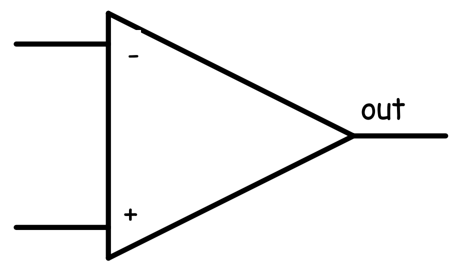
The operational amplifier

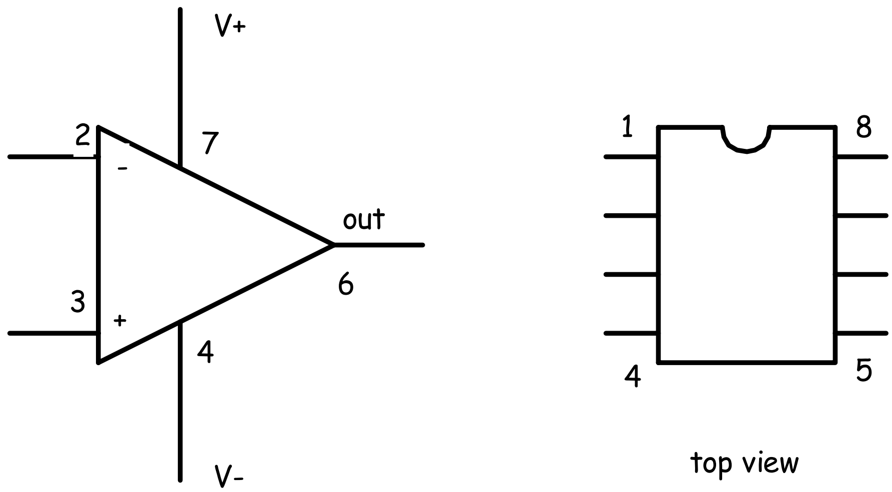
0. Introduction

An operational amplifier, op-amp, is nothing more than a DC-coupled, high-gain differential amplifier. The symbol for an op-amp is



It shows two inputs, marked "+" and "-" and an output. The output voltage is related to the input voltages by $V_{out} = A(V_+ - V_-)$. The open loop gain, A, of the amplifier is ranges from 10^5 to 10^7 at very low frequency, but drops rapidly with increasing frequency. Furthermore, A is strongly dependent on temperature, supply voltage etc. For this reason the op-amp becomes only truly useful when the overall circuit properties are primarily determined by a feedback loop instead of the open loop gain. Thus, in the following exercises, with the use of a voltage divider, part of the output voltage is fed back to the "-" input.

- An amplifier will not work without a power supply. And a more complete diagram looks like the figure below, which also indicates the



standard pin configuration.

Figure 1. Op-amp with pin configuration

- The pin connections on op-amps are to a very high degree standardized. IC pins are numbered counter clockwise (looking from the top) and for 8-pin op-amps you will always find

Pin	Function
2	Inverting input
3	Non-inverting input
4	V- supply
6	Output
7	V+ supply

The other pins are used for offset adjustment or frequency compensation, and are of less importance.

- Note that a positive and a negative supply voltage are shown, but no ground or zero potential. This doesn't mean that your ground can just float. You have to provide return paths for the input and output currents ! The absence of a ground pin only indicates that the op-amp has no intrinsic, build in reference point.

- Most of the time the connections for the power are not indicated in the circuit diagrams, and in this lab manual you will not find them either. Everywhere it is assumed that the op-amp gets connected to the +/- 12V power on the prototyping board.

- More modern op-amps are difficult to destroy, but one thing that usually does them in is interchanging the connections to the power supply. Make sure that you clearly understand the pin configuration before you wire the circuit and switch on the power.

There are a number of op-amps available in the lab. For these initial exercises you should use an OP27.

