Workshop 1 - LTSpice and Front End Filter Design

Introduction

In this workshop we will cover:

- Circuit simulation using SPICE
- LTSPICE tutorial
- 1^{st} and 2^{nd} order filter low-pass active and passive filter design
- Step parameter variation of a simulation
- Op-amp based DC offset circuitry
- Basic LTSpice power analysis

Learning objectives:

- To create schematics within LTSPICE
- To become familiar with simulation within LTSPICE
- To understand the importance of circuit simulation in the electronics system design cycle
- To experiment with circuit design in a simulated environment
- To begin understanding how you will design the digital oscilloscope (DSO) front-end subsystem

LTSPICE Fundamentals

Some of you will be familiar with most features of LTSPICE. If so, feel free to continue onto the next section. However, we recommend that you skim through the following LTSPICE tutorials:

1. Basic
2. Intermediate
3. Advanced

Simulating Filters

Part A: 1^{st} Order Filters

Construct the following low-pass first order passive and active op-amp filters and perform AC analysis between 1Hz and 100MHz with 100 points per decade.

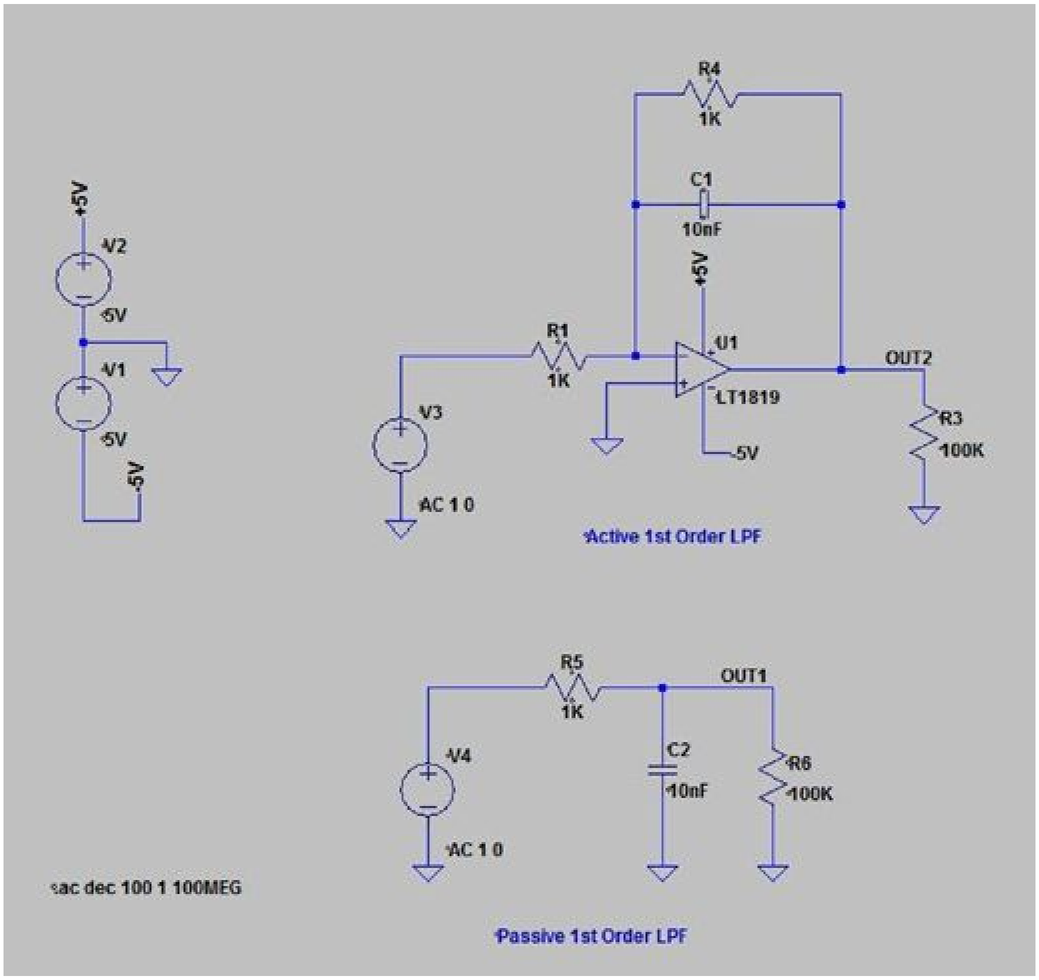


Figure 1: A Passive and Active 1st Order Low-pass Filter

Questions

1. Given each filter has a -3dB roll-off frequency calculated by using the formulae found in appendix A, does the simulation agree with the value expected?
2. Does the passive and active frequency response differ and if so speculate why?
3. If the load is varied for both the active and passive circuit which circuit maintains greater gain stability?

