2.004 Dynamics and Control II
Spring 2008

Massachusetts Institute of Technology
Department of Mechanical Engineering

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Lecture 12[1]

Reading:

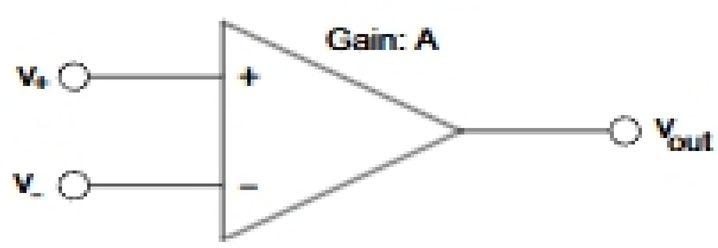
- Class Handout - *Introduction to the Operational Amplifier*
- Nise: pages 55–58 (Operational Amplifiers)

> This lecture is inserted in the course at this point to coincide with Laboratory Session 3, which requires the construction of a proportional controller using a differential amplifier.

1 Introduction to the Operational Amplifier

The integrated-circuit operational-amplifier (op-amp) is a fundamental building block for many electronic circuits, including analog control systems. In this hand-out we examine some of the basic circuits that can be used to implement control systems. We take simplified approaches to the analysis, and this discussion is by no means complete or exhaustive.

What is an operational amplifier? It is simply a very high gain electronic amplifier, with a pair of differential inputs. Its functionality comes about through the use of *feedback* around the amplifier, as we show below.



The op-amp has the following characteristics:

- It is basically a "three terminal" amplifier, with two inputs and an output. It is a *differential* amplifier, that is the output is proportional to the *difference* in the voltages applied to the two inputs, with very high gain A,

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

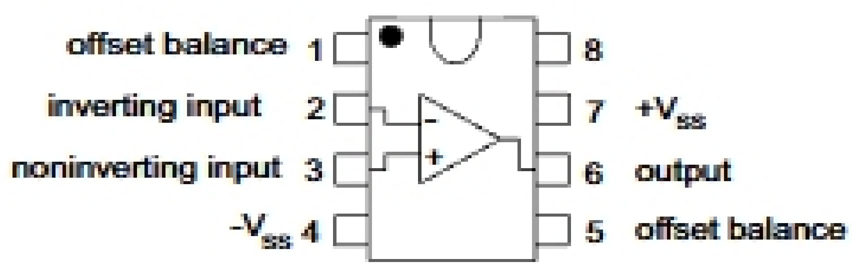
where A is typically $10^4 - 10^5$, and the two inputs are known as the *non-inverting* (v_+) and *inverting* (v_-) inputs respectively. In the ideal op-amp we assume that the gain A is infinite.

- In an ideal op-amp no current flows into either input, that is they are voltage-controlled and have infinite input resistance. In a practical op-amp the input current is in the order of pico-amps (10^{-12}) amp, or less.

- The output acts as a voltage source, that is it can be modeled as a Thevenin source with a very low source resistance.

Op-amps come in many forms and with a bewildering array of specifications. They range in cost from a few cents to many dollars, depending on the specs. These specifications include input impedance, input bias current, output offset voltage, external power requirements, etc. Higher grade amplifiers are known as precision, or instrumentation amplifiers.

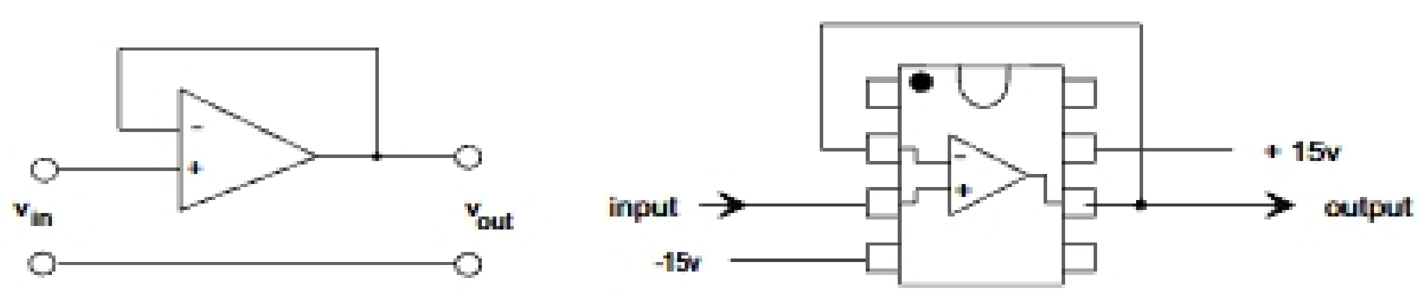
Op-amps come in a variety of packages. A common inexpensive op-amp, the 741, has an 8 pin DIP (dual in-line package) form. Many amps use a common basic pin-out for this package as shown below:



The pins are numbered counter-clockwise from the top left as shown above. (Note that pin 1 is identified by a notch at the top or a dot beside pin 1.) The basic amplifier is connected between pins 2, 3 and 6. The amplifier requires a pair of external supply voltages to operate, these are typically ±15 volts and are are connected to pins 7 (positive) and 4 (negative). Pins 1 and 5 are usually used for optional external offset nulling circuitry - the actual connection is dependent on the type. We will not use this feature if we can get away without it.

Non-Inverting Configurations

The Unity Gain Non-Inverting amplifier: The simplest configuration of the op-amp is as a unity gain "buffer" amplifier:



The output is connected directly to the inverting input. Then

$$\begin{aligned} v_{out} &= A(v_+ - v_-) \\ &= A(v_+ - v_{out}) \\ &= \frac{A}{1+A} v_+ \end{aligned}$$