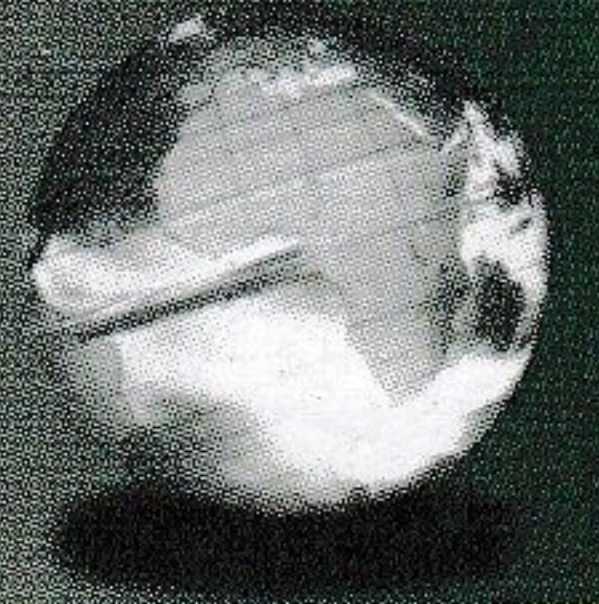


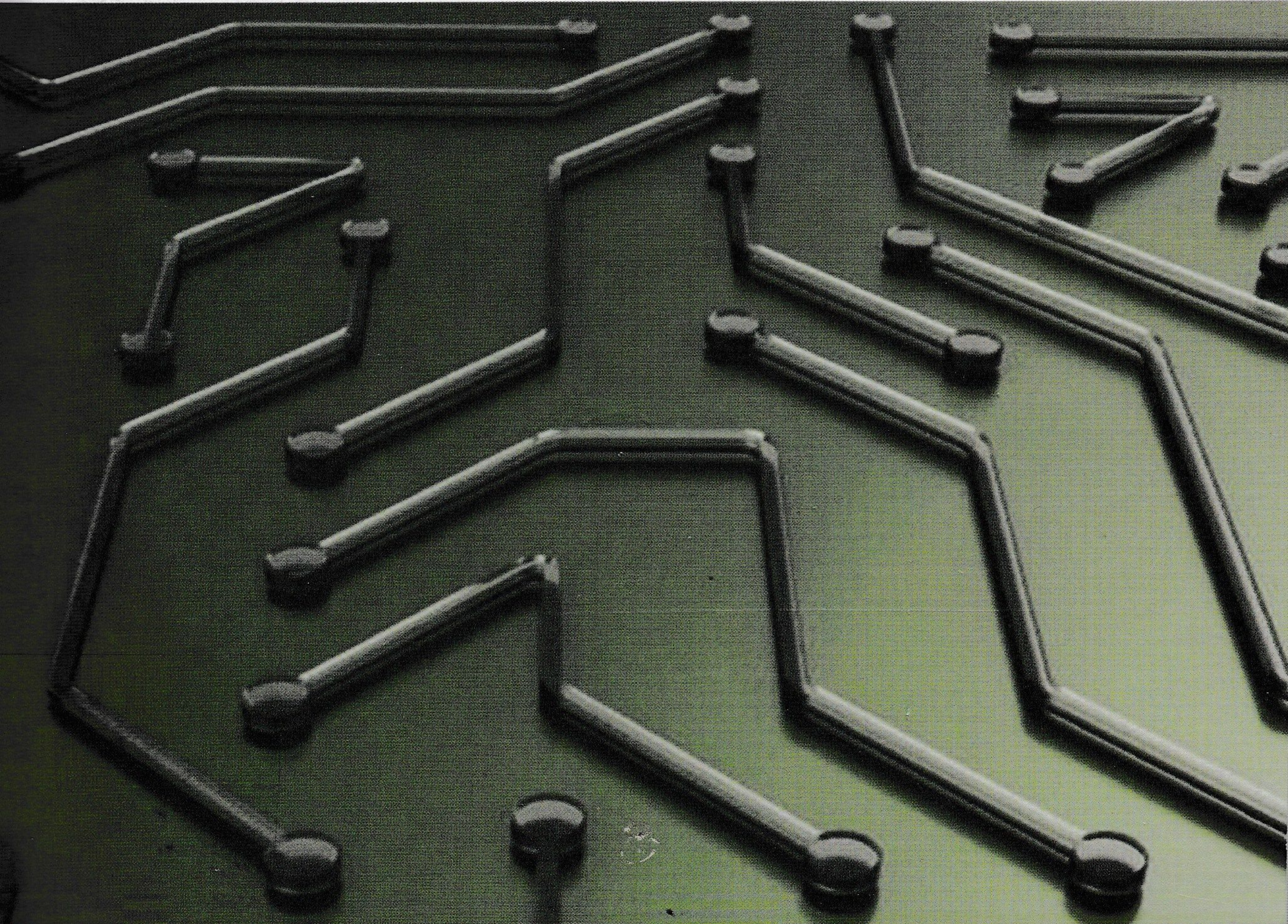
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EDITION



