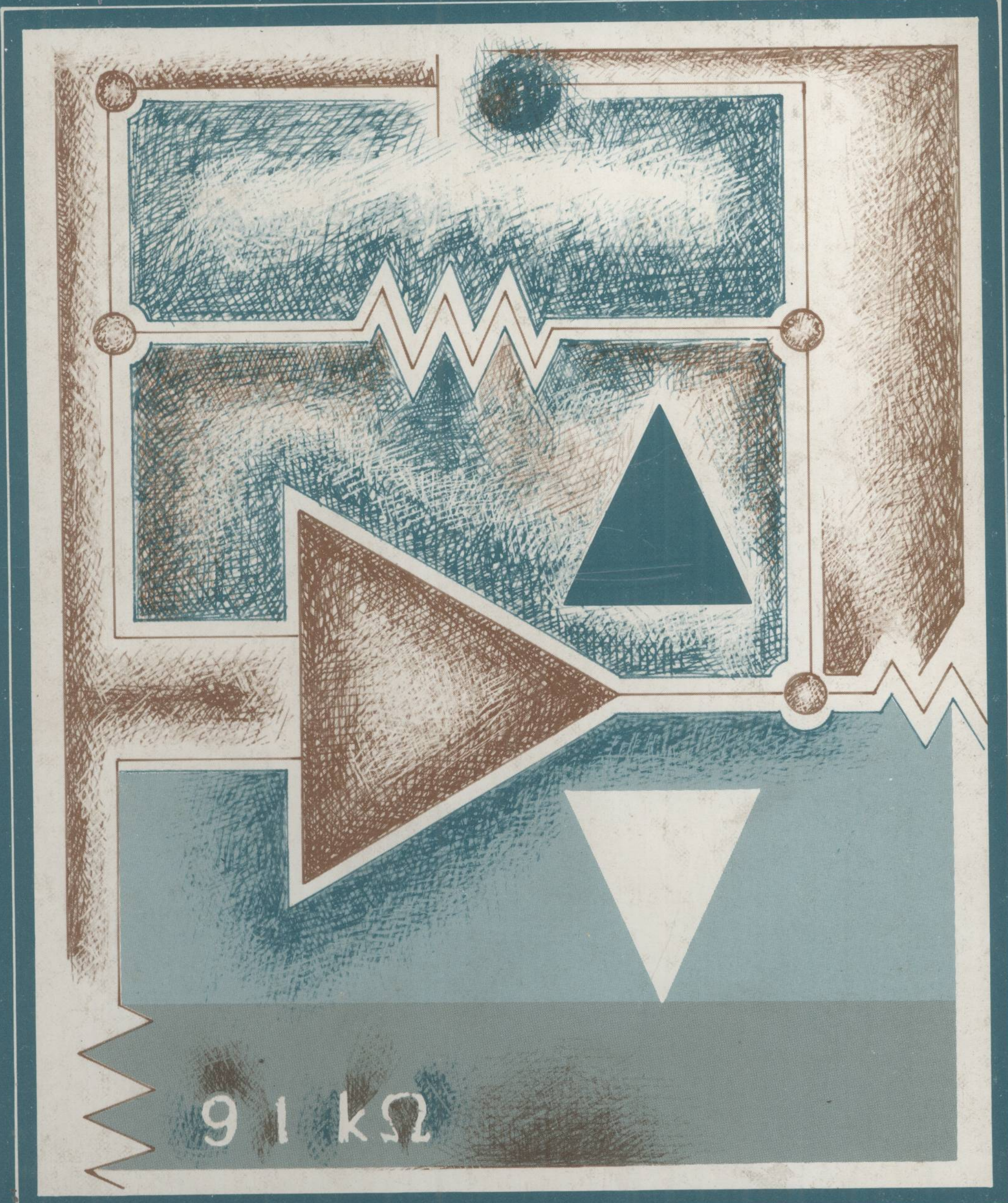
Luces M. Faulkenberry

AN INTRODUCTION TO OPERATIONAL AMPLIFIERS WITH LINEAR IC APPLICATIONS



Second Edition

AN INTRODUCTION TO OPERATIONAL AMPLIFIERS

WITH LINEAR IC APPLICATIONS

SECOND EDITION

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PREFACE

The second edition of this textbook is designed to introduce the student of electronics to operational amplifier operation, parameters, parameter measurement, and basic operational amplifier circuitry in a clear and easily understandable way. In addition, some special purpose linear circuits and amplifiers are presented. All material is presented with a minimum of mathematics consistent with reasonable accuracy. Practical considerations for component calculation and circuit set-up are emphasized throughout the text and laboratories, and important calculations are illustrated by worked examples.

The book is intended as a text for a one-semester course in operational amplifier theory and applications in community colleges, technical institutes, and two- and four-year technology programs. It is also intended for the working electronic technician who needs more information about operational amplifiers.

Each chapter consists of an introduction, objectives, text material and examples, a brief summary, self-test questions, and a laboratory. The laboratories are constructed to use commonly available test equipment that most schools have. The operational amplifiers specified are in widespread use. No special, hard to obtain components or supplies are required. Laboratory experiments are included from which instructors will select those parts of a laboratory exercise of greatest benefit for their particular classes.

Chapters 8, 10, and 11 are new in the second edition. Chapter 8 presents several types of active filters with an absolute minimum of mathematics. The student will, however, be able to construct high performance active filters on completing the chapter. Chapter 10 presents linear and switching power supply voltage regulators.

Both general principles and IC regulators are included. Chapter 11 introduces some special purpose IC amplifiers including comparators and some comparator applications, current differencing amplifiers, instrumentation amplifiers, and isolation amplifiers. 555 timers are also covered in Chapter 11. The rest of the changes in the book are things the author wishes he had done the first time. These primarily include clearer explanations and more examples.

