McMaster University

Electrical and Computer Engineering Department

EE3EJ4 Electronic Devices and Circuits II - Fall 2021

Lab. 5 Active Filter Circuits

Lab Report Due on Nov. 28, 2021

Objective: To design and characterize the performance of active filters.

Attributes Evaluated: These are the attributes you need to demonstrate in your solutions.

- **Competence in specialized engineering knowledge to simulate circuit performance using SPICE-based circuit simulator and conduct analog circuit debugging;**
- **Ability to obtain substantiated conclusions as a result of a problem solution, including recognizing the limitations of the approaches and solutions; and**
- **Ability to assess the accuracy and precision of results.**

Test Equipment:

- Analog Discovery 2 (AD2)
- WaveForms from Digilent Link
- Analog Discovery 2 Quick Start Series Videos
- WaveForms Reference Manual

Components:

- Op-Amp: 1 × TLV2371
- Capacitors: 2 × 1 nF (102) capacitor 1 × 2.2 nF (222) capacitor
- Resistors: 4 × 100 kΩ resistor 1 × 200 kΩ resistor 2 × 240 kΩ resistor

Transistors in the circuit:

For the detailed description of Op-Amp TLV2371 and its SPICE model, please check the following websites:

https://www.ti.com/product/TLV2371?dcmp=dsproject&hqs=sw&#design-development##design-tools-simulation

Reminder: Switch off the DC power suppliers first whenever you need to change the circuit configurations. Switch on the DC power suppliers only when you do not have to change the circuit connection anymore.

Part 1: First-order Low-pass Filter

A. Pre-lab Preparation

1.1 In PartSim (or LTspice), construct the first-order low-pass filter (LPF), as shown in Fig. 1. Follow the same instruction and procedures described in Steps 2.1 and 2.2 in Lab 4 to load the SPICE model and arrange the pin order of the Op-Amp TLV2371.

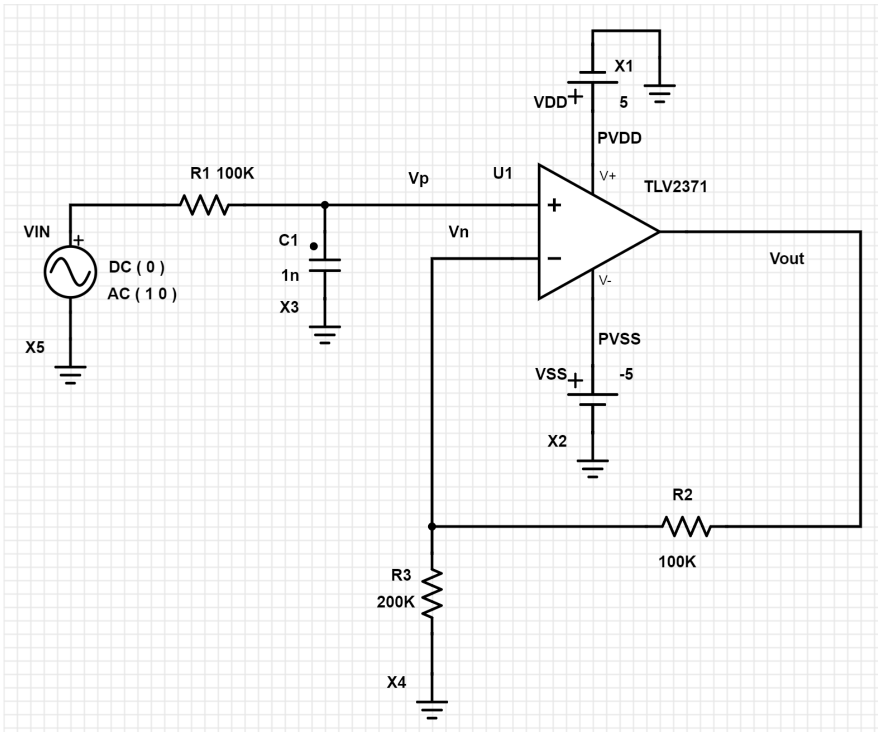

Fig. 1 Schematic diagram of the first-order low-pass filter

1.2 For the input signal V_{IN}, set its DC Voltage = 0 V, AC Magnitude = 1 V, and AC phase = 0, respectively.

1.3 **Frequency Response:** Conduct AC analysis to obtain V_{out} at the output of Op-Amp TLV2371. Set the Sweep Type in DEC with Start Frequency = 1 Hz, Stop Frequency = 100 kHz, and Total Points Per Decade = 101. Choose REAL for the Magnitude Unit and degree (DEG) for the Phase Unit. Record the simulated magnitude and phase of V_{out} in the sheet "Step 1.3" of the Excel file "Lab 5 – Active Filter.xlsx".

