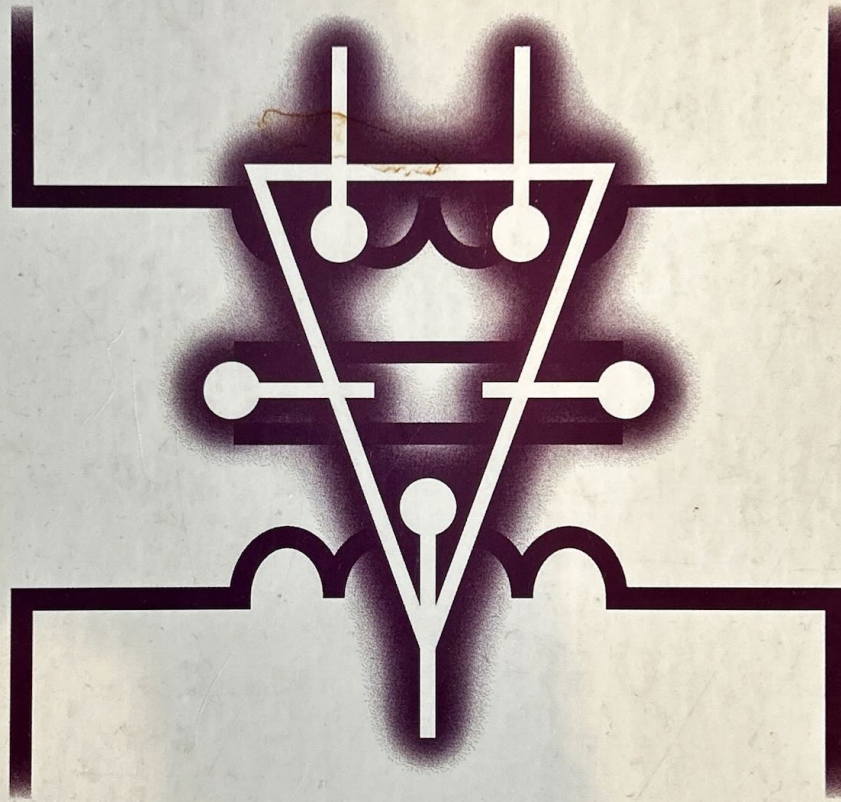


Electric Circuits

FIFTH EDITION



James W. Nilsson
Susan A. Riedel



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F I F T H E D I T I O N

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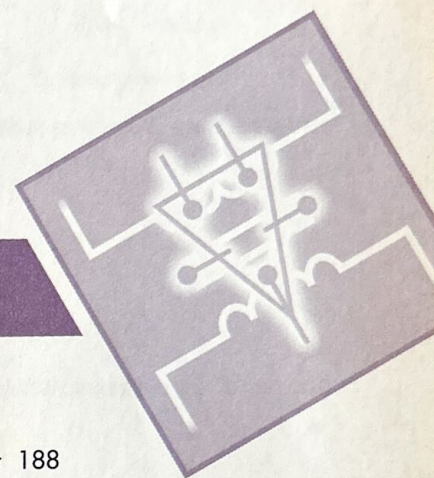
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5

THE OPERATIONAL AMPLIFIER

CHAPTER CONTENTS

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The electronic circuit known as an operational amplifier has become increasingly important. However, a detailed analysis of this circuit requires an understanding of electronic devices such as diodes and transistors. You may wonder, then, why we are introducing the circuit before discussing the circuit's electronic components. There are several reasons. First, you can develop an appreciation for how the operational amplifier can be used as a circuit building block by focusing on its terminal behavior. At an introductory level, you need not fully understand the operation of the electronic components that govern terminal behavior. Second, the circuit model of the operational amplifier requires the use of a dependent source. Thus you have a chance to use this type of source in a practical circuit rather than as an abstract circuit component. Third, you can combine the operational amplifier with resistors to perform some very useful functions, such as scaling, summing, sign changing, and subtracting. Finally, after introducing

inductors and capacitors in Chapter 6, we can show you how to use the operational amplifier to design integrating and differentiating circuits.

Our focus on the terminal behavior of the operational amplifier implies taking a black box approach to its operation; that is, we are not interested in the internal structure of the amplifier, nor in the currents and voltages that exist in this structure. The important thing to remember is that the internal behavior of the amplifier accounts for the voltage and current constraints imposed at the terminals. (For now, we ask that you accept these constraints on faith.)

The operational amplifier circuit first came into existence as a basic building block in analog computers. It was referred to as *operational* because it was used to implement the mathematical operations of integration, differentiation, addition, sign changing, and scaling. In recent years, the range of application has broadened beyond implementing mathematical operations; however, the original name for the circuit persists. Engineers and technicians have a penchant for creating technical jargon; hence the operational amplifier is widely known as the op amp.

