Lab Exercise 2

Low Pass and Band Pass Circuit Design in LT Spice

Objectives

1. **Design first, and second order Low Pass and Band Pass filters.**
2. **Plot the magnitude and phase response of the filters in a Bode plot and compare their performances.**

As we observed in the previous lab, the transmitter in the SONAR consists of a crystal oscillator that generates a 2MHz sinusoidal signal, and further using a frequency divider a 40KHz (f_o) ultrasonic output signal is generated. A low pass filter is used to remove any higher order harmonics that may be generated in processing the signal on the transmitter side. Similarly on the receiver side, the received signal is amplified using a low noise amplifier and passed through a band pass filter to remove higher order harmonics and limit external interference. The filter on the transmitter side may be designed as an active filter to provide voltage amplification to the transmitted signal. The order of a filter is determined by the number of storage elements (capacitors and inductors). The first order LPF filters are series inductor or shunt capacitors.

Filter transfer function and cutoff frequency calculation:

Low Pass Filter

Figure 1 shows a 1st-order low pass filter. “First order” because there is a single R and C.

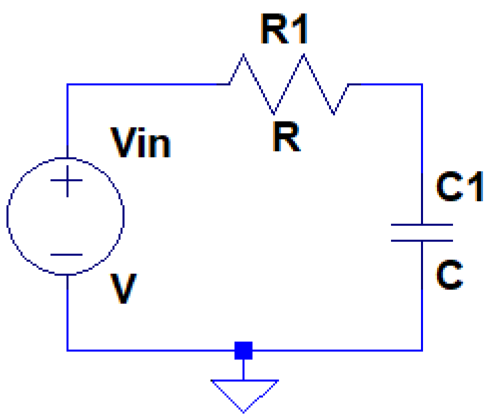

Fig.1

The transfer function for this filter is given as:

$$H(j\omega) = \frac{1}{1+jwRC} \qquad (1)$$

The cutoff frequency or corner frequency of the filter is the frequency either above or below which the power output of a circuit, has fallen to one half the passband power, also referred to as the 3 dB point since a fall of 3 dB corresponds approximately to half power.

Hence, the magnitude response of the transfer function at this corner or cutoff frequency is given by

$$H(j\omega) = \frac{1}{\sqrt{2}} \qquad (2)$$

We see from (1) and (2) that, for the first order LPF the cufoff frequency will turn out be

$$w = \frac{1}{RC}$$

$$f = \frac{1}{2\pi RC} \qquad (3)$$

High Pass Filter

Now consider a first order high pass filter shown in Figure 2 below.

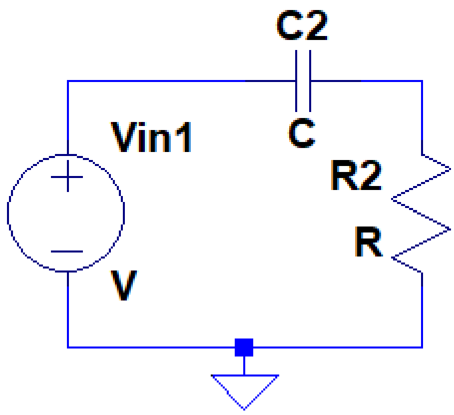

Fig.2

The transfer function for this filter is given as:

$$H(j\omega) = \frac{jwRC}{1+jwRC} \qquad (1)$$

Hence, the magnitude response of the transfer function at this corner or cutoff frequency found at

$$H(j\omega) = \frac{1}{\sqrt{2}} \qquad (2)$$

Hence, the cutoff frequency will turn out be

$$w = \frac{1}{RC}$$

$$f = \frac{1}{2\pi RC} \qquad (3)$$

Hence, we see that the cut-off frequency of the filters can be estimated using the above analysis. The order of the filter can be increased by incorporating more storage elements in the circuit. A higher order filter provides sharper attenuations beyond the pass band wrt the lower order. The cutoff frequency estimation of the higher order filter can be done by analyzing its transfer function, with the criteria that the power output of the circuit falls to one half the passband power.

