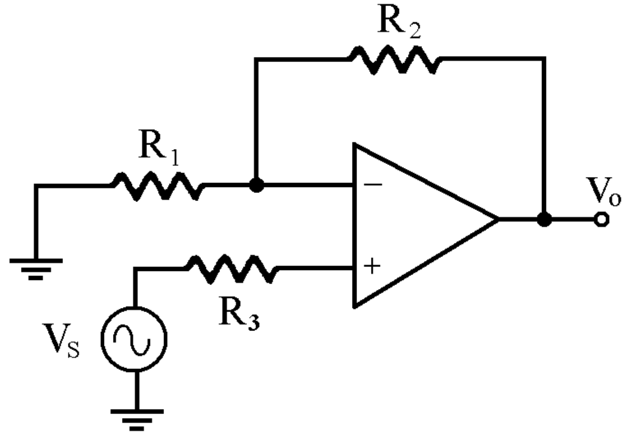
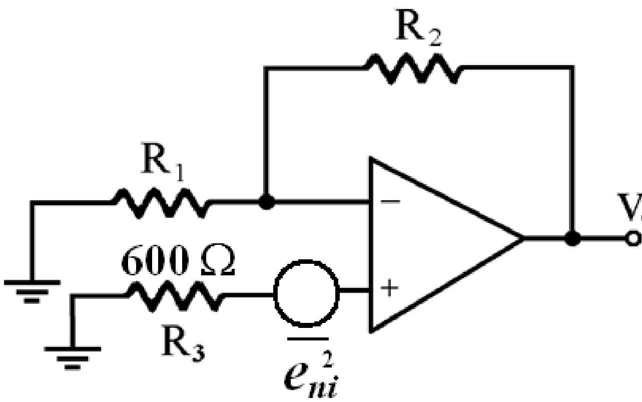
EE4341 TUTORIAL 4 SOLUTION

1a. (i) Non-inverting amplifier





R_1 and R_2 are chosen such that $R_1//R_2 = R_3$ for DC offset cancellation.

$$\overline{e_{ni}^{\,2}} = \overline{v_n^{\,2}} + \overline{i_n^{\,2}}\left(R_3^{\,2} + (R_1 // R_2)^2\right) + 4kT\left(R_3 + R_1 // R_2\right)$$

$$= \overline{v_n^{\,2}} + \overline{i_n^{\,2}}\left(2R_3^{\,2}\right) + 8kTR_3$$

$$= 8\times10^{-16} + 9\times10^{-25}\left(2\times600^2\right) + 2\times1.656\times10^{-22}\times600$$

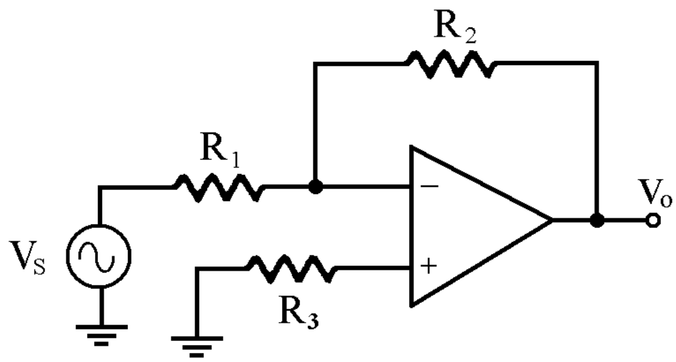
$$= 8\times10^{-16} + 6.48\times10^{-19} + 2\times10^{-17}$$

$$= 8.2\times10^{-16} \quad \mathrm{V}^2 / Hz$$

$$E_{ni} = \sqrt{\overline{e_{ni}^{\,2}}\,\Delta f} = \sqrt{8.2\times10^{-16}\times20k} = 4.05 \ \mu\mathrm{V}$$

$$SNR(dB) = 20\,log\,\frac{V_s}{E_{ni}} = 20\,log\,\frac{5mV}{4.05\mu V} = 61.8 \ \mathrm{dB}$$

1a. (ii) Inverting amplifier



The voltage gain for the noise voltage is non-inverting amplifier gain:

$$\therefore \overline{e_{no}^{\;2}} = \overline{e_{ni+}^{\;2}}\left(1+\frac{R_2}{R_1}\right)^2 = \overline{e_{ni+}^{\;2}}\left(\frac{R_1+R_2}{R_1}\right)^2$$

To reflect the noise at the inverting input:

$$\therefore \overline{e_{ni-}^{\;2}} = \frac{\overline{e_{no}^{\;2}}}{(R_2/R_1)^2} = \overline{e_{ni+}^{\;2}}\left(\frac{R_1+R_2}{R_1}\right)^2\left(\frac{R_1}{R_2}\right)^2$$

$$= \overline{e_{ni+}^{\;2}}\left(\frac{R_1+R_2}{R_2}\right)^2 = \overline{e_{ni+}^{\;2}}\left(1+\frac{R_1}{R_2}\right)^2$$

$$E_{ni-} = \left(1+\frac{R_1}{R_2}\right)E_{ni+} = \left(1+\frac{1}{10}\right)\times 4.05 = 4.46\mu V$$

$$SNR(dB) = 20\,log\,\frac{V_s}{E_{ni}} = 20\,log\,\frac{5mV}{4.46\mu V} = 61\ \text{dB}$$

1b. (i) Non-inverting amplifier

$$\begin{aligned}\overline{e_{ni}^{\,2}} &= \overline{v_n^{\,2}} + \overline{i_n^{\,2}}\left(2R_3^{\,2}\right) + 8kTR_3 \\ &= 16\times10^{-18} + 0 + 2\times1.656\times10^{-22}\times600 \\ &= 3.6\times10^{-17} \quad \mathrm{V}^2 / Hz\end{aligned}$$

$$E_{ni} = \sqrt{\overline{e_{ni}^{\,2}}\,\Delta f} = \sqrt{3.6\times10^{-17}\times20k} = 0.85\ \ \mu\mathrm{V}$$

