Low Pass Filter

The low pass filter shown in Figure 1 will have \( R=3300\,\Omega \) and \( C=0.047\,\mu\text{F} \).

Note that \( R_s \), the internal resistance of the signal generator, is equal to 50 \( \Omega \), but is small enough to be ignored for these calculations.

**Pre-Lab Calculations**

- The cutoff frequency for a filter is where the power is half of the maximum power. This frequency can be determined by the formula, \( \omega_0 = \frac{1}{RC} \). Recall that the radian frequency can be converted to Hz by the formula, \( f_0 = \frac{\omega_0}{2\pi} \). Calculate the theoretical cutoff frequency of the circuit. \( \omega_0 = \), \( f_0 = \)

- If you know Matlab, it may be helpful to have it generate a Bode plot for you to compare to your experimental data. The transfer function for this circuit is \( \frac{V_o(s)}{V_s(s)} = \frac{1}{s + \frac{1}{RC}} \) so the code below will generate the plot. Remember that the frequencies are in radians.

```matlab
R=3300;
C=0.047e-6;
bode([1/(R*C)],[1 1/(R*C)])
grid
```
Experimental

- Construct the circuit in Figure 1.
- You will be using both channels of the oscilloscope to take measurements. It will be helpful to set the oscilloscope to measure the frequency, period, and voltage peak to peak on each channel. Double check to see that both the scope probes and each channel are set to the 1X option. Set the signal generator to 1 Volt peak-to-peak sine waveform.
- Before taking measurements, sweep through the frequencies to see what happens to the output.
- For each of the frequencies in Table 1, measure the output voltage (peak to peak) and the amount of phase lag (the output comes later in time than the input). To measure the phase lag, you will want to measure $\Delta t$ between the zero crossings (make sure AC coupling is used for both channels) of the input and output waveforms. The phase lag is then calculated as:
  \[ \phi = \frac{\Delta t}{T} \cdot 360^\circ. \]
- Find the frequency where the output voltage (peak to peak) is equal to 0.707 V. This is the experimental cutoff frequency.
- Measure the amount of phase lag at the cutoff frequency.

**Table 1: Low Pass Filter Data**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>$T$ (sec) = $1/f$</th>
<th>Input Voltage (Vpp)</th>
<th>Output Voltage (Vpp)</th>
<th>$M = \text{output/input}$</th>
<th>$M_{\text{dB}}$</th>
<th>$\Delta t$</th>
<th>$\Phi$ lag (deg)</th>
</tr>
</thead>
<tbody>
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<tr>
<td>$f_0 =$ ________</td>
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<td>-3</td>
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</table>

Note: Small adjustments to the input voltage may be needed as the frequency varies.
Post Lab

- Calculate the magnitude as $|M_{db}| = \frac{\text{Output voltage}}{\text{Input Voltage}}$.
- Calculate the magnitude in dB as $\log_{10}\left(\frac{\text{output voltage}}{\text{input voltage}}\right)$.
- Arrange the data points from lowest frequency to highest for plotting purposes. Your break frequency will not be the last point.
- Plot the graphs of magnitude in dB vs. the log of the frequency. Note: The graph MUST be as specified and well done (a Excel plot with 1 -> 10 on the x axis will yield zero points!!) It is not easy in Excel to get this plot, but if you chose to use Excel, it is your responsibility to do it correctly. Matlab code can be found in Lab 1 and is repeated here.
  
  ```matlab
  fo= put in whatever you measured;
  freq=[100 500 900 1000 fo 1500 5000 2000 10000 50000];
  amp=[put in your measured values for M];
  ampdb=20*log10(amp);
  semilogx(freq,ampdb)
  grid
  title('Low Pass Filter')
  xlabel('Freq (Hz)'
  ylabel('Amplitude (dB)')
  ```
- Plot the phase (remember it is lag so that means negative) in degrees vs. the log of the frequency. Same remark for Excel as above.
- Is your circuit functioning as a low pass filter? Did the cutoff frequency match what you calculated?

- List one application for a low pass filter.
• High Pass Filter

![High Pass Filter Circuit](image)

Figure 2: High Pass Filter Circuit

• The high pass filter shown in Figure 2 will have $R=3300\,\Omega$ and $C=0.022\,\mu F$.

• Note that $R_s$, the internal resistance of the signal generator, is equal to $50\,\Omega$, but is small enough to be ignored for these calculations.

**Pre-Lab Calculations**

• The cutoff frequency for a filter is where the power is half of the maximum power. This frequency can be determined by the formula, $\omega_0 = \frac{1}{R \cdot C}$. Recall that the radian frequency can be converted to Hz by the formula, $f_0 = \frac{\omega_0}{2\pi}$. Calculate the theoretical cutoff frequency of the circuit.

  $\omega_0 =$ ____________________,  $f_0 =$ ____________________

• If you know Matlab, it may be helpful to have it generate a Bode plot for you to compare to your experimental data. The transfer function for this circuit is $\frac{V_O(s)}{V_s(s)} = \frac{s}{s + \frac{1}{RC}}$ so the code below will generate the plot. Remember that the frequencies are in radians.

```
R=3300;
C=0.022e-6;
bode([1 0],[1 1/(R*C)])
grid
```
**Experimental**

- Construct the circuit in Figure 2.
- You will be using both channels of the oscilloscope to take measurements. It will be helpful to set the oscilloscope to measure the frequency, period, and voltage peak to peak on each channel. Double check to see that both the scope probe and each channel is set to the 1X option. Set the signal generator to 1 Volt peak-to-peak sine waveform.
- Before taking measurements, sweep through the frequencies to see what happens to the output.
- For each of the frequencies in Table 2, measure the output voltage (peak to peak) and the amount of phase lead (the output comes sooner in time than the input). To measure the phase lead, you will want to measure $\Delta t$ between zero crossings of the input and output waveforms.
  
