

Designing Operational Amplifiers

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Executive Summary

Most electronic devices, such as mp3, television, and radios require some sort of signal modulation. Signal modulation is the addition of information to the original signal through amplitude, phase, or frequency (Modulation, 2005). In the case of an mp3 player, the output signal to the speakers is modulated using an operation amplifier to produce a desired volume level. In other devices, signals can be added or subtracted together to produce the desired output. The following material will further discuss ways to modulate signals using an operational amplifier.

Objective

Derive design methods and formulas for inverting and non-inverting amplifiers. Demonstrate a step by step procedure for designing amplifiers using operational amplifiers.

Introduction

Operational amplifiers, also known as op amps, are high gain components with differential inputs, feedback, and typically a single output. First developed in 1941, the op amp was comprised of three vacuum tubes with voltage rails of hundreds of volts (Operation Amplifier, 2008). Currently, op amps are packaged extremely small, allowing for portable music playing devices to be small in size, and can be supplied by only a couple volts. The cost of op amps has significantly decreased over time. The fall in price is associated with production size, technology, and availability to, in some cases, only a few cents.

The topics covered in this application note include:

- Ideal Operational Amplifiers
- Inverting Amplifier
- Non-Inverting Amplifier

The focus of the design topics for this paper will revolve around the LM741 op amp from National Semiconductor. The LM741 operational amplifier is a low cost general purpose amplifier and can be used in many applications. Most of the concepts discussed can be applied to other op amps with few changes. Most changes will occur in the pin assignments.

Ideal Operational Amplifiers

There are two main rules that govern the concept of the ideal op amp. First, the inputs draw no current. This is because the inputs impedance is ideally infinity. Second, the voltage of one input equals that of the other input. If the input voltages are different, the output will do whatever it needs to to make the difference equal to zero, thus producing an amplified output signal. As a result, there exists a relationship between the outputs and the input. The equation can be seen in Equation 1.1.

$$V_{out} = A(\Delta V_{Input})$$

Expanded:

$$V_{out} = A(V_{+} - V_{-})$$

Equation 1.1 – The output voltage, V_{out} , equals some gain A and the difference in input voltages. V_{+} is the non-inverting input and V_{-} is the inverting input.

Circuit design begins on a computer or paper. Op amps are typically represented by a triangle with a plus and minus mark. These two marks represent the non-inverting and inverting inputs. Figure 1.1(A) demonstrates the symbolic form of an op amp, where the two inputs are on the left and the output is on the right.

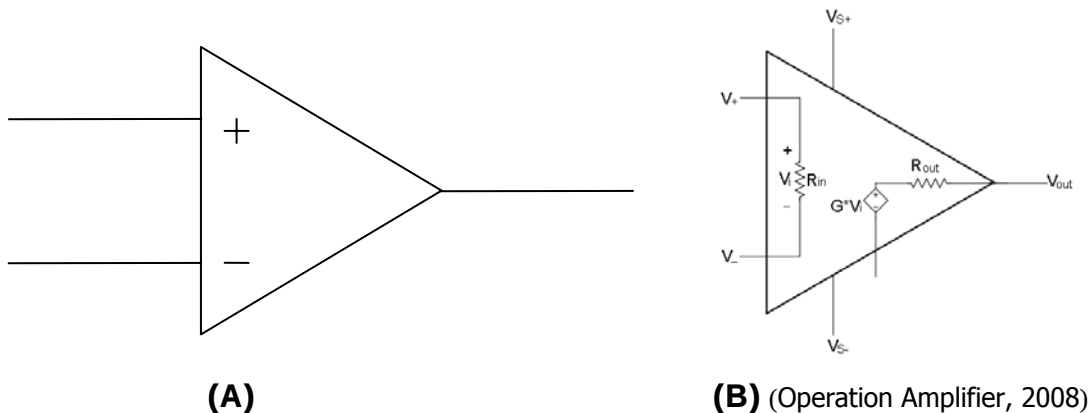


Figure 1.1 – Symbolic form of the operational amplifier

The input to output relationship from Equation 1.1 can be applied to Figure 1.1(A). The result is Figure 1.1(B), where a voltage source dependant upon the inputs is supplying the output. R_{in} has a high resistance, producing no current and R_{out} has low resistance, resulting in no losses from the op amp. In this figure, V_s represents the positive and negative power supply.

Non-Inverting Amplifier

There exist several methods to designing and arranging the inputs to produce a different output. In the case where the output is going to be represented by the input, differing in amplitude, a non-inverting amplifier should be used. This can be designed from the LM741. The non-inverting amplifier design can be seen in Figure 2.1.

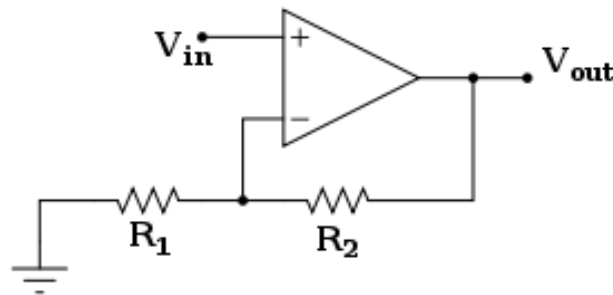


Figure 2.1 – Non-inverting op amp (Operation Amplifier, 2008)

The input signal is V_{in} , the output signal is V_{out} , and the resistors R_1 and R_2 specify the amount of gain. The gain can again be calculated using the two previously established ideal op amp rules.

