McMaster University

Electrical and Computer Engineering Department

EE3EJ4 Electronic Devices and Circuits II - Fall 2020

Lab. 4 Feedback Circuits

Lab Report Due on Nov. 22, 2020

Objective: To design and characterize a negative feedback amplifier and an oscillator.

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

- **Competence in specialized engineering knowledge.**
- **Ability to obtain substantiated conclusions resulting from a problem solution, including recognizing the limitations of the approach and solutions.**
- **Ability to assess the accuracy and precision of results.**

Test Equipment:

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

Components:

• Op-Amp:	1 × TLV2371		
• Transistors:	6 × NPN-BJT 2N3904	3 × PNP-BJT 2N3906	
• Resistors:	2 × 8.25 kΩ resistor	3 × 76.8 kΩ resistor	3 × 57.6 kΩ resistor
	3 × 8.06 kΩ resistor	2 × 100 kΩ resistor	2 × 240 kΩ resistor

Transistors in the circuit:

For a detailed description of these transistors, please check the following websites:

https://www.onsemi.com/products/discretes-drivers/general-purpose-and-low-vcesat-transistors/2n3904 or https://www.onsemi.com/pub/Collateral/2N3903-D.PDF

https://www.onsemi.com/products/discretes-drivers/general-purpose-and-low-vcesat-transistors/2n3906 or https://www.onsemi.com/pub/Collateral/2N3906-D.PDF

For the 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. Turn on the DC power only when you do not change the circuit connection anymore.

Part 1: Negative Feedback Amplifier

Description of the Negative Feedback Amplifier

In this lab, we design a negative feedback amplifier using a directly-coupled (DC), multi-stage operational (Op) amplifier (Amp). We then construct a feedback amplifier by connecting the output of the Op-Amp. In this section, we first characterize the Op-Amp and then the characterize the voltage gain and frequency response of the negative feedback amplifier using the feedback theory.

A. Pre-lab Simulation – Characterization of an Op-Amp

1.1 In PartSim circuit simulator, construct the OP-Amp, as shown in Fig. 1, using the differential amplifier with a current mirror load from Lab 3, and the common-emitter (CE) and common-collector (CC) amplifiers from Lab 2. Here I_x is a test current source to be used to characterize the output resistance of the Op-Amp.

1.2 Set the DC values of V_1 and V_2 = 0 V, and their AC amplitude 1 mV. Set the DC and AC values of the test current source I_x to zero. For differential mode signal, set the phases of the AC signal V_1 and V_2 to be 0° and 180°, respectively, as shown in Fig. 1. In this setting, the differential-model signal $v_{id} = V_1 - V_2 = 1\text{ mV} - (-1\text{ mV}) = 2\text{ mV}$. Conduct AC analysis to obtain the base current i_{b1} of Q1, the voltages V_{o1}, V_{o2}, and V_o at the base of Q3, the base of Q4, and the emitter of Q4, respectively. Set the sweep type in DEC with Start Frequency = 100 Hz, Stop Frequency = 100 kHz, and Total Points Per Decade = 101. Choose REAL for magnitude unit and degree (DEG) for phase unit. Record the simulated magnitudes and phases of i_{b1}, V_{o1}, V_{o2}, and V_o in the sheet "Step 1.2" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

