Electronic Devices and Circuit Theory

Eighth Edition

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EIGHTH EDITION

ELECTRONIC DEVICES AND CIRCUIT THEORY

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SIGNIFICANT EQUATIONS

1 Semiconductor Diodes $W = QV$, $1\text{ eV} = 1.6 \times 10^{-19}\text{ J}$, $I_D = I_s(e^{kV_D/T_K} - 1)$, $R_{DC} = V_D/I_D$, $r_d = \Delta V_d/\Delta I_d = 26\text{ mV}/I_D$, $r_{av} = \Delta V_d/\Delta I_d$, $P_D = V_D I_D$, $T_C = \Delta V_z/[V_z(T_1 - T_0)] \times 100\%$

2 Diode Applications $V_{BE} = V_D = 0.7\text{ V}$; half-wave: $V_{dc} = 0.318V_m$; full-wave: $V_{dc} = 0.636V_m$

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

4 DC Biasing — BJTs In general: $V_{BE} = 0.7\text{ V}$, $I_C \simeq I_E$, $I_C = \beta I_B$; fixed-bias: $I_B = (V_{CC} - V_{BE})/R_B$, $V_{CE} = V_{CC} - I_C R_C$, $I_{C_{sat}} = V_{CC}/R_C$; emitter-stabilized: $I_B = (V_{CC} - V_{BE})/(R_B + (\beta + 1)R_E)$, $R_i = (\beta + 1)R_E$, $V_{CE} = V_{CC} - I_C(R_C + R_E)$, $I_{C_{sat}} = V_{CC}/(R_C + R_E)$; voltage-divider: exact: $R_{Th} = R_1 \| R_2$, $E_{Th} = R_2V_{CC}/(R_1 + R_2)$, $I_B = (E_{Th} - V_{BE})/(R_{Th} + (\beta + 1)R_E)$, $V_{CE} = V_{CC} - I_C(R_C + R_E)$, approximate: $V_B = R_2V_{CC}/(R_1 + R_2)$, $\beta R_E \geq 10R_2$, $V_E = V_B - V_{BE}$, $I_C \simeq I_E = V_E/R_E$; 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: $S(\beta) = I_{C_1}/\beta_1$; emitter-bias: $S(\beta) = I_{C_1}(1 + R_B/R_E)/[\beta_1(1 + \beta_2 + R_B/R_E)]$; voltage-divider: $S(\beta) = I_{C_1}(1 + R_{Th}/R_E)/[\beta_1(1 + \beta_2 + R_{Th}/R_E)]$; feedback-bias: $S(\beta) = I_{C_1}(R_B + R_C)/[\beta_1(R_B + R_C(1 + \beta_2))]$, $\Delta I_C = S(I_{CO})\,\Delta I_{CO} + S(V_{BE})\,\Delta V_{BE} + S(\beta)\,\Delta\beta$

5 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 $V_{GS} \simeq 0.3V_P$), $P_D = V_{DS}I_D$, $I_D = k(V_{GS} - V_T)^2$

6 FET Biasing Fixed-bias: $V_{GS} = -V_{GG}$, $V_{DS} = V_{DD} - I_DR_D$; self-bias: $V_{GS} = -I_DR_S$, $V_{DS} = V_{DD} - I_D(R_S + R_D)$, $V_S = I_DR_S$; voltage-divider: $V_G = R_2V_{DD}/(R_1 + R_2)$, $V_{GS} = V_G - I_DR_S$, $V_{DS} = V_{DD} - I_D(R_D + R_S)$; 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: $V_{DS} = V_{GS}$, $V_{GS} = V_{DD} - I_DR_D$; voltage-divider: $V_G = R_2V_{DD}/(R_1 + R_2)$, $V_{GS} = V_G - I_DR_S$; universal curve: $m = |V_P|/I_{DSS}R_S$, $M = m \times V_G/|V_P|$, $V_G = R_2V_{DD}/(R_1 + R_2)$

