EE 230 – Analog Lab - 2021-22/I (Autumn)

Experiment 8: Special Opamp Linear Circuits - Precision Rectifiers and Active Filters

(Ver 2.1, Sep 29, 2021)

Introduction

In this experiment we shall explore two linear applications of Opamps, viz. Precision rectifiers and Active filters.

Part A – Precision Rectifiers

1.1 Introduction

In the rectifier circuits we used in Expt 2, we neglected the diode drops as these drops (typ. 0.7 V) were much smaller compared to the input ac signal, roughly 20 sin ωt. However, there are several applications where we cannot use those circuits, as the signal itself would be of the order of the diode drops or much smaller. In such applications if we combine a diode and an Opamp (with negative feedback) then the above problem can be easily addressed. The combination of an Opamp and a diode is often called a 'Super diode' or a 'Precision Rectifier' circuit.

Please refer to the experiment sheet '2020-Spring-Precision-RectifierCircuits.pdf' uploaded on Moodle in the folder 'Expt 8 – Precision Rectifiers and Active Filters'.

We shall use all the precision rectifier circuits given there.

1.2 NGSPICE Simulation

Simulate all the precision rectifier circuits of the above sheet.

a) Plot the input and output waveforms.
b) Also plot V_{out} vs V_{in}

Use the IN914 signal diode model for the above simulations. For Opamp, use the UA741 Opamp model. Both these models are included in the Expt 8 folder uploaded on Moodle.

Part B – Active Filters

2.1 Introduction

Active filters are much more versatile than passive filters. At a basic level they may be thought of as a combination of RC circuits along with Opamps or other active elements, with the ability to provide the desired voltage gain to the filtered signal. In addition to the above feature, active filters provide much more power to the designer with the ability to the design filters with larger Q, sharper cut off etc.

Based on the shape of the filter response curve the filters (both passive and active) may be called Butterworth, Chebyshev, or Bessel filters. Each one of these filters has an advantage in certain applications. Butterworth filters are the ones most commonly used. They have a maximally flat response. In our experiment we shall consider the following basic active filter circuits, so as to appreciate their basic features.

i) Single-pole Active Low-pass Filter (Butterworth), ii) Single-pole Active High-pass Filter (Butterworth), iii) Sallen-Key (2-pole) Active Low-pass Filter, and iv) iii) Sallen-Key (2-pole) Active High-pass Filter

2.2 Single-pole Active Low-pass Filter

Opamp: LM741, Power supply: +Vcc = +12 V, -Vcc = -12 V

Circuit values: R_A = 4.7 kΩ, C_A = 0.1 μF, R_1 = 1 kΩ, R_2 = 9.1 kΩ

The circuit diagram of a single-pole active low-pass Butterworth filter is shown in Fig.1. It is nothing but a cascade of a single-pole RC low-pass filter and a non-inverting amplifier. The cut-off frequency of the filter is given by, $f_c = 1/(2\pi\ RC)$. In the circuit shown R = R_A and C= C_A.

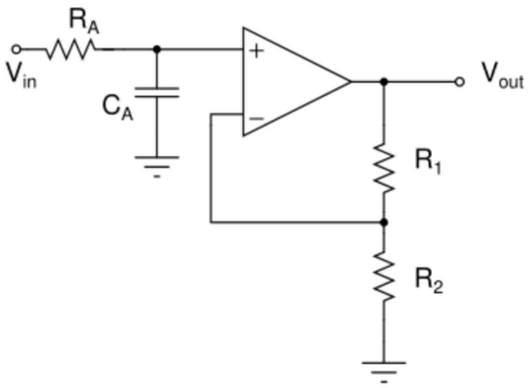

Fig.1 Single-pole active low-pass filter

2.2.1 NGSPICE Simulation

Simulate the filter response of the above circuit. Use the model file of the 741 Opamp (UA741.txt). Plot the filter response and compare the theoretical results with the simulation results.
(Measured results will be shown during the Lab lecture).

2.3 Single-pole Active High-pass Filter

Opamp: LM741, Power supply: +Vcc = +12 V, -Vcc = -12 V

Circuit values: R_A = 4.7 kΩ, C_A = 0.1 μF, R_1 = 1 kΩ, R_2 = 9.1 kΩ

The circuit diagram of a single-pole active high-pass Butterworth filter is shown in Fig.2. Similar to the circuit in Fig.1, the circuit in Fig.2 is a cascade of a single-pole RC high-pass filter and a non-inverting amplifier. The cut-off frequency of the filter is given by, $f_c = 1/(2\pi\ RC)$. In the circuit shown R = R_A and C= C_A.

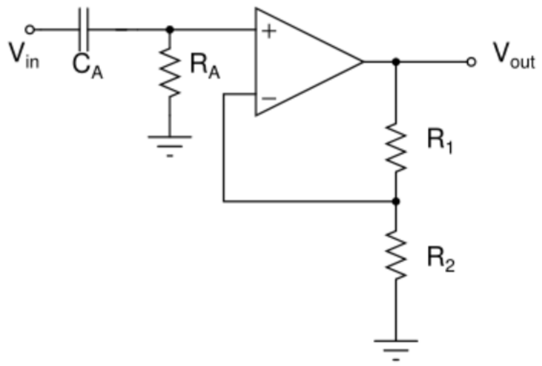

Fig. 2 Single-pole active high-pass filter

2.3.1 NGSPICE Simulation

Simulate the filter response of the above circuit. Use the model file of the 741 Opamp (UA741.txt). Plot the filter response and compare the theoretical results with the simulation results.
(Measured results will be shown during the Lab lecture).