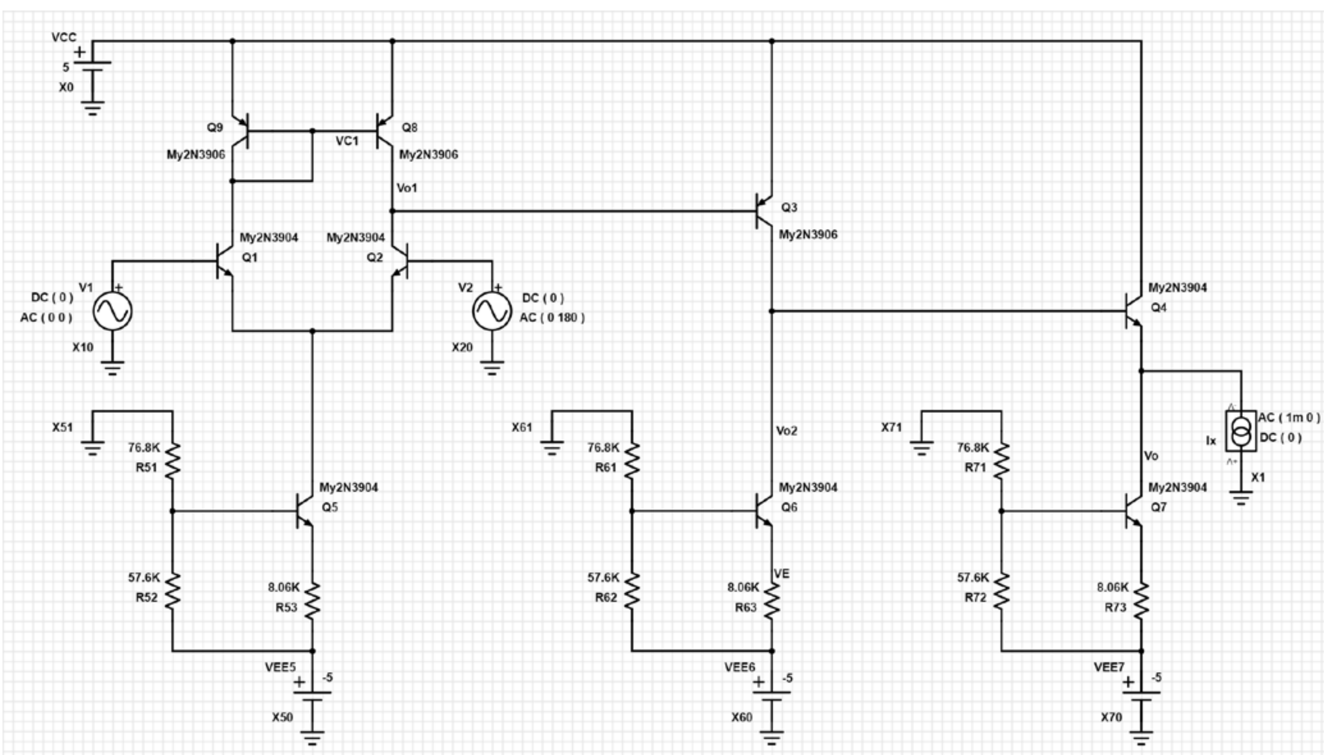

Fig. 1 Schematic diagram of the direct-coupled (DC), multi-stage operational amplifier

1.3 Set the DC and AC values of V_1 and V_2 = 0 V. Set the DC value of I_x = 0 A and AC amplitude of the test current source I_x to 1 mA. Conduct AC analysis to obtain V_o at the emitter of Q4. Set the sweep type in DEC with Start Frequency = 100 Hz, Stop Frequency = 100 kHz, and Total Points Per Decade = 101. Choose REAL for magnitude unit and degree (DEG) for phase unit. Record the simulated magnitude and phase of V_o in the sheet "Step 1.3" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

B. Pre-lab Simulation – Feedback Amplifier

1.4 In PartSim, construct the negative feedback amplifier using the circuit diagram as shown in Fig. 2, with resistance values and supply voltages specified in the figure.

1.5 For the source V1, set its DC voltage to 0 V, its AC Magnitude to 1 mV, and its AC Phase to 0. In addition, enable its Transient Source using "Sine" with Offset = 0 V, Amplitude = 1 mV, and Frequency = 1 kHz, respectively.

1.6 Conduct Transient Response simulation for V_o at the emitter of Q4 with Start Time = 0, Stop Time = 6 mS, Time Step = 25us and Max Step Size = 25us. Record the output voltage V_o versus time in the sheet "Step 1.6" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

1.7 Conduct AC analysis to obtain V_o at the emitter of Q4. Set the Sweep Type in DEC with Start Frequency = 1 kHz, Stop Frequency = 10 MHz, and Total Points Per Decade = 101. Choose REAL for magnitude unit and degree (DEG) for phase unit. Record the simulated magnitudes and phases of V_o in the sheet "Step 1.7" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