7 BJT Transistor Modeling $Z_i = V_i/I_i$, $I_i = (V_s - V_i)/R_{sense}$, $I_o = (V_s - V_o)/R_{sense}$, $Z_o = V_o/I_o$, $A_v = V_o/V_i$, $A_{v_s} = Z_iA_{v_{NL}}/(Z_i + R_s)$, $A_i = -A_vZ_i/R_L$, $r_e = 26\text{ mV}/I_E$; common-base: $Z_i = r_e$, $Z_o \simeq \infty\ \Omega$, $A_v \simeq R_L/r_e$, $A_i \simeq -1$; common-emitter: $Z_i = \beta r_e$, $Z_o = r_o$, $A_v = -R_L/r_e$, $A_i \simeq \beta$, $h_{ie} = \beta r_e$, $h_{fe} = \beta_{ac}$, $h_{ib} = r_e$, $h_{fb} = -\alpha$.

8 BJT Small-Signal Analysis Common-emitter: $A_v = -R_C/r_e$, $Z_i = R_B \| \beta r_e$, $Z_o = R_C$, $A_i \simeq \beta$; voltage-divider: $R' = R_1 \| R_2$, $A_v = -R_C/r_e$, $Z_i = R' \| \beta r_e$, $Z_o = R_C$; emitter-bias: $Z_b = \beta(r_e + R_E) \simeq \beta R_E$, $A_v = -\beta R_C/Z_b = -R_C/(r_e + R_E) \simeq -R_C/R_E$; emitter-follower: $Z_b \simeq \beta(r_e + R_E)$, $A_v \simeq 1$, $Z_o \simeq r_e$; common-base: $A_v \simeq R_C/r_e$, $Z_i = R_E \| r_e$, $Z_o = R_C$; collector feedback: $A_v = -R_C/r_e$, $Z_i = \beta r_e \| R_F/|A_v|$, $Z_o \simeq R_C \| R_F$; collector dc feedback: $A_v = -(R_{F_2} \| R_C)/r_e$, $Z_i = R_{F_1} \| \beta r_e$, $Z_o = R_C \| R_{F_2}$; hybrid parameters: $A_i = h_f/(1 + h_o R_L)$, $A_v = -h_f R_L/[h_i + (h_i h_o - h_f h_r)R_L]$, $Z_i = h_i - h_f h_r R_L/(1 + h_o R_L)$, $Z_o = 1/[h_o - (h_f h_r/(h_i + R_s))]$

9 FET Small-Signal Analysis $g_m = g_{mo}(1 - V_{GS}/V_P)$, $g_{mo} = 2I_{DSS}/|V_P|$; basic configuration: $A_v = -g_m R_D$; unbypassed source resistance: $A_v = -g_m R_D/(1 + g_m R_S)$; source follower: $A_v = g_m R_S/(1 + g_m R_S)$; common gate: $A_v = g_m(R_D \| r_d)$