1. Inverting and non-inverting amplifiers

There are two basic types of amplifiers, the non-inverting amplifier shown in

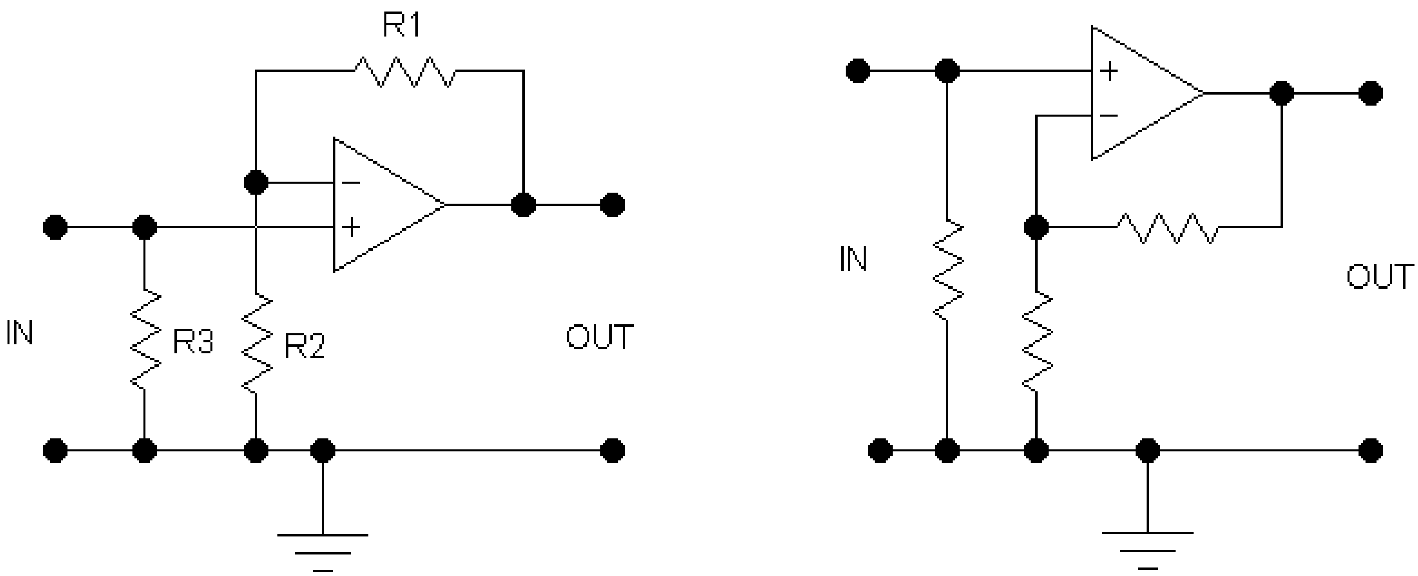


figure 2, and the inverting amplifier discussed later in this section.

Figure 2. The basic non-inverting op-amp circuit, two possible representations of the same circuit.

The low-frequency gain of the non-inverting amplifier is set by the resistors R1 and R2, A = 1 + R1/R2. For a gain of 1 these resistors can be omitted and the output is directly connected to the inverting input (Fig. 3). The input impedance of this amplifier is very high, but you should keep in mind that a path has to be provided for the input current into the non-inverting input. Here, this is take care of by R3. Using a potentiometer and series resistor to provide a dc input voltage, measure the gain of this circuit for a number of values for R1 and R2 in the 1 -- 100 kΩ range. Also check that the unity gain buffer, fig. 3, does provide a gain of exactly 1.

