Operational Amplifiers

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1 Operational Amplifiers

An operational amplifier, which is shown in the circuit of Figure 1, is a differential amplifier. It has two inputs that are called the inverting input, and the noninverting input. The inverting input is denoted with a minus sign, and the noninverting input with a plus sign. The ideal operational amplifier has an infinite amplification factor. In practice the amplification factor α is very large and can be on the order of 200,000.

The output voltage is the product of the amplification factor α and the difference ΔV of the two input voltages. This difference will be very small because the amplification factor is so large.

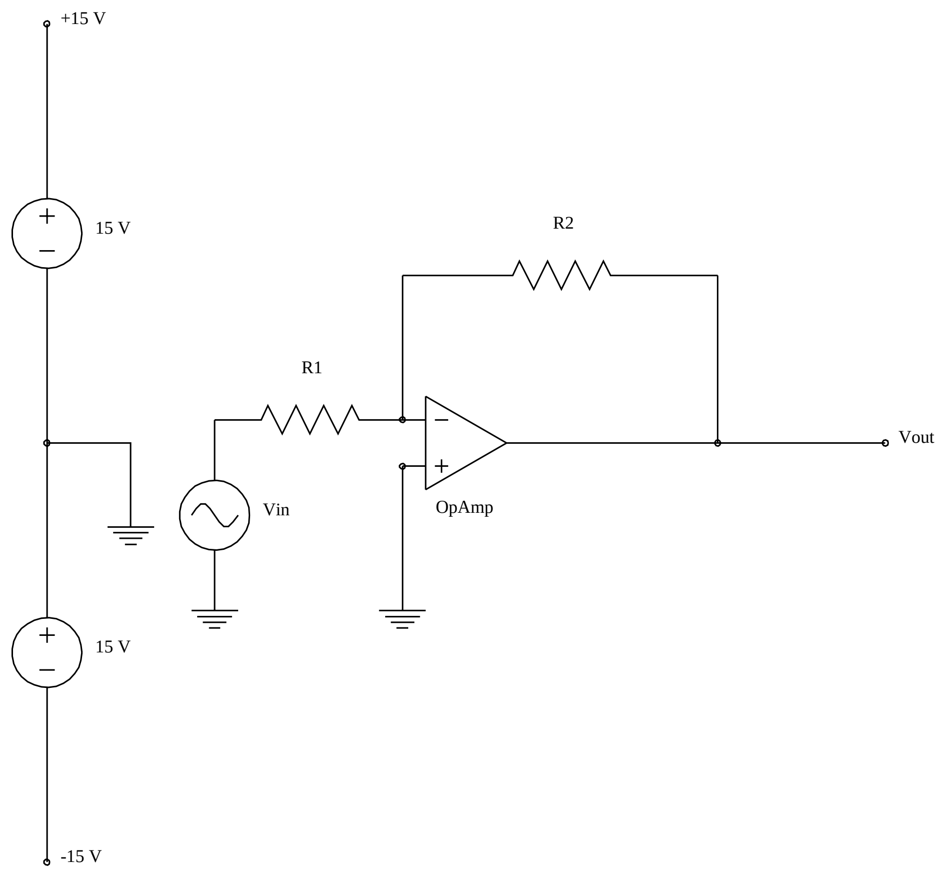

Figure 1: The Opamp Inverting-Amplifier. The opamp is powered by ± 15 volts. The connections are usually not shown on the circuit diagram to avoid clutter. The gain of the Inverting-Amplifier is $\alpha = -R_2/R_1$.

The ideal op amp has infinite input resistance and zero output resistance. Because it has infinite input resistance it has zero input current. The amplificaton factor is infinite. The inverting input is labeled with a "$-$" sign and the noninverting input with a "$+$" sign. If the voltage at "$+$" is above the voltage at "$-$", the output voltage is positive. On the other hand if the voltage at "$-$" is above the voltage at "$+$", the output is negative, that is, it is inverted. The non ideal opamp in practice approaches this ideal behaviour. So the input impedance is very high, the amplification factor is very large, and the inputs take very small current. The practical op amp uses feedback to reach a stable operating point where the ideal op amp characteristics are approached.

The op amp is powered by a split supply, which is usually a ± 15 volt supply, with the center of the supply grounded. However the op amp will operate at other input voltages. The output voltage is measured from ground. α is called the open loop gain. The closed loop gain is controlled by external feedback elements connecting the output back to the input.

1.1 The Inverting Amplifier

Suppose the noninverting input is grounded and an input signal is applied to the inverting input through a resistor R_1. This is shown in Figure 1. A second R_2 resistor connects the inverting input to the output. The noninverting input is connected to ground. For stability the voltage difference between the noninverting input and the inverting input is very small and essentially zero. If this were not so the very large amplification factor would make the output voltage very high and cause a high current I through resistor R_2, because the voltage at the inputs are near zero. The voltage at the inverting input is zero because it is connected to ground. But then the current through R_1 is also I, so there is also a high voltage across R_1. But then the voltages around the circuit could not sum to zero. So for stability the difference between the two input voltages must be zero. So if V_i is the input signal voltage , then the current through the resistor R_1 is

$$I = \frac{V_i}{R_1}.$$

Now the current into the inverting input is zero, so the current I also passes through the second resistor R_2. It follows that the voltage drop across R_2 is IR_2 and this is the magnitude of the output voltage V_o. Now the voltage at