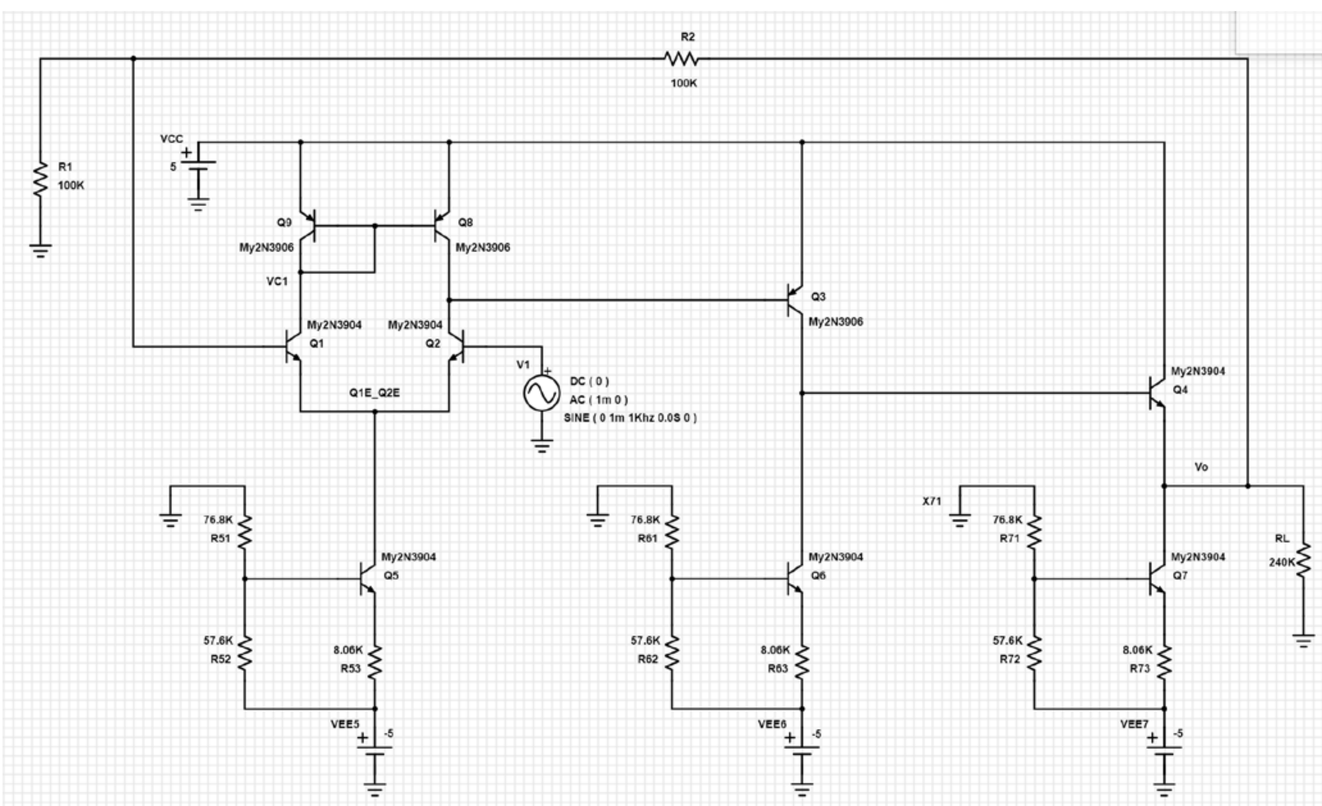

Fig. 2 Schematic diagram of the negative feedback amplifier

C. In-lab Requirement

1.8 Use the port definition diagram of the AD2 shown in Fig. 3 when setting up your circuits.

1.9 Based on Fig. 2, construct the measurement setup for the feedback amplifier using the differential amplifier designed in Lab 3, and the common-emitter (CE) and the common-collector (CC) amplifiers designed in Lab 2.

1.10 Use V+ = 5V for V_{CC} and V- = -5V for V_{EE}. Connect Scope Ch. 1 Negative (1-), GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line.