Electronic Devices and Circuit Theory

ELEVENTH EDITION

Robert L. Boylestad • Louis Nashelsky



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SIGNIFICANT EQUATIONS

1 Semiconductor Diodes $W = QV$, $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$, $I_D = I_s (e^{V_D/nV_T} - 1)$, $V_T = kT/q$, $T_K = T_C + 273^\circ$,
 $k = 1.38 \times 10^{-23} \text{ J/K}$, $V_K \cong 0.7 \text{ V (Si)}$, $V_K \cong 0.3 \text{ V (Ge)}$, $V_K \cong 1.2 \text{ V (GaAs)}$, $R_D = V_D/I_D$, $r_d = 26 \text{ mV}/I_D$, $r_{av} = \Delta V_d/\Delta I_d|_{\text{pt. to pt.}}$,
 $P_D = V_D I_D$, $T_C = (\Delta V_Z/V_Z)/(T_1 - T_0) \times 100\%/^\circ\text{C}$

2 Diode Applications Silicon: $V_K \cong 0.7 \text{ V}$, germanium: $V_K \cong 0.3 \text{ V}$, GaAs: $V_K \cong 1.2 \text{ V}$; half-wave: $V_{dc} = 0.318V_m$;
 full-wave: $V_{dc} = 0.636V_m$

3 Bipolar Junction Transistors $I_E = I_C + I_B$, $I_C = I_{C_{\text{majority}}} + I_{C_{\text{minority}}}$, $I_C \cong I_E$, $V_{BE} = 0.7 \text{ V}$, $\alpha_{dc} = I_C/I_E$, $I_C = \alpha I_E + I_{CBO}$,
 $\alpha_{ac} = \Delta I_C/\Delta I_E$, $I_{CEO} = I_{CBO}/(1 - \alpha)$, $\beta_{dc} = I_C/I_B$, $\beta_{ac} = \Delta I_C/\Delta I_B$, $\alpha = \beta/(\beta + 1)$, $\beta = \alpha/(1 - \alpha)$, $I_C = \beta I_B$, $I_E = (\beta + 1)I_B$,
 $P_{C_{\text{max}}} = V_{CE} I_C$

4 DC Biasing—BJTs In general: $V_{BE} = 0.7 \text{ V}$, $I_C \cong I_E$, $I_C = \beta I_B$; fixed-bias: $I_B = (V_{CC} - V_{BE})/R_B$, $V_{CE} = V_{CC} - I_C R_C$,
 $I_{C_{\text{sat}}} = V_{CC}/R_C$; emitter-stabilized: $I_B = (V_{CC} - V_{BE})/(R_B + (\beta + 1)R_E)$, $R_i = (\beta + 1)R_E$, $V_{CE} = V_{CC} - I_C(R_C + R_E)$,
 $I_{C_{\text{sat}}} = V_{CC}/(R_C + R_E)$; voltage-divider: exact: $R_{Th} = R_1 \parallel R_2$, $E_{Th} = R_2 V_{CC}/(R_1 + R_2)$, $I_B = (E_{Th} - V_{BE})/(R_{Th} + (\beta + 1)R_E)$,
 $V_{CE} = V_{CC} - I_C(R_C + R_E)$, approximate: $\beta R_E \geq 10R_2$, $V_B = R_2 V_{CC}/(R_1 + R_2)$, $V_E = V_B - V_{BE}$, $I_C \cong I_E = V_E/R_E$; voltage-feedback:
 $I_B = (V_{CC} - V_{BE})/(R_B + \beta(R_C + R_E))$; common-base: $I_B = (V_{EE} - V_{BE})/R_E$; switching transistors: $t_{on} = t_r + t_d$, $t_{off} = t_s + t_f$;
 stability: $S(I_{CO}) = \Delta I_C/\Delta I_{CO}$; fixed-bias: $S(I_{CO}) = \beta + 1$; emitter-bias: $S(I_{CO}) = (\beta + 1)(1 + R_B/R_E)/(1 + \beta + R_B/R_E)$;
 voltage-divider: $S(I_{CO}) = (\beta + 1)(1 + R_{Th}/R_E)/(1 + \beta + R_{Th}/R_E)$; feedback-bias: $S(I_{CO}) = (\beta + 1)(1 + R_B/R_C)/(1 + \beta + R_B/R_C)$,
 $S(V_{BE}) = \Delta I_C/\Delta V_{BE}$; fixed-bias: $S(V_{BE}) = -\beta/R_B$; emitter-bias: $S(V_{BE}) = -\beta/(R_B + (\beta + 1)R_E)$; voltage-divider: $S(V_{BE}) =$
 $-\beta/(R_{Th} + (\beta + 1)R_E)$; feedback bias: $S(V_{BE}) = -\beta/(R_B + (\beta + 1)R_C)$, $S(\beta) = \Delta I_C/\Delta \beta$; fixed-bias: $S(\beta) = I_{C1}/\beta_1$;
 emitter-bias: $S(\beta) = I_{C1}(1 + R_B/R_E)/(\beta_1(1 + \beta_2 + R_B/R_E))$; voltage-divider: $S(\beta) = I_{C1}(1 + R_{Th}/R_E)/(\beta_1(1 + \beta_2 + R_{Th}/R_E))$;
 feedback-bias: $S(\beta) = I_{C1}(1 + R_B/R_C)/(\beta_1(1 + \beta_2 + R_B/R_C))$, $\Delta I_C = S(I_{CO}) \Delta I_{CO} + S(V_{BE}) \Delta V_{BE} + S(\beta) \Delta \beta$