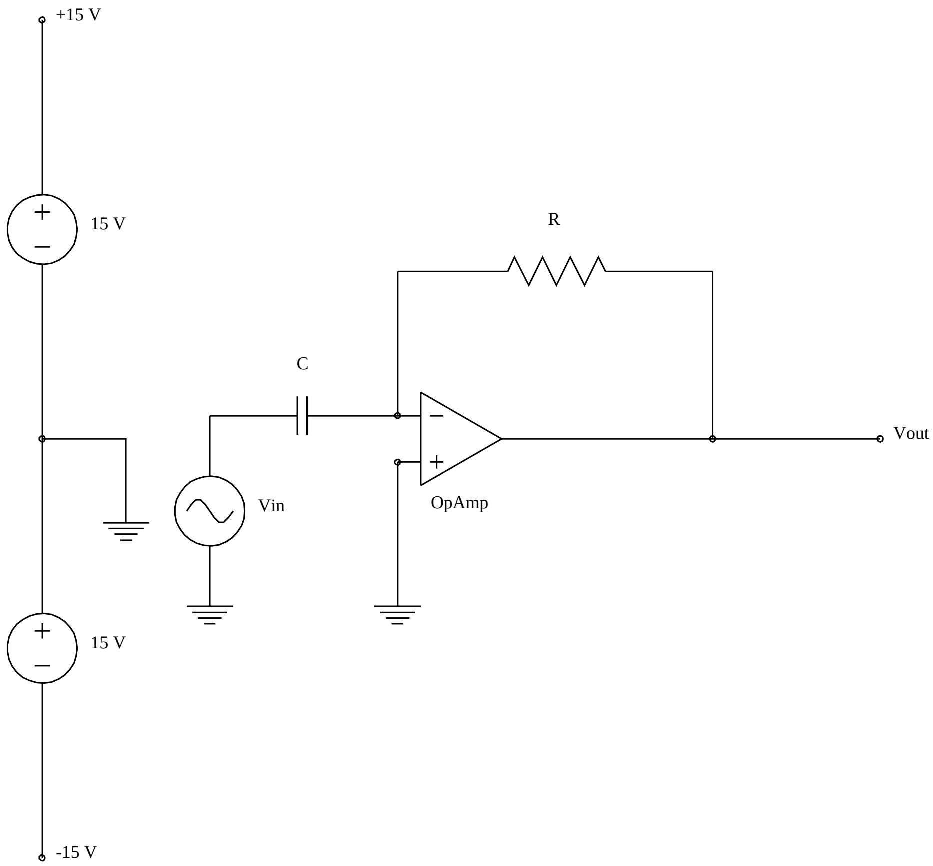

Figure 2: The Differentiating Circuit.

$-$ the inverting input is above the voltage at $+$ the noninverting input so V_o is negative. Thus

$$V_o = -IR_2 = -V_i \frac{R_2}{R_1}.$$

So the closed loop gain is

$$\alpha = -\frac{R_2}{R_1}.$$

So the output voltage is negative if the input voltage is positive.

1.2 The Slew rate

The op amp functions by using feedback to quickly reach a stable point. To fully understand the operation of the opamp we must understand how its internal structure causes this stable point to be reached, under what conditions this happens, and how long it takes for this to happen.

A good op amp must reach a stable point very quickly. The slew rate is a measure of how fast the voltage can change. That is a measure of how fast a positive input pulse that goes to zero, causes the output to go to zero. The slew rate of a 741 op amp is about .5 volt per μs.

1.3 The Noninverting Amplifier

Figure 3 shows the noninverting amplifier circuit. We have

$$I = \frac{V_{out} - V_{in}}{R_2}.$$

$$I = \frac{V_{in}}{R_1}.$$

$$V_{out} = R_2 V_{in} \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$V_{out} = V_{in} R_2 \left(\frac{R_1 + R_2}{R_1 R_2}\right)$$

$$= V_{in} \left(\frac{R_1 + R_2}{R_1}\right)$$

$$\alpha = \frac{R_1 + R_2}{R_1}.$$

1.4 The Voltage Follower

If the input signal is connected to the noninverting input of the opamp, and the inverting input connected directly to the output, then necessarily the output voltage equals the input voltage. And the input signal is now connected to a very high impedance. This circuit can isolate an input from a low impedance that would have an excessive load. For example if the input comes from the midpoint of a voltage divider then the proper divided voltage is obtained from the divider only if a relatively small amount of current flows from the midpoint connection.

1.5 The Differentiating Circuit

Figure 2 shows the Differentiating circuit. The inputs at the opamp are at zero potential. The current flowing through C and R is I. So

$$C\frac{dV_{in}}{dt} = I = \frac{V_{out}}{R}.$$

Therefore

$$V_{out} = RC\frac{dV_{in}}{dt}.$$

1.6 The Integrating Circuit

Figure 3 shows the integrating circuit. We have

$$\frac{V_{in}}{R} = I = C\frac{dV_{out}}{dt}.$$

Integrating we have

$$V_{out} = \frac{1}{RC}\int V_{in}dt.$$

1.7 The 741 Operational Amplifier

The 741 has eight pins numbered counterclockwise from the upper left corner of the chip:
1 offset null
2 inverting input
3 noninverting input

4 power negative
5 offset null
6 output
7 power positive
8 not connected

Ideally when the inputs are zero the output is zero. In practice the output may measure a few millivolts. The offset null connections can be used to zero out this nonzero output.

2 Bibliography

[1]Kaplan Daniel M and White Christopher G. **Hands-On Electronics: A Practicle Introduction to Analog and Digital Circuits**, Cambridge University Press, 2003. This is a book for a laboratory course designed for physics and engineering students, written by two physicists. KCK Library.