Introduction to Analogue Electronics: Operational Amplifiers (Op-Amps)

1 What is an op-amp?

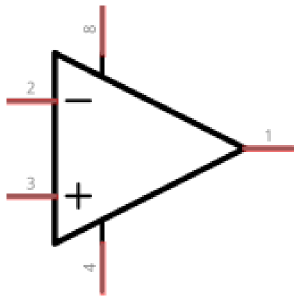

Figure 1: An op-amp schematic

> An operational amplifier ("op-amp") is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. In this configuration, an op-amp produces an output potential (relative to circuit ground) that is typically hundreds of thousands of times larger than the potential difference between its input terminals.
>
> *Definition from* `https://en.wikipedia.org/wiki/Operational_amplifier`

An op-amp has two inputs - inverting ($-$) and non-inverting ($+$) and a single output. The output voltage V_{out} is given by the difference between the two inputs, multiplied by the gain of the amplifier, A_0:

$$V_{out} = A_0 \left(V_+ - V_-\right)$$

2 Comparators

The output voltage of the op-amp cannot exceed the voltage of its power supply. This means that an op-amp wired as shown in figure 1 will switch between the maximum and minimum output voltages based on the difference between the two inputs. If one of the inputs is a reference voltage (from another component, or a potential divider), then the output switches based on whether the 2^{nd} input voltage is greater than or less than the reference input.

3 Linear Amplifier

The output of an op-amp can be stabilised by feeding a proportion of its output to its inverting input. This can be done using a potential divider connected to the output as shown in figure 3. The output voltage can then be given as:

$$V_{out} = V_{in}\left(1 + \frac{R_1}{R_2}\right) \qquad \text{For a non-inverting amplifier} \qquad (1)$$

$$V_{out} = V_{in}\frac{R_1}{R_2} \qquad \text{For an inverting amplifier} \qquad (2)$$

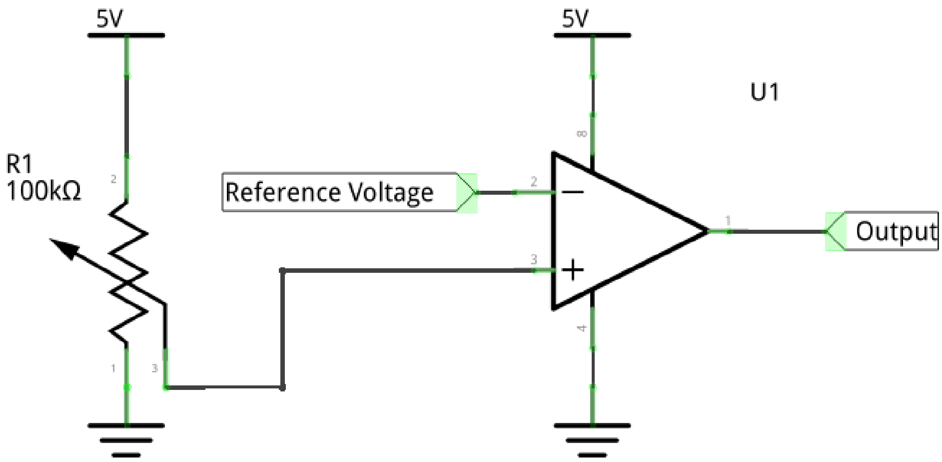

Figure 2: A simple comparator circuit, comparing the voltage of the potential divider $R1$ to a reference value