10 Systems Approach—Effects of R_S and R_L BJT: $A_v = R_L A_{v_{NL}}/(R_L + R_o)$, $A_i = -A_v Z_i/R_L$, $V_i = R_i V_s/(R_i + R_s)$; fixed-bias: $A_v = -(R_C \| R_L)/r_e$, $A_{v_s} = Z_i A_v/(Z_i + R_s)$, $Z_i = \beta r_e$, $Z_o = R_C$; voltage-divider: $A_v = -(R_C \| R_L)/r_e$, $A_{v_s} = Z_i A_v/(Z_i + R_s)$, $Z_i \simeq R_1 \| R_2 \| \beta r_e$, $Z_o = R_C$; emitter-bias: $A_v = -(R_C \| R_L)/R_E$, $A_{v_s} = Z_i A_v/(Z_i + R_s)$, $Z_i \simeq R_B \| \beta R_E$, $Z_o = R_C$; collector-feedback: $A_v = -(R_C \| R_L)/r_e$, $A_{v_s} = Z_i A_v/(Z_i + R_s)$, $Z_i = \beta r_e \| R_F/|A_v|$, $Z_o \simeq R_C \| R_F$; emitter-follower: $R'_E = R_E \| R_L$, $A_v = R'_E/(R'_E + r_e)$, $A_{v_s} = R'_E/(R'_E + R_s/\beta + r_e)$, $Z_i = R_B \| \beta(r_e + R'_E)$, $Z_o = R_E \| (R_s/\beta + r_e)$; common-base: $A_v \simeq (R_C \| R_L)/r_e$, $A_i \simeq 1$, $Z_i \simeq r_e$, $Z_o = R_C$; FET: bypassed R_S: $A_v = -g_m(R_D \| R_L)$, $Z_i = R_G$, $Z_o = R_D$; unbypassed R_S: $A_v = -g_m(R_D \| R_L)/(1 + g_m R_S)$, $Z_i = R_G$, $Z_o = R_D$; source-follower: $A_v = g_m(R_S \| R_L)/[1 + g_m(R_S \| R_L)]$, $Z_i = R_G$, $Z_o = R_S \| r_d \| 1/g_m$; common gate: $A_v = g_m(R_D \| R_L)$, $Z_i = R_S \| 1/g_m$, $Z_O = R_O$; cascaded: $A_{v_T} = A_{v_1} \cdot A_{v_2} \cdot A_{v_3} \cdot\cdot\cdot A_{v_n}$, $A_{i_T} = \pm A_{v_T} Z_{i_1}/R_L$

11 BJT and JFET Frequency Response $\log_e a = 2.3 \log_{10} a$, $\log_{10} 1 = 0$, $\log_{10} a/b = \log_{10} a - \log_{10} b$, $\log_{10} 1/b = -\log_{10} b$, $\log_{10} ab = \log_{10} a + \log_{10} b$, $G_{dB} = 10 \log_{10} P_2/P_1$, $G_{dBm} = 10 \log_{10} P_2/1\ \text{mW}|_{600\Omega}$, $G_{dB} = 20 \log_{10} V_2/V_1$, $G_v = G_{v_1} + G_{v_2} + G_{v_3} + \cdots + G_{v_n}$, $P_{o_{HPF}} = 0.5 P_{o_{mid}}$, BW $= f_1 - f_2$; low frequency (BJT): $f_{L_S} = 1/2\pi(R_s + R_i)C_s$, $f_{L_C} = 1/2\pi(R_o + R_L)C_C$, $f_{L_E} = 1/2\pi R_e C_E$, $R_e = R_E \| (R'_s/\beta + r_e)$, $R'_s = R_s \| R_1 \| R_2$, FET: $f_{L_G} = 1/2\pi(R_{sig} + R_i)C_G$, $f_{L_C} = 1/2\pi R_o C_C$, $f_{L_S} = 1/2\pi R_{eq} C_S$, $R_{eq} = R_S \| 1/g_m (r_d \simeq \infty\ \Omega)$; Miller effect: $C_{M_i} = (1 - A_v)C_f$, $C_{M_o} = (1 - 1/A_v)C_f$; high frequency (BJT): $f_{H_i} = 1/2\pi R_{Th_1} C_i$, $R_{Th_1} = R_s \| R_1 \| R_2 \| R_i$, $C_i = C_{W_i} + C_{be} + C_{M_i}$, $f_{H_o} = 1/2\pi R_{Th_2} C_o$, $R_{Th_2} = R_C \| R_L \| r_o$, $C_o = C_{W_o} + C_{ce} + C_{M_o}$, $f_\beta \simeq 1/2\pi\beta_{mid} r_e(C_{be} + C_{bc})$, $f_T = \beta_{mid} f_\beta$; FET: $f_{H_i} = 1/2\pi R_{Th_1} C_i$, $R_{Th_1} = R_{sig} \| R_G$, $C_i = C_{W_i} + C_{gs} + C_{M_i}$, $f_{H_o} = 1/2\pi R_{Th_2} C_o$, $R_{Th_2} = R_D \| R_L \| r_d$, $C_o = C_{W_o} + C_{ds} + C_{M_o}$; 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 $= [(V - V')/V] \times 100\%$, $f_{L_o} = (P/\pi)f_s$, $P = (V - V')/V$