5 BJT AC Analysis $r_e = 26 \text{ mV}/I_E$; CE fixed-bias: $Z_i \cong \beta r_e$, $Z_o \cong R_C$, $A_v = -R_C/r_e$; voltage-divider bias: $Z_i = R_1 \parallel R_2 \parallel \beta r_e$, $Z_o \cong R_C$,
 $A_v = -R_C/r_e$; CE emitter-bias: $Z_i \cong R_B \parallel \beta R_E$, $Z_o \cong R_C$, $A_v \cong -R_C/R_E$; emitter-follower: $Z_i \cong R_B \parallel \beta R_E$, $Z_o \cong r_e$, $A_v \cong 1$;
 common-base: $Z_i \cong R_E \parallel r_e$, $Z_o \cong R_C$, $A_v \cong R_C/r_e$; collector feedback: $Z_i \cong r_e/(1/\beta + R_C/R_F)$, $Z_o \cong R_C \parallel R_F$, $A_v = -R_C/r_e$; collector
 dc feedback: $Z_i \cong R_{F1} \parallel \beta r_e$, $Z_o \cong R_C \parallel R_{F2}$, $A_v = -(R_{F2} \parallel R_C)/r_e$; effect of load impedance: $A_v = R_L A_{vNL}/(R_L + R_o)$, $A_i = -A_v Z_i/R_L$;
 effect of source impedance: $V_i = R_i V_s/(R_i + R_s)$, $A_{v_s} = R_i A_{vNL}/(R_i + R_s)$, $I_s = V_s/(R_s + R_i)$; combined effect of load and source
 impedance: $A_v = R_L A_{vNL}/(R_L + R_o)$, $A_{v_s} = (R_i/(R_i + R_s))(R_L/(R_L + R_o))A_{vNL}$, $A_i = -A_v R_i/R_L$, $A_{i_s} = -A_{v_s}(R_s + R_i)/R_L$; cascode
 connection: $A_v = A_{v1} A_{v2}$; Darlington connection: $\beta_D = \beta_1 \beta_2$; emitter-follower configuration: $I_B = (V_{CC} - V_{BE})/(R_B + \beta_D R_E)$,
 $I_C \cong I_E \cong \beta_D I_B$, $Z_i = R_B \parallel \beta_1 \beta_2 R_E$, $A_i = \beta_D R_B/(R_B + \beta_D R_E)$, $A_v \cong 1$, $Z_o = r_{e1}/\beta_2 + r_{e2}$; basic amplifier configuration: $Z_i = R_1 \parallel R_2 \parallel Z'_i$,
 $Z'_i = \beta_1(r_{e1} + \beta_2 r_{e2})$, $A_i = \beta_D (R_1 \parallel R_2)/(R_1 \parallel R_2 + Z'_i)$, $A_v = \beta_D R_C/Z'_i$, $Z_o = R_C \parallel r_{o2}$; feedback pair: $I_{B1} = (V_{CC} - V_{BE1})/(R_B + \beta_1 \beta_2 R_C)$,
 $Z_i = R_B \parallel Z'_i$, $Z'_i = \beta_1 r_{e1} + \beta_1 \beta_2 R_C$, $A_i = -\beta_1 \beta_2 R_B/(R_B + \beta_1 \beta_2 R_C)$, $A_v = \beta_2 R_C/(r_e + \beta_2 R_C) \cong 1$, $Z_o \cong r_{e1}/\beta_2$.