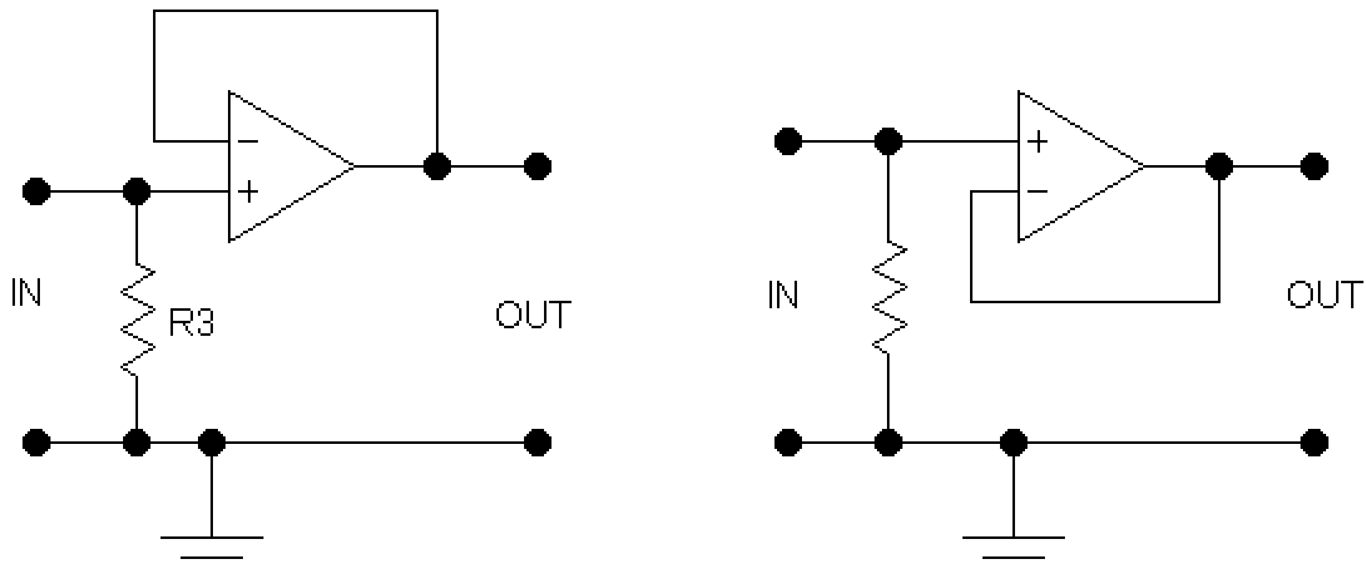


Figure 3. The unity gain buffer.

The inverting amplifier (fig. 4) has a gain $A = -R2/R1$. Note that $|A|$ can be smaller than 1. One complication with the inverting amplifier is that the input impedance is rather low (R1), and that the gain of the circuit is influenced by the output impedance of the source. To check that this circuit works, repeat the measurements that you did for the non-inverting amplifier, preferably using the same resistors. Note the change in the sign of A, and that $|A_{inv}| = |A_{non\text{-}inv}| - 1$.

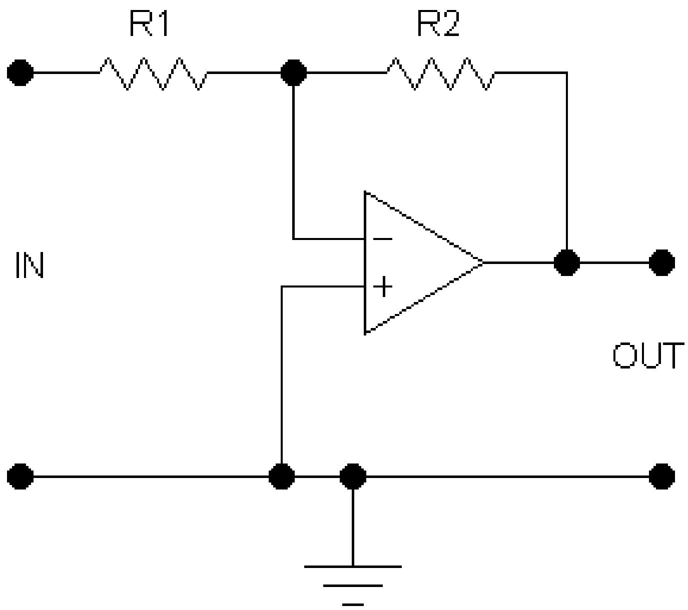


Figure 4. The inverting amplifier.

2. Adding and subtracting

Operational amplifiers got their name because one can perform a number of mathematical operations with them. The simplest operations are addition and subtraction. Figure 5 shows a typical (inverting) adder. The output voltage is given by Vout = -[(Rf/R1) V1 + (Rf/R2) V2). By making R1 = R2 signals are added with equal weight, but this does not necessarily have to be the case. Test this circuit for a range of positive and negative input voltages. Do this for R_f = R1 = R2 = 10 kΩ and for R_f = 50 kΩ, R1 = 20 kΩ, R2 = 10 kΩ.

