Su22-ENGR-40M-01 Prelab 4

Jannah Sabic El-Rayess

TOTAL POINTS

37 / 37

QUESTION 1

1 P1 **1 / 1**

✓ **- 0 pts** **Correct (amplitude 50mV, offset 1V)**

- 0.25 pts Incorrect P1 amplitude

- 0.25 pts Incorrect P1 offset

- 1 pts No Submission

- 3 pts Late Submission

- 0.1 pts didn't label amplitude

- 0.1 pts Forgot units

- 0.5 pts Calculations with no graph

QUESTION 2

2 P2 **2 / 2**

✓ **- 0 pts** **Correct (142-143)**

- 0.3 pts Used wrong voltage for Vout (should be +/- 1.5V) or Vin

- 1 pts Used wrong formula

- 1 pts Didn't calculate gain

- 0.5 pts Used Vpp instead of 0.5Vpp

- 1 pts didn't show work

- 1 pts correct starting point

- 1.5 pts Equations setup incorrectly

- 2 pts no work

- 0.1 pts Div by V instead of mV

- 1 pts Incorrect

- 0.5 pts Wrong Vref

- 0.2 pts Didn't choose the correct Vin (i.e. chose wrong point to compare against the vout)

- 0 pts Carry over error from P1

QUESTION 3

3 P3 **2 / 2**

✓ **- 0 pts** **Correct (580 Ohm)**

- 0 pts carried error

- 0.1 pts wrong units

- 0.2 pts missing units

- 0.5 pts Algebra mistake

- 1 pts Incomplete

- 1.5 pts Didn't use G = 5 + 80k/R_G eqn

- 2 pts no work shown

QUESTION 4

4 P4 **1 / 1**

✓ **- 0 pts** **Correct**

- 0.2 pts One incorrect pin

- 0.5 pts Multiple incorrect pins

- 0.2 pts missing Rg

- 0.25 pts Forgot to label one of the two diagrams

- 1 pts no work or over half the pins labelled incorrectly

- 0.1 pts Missing/unlabeled pin

QUESTION 5

5 P5 **1 / 1**

✓ **- 0 pts** **Correct**

- 0.2 pts one incorrect pin (specified below)

- 0.25 pts Forgot to label one of the two diagrams

- 0.5 pts Multiple incorrectly labelled pins

- 1 pts no work or over half the pins labelled incorrectly

- 0.1 pts Missing/unlabeled pin

QUESTION 6

6 P6 **2 / 2**

✓ **- 0 pts** **Correct**

- 0.1 pts In terms of variables/non-numerical answer

- 1 pts Not simplified

- 0.1 pts missing j

- 0.1 pts Sign error

- 0.3 pts should be in standard form

- 1 pts No work shown

- **1.5 pts** Incorrect work
- **2 pts** No submission
- **0.5 pts** Math error
- **0.2 pts** Error(s) #1
- **1 pts** Error(s) #2
- **0.2 pts** Missing 2pi
- **0.25 pts** Wrong capacitor value/units
- **1 pts** Incorrect; missing steps

QUESTION 7

7 P7 **1 / 1**

✓ **- 0 pts Correct**
- **0 pts** Carry over error
- **0.1 pts** Wrong sign on one current; gain should be negative
- **0.1 pts** Forgot j in frequency term
- **0.2 pts** Minor KCL error
- **1 pts** no work
- **0.5 pts** Want expression in terms of V_out and V_n
- **0.5 pts** incomplete
- **0.75 pts** Incorrect
- **0.2 pts** Math/Algebra error
- **0.1 pts** error(s) #1
- **0.2 pts** Zp expression not used in final answer.
- **0 pts** Carry over error from P6

QUESTION 8

8 P8 **2 / 2**

✓ **- 0 pts Correct**
- **0 pts** Carry over error
- **0.2 pts** sign error
- **0.2 pts** missing j
- **0.5 pts** incorrect band pass gain
- **0.5 pts** incorrect corner frequency
- **0.5 pts** algebra mistake
- **1 pts** no work
- **0.3 pts** should be in standard form
- **0.5 pts** Error(s)
- **2 pts** No submission
- **0.1 pts** Minor Error
- **1.5 pts** Incorrect

QUESTION 9

9 P9 **2 / 2**

✓ **- 0 pts Correct (20dB at low frequencies, -$$\infty$$ at high frequencies)**
- **0.1 pts** gave high frequency gain in linear gain (not dB)
- **0.5 pts** Forgot to convert to dB
- **0.5 pts** incorrect at low frequencies
- **0.5 pts** incorrect at high frequencies
- **2 pts** missing
- **0.1 pts** gave low frequency gain in linear gain (not dB)
- **0 pts** Error carried over from previous part
- **1 pts** Incorrect
- **1.5 pts** Incorrect
- **2 pts** No submission
- **0.2 pts** Error(s) #1

QUESTION 10

10 P10 **3 / 3**

✓ **- 0 pts Correct**
- **0.1 pts** Near correct/ambiguous fall-off slope
- **0.3 pts** Incorrect corner frequency
- **0.5 pts** did not label important feature corner frequency
- **0.3 pts** Corner frequency in wrong place on graph
- **0.5 pts** Incorrect low frequency gain
- **0.5 pts** incorrect fall-off slope (should be 20db/decade)
- **0.5 pts** fall-off slope ambiguous or not specified
- **0.5 pts** Corner frequency not given or labeled
- **1 pts** Incorrect/Missing Corner Frequency
- **1.5 pts** not shaped like a low pass filter
- **3 pts** no work
- **0.5 pts** Error(s)
- **0.3 pts** Error(s)
- **3 pts** Problem blank

QUESTION 11

11 P11 **1 / 1**

✓ **- 0 pts Correct (lowpass)**
- **0.5 pts** incorrect

- **1 pts** no work
- **1 pts** Problem blank

QUESTION 12

12 P12 **3 / 3**

✓ **- 0 pts Correct**

- **0.2 pts** Sign error
- **0.2 pts** missing j
- **0.5 pts** algebra error
- **0.5 pts** Correct but not simplified
- **1 pts** incorrect pass band gain
- **1 pts** incorrect cutoff frequency
- **1.5 pts** Not simplified or no/little work given
- **1.5 pts** no work
- **0.2 pts** Error(s) #1
- **0.3 pts** Not in standard form
- **1 pts** Incorrect
- **1.5 pts** Incorrect
- **3 pts** Problem blank

QUESTION 13

13 P13 **2 / 2**

✓ **- 0 pts Correct (-$$\infty$$ at low frequencies and 20dB at high frequencies)**

- **0.1 pts** Said +infinity at low frequencies
- **0.1 pts** gave linear gain at low frequencies
- **0.5 pts** Forgot to convert to dB
- **0.5 pts** incorrect dB conversion
- **0.5 pts** incorrect at low frequencies
- **0.5 pts** incorrectly said approaches 0dB at high frequencies
- **0.5 pts** incorrect at high frequencies
- **0.5 pts** Incorrect work or derivation
- **1 pts** Incorrect
- **1.5 pts** Incorrect
- **0.2 pts** Small error
- **2 pts** no work
- **2 pts** Problem blank

QUESTION 14

14 P14 **3 / 3**

✓ **- 0 pts Correct (corner frequency .3, high pass 20dB)**

- **0.1 pts** minor error
- **0.3 pts** slope mislabeled
- **0.3 pts** Corner frequency unlabeled
- **0.5 pts** slope at low frequencies not specified or ambiguous
- **0.5 pts** Ambiguous corner frequency
- **0.5 pts** incorrect high frequency gain
- **0.5 pts** slope at low frequencies should be 20dB/decade
- **1 pts** Wrong corner frequency
- **1 pts** line should be flat at high frequencies
- **1.5 pts** Ambiguous/unlabeled graph with generally correct shape
- **2 pts** drew lowpass filter
- **0 pts** Carry over error from P12 or P13
- **3 pts** no work
- **3 pts** Problem blank / Major error
- **0.1 pts** Wrong corner frequency on graph

QUESTION 15

15 P15 **1 / 1**

✓ **- 0 pts Correct (high pass)**

- **0.5 pts** incorrect
- **1 pts** no work

QUESTION 16

16 P16 **1 / 1**

✓ **- 0 pts Correct**

- **0.1 pts** sign error
- **0.2 pts** Error(s) #1
- **0.25 pts** One incorrect current equation
- **0.5 pts** should be a nodal equation
- **0.5 pts** answer not simplified
- **1 pts** no work
- **1 pts** Incorrect
- **1 pts** problem blank
- **0.2 pts** Nodal equation set up incorrectly

QUESTION 17

17 P17 **3 / 3**

✓ **- 0 pts Correct**

- **0 pts** Carry over error
- **0.2 pts** incorrect sign
- **0.2 pts** missing j
- **0.5 pts** algebra error
- **1.5 pts** denominator should have higher order f terms
- **2 pts** wrong approach
- **3 pts** No submission
- **0.75 pts** Right approach but no numerical values given/not simplified to std form
- **0.2 pts** One incorrect fc
- **1.5 pts** No work
- **0.3 pts** Not in standard form
- **0.3 pts** Answer not simplified
- **0.1 pts** missing fc1
- **3 pts** problem blank

QUESTION 18

18 P18 **2 / 2**

✓ **- 0 pts Correct (should approach -$$\infty$$ for high and low frequencies, passband should have gain of 20dB)**

