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

Experiment 10: Opamp based Sinusoidal Oscillators and Astable Multivibrator

(Ver 2, Oct 19, 2021)

Introduction

In this experiment we shall study Opamp based RC sinusoidal oscillators and astable multivibrators. All these circuits are made using general Opamps and RC circuits.

Part A – Wien-bridge Oscillator

1.1 Sinusoidal Oscillations - Basic Principle

All sinusoidal oscillators are made of two parts, viz. a voltage amplifier and a frequency-selective circuit (or a bandpass filter). Sustained oscillations are obtained when the loop gain $A\beta = 1$, i.e. $|A\beta| = 1$ and the phase of $(A\beta) = 0^o$ or 360^o. In the above equation, β is the transfer function of the bandpass filter and A is the voltage gain of the circuit. At the oscillation frequency f_o, the phase of the loop gain should be zero and the magnitude of the loop gain should be unity. This condition is called the Barkhausen criterion. Sustained oscillations are obtained only when the above two conditions of gain and phase are satisfied.

1.2 Basic Wien-bridge Oscillator

Circuit diagram of the basic Wien-bridge oscillator is shown in Fig.1. Wien-bridge oscillator is a very popular circuit and is very widely used for obtaining sinusoidal oscillations in the low to medium frequency range (a few Hz to tens of kHz).

The circuit of Fig. 1 has two sections, viz. a gain section made up of a non-inverting amplifier with (resistors R_2 and R_1 for gain), and a bandpass filter circuit made up of the RC Wien network. At $\omega_o = 1/RC$, the transfer function of the bandpass filter will be (1/3) with zero phase angle. Hence, the circuit will work as an oscillator if the voltage gain = +3 V/V. For sustained oscillations, R_2/R_1 should be slightly > 2.

Circuit details - Opamp: UA741
Circuit values: +Vcc = +12 V, -Vcc = -12 V; R2 = 10 kΩ, R1 = 4.7 kΩ, R = 4.7 kΩ, C = 0.1 μF

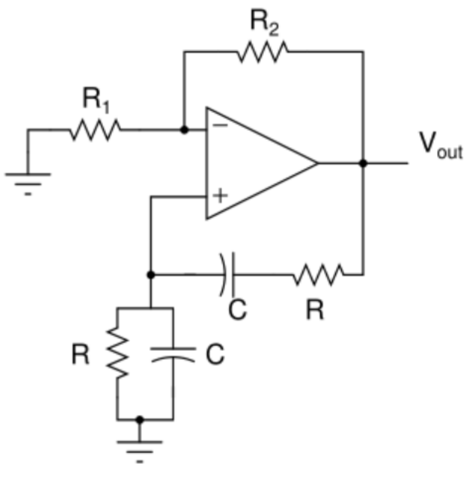

Fig.1 Basic Wien-bridge oscillator

One of the problems of the above circuit is that of amplitude stabilization. In the basic circuit of Fig.1, it is difficult to maintain sustained oscillations with a stable amplitude. This is because of the fact that for sustained oscillations the voltage gain of the non-inverting amplifier must be slightly greater than 3. However, if the above condition is over satisfied the sinusoidal output will be distorted.

1.2 NGSPICE Simulations

Simulate the above basic Wien-bridge oscillator circuit with the given circuit values. Use the model file of the 741 Opamp (UA741.txt). Hint: Use **.tran** analysis (.tran TSTEP TSTOP TSTART). If TSTART is not specified the default value of zero is used. By specifying a TSTART value we will be able to select the time interval for the plot. In this experiment, it is useful to specify the required TSTART value to plot the time segment of interest.

1.2.1 Interesting Observations through Simulations

A sinusoidal oscillator may be thought as the electrical equivalent of the simple harmonic motion in mechanics. In a sinusoidal oscillator circuit, there are no inputs, except for the DC power supply. One common confusion/query is figuring out how the oscillations start without any inputs. This scenario can be seen through NGSPICE simulations by choosing proper values for TSTEP, TSTOP and TSTART. Initially, try **.tran** analysis with smaller TSTOP values to see the onset of oscillations. Later use larger TSTOP values to see sustained oscillations.