Part B: 2nd Order Filters

Using the steps outlined in appendix B and C design both a 2nd order Sallen-Key and Multiple-Feedback (MFB) op-amp filter design for simulation with LTSpice. The design parameters are as follows:

Roll-Off Frequency: f_{-3dB} = 100K
DC Gain: H_0 = 2

Use α **= 1** for the equations in appendix B and C. In lecture 5 you will cover filter design in detail.

Use the same small signal AC analysis settings as in the first order simulation from the last section and observe the output with a 100K load.

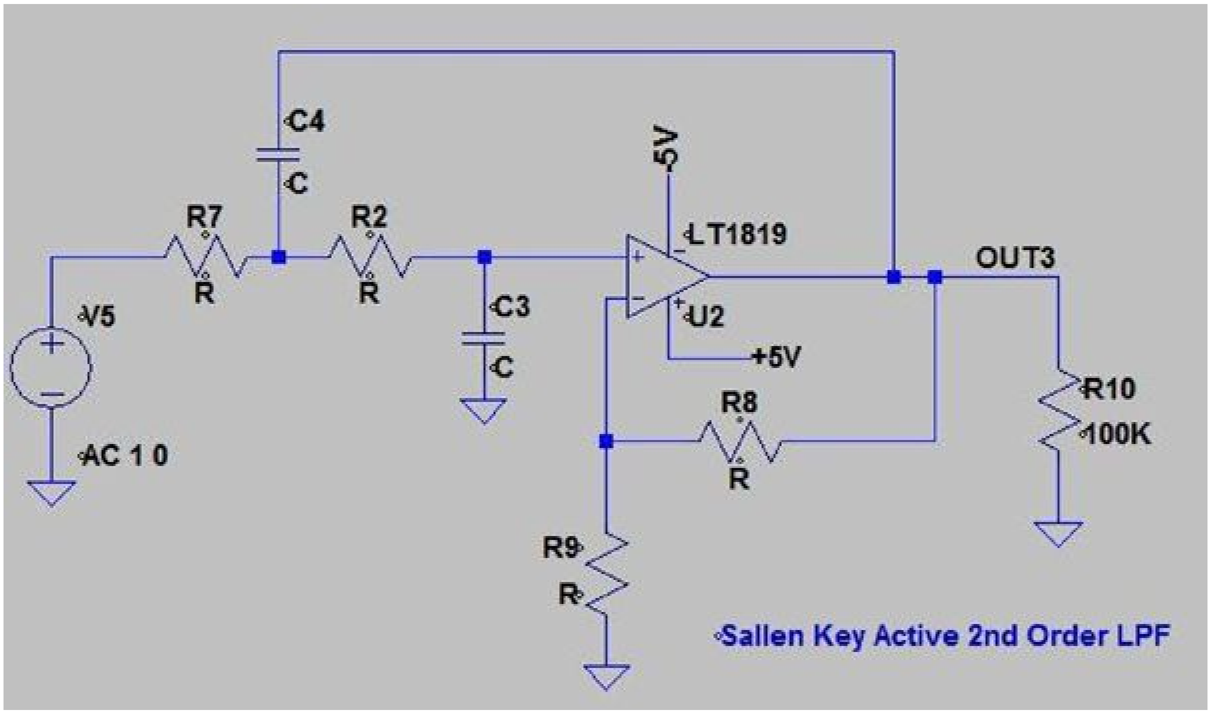


Figure 2: Sallen-Key Active 2nd Order Low-pass Filter

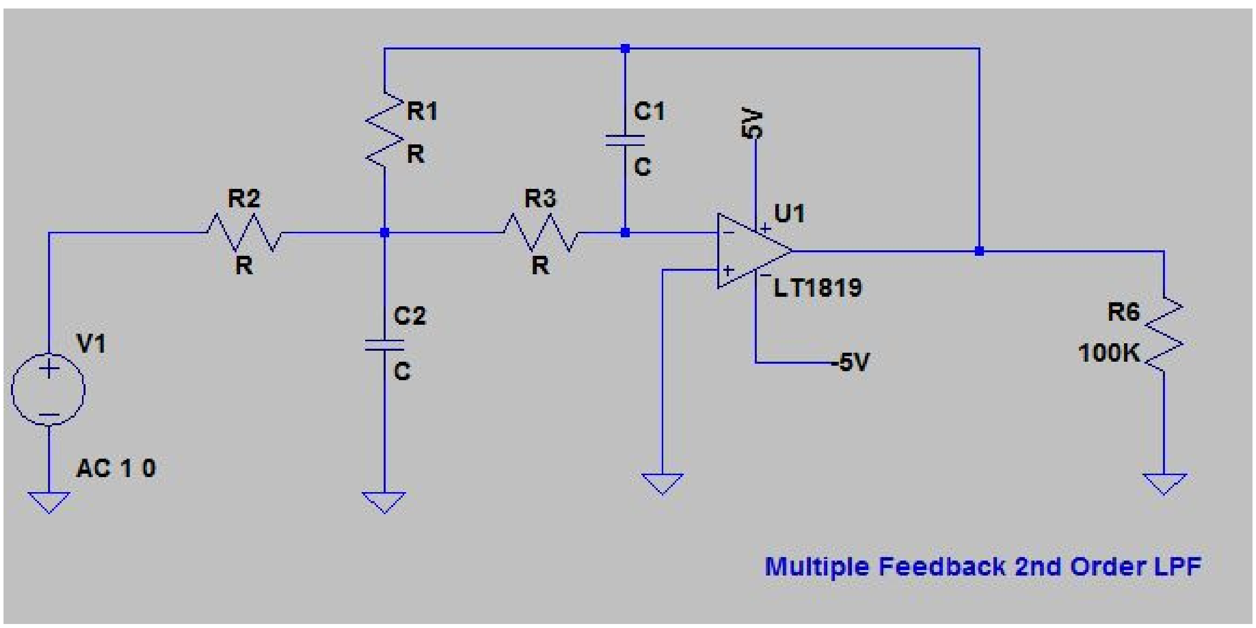


Figure 3: Multiple Feedback Active 2nd Order Low-pass Filter

Questions

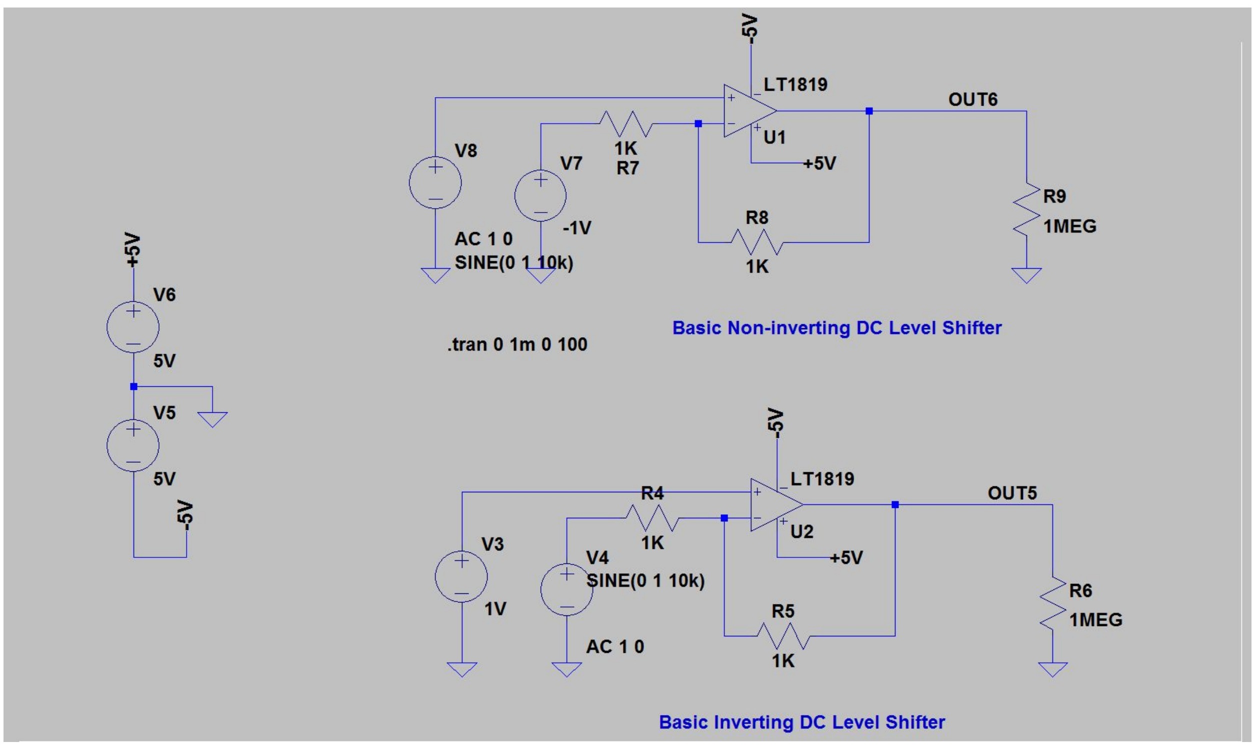
1. Which filter was easier to design?