The author does not feel that the sequencing of the chapters is sacred and expects an instructor to sequence the chapters in a manner that suits that instructor's course, as the author did. Some teachers prefer moving from Chapter 1 to Chapter 5 and the latter portion of the text, returning to the earlier chapters (2, 3, and 4) later. The text is intended to function well in this fashion.

The coverage of the book is as follows: Chapter 1 introduces the operational amplifier, its operation, and the basic amplifier configurations. Chapter 2 discusses negative feedback more generally, introduces some sources of error resulting from nonideal amplifiers, and explains external offset compensation. Chapter 3 covers bias current, CMRR, and their measurement, error due to temperature, and chopper stabilization. Chapter 4 covers frequency response, methods of phase compensation, and slew rate. Chapter 5 covers summing circuits. Chapter 6 covers integrators and differentiators. Chapter 7 presents logarithmic circuits and Chapter 8 active filters. Chapter 9 is a collection of circuits that illustrate common operational amplifier applications. Chapters 10 and 11 are on voltage regulators and special purpose linear ICs, respectively. Chapter 12 discusses noise and grounding. Appendix A is a differential amplifier review, and Appendix B is a discussion of the 741 internal operation. Appendix C is a collection of specifications. Appendixes D, E, and F are derivations too long for the text material. Appendix G is the answers to the self-test questions. A glossary of symbols and terms is included at the end of the book.

The student will need a basic understanding of transistors and algebra to use this text successfully. Chapter 7 uses some elementary differentiation and integration, but this small amount of calculus can be presented during the course, or read around.

My thanks to all who have provided guidance and support in the preparation of this text, especially to the curious and interested students whose questions forced the author to find simple and *clear* explanations.

Luces M. Faulkenberry

CONTENTS

CHAPTER

1

THE BASIC OP-AMP

To use operational amplifiers (op-amps), we must know what they are. This chapter discusses construction, characteristics, and some important specifications of op-amps. The major amplifier configurations using op-amps are also discussed.