1.3 Wien-bridge Oscillator with Amplitude Stabilization

One of the problems/observations you must have faced while doing the NGSPICE simulations of the basic Wien-bridge oscillator is that for $R_2/R_1 > 2$, the V_{out} amplitude levels get saturated. Hence, we need to design some scheme to stabilize the V_{out} amplitude at the desired level. Several methods are used for amplitude stabilization. The strategy used in all these methods is to introduce some non-linearity in the feedback resistor such that when V_{out} amplitude exceeds a pre-defined value, the gain of the amplifier reduces. Such a scheme can prevent V_{out} levels getting saturated.

Fig.2 gives a modified version of Fig.1 with a simple amplitude stabilization scheme. Notice the two diodes, D_1 and D_2 used in the feedback path across R_{2B}. At small amplitudes of V_{out}, the diodes D_1 and D_2 would be off. However, when the V_{out} amplitude increases above a pre-defined value, the diodes turn own thereby reducing overall R_2 value, thus keeping V_{out} levels at the desired level. In the experiment, we shall use $R_1 = 4.7$ kΩ, $R_{2A} = 6.8$ kΩ and $R_{2B} = 3.3$ kΩ. We shall use signal diodes for D_1 and D_2.

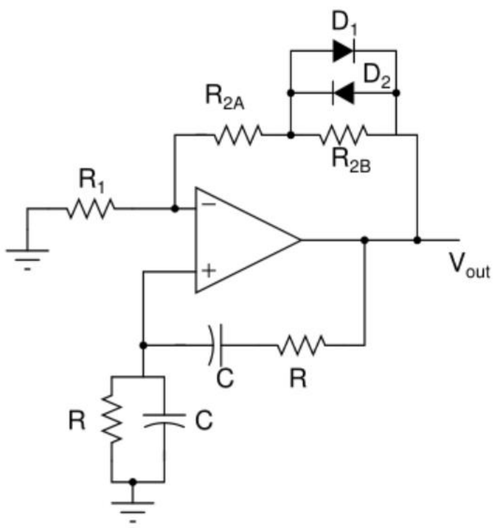

Fig.2 Wien-bridge oscillator with amplitude stabilization

1.3 NGSPICE Simulations

Simulate the modified Wien-bridge oscillator circuit of Fig.2. Use R_1 = 4.7 kΩ, R_{2A} = 6.8 kΩ and R_{2B} = 3.3 kΩ. Verify that the V_{out} amplitude is well below the saturation limits.

Do **.tran** analysis with appropriate TSTEP, TSTOP and TSTART values.

Part B – Phase-shift Oscillator

Another RC oscillator that may be used to generate sinusoidal oscillations is the phase-shift oscillator. This circuit however, is not as popular as the Wien-bridge oscillator.

Circuit diagram of the basic phase-shift oscillator is shown in Fig.3. It consists of a negative-gain amplifier (–K) with a three-section (third-order) RC ladder network in the feedback. The circuit will oscillate at the frequency for which the phase shift of the RC network is 180°, such that the total phase shift around the loop is 0° or 360°.

A three-section RC network is the minimum number of sections (i.e., lowest order) that is capable of producing a 180° phase shift at a finite frequency. For oscillations to be sustained, the value of K should be equal to the inverse of the magnitude of the RC network transfer function at the frequency of oscillation.

2.1 Basic Phase-shift Oscillator

Circuit diagram of the basic phase-shift oscillator is shown in Fig.3.

Opamp: UA741
Circuit values: +Vcc = +12 V, -Vcc = -12 V; R_{FA} = 47k kΩ, R_{FB} = 82 kΩ, R = 4.7 kΩ, C = 0.1 µF

