1) Consider the circuit shown in Figure 1 below, constructed with an ideal opamp. (NOTE: Verification of your answers with LTSpice, Matlab, etc. is not required for this assignment.)

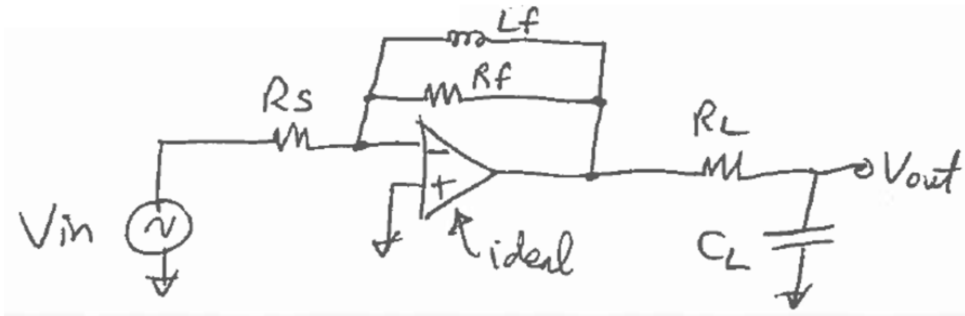


Figure 1. Circuit for Problem 1.

a) The transfer function from input to output for the above circuit in proper Bode approximation form can be shown to be

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-(s/\omega_{ZDC})}{(1+s/\omega_{p1})(1+s/\omega_{p2})}.$$

Derive analytic expressions for the key angular frequencies ω_{ZDC}, ω_{p1}, and ω_{p2} in terms of the passive components R_s, L_f, R_f, R_L, and/or C_L. **Box your three expressions so they are easy for me to find**. *Show your work*. DO NOT use the numerical components values given in part (d) for this part!

b) What is the frequency response magnitude $|V_{out}/V_{in}|$ at DC, i.e., at $\omega = 0$? **Box your numerical result so that it is easy for me to find**. DO NOT use the numerical components values given in part (d) for this part!

c) What is the frequency response magnitude $|V_{out}/V_{in}|$ at very high frequencies, i.e., as $\omega \to \infty$? **Box your numerical result so that it is easy for me to find**. DO NOT use the numerical components values given in part (d) for this part!

[**continued on next page**]

d) Now, for this part, let the passive component values be as follows:
R_s = 100 Ω, R_f = 1 kΩ, R_L = 1 kΩ, L_f = 15.92 mH, C_L = 1.59 nF (**but, again, do not use these numbers for the above parts!**).

The Bode plot approximation sketch of the circuit of Figure 1 with the above numerical values is shown in Figure 2 below.