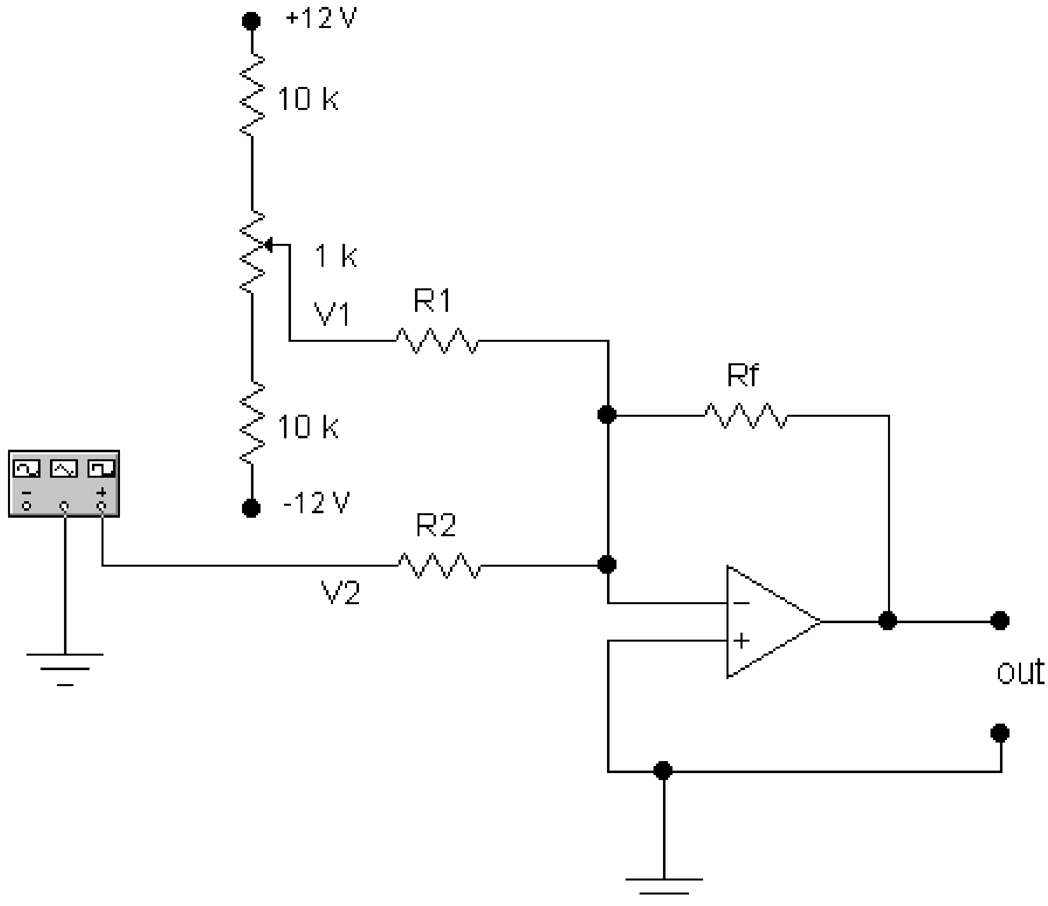


Figure 5. The (inverting) adder. (including a resistance-potentiometer networks to set V1 and a function generator to control V2.)

Subtraction is done with a circuit that is usually called a differential amplifier (fig. 6). When R1 = R3 and R2 = R4, Vout = (R2/R1) × (V2 – V1), i.e., the output voltage is proportional to the difference between V2 and V1 and the gain A = R2/R1. Take R1 = R3 = 10 kΩ, and R2 = R4 = 100 kΩ, and again test the circuit for a number of input voltages.

