# electronic devices and circuit theory

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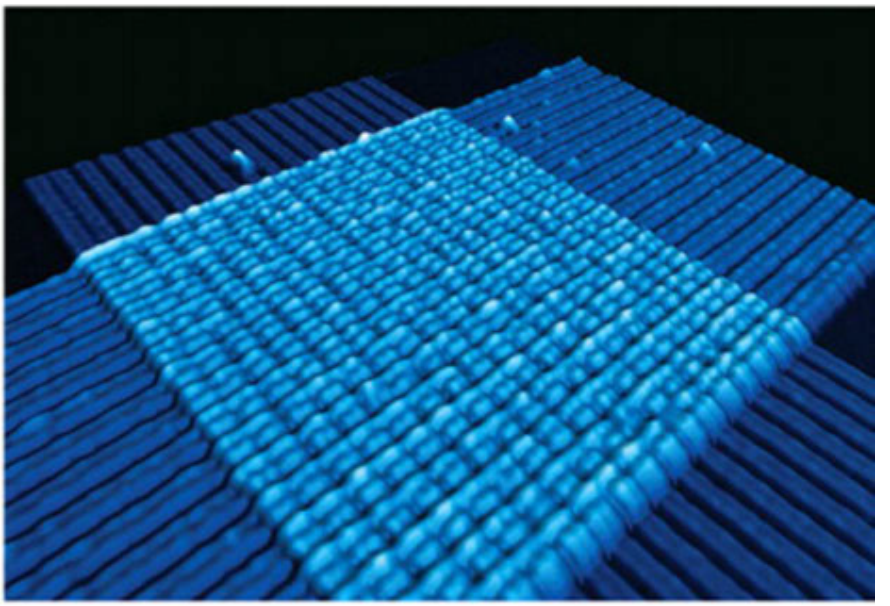

eleventh edition

# SIGNIFICANT EQU

**1 Semiconductor Diodes** $W = QV$, 1 eV $= 1.6 \times 10^{-19}$ J, $I_D = I_s\,(e^{V_D/nV_T} -$ $k = 1.38 \times 10^{-23}$ J/K, $V_K \cong 0.7$ V (Si), $V_K \cong 0.3$ V(Ge), $V_K \cong 1.2$ V (GaAs), $R_D$ $P_D = V_D I_D, T_C = (\Delta V_Z/V_Z)/(T_1 - T_0) \times 100\%/°\text{C}$

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

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

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

**5 BJT AC Analysis** $r_e = 26\text{ mV}/I_E$; CE fixed-bias: $Z_i \cong \beta r_e, Z_o \cong R_C, A_v = -R$ $A_v = -R_C/r_e$; CE emitter-bias: $Z_i \cong R_B \| \beta R_E, Z_o \cong R_C, A_v \cong -R_C/R_E$; emitter-foll common-base: $Z_i \cong R_E \| r_e, Z_o \cong R_C, A_v \cong R_C/r_e$; collector feedback: $Z_i \cong r_e/(1/\beta$ dc feedback: $Z_i \cong R_{F_1} \| \beta r_e, Z_o \cong R_C \| R_{F_2}, A_v = -(R_{F_2} \| R_C)/r_e$; effect of load imp effect of source impedance: $V_i = R_iV_s/(R_i + R_s)$, $A_{v_s} = R_iA_{v_{\text{NL}}}/(R_i + R_s), I_s = V_s/($ impedance: $A_v = R_LA_{v_{\text{NL}}}/(R_L + R_o)$, $A_{v_s} = (R_i/(R_i + R_s))(R_L/(R_L + R_o))A_{v_{\text{NL}}}, A_i =$ connection: $A_v = A_{v_1}A_{v_2}$; Darlington connection: $\beta_D = \beta_1\beta_2$; emitter-follower config $I_C \cong I_E \cong \beta_D I_B, Z_i = R_B \| \beta_1\beta_2 R_E, A_i = \beta_D R_B/(R_B + \beta_D R_E), A_v \cong 1, Z_o = r_{e_1}/\beta_2$

**9 BJT and JFET Frequency Response** $\log_e a = 2.3 \log_{10} a$, $\log_{10} 1 = 0$, $\log_{10} a/b = \log$
$\log_{10} ab = \log_{10} a + \log_{10} b$, $G_{\text{dB}} = 10 \log_{10} P_2/P_1$, $G_{\text{dBm}} = 10 \log_{10} P_2/1 \text{ mW}|_{600\,\Omega}$, $G_{\text{dB}} = 2$
$G_{dB_T} = G_{dB_1} + G_{dB_2} + \cdots + G_{dB_n}$ $P_{o_{HPF}} = 0.5 P_{o_{\text{mid}}}$, BW $= f_1 - f_2$; low frequency (BJT): $f_{L_S}$ =
$f_{L_C} = 1/2\pi(R_o + R_L)C_C$, $f_{L_E} = 1/2\pi R_e C_E$, $R_e = R_E \| (R'_s/\beta + r_e)$, $R'_s = R_s \| R_1 \| R_2$, FET: $f_L$
$f_{L_C} = 1/2\pi(R_o + R_L)C_C$, $f_{L_S} = 1/2\pi R_{eq} C_S$, $R_{eq} = R_S \| 1/g_m (r_d \cong \infty\ \Omega)$; Miller effect: $C_{M_i}$ =
high frequency (BJT): $f_{H_i} = 1/2\pi R_{\text{Th}_i} C_i$, $R_{\text{Th}_i} = R_s \| R_1 \| R_2 \| R_i$, $C_i = C_{w_i} + C_{be} + (1 - A_v)$
$R_{\text{Th}_o} = R_C \| R_L \| r_o$, $C_o = C_{W_o} + C_{ce} + C_{M_o}$, $f_\beta \cong 1/2\pi\beta_{\text{mid}} r_e (C_{be} + C_{bc})$, $f_T = \beta_{\text{mid}} f_\beta$; FE
$C_i = C_{W_i} + C_{gs} + C_{M_i}$, $C_{M_i} = (1 - A_v) C_{gd}$ $f_{H_o} = 1/2\pi R_{\text{Th}_o} C_o$, $R_{\text{Th}_o} = R_D \| R_L \| r_d$, $C_o =$
multistage: $f'_1 = f_1/\sqrt{2^{1/n} - 1}$, $f'_2 = (\sqrt{2^{1/n} - 1}) f_2$; square-wave testing: $f_{H_i} = 0.35/t_r$, % ti
$f_{L_o} = (P/\pi) f_s$