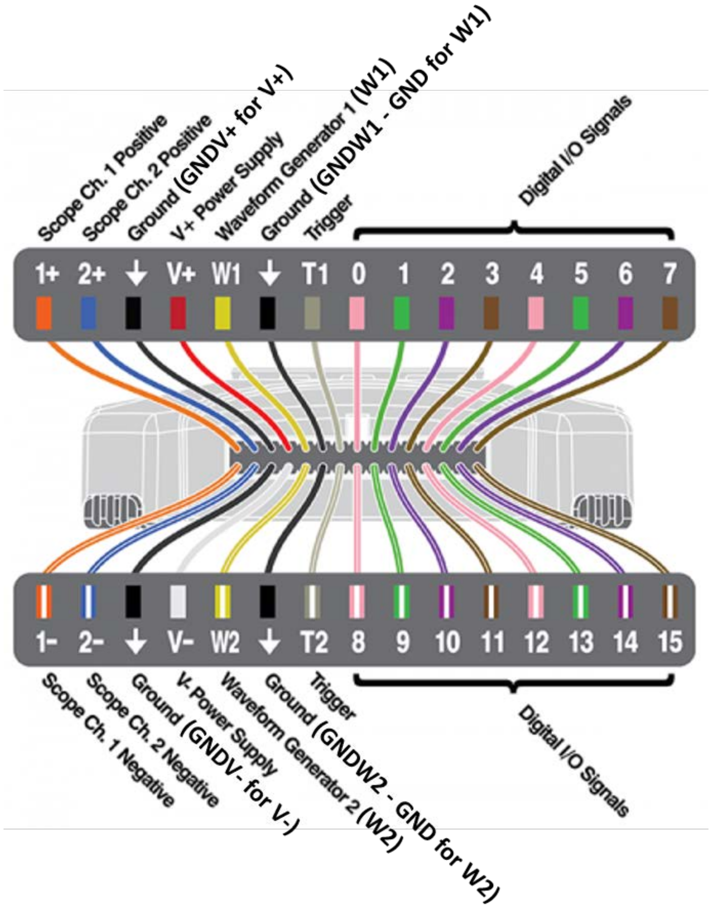

Fig. 3 Diagram for the port definition of an Analog Discovery 2 (AD2)

1.11 Connect the Waveform Generator (W1) and Scope Ch. 1 Positive (1+) to the input V_1 of the amplifier. Connect Scope Ch. 2 Positive (2+) to the output V_o of the amplifier at the emitter of Q_4. Connect both Scope Channels Negative terminals (1-) and (2-) to the ground (GND) of AD2, and also connect the V+ and V- Power Supply as shown in Fig. 2. In the WaveForms software open the Wavegen, Scope, and Supplies tools. In the Wavegen Channel 1 (W1), launch a sine wave with Frequency = 1 kHz, Amplitude = 1 V, and Offset = 0 V, and then press Run. Next, in the Supplies tab, enable the voltages with V+ = 5 V and V- = -5 V, respectively. In the Scope tab, press Run to see the input (Ch.1) and output (Ch.2) signals. Set the Base (sec/div) and Range (V/div) to be the same as these in both channels to see the signals clearly. Next, press Single to take a screenshot of the data. Finally, go to the upper toolbar and select Export to copy both input

V1 and output V_o voltage signals. Uncheck the Comments, Copy to Clipboard, and Paste these data into the sheet "Step 1.11" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

1.12 With the same wire connections as those in Step 1.11, go to Waveforms software and from the Supplies tab, enable the voltages V+ = 5 V and V- = -5 V, respectively. Next, open the Network Analyzer tool and press Run to see the input (Ch.1) and output (Ch.2) magnitude and output phase versus frequency characteristics. Set the start frequency = 100 Hz, stop frequency = 4 MHz, Scale = Logarithmic, and samples = 201/decade. Set the Wavegen Amplitude = 1 V and set Magnitude Top equal 3X and Bottom equal 0 X. Also, set Channel 1 and Channel 2 Gain to 1 X and offset to zero. Then, press Single to take a screenshot of the data. Finally, select File then Export to copy the input V_1, output V_o magnitude and phase response versus frequency characteristics. Uncheck the Comments, Copy to Clipboard, and Paste these data into the sheet "Step 1.12" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

