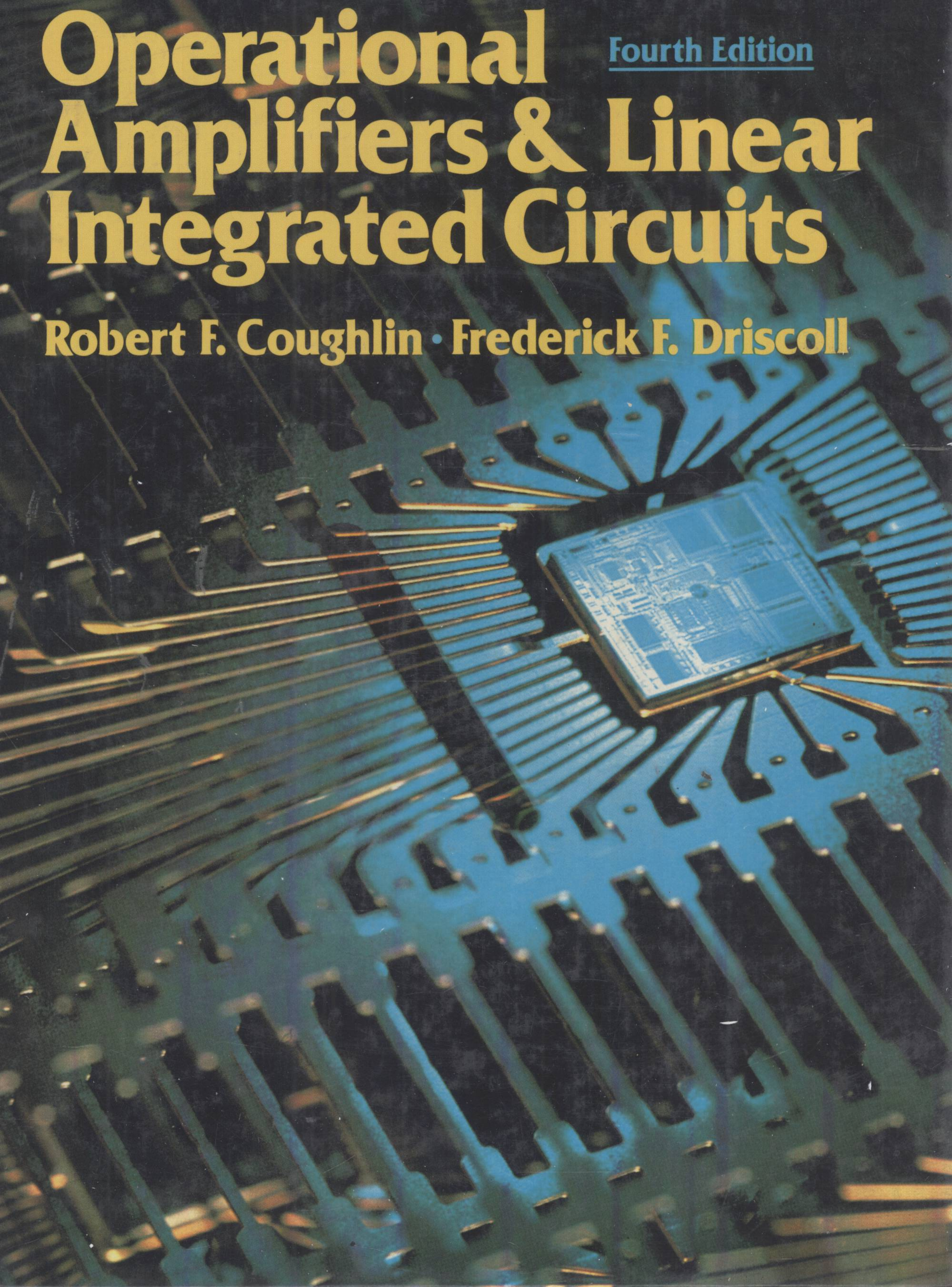
Operational Amplifiers & Linear Integrated Circuits

