For the circuit above, $V_i = 10 \text{ mV}$:

- What is $V_o$ if the amplifier is ideal?

- What is $V_o$ if the offset voltage, $V_{OS} = 10 \mu V$?

- What is $V_o$ if the bias current, $I_B = 10 \text{ nA}$?

- What is $V_o$ if the amplifier is ideal?

Represent ideal as $\bar{V}_o$

\[
V_+ = \frac{23 \text{ k}\Omega}{23 + 1.5 \text{ k}\Omega} V_i = (9.390 \text{ mV)}, \quad \bar{V}_o = \left(1 + \frac{23 \text{ k}\Omega}{1.5 \text{ k}\Omega}\right) V_+ = 16.333 V_+ = 153.367 \text{ mV}
\]

- What is $V_o$ if the offset voltage, $V_{OS} = 10 \mu V$?

Use superposition to get $(V_o')$ then add to ideal $V_{OS}$:

\[
V_o' = \left(1 + \frac{23 \text{ k}\Omega}{1.5 \text{ k}\Omega}\right) V_{OS} = 16.333 \times V_{OS} = 0.163 \text{ mV}
\]

\[
V_o = \bar{V}_o + V_o' = 153.530 \text{ mV}
\]

- What is $V_o$ if the bias current, $I_B = 10 \text{ nA}$?

First, use superposition to get $(V_o'')$ for $I_B$ into $V_+$. Current travels through parallel resistors.

\[
V_o'' = -\left(1 + \frac{23 \text{ k}\Omega}{1.5 \text{ k}\Omega}\right) (R_1 || R_2) I_B = -16.333 \times 1.408 \text{k}\Omega \times I_B = -0.230 \text{ mV}
\]

Next, use superposition to get $(V_o''')$ for $I_B$ into $V_-$. Current through $R_1$, since FB keeps $V_-$ at ground. Note that this resistor configuration cancels $I_B$.

\[
V_o''' = (23 \text{ k}\Omega) I_B = 0.230 \text{ mV}
\]

\[
V_o = \bar{V}_o + V_o' + V_o''' = 153.367 \text{ mV}
\]
The op amp is ideal, except $f_T$ (= Gain-Bandwidth) is 120 kHz.

For the circuit above, $V_i = (20 \text{ mV}) \cos(2\pi ft)$:

- What is the peak-to-peak amplitude of $V_o$ if $f = 3 \text{ kHz}$?
- What is the peak-to-peak amplitude of $V_o$ if $f = 30 \text{ kHz}$?

First, analyse ideal gain, $V_o$

$$V_+ = \frac{24 \text{ k}\Omega}{24 + 3.3 \text{ k}\Omega} V_i = 0.879 V_i \quad \bar{V}_o = \left(1 + \frac{24 \text{ k}\Omega}{3.3 \text{ k}\Omega}\right) V_+ = 8.273 V_+ = 7.272 V_i$$

- What is the peak-to-peak amplitude of $V_o$ if $f = 3 \text{ kHz}$?
  Given Gain-Bandwidth, maximum possible gain is $G = (G \cdot BW)/f = 120/3 = 40$.
  We specify a gain of 7.272 which is less than 40, so we get the specified gain.
  $V_o = 7.272 \times (20 \text{ mV}) \cos(2\pi ft)$, and peak-peak voltage is $2 \times max(V_o)$.
  Answer: 290.9 mV.

- What is the peak-to-peak amplitude of $V_o$ if $f = 30 \text{ kHz}$?
  Given Gain-Bandwidth, maximum possible gain is $G = (G \cdot BW)/f = 120/30 = 4$.
  We specify a gain of 7.272 which is greater than 4, so we only get a gain of 4.
  $V_o = 4 \times (20 \text{ mV}) \cos(2\pi ft)$, and peak-peak voltage is $2 \times max(V_o)$.
  Answer: 160.0 mV.
For the circuit above:

- **What type of filter is this?** (high pass, low pass, band pass, band stop)
- Sketch the amplitude of \( \frac{V_o}{V_i} \) as a function of frequency. Label the passband, stopband and roll-off rate.
- What is the cut-off frequency \( (f_c) \) and damping constant \( (\zeta) \)?

- **What type of filter is this?** (high pass, low pass, band pass, band stop)
  This is a low pass filter
- What is the cut-off frequency \( (f_c) \) and damping constant \( (\zeta) \)?

\[
\omega_c = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5.4 \, \text{mH} \cdot 16.7 \, \mu\text{F}}} = 3330.005 \, \text{rad/s}, \quad f_c = 2\pi \omega_c = 20922.601 \, \text{Hz}
\]

and,

\[
\zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{238 \, \text{k}\Omega}{2} \sqrt{\frac{16.7 \, \mu\text{F}}{5.4 \, \text{mH}}} = 6.618
\]

- Sketch the amplitude of \( \frac{V_o}{V_i} \) as a function of frequency. Label the passband, stopband and roll-off rate.
  \( \frac{V_o}{V_i} \) starts near 1.0. After \( f_c \), graph decreases at 40 dB/decade.