B. In-lab Measurement

1.4 Use the port definition diagram of the AD2 shown in Fig. 2 and the pin configuration of Op-Amp TLV2371 in Fig. 3 when setting up your circuits.

1.5 Based on Fig. 1, construct the measurement setup for the first-order LPF, as shown in Fig. 4.

1.6 In AD2, use V+ = 5V for V_{DD} and V- = -5V for V_{SS}. Connect Scope Ch. 1 Negative (1-), Scope Ch. 2 Negative (2-), GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line. For the

Op-Amp, connect its GND (pin 4) to the V- (i.e., -5 V).

1.7 Connect the Waveform Generator (W1) and Scope Ch. 1 Positive (1+) to the input V_{IN} of the LPF and connect Scope Ch. 2 Positive (2+) to the output (the pin 6) of the TLV2371.

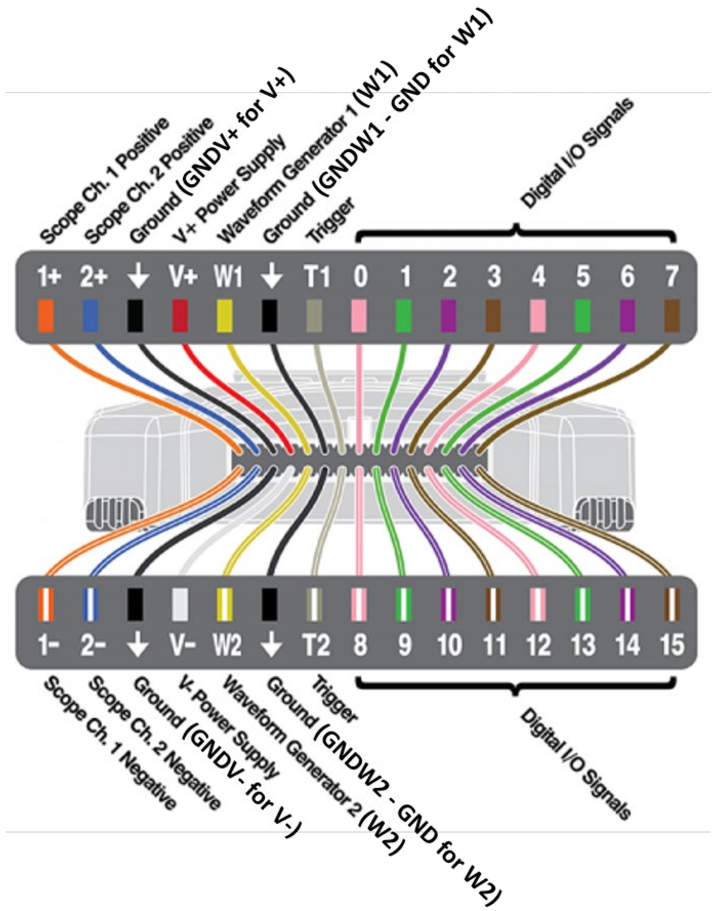

Fig. 2 Diagram for the port definition of an Analog Discovery 2 (AD2)

