33 1.82

14.35 40.1

14.37 (a) 0.78 μm, 0.127 μm^2; (b) 1.3 V, 0 V, 0.7125 V, 0.5875 V, 0.59 V, 0.59 V, 0.0625 V, 1.24 V, 0.53 V, 0.53 V; (c) 1.48 kΩ, 1.48 kΩ; (d) -5.8 V/V, 0.762 V, 0.538 V, 0.224 V; (e) 0.57 V, -0.08 V, 60%; (f) 0.61 V, -0.04 V, 40%

14.39 (a) $v_O(t) = 10\, e^{-t/\tau}$; (b) 69 ns, 220 ns

14.41 69 ps, 35 ps, 52 ps

14.43 (a) 1.2 ns, 0.6 ns; (b) 1 pF; (c) $C_{\text{out}} = 0.6$ pF, $C_{\text{load}} = 0.4$ pF

14.45 30 ps, 60 ps, 45 ps

14.47 57.5 ps, 69 ps, 63.3 ps

14.49 $(W/L)_n \geq 1.725$, $(W/L)_p \geq 4.14$

14.51 34.4 ps, 42.6 ps, 38.5 ps; 13 GHz

14.53 36.3 ps, 36.3 ps, 36.3 ps; 9.35 fF

14.55 (c) $14.66 \times 10^3\ (2C_n + C_w)$; (d) $8.625 \times 10^3\ (3.4C_n + C_w)$ (e) (i) In both cases, $t_P = 29.32 \times 10^3 C_n$, thus when C is entirely intrinsic, scaling does not affect t_P; (ii) For $W_p = W_n$, $t_P = 14.66 \times 10^3 C_w$, and for $W_p = 2.4W_n$, $t_P = 8.625 \times 10^3 C_w$, thus using a matched design reduces t_P only when C is dominated by external capacitance.

14.60 (a) 2.65 V; (b) 2.24 V

14.63 32.4 fJ; 64.8 W; 36 A

14.65 0.36 pF

14.67 32 pJ

14.69 (a) t_P and the maximum operating frequency remain unchanged, PDP is reduced by a factor of 0.52; (b) t_P increases by a factor (1/0.72) and the maximum operating frequency is reduced by the factor of 0.72. The PDP decreases by a factor of 0.72.

CHAPTER 15

15.1 4.88×10^8 or 488 million transistors

15.3 260 cm^2/Vs, 144.4 cm^2/Vs; E_{cr}(NMOS) $= 3.85 \times 10^4$ V/cm; E_{cr}(PMOS) $= 6.92 \times 10^4$ V/cm

15.5 (b) 0.62

15.7 (b) 2.75

15.9 (a) 207 pA; (b) 207 mA, 207 mW

15.11 (a) 270 Ω; (b) 0.1 pF; (c) 93.2 ps

15.13 1.3 V; 0.095 V; 40.5 μA; 52.7 μW

15.15 167 ps; 36.9 ps; 102 ps

15.17 2.1; 0.5 V; 0.5 V, 0.47 V, 0.44 V

15.19 1.69; 0.58 V; 152 μW

15.23 1.26

15.26 0.834 V

15.28 25.8 ps

15.30 2.07 V, 0 V; 10.4 μA; 0.9 ns; 0.5 ns

15.34 13.5 μA; 351.6 μA; 182.6 μA; 0.18 ns

15.36 (a) 1.2 V, 0 V; (b) 240 μA, 60 μA, 7.8 μA, 56.25 μA, 49.4 ps; (c) 240 μA, 60 μA, 225 μA, 1.9 μA, 34.2 ps, 0.466 V; 41.8 ps

15.39 8.3 kΩ; 83 ps

15.45 0.188 ns

15.47 0.188 ns; 0.077 ns

15.49 (d) 0.35 V, 0.6 V

15.51 2 GHz

15.53 −1.453 V, −1.205 V, −1.73 V, −0.88 V; 0.230 V, 0.325 V, 0.345 V

15.55 22.45 mW

15.57 1 V; +5 V; $(A+B).(C+D)$

15.59 2.6 V; 8.18 mA

CHAPTER 16

16.1 A(0 V, 0 V), B(2.5 V, 2.5 V), C(5 V, 5 V); 25 V/V; 0.2 V

16.4 $(W/L)_{1,3}$ = 0.13 μm/0.13 μm, $(W/L)_{2,4}$ = 0.52 μm/0.13 μm, $(W/L)_{5,8}$ = 0.26 μm/0.13 μm

16.6 $(W/L)_{5,6} = 3.83$, higher than the values without velocity saturation to compensate for the current reduction resulting from velocity saturation.

