Lab 8: Operational Amplifiers – Part II

Objectives
This is the second part of the op-amp lab. We will be simulating and building some other op-amp circuits, including the Wien-bridge oscillator, Schmitt trigger, differentiator, and integrator.

Introduction

1. Wien-bridge oscillator
A Wien-bridge oscillator is an autonomous circuit that can derive a sinusoidal output waveform without any input. An example Wien-bridge oscillator is shown in Fig. 8-1, which consists of a feedback amplifier with an RC band-pass filter connected in the positive feedback path and a resistive divider connected in the negative feedback path. The RC network applies an attenuated, phase-shifted version of $V_{out}$ to the positive input terminal, while the negative input terminal receives an also attenuated but not phase-shifted version of $V_{out}$. The dynamics of the feedback loop in an attempt to equalize the potentials of the positive and negative terminals produces the final oscillatory waveform of the output.

The best way to understand the Wien-bridge oscillator is to invoke the “virtual ground” property of feedback amplifier. Assuming that the open-loop gain of the op amp is large, the voltage difference between the positive and negative terminals must be very small, i.e., $V_+$ and $V_-$ are essentially equipotential. Therefore we have

$$V_+ = V_{out} \left( \frac{sRC}{1 + 3sRC + s^2R^2C^2} \right) \text{ and } V_- = V_{out} \left( \frac{R_1}{R_2 + R_4} \right) \approx V_+ \quad (8-1)$$

where $R_1 = R_2 = R$ and $C_1 = C_2 = C$ are assumed. Note that the transfer function of the band-pass filter is real only when $\omega = 1/RC$, which yields $V_+ = V_{out}/3$. In turn, this leads to the following constraint for $R_3$.
and \( R_4 \) to yield oscillation

\[
\frac{R_4}{R_3 + R_4} = \frac{sRC}{1 + 3sRC + s^2 R^2 C^2} \bigg|_{\omega \approx \frac{1}{RC}} = \frac{1}{3} \quad \Rightarrow \quad R_4 = \frac{R_3}{2}
\]

(8-2)

A small-signal loop-gain analysis reveals that \( R_4 \leq \frac{R_3}{2} \) should be satisfied in order to have RHP (right half plane) poles for sustained oscillation of the Wien-bridge oscillator.

![Figure 8-2: Schmitt trigger](image)

2. **Schmitt trigger**

The Schmitt trigger is essentially a comparator in which the reference voltage is derived from a divided-down version of the output voltage. As in a comparator, the output is forced to either a positive or negative saturation limit (e.g., \( V_{POS} \) or \( V_{NEG} \) in Fig. 8-2) whenever the magnitude of \( V_{in} \) passes the reference voltage. Unlike the comparator, the Schmitt trigger “remembers” its most recent positive or negative output and holds its output voltage even when the input voltage returns to zero. We can see in Fig. 8-2 the Schmitt trigger configuration using feedback op amp as well as its transfer characteristic.

The reference voltages are determined using the following equation

\[
\pm V_R = \pm V_{OUT} \left( \frac{R_1}{R_1 + R_2} \right)
\]

(8-3)

3. **Differentiator**

The differentiator configuration is obtained by replacing the input resistor with a capacitor in an inverting feedback amplifier configuration (Fig. 7-1 of Lab 7). This circuit produces an output voltage proportional to the time derivative of the input voltage. Its voltage transfer function is given by

\[
\frac{V_{OUT}}{V_{IN}} = -sRC
\]

(8-4)

A differentiator is often intended to shape the input waveform, not to amplify or attenuate it. So we should be looking at the frequency point where the circuit gain is close to unity, i.e., \( \omega \approx 1/RC \).

4. **Integrator**

The integrator configuration is obtained by replacing the feedback resistor with a capacitor in an
inverting feedback amplifier configuration (Fig. 7-1 of Lab 7). This circuit produces an output voltage proportional to the running integral of the input voltage. Its voltage transfer function is given by

\[
\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{1}{sRC}
\]  

(8-5)

Similar to the differentiator, the frequency of operation should be close to \(\omega = 1/\text{RC}\) to avoid a too large or too small output of the circuit.

Both differentiator and integrator are fundamental building blocks for active frequency-selective filters.

**Preparation**

*Note: The supply voltages for all circuits are ±10V.*

1. **Oscillator:** Enter the schematics of the Wien-bridge oscillator into PSpice, simulate it for the case where \(C_1 = C_2 = C\) and \(R_1 = R_2 = R\). Set \(C = 10\text{nF}, R = 3\text{k}, R_4 = 1\text{k}\) and \(R_3 = 2\text{k}\). Run a transient simulation with the following parameters
   - Run to time: 101ms
   - Start saving data after: 100ms
   - Maximum Step Size: 10us
   - Skip the initial transient bias point calculation: Checked
   This should give you an output with a frequency of about 5kHz. If you would like to vary the frequency then you need to change the R value. Repeat the same simulation with \(R = 1\text{k}\) and then \(R = 10\text{k}\).

