Introduction to Operational Amplifiers

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Introduction

Operational amplifier is the name given to a certain type of amplifier designed to be a basic building block for many types of circuits. The operational amplifier is characterized by a high impedance differential input stage followed by one or more high gain stages and a low impedance output stage. Each stage is designed to have near ideal characteristics.

Internally, an operational amplifier is very complicated. Considerable knowledge of electronics is required to design or analyze an internal operational amplifier circuit.

Externally, an operational amplifier is very simple to use thanks to the near ideal nature of its characteristics. Only a basic knowledge of electronics is needed to design or analyze circuits built with operational amplifiers. This feature makes operational amplifiers or op-amps as they are more commonly called very popular. Op-amps make it easy to construct very sophisticated circuits.

Operational amplifiers were developed using vacuum tubes in the 1940s for use in analog computers. The name, operational, comes from the characteristic that by changing the external feedback circuit, different analog operations such as addition, subtraction, integration, differentiation, etc. could be performed. This is the salient characteristic that makes op-amps so popular. Instead of designing a lot of custom circuits, a single building block can be used to build a wide variety of circuits ranging from linear to non-linear. In the 1950s, op-amps were built with discrete transistors. In the 1960s, the first monolithic (integrated circuit) op-amps were built. By the 1990s, the performance of op-amps had improved over a hundred times that available in the 1960s while the price has come down about one hundred. Today, most analog electronics are constructed exclusively with op-amps.

Connections

Figure 1 shows the external connections of an op-amp. Note that there are two inputs, one output, and two power supply connections. There is generally no ground connection. The connections are described as follows:

Vin+ is the non-inverting input. This input has a very high impedance that ranges from several megohms to thousands of megohms depending on the device technology. It is referred to as non-inverting because the output voltage of the op-amp is in-phase with this input.

Vin- is the inverting input. This input has a very high impedance that ranges from several megohms to thousands of megohms depending on the device technology. It is referred to as inverting because the output voltage of the op-amp is phase-inverted relative to this input.

Vo is the output and is given by Vo = (Vin+ - Vin-) * Av where Av is the differential voltage gain of the op-amp and is typically between 10,000 and 1,000,000. The output voltage can not exceed the power supply voltages and typically can not be any closer than about 2.5 volts from either power supply. Note that the transfer equation implies that Vin+ and Vin- must be very close in voltage or the output voltage would be driven to the power supply limits.

V_{CC} is the positive power supply connection and is typically +15 Volts. The CC subscript refers to the collector circuits of bipolar NPN transistors that are used to construct many op-amps. An alternate name, V_{DD}, is used to refer to the drain circuits if the op-amp is constructed out of n-channel field-effect transistors. The two names are interchangeable.

V_{EE} is the negative power supply connection and is typically -15 Volts. The EE subscript refers to the emitter circuits of bipolar NPN transistors that are used to construct many op-amps. An alternate name, V_{SS}, is used to refer to the source circuits if the op-amp is constructed out of n-channel field-effect transistors. The two names are interchangeable.

There are a variety of circuits used to construct op-amps. All the many different internal circuits for op-amps have the same basic five external pins shown in Figure 1 and act the same way. The different internal circuits optimize a particular performance characteristic of the op-amp. All of the circuits have essentially the identical black-box model – that is Vo = (Vin+ - Vin-) * Av. Thus, the basic mathematics will apply to all op-amps. This very simple looking transfer function is very powerful and enables us to create a wide variety of useful circuits.

In many op-amp circuits the V_{CC} and V_{EE} pins are omitted from the schematic for convenience to eliminate clutter. Understand that there is always a connection – the part will not work without power.

We do not generally use an op-amp in its open-loop configuration. The op-amp is intended for negative feedback applications. With the right feedback network we can build amplifiers with specific gains, signal processing circuits such as integrators and differentiators, and various non-linear functions. Figure 2 shows some common examples. Notice that there is always a feedback resistor connected between the output in the inverting input. In some circuits this may be a complex impedance but the concept of negative feedback always applies. Notice how simple the four example circuits are. All of the complexity is hidden from us inside the op-amp. The power supply connections are omitted for clarity.

