ee101_inv_amp_3.sqproj

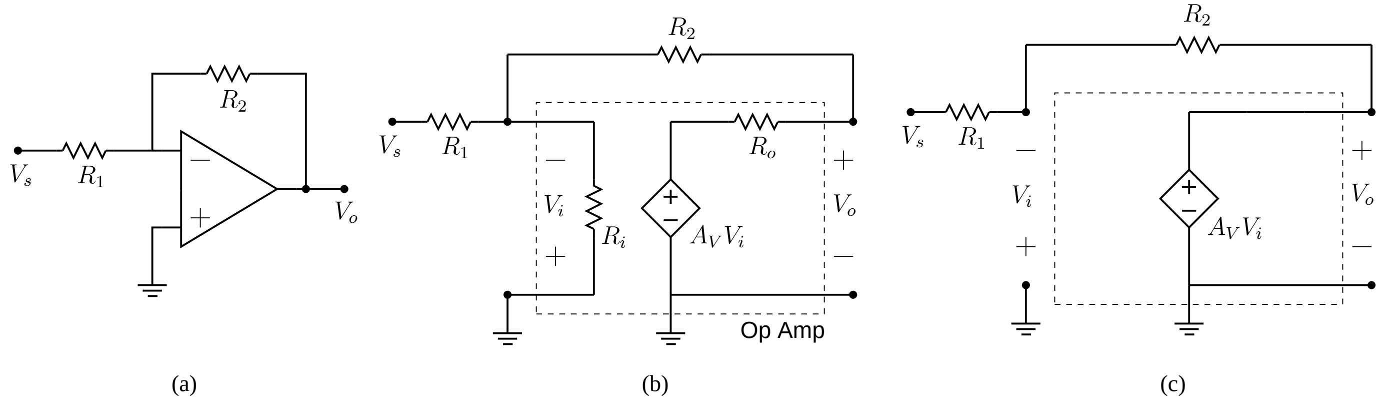

Figure 1: (a) inverting amplifier, (b) equivalent circuit, (c) equivalent circuit with $R_i \to \infty$, $R_o \to 0$.

Shown in Fig. 1 (a) is an inverting amplifier for which

$$V_o(t) = -\frac{R_2}{R_1} V_i(t) \,. \tag{1}$$

If a sinusoidal input voltage $\mathbf{V}_i(j\omega) = \widehat{V}_i \angle 0$ is applied, the output voltage is expected to be

$$\mathbf{V}_o(j\omega) = \frac{R_2}{R_1} \widehat{V}_i \angle \pi \,. \tag{2}$$

Eq. 2 is valid if the open-loop gain of the Op Amp (A_V) is large at all frequencies of interest. For a real Op Amp, however, A_V falls at high frequencies, thus limiting the gain $|\mathbf{V}_o|/|\mathbf{V}_i|$ of the inverting amplifier. The open-loop gain of a 741 Op Amp is given by,

$$A_V(s) = \frac{A_0}{1 + s/\omega_c} \,, \tag{3}$$

with $A_0 \approx 10^5$ (i.e., 100 dB), $\omega_c \approx 2\pi \times 10$ rad/s.
By replacing the Op Amp in Fig. 1 (a) by its equivalent circuit (see Fig. 1 (b)) and then further simplifying it by assuming R_i to be large and R_o to be small (see Fig. 1 (c)), we get

$$-V_i(s) = V_s(s) \frac{R_2}{R_1 + R_2} + V_o(s) \frac{R_1}{R_1 + R_2} \,. \tag{4}$$

Using $V_o(s) = A_V(s)\, V_i(s)$,

$$\frac{V_o(s)}{V_s(s)} = -\frac{R_2}{R_1}\,\frac{1}{\left[1+\left(\dfrac{R_1+R_2}{R_1}\right)\dfrac{1}{A_0}\right]+\left(\dfrac{R_1+R_2}{R_1 A_0}\right)\dfrac{s}{\omega_c}} \tag{5}$$

$$\approx -\frac{R_2}{R_1}\,\frac{1}{1+s/\omega_c'}\,, \tag{6}$$

with $\omega_c' = \dfrac{\omega_c A_0}{1+R_2/R_1} = \dfrac{\omega_t}{1+R_2/R_1}$.

In other words, as ω increases, the gain of the inverting amplifier is no longer constant, but falls at the rate of 20 dB/dec.

If $R_2/R_1 \gg 1$, the product of the gain (i.e., R_2/R_1) and the bandwidth ω_c' is a constant, resulting in the well-known trade-off between gain and bandwidth of amplifiers.

Exercise Set

1. For $R_1 = 1\,\text{k}\Omega$, $R_2 = 50\,\text{k}\Omega$, and a 741 Op Amp model, obtain a plot of $\log|\mathbf{V}_o|$ versus $\log f$ by AC simulation, keeping $|\mathbf{V}_i| = 0.01\,V$. What is the 3-dB frequency for this amplifier?

2. Repeat (1) for three other values of R_2: (a) $25\,\text{k}\Omega$, (b) $10\,\text{k}\Omega$, (c) $5\,\text{k}\Omega$. Plot $\log|\mathbf{V}_o|$ versus $\log f$ for the various values of R_2 together and correlate your observations with the theoretical considerations given above.

3. Verify that the product of the low-frequency gain A_V^0 and the 3-dB frequency f_H of the inverting amplifier is approximately constant, irrespective of the R_2 value in (1) and (2).