16.7 0.4 μm/0.13 μm; 65 ps

16.11 4,294,967,296

16.13 16

16.15 57%

16.17 $(W/L)_a \leq 4.5$

16.19 4.5; (i) 0.23 V, 121.8 μA; (ii) 0.34 V, 158.7 μA; (iii) 0.4 V, 180 μA

16.22 1.75, greater than the value without velocity saturation because of the current reduction due to velocity saturation.

16.24 (a) 3; (b) 4.93 ns; (c) 3.33 ns

16.26 3

16.29 $L = 0.13$ μm, $(W/L)_n = (W/L)_p = (W/L)_a = 1$

16.31 128 Mbits

16.33 0.5 pA

16.35 0.4 mA/V; 353 mV; 130 mV; 100% (doubling); 4 ns

16.37 $(W/L)_n = 3.33$, $(W/L)_p = 13.32$; 1.44 ns; 2 ns

16.39 (a) 0.4 V; (b) 0.1 V, 0.3 V; (c) 132 μA; (d) $(W/L)_{1,2} = 26.4$, $(W/L)_{3,4} = 6.6$, $(W/L)_5 = 52.8$

16.41 10; 1024; 10,240; 1024; 12,288

16.43 40 MHz, 48%

16.45 4

16.48 (a) 2.4 ns; (b) 22 ns, 3.16 V; (c) 1.9 ns

CHAPTER 17

17.2 (a) 0.995 V, −5.7°; (b) 0.707 V, −45°; (c) 0.1 V, −84.3°; (d) 0.01 V, −89.4°

17.4 1 V/V; 0.977 V/V; 0.001 V/V

17.6 0.97 dB; 14.15 dB

17.10 (a) LP: $T(s) = 10^{20}/(s + 10^4)(s^2 + 0.618 \times 10^4 s + 10^8)(s^2 + 1.618 \times 10^4 s + 10^8)$ (b) HP: $T(s) = s^5/(s + 10^4)(s^2 + 0.618 \times 10^4 s + 10^8)(s^2 + 1.618 \times 10^4 s + 10^8)$;

17.12 $T(s) = 0.2656\,(s^2 + 4)/(s^2 + 0.5s + 1.0625)$; 0.2656

17.14 $1/(s^3 + 2s^2 + 3s + 2)$; -1, $-0.5 \pm j1.323$

17.17 35.7 dB

17.19 $N = 4$; $2\pi \times 10^4(-0.383 \pm j0.924)$, $2\pi \times 10^4\ (-0.924 \pm j0.383)$; $\omega_0^4/(s^2 + 0.765\,\omega_0 s + \omega_0^2) \times (s^2 + 1.848\,\omega_0 s + \omega_0^2)$ where $\omega_0 = 2\pi \times 10^4$ rad/s; 38.2 dB

17.22 0.975 rad/s, 0.782 rad/s, 0.434 rad/s, 0 rad/s; 1 rad/s, 0.901 rad/s, 0.623 rad/s, 0.223 rad/s; −64.9 dB; 42 dB/octave

17.24 (a) $N = 10$, 4 dB; (b) Normalized to $\omega_p = 2\pi \times 3.4 \times 10^4$ rad/s, the poles are: $-0.0224 \pm j0.9978$; $-0.0651 \pm j0.9001$; $-0.1013 \pm j0.7143$; $-0.1277 \pm j0.4586$; $-0.1415 \pm j0.1580$, $T(s) = 7.60 \times 10^4/(s^2 + s\,0.0448\,\omega_p + 0.9961\,\omega_p^2)(s^2 + 0.1302\,\omega_p + 0.8144\,\omega_p^2)\,(s^2 + s\,0.2026\,\omega_p + 0.5205\,\omega_p^2)(s^2 + 0.2554\,\omega_p + 0.2266\,\omega_p^2)(s^2 + s\,0.2830\,\omega_p + 0.0450\,\omega_p^2)$

17.26 $R_1 = 120\text{ k}\Omega$; $C = 6.63\text{ nF}$; $R_2 = 120\text{ k}\Omega$

17.28 $R_1 = 10\text{ k}\Omega$, $R_2 = 10\text{ k}\Omega$, $C_1 = 0.16\ \mu\text{F}$, $C_2 = 1.6\text{ nF}$; High-frequency gain= 40 dB

17.30 $T(s) = -(s - \omega_0)/(s + \omega_0)$ where $\omega_0 = 1/CR$; $T(j\omega) = \left(1 - j\dfrac{\omega}{\omega_0}\right)\Big/\left(1 + j\dfrac{\omega}{\omega_0}\right)$; $-2\tan^{-1}(\omega/\omega_0)$; 5.36 kΩ, 11.55 kΩ, 20 kΩ, 34.60 kΩ, 74.63 kΩ.