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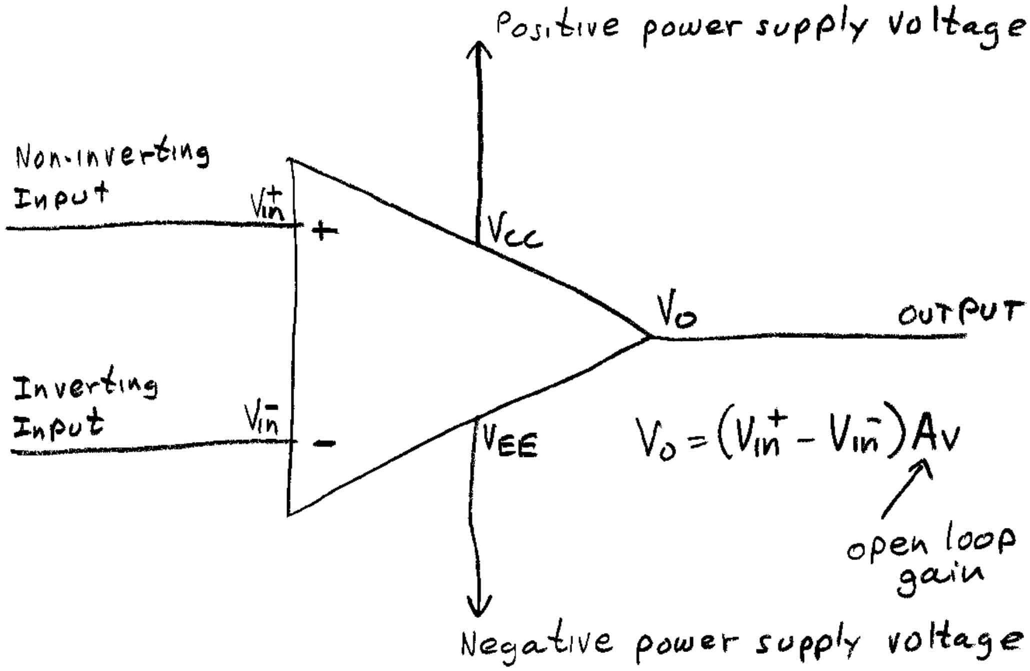

Figure 1: Op-amp connections

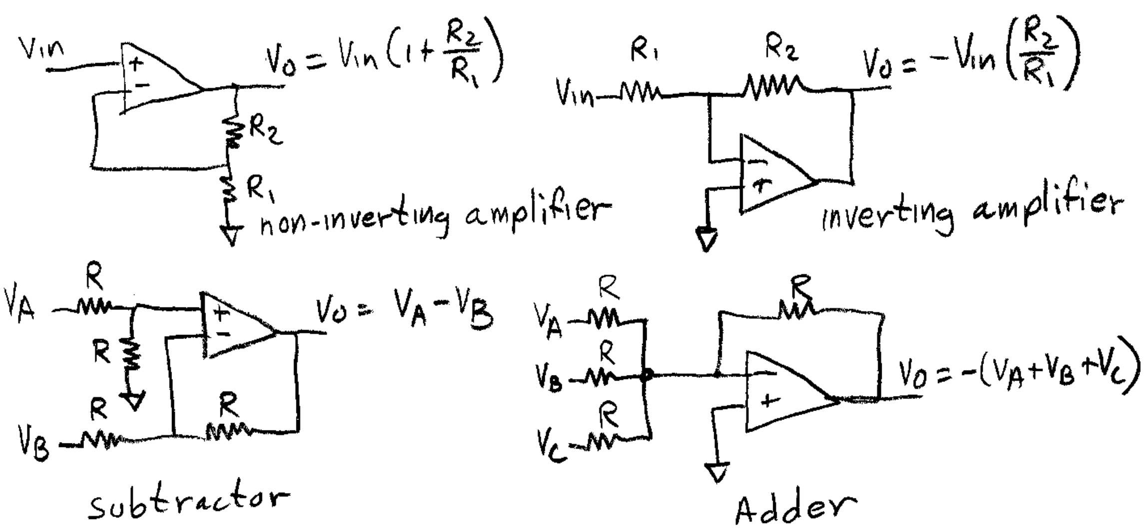

Figure 2: Example op-amp circuits