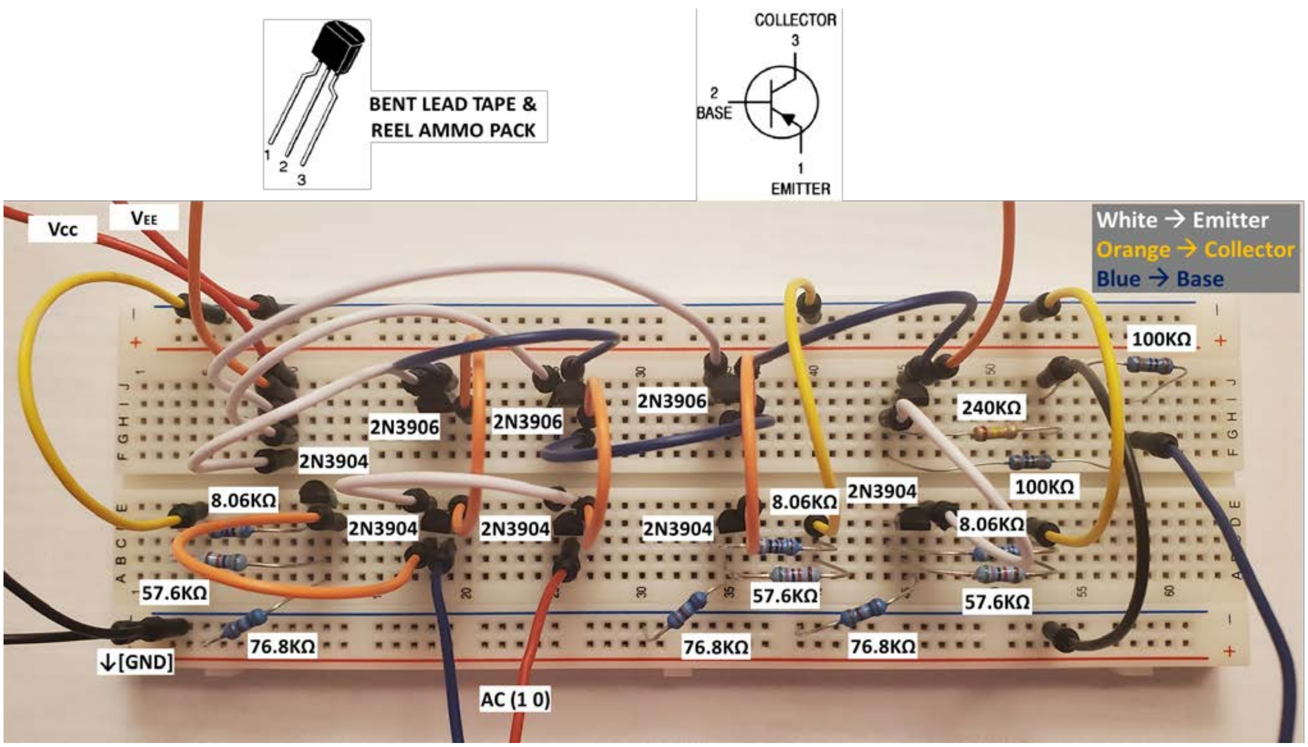

Fig. 4 Experimental setup for the negative feedback amplifier

D. Questions for Part 1

For the non-inverting amplifier designed, answer the following questions with simulated and measured data, and discuss any discrepancy between the simulation and measurement results.

Q1. (1) Based on the simulation data obtained in Step 1.2, what is the low-frequency (i.e., f = 100 Hz) voltage gain in dB for the first stage differential amplifier A_{d1}, the second state CE amplifier A_{d2}, and the third stage CC amplifier A_{d3}, respectively for the differential-mode signal? (2) What is the overall voltage gain for the differential-mode signal? (3) Which input (V_1 or V_2) is the non-inverting input of the operational amplifier? (4) What is the upper 3-dB frequency f_H of the operational amplifier?

Q2. Compare the differential-mode gain A_{d1} found in Q1 and the differential-mode gain A_d in Q3. What causes these two gains so different from each other for the same differential amplifier?

Q3. Based on the simulated results obtained in Steps 1.2 and 1.3, what are the input resistance R_{in} and the output resistance R_o of the Op-Amp?

