

INEI 5207 Analog System Design with Operational Amplifiers
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Solution to problem textbook's problem 7-21. See diagram in figure 2-23.

Use $R_2 = 999 \times R_1$.

The output of the first stage is

$$v_{O1} = v_1 \left(1 + \frac{R_1}{R_2} \right) \approx 1$$

Thus the first stage bandwidth is $f_t = 8MHz$. While the noise gain for this first stage is 1, that of the second stage is 1000. The bandwidth for the second stage is $f_B = \frac{8MHz}{1000} = 8kHz$. This pole dominates the response of the whole amplifier. Thus the amplifier behaves as having a single-pole and has a bandwidth equal to $f_B = 8kHz$.

The total noise can be found by adding the noise from each opamp. Because the noise from the first stage is amplified only by the second stage, the output noise due to the first and second stages are equal. Since the noise sources are uncorrelated, $E_{NO} = \sqrt{E_{NO2}^2 + E_{NO1}^2} = \sqrt{2}E_{NO2}$.

Using eq. 7-25 we get the following expression for the total noise:

$$\begin{aligned} E_{NO} = & \sqrt{2} \times 1000 \times \left[\left(3 \times 10^9 \times \left(2.7Hz \ln \frac{8 \times 10^3}{0.1} + 1.57 \times 8 \times 10^3 - 0.1 \right) \right) \right. \\ & + (R_1 || R_2) \times \left(0.4 \times 10^{-12} \frac{A}{\sqrt{Hz}} \right)^2 \times \left(140 \ln \frac{8 \times 10^3}{0.1} + 1.57 \times 8 \times 10^3 - 0.1 \right) \\ & \left. + \left(1.65 \times 10^{20} \frac{W}{Hz} \right) \times (R_1 || R_2) \times \left(1.57 \times 8 \times 10^3 \right) \right]^{\frac{1}{2}} \end{aligned}$$

Since $R_2 = 999R_1$, $R_2 || R_1 \approx R_1$. Simplifying the above expression produces

$$E_{NO} = \sqrt{2} \times 1000 \times \left[1.1 \times 10^{-13} + R_1^2 \times 2.26 \times 10^{-21} + R_1 \times 2 \times 10^{-16} \right]^{\frac{1}{2}}$$

To minimize noise, the first term should be dominant. This requires that

$$1.1 \times 10^{-13} \gg R_1^2 \times 2.26 \times 10^{-21}$$

and

$$1.1 \times 10^{-13} \gg R_1 \times 2 \times 10^{-16}$$

which yields $R_1 < 7k\Omega$ and $R_1 < 550\Omega$. If we select $R_1 = \frac{550\Omega}{3} \approx 180\Omega$ then our solution will agree with the book, but a value like 100Ω would work as well.

Thus $\boxed{R_1 = 180\Omega}$ and $\boxed{R_2 = 180k\Omega}$. The output noise becomes $\boxed{E_{NO} = 540\mu V}$.