2. Are the simulation results as expected?
3. If the capacitor C2 is varied in the MFB LPF what happens to the Q and corner frequency of the filter?
4. If the gain is varied for the Sallen-key 2nd order filter how is the frequency response changed?
5. If the load is varied for the MFB and Sallen-Key circuits which circuit maintains more stable frequency response and gain?

Part C: Level Shifting Circuits

Now we seek to examine the performance of two level shifting circuits which achieve inverting and non-inverting DC voltage translation when an AC signal is applied to the input. Using a 2Vp-p input analyse the transient response at the output of each of the following circuits using varied DC voltage settings for sources V7 and V3.

Note the polarity of the DC reference is different for each level shifting topology.

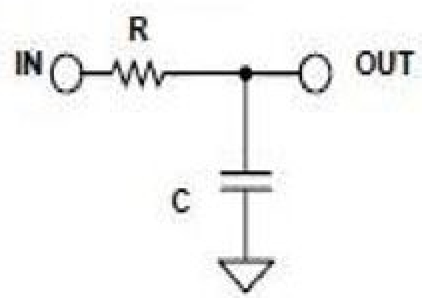


Questions

1. What effect does changing the gain do to the level shifting function for a given DC reference voltage?
2. What change is observable for very low load resistance?
3. What is the output waveform for a pulse input signal? Does it differ from a pure sine?

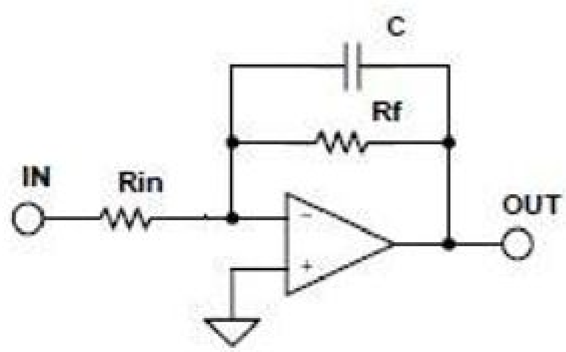
4. What issues might arise if the DC reference is unable to sink high frequency currents through it?
5. How does the LT1819 simulation differ from an ideal opamp used in the same configuration?
6. Can you determine which component within the DC level shifter circuit is dissipating the greatest amount of power (as heat)
7. How might you reduce the power consumption of the level shifter circuit?

Appendix A: 1st Order LPF Design



$$\frac{V_O}{V_{IN}} = \frac{1}{sCR+1}$$

$$F_o = \frac{1}{2\pi RC}$$



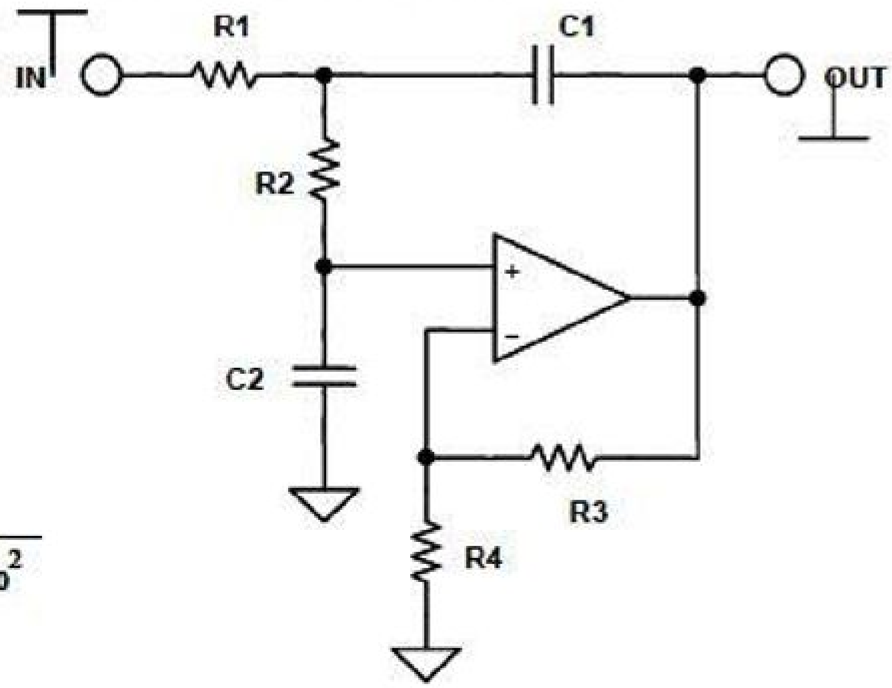
$$\frac{V_O}{V_{IN}} = -\frac{Rf}{Rin}\,\frac{1}{sC\underset{Rf}{\cancel{R2}}+1}$$