6 Field-Effect Transistors $I_G = 0 \text{ A}$, $I_D = I_{DSS}(1 - V_{GS}/V_P)^2$, $I_D = I_s$, $V_{GS} = V_P(1 - \sqrt{I_D/I_{DSS}})$, $I_D = I_{DSS}/4$ (if $V_{GS} = V_P/2$),
 $I_D = I_{DSS}/2$ (if $V_{GS} \cong 0.3 V_P$), $P_D = V_{DS} I_D$, $r_d = r_o/(1 - V_{GS}/V_P)^2$; MOSFET: $I_D = k(V_{GS} - V_T)^2$, $k = I_{D(on)}/(V_{GS(on)} - V_T)^2$

7 FET Biasing Fixed-bias: $V_{GS} = -V_{GG}$, $V_{DS} = V_{DD} - I_D R_D$; self-bias: $V_{GS} = -I_D R_S$, $V_{DS} = V_{DD} - I_D(R_S + R_D)$, $V_S = I_D R_S$;
 voltage-divider: $V_G = R_2 V_{DD}/(R_1 + R_2)$, $V_{GS} = V_G - I_D R_S$, $V_{DS} = V_{DD} - I_D(R_D + R_S)$; common-gate configuration: $V_{GS} = V_{SS} - I_D R_S$,
 $V_{DS} = V_{DD} + V_{SS} - I_D(R_D + R_S)$; special case: $V_{GS_Q} = 0 \text{ V}$: $I_{D_Q} = I_{DSS}$, $V_{DS} = V_{DD} - I_D R_D$, $V_D = V_{DS}$, $V_S = 0 \text{ V}$. enhancement-type
 MOSFET: $I_D = k(V_{GS} - V_{GS(Th)})^2$, $k = I_{D(on)}/(V_{GS(on)} - V_{GS(Th)})^2$; feedback bias: $V_{DS} = V_{GS}$, $V_{GS} = V_{DD} - I_D R_D$; voltage-divider:
 $V_G = R_2 V_{DD}/(R_1 + R_2)$, $V_{GS} = V_G - I_D R_S$; universal curve: $m = |V_P|/I_{DSS} R_S$, $M = m \times V_G/|V_P|$, $V_G = R_2 V_{DD}/(R_1 + R_2)$

8 FET Amplifiers $g_m = y_{fs} = \Delta I_D/\Delta V_{GS}$, $g_{m0} = 2I_{DSS}/|V_P|$, $g_m = g_{m0}(1 - V_{GS}/V_P)$, $g_m = g_{m0} \sqrt{I_D/I_{DSS}}$, $r_d = 1/y_{os} =$
 $\Delta V_{DS}/\Delta I_D|_{V_{GS}=\text{constant}}$; fixed-bias: $Z_i = R_G$, $Z_o \cong R_D$, $A_v = -g_m R_D$; self-bias (bypassed R_S): $Z_i = R_G$, $Z_o \cong R_D$, $A_v = -g_m R_D$; self-bias
 (unbypassed R_S): $Z_i = R_G$, $Z_o = R_D$, $A_v \cong -g_m R_D/(1 + g_m R_S)$; voltage-divider bias: $Z_i = R_1 \parallel R_2$, $Z_o = R_D$, $A_v = -g_m R_D$; source follower:
 $Z_i = R_G$, $Z_o = R_S \parallel 1/g_m$, $A_v \cong g_m R_S/(1 + g_m R_S)$; common-gate: $Z_i = R_S \parallel 1/g_m$, $Z_o \cong R_D$, $A_v = g_m R_D$; enhancement-type MOSFETs:
 $g_m = 2k(V_{GS_Q} - V_{GS(Th)})$; drain-feedback configuration: $Z_i \cong R_F/(1 + g_m R_D)$, $Z_o \cong R_D$, $A_v \cong -g_m R_D$; voltage-divider bias: $Z_i = R_1 \parallel R_2$,
 $Z_o \cong R_D$, $A_v \cong -g_m R_D$.