**10 Operational Amplifiers** CMRR $= A_d/A_c$; CMRR(log) $= 20 \log_{10}(A_d/A_c)$; constant-gai
noninverting amplifier: $V_o/V_1 = 1 + R_f/R_1$; unity follower: $V_o = V_1$; summing amplifier: $V_o$ =
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: $A = 1 +$
$V_o = -[(R_f/R_1)V_1 + (R_f/R_2)V_2 + (R_f/R_3)V_3]$; high-pass active filter: $f_{oL} = 1/2\pi R_1 C_1$; low-pa

**12 Power Amplifiers**

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

power out: $P_o = V_{CE} I_C = I_C^2 R_C = V_{CE}^2/R_C$ 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,
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 o
$(I_{C\,\max} - I_{C\,\min})]/8$; class B power amplifier: $P_i = V_{CC}[(2/\pi) I_{\text{peak}}]$; $P_o = V_L^2(\text{peak})/(2R_L)$; %
$P_Q = P_{2Q}/2 = (P_i - P_o)/2$; maximum $P_o = V_{CC}^2/2R_L$; maximum $P_i = 2V_{CC}^2/\pi R_L$; maximun
distortion (% THD) $= \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} \times 100\%$; heat-sink: $T_J = P_D \theta_{JA} + T_A$, $\theta_{JA}$ =
$P_D = (T_J - T_A)/(\theta_{JC} + \theta_{CS} + \theta_{SA})$

**13 Linear-Digital ICs** Ladder network: $V_o = [(D_0 \times 2^0 + D_1 \times 2^1 + D_2 \times 2^2 + \cdots +$
555 oscillator: $f = 1.44(R_A + 2R_B)C$; 555 monostable: $T_{\text{high}} = 1.1 R_A C$; VCO: $f_o = (2/R_1 C_1)[$
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: $Z_{if} = Z_i(1 + \beta A$

# Electronic Devices and Circuit Theory

Eleventh Edition

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# D

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

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

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# PR

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

We are often asked about the revision process and how the content of a ne
defined. In some cases, it is quite obvious that the computer software has be
and the changes in application of the packages must be spelled out in deta
was the first to emphasize the use of computer software packages and prov
of detail unavailable in other texts. With each new version of a software p
have found that the supporting literature may still be in production, or the n
the detail for new users of these packages. Sufficient detail in this text en
student can apply each of the software packages covered without additio
tional material.

The next requirement with any new edition is the need to update the conte
changes in the available devices and in the characteristics of commercial d
can require extensive research in each area, followed by decisions regardi
coverage and whether the listed improvements in response are valid and des
nition. The classroom experience is probably one of the most important re
defining areas that need expansion, deletion, or revision. The feedback fr
results in marked-up copies of our texts with inserts creating a mushrooming

the last edition. When you consider the number
along with the length of the text material, this stat
error-free as possible. Any contributions from us
edged, and the sources were thanked for taking th
lisher and to us.

Although the current edition now reflects all t
expect that a revised edition will be required some
respond to this edition so that we can start developi
will help us improve the content for the next editio
comments, whether positive or negative.

## NEW TO THIS EDITION

- Throughout the chapters, there are extensive cha
new problems have been added, and a significan
the existing problems.
- A significant number of computer programs wer
to include the effects of using OrCAD version 1
tion, the introductory chapters are now assumin
methods, resulting in a revised introduction to th
- Throughout the text, photos and biographies of i
Included among these are Sidney Darlington, V
Colpitts, and Ralph Hartley.
- New sections were added throughout the text. T
of combined dc and ac sources on diode netwo
and UMOS power FETs, Early voltage, freq
effect of $R_S$ on an amplifier's frequency resp
number of other topics.
- A number of sections were completely rewr
changing priorities. Some of the areas revis
sources, feedback in the dc and ac modes, m
response, transition and diffusion capacitive ef
characteristics, reverse-saturation current, brea
the hybrid model.
- In addition to the revision of numerous sections
sections that have been expanded to respond to
kind. The section on solar cells now includes a
employed, additional response curves, and a nu
coverage of the Darlington effect was totally rev
examination of the emitter-follower and collect

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

**PowerPoint Presentation**–(ISBN 0132783746). This supplement contains from the text as well as a new set of lecture notes highlighting important conc

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

**Instructor's Resource Manual**–(ISBN 0132783738). This supplement conta tions to the problems in the text and lab manual.

## STUDENT SUPPLEMENTS

**Laboratory Manual**–(ISBN 0132622459) . This supplement contains over 35 experiments for students to use to demonstrate their comprehension of course

**Companion Website**–Student study resources are available at **www.pearsc com/boylestad**

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