12 Compound Configurations Differential voltage gain: $A_v = \beta R_C/2r_i$; common-mode voltage gain: $\beta R_C/[r_i + 2(\beta + 1)R_E]$

13 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: $v_o(t) = -(1/R_1C_1)\int v_1 dt$

14 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: $f_{oH} = 1/2\pi R_1 C_1$

15 Power Amplifiers

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

power out: $P_o = V_{CE}I_C = I_C^2R_C = V_{CE}^2/R_C$ rms

$= V_{CE}I_C/2 = (I_C^2/2)R_C = V_{CE}^2/(2R_C)$ peak

$= V_{CE}I_C/8 = (I_C^2/8)R_C = V_{CE}^2/(8R_C)$ 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: $V_2/V_1 = N_2/N_1 = I_1/I_2$, $R_2 = (N_2/N_1)^2R_1$; 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 $P_i = 2V_{CC}^2/\pi R_L$; maximum $P_{2_Q} = 2V_{CC}^2/\pi^2R_L$; % total harmonic distortion (% THD) $= \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} \times 100\%$; heat-sink: $T_j = P_D\theta_{JA} + T_A$, $\theta_{JA} = 40°\text{C/W}$ (free air); $P_D = (T_J - T_A)/(\Theta_{JC} + \Theta_{CS} + \Theta_{SA})$

16 Linear-Digital ICs

Ladder network: $V_o = [(D_0 \times 2^0 + D_1 \times 2^1 + D_2 \times 2^2 + \cdots + D_n \times 2^n)/2^n]V_{ref}$; 555 oscillator: $f = 1.44(R_A + 2R_B)C$; 555 monostable: $T_{high} = 1.1R_AC$; VCO: $f_o = (2/R_1C_1)[(V^+ - V_C)/V^+]$; phase-locked loop (PLL): $f_o = 0.3/R_1C_1$, $f_L = \pm 8f_o/V$, $f_C = \pm(1/2\pi)\sqrt{2\pi f_L/(3.6 \times 10^3)C_2}$

17 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: $|A| = g_mR_L$, $R_L = R_Dr_d/(R_D + r_d)$; 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: $R_3/R_4 = R_1/R_2 + C_2/C_1$, $f_o = 1/2\pi\sqrt{R_1C_1R_2C_2}$; tuned: $f_o = 1/2\pi\sqrt{LC_{eq}}$, $C_{eq} = C_1C_2/(C_1 + C_2)$, Hartley: $L_{eq} = L_1 + L_2 + 2M$, $f_o = 1/2\pi\sqrt{L_{eq}C}$

18 Power Supplies (Voltage Regulators)

Filters: $r = V_r(\text{rms})/V_{dc} \times 100\%$, V.R. $= (V_{NL} - V_{FL})/V_{FL} \times 100\%$, $V_{dc} = V_m - V_r\ (\text{p-p})/2$, $V_r(\text{rms}) = V_r(\text{p-p})/2\sqrt{3}$, $V_r(\text{rms}) \simeq (I_{dc}/4\sqrt{3})(V_{dc}/V_m)$; full-wave, light load $V_r(\text{rms}) = 2.4I_{dc}/C$, $V_{dc} = V_m - 4.17I_{dc}/C$, $r = (2.4I_{dc}CV_{dc}) \times 100\% = 2.4/R_LC \times 100\%$, $I_{peak} = T/T_1 \times I_{dc}$; 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: $IR = (I_{NL} - I_{FL})/I_{FL} \times 100\%$, $V_L = V_Z(1 + R_1/R_2)$, $V_o = V_{ref}(1 + R_2/R_1) + I_{adj}R_2$