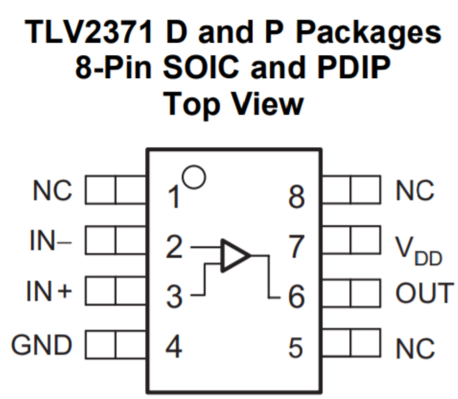

Fig. 3 Pin Configuration of Op-Amp TLV2371

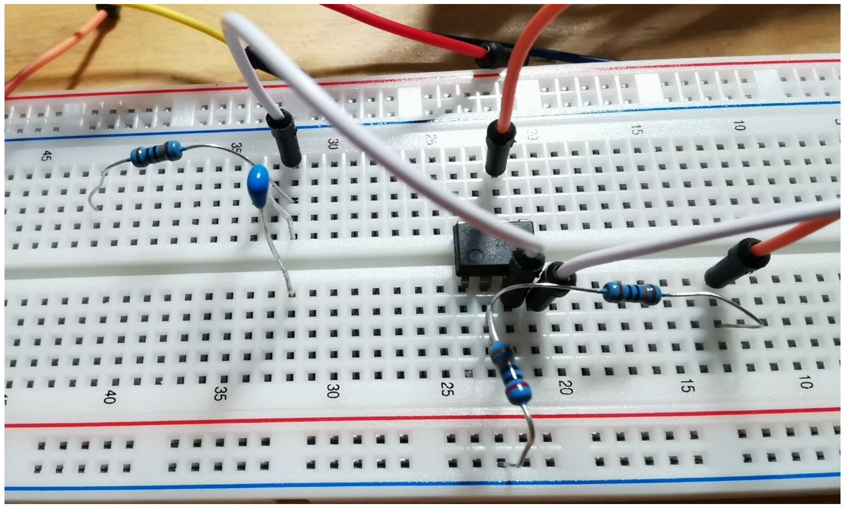

Fig. 4 Experimental setup for the first-order low-pass filter

1.8 **Frequency Response:** In Waveforms, use the Network Analyzer tool and set Wavegen (W1) to generate a sinewave with Amplitude = 100 mV and Offset = 0 V. For frequency, set Scale = Logrithimc, Start = 1 Hz, Stop = 100 kHz, Samples = 501. Measure and record the measured magnitude and phase versus frequency characteristics of the voltage gain in the sheet "Step 1.8" of the Excel file "Lab 5 – Active Filter.xlsx".

C. Questions for Part 1:

For the first-order LPF designed, answer the following questions with simulated and measured data, and discuss any discrepancy between the simulation and measurement results.

Q1. (20 Points) (1) Find the transfer function of the first-order LPF, its low-frequency gain, and its -3dB frequency f_c. (2) Compare the calculated low-frequency gain and the -3dB frequency f_c with the simulated data from Step 1.3 and the measured data from Step 1.8, respectively. Justify/discuss the observation and comparison.

Part 2: **Second-order Low-pass Filter**

A. Pre-lab Simulation

2.1 In PartSim (or LTspice), construct the second-order low pass filter (LPF) as shown in Fig. 5. using an operational amplifier TLV2371IP, four 100 kΩ resistors, one 1 nF capacitor, and one 2.2 nF capacitor, respectively. Here VIN provides the AC signal input for this second-order LPF. The DC and AC value of the AC voltage source VIN are set to 0 V and 1 V, respectively.

