

Operational Amplifiers

Application and Design

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11/16/2012

Operational Amplifiers have been an important building block in circuits for the past fifty years. Most students learn about operational amplifiers in school but few realize their potential in signal processing. The goal of this application note is to fill in the learning gaps so that aspiring designers can solve real problems. The reader will be able to understand those basic applications of operational amplifiers and the roles that they play. It is vital to a designer to have a good understanding of operational amplifiers and how they fit into analog signal processing.

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Introduction

Operational Amplifiers or Op-Amps are electrical devices whose concept has been around since 1941. The first vacuum tube op-amp was created in 1941 and in 1961 the first discrete op-amp was manufactured. Op-amps are devices that attempt to reduce loading effects on circuits that are connected to the device while performing various tasks such as amplifying, adding, and subtracting analog signals. Op-amps can be used as merely a voltage follower or buffer with unity gain to prevent current flow from one side of the buffer to the other. More complex circuits can be constructed with the op-amp building block such as differentiators and integrators. They also play a critical role in filter design which is used in many modern applications. Op-amps are a crucial building block for analog circuit design and provide hobbyists with a cheap way to construct complex circuits.

Objectives

The objective of this paper is to provide some basic knowledge of several different op-amp application circuits. Uses for the various applications will also be discussed as well as examples of basic signal processing. After reading through this document the reader should have a good understanding of the uses of op-amp circuits in analog project design and be able to construct these circuits for use in their own projects. The buffering capabilities of op-amps will give the designer free reign to combine circuits, which were discovered, into personalized signal processing units. These units are great for testing equipment and audio applications as well as custom design.

Keywords

Operational Amplifier, Buffer, Voltage Follower, Non-inverting, Inverting, Differentiator, Integrator

Operational Amplifier Basics

When designing with op-amps it is key that the designer understands the ideal parameters of an op-amp; the way in which the op-amp was intended to be used. Only after understanding these parameters can someone design with an op-amp. The ideal parameters are shown in Table 1 below.

PARAMETER NAME	PARAMETERS SYMBOL	VALUE
Input current	I_{IN}	0
Input offset voltage	V_{OS}	0
Input impedance	Z_{IN}	∞
Output impedance	Z_{OUT}	0
Gain	a	∞

TABLE 1

When designing, it is important to keep in mind that the input current and input offset voltage to an op-amp is nearly zero. The input impedance is nearly infinite and the output impedance is nearly zero. These parameters provide the buffering feature. There is also an infinite open loop gain 'a' which allows for amplification.

The pinout for a basic 8 pin op-amp, known as a single package, can be seen in Figure 1. There are also dual and quad packages that have two and four op-amps in one integrated circuit (IC). Pins 4 and 7 are the negative and positive power supply pins commonly known as. The voltage ranges can be found in the specific datasheet for the op-amp, but it is important to remember that output voltages can never exceed the power supply voltage. Pin 3 is known as the non-inverting input, Pin 2 is the inverting input, and Pin 6 is the output. These pins are used for the basic function of the op-amp. The remaining pins are for more advanced input offset correction features.

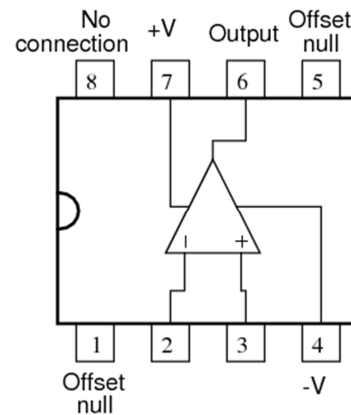


FIGURE 1

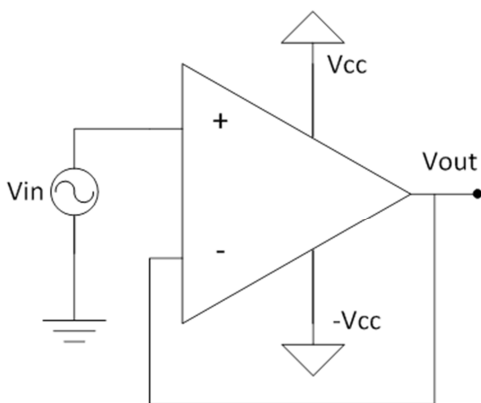


FIGURE 2

Simple Buffer or Voltage Follower

One of the basic functions of an op-amp is buffering. A simple buffer of voltage follower can be created by first hooking up an op-amp to positive and negative voltage, or positive and ground in the case of a single supply op-amp, and hooking the inverting input to the output. This creates a negative feedback that gives the op-amp a unity gain. The simple voltage follower can be seen in Figure 2 below.