19 Other Two-Terminal Devices

Varactor diode: $C_T = C(0)/(1 + |V_r/V_T|)^n$, $T_{C_c} = (\Delta C/C_o(T_1 - T_0)) \times 100\%$; photodiode: $W = hf$, $\lambda = v/f$, $1\ \text{lm} = 1.496 \times 10^{-10}$ W

20 pnpn and Other Devices

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: $I_C \simeq h_{fe}I_\lambda$; PUT: $\eta = R_{B_1}/(R_{B_1} + R_{B_2})$, $V_P = \eta V_{BB} + V_D$

Dedicated to

ELSE MARIE; ALISON, MARK, KELCY, and MORGAN; ERIC, RACHEL, and SAMANTHA; STACEY, JONATHAN, and BRITT; JOHANNA

and to

KATRIN; KIRA, TOMMY, JUSTIN, and TYLER; LARREN, PATTY, BRENDAN, and OWEN

Preface

In this edition we have written additional practical examples and summaries at the end of each chapter, and have expanded coverage of computer software. The chapter on IC construction was deleted and replaced with a well-written description of the process that first appeared in *Smithsonian Magazine.* It has some stunning photographs and content that is excellent for the new students of this rapidly changing field.

Over the years we have learned that improved readability can be obtained through the general appearance of the text, so we are committed to the format you find in this and recent editions of the text. We hope you agree that it makes the text material appear "friendlier" to the broad range of students using the text. As in the past, we continue to be committed to the strong pedagogical sense of the text, accuracy, completeness, and a broad range of ancillary materials that support the educational process.

PEDAGOGY

Reviewers and current users appear to be quite satisfied with the manner in which the content lends itself to a typical course syllabus. The improved pedagogy of the last two editions seems to support the instructor's lecture and helps students build the foundation necessary for future studies. The number of examples continues to grow, and isolated boldface statements continue to identify important concepts and conclusions. Color continues to be employed in a manner that helps define important regions of characteristics, or identifies important regions or parameters of a network. Icons at the top of the page, developed for each chapter of the text, facilitate referencing a particular area of text as quickly as possible. Problems, which have been developed for each section of the text, progress from the simple to the more complex. The title of each section is repeated in the problem section to identify the problems associated with a particular subject matter.

SYSTEMS APPROACH

There is no question that the growing development of packaged systems requires that the student become aware at the earliest opportunity of a "systems approach" to the design and analysis of electronic systems. Isolated no-load networks are first discussed in Chapters 8 and 9 to introduce the important parameters of any package and develop the important equations for the configuration. The impact of a source or load impedance on the individual package is then defined in Chapter 10 on a general basis before examining specific networks. Finally, the impact of tying the individual packages together is examined in the same chapter to establish some understanding of the systems approach. The later chapters on op-amps and IC units further develop the concepts introduced in these early chapters.

ACCURACY

The goal of any educational publication is to be absolutely free of errors. There is nothing more distressing to a student than to find that he or she has suffered for hours over a simple printing error. In fact, after all the hours that go into preparing a manuscript and checking every word, number, or letter there is nothing more distressing to an author than to find that errors have crept into the publication. Based on past history and the effort put into this publication, we believe you will find the highest level of accuracy obtainable for a publication of this kind.

SUMMARIES

In response to current users, summaries are added at the end of each chapter, reviewing the salient concepts and conclusions. To emphasize specific words and phrases, boldface lettering is used in much the same manner as a student would use a highlighting marker. The list of equations appearing with each summary was limited to those an instructor realistically hopes the student will bring away from the course.