17.33 $T(s) = 10^8/(s^2 + 5000\,s + 10^8)$; 9.354 krad/s, 2.066

17.35 $T(s) = s^2/(s^2 + \sqrt{2}\,s + 1)$; Zeros: two at $s = 0$; Poles: $-0.707 \pm j0.707$

17.37 $T(s) = \pi \times 10^4 s/[s^2 + \pi \times 10^3 s + (2\pi \times 10^4)^2]$; Zeros: $s = 0$ and $s = \infty$; Poles: $1.57 \times 10^3 \times (-1 \pm j39.988)$

17.39 $[s^2 + (2\pi \times 60)^2]/[s^2 + s(2\pi \times 60) + (2\pi \times 60)^2]$

17.42 $T(s) = (1/LC)/[s^2 + s/CR + (1/LC)]$

17.44 (a) −0.5%; (b) −0.5%; (c) no change

17.46 $s^2\Big/\left(s^2 + \dfrac{1}{CR} + \dfrac{1}{LC}\right)$

17.49 $V_o = \left[s^2 V_y + s\left(\dfrac{\omega_0}{Q}\right)V_z + \omega_0^2 V_x\right]\Big/\left[s^2 + s\left(\dfrac{\omega_0}{Q}\right) + \omega_0^2\right]$

17.51 $R_1 = R_2 = R_3 = 10\text{ k}\Omega$; (a) $C_4 = 0.15\ \mu\text{F}$; (b) $C_4 = 15\text{ nF}$; (c) $C_4 = 1.5\text{ nF}$

17.55 First-order section (Fig. 17.13a): $R_1 = R_2 = 100\text{ k}\Omega$, $C = 10\text{ nF}$; Second-order section (Fig. 17.22a): $C_4 = C_6 = 10\text{ nF}$, $R_1 = R_2 = R_3 = R_5 = 100\text{ k}\Omega$, $R_6 = 161.8\text{ k}\Omega$, $K = 1$; Second-order section (Fig. 17.22a): $C_4 = C_6 = 10\text{ nF}$, $R_1 = R_2 = R_3 = R_5 = 100\text{ k}\Omega$, $R_6 = 61.8\text{ k}\Omega$, $K = 1$

17.57 $C_4 = C_6 = 1\text{ nF}$, $R_1 = R_2 = R_3 = R_5 = 79.6\text{ k}\Omega$, $R_6 = 159.2\text{ k}\Omega$, $r_1 = r_2 = 10\text{ k}\Omega$

17.60 (b) First-order section: $C = 1\text{ nF}$, $R_1 = R_2 = 13.71\text{ k}\Omega$, Second-order LPN section: $R_1 = R_2 = R_3 = R_5 = 9.76\text{ k}\Omega$, $C_{61} = 618\text{ pF}$, $C_{62} = 382\text{ pF}$, $R_6 = 35.9\text{ k}\Omega$, $K = 1$

17.62 (b) $C = 1\text{ nF}$, $R = 10\text{ k}\Omega$, $R_1 = 10\text{ k}\Omega$, $R_f = 10\text{ k}\Omega$, $R_2 = 10\text{ k}\Omega$, $R_3 = 70\text{ k}\Omega$, $R_L = R_H = 10\text{ k}\Omega$, $R_B = 40\text{ k}\Omega$, $R_F = 57.1\text{ k}\Omega$

17.64 1%

17.67 (b) First-order section: $C = 1\text{ nF}$, $R_1 = R_2 = 13.71\text{ k}\Omega$, Second-order LPN section: $C = 1\text{ nF}$, $R = 9.76\text{ k}\Omega$, $R_d = 35.9\text{ k}\Omega$, $r = 10\text{ k}\Omega$, $C_1 = 618\text{ pF}$, $R_1 = R_3 = \infty$, $R_2 = 9.76\text{ k}\Omega$

17.71 $\omega_0 = 6/CR$, $Q = 3$, Center-frequency gain= −18 V/V.