The frequency response of a filter can be analyzed using Bode plots. Where, magnitude and phase are plotted wrt frequency.

Active Low Pass Filter

An active filter is a type of filter that includes one or more active circuit components such as a transistor or an operational amplifier (Op-Amp). If an active filter permits only low-frequency components and denies all other high-frequency components, then it is termed as an Active Low Pass Filter.

First Order Active Low Pass Filter

It is a simplistic filter that is composed of only one reactive component (Capacitor) accompanied with an active component (Op-Amp). A resistor is utilized with the capacitor or inductor to form RC or RL low pass filter respectively.

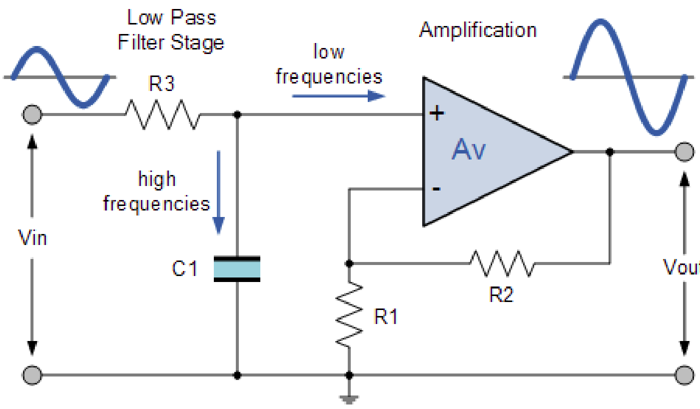

Fig.3

$$Voltage\,Gain,(Av) = \frac{Vout}{Vin} = \frac{A_F}{\sqrt{1+\left(\frac{f}{fc}\right)^2}}$$

Where:

AF = the pass band gain of the filter, (1 + R2/R1)

f = the frequency of the input signal in Hertz, (Hz)

fc = the cut-off frequency in Hertz, (Hz)