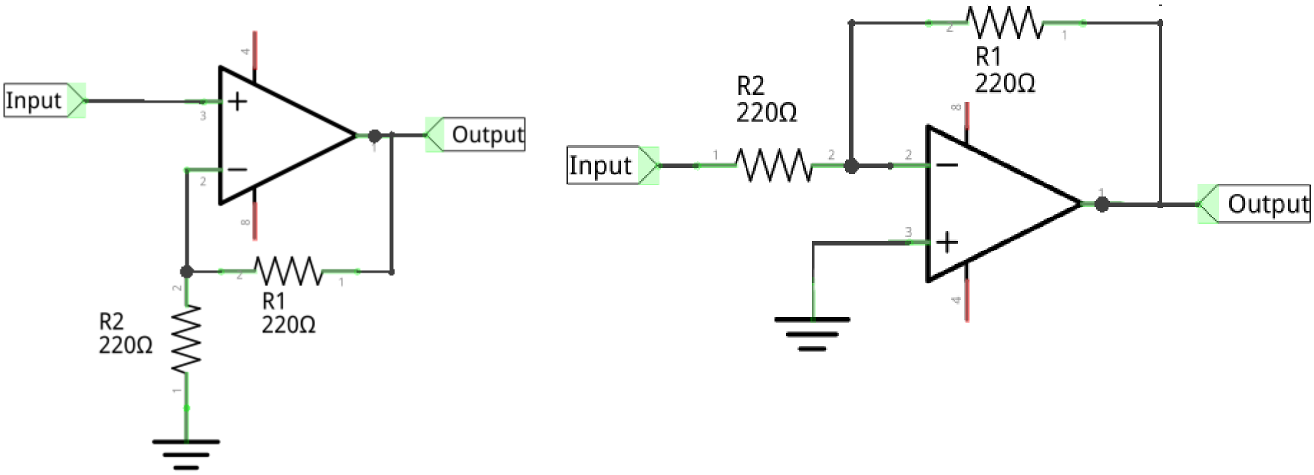

Figure 3: Example non inverting (left) and inverting (right) amplifiers

4 Op-Amp based filters

An op-amp based circuit like thoses shown in figure 3 can be considered in three sections: input, output and feedback. In these circuits, the feedback part of the circuit is given by the combination of R_1 and R_2. These circuits apply the same gain to any signal applied to the input - the behaviour of resistors does not vary with frequency. These circuits can be turned into active high or low pass filters by replacing R_1 or R_2 with a capacitor.

4.1 Active low pass filter

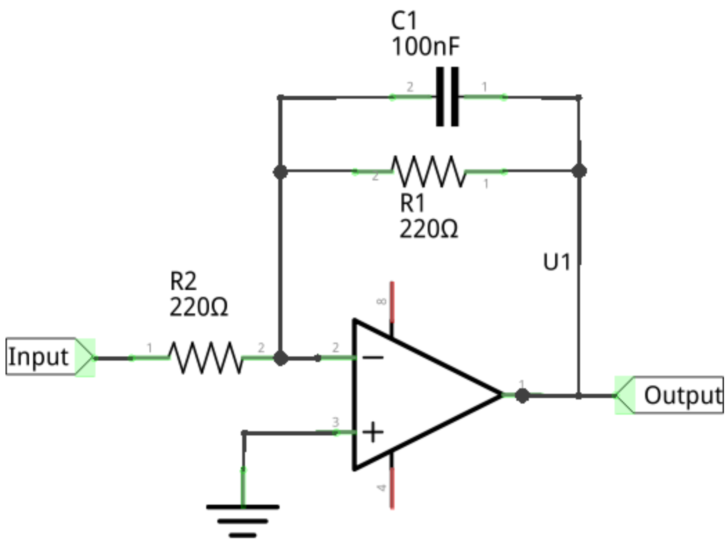

Figure 4: Active low pass filter

Adding a capacitor to the feedback loop reduces the amount of feedback at low frequencies. This means that low frequencies have a higher gain than high frequencies (more feedback → lower gain). This is shown in figure 4. The cutoff frequency of this filter is given by

$$f_0 = \frac{1}{2\pi R_1 C_1}$$

The gain is given by

$$G = \frac{-R1}{R2}$$

Unlike passive filters, these filters can have a gain $G > 1$

4.2 Active high pass filter

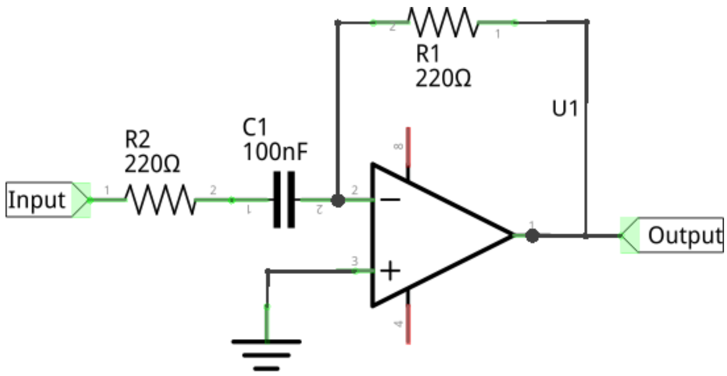

Figure 5: Active high pass filter

In an active high pass filter, the feedback loop contains a low pass filter (Output $\rightarrow R_1 \rightarrow C_1$). This reduces the feedback at high frequencies. The cut-off frequency and gain are given by the same equations as the active low pass filter.