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, $I_B = 10 \text{nA}$?

### If the Amplifier is Ideal

Represent ideal as $\bar{V}_o$

\[
V_+ = \frac{21 \text{k}\Omega}{21 + 1.1 \text{k}\Omega} V_i = (9.500 \text{ mV}) \quad \bar{V}_o = \left(1 + \frac{21 \text{k}\Omega}{1.1 \text{k}\Omega}\right) V_+ = 20.091 \text{ V}_+ = 190.864 \text{ mV}
\]

### Offset Voltage

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

\[
V_o' = \left(1 + \frac{21 \text{k}\Omega}{1.1 \text{k}\Omega}\right) V_{OS} = 20.091 \times V_{OS} = 0.201 \text{ mV}
\]

\[
V_o = \bar{V}_o + V_o' = 191.065 \text{ mV}
\]

### Bias Current

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

\[
V_o' = -\left(1 + \frac{21 \text{k}\Omega}{1.1 \text{k}\Omega}\right) (R_1\|R_2) I_B = -20.091 \times 1.045 \text{k}\Omega \times I_B = -0.210 \text{ mV}
\]

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 $I_B$.

\[
V_o'' = (21 \text{k}\Omega) I_B = 0.210 \text{ mV}
\]

\[
V_o = \bar{V}_o + V_o' + V_o'' = 190.864 \text{ mV}
\]
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, \( \bar{V}_o \)

\[
V_+ = \frac{29 \text{ k}\Omega}{29 + 2.1 \text{ k}\Omega} V_i = 0.932 V_i
\]
\[
\bar{V}_o = \left(1 + \frac{29 \text{ k}\Omega}{2.1 \text{ k}\Omega}\right) V_+ = 14.810 V_+ = 13.803 V_i
\]

- What is the peak-to-peak amplitude of \( V_o \) if \( f = 3 \text{ kHz} \)?
  Given Gain-Bandwidth, maximum possible gain is \( G = \frac{G \cdot \text{BW}}{f} = \frac{120}{3} = 40 \).
  We specify a gain of 13.803 which is less than 40, so we get the specified gain.
  \( V_o = 13.803 \times (20 \text{ mV}) \cos(2\pi ft) \), and peak-peak voltage is \( 2 \times \max(V_o) \).
  Answer: 552.1 mV.

- What is the peak-to-peak amplitude of \( V_o \) if \( f = 30 \text{ kHz} \)?
  Given Gain-Bandwidth, maximum possible gain is \( G = \frac{G \cdot \text{BW}}{f} = \frac{120}{30} = 4 \).
  We specify a gain of 13.803 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 ($\zeta$)?

  \[
  \omega_c = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{4.7 \text{ mH} \cdot 10.4 \mu \text{F}}} = 4523.081 \text{ rad/s, } \quad f_c = 2\pi \omega_c = 28418.761 \text{ Hz}
  \]

  and,

  \[
  \zeta = \frac{R}{2} \sqrt{\frac{C}{L}} = \frac{294 \text{ kΩ}}{2} \sqrt{\frac{10.4 \mu \text{F}}{4.7 \text{ mH}}} = 6.915
  \]

- 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.