

SCHAUM'S
ouTlines

BASIC CIRCUIT ANALYSIS

Second Edition

JOHN O'MALLEY

- The perfect aid for better grades!
- Covers all course fundamentals—including op-amp circuits and PSpice
- Teaches effective problem solving
- 700 problems solved step-by-step
- Ideal for independent study!



Buy with Best Overall: New Circuit Analysis Revised Edition
 Revised Engineering Circuit Analysis Introduction to Circuit Analysis AC & DC Circuits

SCHAUM'S OUTLINE OF

THEORY AND PROBLEMS

of

**BASIC CIRCUIT
ANALYSIS**

Second Edition

JOHN O'MALLEY, Ph.D.

*Professor of Electrical Engineering
University of Florida*

SCHAUM'S OUTLINE SERIES

McGRAW-HILL

*New York San Francisco Washington, D.C. Auckland Bogotá Caracas Lisbon
London Madrid Mexico City Milan Montreal New Dehli
San Juan Singapore Sydney Tokyo Toronto*

visit www.mrlupen.com

JOHN R. O'MALLEY is a Professor of Electrical Engineering at the University of Florida. He received a Ph.D. degree from the University of Florida and an LL.B. degree from Georgetown University. He is the author of two books on circuit analysis and two on the digital computer. He has been teaching courses in electric circuit analysis since 1959.

Schaum's Outline of Theory and Problems of
BASIC CIRCUIT ANALYSIS

Copyright © 1992, 1982 by The McGraw-Hill Companies Inc. All rights reserved. Printed in the United States of America. Except as permitted under the Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

9 10 11 12 13 14 15 16 17 18 19 20 PRS PRS 9

ISBN 0-07-047824-4

Sponsoring Editor: John Aliano
Production Supervisor: Louise Karam
Editing Supervisors: Meg Tobin, Maureen Walker

Library of Congress Cataloging-in-Publication Data

O'Malley, John.
Schaum's outline of theory and problems of basic circuit analysis
John O'Malley. -- 2nd ed.
p. c.m. (Schaum's outline series)
Includes index.
ISBN 0-07-047824-4
1. Electric circuits. 2. Electric circuit analysis. I. Title.
TK454.O46 1992
621.319'2 dc20

90-26615

McGraw-Hill

A Division of The McGraw-Hill Companies



visit www.mrlupen.com

*Dedicated to the loving memory of my brother
Norman Joseph O'Malley
Lawyer, engineer, and mentor*

visit www.mrlupen.com

This page intentionally left blank

visit www.mrlupen.com

Preface

Studying from this book will help both electrical technology and electrical engineering students learn circuit analysis with, it is hoped, less effort and more understanding. Since this book begins with the analysis of dc resistive circuits and continues to that of ac circuits, as do the popular circuit analysis textbooks, a student can, from the start, use this book as a supplement to a circuit analysis textbook.

The reader does not need a knowledge of differential or integral calculus even though this book has derivatives in the chapters on capacitors, inductors, and transformers, as is required for the voltage-current relations. The few problems with derivatives have clear physical explanations of them, and there is not a single integral anywhere in the book. Despite its lack of higher mathematics, this book can be very useful to an electrical engineering reader since most material in an electrical engineering circuit analysis course requires only a knowledge of algebra. Where there are different definitions in the electrical technology and engineering fields, as for capacitive reactances, phasors, and reactive power, the reader is cautioned and the various definitions are explained.

One of the special features of this book is the presentation of PSpice, which is a computer circuit analysis or simulation program that is suitable for use on personal computers (PCs). PSpice is similar to SPICE, which has become the standard for analog circuit simulation for the entire electronics industry. Another special feature is the presentation of operational-amplifier (op-amp) circuits. Both of these topics are new to this second edition. Another topic that has been added is the use of advanced scientific calculators to solve the simultaneous equations that arise in circuit analyses. Although this use requires placing the equations in matrix form, absolutely no knowledge of matrix algebra is required. Finally, there are many more problems involving circuits that contain dependent sources than there were in the first edition.

I wish to thank Dr. R. L. Sullivan, who, while I was writing this second edition, was Chairman of the Department of Electrical Engineering at the University of Florida. He nurtured an environment that made it conducive to the writing of books. Thanks are also due to my wife, Lois Anne, and my son Mathew for their constant support and encouragement without which I could not have written this second edition.