- **0.5 pts** no answer for bandpass gain
- **0.5 pts** Incorrect bandpass gain (accept anything between 10-20dB)
- **0.5 pts** infinity instead of -infinity
- **0.5 pts** Incorrectly said zero for low/high frequency
- **0.5 pts** incorrect low frequencies
- **0.5 pts** incorrect high frequencies
- **2 pts** no work
- **0.5 pts** Did not convert to dB
- **2 pts** problem blank
- **0.4 pts** No answer for high/low frequency case.
- **1 pts** no numerical value given for multiple regions

QUESTION 19

19 P19 **3 / 3**

✓ **- 0 pts Correct (bandpass 20dB, corner frequencies at .33 and 15.9 Hz)**

- **0.3 pts** said slope is +/- 1 for low and high frequency regions
- **0.3 pts** Low corner frequency incorrectly graphed
- **0.3 pts** High corner frequency incorrectly graphed
- **0.5 pts** one incorrect corner frequency
- **0.5 pts** graphing errors (see comments or graph)
- **0.5 pts** Incorrect bandpass gain
- **1 pts** Incorrect corner frequencies
- **0.5 pts** slope incorrect (should be 20db/decade)
- **0.5 pts** Corner frequencies not labeled
- **1 pts** forgot to label corner frequencies
- **2 pts** Not shaped like a bandpass filter
- **1 pts** Incorrect low/high frequency behavior
- **3 pts** Incomplete
- **0 pts** Carry over error from P18, but graph is correct.
- **1.5 pts** Graph vague, corner frequencies not labeled but correct shape

QUESTION 20

20 P20 **1 / 1**

✓ **- 0 pts Correct (Bandpass)**

- **0.5 pts** Incorrect
- **1 pts** no submission

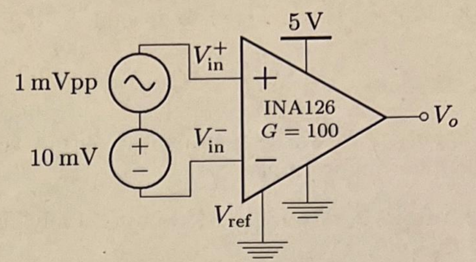
P1: Consider the circuit on the right. We use a test input signal, representing a "heartbeat", of a 1 mVpp sine wave with a 10 mV offset. The test input signal ($V_{in}^{+} - V_{in}^{-}$) is graphed below right.

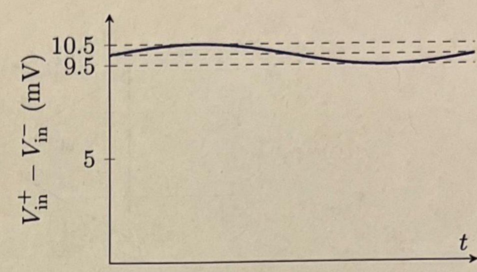
We connect V+ and V− to 5 V and ground respectively, and we set $G = 100$.

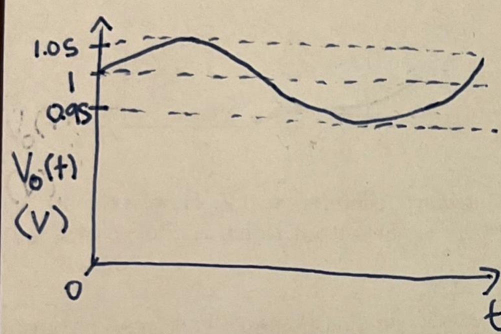
Sketch the output waveform. Label the offset, minimum and maximum voltages.

Hint: Equation (1) on page 2 might be helpful.

Hint: The gain applies to the entire input signal, including the offset!







offset = 1V
max = 1.05V
min = 0.95V

In practice, clipping actually occurs *before* the output voltage would hit the rails.

P2: To be safe, we will try to keep our peak output voltages 1 V away from our supplies (-1.5 V $< V_{out} < 1.5$ V). With an input signal of amplitude of 1 mVpp but with offsets of up to ±10 mV, use equation (1) to calculate the maximum gain you can achieve with your instrumentation amplifier, before you risk clipping.

$V_o = G(\text{signal}) + V_{ref}$

$1.5V = G(10.5mV)$

$G = \boxed{143}$

To set G, we choose a suitable resistor R_G. The INA126 datasheet indicates how to choose R_G.

P3: The datasheet gives an equation that describes what the gain G is, in terms of the resistor R_G. Using the INA126 datasheet on Canvas, find this equation, and use it to calculate a resistor value R_G that will give you the gain you calculated in question P2.

$G = 5 + \frac{80k\Omega}{R_G}$

$143 = 5 + \frac{80k\Omega}{R_G}$

$R_G = 580\Omega$

1 P1 **1 / 1**

- ✓ **- 0 pts** **Correct (amplitude 50mV, offset 1V)**
- **- 0.25 pts** Incorrect P1 amplitude
- **- 0.25 pts** Incorrect P1 offset
- **- 1 pts** No Submission
- **- 3 pts** Late Submission
- **- 0.1 pts** didn't label amplitude
- **- 0.1 pts** Forgot units
- **- 0.5 pts** Calculations with no graph

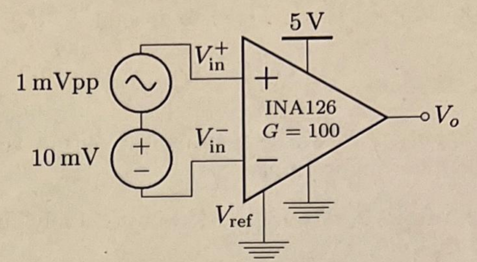
P1: Consider the circuit on the right. We use a test input signal, representing a "heartbeat", of a 1 mVpp sine wave with a 10 mV offset. The test input signal ($V_{in}^{+} - V_{in}^{-}$) is graphed below right.

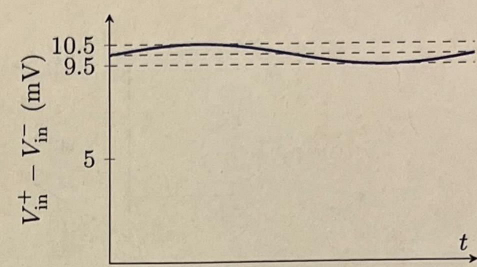
We connect V+ and V− to 5 V and ground respectively, and we set $G = 100$.

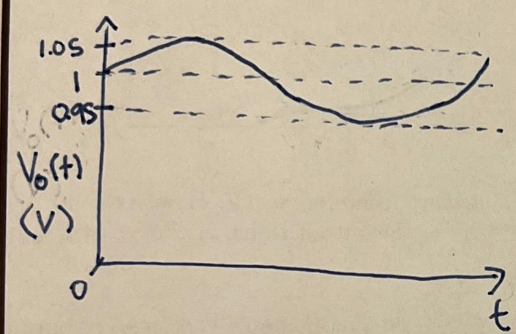
Sketch the output waveform. Label the offset, minimum and maximum voltages.

Hint: Equation (1) on page 2 might be helpful.

Hint: The gain applies to the entire input signal, including the offset!







offset = 1V
max = 1.05V
min = 0.95V

In practice, clipping actually occurs *before* the output voltage would hit the rails.

P2: To be safe, we will try to keep our peak output voltages 1 V away from our supplies (−1.5 V $< V_{out} <$ 1.5 V). With an input signal of amplitude of 1 mVpp but with offsets of up to ±10 mV, use equation (1) to calculate the maximum gain you can achieve with your instrumentation amplifier, before you risk clipping.

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$1.5V = G(10.5mV)$

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To set G, we choose a suitable resistor R_G. The INA126 datasheet indicates how to choose R_G.

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$G = 5 + \frac{80k\Omega}{R_G}$

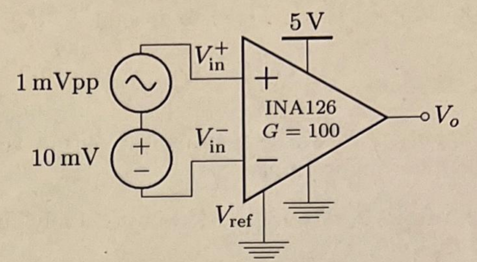
$143 = 5 + \frac{80k\Omega}{R_G}$

$R_G = 580\Omega$

2 P2 **2 / 2**

- ✓ **- 0 pts** **Correct (142-143)**
- **- 0.3 pts** Used wrong voltage for Vout (should be +/- 1.5V) or Vin
- **- 1 pts** Used wrong formula
- **- 1 pts** Didn't calculate gain
- **- 0.5 pts** Used Vpp instead of 0.5Vpp
- **- 1 pts** didn't show work
- **- 1 pts** correct starting point
- **- 1.5 pts** Equations setup incorrectly
- **- 2 pts** no work
- **- 0.1 pts** Div by V instead of mV
- **- 1 pts** Incorrect
- **- 0.5 pts** Wrong Vref
- **- 0.2 pts** Didn't choose the correct Vin (i.e. chose wrong point to compare against the vout)
- **- 0 pts** Carry over error from P1

P1: Consider the circuit on the right. We use a test input signal, representing a "heartbeat", of a 1 mVpp sine wave with a 10 mV offset. The test input signal ($V_{in}^+ - V_{in}^-$) is graphed below right.