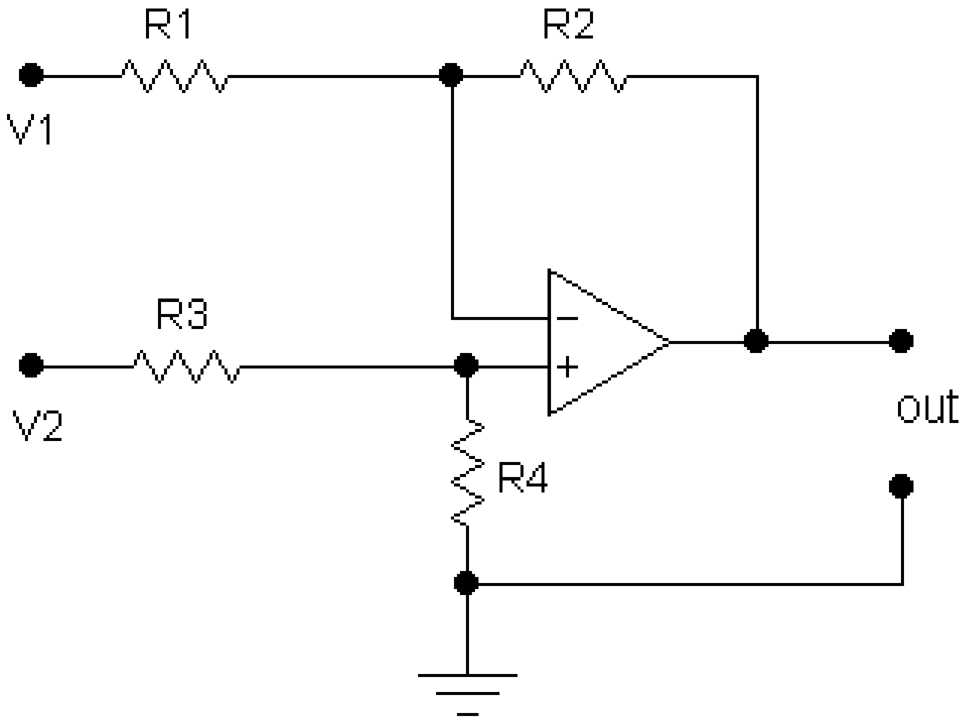


Figure 6.
The differential amplifier

3. Integration and differentiation

Two other fairly easy operations that can be performed using op-amps are integration and differentiation. If the op-amp were ideal, an integrator (Fig. 7) would require just one resistor, R, and one capacitor, C, and the relation between the output and input voltages would be given by

$$V_{out}(t) = -\int \frac{V_{in}(t)}{RC} dt$$

However, the input offset voltage, which for a non-ideal op-amp is not zero, also gets integrated. As a result the output voltage starts to drift. To fix this R_f is added to the circuit. This makes the gain for very low frequency signals finite again, but of course this means that signals with frequency components below a certain value ($f < 1/2\pi R_f C$) are not properly integrated anymore.

The integrator is most conveniently tested using a function generator and oscilloscope. First qualitatively check that square waves are integrated to triangles, triangles to parabolas etc. Then measure the ratio Vout/Vin as a function of frequency (with a sine-wave input signal). Compare with the expected behavior.