JOHN R. O'MALLEY

This page intentionally left blank

visit www.mrlupen.com

Contents

Chapter 1	BASIC CONCEPTS	1
	Digit Grouping	1
	International System of Units	1
	Electric Charge	1
	Electric Current	2
	Voltage	3
	Dependent Sources	4
	Power	5
	Energy	5
<hr/>		
Chapter 2	RESISTANCE	17
	Ohm's Law	17
	Resistivity	17
	Temperature Effects	18
	Resistors	19
	Resistor Power Absorption	19
	Nominal Values and Tolerances	19
	Color Code	20
	Open and Short Circuits	20
	Internal Resistance	20
<hr/>		
Chapter 3	SERIES AND PARALLEL DC CIRCUITS	31
	Branches, Nodes, Loops, Meshes, Series- and Parallel-Connected Components	31
	Kirchhoff's Voltage Law and Series DC Circuits	31
	Voltage Division	32
	Kirchhoff's Current Law and Parallel DC Circuits	32
	Current Division	34
	Kilohm-Milliampere Method	34
<hr/>		
Chapter 4	DC CIRCUIT ANALYSIS	54
	Cramer's Rule	54
	Calculator Solutions	55
	Source Transformations	56
	Mesh Analysis	56
	Loop Analysis	57
	Nodal Analysis	58
	Dependent Sources and Circuit Analysis	59
<hr/>		
Chapter 5	DC EQUIVALENT CIRCUITS, NETWORK THEOREMS, AND BRIDGE CIRCUITS	82
	Introduction	82
	Thévenin's and Norton's Theorems	82
	Maximum Power Transfer Theorem	84
	Superposition Theorem	84
	Millman's Theorem	84
	Y- Δ and Δ -Y Transformations	85
	Bridge Circuits	86

Chapter 6	OPERATIONAL-AMPLIFIER CIRCUITS	112
	Introduction	112
	Op-Amp Operation	112
	Popular Op-Amp Circuits	114
	Circuits with Multiple Operational Amplifiers	116
<hr/>		
Chapter 7	PSPICE DC CIRCUIT ANALYSIS	136
	Introduction	136
	Basic Statements	136
	Dependent Sources	138
	.DC and .PRINT Control Statements	139
	Restrictions	140
<hr/>		
Chapter 8	CAPACITORS AND CAPACITANCE	153
	Introduction	153
	Capacitance	153
	Capacitor Construction	153
	Total Capacitance	154
	Energy Storage	155
	Time-Varying Voltages and Currents	155
	Capacitor Current	156
	Single-Capacitor DC-Excited Circuits	156
	RC Timers and Oscillators	157
<hr/>		
Chapter 9	INDUCTORS, INDUCTANCE, AND PSPICE TRANSIENT ANALYSIS	174
	Introduction	174
	Magnetic Flux	174
	Inductance and Inductor Construction	175
	Inductor Voltage and Current Relation	175
	Total Inductance	176
	Energy Storage	177
	Single-Inductor DC-Excited Circuits	177
	PSpice Transient Analysis	177
<hr/>		
Chapter 10	SINUSOIDAL ALTERNATING VOLTAGE AND CURRENT	194
	Introduction	194
	Sine and Cosine Waves	195
	Phase Relations	197
	Average Value	198
	Resistor Sinusoidal Response	198
	Effective or RMS Values	198
	Inductor Sinusoidal Response	199
	Capacitor Sinusoidal Response	200
<hr/>		
Chapter 11	COMPLEX ALGEBRA AND PHASORS	217
	Introduction	217
	Imaginary Numbers	217
	Complex Numbers and the Rectangular Form	218
	Polar Form	219
	Phasors	221
<hr/>		
Chapter 12	BASIC AC CIRCUIT ANALYSIS, IMPEDANCE, AND ADMITTANCE	232
	Introduction	232
	Phasor-Domain Circuit Elements	232
	AC Series Circuit Analysis	234

	Impedance	234
	Voltage Division	236
	AC Parallel Circuit Analysis	237
	Admittance	238
	Current Division	239
<hr/>		
Chapter 13	MESH, LOOP, NODAL, AND PSPICE ANALYSES OF AC CIRCUITS	265
	Introduction	265
	Source Transformations	265
	Mesh and Loop Analyses	265
	Nodal Analysis	267
	PSpice AC Analysis	268
<hr/>		
Chapter 14	AC EQUIVALENT CIRCUITS, NETWORK THEOREMS, AND BRIDGE CIRCUITS	294
	Introduction	294
	Thévenin's and Norton's Theorems	294
	Maximum Power Transfer Theorem	295
	Superposition Theorem	295
	AC Y- Δ and Δ -Y Transformations	296
	AC Bridge Circuits	296
<hr/>		
Chapter 15	POWER IN AC CIRCUITS	324
	Introduction	324
	Circuit Power Absorption	324
	Wattmeters	325
	Reactive Power	326
	Complex Power and Apparent Power	326
	Power Factor Correction	327
<hr/>		
Chapter 16	TRANSFORMERS	349
	Introduction	349
	Right-Hand Rule	349
	Dot Convention	350
	The Ideal Transformer	350
	The Air-Core Transformer	352
	The Autotransformer	354
	PSpice and Transformers	356
<hr/>		
Chapter 17	THREE-PHASE CIRCUITS	384
	Introduction	384
	Subscript Notation	384
	Three-Phase Voltage Generation	384
	Generator Winding Connections	385
	Phase Sequence	386
	Balanced Y Circuit	387
	Balanced Δ Load	389
	Parallel Loads	390
	Power	391
	Three-Phase Power Measurements	391
	Unbalanced Circuits	393
	PSpice Analysis of Three-Phase Circuits	393
<hr/>		
	INDEX	415