PRACTICAL EXAMPLES

While the text now has over 80 practical examples, over 40 were added to this edition and they appear in their own sections. They provide an understanding of the design process that is normally not available at this level. Practical considerations associated with using the electronic devices introduced in this text are discussed as experienced by professionals in the field. The level of coverage is well beyond the surface description of the operation of a particular product. Networks are reduced for clarity and equations are developed to explain why specific response levels are obtained. An effort was made to give some idea of the range of application for each device introduced. Too often the student believes that each electronic device serves a particular purpose, and that's it. In general, the authors are pleased with the results of this demanding effort and invite your comments and suggestions so that the content can be improved upon in the future.

TRANSISTOR MODELING

BJT transistor modeling is an area that can be approached in a variety of ways. Some institutions employ the r_e model exclusively, while others lean toward the hybrid approach or to a combination of the two. This edition will emphasize the r_e model with sufficient coverage of the hybrid model to permit a comparison between the results obtained with each approach. An entire chapter (Chapter 7) has been devoted to the introduction of the models to ensure a clear, correct understanding of each and the relationships that exist between the two.

EQUATION DEVELOPMENT

For years the development of the equations for small-signal BJT and JFET networks avoided the impact of the output parameter r_o. In addition, results were often provided with no idea how they were obtained. Further, approximate equations were provided with no idea what conditions had to be satisfied to permit use of the equations. For these reasons, and probably others, the details of each derivation are provided in this text. The effect of r_o was separated for each development to first permit a less complex development. The effect of r_o was then demonstrated and the conditions under which the effect of r_o can be ignored were introduced. In most cases, the derivations are unique to any publication of this type. They were the result of extensive hours searching for the best path for the analysis. However, the result is a complete development of each equation that we hope will remove any doubt as to their validity.

COMPUTER SOFTWARE

In recent editions, both PSpice and Electronics Workbench examples were included. For this edition Mathcad was added to demonstrate the versatility of the package for an area such as electronics. Not only can it be used to quickly solve simultaneous equations, but also long series of calculations can be placed in storage for retrieval when a particular configuration is encountered. Numerous examples appear throughout the text, and we believe the student and instructor will find them quite interesting. The detailed coverage of PSpice was expanded slightly, but there is a larger expansion of the coverage of Electronics Workbench due to its growing popularity. For all the software packages there is no requirement that the student become versed in their use to proceed through the text. Although sufficient detail is provided for each application to permit a student to apply each to a variety of configurations, there is no requirement that the packages actually be used.

TROUBLESHOOTING

Troubleshooting is undoubtedly one of the most difficult subjects to discuss and develop in an introductory text. A student is just becoming familiar with the characteristics and operation of a device and now is asked to find an answer to an unexpected result. It is an art that has to develop with experience and exposure. The content of this text is essentially a review of situations that frequently occur in the laboratory environment. Some general hints as to how to isolate a problem are introduced along with a list of typical causes.

ANCILLARIES

The range of ancillary material is quite extensive, including a laboratory manual to which new experiments have been added. There is also an instructor's resource manual, which contains solutions to the in-text problems and the laboratory experiments as well as a test item file. PowerPoint® transparencies and a Prentice Hall Test Manager are also available.

The CD-ROM included with every copy of the book contains Electronics Workbench Version 5 and Multisim circuit files and CircuitMaker Student Version Software and circuit files. Circuits appearing on the CD-ROM are designated in the text by a special icon next to the selected illustration.

Additional support for the student can be found at www.prenhall.com/boylestad in the form of an online student study guide. CourseCompass and Blackboard complete the supplements package.

USE OF THE TEXT

In general the text is divided into two main components: the dc analysis and the ac or frequency response. For some schools the dc section is sufficient for a one-semester introductory sequence, while for others the entire text may be covered in one semester by picking and choosing specific topics. In any event, the text is one that "builds" from the earlier chapters. Superfluous material is relegated to the later chapters to avoid excessive content on a particular subject early in the development stage. For each device the text covers a majority of the important configurations and applications—the text is very complete! By choosing specific examples and applications the instructor can reduce the content of a course without losing the progressive building characteristics of the text. Then again, if an instructor feels that a specific area is particularly important, the detail is provided for a more extensive review.

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Louis Nashelsky

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