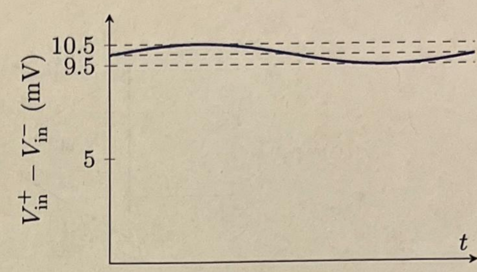


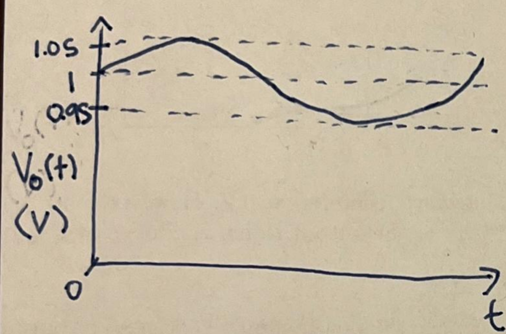
We connect V+ and V− to 5 V and ground respectively, and we set $G = 100$.

Sketch the output waveform. Label the offset, minimum and maximum voltages.

Hint: Equation (1) on page 2 might be helpful.

Hint: The gain applies to the entire input signal, including the offset!





offset = 1V
max = 1.05V
min = 0.95V

In practice, clipping actually occurs *before* the output voltage would hit the rails.

P2: To be safe, we will try to keep our peak output voltages 1 V away from our supplies (-1.5 V $< V_{out} <$ 1.5 V). With an input signal of amplitude of 1 mVpp but with offsets of up to ±10 mV, use equation (1) to calculate the maximum gain you can achieve with your instrumentation amplifier, before you risk clipping.

$V_o = G(\text{signal}) + V_{ref}$

$1.5V = G(10.5mV)$

$G = \boxed{143}$

To set G, we choose a suitable resistor R_G. The INA126 datasheet indicates how to choose R_G.

P3: The datasheet gives an equation that describes what the gain G is, in terms of the resistor R_G. Using the INA126 datasheet on Canvas, find this equation, and use it to calculate a resistor value R_G that will give you the gain you calculated in question P2.

$G = 5 + \frac{80k\Omega}{R_G}$

$143 = 5 + \frac{80k\Omega}{R_G}$

$R_G = 580\Omega$

3 P3 **2 / 2**

- ✓ **- 0 pts** Correct (580 Ohm)
- **- 0 pts** carried error
- **- 0.1 pts** wrong units
- **- 0.2 pts** missing units
- **- 0.5 pts** Algebra mistake
- **- 1 pts** Incomplete
- **- 1.5 pts** Didn't use G = 5 + 80k/R_G eqn
- **- 2 pts** no work shown

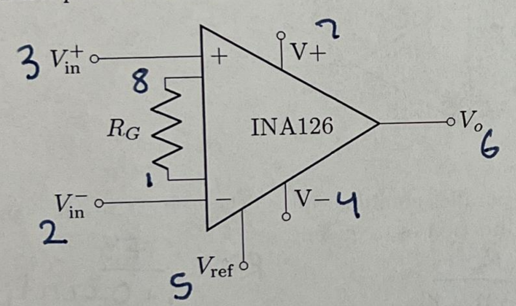
Hint: The equation appears three times on page 1 of the datasheet.

One last thing on the instrumentation amplifier: The INA126 comes in a "dual inline" package with eight pins (DIP-8). We'll need to know which pin corresponds to which terminal.

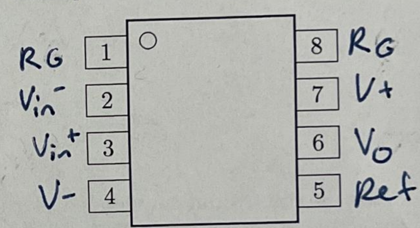
P4: Using the INA126 datasheet on Canvas, label each of the eight terminals on the schematic symbol with their corresponding pin numbers, and each of the eight pins on the package diagram with their corresponding terminal names.

Remark: V_{in}^+ *and* V_{in}^- *are the input terminals. V+ and V− are the the power supply terminals.*

Label pin numbers on schematic symbol:



Label pin names on package diagram:



3.2 Operational Amplifier (MCP601)

We'll use an op-amp to implement the bandpass filter stage of our circuit. While we're looking at datasheets, let's start by taking note of its pinout. The MCP601 also comes in a DIP-8 package.

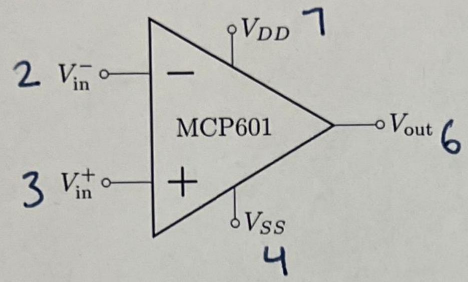
P5: Using the MCP601 datasheet on Canvas, label each of the eight terminals on the schematic symbol with their corresponding pin numbers, and each of the eight pins on the package diagram with their corresponding terminal names.

Remark: V_{in}^+ *and* V_{in}^- *are the input terminals. This manufacturer calls the positive power supply terminal* V_{DD}*, and the negative power supply terminal* V_{SS}*. "NC" stands for "not connected".*

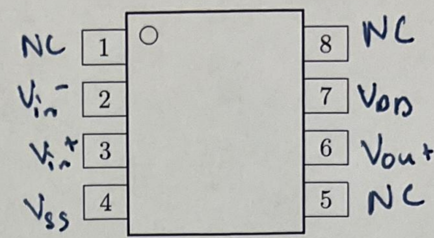
4 P4 **1 / 1**

- ✓ **- 0 pts** Correct
- **- 0.2 pts** One incorrect pin
- **- 0.5 pts** Multiple incorrect pins
- **- 0.2 pts** missing Rg
- **- 0.25 pts** Forgot to label one of the two diagrams
- **- 1 pts** no work or over half the pins labelled incorrectly
- **- 0.1 pts** Missing/unlabeled pin

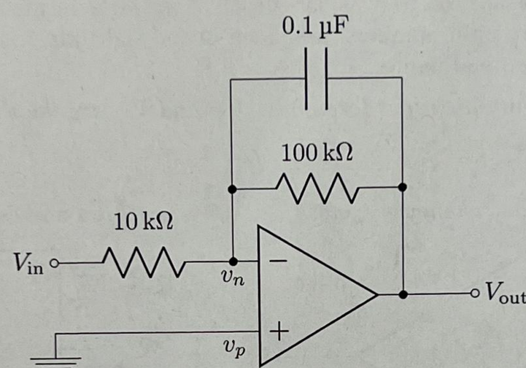
Label pin numbers on schematic symbol:



Label pin names on package diagram:



For questions P6 through P11, consider the circuit below. In all circuits in this lab, $V_{DD} = 2.5\,\text{V}$ and $V_{ss} = -2.5\,\text{V}$.



P6: What is the overall impedance of the parallel combination of the 100 kΩ resistor and 0.1 µF capacitor in this circuit? This will be a function of frequency.

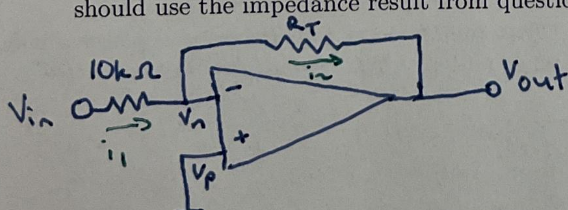
$$\frac{1}{R_T} = \frac{1}{R} + 2\pi f j c \qquad R_T = \frac{R}{1+2R\pi f j c} \qquad R_T = \frac{1E5}{1+0.02\pi f j}$$

$$R_T = \frac{1}{\frac{1}{R} + 2\pi f j c} \qquad R_T = \frac{1E5}{1+2(1E5)\pi f_j (1E-7)}$$

$$\boxed{R_T = \frac{100k\Omega}{1+20\pi ms f j}}$$

$$R_T = \frac{1}{\frac{1+2R\pi f j c}{R}}$$

P7: Use Kirchoff's current law, applied at the node at the inverting (−) input to the op-amp, v_n, to find a relationship between V_{in}, V_{out} and v_n. You can assume that the op-amp is ideal, and you should use the impedance result from question P6.



$$-\frac{V_{out}}{V_{in}} = \frac{100k\Omega}{1+20\pi ms f j} \cdot \frac{1}{10k\Omega}$$

$$-\frac{V_{out}}{V_{in}} = \frac{10}{1+20\pi ms f j}$$

$$i_1 = i_2 \qquad \frac{V_{in}}{10k\Omega} = \frac{-V_{out}}{R_T}$$

$$\frac{V}{R} = i$$

$$\boxed{V_{out} = -V_{in}\left(\frac{10}{1+20\pi ms f j}\right)}$$

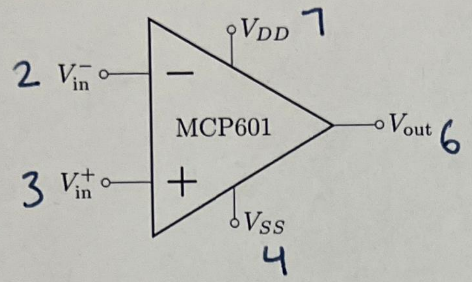
$$-V_{out}\,10k\Omega = V_{in} R_T$$

$$-\frac{V_{out}}{V_{in}} = \frac{R_T}{10k\Omega} \qquad \boxed{V_n = 0V}$$

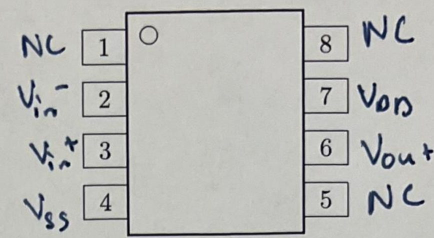
5 P5 **1 / 1**

- ✓ **- 0 pts** Correct
- **- 0.2 pts** one incorrect pin (specified below)
- **- 0.25 pts** Forgot to label one of the two diagrams
- **- 0.5 pts** Multiple incorrectly labelled pins
- **- 1 pts** no work or over half the pins labelled incorrectly
- **- 0.1 pts** Missing/unlabeled pin