(A)

9 BJT and JFET Frequency Response $\log_e a = 2.3 \log_{10} a$, $\log_{10} 1 = 0$, $\log_{10} a/b = \log_{10} a - \log_{10} b$, $\log_{10} 1/b = -\log_{10} b$,
 $\log_{10} ab = \log_{10} a + \log_{10} b$, $G_{dB} = 10 \log_{10} P_2/P_1$, $G_{dBm} = 10 \log_{10} P_2/1 \text{ mW}|_{600 \Omega}$, $G_{dB} = 20 \log_{10} V_2/V_1$,
 $G_{dB_T} = G_{dB_1} + G_{dB_2} + \dots + G_{dB_n}$, $P_{O_{HPF}} = 0.5 P_{O_{mid}}$, $BW = f_1 - f_2$; low frequency (BJT): $f_{LS} = 1/2\pi(R_s + R_i)C_s$,
 $f_{LC} = 1/2\pi(R_o + R_L)C_C$, $f_{LE} = 1/2\pi R_e C_E$, $R_e = R_E \parallel (R_s/\beta + r_e)$, $R_s = R_s \parallel R_1 \parallel R_2$, FET: $f_{LG} = 1/2\pi(R_{sig} + R_i)C_G$,
 $f_{LC} = 1/2\pi(R_o + R_L)C_C$, $f_{LS} = 1/2\pi R_{eq} C_S$, $R_{eq} = R_S \parallel 1/g_m (r_d \cong \infty \Omega)$; Miller effect: $C_{M_i} = (1 - A_v)C_f$, $C_{M_o} = (1 - 1/A_v)C_f$;
high frequency (BJT): $f_{H_i} = 1/2\pi R_{Th_i} C_i$, $R_{Th_i} = R_s \parallel R_1 \parallel R_2 \parallel R_i$, $C_i = C_{w_i} + C_{be} + (1 - A_v)C_{bc}$, $f_{H_o} = 1/2\pi R_{Th_o} C_o$,
 $R_{Th_o} = R_C \parallel R_L \parallel r_o$, $C_o = C_{w_o} + C_{ce} + C_{M_o}$, $f_{\beta} \cong 1/2\pi \beta_{mid} r_e (C_{be} + C_{bc})$, $f_T = \beta_{mid} f_{\beta}$; FET: $f_{H_i} = 1/2\pi R_{Th_i} C_i$, $R_{Th_i} = R_{sig} \parallel R_G$,
 $C_i = C_{w_i} + C_{gs} + C_{M_i}$, $C_{M_i} = (1 - A_v)C_{gd}$, $f_{H_o} = 1/2\pi R_{Th_o} C_o$, $R_{Th_o} = R_D \parallel R_L \parallel r_d$, $C_o = C_{w_o} + C_{ds} + C_{M_o}$, $C_{M_o} = (1 - 1/A_v)C_{gd}$;
multistage: $f'_1 = f_1/\sqrt{2^{1/n} - 1}$, $f'_2 = (\sqrt{2^{1/n} - 1})f_2$; square-wave testing: $f_{H_i} = 0.35/t_r$, % tilt = $P\% = ((V - V')/V) \times 100\%$,
 $f_{L_o} = (P/\pi)f_s$

10 Operational Amplifiers $CMRR = A_d/A_c$; $CMRR(\log) = 20 \log_{10}(A_d/A_c)$; constant-gain multiplier: $V_o/V_1 = -R_f/R_1$;
noninverting amplifier: $V_o/V_1 = 1 + R_f/R_1$; unity follower: $V_o = V_1$; summing amplifier: $V_o = -[(R_f/R_1)V_1 + (R_f/R_2)V_2 + (R_f/R_3)V_3]$;
integrator: $v_o(t) = -(1/R_1 C_1) \int v_1 dt$

11 Op-Amp Applications Constant-gain multiplier: $A = -R_f/R_1$; noninverting: $A = 1 + R_f/R_1$; voltage summing:
 $V_o = -[(R_f/R_1)V_1 + (R_f/R_2)V_2 + (R_f/R_3)V_3]$; high-pass active filter: $f_{oL} = 1/2\pi R_1 C_1$; low-pass active filter: $f_{oH} = 1/2\pi R_1 C_1$