OBJECTIVES

After completing the study of this chapter and the self-test questions, the student should be able to:

1. List and state the operation of the major parts of an op-amp.
2. State the name and purpose of the op-amp terminals.
3. State the name and definition of the following op-amp specs: A_{ol}, V_{os}, I_B, I_{os}, R_{in}, R_{out}.
4. Calculate the components of the feedback loop for a given closed loop gain and draw from memory a voltage follower, noninverting amplifier, inverting amplifier, and differential input amplifier.
5. Given the feedback components, calculate the closed loop gain for the circuits listed in objective 4.
6. Perform the laboratory for Chapter 1.

1-1 WHAT IS AN OP-AMP?

An operational amplifier is a modular, multistage amplifier with a differential input that approximates most of the characteristics of the mythical "ideal amplifier." The properties associated with an ideal amplifier are:

1. Infinite voltage gain ($A_v \rightarrow \infty$).
2. Infinite input impedance ($Z_{in} \rightarrow \infty$).
3. Zero output impedance ($Z_{out} \rightarrow 0$).
4. Output voltage $V_{out} = 0$ when input voltages $V_1 = V_2$.
5. Infinite bandwidth (no delay of the signal through the amplifier).

In practice, none of these properties can be achieved, but they can be approximated closely enough for many applications. For example, if feedback is used to limit the amplifier circuit gain to 10, an amplifier gain (without feedback) of 1000 is close enough to infinity for practical purposes.

The first stage of an operational amplifier is a differential amplifier. The differential amplifier provides a high gain to difference signals (i.e., $V_2 - V_1$ in Figures

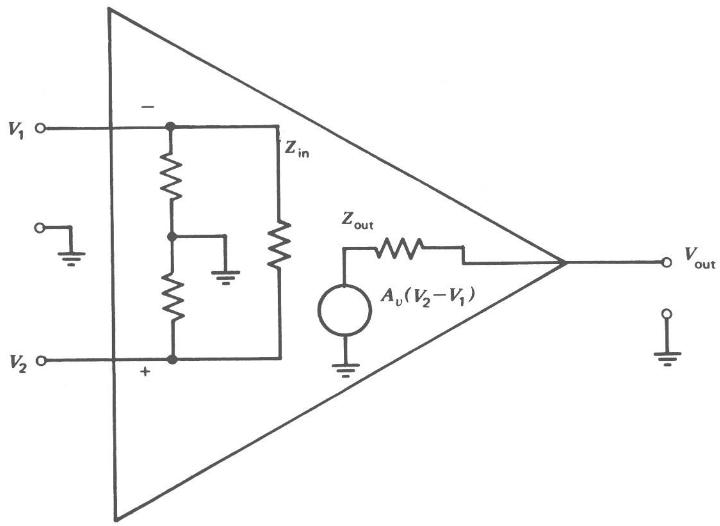

FIGURE 1.1 Amplifier representation.

1.1 and 1.2) and a low gain to signals applied to both inputs simultaneously (common-mode signals).[1]

The differential amplifier also provides a high impedance to any input signal applied to it. The input stage of an operational amplifier is the most critical since that is where input impedance is set and the common-mode response and offset voltages are minimized.[2]

One or more intermediate stages follow the input stage, as shown in Figure 1.3, to shift the quiescent voltage level to zero at the output and provide both voltage and current gain. The added voltage gain is needed for a high overall voltage gain, and the current gain is needed to supply drive current to the output stage without loading the input stage. Both single-ended and differential configurations are used for the intermediate amplification stages.

The output stage must supply a low output impedance and enough current to drive the expected load. It should also have a high enough input impedance that it does not load the last intermediate amplification stage. The output stage is usually an emitter follower or a complementary configuration.

Figure 1.4 is a schematic of a simple operational amplifier. There are a few things we should note about the input circuit. The emitter resistors of Q_1 and Q_2 increase the input impedance of the input stage. The collector currents in the input

[1] Common-mode signals are those of the same phase and amplitude applied to both inputs simultaneously.

[2] Offset voltages are small, undesired signals internally generated by the amplifier that cause some output voltage with zero volts applied to both inputs. They are caused by imperfect matching of the emitter-base voltages of the input transistors.