The voltage difference between the inputs is equal to zero. The voltage drop across R_1 must then equal V_{in} . The current produced from the voltage drop can be determined using Ohms Law in Equation 2.1.

$$V = IR$$

Equation 2.1 – Ohms Law equation

The current through R_1 can be determined by manipulating Equation 2.1 to determine current in terms of voltage and resistance.

$$\frac{V_{IN}}{R_1} = I_1$$

Equation 2.2 – Current through resistor one

The second ideal op amp rule states that there is no current at the inputs. This means all the current through R_1 is coming from R_2 .

$$I_2 = I_1$$

Equation 2.3 – Determining I_2 current in a non-inverting op amp

The output voltage can be determined by creating a loop from the output to ground, in this case, the path is equal to the voltage drop across R_1 and R_2 . The voltage drop across R_1 is known to be V_{in} . The voltage drop of R_2 is calculated below using Ohms Law, the known current through R_2 , and the value of R_2 .

$$V_2 = I_2 R_2$$

Equation 2.4 – Voltage drop across R_2

The output voltage is the sum of voltages from V_{out} to ground. Manipulating the previous equations, the output can be determined.

$$\begin{aligned}V_{out} &= V_1 + V_2 \\V_{out} &= I_1 R_1 + I_2 R_2 \\I_2 &= I_1 \\V_{out} &= I_1 R_1 + I_1 R_2 \\I_1 &= \frac{V_{in}}{R_1} \\V_{out} &= V_{in} + \frac{V_{in} R_2}{R_1} = V_{in} \left(1 + \frac{R_2}{R_1} \right)\end{aligned}$$

Equation 2.5 – The output voltage with respect to input voltage and resistor values

The output is dependent upon the input, but more importantly, the gain produced is determined through the resistor values of R_1 and R_2 . If designing an op amp with a gain of 3, the resistor values are established using the gain portion of the final equation, see Equation 2.6. If this case, R_2 has to be twice the resistance of R_1 to produce the appropriate gain. Resistor values 20k Ω for R_2 and 10k Ω for R_1 will satisfy the requirements.

$$gain = \left(1 + \frac{R_2}{R_1} \right)$$

Equation 2.6 – Gain for a non-inverting op amp

Inverting Amplifier

Similar to the non-inverting op amp, an inverting op amp is also capable of producing an output that represents the inversion of the input, also with a scaled amplitude. The inverting amplifier design can be seen in Figure 3.1 with the input voltage on the negative input. This differs from the non-inverting amplifier, in Figure 2.1, where the input voltage is on the positive input.

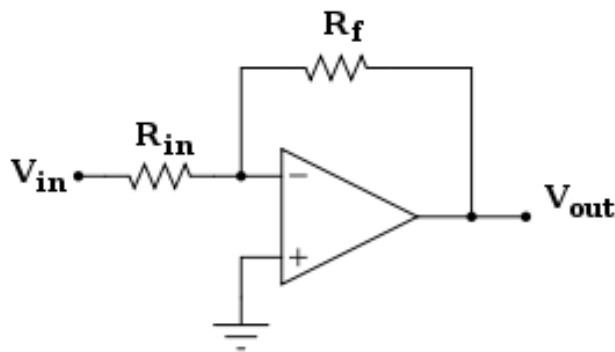


Figure 3.1 – Inverting op amp (Operation Amplifier, 2008)

The input signal is V_{in} , the output signal is V_{out} , and the resistors R_{in} and R_f specify the amount of gain. The gain can be calculated using the two previously established ideal op amp rules.

The voltage difference between the inputs is equal to zero. The voltage drop across R_{in} must then equal V_{in} . This is because the positive terminal is at a ground potential, since the difference between the op amp inputs must be equal to zero, the drop across R_{in} must be V_{in} . The current produced from the voltage drop can be determined using Ohms Law in Equation 2.1. The current through R_{in} can be determined by manipulating Equation 2.1 to determine current in terms of voltage and resistance.

$$I_{in} = \frac{V_{IN}}{R_{in}}$$

Equation 3.1 – Current through the input resistor

The second ideal op amp rule states that there is no current at the inputs. This means all the current through R_{in} is going through R_f .

$$I_f = I_{in}$$

Equation 3.2 – Determining I_f current in an inverting op amp

The output voltage can be determined by creating a loop from the output to ground, and in this case, is equal to the voltage drop across R_f . The voltage drop across R_f is dependant upon how much current is going through it and its resistance. Again, Equation 3.2 says the current through R_f is equal to the current through R_{in} . The voltage drop of R_f is calculated below using Ohms Law, the known current through R_{in} , and the value of R_f .

$$V_f = I_{in} R_f$$

Equation 3.3 – Voltage drop across R_f

Manipulating the previous equations, the output can be determined.

$$\begin{aligned}V_f &= I_{in} R_f \\I_{in} &= \frac{V_{IN}}{R_{in}} \\V_f &= V_{IN} \left(\frac{R_f}{R_{in}} \right)\end{aligned}$$

Equation 3.4 – The output voltage with respect to input voltage and resistor values

The output is dependent upon the input, but more importantly, the gain produced is determined through the resistor values of R_{in} and R_f . If designing an op amp with a gain of 2, the resistor values are established using the gain portion of the final equation, see Equation 3.5. If this case, R_f has to be twice the resistance of R_{in} to produce the appropriate gain. Resistor values 20k Ω for R_f and 10k Ω for R_{in} will satisfy the requirements.

$$gain = \left(\frac{R_f}{R_{in}} \right)$$

Equation 3.5 – Gain for an inverting op amp

Conclusion and Recommendations

Using op amps to manipulate signals is both an appropriate method and inexpensive one. It allows the designer to design the op amps around the existing circuit using only a few additional discrete components. This saves the circuit from consuming additional software or hardware design labor and the expense of additional hardware. Op amps can further be used to manipulate signals in fashions such as addition, differentiation, or as a comparator.

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