  The phase lead is then calculated as: $\phi = \frac{\Delta t}{T} \cdot 360^\circ$.

- Find the frequency where the output voltage (peak to peak) is equal to 0.707 V. This is the experimental cutoff frequency.
- Measure the amount of phase lead at the cutoff frequency.

Table 2: High Pass Filter Data

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>T (sec)</th>
<th>Input Voltage (Vpp)</th>
<th>Output Voltage (Vpp)</th>
<th>$M$= output/input</th>
<th>$M_{dB}$</th>
<th>$\Delta t$</th>
<th>$\Phi$ lead (deg)</th>
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<td>$f_0$ = _____</td>
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<td>0.707</td>
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</tbody>
</table>

Note: Small adjustments to the input voltage may be needed as the frequency varies.
Post Lab

- Calculate the magnitude as \( \frac{\text{Output voltage}}{\text{Input Voltage}} \).

- Calculate the magnitude in dB as \( |M_{db}| = 20 \cdot \log\left(\frac{\text{output voltage}}{\text{input voltage}}\right) \).

- Arrange the data points from lowest frequency to highest for plotting purposes. Your break frequency will not be the last point.

- Plot the graphs of magnitude in dB vs. the log of the frequency. Note: The graph MUST be as specified and well done (a Excel plot with 1 -> 9 on the x axis will yield zero points!!) It is not easy in Excel to get this plot, but if you chose to use Excel, it is your responsibility to do it correctly.

- Plot the phase (remember it is lead so that means positive) vs. the log of the frequency. Same Excel warnings as above.

- Is your circuit functioning as a high pass filter? Did the cutoff frequency match what you calculated?

- List one application for a high pass filter.
• Bandpass Filter

![Bandpass Filter Circuit](image)

Figure 3: Band Pass Filter Circuit

• The band pass filter shown in Figure 3 will have $R=550\Omega$ (series of 220 and 330) and $C=0.047\mu F$ and $L=90mH$.

• Note that $R_s$, the internal resistance of the signal generator, is equal to 50 $\Omega$ and recall that the inductor has a resistance of about 10 $\Omega$. These were neglected in the model and will be the reason that the magnitude is always below 0db.

**Pre-Lab Calculations**

• The center frequency for a filter is where the power is at the maximum power. This frequency can be determined by the formula, $\omega_0 = \frac{1}{\sqrt{L \cdot C}}$. Recall that the radian frequency can be converted to Hz by the formula, $f_0 = \frac{\omega}{2\pi}$. Calculate the theoretical center frequency of the circuit. $\omega_0 =$ __________, $f_0 =$ __________

• If you know Matlab, it may be helpful to have it generate a Bode plot for you to compare to your experimental data. The transfer function for this circuit is $\frac{V_o(s)}{V_i(s)} = \frac{R}{Ls}$ so the code below will generate the plot. Remember that the frequencies are in radians.

```matlab
R=550;
C=0.047e-6;
L=90e-3;
bode([R/L 0],[1 R/L 1/(L*C))]
grid
```
Experimental

- Construct the circuit in Figure 3.
- You will be using both channels of the oscilloscope to take measurements. It will be helpful to set the oscilloscope to measure the frequency, period, and voltage peak to peak on each channel. Double check to see that both the scope probe and each channel is set to the 1X option. Set the signal generator to 1 Volt peak-to-peak sine waveform.
- Before taking measurements, sweep through the frequencies to see what happens to the output.
- For each of the frequencies in Table 3, measure the output voltage (peak to peak) and the amount of phase lead or lag. To measure the phase, you will want to measure $\Delta t$ between the zero crossings of the input and output waveforms noting which comes first in time to decide if it is leading or lagging. The phase is then calculated as: $\phi = \frac{\Delta t}{T} \cdot 360^\circ$.
- Find the frequency where the output voltage (peak to peak) is maximum. This is the experimental center frequency.
- Measure the amount of phase lead or lag at the center frequency. Hint: Another way to determine center frequency is when the output waveform has no phase shift.

Table 3: Band Pass Filter Data

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>T (sec)</th>
<th>Input Voltage (Vpp)</th>
<th>Output Voltage (Vpp)</th>
<th>$M = \frac{\text{output}}{\text{input}}$</th>
<th>$M_{\text{dB}}$</th>
<th>$\Delta t$</th>
<th>$\Phi$ (deg)</th>
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</tbody>
</table>

Note: Small adjustments to the input voltage may be needed as the frequency varies.
Post Lab

- Calculate the magnitude $M_{dB} = \frac{\text{Output voltage}}{\text{Input Voltage}}$.
- Calculate the magnitude in dB as $|M_{dB}| = 20 \cdot \log\left(\frac{\text{output voltage}}{\text{input voltage}}\right)$.
- Arrange the data points from lowest frequency to highest for plotting purposes. Your break frequency will not be the last point.
- Plot the graphs of magnitude in dB vs. the log of the frequency. Note: The graph MUST be as specified and well done (a Excel plot with 1 -> 9 on the x axis will yield zero points!!) It is not easy in Excel to get this plot, but if you chose to use Excel, it is your responsibility to do it correctly.
- Plot the phase (- for lag, + for lead) vs. the log of the frequency. Same Excel warnings as above.
- Is your circuit functioning as a bandpass filter? Did the center frequency match what you calculated?

- List one application for a bandpass filter.