Q4. (1) Based on the simulated and measured results from Steps 1.6 and 1.11, plot the simulated and measured output voltages V_o vs. time characteristics at 1 kHz. (2) Calculate the simulated and measured peak to peak voltage V_{pp}, the AC amplitude V_p, and the dc voltage V_{dc} of V_o, and compare the results between the simulation and measurement results.

Q5. (1) Based on the simulated and measured results from Steps 1.7 and 1.12, plot the simulated and measured voltage gain magnitude and phase vs. frequency characteristics. (2) Discuss and compare the simulated and measured results.

Q6. What kind of feedback configurations (e.g., shunt-shunt or others) is it for the circuit in Fig. 2?

Q7. Find the beta network and the feedback components β, R_{11}, and R_{22}, respectively.

Q8. Use the feedback theory and simulation results to find the voltage gain, the input impedance, and output impedance of the amplifier.

Part 2: Positive Feedback Circuit – Oscillator

Description of the Positive Feedback Circuit – Oscillator

The oscillator circuit utilizing a positive feedback network consists of an Op-Amp connected in the non-inverting configuration, with a closed-loop gain of $1+R_2/R_1$. In the feedback path of this amplifier, an RC network is connected. In this lab, we will design a positive feedback oscillator circuit using an Op-Amp (TLV2371). In order to ensure the oscillation to start, the value of R_2/R_1 should be slightly greater than 2.

A. Pre-lab Preparation

2.1 In PartSim, add an OPAMP (Power Terminals) from Components - Generic Parts - Amplifiers. Download the Op-Amp TLV2371 Spice model from the link provided on Page 1. Copy and paste the Op-Amp model from the TLV2371.LIB file to the Spice Model of the Op-Amp in PartSim as done before with the BJT models. You can also use the model in "Op-Amp TLV2371.txt" in the Lab Module on Avenue to Learn.

2.2 Re-arrange by drag and drop the pin of the Op-Amp TLV2371 in the Spice Model window to have the order: IN+, IN-, V+, V- and OUT, as shown in Fig. 5.

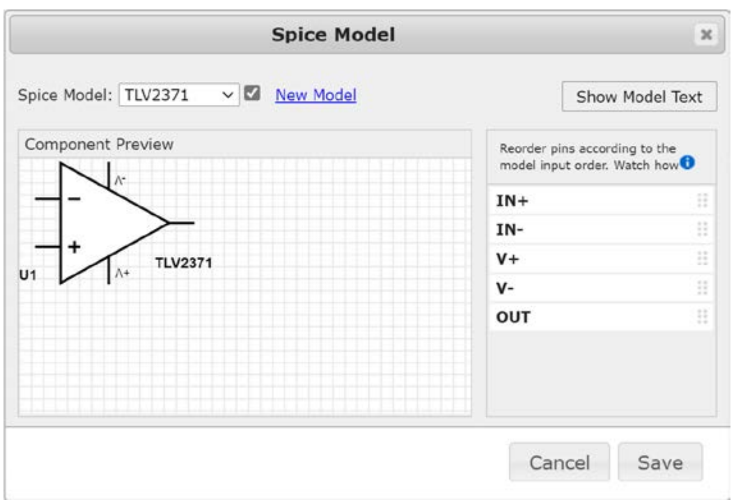

Fig. 5 Pin order of the schematic diagram for the Op-Amp TLV2371

2.3 Using the circuit diagram shown in Fig. 6, construct the oscillator circuits with the specified resistance, capacitor values, and supply voltages.

2.4 Conduct the Transient Response simulation with Start Time = 0 s, Stop Time = 5 ms, Time Step = 10 us, and Max Step Size = 20 us. Record the OP-AMP output voltage (V_{out}) vs time in the sheet "Step 2.4" of the Excel file "Lab 4 – Feedback Amplifier.xlsx". Find the settling time which is the time required for the peak value of V_{out} to reach and remain at around 5 V.