Non-inverting and Inverting Amplifier

Non-inverting and Inverting amplifier circuits can be used when a specific gain is needed for an input signal. This gain can be a multiple of the input or a fraction of the input. If a positive gain is needed then the non-inverting amplifier should be used. If a negative gain is needed then the inverting amplifier should be used. The non-inverting and inverting amplifiers are shown in Figures 3 and 4 respectively.

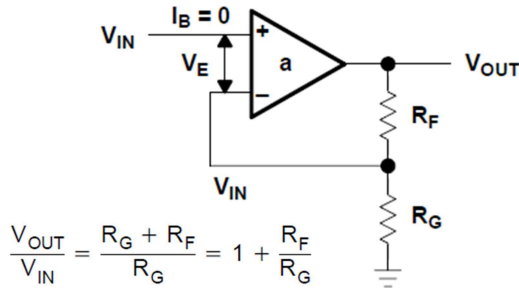


FIGURE 3

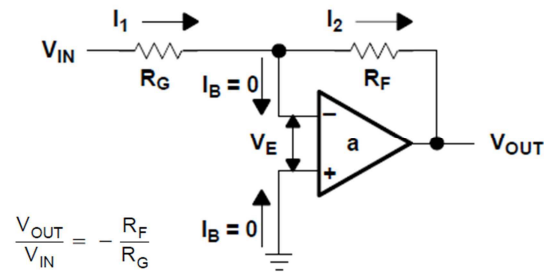


FIGURE 4

The transfer functions for these circuits can be derived by summing voltage drops around the loops of the equation. The equivalent transfer functions or gains for the non-inverting and inverting amplifiers are shown at the bottom left of each circuit diagram. A simple example for the non-inverting amplifier would be to use resistors of equal value, 10kΩ. The gain is one plus the division of the two resistors for a total gain of two.

Summing and Differential Amplifier

Summing amplifiers can be non-inverting and inverting. These types of amplifiers are great for adding signals together. For instance a DC offset can be added to a signal by using a non-inverting summing amplifier. The non-inverting and inverting summing amplifiers are shown in Figures 5 and 6 respectively.

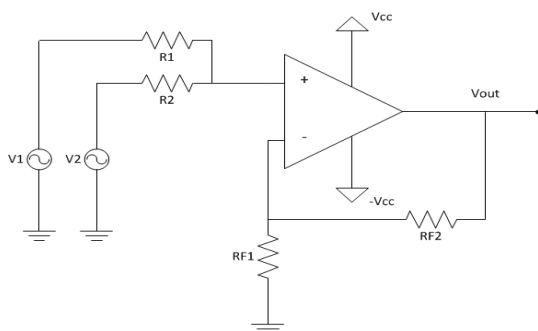


FIGURE 5

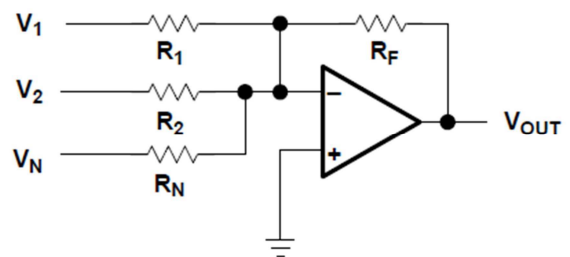


FIGURE 6

$$V_{out} = \left(1 + \frac{R_{F2}}{R_{F1}}\right) \cdot \left(V1 \cdot \frac{R2}{R1 + R2} + V2 \cdot \frac{R1}{R1 + R2}\right)$$

$$V_{OUT} = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \frac{R_F}{R_N} V_N\right)$$

An example of adding a DC offset would be to use equal value resistors for every resistor value in Figure 5. This simplifies the transfer function to be the addition of the input voltages. A signal and a DC offset can now be added together the DC offset can be adjusted with a potentiometer to whatever level is required for the circuit.

A differential amplifier is one that can subtract signals. The schematic for this circuit is shown in Figure 7.