Fourth Edition

Robert F. Coughlin · Frederick F. Driscoll



FOURTH EDITION

OPERATIONAL AMPLIFIERS AND LINEAR INTEGRATED CIRCUITS

Robert F. Coughlin
Frederick F. Driscoll

PRENTICE HALL, Englewood Cliffs, New Jersey 07632

Library of Congress Cataloging-in-Publication Data

Coughlin, Robert F.
Operational amplifiers and linear integrated circuits / Robert F. Coughlin, Frederick F. Driscoll. -- 4th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-639923-1
1. Operational amplifiers. 2. Linear integrated circuits. I. Driscoll, Frederick F., 1943- . II. Title.
TK7871.58.06C68 1991
621.39'5--dc20 90-43585
CIP

Editorial/production supervision: *Ellen Denning*
Interior design: *Jayne Conte*
Cover design: *Bruce Kenselaar*
Manufacturing buyer: *Ed O'Dougherty*
Cover photograph: Gary Gladstone/The Image Bank

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

ISBN 0-13-639923-1

PRENTICE-HALL INTERNATIONAL (UK) LIMITED, *London*
PRENTICE-HALL OF AUSTRALIA PTY. LIMITED, *Sydney*
PRENTICE-HALL CANADA INC., *Toronto*
PRENTICE-HALL HISPANOAMERICANA, S.A., *Mexico*
PRENTICE-HALL OF INDIA PRIVATE LIMITED, *New Delhi*
PRENTICE-HALL OF JAPAN, INC., *Tokyo*
SIMON & SCHUSTER ASIA PTE. LTD., *Singapore*
EDITORA PRENTICE-HALL DO BRASIL, LTDA., *Rio de Janeiro*

To Our Partners in Ballroom Dancing
and
Our Lifetime Partners,
Barbara and *Jean*

As
We Grow Older
We Grow Closer

Preface

It has been our purpose in the first three editions, and again now in the fourth edition of this text, to show that operational amplifiers and other linear integrated circuits are both fun and easy to use, especially if the application does not require the devices to operate near their design limits. It is the purpose of this book to show just how easy they are to use in a variety of applications involving instrumentation, signal generation, filter, and control circuits.

When first learning how to use an op amp, one should *not* be presented with a myriad of op amps and asked to make an informed selection. For this reason, our introduction begins with an inexpensive, reliable op amp that forgives most mistakes in wiring, ignores long lead capacitance, and does not burn out easily. Such an op amp is the 741, whose characteristics are documented in Appendix 1 and whose applications are sprinkled throughout the text.

If a slightly faster op amp is needed for a wider bandwidth, another inexpensive and widely used op amp is the 301. See Appendix 2 for its electrical characteristics and Chapter 10 to learn when one might prefer the 301 over the 741. We also use the stable CA3140 and TL081, which are pin-for-pin higher-frequency replacements for the 741.

Where appropriate, we have added specialized op amps: the LM339 single supply comparator in Chapter 2 and the LM311 high-performance comparator in Chapter 4. Where better dc performance is required, we have added BiFET op amps in Chapter 7. The excellent low-bias-current and low-offset-voltage OP-07 is also employed for instrumentation applications.

The fourth edition is organized into a set of core chapters that should be read first. They are Chapters 1 through 6 and proceed in a logical teaching sequence to show how the op amp can be used to solve a variety of application problems.

The limitations of op amps are not discussed in Chapters 1 to 6 because it is very important to gain confidence in using op amps before pushing performance to its limits. When studying transistors or other devices, we do not begin with their limitations. Regrettably, much of the early literature on integrated circuits begins with their limitations and thus obscures the inherent simplicity and overwhelming advantages of basic integrated circuits over basic transistor circuits. For these reasons, op amp limitations are not presented until Chapters 9 and 10 for those readers who need to understand some of their limitations with respect to dc and ac performance. Furthermore, not all op amp limitations apply to every op amp circuit. For example, dc op amp limitations such as offset voltages are usually not important if the op amp is used in an ac amplifier circuit. Thus dc limitations (Chapter 9) are treated separately from ac limitations (Chapter 10). The remaining chapters have been written to stand alone. They can be studied in any order after completion of Chapters 1 through 6.