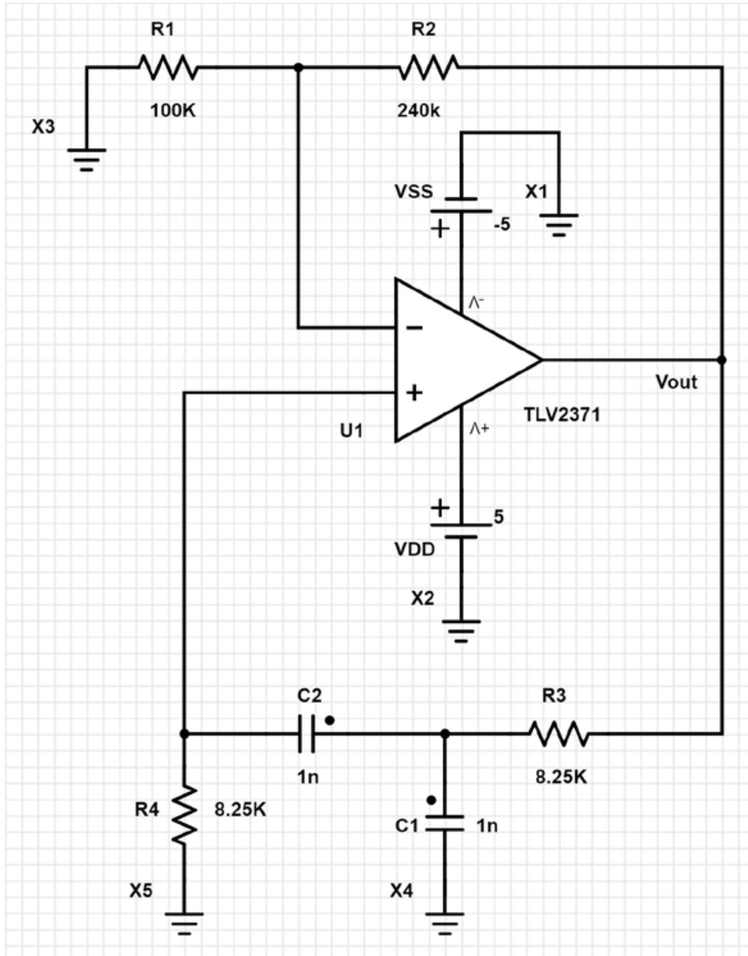

Fig. 6 Schematic diagram of the oscillator circuit

2.5 Change R_2 value to 220 kΩ, 240 kΩ, 280 kΩ, respectively, repeat Step 2.4, and record their settling times in the sheet "Step 2.5" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

2.6 With R_2 = 240 kΩ, change $R_3 = R_4$ from 8.25 kΩ to 4.02 kΩ, repeat Step 2.4, and record the output voltage (V_{out}) vs time in the sheet "Step 2.6" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

B. In-lab Requirement:

2.7 Based on the circuit diagram shown in Fig. 6, construct the measurement setup as shown in Fig. 7 for the oscillator circuit using the same settings in Step 2.3 with R_2 = 240 kΩ.

2.8 Use V+ = 5V for V_{DD} and V- = -5V for V_{SS}. Connect Scope Ch. 1 Negative (1-), GNDV+, GNDV-, GNDW1, and GNDW2 to a common ground line

2.9 Connect the Scope Ch. 1 Positive (1+) to the OP-AMP TLV2371 output. Conduct the time domain measurement using Scope 1 with the 'data' tab in the waveform to display and copy the data columns (Time, C1 (V) and C2 (V)) and 'Measurement' tab to show the measurements of the graph such as frequency and amplitude. Record the output voltage (V_{out}) versus time characteristics in the sheet "Step 2.9" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

2.10 Based on Fig. 9, change $R_3 = R_4$ from 8.25 kΩ to 4.02 kΩ, repeat Step 2.9, and record the output voltage (V_{out}) versus time characteristics in the sheet "Step 2.10" of the Excel file "Lab 4 – Feedback Amplifier.xlsx".