5.1 OPERATIONAL AMPLIFIER TERMINALS

Because we are stressing the terminal behavior of the operational amplifier, we begin by discussing the terminals on a commercially available device. In 1968, Fairchild Semiconductor introduced an op amp that has found widespread acceptance: the $\mu A741$. (The μA prefix is used by Fairchild to indicate a microcircuit fabrication of the amplifier.) This amplifier is available in several different packages. For our discussion, we assume an eight-lead DIP.¹ Figure 5.1 shows a top view of the package, with the terminal designations given alongside the terminals. The terminals of primary interest are

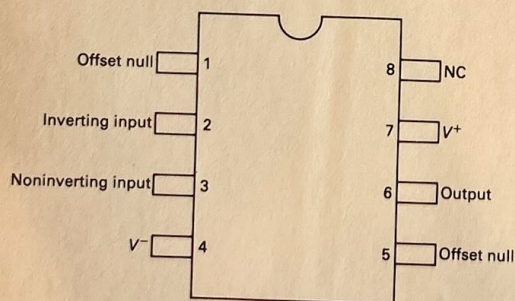


FIGURE 5.1 The eight-lead DIP package (top view).

- the inverting input,
- the noninverting input,
- the output,
- the positive power supply (V^+), and
- the negative power supply (V^-).

The remaining three terminals are of little or no concern. The offset null terminals may be used in an auxiliary circuit to compensate for

¹DIP is an abbreviation for *dual in-line package*. This means that the terminals on each side of the package are in line, and that the terminals on opposite sides of the package also line up.

a degradation in performance because of aging and imperfections. However, the degradation in most cases is negligible, so the offset terminals often are unused and play a secondary role in circuit analysis. Terminal 8 is of no interest simply because it is an unused terminal; NC stands for no connection, which means that the terminal is not connected to the amplifier circuit.

Figure 5.2 shows a widely used circuit symbol for an op amp that contains the five terminals of primary interest.

Using word labels for the terminals is inconvenient in circuit diagrams, so we simplify the terminal designations in the following way. The noninverting input terminal is labeled plus (+), and the inverting input terminal is labeled minus (-). The power supply terminals, which are always drawn outside the triangle, are marked V^+ and V^- . The terminal at the apex of the triangular box always is understood to be the output terminal. Figure 5.3 summarizes these simplified designations.

5.2 TERMINAL VOLTAGES AND CURRENTS

We are now ready to introduce the terminal voltages and currents used to describe the behavior of the op amp. The voltage variables are measured from a common reference node.² Figure 5.4 shows the voltage variables with their reference polarities. All voltages are considered as voltage rises from the common node. This convention is the same as that used in the node-voltage method of analysis. A positive supply voltage (V_{CC}) is connected between V^+ and the common node. A negative supply voltage ($-V_{CC}$) is connected between V^- and the common node. The voltage between the inverting input terminal and the common node is denoted v_n . The voltage between the noninverting input terminal and the common node is designated as v_p . The voltage between the output terminal and the common node is denoted v_o .

Figure 5.5 shows the current variables with their reference directions. Note that all the current reference directions are into the terminals of the operational amplifier: i_n is the current into the inverting input terminal; i_p is the current into the noninverting input terminal; i_o is the current into the output terminal; i_{c+} is the current into the positive power supply terminal; and i_{c-} is the current into the negative power supply terminal.

The terminal behavior of the op amp as a linear circuit element is characterized by constraints on the input voltages and the input

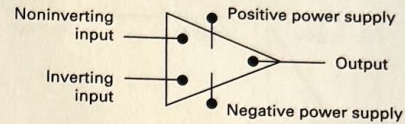


FIGURE 5.2 The circuit symbol for an operational amplifier.

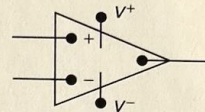


FIGURE 5.3 A simplified circuit symbol for an op amp.

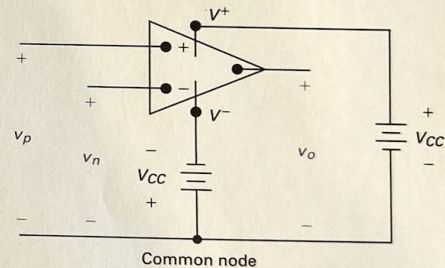


FIGURE 5.4 Terminal voltage variables.

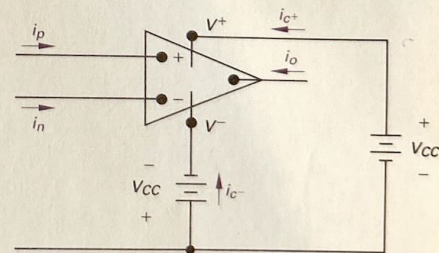


FIGURE 5.5 Terminal current variables.

²The common node is external to the op amp. It is the reference terminal of the circuit in which the op amp is embedded.