17.73 (a) Q^2; (b) $2Q^2$

17.75 (b) Second-order section [Fig. 17.34(c)]: $R_1 = R_2 = 10\ \text{k}\Omega$, $C_3 = 492$ pF, $C_4 = 5.15$ nF; Second-order section [Fig. 17.34(c)]: $R_1 = R_2 = 10\ \text{k}\Omega$, $C_3 = 1.29$ nF, $C_4 = 1.97$ nF; First-order section (Fig. 17.13a): $R_1 = R_2 = 10\ \text{k}\Omega$, $C = 1.59$ nF

17.77 $S_L^{\omega_0} = -\frac{1}{2}, S_C^{\omega_0} = -\frac{1}{2}, S_R^{\omega_0} = 0; S_L^Q = -\frac{1}{2}, S_C^Q = \frac{1}{2}, S_R^Q = 1$

17.79 $S_A^{\omega_0} = 0, S_A^Q = 2Q^2/A$

17.81 $S_{C_4}^{\omega_0} = S_{C_6}^{\omega_0} = S_{R_1}^{\omega_0} = S_{R_3}^{\omega_0} = S_{R_5}^{\omega_0} = -\frac{1}{2},\ S_{R_2}^{\omega_0} = +\frac{1}{2},\ S_{R_6}^Q = +1,\ S_{C_6}^Q = S_{R_2}^Q = +\frac{1}{2},$
$S_{C_4}^Q = S_{R_1,\,R_2,\,R_3}^Q = -\frac{1}{2},$

17.83 1 mA/V; 0.99 kΩ

17.85 0.314 mA/V

17.87 $G_{m1} = 2.51$ mA/V; $G_{m2} = 0.251$ mA/V

17.90 $C_1 = Q^2C$; $G_m = \omega_0 QC$

17.92 $G_m = 0.785$ mA/V; $G_{m2} = 0.785$ mA/V; $G_{m3} = 0.157$ mA/V; $G_{m4} = 0.785$ mA/V

17.94 1 pC; 0.1 μA; 0.1 V; 100 cycles; 10^4 V/s

17.96 $C_3 = C_4 = 6.283$ pF; $C_5 = 0.126$ pF; $C_6 = 0.126$ pF

17.98 80.3 rad/s; 83; 967 kHz; 66.7 V/V

17.100 838.8 kHz; 47.4

17.103 A (dB): 7, 8.5, 9.3, 9.8, 10.1; W/B: 31.6, 8.6, 5.9, 4.9, 4.5

CHAPTER 18

18.1 ω_0; $AK = 1$

18.3 (a) 1; (b) 2

18.5 0.6 mA/V; 15.92 MHz

18.7 120°; $\omega_0 = \sqrt{3}/CR$; $2/R$

18.11 $\omega_0 = 1/CR$; $Q = 1/3$; Gain$= 1/3$

18.13 $\omega_0 = 1/CR$; $Q = 1\Big/\left(2 - \frac{R_2}{R_1}\right)$

18.15 $\omega_0 = 1/CR$; $R_2/R_1 \geq 2$

18.17 7.88 V

18.19 $f_0 = 406$ Hz; $R_f = 290\ \text{k}\Omega$

18.22 9.95 kΩ; 3.6 V; add a diode in series with each of the limiter diodes.

18.24 $\omega_0 = 1\Big/\sqrt{L\left(\frac{C_1C_2}{C_1 + C_2}\right)}$; simplified condition: $g_m R_L > \frac{C_2}{C_1}$

18.26 $\omega_0 = 1\Big/\sqrt{L\left(\dfrac{C_1C_2}{C_1+C_2}\right)}$; $g_mR'_L > \dfrac{C_1}{C_2}$

18.28 (b) $\omega_0 = 1/\sqrt{LC}$; $IR_C > 0.1$ V, (c) $(4/\pi)$ V

18.30 2.0165 MHz to 2.0173 MHz, a range of 800 Hz.

18.32 (a) $V_{TH} = \left(\dfrac{L_+}{R_2} + \dfrac{V}{R_3}\right)(R_1\|R_2\|R_3)$; $V_{TL} = \left(\dfrac{L_-}{R_2} + \dfrac{V}{R_3}\right)(R_1\|R_2\|R_3)$;
(b) $R_2 = 656.7$ kΩ, $R_3 = 19.7$ kΩ

18.36 (a) Output will be either +12 V or −12 V; (b) The output is a symmetric square wave (±12 V) of frequency f and it lags the sine wave by an angle of 65.4°; 0.1 V.

18.38 1989 Hz

18.40 $V_Z = 3.6$ V; $R_1 = R = 25$ kΩ; $R_3 = 5.83$ kΩ; $C = 0.01$ μF; $R = 25$ kΩ

18.42 96 μs

18.44 $C_1 = 1$ nF, $C_2 = 0.1$ nF, $R_1 = R_2 = 100$ kΩ, $R_3 = 134.1$ kΩ, $R_4 = 470$ kΩ; 5.8 V; 61.8 μs

18.46 (a) 18.2 kΩ; (b) 10.67 V

18.48 (b) 100.6 kHz, 75%; (c) 15.6 μs, 55.2 kHz, 86.2%; 3.90 μs, 156 kHz, 61%

18.50 1.85 V