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, $V_{OS} = 10 \mu \text{V}$?
- 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 $\bar{V}_o$

  $$V_+ = \frac{23 \text{ k}\Omega}{23 + 2.1 \text{ k}\Omega} V_i = (9.160 \text{ mV}) \quad \bar{V}_o = \left(1 + \frac{23 \text{ k}\Omega}{2.1 \text{ k}\Omega}\right) V_+ = 11.952 \ V_+ = 109.480 \text{ mV}$$

- What is $V_o$ if the offset voltage, $V_{OS} = 10 \mu \text{V}$?
  
  Use superposition to get $(V_o')$ then add to ideal $V_{OS}$:

  $$V_o' = \left(1 + \frac{23 \text{ k}\Omega}{2.1 \text{ k}\Omega}\right) V_{OS} = 11.952 \times V_{OS} = 0.120 \text{ mV}$$

  $$V_o = \bar{V}_o + V_o' = 109.600 \text{ mV}$$

- 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.

  $$V_o'' = -\left(1 + \frac{23 \text{ k}\Omega}{2.1 \text{ k}\Omega}\right) (R_1\|R_2) I_B = -11.952 \times 1.924 \text{ k}\Omega \times I_B = -0.230 \text{ mV}$$

  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 $I_B$.

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

  $$V_o = \bar{V}_o + V_o' + V_o'' = 109.480 \text{ mV}$$
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, $\bar{V}_o$

\[
V_+ = \frac{22 \text{ k}\Omega}{22 + 3.2 \text{ k}\Omega} V_i = 0.873 V_i \quad \bar{V}_o = \left(1 + \frac{22 \text{ k}\Omega}{3.2 \text{ k}\Omega}\right) V_+ = 7.875 V_+ = 6.875 V_i
\]

- 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 6.875 which is less than 40, so we get the specified gain.
$V_o = 6.875 \times (20 \text{ mV}) \cos(2\pi ft)$, and peak-peak voltage is $2 \times max(V_o)$.
Answer: 275.0 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 6.875 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 ($\zeta$)?

  $$\omega_c = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5.6 \text{ mH} \cdot 16.1 \mu\text{F}}} = 3330.374 \text{ rad/s}, \quad f_c = 2\pi \omega_c = 20924.919 \text{ Hz}$$

  and,

  $$\zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{223 \text{ k}\Omega}{2} \sqrt{\frac{16.1 \mu\text{F}}{5.6 \text{ mH}}} = 5.979$$

- 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.