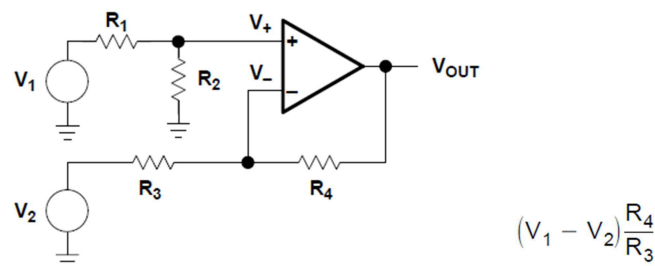


FIGURE 7

Differentiator and Integrator

Op-amps can be used as differentiators and Integrators. The easiest way to think about these two circuits is to input a wave and see what output is produced. A differentiator will produce a square wave with a triangle wave input. An integrator will produce a triangle wave with a square wave input. Both of these circuits are very convenient to use in signal processing. A differentiator and integrator are shown in Figures 8 and 9 respectively.

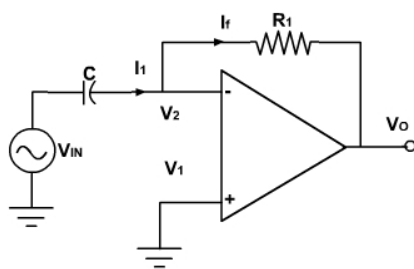


FIGURE 8

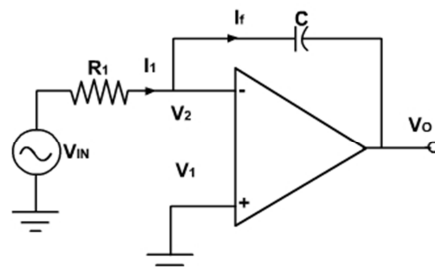


FIGURE 9

It can be seen for Figure 10 the exact way in which the signal is manipulated. If these circuits were to be attached in series it would theoretically have no effect from input to output.

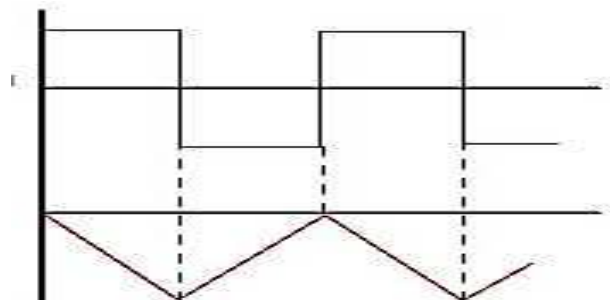


FIGURE 10

Active Filter Design

Op-amps can be used in active filter design to replace noisy components such as inductors. Many famous filter designs make use of this active architecture including Bessel, Butterworth, and Chebyshev filters. The following is an example of a second order low pass passive (Figure 11) and active (Figure 12) Butterworth filter.

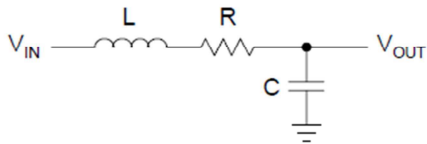


FIGURE 11

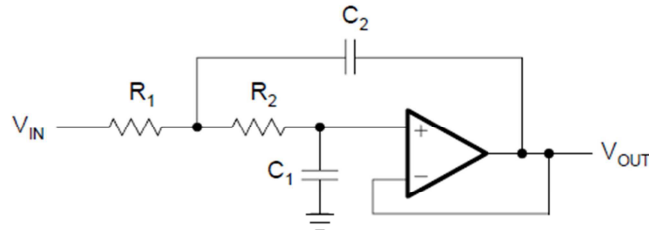


FIGURE 12

The Active filter does not have an inductor, but simulates one using a capacitor and an op-amp. The corner frequency or the frequency where the input signal starts to be attenuated can be shifted depending on the resistor and capacitor values. These circuits can be used in series and parallel to make many different types of filters.

Conclusion

The circuits that were discussed are building blocks for all types of analog signal processing. Addition, subtraction, differentiation, and integration as well as many other complex math functions can be performed with these circuits and combinations of these circuits. Following the transfer functions for the building blocks can greatly improve the ability of the designer to achieve a more precise output. Having the ability to filter signals is an important tool to have and is the key to all types of audio and signal processing circuits. To be a great designer it is imperative to understand and be able to implement the various building blocks that revolve around the operational amplifier.

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