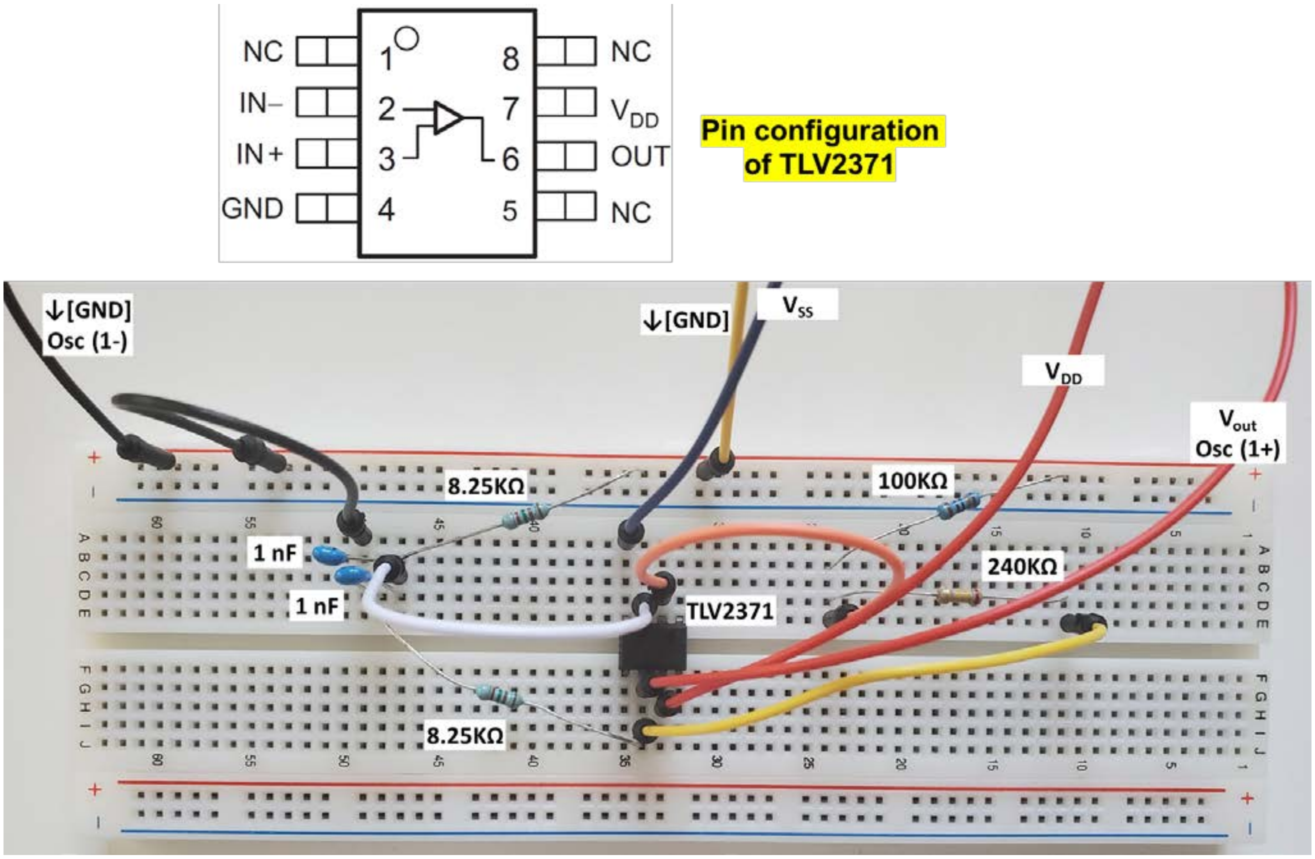

Fig. 7 Experimental setup of the oscillator

C. Questions for Part 2:

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

Q9. Find the loop gain $L(s)$, the frequency for zero loop phase, and R_2/R_1 for oscillation.

Q10. Find the characteristic equation of the system, give the expression for its pole Q and find the Q value with R_2/R_1 found in Q9.

Q11. Based on the simulated results from Step 2.5, what are the settling times for R2 = 220 kΩ, 240 kΩ, and 280 kΩ, respectively? What do you observe and explain the observed trend.

Q12. (1) Based on the setup in Step 2.4, Step 2.6, Step 2.9, and Step 2.10, plot the simulated and measured V_o. (2) Calculate the simulated and measured oscillation frequencies in each case. Compare and discuss them with the results from theory.