12 Power Amplifiers

Power in: $P_i = V_{CC} I_{CQ}$

power out: $P_o = V_{CE} I_C = I_C^2 R_C = V_{CE}^2 / R_C \text{ rms}$
 $= V_{CE} I_C / 2 = (I_C^2 / 2) R_C = V_{CE}^2 / (2R_C) \text{ peak}$
 $= V_{CE} I_C / 8 = (I_C^2 / 8) R_C = V_{CE}^2 / (8R_C) \text{ peak-to-peak}$

efficiency: $\% \eta = (P_o / P_i) \times 100\%$; maximum efficiency: Class A, series-fed = 25%; Class A, transformer-coupled = 50%; Class B,
push-pull = 78.5%; transformer relations: $V_2/V_1 = N_2/N_1 = I_1/I_2$, $R_2 = (N_2/N_1)^2 R_1$; power output: $P_o = [(V_{CE_{max}} - V_{CE_{min}}) (I_{C_{max}} - I_{C_{min}})] / 8$; class B power amplifier: $P_i = V_{CC} [(2/\pi) I_{peak}]$; $P_o = V_L^2(\text{peak}) / (2R_L)$; $\% \eta = (\pi/4) [V_L(\text{peak}) / V_{CC}] \times 100\%$;
 $P_Q = P_{2Q} / 2 = (P_i - P_o) / 2$; maximum $P_o = V_{CC}^2 / 2R_L$; maximum $P_i = 2V_{CC}^2 / \pi^2 R_L$; maximum $P_{2Q} = 2V_{CC}^2 / \pi^2 R_L$; % total harmonic
distortion (% THD) = $\sqrt{D_2^2 + D_3^2 + D_4^2 + \dots} \times 100\%$; heat-sink: $T_J = P_D \theta_{JA} + T_A$, $\theta_{JA} = 40^\circ\text{C/W}$ (free air);
 $P_D = (T_J - T_A) / (\theta_{JC} + \theta_{CS} + \theta_{SA})$

13 Linear-Digital ICs Ladder network: $V_o = [(D_0 \times 2^0 + D_1 \times 2^1 + D_2 \times 2^2 + \dots + D_n \times 2^n) / 2^n] V_{ref}$;
555 oscillator: $f = 1.44(R_A + 2R_B)C$; 555 monostable: $T_{high} = 1.1 R_A C$; VCO: $f_o = (2/R_1 C_1) [(V^+ - V_C) / V^+]$; phase-
locked loop (PLL): $f_o = 0.3 / R_1 C_1$, $f_L = \pm 8 f_o / V$, $f_C = \pm (1/2\pi) \sqrt{2\pi f_L / (3.6 \times 10^3) C_2}$

14 Feedback and Oscillator Circuits $A_f = A / (1 + \beta A)$; series feedback; $Z_{if} = Z_i (1 + \beta A)$; shunt feedback: $Z_{if} = Z_i / (1 + \beta A)$;
voltage feedback: $Z_{of} = Z_o / (1 + \beta A)$; current feedback; $Z_{of} = Z_o (1 + \beta A)$; gain stability: $dA_f / A_f = 1 / (|1 + \beta A|) (dA / A)$; oscillator;
 $\beta A = 1$; phase shift: $f = 1/2\pi RC \sqrt{6}$, $\beta = 1/29$, $A > 29$; FET phase shift: $|A| = g_m R_L$, $R_L = R_D r_d / (R_D + r_d)$; transistor phase shift:
 $f = (1/2\pi RC) [1 / \sqrt{6 + 4(R_C/R)}]$, $h_{fe} > 23 + 29(R_C/R) + 4(R/R_C)$; Wien bridge: $R_3/R_4 = R_1/R_2 + C_2/C_1$, $f_o = 1/2\pi \sqrt{R_1 C_1 R_2 C_2}$;
tuned: $f_o = 1/2\pi \sqrt{L C_{eq}}$, $C_{eq} = C_1 C_2 / (C_1 + C_2)$, Hartley: $L_{eq} = L_1 + L_2 + 2M$, $f_o = 1/2\pi \sqrt{L_{eq} C}$