2. **Schmitt trigger:** Enter the schematics of the Schmitt trigger into PSpice, simulate it for \(R_1 = 1\text{k}\) and \(R_2 = 4.7\text{k}\). Do the following
   - Use the part called VPWL_RE_FOREVER to generate a triangular wave and use it as the input to the Schmitt trigger. Plot the output and input.
     - TSF: 1
     - VSF: 1
     - FIRST NPAIRS: 0, 0, 50u, 5, 150u, -5, 200u, 0
   - Use the part called Vsin to generate a sine wave and use it as the input to the Schmitt trigger. Plot the output and input.
     - VOFF: 0V
     - VAMPL: 5V
     - FREQ: 5kHz

3. **Differentiator:** Enter the schematics of the differentiator into PSpice, simulate it for \(R = 3\text{k}\) and \(C = 1\text{nF}\). Do the following
   - Use the part called Vpulse to generate a square wave and use it as the input to the differentiator. Plot the output and the input.
• Use the part called VPWL_RE_FOREVER to generate a triangle wave and use it as the input to the differentiator. Plot the output and input.
  o TSF: 1
  o VSF: 1
  o FIRST NPAIRS: 0, 0, 50u, 5, 150u, -5, 200u, 0

• Use the part called Vsin to generate a sine wave and use it as the input to the differentiator. Plot the output and input.
  o VOFF: 0V
  o VAMPL: 5V
  o FREQ: 5kHz

• Use the part called Vac to perform an AC sweep. Plot the output/input ratio in dB.
  o VDC=0V
  o VAC=1V
  o Set the sweep type to Logarithmic and select decades
  o Start frequency: 100
  o Stop frequency: 100K
  o Points/decade: 10

4. **Integrator**: Enter the schematics of the integrator into PSpice, simulate it for R = 3k and C = 10nF. Note that you should use a resistor in parallel to the feedback capacitor to provide DC path for the feedback network. Use a 6.2k resistor for this purpose. Do the following

• Use the part called Vpulse to generate a square wave and use it as the input to the integrator. Plot the output and the input.
  o V1: -5V
  o V2: 5V
  o TD: 0
  o TR: 1u
  o TF: 1u
  o PW: 100u
  o PER: 200u

• Use the part called VPWL_RE_FOREVER to generate a triangle wave and use it as the input to the integrator. Plot the output and input.
  o TSF: 1
  o VSF: 1
- FIRST NPAIRS: 0, 0, 50u, 5, 150u, -5, 200u, 0

- Use the part called Vsin to generate a sine wave and use it as the input to the integrator. Plot the output and input.
  - VOFF: 0V
  - VAMPL: 5V
  - FREQ: 5kHz

- Use the part called Vac to perform an AC sweep. Plot the output/input ratio in dB.
  - VDC=0V
  - VAC=1V
  - Set the sweep type to Logarithmic and select decades
  - Start frequency: 100
  - Stop frequency: 100K
  - Points/decade: 10

**Procedure**

You need to perform the same experiments in lab as you did in the Preparation section.

Use the program `freqlog.vi` to obtain the frequency response (Bode plot) in magnitude for the integrator and differentiator circuits. The plots should be similar to the ones you measured from the AC sweep.

**Analysis**

1. Re-derive the equations of (8-1) to (8.5) of the circuits studied in this lab by hand.
2. What is the constraint for $R_3$ and $R_4$ to yield oscillation when the assumption of $R_1 = R_2$ and $C_1 = C_2$ in (8-1) do not hold in general?

**Thoughtful Questions**

1. What output do you expect from a differentiator with a DC input?
2. What output do you expect from an integrator with a DC input?
Lab 8 Report Instructions

Prelab: you need to have a total of 13 plots to turn in as your Prelab:

- the output for the oscillator for each of the three different values of R,
- two plots for the Schmitt trigger,
- four plots for the differentiator,
- and four plots for the integrator.

Lab report: besides the general guidelines, report the following for this lab:

- The lab report should be segmented into 4 parts:
  - Wien-bridge oscillator
  - Schmitt trigger
  - Differentiator
  - Integrator

- Each part should be comprised of
  - the same 13 plots from your measurement,
  - and your analysis/explanation of the results.

- In addition
  - Plot frequency in kHz (y-axis) vs. resistance in kΩ (x-axis) with your measurement results from part 1 for the Wien-bridge oscillator.
  - Compare the AC sweep results from part 3 and part 4 with the Bode plots obtained with freqlog.vi for the differentiator and integrator, respectively.

- Answer the questions in the Analysis and Thoughtful Questions.