$$H_o = -\frac{Rf}{Rin}$$

$$F_o = \frac{1}{2\pi Rf\,C}$$

Appendix B: 2nd Order Sallen-Key LPF Design

SALLEN-KEY LOWPASS



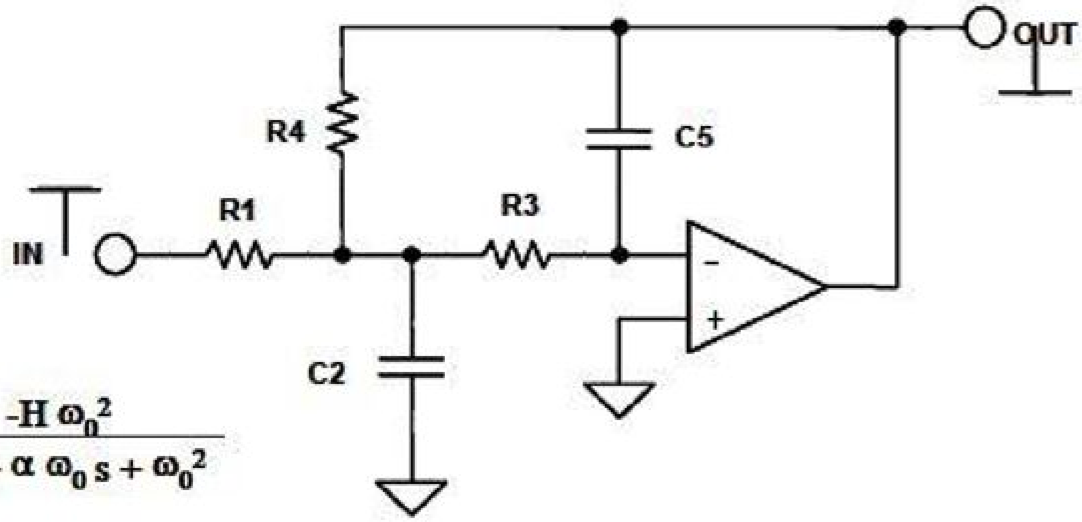
$$\frac{+H\,\omega_0^2}{s^2 + \alpha\,\omega_0\,s + \omega_0^2}$$

$$\frac{V_O}{V_{IN}} = \frac{H\,\dfrac{1}{R1\,R2\,C1\,C2}}{s^2 + s\left[\left(\dfrac{1}{R1} + \dfrac{1}{R2}\right)\dfrac{1}{C1} + \dfrac{(1\text{-}H)}{R2\,C2}\right] + \dfrac{1}{R1\,R2\,C1\,C2}}$$

CHOOSE:	C1	R3
THEN:	$k = 2\,\pi\,F_O\,C1$	$R4 = \dfrac{R3}{(H\text{-}1)}$
	$m = \dfrac{\alpha^2}{4} + (H\text{-}1)$	
	$C2 = m\,C1$	
	$R1 = \dfrac{2}{\alpha k}$	
	$R2 = \dfrac{\alpha}{2mk}$	

Appendix C: 2nd Order Multiple Feedback LPF Design

MULTIPLE FEEDBACK LOWPASS



$$\frac{-H\,\omega_0^2}{s^2 + \alpha\,\omega_0\,s + \omega_0^2}$$

$$\frac{V_O}{V_{IN}} = \frac{-H\dfrac{1}{R1\,R3\,C2\,C5}}{s^2 + s\,\dfrac{1}{C2}\left(\dfrac{1}{R1}+\dfrac{1}{R3}+\dfrac{1}{R4}\right) + \dfrac{1}{R3\,R4\,C2\,C5}}$$

CHOOSE: C5

THEN: $k = 2\,\pi\,F_O\,C5$

$$C2 = \frac{4}{\alpha^2}\,(H+1)\,C5$$

$$R1 = \frac{\alpha}{2\,H\,k}$$

$$R3 = \frac{\alpha}{2\,(H+1)\,k}$$

$$R4 = \frac{\alpha}{2\,k}$$