Examples: Noise

1. The Gain-Bandwidth of an op-amp is 6 MHz. If the gain is 100:
   a. What is the cut-off frequency if the amplifier is non-inverting?

   $$f_c = \frac{GBW}{Gain} = \frac{6\times10^6}{100} = 60 \text{ kHz}$$

   b. What is the white noise equivalent bandwidth?

   This will depend if it is non-inverting or inverting. If it is non-inverting the gain and noise gain will be the same so:

   $$NEB = 1.57\times\frac{GBW}{\text{Noise Gain}} = 1.57\times 60 \text{ kHz} = 94.2 \text{ kHz}$$

   If it is inverting the Noise Gain will be 101.

   $$NEB = 1.57\times\frac{GBW}{\text{Noise Gain}} = 1.57\times\frac{6\times10^6}{101} = 93.27 \text{ kHz}$$

2. Consider Figure 1 where R2=10 kΩand R1=2 kΩ:
   a. What is the voltage gain of the amplifier?
      Signal gain = -5
   b. What is the noise gain of the amplifier?
      Noise gain = 6
      Why? Because the voltage noise is always referred to the non-inverting input.

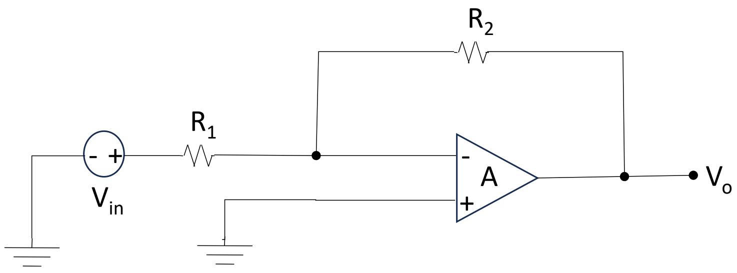



*Figure 1.*

3. An inverting amplifier is shown in Figure 2. The data sheet for the op-amp gives the value of Gain Bandwidth (GBW) as 5 MHz, a voltage spectral density of white noise of $e_{nw} = 20nV/\sqrt{Hz}$ and a current spectral density of white noise of $i_{nw} = 0.4pA/\sqrt{Hz}$.

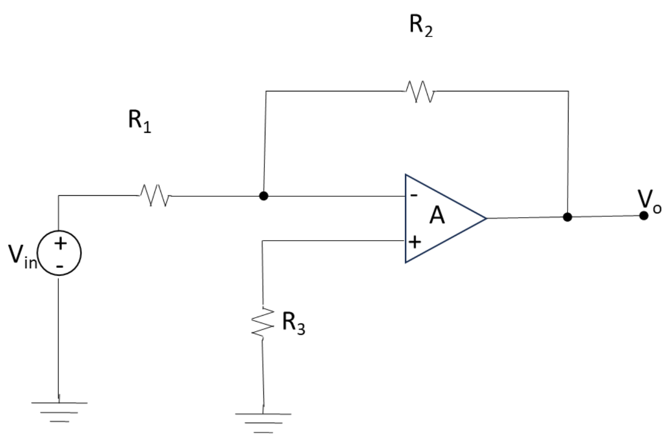


*Figure 2*

a. If a gain of 100 is required and R2 is 101 kΩ calculate R1 and R3.

The gain is given by G=-$\frac{R_2}{R_1}$ so:

$$100 = \frac{101\ \text{k}\Omega}{R_1} \text{ so:}$$

$$\text{R}_1 = 1.01\ \text{k}\Omega$$

b. What is the noise gain?

$G_n$=101 (Remember noise is always referred to the non-inverting input)

c. What is the value of $f_H$?

$$f_H = \frac{GBW}{G_n} = \frac{5\times10^6}{101} = 49.5\ \text{kHz}$$

d. What in the value of NEB?

NEB=1.57x49.5 kHz=77.715 kHz

e. What is the thermal noise voltages at the inverting and non-inverting inputs?

$$E_3 = E_{RP} = \sqrt{4kT\times1.57\times f_H\times1000} = \sqrt{4\times1.38\times10^{-23}\times300\times77700\times1000} = 1.13\ \mu\text{V}$$

f. What is the RMS input noise due to $e_{nw}$?

$$E_n = e_{nw}\sqrt{1.57\,f_H} = 20\times10^{-9}\sqrt{1.57\times49500} = 5.58\ \mu\text{V}$$

g. What is the RMS input noise due to $i_{nw}$?

$$E_{nn} = E_{np} = R_1 \| R_2 \times i_{nw}\sqrt{1.57\,f_H} = 1000\times0.4\times10^{-12}\sqrt{1.57\times49500} = 111.5\ \text{nV}$$

h. What is the total input noise?

$$E_{ni} = \sqrt{E_{RP}^2 + E_{R3}^2 + E_{nn}^2 + E_{np}^2 + E_n^2} = \sqrt{2\times1.2769\times10^{-12} + 2\times1.243\times10^{-14} + 3.114\times10^{-11}} = 5.8\ \mu\text{V}$$

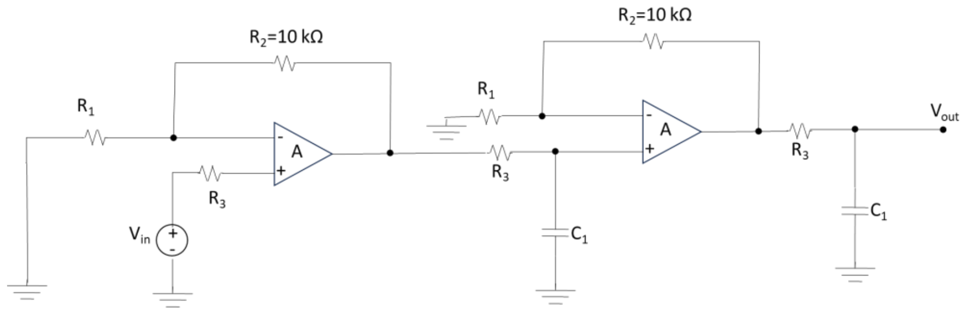
i. What is the output noise?

*$E_{no}$=$E_{ni}$ x $G_n$ = 586 μV*

4. It is proposed to use a two-stage amplifier with symmetrical lower gains for an overall gain of 100. The op amps to be used are in a single package and have a voltage spectral density of white noise, $e_{nw}$, of $5nV/\sqrt{Hz}$ and a GBW of 5 MHz (note that there is negligable current spectral densities of white noise, so $i_{nw}$ can be ignored.

   a. Using a feedback resistor of 10 kΩ in both stages, and inserting external low pass filters with a cut-off frequency, $f_H$, of 70 kHz:

      i. Draw a schematic of the 2-stage amplifier and determine the component values. You should assume that the external filter provides a much lower cut-off than the closed loop bandwidth of each stage.




We should distribute the gain evenly over two stages so Gain of each stage =10. Then find R1, R3 and C1.

      ii. Calculate the rms output noise. In your calculations you may assume that the input current noise is negligible, and that the temperature is 25°C.

The important thing to realize is that the NEB of the two stages will differ since the noise of the 1st stage will see 2 low pass filter functions.

      iii. What is the SNR for an output voltage of 4V peak-to-peak?

Note that the output voltage is peak to peak. Need to get to rms.