Chapter 8

Capacitors and Capacitance

INTRODUCTION

A *capacitor* consists of two conductors separated by an insulator. The chief feature of a capacitor is its ability to store electric charge, with negative charge on one of its two conductors and positive charge on the other. Accompanying this charge is energy, which a capacitor can release. Figure 8-1 shows the circuit symbol for a capacitor

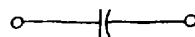


Fig. 8-1

CAPACITANCE

Capacitance, the electrical property of capacitors, is a measure of the ability of a capacitor to store charge on its two conductors. Specifically, if the potential difference between the two conductors is V volts when there is a positive charge of Q coulombs on one conductor and a negative charge of the same amount on the other, the capacitor has a capacitance of

$$C = \frac{Q}{V}$$

where C is the quantity symbol of capacitance.

The SI unit of capacitance is the *farad*, with symbol F. Unfortunately, the farad is much too large a unit for practical applications, and the microfarad (μF) and picofarad (pF) are much more common.

CAPACITOR CONSTRUCTION

One common type of capacitor is the parallel-plate capacitor of Fig. 8-2a. This capacitor has two spaced conducting plates that can be rectangular, as shown, but that often are circular. The insulator between the plates is called a *dielectric*. The dielectric is air in Fig. 8-2a, and is a slab of solid insulator in Fig. 8-2b.

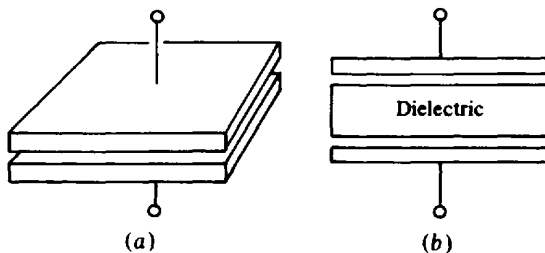


Fig. 8-2

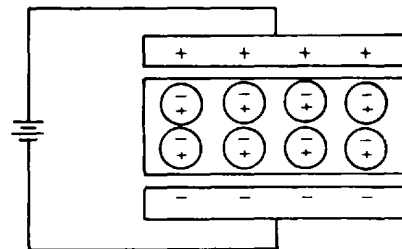


Fig. 8-3

A voltage source connected to a capacitor, as shown in Fig. 8-3, causes the capacitor to become charged. Electrons from the top plate are attracted to the positive terminal of the source, and they pass through the source to the negative terminal where they are repelled to the bottom plate. Because each electron lost by the top plate is gained by the bottom plate, the magnitude of charge Q is the same on

both plates. Of course, the voltage across the capacitor from this charge exactly equals the source voltage. The voltage source did work on the electrons in moving them to the bottom plate, which work becomes energy stored in the capacitor.

For the parallel-plate capacitor, the capacitance in farads is

$$C = \epsilon \frac{A}{d}$$

where A is the area of either plate in square meters, d is the separation in meters, and ϵ is the *permittivity* in farads per meter (F/m) of the dielectric. The larger the plate area or the smaller the plate separation, or the greater the dielectric permittivity, the greater the capacitance.

The permittivity ϵ relates to atomic effects in the dielectric. As shown in Fig. 8-3, the charges on the capacitor plates distort the dielectric atoms, with the result that there is a net negative charge on the top dielectric surface and a net positive charge on the bottom dielectric surface. This dielectric charge partially neutralizes the effects of the stored charge to permit an increase in charge for the same voltage.

The permittivity of vacuum, designated by ϵ_0 , is 8.85 pF·m. Permittivities of other dielectrics are related to that of vacuum by a factor called the *dielectric constant* or *relative permittivity*, designated by ϵ_r . The relation is $\epsilon = \epsilon_r \epsilon_0$. The dielectric constants of some common dielectrics are 1.0006 for air, 2.5 for paraffined paper, 5 for mica, 7.5 for glass, and 7500 for ceramic.

