Experiment 2

Active Filters

(Experimental)

OBJECTIVE

To design second-order low –pass filters using the Sallen & Key (finite positive- gain) and infinite-gain amplifier models. One circuit will exhibit a Butterworth response and the other will be based on a Chebyshev response. Scaling techniques will be used to ensure practical component values.

INTRODUCTION

Active filters are constructed using a combination of resistors, capacitors and an active device. The active device is usually an op-amp. The main advantages of these filters are:

-Expensive and bulky coils are eliminated.

-Arbitrary circuit gain can be realized.

-High input/low output impedances yield good isolating properties.

Some disadvantages include:

 -Op-amps require power supplies.

 -At higher frequencies op-amp gain is reduced considerably.

 -The circuit is sensitive to component change.

Two common filter configurations are the Sallen & Key positive gain and the Negative-feedback class of filters. In this lab you will design and build, a second –order low-pass Butterworth filter using the Sallen & Key model, and a second-order low-pass Chebyshev filter using the Negative-feedback model.

Butterworth Response

A Butterworth response exhibits specific characteristics. A Butterworth response has a transfer function



For a normalized frequency,  the transfer function is:



Where = *half -power-frequency*, and n= number of poles

Let , then , and , or 

The Butterworth characteristics can be summarized:

 1.  at  is 1 for all n.

 2.  at  is 0.707 for all n.

 3. For a large ,  exhibits n-pole roll-off.

 4. The response is maximally flat, since the first *(n-1)* derivatives of the Taylor series expansion of | is zero at  (i.e., DC).

Chebyshev Response

The Chebyshev or *equal-ripple* approximation has a transfer function:



Where  for 

  for .

*w* is the normalized frequency with respect to the pass-band edge frequency *wo*.

*Tn(jw)* is the order Chebyshev polynomial. Therefore:



The Chebyshev characteristics can be summarized as follows.

1. At  = 0;   for n even

   for n odd

2. At  = 1;

   for all n

The magnitude of the Chebyshev response decreases monotonically in the stop band. Because of the ripples in the pass-band the Chebyshev filter exhibits a sharper attenuation in the stopband than a Butterworth filter of the same order.

Sallen & Key Filter

The Sallen & Key low-pass filter which uses a positive gain amplifier is shown in figure 1.



A special case of the Sallen & Key model is the unity gain S&K shown in figure 2.

INFINITE GAIN AMPLIFIER BASED MULTIPLE FEED BACK SINGLE AMPLIFIER BIQUADRATIC (sab) LOW-PASS FILTER

The multiple feedback (infinite gain amplifier based) low-pass filter is shown in figure 3.



Scaling (magnitude & frequency scaling)

A circuit can be designed for practical component values employing magnitude scaling. To magnitude scale components the following equations are used.







For example if the design value of the capacitor is 0.1µF and you only have 1uF capacitors, then you need a scaling factor,.

A circuit designed for one frequency can be transformed to operate at another frequency by employing frequency scaling. The equations for frequency scaling are similar to the magnitude scaling equations. With the exception that resistors are not frequency scaled.

, 

Where ratio of final to initial cut-off frequencies in radians = wf/wi.

This technique is particularly useful when you design a filter that is normalized for *wi* = . In this case Kf = wf .

Procedure

1. Design a second- order Butterworth low-pass filter using the unity gain Sallen & Key model (Fig. 2) for the cut-off frequency of 10KHz. Design the circuit to operate using 1nF capacitors and equal resistors. The pole frequency (cut-off frequency) is given by: . Apply a 1V peak-peak sinusoidal input signal, starting at 1 KHz and sweep through the cut-off frequency to 25 KHz, in steps of 500Hz. Make sure to take more readings, at smaller intervals, around the cut-off frequency i.e. from 9 KHz to 15 KHz reduce the interval size to 250Hz.
2. Design a second-order Chebyshev low-pass filter with a pass-band ripple of 1 dB, using the configuration in Fig.3, for the cut-off frequency of 10KHz. The normalized transfer function for this configuration is1 0.9825/(s2+1.098s+1.103). The theoretical transfer function is given as

$$T=\frac{-ω\_{p}^{2}\left(^{R\_{2}}/\_{R\_{1}}\right)}{s^{2}+s\left(^{ω\_{p}}/\_{Q\_{p}}\right)+ω\_{p}^{2}}$$

 Design the circuit to operate using one 10nF capacitor. One possible implementation for this problem is as follows: R1=R2=15KΩ, R3=2KΩ, C1=10nF, and C2=1nF. Apply a 1V peak-peak sinusoidal input signal, starting at 1KHz and sweep through the cut-off frequency to 25KHz, in steps of 500Hz. Make sure to take more readings, at smaller intervals, around the cut-off frequency, i.e.: from 9KHz reduce the interval size to 250Hz.

1. Using the frequency scaling technique, re-design and test the filter in step-2 for a cut-off frequency of 1 KHz.

1 See Appendix A3 in Modern Analog Filter Analysis and Design- By Raut and Swamy

Results & Discussion

1. Derive the transfer function Vout/Vin for the filter circuits in figures 1, 2, and 3.
2. Plot experimental and theoretical curves (Vout/Vin) on the same graph for the filters in Figs. 2 and 3.
3. What is the value of Qp produced by your design in procedure step #1?