Experiment 1 (Low-pass RL filters):

An ideal inductor has no DC resistance. A practical inductor is made of a wire wrapped around a ferromagnetic core. The resistance of this wire may have to be taken into account in some applications. A practical inductor can be modeled as an ideal inductor in series with a resistor.

Consider the low-pass RL filter shown below (infinite load resistance) with \( R_i \) denoting the resistance of the practical inductor.

\[
\begin{align*}
\text{L} & \quad \text{R}_i \\
V_i & \quad \text{R} \\
\end{align*}
\]

\( V_o \)

Circuit Analysis: a) Derive the expression for \( H(j\omega) \) and calculate the magnitude and phase of the transfer function and the cut-off frequency. b) Show that for \( R_i \ll R \), this circuit acts like a RL filter with an ideal inductor?

PSpice Simulation: Use PSpice to simulate this circuit and obtain the frequency response of the filter for \( L = 10 \, \text{mH}, R_i = 10 \, \Omega, \) and \( R = 2 \, \text{k}\Omega \) (Hint: You can ignore \( R_i \) based on the circuit analysis results above). Attach the Bode plots (both magnitude and phase) to your report. From the Bode plots, find the cut-off frequency of the filter and compare with your circuit analysis results.

Lab Exercise: First measure and record the inductance and the resistance of the 10-mH inductor. Does the measurement of inductor inductance match its spec (10 mH \pm 20%)? Build the circuit. Attach the function generator to the input. Attach Scope channel A to input and Scope channel B to the output. Set the input to a sinusoidal wave with an amplitude of 5 V (and no DC offset). Vary the frequency and at the each frequency measure the output voltage and the phase shift between input and output. Do enough measurements to have sufficient data points to make meaningful plots (See notes after experiment 3). Report the data in tabular form and plot the Bode plots. Find the cut-off frequency of the filter and compare with your simulation and calculations. Write down your observations from this set of experiments and calculations.
Experiment 2: Band pass filter

*Design and Circuit Analysis:* In this exercise, we will design, build and experiment with a band-pass filter made of a high-pass and a low-pass RC filter (See circuit below). An example of this circuit is given in the “Student manual for the ART of Electronics,” pp49 and 50.

![Circuit Diagram](image)

Design parameters: This circuit should drive a load \( \geq 100 \, \text{k}\Omega \), and have lower and upper cut-off frequencies of 100 Hz and 10 kHz, respectively. We also want this filter to have the highest input impedance that we can manage. Find the appropriate values of resistors and capacitors. Use commercially available resistor and capacitors. The following capacitors are available in the Lab (20% tolerence): 1, 2, 3.3, 5, 6.8, 10, 22, 33, 50, 68, and 100 nF. Commercial resistor values are 1, 1.1, 1.2, 1.3, 1.5, 1.6, 1.8, 2, 2.2, 2.4, 2.7, 3, 3.3, 3.6, 3.9, 4.3, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.1 \( (\times 10^n \text{ where } n \text{ is an integer}) \).

*PSpice Simulation:* Use PSpice to simulate the frequency response of the circuit you have designed. Attach the Bode Plots to your report. From the Bode plots find the center and lower and upper cut-off frequencies. How close are you to the design values?

*Lab Exercise:* Build the circuit you have designed in the Laboratory. Obtain frequency response of the filter (both amplitude and phase shift) using a procedure similar to exercise 1. Report the data in tabular form and plot the Bode plots. Compare the Bode plots and center and cutoff frequencies with design values and PSpice simulations. What is the bandwidth, \( B \), of this filter? What is its quality factor, \( Q \). Write down your observations from this set of experiments and calculations.

Experiment 3: RLC band pass filter

Consider the band-pass RLC filter shown below. The inductor is a real inductor so you have to add to the circuit the resistance of the practical inductor, \( R_i \).

*Circuit Analysis:* Derive an analytical expression for \( H(j\omega) \). Show that for \( R_i \ll R \) it will reduce to \( H(j\omega) \) for a RLC circuit with an ideal inductor.

![Circuit Diagram](image)
PSpice Simulation 1: Use PSpice to simulate this circuit and obtain the frequency response of the filter for \( L = 10 \text{ mH}, R_i = 10 \, \Omega, C = 0.01 \, \mu\text{F}, \) and \( R = 5 \, \text{k}\Omega \) (Hint: You can ignore \( R_i \) based on the circuit analysis results above). Attach the Bode plots (both magnitude and phase) to your report. From the Bode plots, find the center frequency, quality factor, and band width of the two filters and compare with your circuit analysis.

PSpice Simulation 2: Repeat PSpice Simulation 1 with the following parameters: \( L = 10 \, \text{mH}, R_i = 10 \, \Omega, C = 1 \, \text{nF}, \) and \( R = 500 \, \Omega \)

Lab Exercise 1: Build the circuit with \( L = 10 \, \text{mH}, C = 0.01 \, \mu\text{F}, \) and \( R = 5 \, \text{k}\Omega \). Obtain the frequency response (only amplitude) of this filter using a procedure similar to exercise 1. Take sufficient data points to make meaningful plot. Report the data in tabular form and plot the Bode plot. Compare the Bode plot, center and cutoff frequencies, bandwidth, and quality factor of the filter with your PSpice simulations 1. Write down your observations from this set of experiments and calculations.

Lab Exercise 2: Repeat the experiment with \( L = 10 \, \text{mH}, R_i = 10 \, \Omega, C = 1 \, \text{nF}, \) and \( R = 500 \, \Omega \).

Question: Describe the advantages and disadvantages of the two types of band-pass filters of Exp. 2 and 3.

Notes:

1) In order to measure phase shift between two signals on Channels A and B of the scope, first set the scope to trigger on Channel A. Next measure the time difference, \( \Delta t \), between the points when both signals cross zero voltage (or any other voltage for that matter but zero is the best as the sinusoidal signals have a maximum slope at zero voltage). Since one wave period, \( T \), is the same as \( 360^\circ \), the phase shift would \( 360 \times (\Delta t)/T \).

2) A good approach to find the frequency response of a filter is as follows.
   a) Find the maximum value of the transfer function (for a fixed \( V_i \) amplitude, this is equivalent to finding maximum \( V_o \) amplitude).
   b) Calculate the value of transfer function at cut-off frequency, \( H(j\omega_c) = |H(j\omega)|_{max}/\sqrt{2} \). For a fixed \( V_i \) amplitude, this is equivalent to finding amplitude of \( V_o(j\omega_c) = V_o|_{max}/\sqrt{2} \).
   c) Scan the input frequency (without changing amplitude of \( V_i \)) and find the frequency in which the amplitude of \( V_o \) matches what you calculated in step b. This is the cut-off frequency. You should be within 5%-10% of your calculated value. Measure the phase at this frequency. It should be what you expect (e.g., \( \approx -45^\circ \) for a low-pass filter).
   d) Find the frequency response of the filter (amplitude and phase) at 0.02, 0.1, 0.5 0.2, 2, 5, 10, and 50 times the cut-off frequency (you can round-up these frequencies as we want to make a plot). You have nine points of data that will give a reasonable Bode plots.
   e) Think how you can modify this procedure for band-pass filters? Look at the Bode plots and let it guide you.