2.4 Sallen-Key (2-pole) Active Low-pass Filter

Opamp: LM741, Power supply: +Vcc = +12 V, -Vcc = -12 V

Circuit values: $R_A = R_B = 4.7$ kΩ, $C_A = C_B = 0.1$ μF, $R_1 = 1.8$ kΩ, $R_2 = 3.3$ kΩ

The cut-off frequency of the filter is given by, $f_c = 1/(2\pi\, RC)$, where $R = R_A = R_B$ and $C = C_A = C_B$. Note that this filter is a two-pole filter and hence it has a much sharper roll-off of -40 dB/decade beyond the cut-off frequency. R_1 and R_2 values are chosen such that $R_1 = 0.586\, R_2$. (Refer to the following pages of the reference material uploaded on Moodle: Damping Factor Sec 15.2, page 770, Flyod 9e).

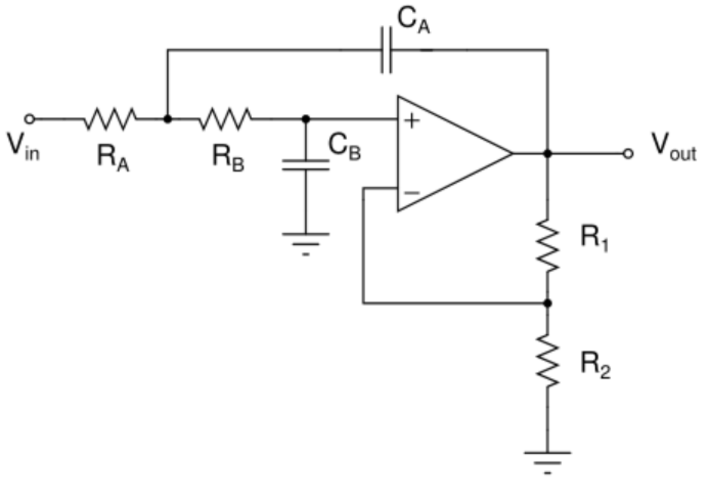

Fig. 3 Sallen-Key (2-pole) active low-pass filter

2.4.1 NGSPICE Simulation

Simulate the filter response of the above circuit. Use the model file of the 741 Opamp (UA741.txt). Plot the filter response and compare the theoretical results (cut-off frequency and roll-off) with the simulation results.

(Measured results will be shown during the Lab lecture).

2.5 Sallen-Key (2-pole) Active High-pass Filter

Opamp: LM741, Power supply: +Vcc = +12 V, -Vcc = -12 V

Circuit values: $R_A = R_B = 4.7$ kΩ, $C_A = C_B = 0.1$ μF, $R_1 = 1.8$ kΩ, $R_2 = 3.3$ kΩ

The cut-off frequency of the filter is again given by, $f_c = 1/(2\pi RC)$, where $R = R_A = R_B$ and $C = C_A = C_B$. Note that this filter also being a two-pole filter has a sharper roll-off of -40 dB/decade beyond the cut-off frequency. R_1 and R_2 values are chosen such that $R_1 = 0.586\, R_2$. (Refer to the following pages of the reference material uploaded on Moodle: Damping Factor Sec 15.2, page 770, Flyod 9e).

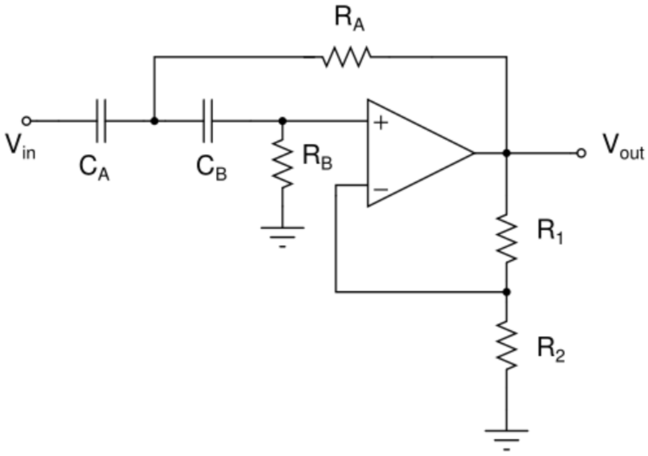

Fig. 4 Sallen-Key (2-pole) active high-pass filter

2.5.1 NGSPICE Simulation

Simulate the filter response of the above circuit. Use the model file of the 741 Opamp (UA741.txt). Plot the filter response and compare the theoretical results (cut-off frequency and roll-off) with the simulation results.
(Measured results will be shown during the Lab lecture).

<u>Lab Report</u>

1. For Experiment 8, please limit your Lab report to 4 pages –
   Page 1: Improved Half-wave rectifier-A,
   Page2: Full-wave rectifier.
   Page 3: Single-pole Active Low-pass Filter (all odd Roll Nos.), Single-pole Active High-pass Filter (all even Roll Nos.).
   Page 4: Sallen-Key (2-pole) Active High-pass Filter (all odd Roll Nos.), : Sallen-Key (2-pole) Active Low-pass Filter (all even Roll Nos.).
2. Each page should have circuit diagram, your NGSPICE program, and the plot.
3. Line 1 of your NGSPICE programs should have your Roll no., Name and the Title of the program.
4. Deadline for Lab Report 8: Oct 3, 2021 (Sunday), 11pm.
5. Please do not email the Lab instructor with late submission requests of Lab Reports. Instead, you may write to your Tutor, who would assess your request, and might allow late submission (by say, a maximum of 12 hours) as a one-time concession.

Note: Request all students to refrain from any unfair means, such as copying Lab Reports of others, in part or in full. Defaulters (both parties) will attract very severe punishment – including negative marks (i.e. minus marks, instead of 0 marks for non-submission), and grade penalty.