The servoamplifier and subtractor circuits have been added to Chapter 5. Chapter 6 has been extensively rewritten to show the latest techniques using a modulator/demodulator IC and trigonometric function generator IC to make a *precision* triangle/square/sine-wave generator whose frequency can be adjusted over a wide range by a *single* resistor and whose amplitude can be adjusted without affecting frequency, or vice versa.

Chapter 7 deals with the specialized applications that can best be accomplished by op amps combined with diodes.

Chapter 8 is concerned with problems of measuring physical variables such as force, pressure weight, and temperature. Bridge and instrumentation amplifiers are ideal for these measurements.

Chapter 11 simplifies the design of active filters. The four basic types of active filters are shown: low-pass, high-pass, band-pass, and band-reject filters. Butterworth filters were selected because they are often used and easy to design. If you want to design a three-pole (60-dB/decade) Butterworth low- or high-pass filter, Chapter 11 tells you how to do it in four steps with a pencil and paper. No calculator or computer program is required. Basic algebra is the only mathematics that is required throughout the text. The sections on bandpass and notch filters have been completely rewritten to simplify both their design procedures and fine tuning.

A fascinating integrated circuit, the multiplier, is presented in Chapter 12 because it makes analysis and design of communication circuits very easy. Modulators, demodulators, frequency shifters, a universal AM radio receiver, and a host of other applications are performed by the multiplier, an op amp, and a few resistors. This chapter has been retained because numerous instructors have written to say how useful it is as a hardware-oriented teaching tool that introduces the principles of single-sideband, suppressed-carrier, and standard amplitude-modulation principles used in radio communication.

Chapter 13 is included for those who need to use the ubiquitous 555 IC timer and/or the XR2240 counter timer.

A chapter (14) has been added (because of requests of many instructors) on digital-to-analog and analog-to-digital converters. More specifically, instructors have requested information on converters that (1) are microprocessor compatible, (2) simple to select via a data bus, (3) low in cost and easy to use, and (here comes the hard one) (4) stand-alone circuits for both a microprocessor-compatible DAC and an ADC that can be (a) breadboarded by students in a laboratory and (b) do *not* require a microprocessor. This has been done!

Since almost all linear integrated circuits require a regulated power supply, we have, because of requests from readers, retained material on power supply design and analysis and moved it to Chapter 15. The latest IC regulators are used to show how you can make excellent linear regulated supplies at low cost for (a) 5-V digital logic ICs, (b) $\pm$15-V linear ICs, (c) combined (a) and (b) for microprocessor supplies, and (d) either positive or negative adjustable supplies.

In this fourth edition we have incorporated suggestions from students, instructors, and practicing engineers and technicians from all parts of the United States and from Indonesia, Poland, Japan, and the USSR.

This edition contains more than enough material for a single-semester course. All circuits have been personally lab tested by the authors and their recommendations for laboratory work have been added to the end of each chapter. The material is suitable for both nonelectronic specialists who just want to learn something about linear ICs and for electronic majors who wish to use linear ICs. In addition, we have added Learning Objectives to the beginning of each chapter, again in response to requests from readers.

We thank Mrs. Phyllis Wolff for the preparation of the original manuscript and continued support in this fourth edition. A special thanks to our colleague Robert S. Villanucci who has been particularly helpful with his suggestions and for testing of ideas and to Dean Alexander Avtgis for his continued support.

We also thank two highly respected analog engineers, Dan Sheingold of

Analog Devices and Bob Pease of National Semiconductors, for their constructive criticism, technical corrections, and guidance in areas we found difficult.

Finally, we thank our students for their insistence on relevant instruction that is immediately useful, and our readers for both their enthusiastic reception of this book and their perceptive comments.

ROBERT F. COUGHLIN
FREDERICK F. DRISCOLL

Boston, Mass.

Contents