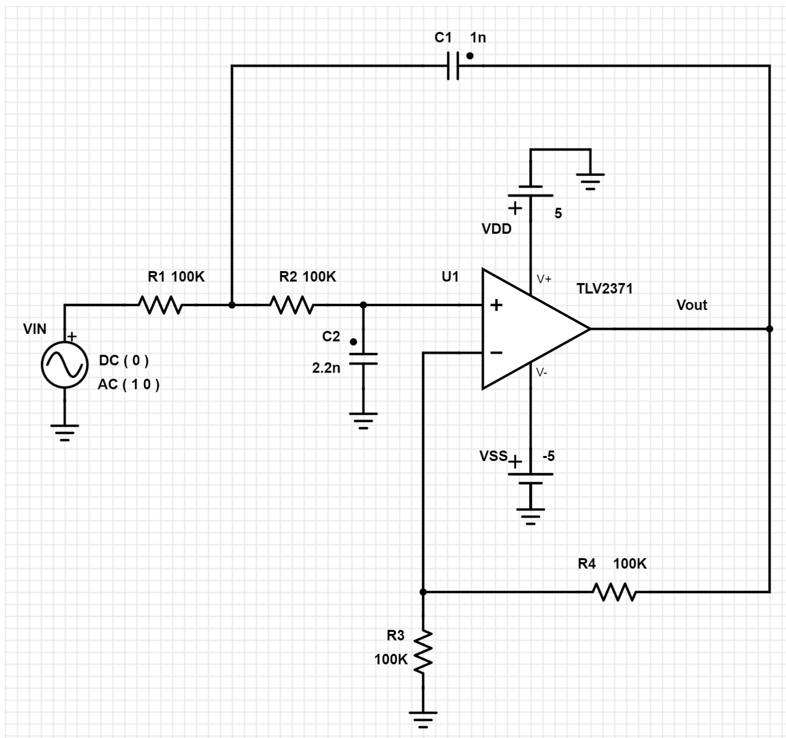

Fig. 5 Schematic diagram of the second-order low-pass filter

2.2 **Frequency Response:** Conduct AC analysis to obtain V_{out} at the output of Op-Amp TLV2371. Set the Sweep Type in DEC with Start Frequency = 1 Hz, Stop Frequency = 100 kHz, and Total Points Per Decade = 101. Choose DB for the Magnitude Unit and degree (DEG) for the Phase Unit. Record the simulated magnitude and phase of V_{out} in the sheet "Step 2.2" of the Excel file "Lab 5 – Active Filter.xlsx".

B. In-lab Measurement

2.3 Based on Fig. 5, construct the measurement setup for the second-order LPF.

2.4 For the AD2, Use V+ = 5V for V_{DD} and V- = -5V for V_{SS}. Connect Scope Ch. 1 Negative (1-), Scope Ch. 2 Negative (2-), GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line. For the Op-Amp, connect its GND (pin 4) to the V- (-5 V).

2.5 Connect the Waveform Generator (W1) and Scope Ch. 1 Positive (1+) to the input V_{IN} of the LPF and connect Scope Ch. 2 Positive (2+) to the output (the pin 6) of the TLV2371.

2.6 **Frequency Response:** In Waveforms, use the Network Analyzer tool and set Wavegen (W1) to generate a sine wave with Amplitude = 100 mV and Offset = 0 V. For frequency, set Scale = Logrithimc, Start = 1 Hz, Stop = 100 kHz, Samples = 501. Measure and record the measured magnitude and phase versus frequency characteristics of the voltage gain in the sheet "Step 2.6" of the Excel file "Lab 5 – Active Filter.xlsx".

C. Questions for Part 2:

For the second-order low-pass filter designed, answer the following questions with simulated and measured data, and discuss any discrepancy between the simulation and measurement results

Q2. (20 Points) Derive the transfer function and calculate the low-frequency gain. Verify the calculated gain using the simulated data obtained in Step 2.2 and the measured data obtained in Step 2.6, respectively.

Q3. (20 Points) Calculate (1) the pole frequency f_o, (2) the cut-off frequency (or -3dB frequency) f_c, (3) the pole quality factor Q, (4) the peak value of the magnitude of the transfer function, and (5) the frequency f_{max} where the peak value of the magnitude of the transfer function happens. Verify the calculated results using the simulated data obtained in Step 2.2 and the measured data obtained in Step 2.6, respectively.

Part 3: Second-order Band-pass Filter

A. Pre-lab Simulation

3.1 Construct the second-order band-pass filter (BPF) as shown in Fig. 6 using an operational amplifier TLV2371IP, two 240 kΩ resistors, and two 1 nF capacitors, respectively. Here VIN provides the AC signal input for this second-order BPF. The DC and AC value of the AC voltage source VIN are set to 0 V and 1 V, respectively.