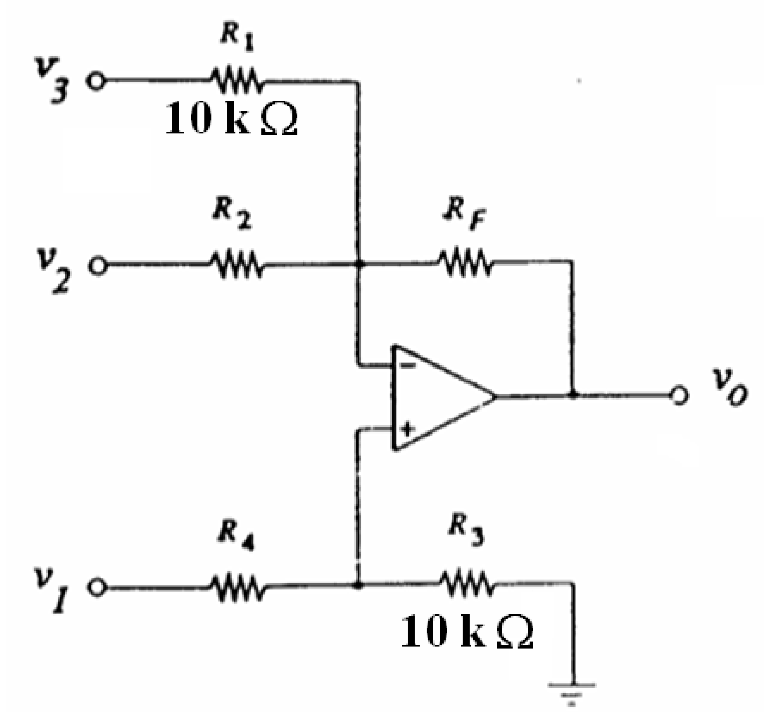
$$SNR(dB) = 20\,log\,\frac{V_s}{E_{ni}} = 20\,log\,\frac{5mV}{0.85\mu V} = 75.4\ \ \mathrm{dB}$$

(ii) Inverting amplifier:

$$E_{ni-} = \left(1+\frac{R_1}{R_2}\right)E_{ni+} = \left(1+\frac{1}{10}\right)\times0.85 = 0.94\mu V$$

$$SNR(dB) = 20\,log\,\frac{V_s}{E_{ni}} = 20\,log\,\frac{5mV}{0.94\mu V} = 74.5\ \ \mathrm{dB}$$

2.



$$v_o = 2(v_1 - v_2 - v_3) = 2v_1 - 2v_2 - 2v_3$$

$$v_{o3} = -\frac{R_F}{R_1} v_3 = -2v_3$$

$$\therefore \frac{R_F}{R_1} = 2 \Rightarrow R_F = 2R_1 = 20\text{k}\Omega$$

$$v_{o2} = -\frac{R_F}{R_2} v_2 = -2v_2$$

$$\therefore \frac{R_F}{R_2} = 2 \Rightarrow R_2 = \frac{R_F}{2} = 10\text{k}\Omega$$

$$v_{o1} = \left(\frac{R_3}{R_3 + R_4}\right) v_1 \left(1 + \frac{R_F}{R_1 // R_2}\right) = \left(\frac{R_3}{R_3 + R_4}\right) v_1 \left(1 + \frac{20k}{5k}\right)$$

$$= 5v_1 \left(\frac{R_3}{R_3 + R_4}\right) = 2v_1$$

$$\therefore\ \frac{5R_3}{R_3+R_4}=2 \Rightarrow R_4=\frac{3R_3}{2}=15\text{k}\Omega$$

$$R_n = R_1 // R_2 // R_F = 10k // 10k // 20k = 4\text{k}\Omega$$
$$R_p = R_4 // R_3 = 15k // 10k = 6\text{k}\Omega$$

The non-inverting amplifier gain for the noise:

$$A_v = 1+\frac{R_F}{R_1 // R_2} = 1+\frac{20k}{5k} = 5$$

The -3dB bandwidth of the non-inverting amplifier:

$$f_A = \frac{GBW}{A_v} = \frac{10^6}{5} = 200kHz$$

$$E_{no} = A_v\left[\overline{e_{nw}}^2\left(f_{ce}\,ln\frac{1.57f_A}{f_L}+1.57f_A-f_L\right)+\right.$$
$$\left.\left(R_p{}^2+R_n{}^2\right)\overline{i_{nw}}^2\left(f_{ci}\,ln\frac{1.57f_A}{f_L}+1.57f_A-f_L\right)+4kT\left(R_p+R_n\right)\left(1.57f_A-f_L\right)\ \right]^{\frac{1}{2}}$$
$$=5\left[\left(20\times10^{-9}\right)^2\left(200\,ln\frac{314k}{1}+314k-1\right)+\right.$$
$$\left(\left(6k\right)^2+\left(4k\right)^2\right)\left(0.5\times10^{-12}\right)^2\left(2000\,ln\frac{314k}{1}+314k-1\right)+$$
$$\left.1.656\times10^{-20}\left(6k+4k\right)\left(314k-1\right)\ \right]^{\frac{1}{2}}$$
$$E_{no}=5\left[1.27\times10^{-10}+4.41\times10^{-12}+5.20\times10^{-11}\ \right]^{\frac{1}{2}}=67.64\mu V$$

$$E_{no,p-p}=6.6E_{no,ems}=6.6\times67.64\mu V=0.45mV$$