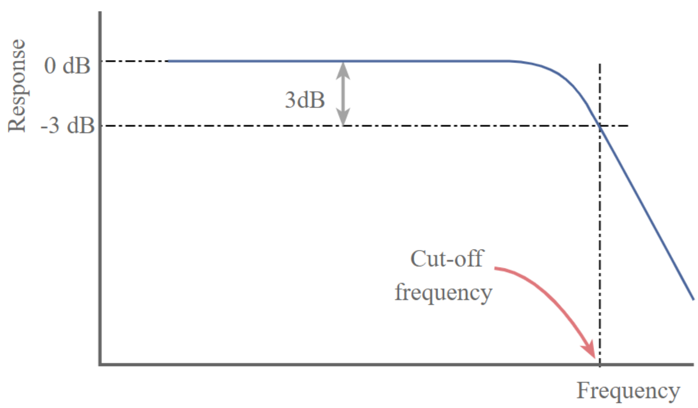

Fig.4

Second Order Active Low Pass Filter

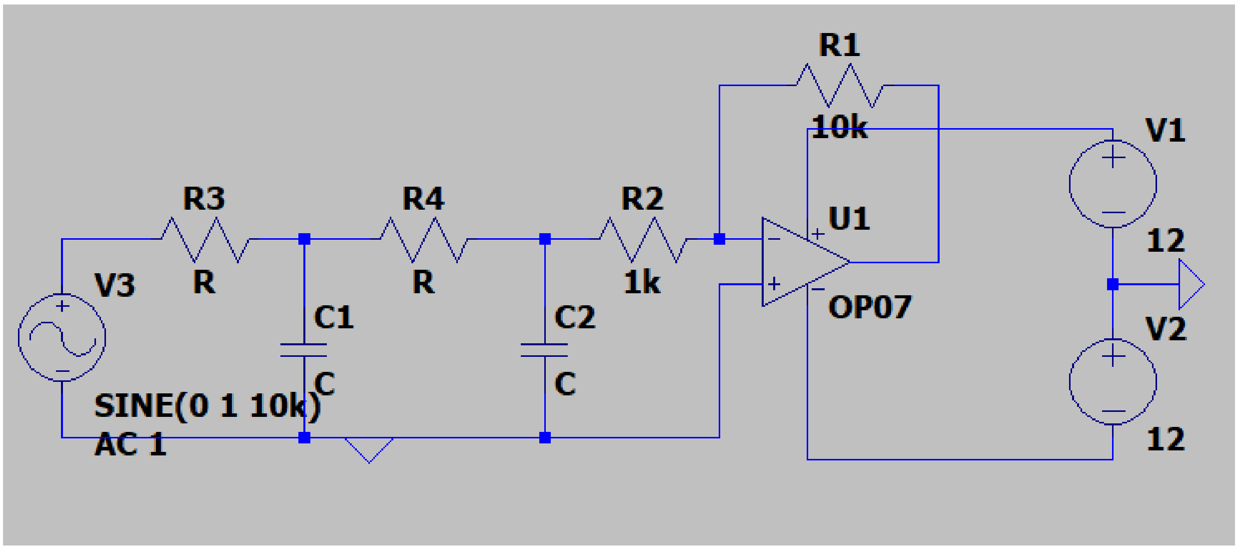

Fig.5

We could make a LPF of higher order by increasing the order of storage elements or cascading another LPF network with the previous network. The second order LPF attenuates the frequencies with a faster rate beyond the pass band.

The cut off of the 2nd order LPF section can be calculated using its transfer function and the same is given as:

$$fL = \frac{1}{2\pi\sqrt{R3C1R4C2}}$$

Lab exercise1: Design of a first order RC Low Pass Filter

2.5 marks (screenshot of circuit & results should be attached on the report)

1. Insert an AC input of 1V amplitude to the filter circuit in Fig. 3. Select the passive components to set the cutoff frequency of the filter to 40KHz.
2. Sweep the frequency from 5Hz to 500KHz and plot the magnitude of the transfer function of the filter in a Bode plot. Mark the roll off rate of the filter response.
3. For the same circuit, plot the phase response of the filter circuit from 5Hz to 500KHz.

Simulation Design of a second order RC Low Pass Filter

2.5 marks (screenshot of circuit & results should be attached on the report)

4. Sweep the frequency from 5Hz to 500KHz and plot the magnitude of the transfer function of the filter in a Bode plot. Mark the roll off rate of the filter response.
5. For the same circuit, plot the phase response of the filter circuit from 5Hz to 500KHz.

Passive Band Pass Filter

A bandpass filter circuit is used to allow only a pre-defined set of frequencies to pass through it. It will filter out all the frequencies that is outside of it's pass band. One of way of designing the band pass filter is to cascade LPF and HPF together. We design the network of LPF and HPF such that, the cutoff frequency of the LPF is set higher than that of the HPF. In this lab we will be simulating a first and second order passive BPF and compare their performances. We may also use inductors along with the capacitors in the design of this filter, however inductors sometimes are bulky, this circuit generates unwanted peaks. A typical response of a BPF has been shown below in Fig. 6.

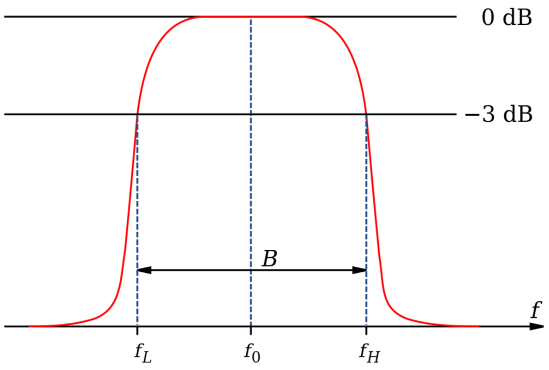

Fig. 6 (Image Source: Wikepedia)

The key parameters that has to be considered, while designing the BPF is:

1. Lower cut-off frequency(fL): the cutoff frequency , which separates pass-band and lower stopband.
2. Upper cut-off frequency (fH): the cutoff frequency fH, which separates passband and upper stopband.
3. Bandwidth (B): width of the passband. B = (fH - fL).
4. Center frequency (fo): This is the frequency that lies between the upper and lower cutoff frequencies (geometric center of passband).
5. Quality factor (Q): The ratio of the center frequency to the bandwidth which is an indication of the selectivity of a band-pass filter.

