8 Operational Amplifiers

8.1 Op amp Basics

Operational amplifiers (op amps) are pre-packaged transistor amplifier building blocks designed for analog signal processing. Its name is a legacy of its original purpose to perform arithmetic operations in analog computing. First sold as a monolithic component in the 1960's, op amps have proven to be the most versatile building block in analog circuit design. Today, the availability of low-cost and high performance of op amps makes them ubiquitous in almost all analog circuits.

Op amp circuits are used to amplify, offset, filter, sum, and buffer analog signals, among many other functions. The non-linear nature of transistors makes these operations difficult to perform without distortion. Op amps are able to avoid this problem by using the mechanisms of negative feedback.

An op amp has five terminals, shown in *Figure 8.1*: the non-inverting input, inverting input, output, positive supply, and negative supply. In this text, the non-inverting input is referred to as the plus terminal, and the inverting input as the minus terminal.

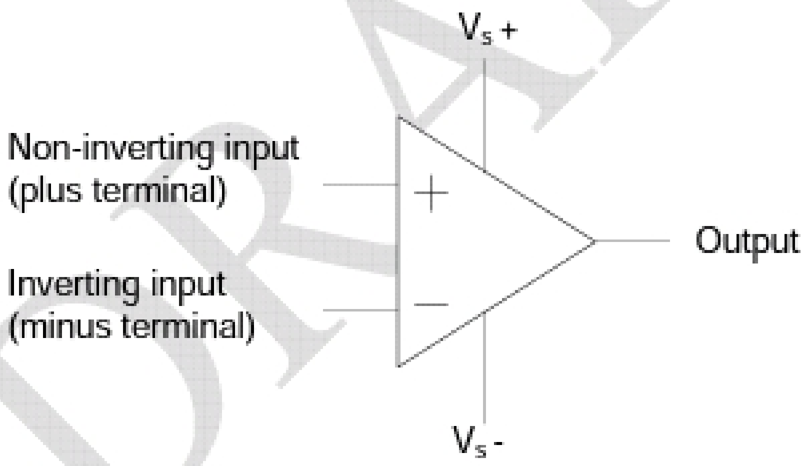

Figure 8.1: Circuit symbol for an op amp

The op amp's power supply terminals are typically omitted from conceptual circuit sketches; although, the power supply is often a source of circuit problems and requires special attention from the designer. Typically, op amps are powered by bipolar supplies such as ±12 V or ±5 V. The op amp's maximum output cannot exceed the supply voltage range, and is usually at least 1V less than either supply limit. When the op amp's output has reached its positive or negative maximum, the output has "railed". This condition should be avoided in most instances.

The internal circuitry in an op amp is designed to give two basic characteristics: (1) very high impedance at the input terminals, and (2) very high differential gain from the input to the output. In fact, an ideal op amp has infinite input impedance and infinite differential gain. For practical op amps, the differential gain exceeds 10^5 and input

impedance is a few GΩ. At first, it may be difficult to understand how a very high gain amplifier can be useful since a very small differential voltage will send the output to rail to its maximum or minimum value. However, op amps are designed to operate in feedback, which regulates the output voltage according to the input as a result of amplifier's configuration.

An intuitive grasp of op amps in feedback can be found by examining the voltage follower circuit shown in *Figure 8.2*. The input voltage is applied at the plus terminal while the output voltage is fed back into the minus terminal. The voltage follower will replicate the input voltage at its output while isolating disturbances at the output from affecting the input.

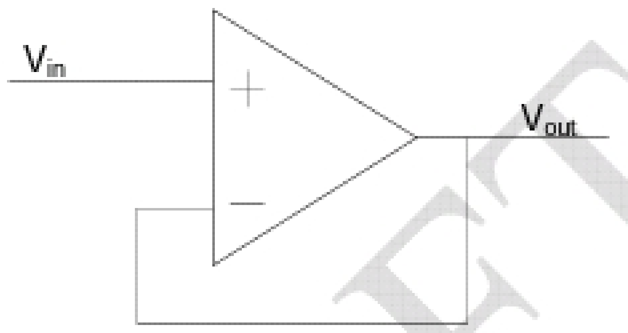

Figure 8.2: Op amp voltage follower circuit

The voltage follower circuit functions in the follow way: if the negative terminal (also the output) is lower than the positive terminal, the gain of the amplifier will make the output more positive and thereby bringing the negative terminal closer to the positive terminal. If the negative terminal is above the positive terminal, the gain of the amplifier will make the output more negative and thereby bringing the negative terminal closer to the positive terminal. From this crude analysis, it is possible to see that regardless of the output starts higher or lower than the input, the feedback mechanism will make the output approach the input voltage. The exact nature of the errors between output and input and the dynamic properties of the voltage signals will be discussed in detail in Section 10 - Feedback.

8.2 Op amp Circuits

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The first order analysis of op amp circuits can be made following two simple rules: (1) the plus and minus terminals draw no current; and (2) the output will produce whatever voltage is necessary to equalize the voltages at the plus and minus terminals. The prerequisites for using these rules are that the op amp must be in negative feedback and the required output must be within the valid output range of the op amp.