15 Power Supplies (Voltage Regulators) Filters: $r = V_r(\text{rms}) / V_{dc} \times 100\%$, V.R. = $(V_{NL} - V_{FL}) / V_{FL} \times 100\%$, $V_{dc} = V_m - V_r(\text{p-p}) / 2$,
 $V_r(\text{rms}) = V_r(\text{p-p}) / 2\sqrt{3}$, $V_r(\text{rms}) \cong (I_{dc} / 4\sqrt{3}) (V_{dc} / V_m)$; full-wave, light load $V_r(\text{rms}) = 2.4 I_{dc} / C$, $V_{dc} = V_m - 4.17 I_{dc} / C$, $r =$
 $(2.4 I_{dc} C V_{dc}) \times 100\% = 2.4 / R_L C \times 100\%$, $I_{peak} = T / T_1 \times I_{dc}$; RC filter: $V'_{dc} = R_L V_{dc} / (R + R_L)$, $X_C = 2.653 / C$ (half-wave), $X_C =$
 $1.326 / C$ (full-wave), $V'_r(\text{rms}) = (X_C / \sqrt{R^2 + X_C^2})$; regulators: $IR = (I_{NL} - I_{FL}) / I_{FL} \times 100\%$, $V_L = V_Z (1 + R_1/R_2)$, $V_o =$
 $V_{ref} (1 + R_2/R_1) + I_{adj} R_2$

16 Other Two-Terminal Devices Varactor diode: $C_T = C(0) / (1 + |V_r/V_T|)^n$, $TC_C = (\Delta C / C_o) (T_1 - T_0) \times 100\%$; photodiode:
 $W = hf$, $\lambda = v/f$, $1 \text{ lm} = 1.496 \times 10^{-10} \text{ W}$, $1 \text{ \AA} = 10^{-10} \text{ m}$, $1 \text{ fc} = 1 \text{ lm/ft}^2 = 1.609 \times 10^{-9} \text{ W/m}^2$

17 pnpn and Other Devices Diac: $V_{BR_1} = V_{BR_2} \pm 0.1 V_{BR_2}$ UJT: $R_{BB} = (R_{B_1} + R_{B_2}) |_{I_E=0}$, $V_{R_{B_1}} = \eta V_{BB} |_{I_E=0}$,
 $\eta = R_{B_1} / (R_{B_1} + R_{B_2}) |_{I_E=0}$, $V_P = \eta V_{BB} + V_D$; phototransistor: $I_C \cong h_{fe} I_A$; PUT: $\eta = R_{B_1} / (R_{B_1} + R_{B_2})$, $V_P = \eta V_{BB} + V_D$

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To Else Marie, Alison and Mark, Eric and Rachel, Stacey and Jonathan,
and our eight granddaughters: Kelcy, Morgan, Codie, Samantha, Lindsey,
Britt, Skylar, and Aspen.

To Katrin, Kira and Thomas, Larren and Patricia, and our six grandsons:
Justin, Brendan, Owen, Tyler, Colin, and Dillon.

PREFACE

The preparation of the preface for the 11th edition resulted in a bit of reflection on the 40 years since the first edition was published in 1972 by two young educators eager to test their ability to improve on the available literature on electronic devices. Although one may prefer the term *semiconductor* devices rather than *electronic* devices, the first edition was almost exclusively a survey of vacuum-tube devices—a subject without a single section in the new Table of Contents. The change from tubes to predominantly semiconductor devices took almost five editions, but today it is simply referenced in some sections. It is interesting, however, that when field-effect transistor (FET) devices surfaced in earnest, a number of the analysis techniques used for tubes could be applied because of the similarities in the ac equivalent models of each device.

We are often asked about the revision process and how the content of a new edition is defined. In some cases, it is quite obvious that the computer software has been updated, and the changes in application of the packages must be spelled out in detail. This text was the first to emphasize the use of computer software packages and provided a level of detail unavailable in other texts. With each new version of a software package, we have found that the supporting literature may still be in production, or the manuals lack the detail for new users of these packages. Sufficient detail in this text ensures that a student can apply each of the software packages covered without additional instructional material.

The next requirement with any new edition is the need to update the content reflecting changes in the available devices and in the characteristics of commercial devices. This can require extensive research in each area, followed by decisions regarding depth of coverage and whether the listed improvements in response are valid and deserve recognition. The classroom experience is probably one of the most important resources for defining areas that need expansion, deletion, or revision. The feedback from students results in marked-up copies of our texts with inserts creating a mushrooming copy of the material. Next, there is the input from our peers, faculty at other institutions using the text, and, of course, reviewers chosen by Pearson Education to review the text. One source of change that is less obvious is a simple rereading of the material following the passing of the years since the last edition. Rereading often reveals material that can be improved, deleted, or expanded.

For this revision, the number of changes far outweighs our original expectations. However, for someone who has used previous editions of the text, the changes will probably be less obvious. However, major sections have been moved and expanded, some 100-plus problems have been added, new devices have been introduced, the number of applications has been increased, and new material on recent developments has been added throughout the text. We believe that the current edition is a significant improvement over the previous editions.