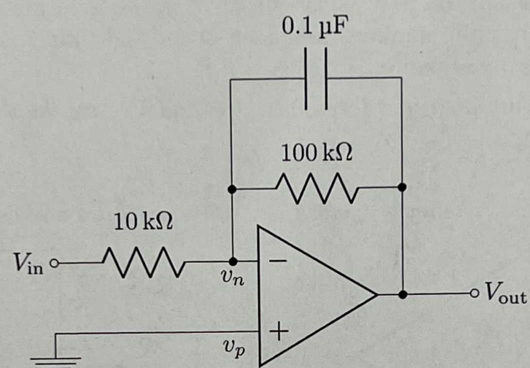
Label pin numbers on schematic symbol:



Label pin names on package diagram:



For questions P6 through P11, consider the circuit below. In all circuits in this lab, $V_{DD} = 2.5\,\text{V}$ and $V_{ss} = -2.5\,\text{V}$.



P6: What is the overall impedance of the parallel combination of the 100 kΩ resistor and 0.1 µF capacitor in this circuit? This will be a function of frequency.

$$\frac{1}{R_T} = \frac{1}{R} + 2\pi f j C$$

$$R_T = \frac{1}{\frac{1}{R} + 2\pi f j C}$$

$$R_T = \frac{1}{\frac{1+2R\pi f j C}{R}}$$

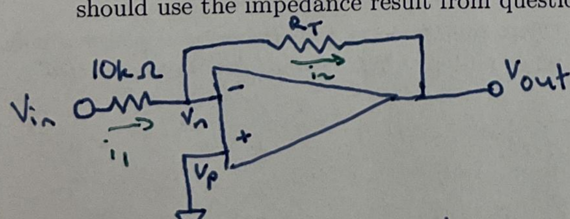
$$R_T = \frac{R}{1+2R\pi f j C}$$

$$R_T = \frac{1E5}{1+2(1E5)\pi f j(1E-7)}$$

$$R_T = \frac{1E5}{1+0.02\pi f j}$$

$$\boxed{R_T = \frac{100k\Omega}{1+20\pi ms f j}}$$

P7: Use Kirchoff's current law, applied at the node at the inverting (−) input to the op-amp, v_n, to find a relationship between V_{in}, V_{out} and v_n. You can assume that the op-amp is ideal, and you should use the impedance result from question P6.



$$i_1 = i_2$$

$$\frac{V}{R} = i$$

$$\frac{V_{in}}{10k\Omega} = \frac{-V_{out}}{R_T}$$

$$-V_{out}\,10k\Omega = V_{in} R_T$$

$$-\frac{V_{out}}{V_{in}} = \frac{R_T}{10k\Omega}$$

$$-\frac{V_{out}}{V_{in}} = \frac{100k\Omega}{1+20\pi ms f j} \cdot \frac{1}{10k\Omega}$$

$$-\frac{V_{out}}{V_{in}} = \frac{10}{1+20\pi ms f j}$$

$$\boxed{V_{out} = -V_{in}\left(\frac{10}{1+20\pi ms f j}\right)}$$

$$\boxed{V_n = 0V}$$

6 P6 2 / 2

✓ **- 0 pts** **Correct**

- 0.1 pts In terms of variables/non-numerical answer

- 1 pts Not simplified

- 0.1 pts missing j

- 0.1 pts Sign error

- 0.3 pts should be in standard form

- 1 pts No work shown

- 1.5 pts Incorrect work

- 2 pts No submission

- 0.5 pts Math error

- 0.2 pts Error(s) #1

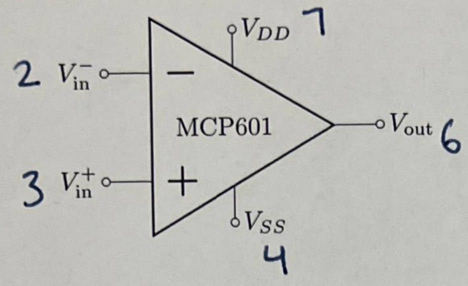
- 1 pts Error(s) #2

- 0.2 pts Missing 2pi

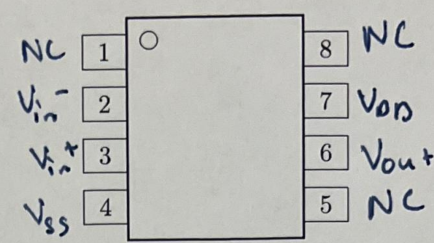
- 0.25 pts Wrong capacitor value/units

- 1 pts Incorrect; missing steps

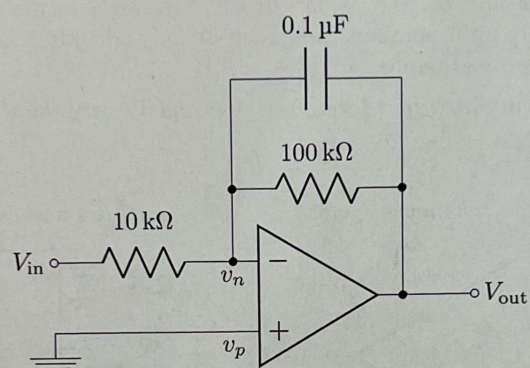
Label pin numbers on schematic symbol:



Label pin names on package diagram:



For questions P6 through P11, consider the circuit below. In all circuits in this lab, $V_{DD} = 2.5\,\text{V}$ and $V_{ss} = -2.5\,\text{V}$.



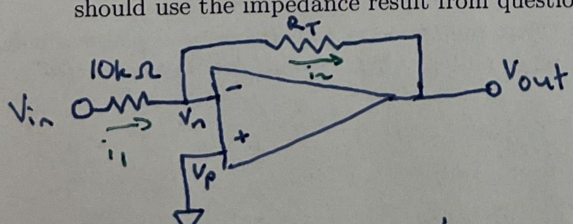
P6: What is the overall impedance of the parallel combination of the 100 kΩ resistor and 0.1 µF capacitor in this circuit? This will be a function of frequency.

$$\frac{1}{R_T} = \frac{1}{R} + 2\pi f j c \qquad R_T = \frac{R}{1+2R\pi f j c} \qquad R_T = \frac{1E5}{1+0.02\pi f j}$$

$$R_T = \frac{1}{\frac{1}{R} + 2\pi f j c} \qquad R_T = \frac{1E5}{1+2(1E5)\pi f j (1E-7)} \qquad \boxed{R_T = \frac{100k\Omega}{1+20\pi ms f j}}$$

$$R_T = \frac{1}{\frac{1+2R\pi f j c}{R}}$$

P7: Use Kirchoff's current law, applied at the node at the inverting (−) input to the op-amp, v_n, to find a relationship between V_{in}, V_{out} and v_n. You can assume that the op-amp is ideal, and you should use the impedance result from question P6.



$$-\frac{V_{out}}{V_{in}} = \frac{100k\Omega}{1+20\pi ms f j} \cdot \frac{1}{10k\Omega}$$

$$-\frac{V_{out}}{V_{in}} = \frac{10}{1+20\pi ms f j}$$

$$i_1 = i_2 \qquad \frac{V_{in}}{10k\Omega} = \frac{-V_{out}}{R_T}$$

$$\frac{V}{R} = i \qquad -V_{out}\,10k\Omega = V_{in} R_T$$

$$-\frac{V_{out}}{V_{in}} = \frac{R_T}{10k\Omega}$$

$$\boxed{V_{out} = -V_{in}\left(\frac{10}{1+20\pi ms f j}\right)}$$

$$\boxed{V_n = 0V}$$

7 P7 **1 / 1**

- ✓ **- 0 pts** Correct
- **- 0 pts** Carry over error
- **- 0.1 pts** Wrong sign on one current; gain should be negative
- **- 0.1 pts** Forgot j in frequency term
- **- 0.2 pts** Minor KCL error
- **- 1 pts** no work
- **- 0.5 pts** Want expression in terms of V_out and V_n
- **- 0.5 pts** incomplete
- **- 0.75 pts** Incorrect
- **- 0.2 pts** Math/Algebra error
- **- 0.1 pts** error(s) #1
- **- 0.2 pts** Zp expression not used in final answer.
- **- 0 pts** Carry over error from P6

P8: Using your equation from P7, find an expression for the transfer function for this circuit as a function of frequency, which should be in the form $\frac{V_{out}}{V_{in}} = \frac{A}{1+j\frac{f}{f_c}}$.

