Inverting amplifier

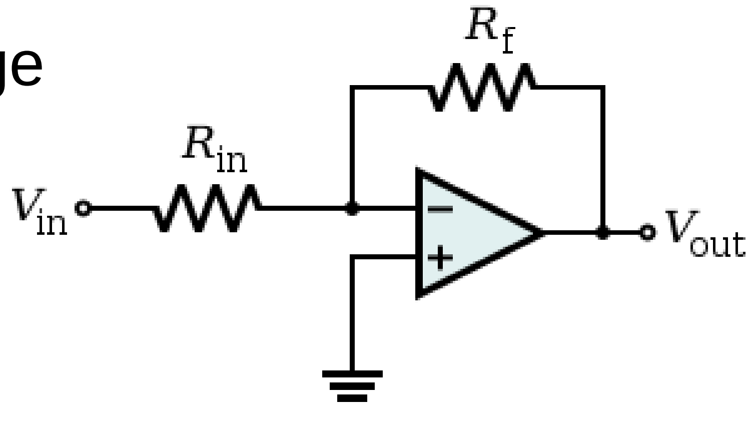
Inverting operational amplifier

The principle of operation is that the voltage difference at the + and – inputs will be maintained at zero and no current flows into the input terminals.If the + input is grounded then the – input must satisfy V = 0. The currents through the two resistors must be equal and opposite. Ohm's law gives:

$$\frac{V_{out}}{V_{in}} = \frac{-iR_f}{iR_{in}}$$

The minus sign on the output voltage gives rise to the name "inverting". The gain in signal is:

$$Gain = \frac{R_f}{R_{in}}$$



Consideration of size of R_{in}

Using the principles of the inverting amplifier we can study the intrinsic limitations on circuit time response that arise when we use such an amplifier to boost the signal.
Let's consider a signal from a photodiode. The light incident on the photodiode results in a photocurrent, which is usually quite small. In order to convert that current into a voltage we let it pass through a resistor. The larger the resistor, the larger the current since

$$\mathrm{V} = IR_{in}$$

Thus, R cannot be very small or the voltage will also be small. Remember that we want to be able to "fill" an ADC, meaning that we want the voltage to be large enough that it will be digitized accurately.

An example showing time-response

Imagine that the current coming from a typical photodiode is in the microamp range, i.e. ~ 10^{-5} amp. If the value of R_{in} is 100 ohms then we have an input voltage of 10^{-3} V or 1 millivolt. To fill the ADC we would want the signal to be approximately 10 V. Usually we do not need to fill the ADC (and in fact, we want to be careful not to chop off the top or bottom) so let's say that we want the magnitude of the signal to be 1 V. This means that we need an amplification of 1000 in the inverting amplifier. Since R_{in} = 100 ohms, we need $R_{out} = 10^5$ ohms.
Using these reasonable values, and assuming that the capacitance is minimal (i.e. 10^{-12} Farads) we see that the RC time constant of the circuit will be $\tau_{RC} = (10^5 \text{ ohms})(10^{-12} \text{ F})$ or $\tau_{RC} = 10^{-7}$ s. Thus, the time response of the circuit is 100 nanoseconds. Many processes involve more rapid changes than this. Can we possibly measure the time response of such processes using photodiodes?

Gain vs. time-response

From this example we can see that there is a trade-off between the gain and time-response of the circuit. For example, it we used a smaller value of Rout = 10,000 ohms, then the gain of the inverting amplifier would be 100 and the signal size would be 0.1 V. However, the RC time constant would be a factor of 10 smaller as well so the time resolution would be 10 nanoseconds. This is a crucial difference. Many lasers (e.g. Nd-YAG) have 10 ns pulses and many processes occur on the nanosecond time scale. So the ability to measure the change on the 10 ns vs. 100 vs time scale is important. However, as the signal gets smaller our ability to digitize is accurately also decreases. If we use a 16-bit ADC we can measure the signal in increments of 1.5×10^{-4} V (i.e. this is the voltage difference for each bit. This means that a 0.1 V signal will be digitized with an accuracy of 1 part in 600. This is reasonable. Thus, such a configuration can be used.

Realistic considerations

However, the signal we assumed from the photodiode (10^{-5} amp) was quite generous. There are many applications where our signal size could be quite a bit smaller. Thus, the design of circuits that can both amplify and obtain good time resolution is quite difficult in practice.