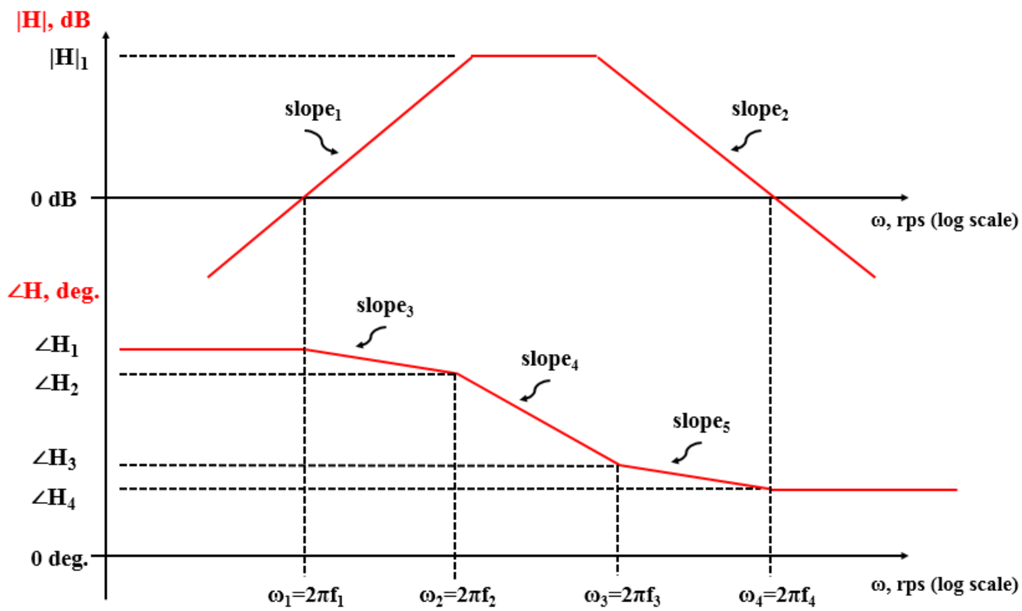


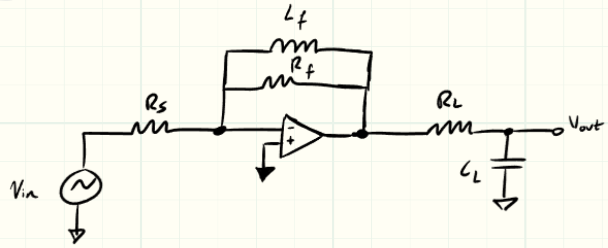
Figure 2. Bode plot approximation for Problem 1, part (d).

Referring to Figure 2 above, **determine the numerical values of the following** (*note that you are being asked to provide these numerical values which are* ***valid for the Bode plot approximation****, not the high-accuracy Bode plot from either LTSpice or Matlab; so expect zero credit if you simulate this circuit and grab these values from the simulated plot*):

- $|H|_1$ (with units of dB)
- slope$_1$ and slope$_2$ (with units of dB/decade)
- slope$_3$, slope$_4$, and slope$_5$ (with units of degrees/decade)
- ∠H_1, ∠H_2, ∠H_3, and ∠H_4 (with units of degrees)
- f_1, f_2, f_3, and f_4 (with units of Hz)

Include units with your numerical answers (*that is why the units are listed*). You should first sketch the Bode approximation plot (by-hand) and then simply get the above values from your by-hand sketch. *Show your work*.

1.)



a.)

$$H(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{-\left(s/\omega_{zdc}\right)}{\left(1+s/\omega_{p_1}\right)\left(1+s/\omega_{p_2}\right)}$$

$$\frac{-R_f L_{fs}}{R_f + C_{fs}} = H(s) = \frac{-R_f L_{fs}}{R_f L_{fs}} \cdot \frac{1}{R_{fs}} = \frac{-R_f(L_{fs})}{R_f\left(1+L_{fs}/R_f\right)} \cdot \frac{1}{R_s}$$

$$= \frac{-L_{ss}/R_s}{(s+L_{fs})/R_s} = \frac{-L_{ss}}{\cancel{R_s}} \cdot \frac{\cancel{R_s}}{(s+L_{fs})} = \frac{-L_{ss}}{(s+L_{fs})} = \frac{-s/(R_s/L_f)}{1+s/(R_s/L_f)}$$

$$\boxed{\omega_{zdc} = \frac{R_s}{L_f}, \quad \omega_{p_1} = R_f/L_f \quad \omega_{p_2} = 1/R_L C_L}$$

$$H(s)_{out} = \frac{V_{out}}{V_{in}} = \frac{C_L}{R_L + C_L}$$

$$R_c = H(s) = \frac{1}{1+sR_c} = \frac{1}{1+s/\omega_{p_2}}$$

$$\omega_{p_2} = 1/R_L C_L$$

$$= \boxed{\frac{-\frac{s}{R_L/L_f}}{\left(1+\frac{s}{R_f/R_L}\right)\left(1+\frac{s}{1/R_L C_L}\right)}}$$

b.)

$$\left.\frac{-\frac{s}{\omega_z R_L}}{\left(1+\frac{s}{\omega_{p_1}}\right)\left(1+\frac{s}{1/R_L C_L}\right)}\right|_{\omega=0}$$

$$= \frac{-\frac{s}{(0)R_L}}{\left(1+\frac{s}{0}\right)\left(1+\frac{s}{0}\right)} = \frac{-0}{1\cdot 1}$$

$$= \boxed{0V}$$

c.)

$$\left.\frac{-\frac{s}{\omega_z R_L}}{\left(1+\frac{s}{\omega_{p_1}}\right)\left(1+\frac{s}{\omega_{p_2}}\right)}\right|_{\omega=\infty}$$

$$= \frac{\left(\frac{\infty}{\omega_z R_L}\right)}{(1+\infty)(1+\infty)} = \frac{1}{\infty} = \boxed{0V}$$

d.)