$$V_{out} = -V_{in}\left(\frac{10}{1+20\pi m s f j}\right)$$

$$\frac{V_{out}}{V_{in}} = -\frac{10}{1+20\pi m s f j}$$

$$1 = 20\pi m s f$$

$$f = 15.9$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{10}{1+j\frac{f}{15.9}}}$$

P9: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (Remember, the magnitude in dB is given by $20\log_{10}\left|\frac{V_{out}}{V_{in}}\right|$.)

$$\lim_{f\to 0} -\frac{10}{1+j\frac{f}{15.9}} = -\frac{10}{1} = -10$$

$$\lim_{f\to\infty} -\frac{10}{1+j\frac{f}{15.9}} = 0$$

$$20\log|-10| = 20$$

$$\lim_{n\to 0} 20\log|n| = -\infty$$

$$\boxed{\begin{array}{l}(i)\ 20 \\ (ii)\ -\infty\end{array}}$$

8 P8 2 / 2

- ✓ **- 0 pts** Correct
- **- 0 pts** Carry over error
- **- 0.2 pts** sign error
- **- 0.2 pts** missing j
- **- 0.5 pts** incorrect band pass gain
- **- 0.5 pts** incorrect corner frequency
- **- 0.5 pts** algebra mistake
- **- 1 pts** no work
- **- 0.3 pts** should be in standard form
- **- 0.5 pts** Error(s)
- **- 2 pts** No submission
- **- 0.1 pts** Minor Error
- **- 1.5 pts** Incorrect

P8: Using your equation from P7, find an expression for the transfer function for this circuit as a function of frequency, which should be in the form $\frac{V_{out}}{V_{in}} = \frac{A}{1+j\frac{f}{f_c}}$.

$$V_{out} = -V_{in}\left(\frac{10}{1+20\pi ms fj}\right)$$

$$\frac{V_{out}}{V_{in}} = -\frac{10}{1+20\pi ms fj}$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{10}{1+j\frac{f}{15.9}}}$$

$$1 = 20\pi ms f$$

$$f = 15.9$$

P9: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (Remember, the magnitude in dB is given by $20\log_{10}\left|\frac{V_{out}}{V_{in}}\right|$.)

$$\lim_{f \to 0} -\frac{10}{1+j\frac{f}{15.9}} = -\frac{10}{1} = -10$$

$$\lim_{f \to \infty} -\frac{10}{1+j\frac{f}{15.9}} = 0$$

$$20\log|-10| = 20$$

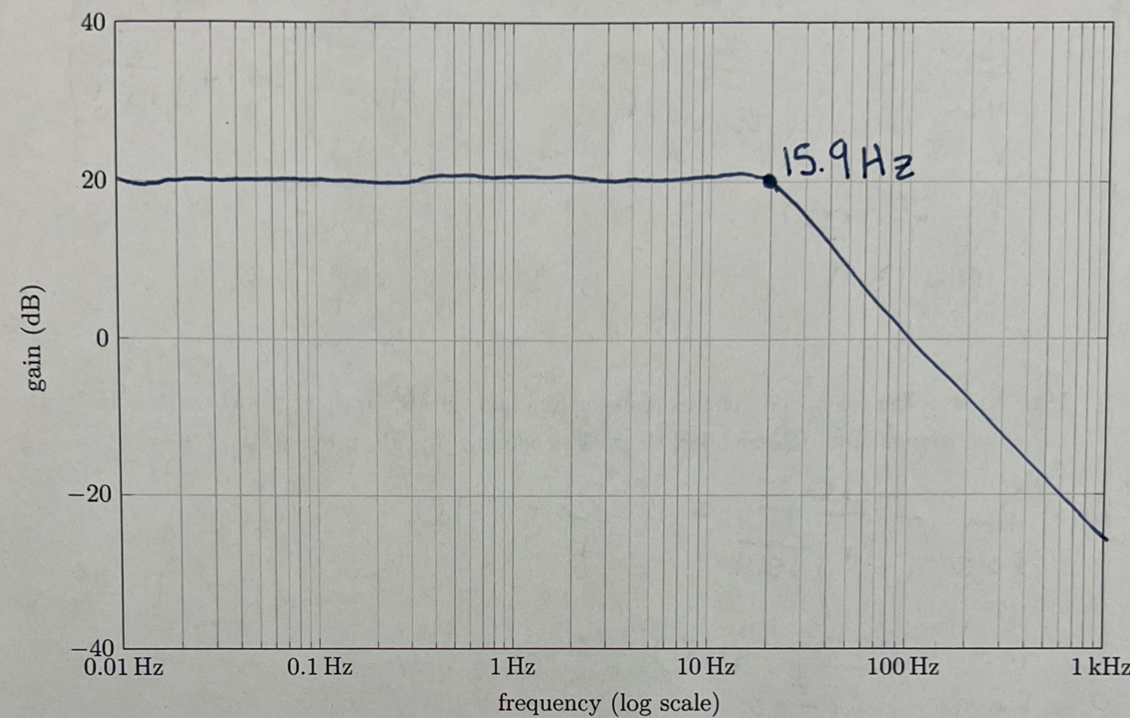
$$\lim_{n \to 0} 20\log|n| = -\infty$$

$$\boxed{\begin{array}{l}(i)\ 20 \\ (ii)\ -\infty\end{array}}$$

9 P9 **2 / 2**

- ✓ **- 0 pts** **Correct (20dB at low frequencies, -$$\infty$$ at high frequencies)**
- **- 0.1 pts** gave high frequency gain in linear gain (not dB)
- **- 0.5 pts** Forgot to convert to dB
- **- 0.5 pts** incorrect at low frequencies
- **- 0.5 pts** incorrect at high frequencies
- **- 2 pts** missing
- **- 0.1 pts** gave low frequency gain in linear gain (not dB)
- **- 0 pts** Error carried over from previous part
- **- 1 pts** Incorrect
- **- 1.5 pts** Incorrect
- **- 2 pts** No submission
- **- 0.2 pts** Error(s) #1

P10: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.



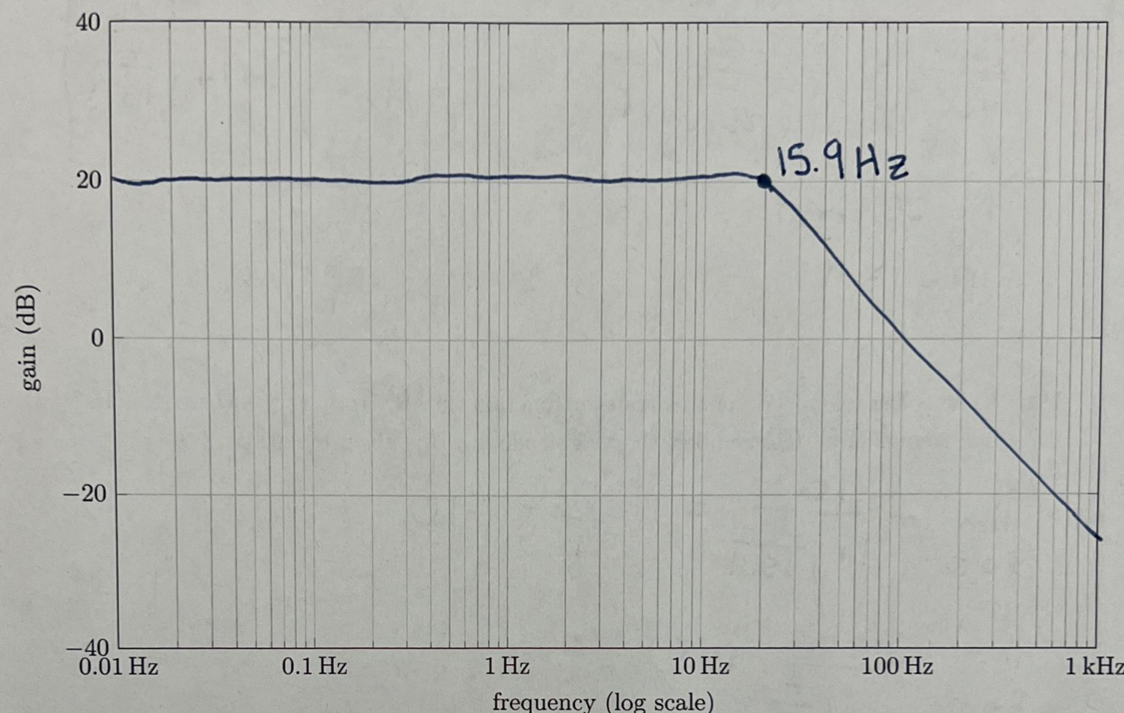
P11: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Lowpass filter

10 P10 **3 / 3**

- ✓ **- 0 pts** Correct
- **- 0.1 pts** Near correct/ambiguous fall-off slope
- **- 0.3 pts** Incorrect corner frequency
- **- 0.5 pts** did not label important feature corner frequency
- **- 0.3 pts** Corner frequency in wrong place on graph
- **- 0.5 pts** Incorrect low frequency gain
- **- 0.5 pts** incorrect fall-off slope (should be 20db/decade)
- **- 0.5 pts** fall-off slope ambiguous or not specified
- **- 0.5 pts** Corner frequency not given or labeled
- **- 1 pts** Incorrect/Missing Corner Frequency
- **- 1.5 pts** not shaped like a low pass filter
- **- 3 pts** no work
- **- 0.5 pts** Error(s)
- **- 0.3 pts** Error(s)
- **- 3 pts** Problem blank

P10: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.