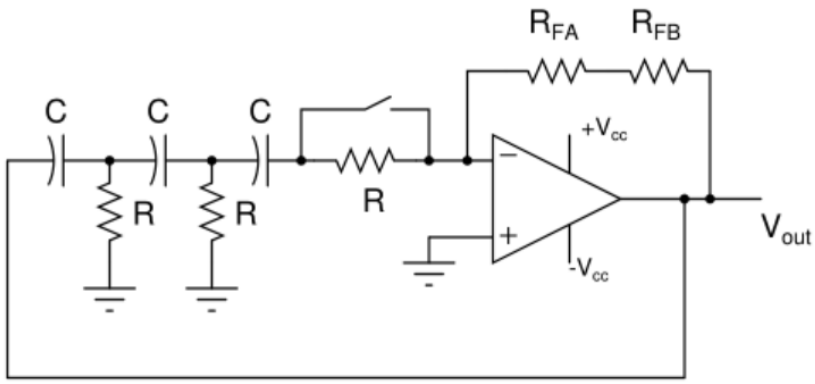

Fig.3 Basic Phase-shift oscillator

Frequency of oscillation, $f_o = \frac{1}{2\pi\, RC\, \sqrt{6}}$

2.2 NGSPICE Simulations

Simulate the basic phase-shift oscillator circuit shown in Fig.3. Use the circuit values given above. Try your simulations for two cases: Case (i): with the third resistor R connected to the V- input as shown in Fig.3. ; Case (ii): short the third resistor, but keep all the other components as they are. Once gain perform **.tran** analysis with appropriate TSTEP, TSTOP and TSTART values. You will observe that V_{out} amplitudes get saturated (in both cases).

2.3 Phase-shift Oscillator with Amplitude Stabilization

Modified circuit diagram of the phase-shift oscillator with a simple amplitude stabilization is shown in Fig.4. Here again two diodes, D_1 and D_2 are introduced across one of the feedback resistors.

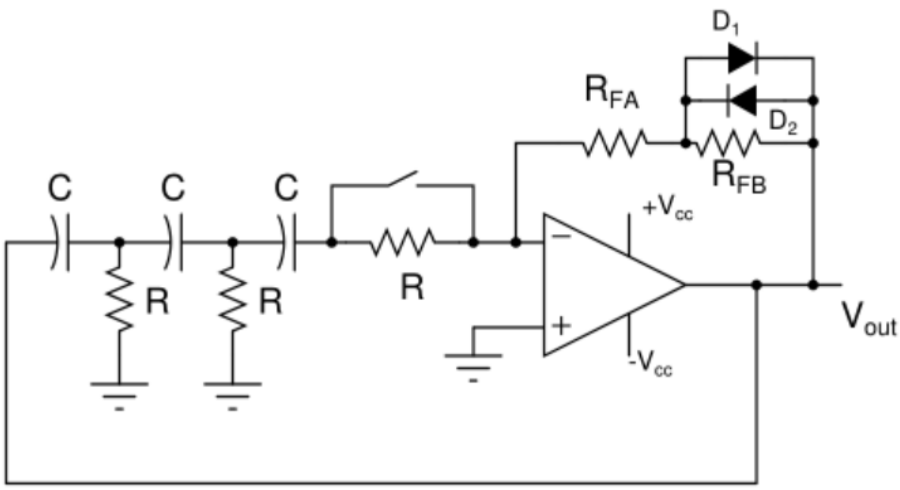

Fig.4 Phase-shift oscillator with amplitude stabilization

2.2 NGSPICE Simulations

Simulate the modified phase-shift oscillator circuit shown in Fig.4. Use the circuit values given above. Perform **.tran** analysis with appropriate TSTEP, TSOP and TSTART values. Verify that V_{out} amplitudes are well below the Opamp saturation limits.

Part C – Astable Multivibrator

3.1 Oscillators and Multivibrators

The sinusoidal oscillators we studied in this experiment, viz. Wien-bridge oscillator and Phase-shift oscillator, employed the Opamp as an amplifier with a frequency-selective circuit and positive-feedback to obtain a sinusoidal signal. These circuits come under the category of linear oscillators as the Opamp is always operating in the linear region. Opamps can also be used to generate square and triangular waveforms which come under the category of nonlinear oscillators or function generators. These are called nonlinear oscillators because the Opamp outputs are driven from one extreme to the other. Thus, these circuits operate in both linear and nonlinear regions. These types of circuits are called multivibrators. The word ‘multivibrators’ implies waveforms with multiple vibrations or frequency components. This is in contrast with the linear oscillator circuits which generate only sinusoids at a single frequency.