In this lab while characterizing the BPF we will be measuring the parameters fL, fH, fo, and B.

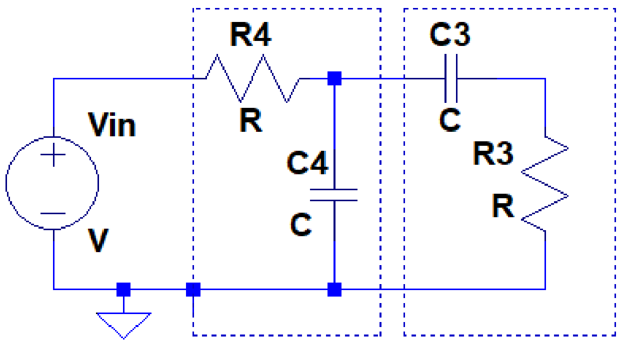

Fig. 7 (1st order Passive Band Pass Filter)

Figure 7 shows a first order BPF. The output is measured across R3. Note that the low-pass section (R3C3) sets the upper cutoff limit ωH (or fH). Similarly, the high-pass section (R4C4) sets the lower cutoff limit ωL (or fL).

The lower cut-off frequency can be estimated using the HPF segment, which will be given as,

$$fL = \frac{1}{2\pi R4C4}$$

And, the higher cutoff limit can be estimated using the LPF segment, which will be given as,

$$fH = \frac{1}{2\pi R3C3}$$

Increasing the order of the BPF:

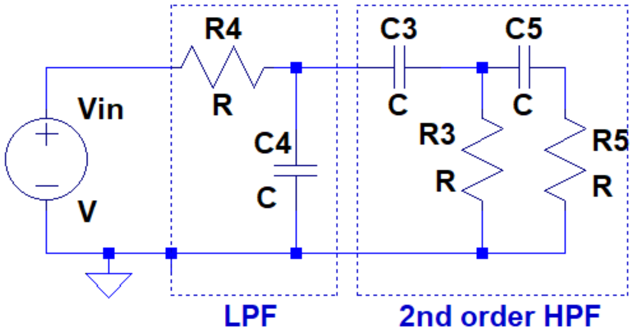

Fig. 8

we could make a BPF of higher order by increasing the order of the respective LPF and HPF networks. The circuit given in Fig. 8 has 3 total sections: 1 LPF cascaded with 2 HPF sections. The single LPF section cuts off the high frequencies with a lower attenuation rate while the 2 HPF sections cascaded more strongly cutoff the low frequencies.

The cut off of the 2nd order HPF section can be calculated using its transfer function and the same is given as:

$$fH = \frac{1}{2\pi\sqrt{R3C3R5C5}}$$

Lab exercise2: Design of a first order RC Band Pass Filter

2.5 marks (screenshot of circuit & results should be attached on the report)

1. Insert an AC input of 1V amplitude to the filter circuit in Fig. 7. Select the passive components to set the centre frequency of the filter to 40KHz, and Bandwidth(B) of the filter should be 10KHz.
2. Sweep the frequency from 5Hz to 500KHz and plot the magnitude of the transfer function of the filter in a Bode plot. Mark the roll off rate of the filter response.
3. For the same circuit, plot the phase response of the filter circuit from 5Hz to 500KHz.

Simulation Design of a second order RC Band Pass Filter

2.5 marks (screenshot of circuit & results should be attached on the report)

4. Sweep the frequency from 5Hz to 500KHz and plot the magnitude of the transfer function of the filter in a Bode plot. Mark the roll off rate of the filter response.
5. For the same circuit, plot the phase response of the filter circuit from 5Hz to 500KHz.

Note:

Proper cascades of passive filters require each successive stage to use a resistor (at least) a factor of 10× greater than the one in the previous stage. This prevents current from leaking out of the earlier stages, which would make the design parameter more accurately matched to the analysis done using cascade methods. For example in figure 8, R5>>R3>>R4.