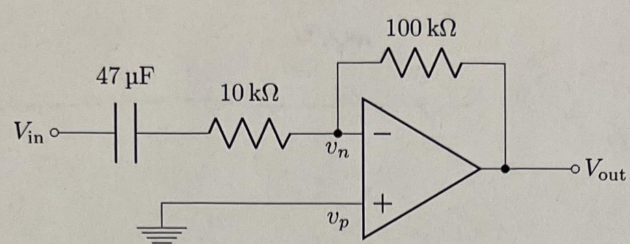
P11: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

$\boxed{\text{Lowpass filter}}$

11 P11 **1 / 1**

- ✓ **- 0 pts** **Correct (lowpass)**
- **- 0.5 pts** incorrect
- **- 1 pts** no work
- **- 1 pts** Problem blank

For questions P12 through P15, consider the following circuit.



P12: Using the same steps as for the previous circuit, find an equation for the transfer function of this circuit.

Hint: This transfer function will be in the form $\frac{j\frac{f}{f_{c1}}}{1+j\frac{f}{f_{c2}}}$.

$$R_T = \frac{1}{2\pi f j c} + R$$

$$R_T = \frac{1}{2\pi f j c} + \frac{R 2\pi f j c}{2\pi f j c}$$

$$R_T = \frac{1 + 2\pi R f j c}{2\pi f j c}$$

$$\frac{V_{out}}{V_{in}} = -\frac{100k\Omega}{\frac{1+2\pi R f j c}{2\pi f j c}}$$

$$\frac{V_{out}}{V_{in}} = -100k\Omega \cdot \frac{2\pi f j 47E\text{-}6}{1+2\pi 10k\Omega f j 47E\text{-}6}$$

$$\frac{V_{out}}{V_{in}} = \frac{-9.4\pi s f j}{1+0.94\pi s f j}$$

$$f_{c2} = \frac{1}{0.94\pi} = 0.339$$

$$f_{c1} = \frac{1}{9.4\pi} = 0.0339$$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{-j\frac{f}{0.0339}}{1+j\frac{f}{0.339}}}$$

P13: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (Remember, the magnitude in dB is given by $20\log_{10}\left|\frac{V_{out}}{V_{in}}\right|$.)

$\lim_{f\to 0} \frac{V_{out}}{V_{in}} = 0$ $\lim_{n\to 0} 20\log|n| = -\infty$

$\lim_{f\to\infty} \frac{V_{out}}{V_{in}} = -10$ $20\log|-10| = 20$

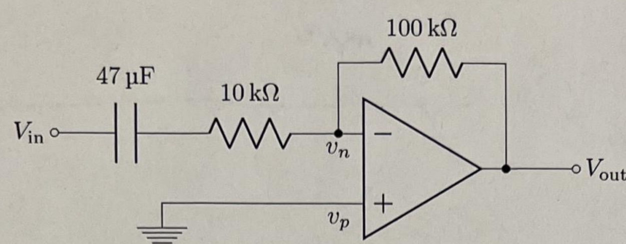
$\boxed{\text{(i) } -\infty \quad \text{(ii) } 20}$

P14: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.

12 P12 3 / 3

- ✓ **- 0 pts** Correct
- **- 0.2 pts** Sign error
- **- 0.2 pts** missing j
- **- 0.5 pts** algebra error
- **- 0.5 pts** Correct but not simplified
- **- 1 pts** incorrect pass band gain
- **- 1 pts** incorrect cutoff frequency
- **- 1.5 pts** Not simplified or no/little work given
- **- 1.5 pts** no work
- **- 0.2 pts** Error(s) #1
- **- 0.3 pts** Not in standard form
- **- 1 pts** Incorrect
- **- 1.5 pts** Incorrect
- **- 3 pts** Problem blank

For questions P12 through P15, consider the following circuit.



P12: Using the same steps as for the previous circuit, find an equation for the transfer function of this circuit.

Hint: This transfer function will be in the form $\frac{j\frac{f}{f_{c1}}}{1+j\frac{f}{f_{c2}}}$.

$$R_T = \frac{1}{2\pi f j c} + R$$

$$R_T = \frac{1}{2\pi f j c} + \frac{R 2\pi f j c}{2\pi f j c}$$

$$R_T = \frac{1 + 2\pi R f j c}{2\pi f j c}$$

$$\frac{V_{out}}{V_{in}} = -\frac{100k\Omega}{\frac{1+2\pi R f j c}{2\pi f j c}}$$

$$\frac{V_{out}}{V_{in}} = -100k\Omega \cdot \frac{2\pi f j 47E\text{-}6}{1+2\pi 10k\Omega f j 47E\text{-}6}$$

$$\frac{V_{out}}{V_{in}} = \frac{-9.4\pi s f j}{1+0.94\pi s f j}$$

$$f_{c2} = \frac{1}{0.94\pi} = 0.339$$

$$f_{c1} = \frac{1}{9.4\pi} = 0.0339$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{j\frac{f}{0.0339}}{1+j\frac{f}{0.339}}}$$

P13: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (Remember, the magnitude in dB is given by $20\log_{10}\left|\frac{V_{out}}{V_{in}}\right|$.)

$\lim_{f\to 0} \frac{V_{out}}{V_{in}} = 0$ $\lim_{n\to 0} 20\log|n| = -\infty$

$\lim_{f\to\infty} \frac{V_{out}}{V_{in}} = -10$ $20\log|-10| = 20$

$\boxed{\begin{array}{l}\text{(i) } -\infty \\ \text{(ii) } 20\end{array}}$

P14: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.

13 P13 **2 / 2**

✓ **- 0 pts Correct (-$$\infty$$ at low frequencies and 20dB at high frequencies)**