$$\omega_1 = \frac{R_s}{L_f} = \frac{100}{15.92m} = 6281.4 \text{ rps}$$

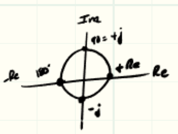
$$f_1 = \frac{\omega_1}{2\pi} = \frac{6281.4}{2\pi} = 999.7 \text{ Hz}$$

$$f_1 = 1\text{kHz}$$

$$\omega_2 = \frac{R_f}{L_f} = \frac{1000}{15.92m} = 62814.1 \text{ rps}$$

$$f_2 = \frac{\omega_2}{2\pi} = \frac{62814.1}{2\pi} = 9997.2 = 10\text{kHz}$$

$$f_2 = 10\text{kHz}$$



$$\angle H_1 = 180° + 90° = 270°$$

$$\angle H_2 = 180° + 90° - 45° = 225°$$

$$\angle H_3 = 180° + 90° - 90° - 45° = 135°$$

$$\angle H_4 = 180° + 90° - 90° - 90° = 90°$$

$$\omega_3 = \frac{1}{R_L C_L} = \frac{1}{(1000)(1.59n)} = 628930.8 \text{ rps}$$

$$f_3 = \frac{\omega_3}{2\pi} = \frac{628930.8}{2\pi} = 100097 \approx 100\text{kHz}$$

$$f_3 = 100\text{kHz}$$

$$\omega_4 = \omega_3 \times 10 = 628930.8 \times 10 = 6289308$$

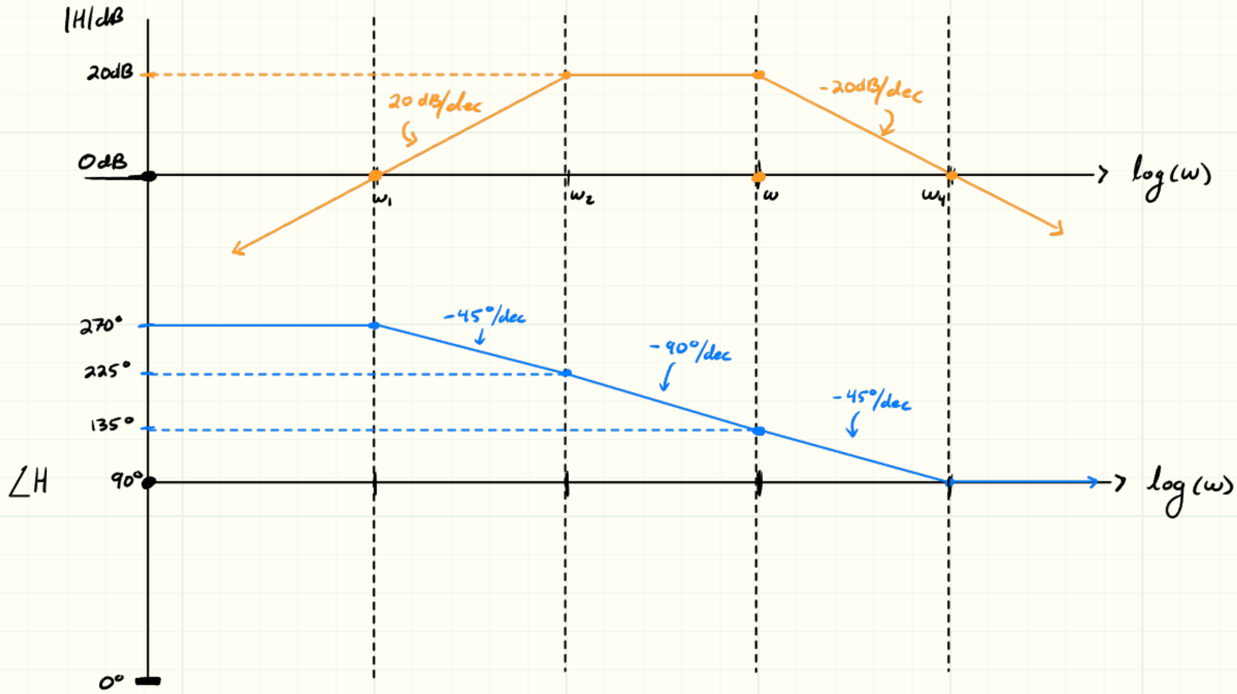
$$f_4 = \frac{\omega_4}{2\pi} = \frac{6289308}{2\pi} = 9879221.9 \approx 1000 \text{ kHz}$$

$$f_4 = 1000\text{kHz or } 1\text{MHz}$$

$$|H_1| = \left|\frac{-R_f}{R_s}\right| = \left|-\frac{1000}{100}\right| = 10$$

$$20\log_{10}(|H_1|) = 20\log_{10}(10) = \underline{20dB}$$

$$|H_1| = 20dB$$



$$m_3 = \angle H_2 - \angle H_1$$

$$225 - 270$$

$$m_3 = -45°/dec.$$