3.2 Astable Multivibrator

3.2.1 Astable Multivibrator – at lower frequencies

Astable multivibrators are circuits that generate square/pulse waveforms. The word astable refers to free-running or quasi-stable operation. Designing these circuits using Opamps is quite straight forward and are used commonly for applications, typically up to a few kHz. Because of the large excursions of the output waveforms (from approximately +Vcc to -Vcc), the slew-rate limitations of the Opamps can be easily observable. We shall first study an astable multivibrator at a lower frequency and then shall operate it at larger frequencies to appreciate the slew rate limitations.

Circuit diagram of the astable multivibrator used in our experiment is shown in Fig.5. The circuit also employs two Zener diodes, connected back-to-back, at the output to limit the V_{out} swings. Because of the symmetry of the circuit, V_{out} will be a symmetrical square wave signal, with $T_H = T_L = \ln 3\ RC$, where T_H and T_L are the output waveform pulse widths corresponding to the high and low pulse intervals respectively.

We shall also use a few terms/nomenclatures, such as V_{OH}, V_{OL}, V_{IH} and V_{IL}.

V_{OH} : Output high-level voltage ; V_{OL} :Output low-level voltage

V_{IH} : Input high-level voltage) ; V_{IL} : Input low-level voltage

Opamp: UA741
Circuit values: +Vcc = +12 V, -Vcc = -12 V; R_1 = 10k kΩ, R_2 = 10 kΩ,
Zener diodes: 5.6 V Zener diodes

Case: A
R = 4.7 kΩ, C = 0.1 μF

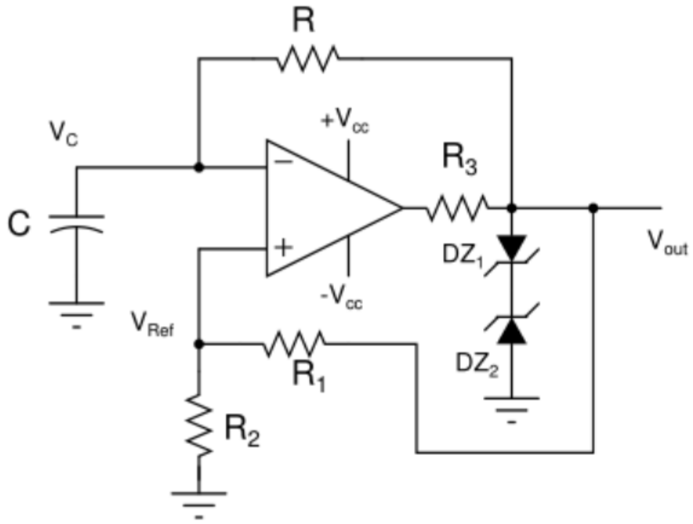

Fig.5 Astable multivibrator

3.3 NGSPICE Simulations

Simulate the astable multivibrator circuit shown in Fig.5. Use the circuit values given above. Perform **.tran** analysis with appropriate TSTEP, TSTOP and TSTART values. Plot V_c and V_{out} waveforms and note down V_{OH}, V_{OL}, V_{IH} and V_{IL} values.

Note: Obtain V_{IH} and V_{IL} values from the Vc waveform, and V_{OH} and V_{OL} from the V_{out} waveform.

3.4 Astable Multivibrator – at medium frequencies

In order to study the slew rate limitations of the Opamp, we shall use the following circuit values.

Case B:

R = 4.7 kΩ, C = 0.01 μF, (all other circuit components as earlier).

Case C:

R = 4.7 kΩ, C = 0.001 μF, (all other circuit components as earlier).

3.5 NGSPICE Simulations

Simulate the astable multivibrator circuits of Cases B and C. Plot V_c and V_{out} waveforms and observe the slew-rate problem. Measure the slew rate for Case C (= dV_{out}/dt in V/μs). Compare your results with the typical slew rate values found in the UA741 data sheet.

Lab Report

1. For Experiment 10, please limit your Lab report to 3 pages, as detailed below:
   Page 1 : Wien-bridge oscillator
   Page 2 : Phase-shift oscillator
   Page 3: Astable multivibrator.
   On each page, please include your NGSPICE simulations and the learnings.
2. Deadline for Lab Report 10: Oct 24, 2021 (Sunday), 11pm.
3. 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.