- 0.1 pts Said +infinity at low frequencies

- 0.1 pts gave linear gain at low frequencies

- 0.5 pts Forgot to convert to dB

- 0.5 pts incorrect dB conversion

- 0.5 pts incorrect at low frequencies

- 0.5 pts incorrectly said approaches 0dB at high frequencies

- 0.5 pts incorrect at high frequencies

- 0.5 pts Incorrect work or derivation

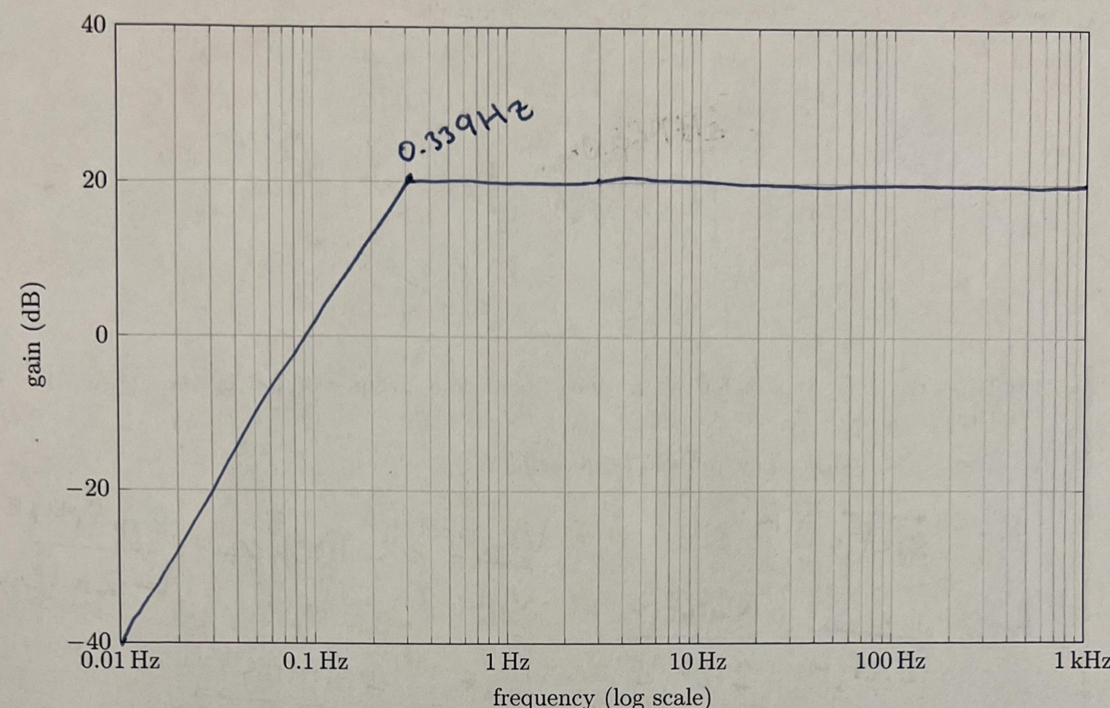
- 1 pts Incorrect

- 1.5 pts Incorrect

- 0.2 pts Small error

- 2 pts no work

- 2 pts Problem blank



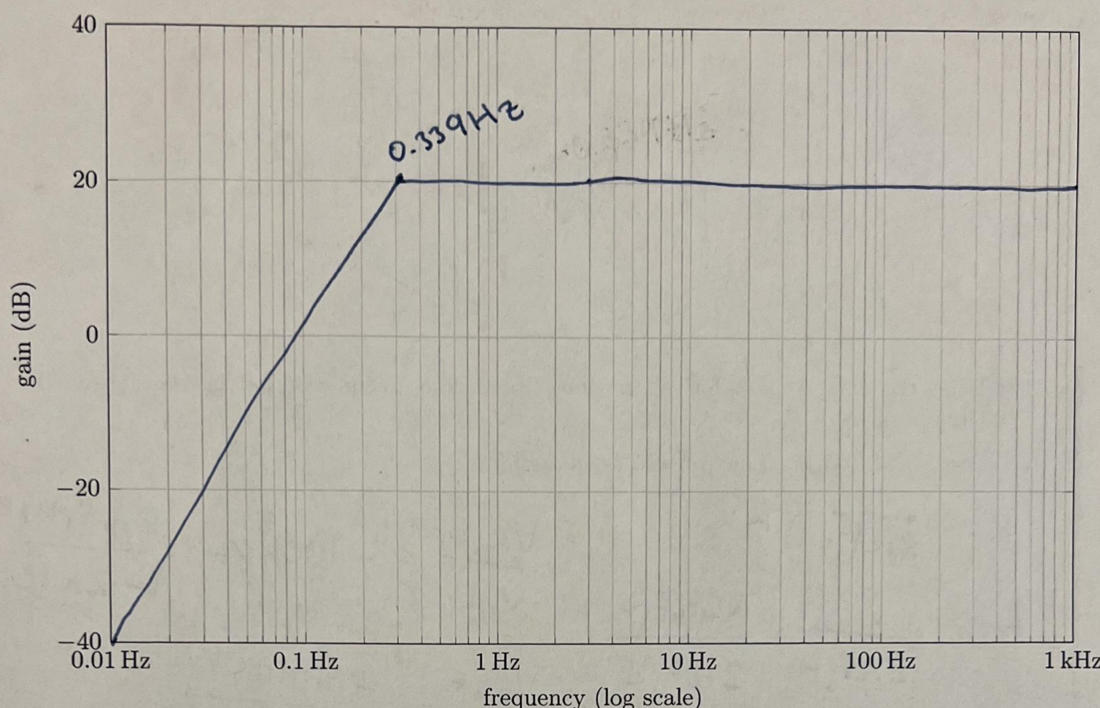
P15: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Highpass filter

14 P14 3 / 3

✓ - **0 pts** Correct (corner frequency .3, high pass 20dB)

- **0.1 pts** minor error
- **0.3 pts** slope mislabeled
- **0.3 pts** Corner frequency unlabeled
- **0.5 pts** slope at low frequencies not specified or ambiguous
- **0.5 pts** Ambiguous corner frequency
- **0.5 pts** incorrect high frequency gain
- **0.5 pts** slope at low frequencies should be 20dB/decade
- **1 pts** Wrong corner frequency
- **1 pts** line should be flat at high frequencies
- **1.5 pts** Ambiguous/unlabeled graph with generally correct shape
- **2 pts** drew lowpass filter
- **0 pts** Carry over error from P12 or P13
- **3 pts** no work
- **3 pts** Problem blank / Major error
- **0.1 pts** Wrong corner frequency on graph



P15: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Highpass filter

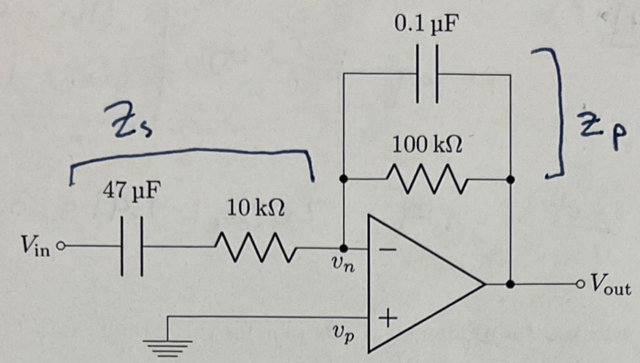
15 P15 **1 / 1**

✓ **- 0 pts** **Correct (high pass)**

- 0.5 pts incorrect

- 1 pts no work

Finally, here's the circuit we're going to build. For questions P16 through P20, consider this circuit.



P16: Use Kirchoff's current law, applied at the node at the inverting (−) input to the op-amp, v_n, to find a relationship between V_{in}, V_{out} and v_n, in terms of Z_s, the combined impedance of the 47 µF capacitor and the 10 kΩ resistor in series, and Z_p, the combined impedance of the 0.1 µF capacitor and the 100 kΩ resistor in parallel. You can assume that the op-amp is ideal.

$$\frac{V_{in}}{Z_s} = -\frac{V_{out}}{Z_p} \qquad \frac{V_{in}}{\frac{1+2\pi Rfjc}{2\pi fjc}} = -\frac{V_{out}}{\frac{100k\Omega}{1+20\pi msfj}} \qquad \frac{V_{out}}{V_{in}} = -\frac{100k\Omega}{1+20\pi msfj} \cdot \frac{2\pi fjc}{1+2\pi Rfjc}$$

$$\boxed{V_{out} = -V_{in}\frac{9.4sfj\pi}{(1+20\pi msfj)(1+0.94\pi s fj)}}$$

P17: Find an equation for the transfer function of this circuit by rearranging your equation from P16, and substituting in equations for Z_p and Z_s (in terms of f, resistances and capacitances).

Leave your answer in the form $\frac{j\frac{f}{f_{c1}}}{(1+j\frac{f}{f_{c2}})(1+j\frac{f}{f_{c3}})}$.

$$f_{c1} = \frac{1}{9.4\pi} = 0.0339\,Hz$$

$$f_{c2} = \frac{1}{20\pi ms} = 15.915\,Hz$$

$$f_{c3} = \frac{1}{0.94\pi} = 0.339\,Hz$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{j\frac{f}{0.0339}}{(1+j\frac{f}{15.915})(1+j\frac{f}{0.339})}}$$

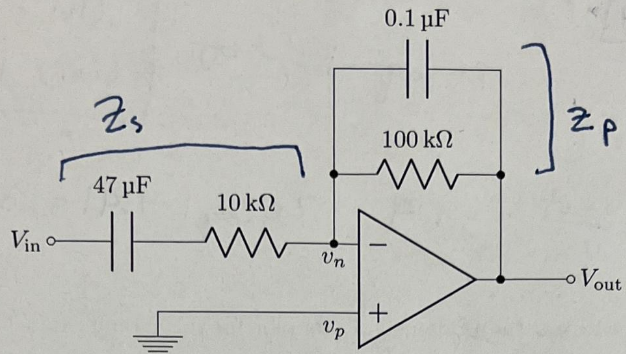
P18: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (iii) between the two corner frequencies?

Hint: There's a corner frequency associated with each of the terms in the denominator. Between the two corner frequencies, jf will dominate one these terms, while the 1 will still dominate the

16 P16 **1 / 1**

- ✓ **- 0 pts** Correct
- **- 0.1 pts** sign error
- **- 0.2 pts** Error(s) #1
- **- 0.25 pts** One incorrect current equation
- **- 0.5 pts** should be a nodal equation
- **- 0.5 pts** answer not simplified
- **- 1 pts** no work
- **- 1 pts** Incorrect
- **- 1 pts** problem blank
- **- 0.2 pts** Nodal equation set up incorrectly

Finally, here's the circuit we're going to build. For questions P16 through P20, consider this circuit.



P16: Use Kirchoff's current law, applied at the node at the inverting (−) input to the op-amp, v_n, to find a relationship between V_{in}, V_{out} and v_n, in terms of Z_s, the combined impedance of the 47 µF capacitor and the 10 kΩ resistor in series, and Z_p, the combined impedance of the 0.1 µF capacitor and the 100 kΩ resistor in parallel. You can assume that the op-amp is ideal.

$$\frac{V_{in}}{Z_s} = -\frac{V_{out}}{Z_p} \qquad \frac{V_{in}}{\frac{1+2\pi Rfjc}{2\pi fjc}} = -\frac{V_{out}}{\frac{100k\Omega}{1+20\pi msfj}} \qquad \frac{V_{out}}{V_{in}} = -\frac{100k\Omega}{1+20\pi msfj} \cdot \frac{2\pi fjc}{1+2\pi Rfjc}$$

$$V_{out} = -V_{in}\frac{9.4sfj\pi}{(1+20\pi msfj)(1+0.94\pi sfj)}$$

P17: Find an equation for the transfer function of this circuit by rearranging your equation from P16, and substituting in equations for Z_p and Z_s (in terms of f, resistances and capacitances).

Leave your answer in the form $\frac{j\frac{f}{f_{c1}}}{(1+j\frac{f}{f_{c2}})(1+j\frac{f}{f_{c3}})}$.

$$f_{c1} = \frac{1}{9.4\pi} = 0.0339\,Hz$$

$$f_{c2} = \frac{1}{20\pi ms} = 15.915\,Hz$$

$$f_{c3} = \frac{1}{0.94\pi} = 0.339\,Hz$$

$$\boxed{\frac{V_{out}}{V_{in}} = -\frac{j\frac{f}{0.0339}}{(1+j\frac{f}{15.915})(1+j\frac{f}{0.339})}}$$

P18: What is the magnitude of this transfer function, in dB, (i) at very low frequencies? (ii) at very high frequencies? (iii) between the two corner frequencies?