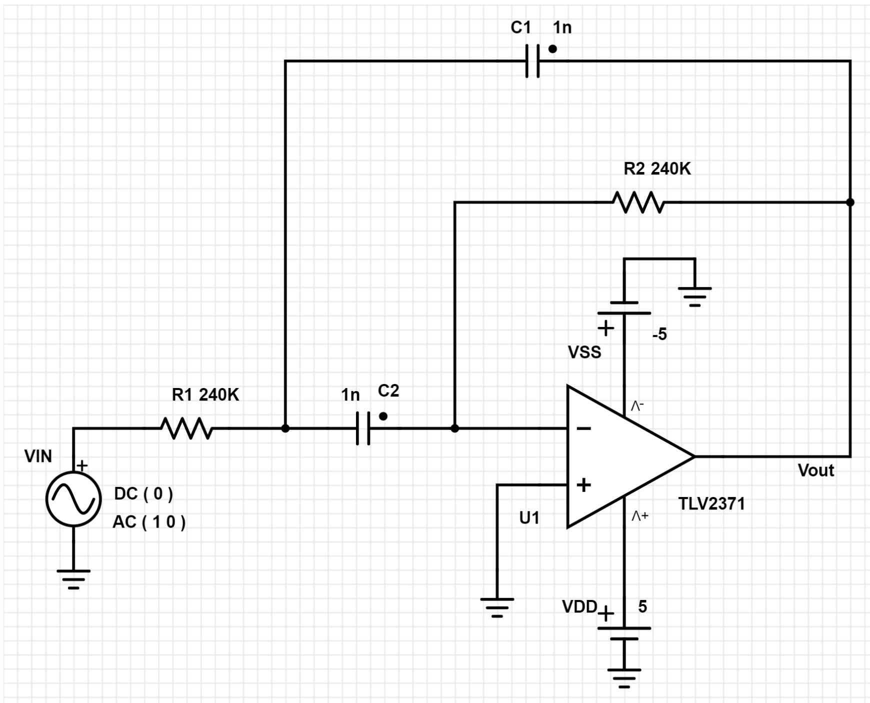

Fig. 6 Schematic diagram of the second-order band-pass filter

3.2 **Frequency Response:** Conduct AC analysis to obtain V_{out} at the output of Op-Amp TLV2371. Set the Sweep Type in DEC with Start Frequency = 1 Hz, Stop Frequency = 100 kHz, and Total Points Per Decade = 101. Choose DB for the Magnitude Unit and degree (DEG) for the Phase Unit. Record the simulated magnitude and phase of V_{out} in the sheet "Step 3.2" of the Excel file "Lab 5 – Active Filter.xlsx".

B. In-lab Measurement

3.3 Based on Fig. 5, construct the measurement setup for the second-order BPF.

3.4 For the AD2, Use V+ = 5V for V_{DD} and V- = -5V for V_{SS}. Connect Scope Ch. 1 Negative (1-), Scope Ch. 2 Negative (2-), GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line. For the Op-Amp, connect its GND (pin 4) to the V- (-5V).

3.5 Connect the Waveform Generator (W1) and Scope Ch. 1 Positive (1+) to the input V_{IN} of the LPF and connect Scope Ch. 2 Positive (2+) to the output (the pin 6) of the TLV2371.

3.6 **Frequency Response:** In Waveforms, use the Network Analyzer tool and set Wavegen (W1) to generate a sinewave with Amplitude = 100 mV and Offset = 0 V. For frequency, set Scale = Logrithimc, Start = 1 Hz, Stop = 100 kHz, Samples = 501. Measure and record the measured magnitude and phase versus frequency characteristics of the voltage gain in the sheet "Step 3.6" of the Excel file "Lab 5 – Active Filter.xlsx".

C. Questions for Part 3:

For the second-order band-pass filter designed, answer the following questions with simulated and measured data, and discuss any discrepancy between the simulation and measurement results

Q4. (20 Points) Derive the transfer function and calculate the center frequency gain. Verify the calculated gain using the simulated data obtained in Step 3.2 and the measured data obtained in Step 3.6, respectively.

Q5. (20 Points) Calculate (1) the center frequency ω_o, (2) pole quality factor Q, (3) two pole frequencies ω_{p1} and ω_{p2}, and (4) the 3-dB bandwidth BW = ω_{p2} - ω_{p1}. Verify the calculated results using the simulated data obtained in Step 3.2 and the measured data obtained in Step 3.6, respectively.