TOTAL CAPACITANCE

The total or equivalent capacitance (C_T or C_{eq}) of parallel capacitors, as seen in Fig. 8-4a, can be found from the total stored charge and the $Q = CV$ formula. The total stored charge Q_T equals the sum of the individual stored charges: $Q_T = Q_1 + Q_2 + Q_3$. With the substitution of the appropriate $Q = CV$ for each Q , this equation becomes $C_T V = C_1 V + C_2 V + C_3 V$. Upon division by V , it reduces to $C_T = C_1 + C_2 + C_3$. Because the number of capacitors is not significant in this derivation, this result can be generalized to any number of parallel capacitors:

$$C_T = C_1 + C_2 + C_3 + C_4 + \dots$$

So, the total or equivalent capacitance of parallel capacitors is the sum of the individual capacitances.

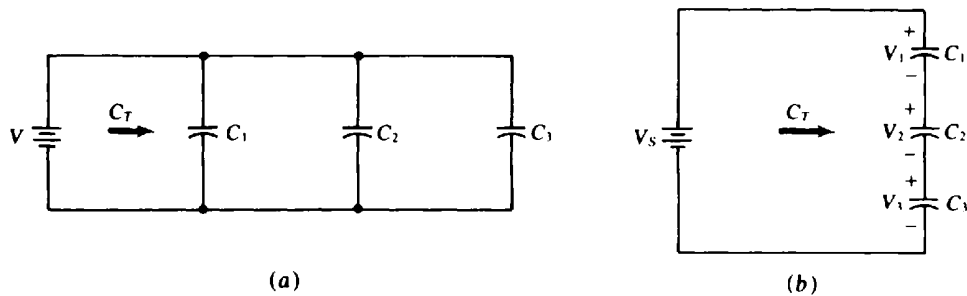


Fig. 8-4

For series capacitors, as shown in Fig. 8-4b, the formula for the total capacitance is derived by substituting Q/C for each V in the KVL equation. The Q in each term is the same. This is because the charge gained by a plate of any capacitor must have come from a plate of an adjacent capacitor. The KVL equation for the circuit shown in Fig. 8-4b is $V_S = V_1 + V_2 + V_3$. With the substitution of the appropriate Q/C for each V , this equation becomes

$$\frac{Q}{C_T} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \quad \text{or} \quad \frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

upon division by Q . This can also be written as

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Generalizing,

$$C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4} + \dots}$$

which specifies that the total capacitance of series capacitors equals the reciprocal of the sum of the reciprocals of the individual capacitances. Notice that the total capacitance of series capacitors is found in the same way as the total resistance of parallel resistors.

For the special case of N series capacitors having the same capacitance C , this formula simplifies to $C_T = C/N$. And for two capacitors in series it is $C_T = C_1 C_2 / (C_1 + C_2)$.

ENERGY STORAGE

As can be shown using calculus, the energy stored in a capacitor is

$$W_C = \frac{1}{2} C V^2$$

where W_C is in joules, C is in farads, and V is in volts. Notice that this stored energy does not depend on the capacitor current.

TIME-VARYING VOLTAGES AND CURRENTS

In dc resistor circuits, the currents and voltages are constant—never varying. Even if switches are included, a switching operation can, at most, cause a voltage or current to jump from one constant level to another. (The term “jump” means a change from one value to another in zero time.) When capacitors are included, though, almost never does a voltage or a current jump from one constant level to another when switches open or close. Some voltages or currents may initially jump at switching, but the jumps are almost never to final values. Instead, they are to values from which the voltages or currents change *exponentially* to their final values. These voltages and currents vary with time—they are *time-varying*.

Quantity symbols for time-varying quantities are distinguished from those for constant quantities by the use of lowercase letters instead of uppercase letters. For example, v and i are the quantity symbols for time-varying voltages and currents. Sometimes, the lowercase t , for time, is shown as an argument with lowercase quantity symbols as in $v(t)$ and $i(t)$. Numerical values of v and i are called *instantaneous values*, or *instantaneous voltages* and *currents*, because these values depend on (vary with) exact instants of time.

As explained in Chap. 1, a constant current is the quotient of the charge Q passing a point in a wire and the time T required for this charge to pass: $I = Q/T$. The specific time T is not important because the charge in a resistive dc circuit flows at a steady rate. This means that doubling the time T doubles the charge Q , tripling the time triples the charge, and so on, keeping I the same.

For a time-varying current, though, the value of i usually changes from instant to instant. So, finding the current at any particular time requires using a very short time interval Δt . If Δq is the small charge that flows during this time interval, then the current is approximately $\Delta q / \Delta t$. For an exact value of current, this quotient must be found in the limit as Δt approaches zero ($\Delta t \rightarrow 0$):

$$i = \lim_{\Delta t \rightarrow 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

This limit, designated by dq/dt , is called the *derivative* of charge with respect to time.