Hint: There's a corner frequency associated with each of the terms in the denominator. Between the two corner frequencies, jf will dominate one these terms, while the 1 will still dominate the

17 P17 **3 / 3**

- ✓ **- 0 pts** Correct
- **- 0 pts** Carry over error
- **- 0.2 pts** incorrect sign
- **- 0.2 pts** missing j
- **- 0.5 pts** algebra error
- **- 1.5 pts** denominator should have higher order f terms
- **- 2 pts** wrong approach
- **- 3 pts** No submission
- **- 0.75 pts** Right approach but no numerical values given/not simplified to std form
- **- 0.2 pts** One incorrect fc
- **- 1.5 pts** No work
- **- 0.3 pts** Not in standard form
- **- 0.3 pts** Answer not simplified
- **- 0.1 pts** missing fc1
- **- 3 pts** problem blank

other.

$$\lim_{f \to 0} \frac{V_{out}}{V_{in}} = 0 \qquad 20\log|0| = -\infty$$

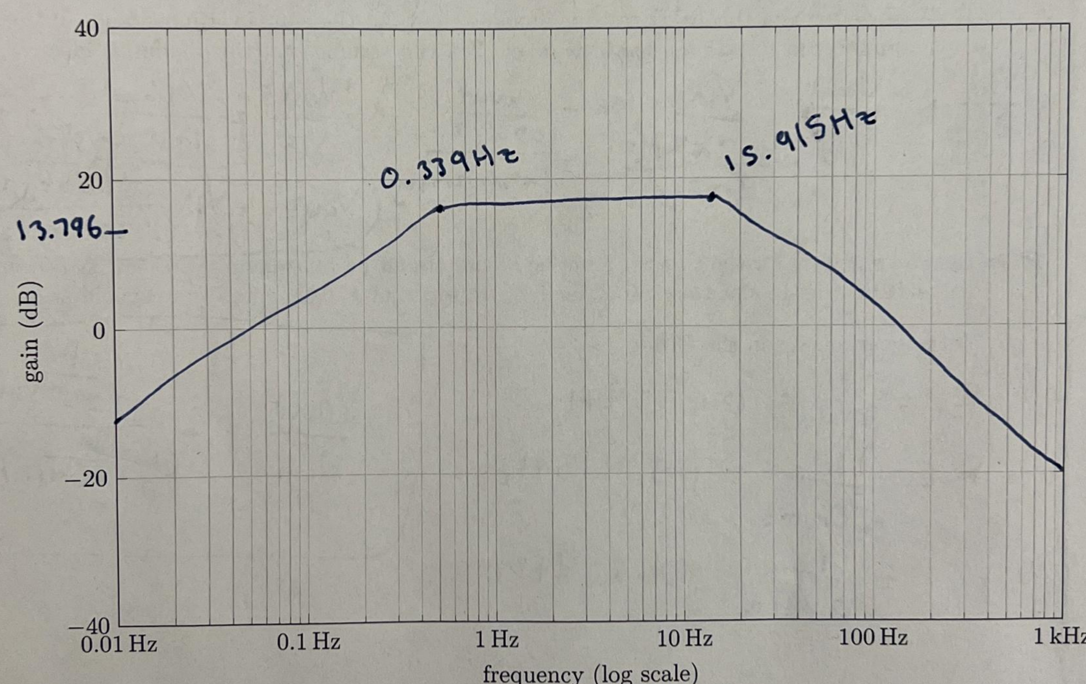
$$\lim_{f \to \infty} \frac{V_{out}}{V_{in}} = 0$$

$f = 15.9$ $\quad \frac{V_{out}}{V_{in}} = -4.9 \quad 20\log|-4.9| = 13.796$

$f = 0.339$

$$\boxed{\begin{array}{l} \text{(i) } -\infty \\ \text{(ii) } -\infty \\ \text{(iii) } 13.796 \end{array}}$$

P19: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.



P20: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Bandpass filter

18 P18 **2 / 2**

✓ **- 0 pts** **Correct (should approach -$$\infty$$ for high and low frequencies, passband should have gain of 20dB)**

- **- 0.5 pts** no answer for bandpass gain
- **- 0.5 pts** Incorrect bandpass gain (accept anything between 10-20dB)
- **- 0.5 pts** infinity instead of -infinity
- **- 0.5 pts** Incorrectly said zero for low/high frequency
- **- 0.5 pts** incorrect low frequencies
- **- 0.5 pts** incorrect high frequencies
- **- 2 pts** no work
- **- 0.5 pts** Did not convert to dB
- **- 2 pts** problem blank
- **- 0.4 pts** No answer for high/low frequency case.
- **- 1 pts** no numerical value given for multiple regions

other.

$$\lim_{f \to 0} \frac{V_{out}}{V_{in}} = 0$$

$$20\log|0| = -\infty$$

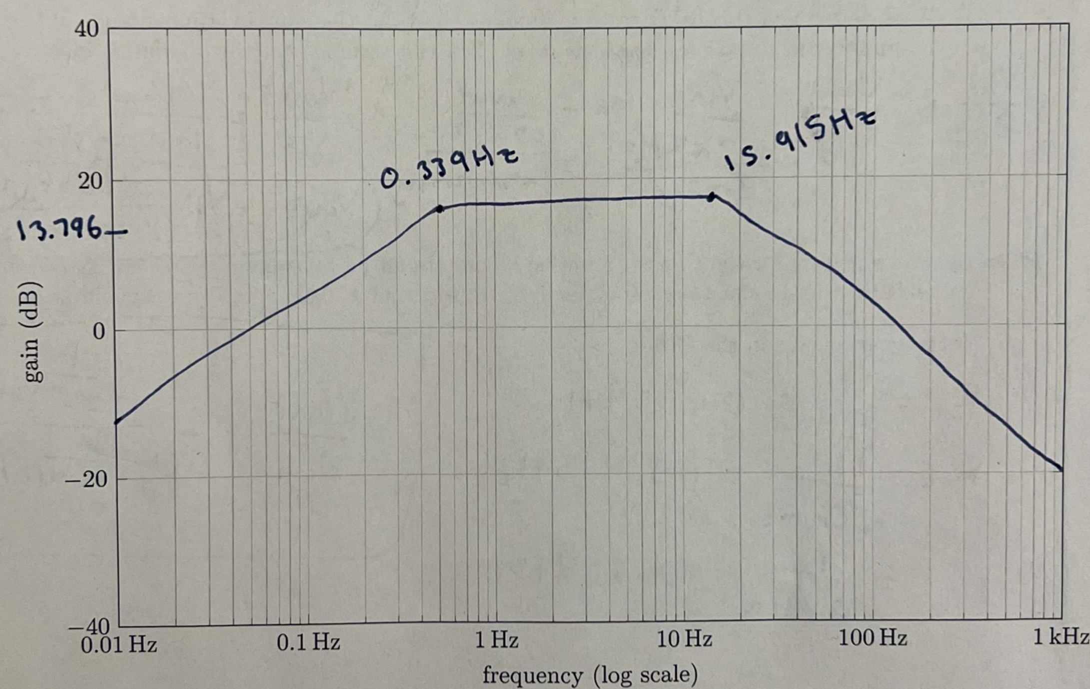
$$\boxed{\begin{array}{l} \text{(i) } -\infty \\ \text{(ii) } -\infty \\ \text{(iii) } 13.796 \end{array}}$$

$$\lim_{f \to \infty} \frac{V_{out}}{V_{in}} = 0$$

$f = 15.9$ $\quad \frac{V_{out}}{V_{in}} = -4.9 \quad 20\log|-4.9| = 13.796$

$f = 0.339$

P19: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.



P20: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Bandpass filter

19 P19 **3 / 3**

✓ - **0 pts** **Correct (bandpass 20dB, corner frequencies at .33 and 15.9 Hz)**

- **0.3 pts** said slope is +/- 1 for low and high frequency regions
- **0.3 pts** Low corner frequency incorrectly graphed
- **0.3 pts** High corner frequency incorrectly graphed
- **0.5 pts** one incorrect corner frequency
- **0.5 pts** graphing errors (see comments or graph)
- **0.5 pts** Incorrect bandpass gain
- **1 pts** Incorrect corner frequencies
- **0.5 pts** slope incorrect (should be 20db/decade)
- **0.5 pts** Corner frequencies not labeled
- **1 pts** forgot to label corner frequencies
- **2 pts** Not shaped like a bandpass filter
- **1 pts** Incorrect low/high frequency behavior
- **3 pts** Incomplete
- **0 pts** Carry over error from P18, but graph is correct.
- **1.5 pts** Graph vague, corner frequencies not labeled but correct shape

other.

$\lim_{f \to 0} \frac{V_{out}}{V_{in}} = 0$

$20\log|0| = -\infty$

$\lim_{f \to \infty} \frac{V_{out}}{V_{in}} = 0$

$f = 15.9$ $\frac{V_{out}}{V_{in}} = -4.9$ $20\log|-4.9| = 13.796$

$f = 0.339$

$$\boxed{\begin{array}{l}(i)\ -\infty \\ (ii)\ -\infty \\ (iii)\ 13.796\end{array}}$$

P19: On the axes below, draw the Bode magnitude plot for this circuit. Label all important features of the plot.

P20: Using your Bode magnitude plot, is this a lowpass, highpass, bandpass or bandstop filter?

Bandpass filter

20 P20 1 / 1

✓ **- 0 pts** **Correct (Bandpass)**

- 0.5 pts Incorrect

- 1 pts no submission