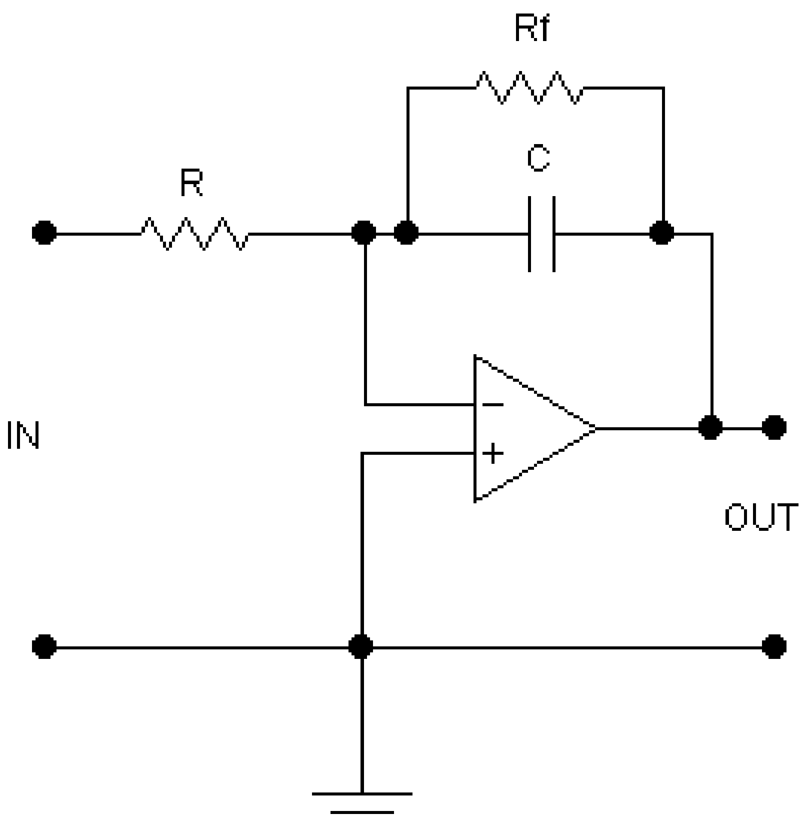


Figure 7. The integrator

Initial values

$R = 10\ k\Omega$

$C = 10\ nF$

$R_f = 1\ M\Omega$

By switching R and C, you get a differentiator (Fig. 8). This circuit is intrinsically unstable and will start to oscillate a high frequency. To avoid this, you can reduce the high frequency gain of the circuit by adding C_f. (Often, stray capacitance is enough to stabilize the circuit, but it tends to be noisy.) The price you pay is that the circuit doesn't function as a differentiator for frequencies, $f > 1/2\pi R\ C_f$. Again, the circuit is most conveniently tested with a function generator and an oscilloscope. A triangle wave input should be differentiated to a square wave, a square wave to alternating positive and negative going pulses.

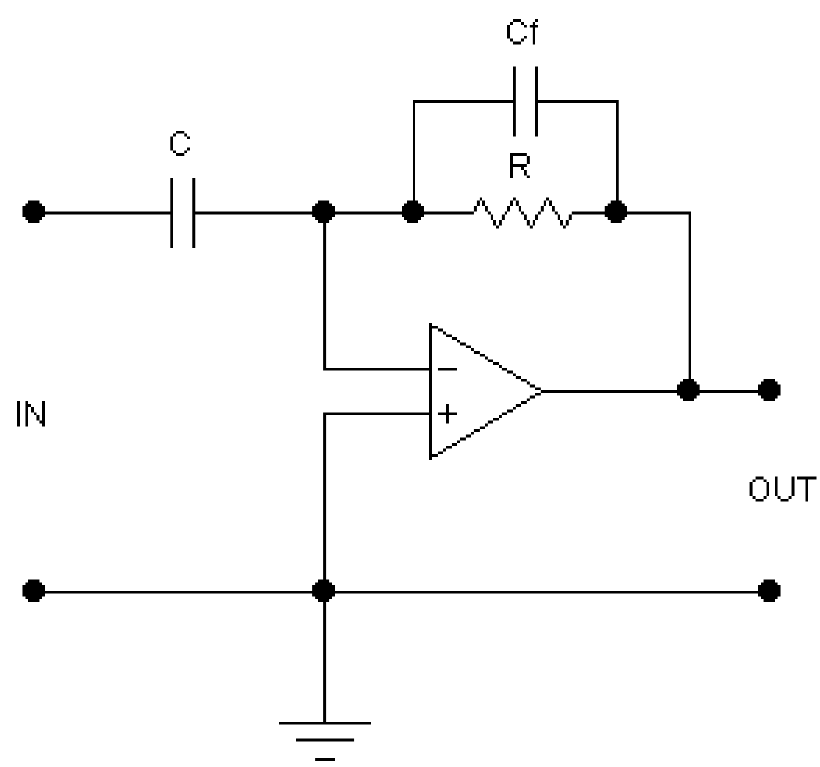


Figure 8.The differentiator

Initial values: R = 10 kΩ, C = 10 nF, C_f = 330 pF

As a last exercise, verify experimentally that the integrator and differentiator act as each other's inverse.