As instructors, we are all well aware of the importance of a high level of accuracy required for a text of this kind. There is nothing more frustrating for a student than to work a problem over from many different angles and still find that the answer differs from the solution at the back of the text or that the problem seems undoable. We were pleased to find that there were fewer than half a dozen errors or misprints reported since

the last edition. When you consider the number of examples and problems in the text along with the length of the text material, this statistic clearly suggests that the text is as error-free as possible. Any contributions from users to this list were quickly acknowledged, and the sources were thanked for taking the time to send the changes to the publisher and to us.

Although the current edition now reflects all the changes we feel it should have, we expect that a revised edition will be required somewhere down the line. We invite you to respond to this edition so that we can start developing a package of ideas and thoughts that will help us improve the content for the next edition. We promise a quick response to your comments, whether positive or negative.

NEW TO THIS EDITION

- Throughout the chapters, there are extensive changes in the problem sections. Over 100 new problems have been added, and a significant number of changes have been made to the existing problems.
- A significant number of computer programs were all rerun and the descriptions updated to include the effects of using OrCAD version 16.3 and Multisim version 11.1. In addition, the introductory chapters are now assuming a broader understanding of computer methods, resulting in a revised introduction to the two programs.
- Throughout the text, photos and biographies of important contributors have been added. Included among these are Sidney Darlington, Walter Schottky, Harry Nyquist, Edwin Colpitts, and Ralph Hartley.
- New sections were added throughout the text. There is now a discussion on the impact of combined dc and ac sources on diode networks, of multiple BJT networks, VMOS and UMOS power FETs, Early voltage, frequency impact on the basic elements, effect of R_S on an amplifier's frequency response, gain-bandwidth product, and a number of other topics.
- A number of sections were completely rewritten due to reviewers' comments or changing priorities. Some of the areas revised include bias stabilization, current sources, feedback in the dc and ac modes, mobility factors in diode and transistor response, transition and diffusion capacitive effects in diodes and transistor response characteristics, reverse-saturation current, breakdown regions (cause and effect), and the hybrid model.
- In addition to the revision of numerous sections described above, there are a number of sections that have been expanded to respond to changes in priorities for a text of this kind. The section on solar cells now includes a detailed examination of the materials employed, additional response curves, and a number of new practical applications. The coverage of the Darlington effect was totally rewritten and expanded to include detailed examination of the emitter-follower and collector gain configurations. The coverage of transistors now includes details on the cross-bar latch transistor and carbon nanotubes. The discussion of LEDs includes an expanded discussion of the materials employed, comparisons to today's other lighting options, and examples of the products defining the future of this important semiconductor device. The data sheets commonly included in a text of this type are now discussed in detail to ensure a well-established link when the student enters the industrial community.
- Updated material appears throughout the text in the form of photos, artwork, data sheets, and so forth, to ensure that the devices included reflect the components available today with the characteristics that have changed so rapidly in recent years. In addition, the parameters associated with the content and all the example problems are more in line with the device characteristics available today. Some devices, no longer available or used very infrequently, were dropped to ensure proper emphasis on the current trends.
- There are a number of important organizational changes throughout the text to ensure the best sequence of coverage in the learning process. This is readily apparent in the early dc chapters on diodes and transistors, in the discussion of current gain in the ac chapters for BJTs and JFETs, in the Darlington section, and in the frequency response chapters. It is particularly obvious in Chapter 16, where topics were dropped and the order of sections changed dramatically.

INSTRUCTOR SUPPLEMENTS

To download the supplements listed below, please visit: <http://www.pearsonhighered.com/irc> and enter "Electronic Devices and Circuit Theory" in the search bar. From there, you will be able to register to receive an instructor's access code. Within 48 hours after registering, you will receive a confirming email, including an instructor access code. Once you have received your code, return to the site and log on for full instructions on how to download the materials you wish to use.

PowerPoint Presentation—(ISBN 0132783746). This supplement contains all figures from the text as well as a new set of lecture notes highlighting important concepts.

TestGen® Computerized Test Bank—(ISBN 013278372X). This electronic bank of test questions can be used to develop customized quizzes, tests, and/or exams.

Instructor's Resource Manual—(ISBN 0132783738). This supplement contains the solutions to the problems in the text and lab manual.

STUDENT SUPPLEMENTS

Laboratory Manual—(ISBN 0132622459). This supplement contains over 35 class-tested experiments for students to use to demonstrate their comprehension of course material.

Companion Website—Student study resources are available at www.pearsonhighered.com/boylestad

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