8: Oscillator Circuits

ECE 3200 Electronics II
updated 21 April 2020

References

1. A. S. Sedra and K. C. Smith, Microelectronic Circuits, 7th ed., Oxford University Press, 2015.
2. W. H. Middendorf and R. H. Engelmann, *Design of Devices and Systems*, Marcel Dekker, 3rd ed., 1998. This is the current text for the ECE Senior Design Sequence. In that class you will explore design methods to turn *specifications* (what the device is supposed to do) to *parameters* (information to build the device that meets the specs, e.g. schematics and component values).

Objectives

1. To demonstrate the use of operational amplifiers in oscillator circuits.
2. To develop oscillator designs based on a set of specifications.
3. To develop an understanding of the magnitude and phase requirements for a system to oscillate.
4. To improve and further develop an ability to effectively communicate technical information via a written report.

Pre-Laboratory Assignment
(MUST BE COMPLETED INDIVIDUALLY)

As always, include a copy of the pre-lab results in your notebook.

1. Bring your active bandpass filter materials (including the lab assignment) to lab.

2. Read the introduction and section 1 of Chapter 18 in [1].

3. Review the circuit of Figure 1. Node C is the circuit output (there is no “input” - this is an oscillator!)

4. Consider the block diagram of Figure 2. This is a model of the circuit of Figure 1 in which the nonlinear limiter is replaced by a linear amplifier of gain A and the bandpass filter is represented by a frequency selective network $\beta(s)$. Derive the ratio $X_o(s)/X_s(s)$ and determine the two conditions which will cause this system to oscillate.

5. Set A_1=1V as the desired peak amplitude of the sine wave output from the oscillator.

6. Select the attenuator resistors R_1 and R_2 such that:

    a. If a sine wave of 2 A_1 volts peak-to-peak (A_1volts peak) is applied to input node D of the limiter, a square wave of volts $\frac{\pi}{36}$ A_1 peak-to-peak ($\frac{\pi}{72}$ A_1volts peak) is at output node A of the limiter.

b. The parallel combination of R_1 and R_2 should be much smaller that the input resistor R_4 of the bandpass filter; otherwise, the bandpass filter performance will be affected. An R_2 less than 60Ω is recommended.

c. To avoid a significant current drain from the op-amp, R_1 should be at least 1K.

7. Read sections 4 and 5 of chapter 18 in [1].

8. Design the circuit of Figure 3 to produce a square wave output with a period of one millisecond. The sawtooth voltage at the capacitor should be 15 volts peak-to-peak. To avoid a significant current drain from the op-amp, choose R_2 and R at least 2K each.

Procedures

1. "LINEAR" OSCILLATOR CIRCUIT CONSTRUCTION. Construct the circuit of Figure 1. Denote the center frequency of the bandpass filter as f_0. Node B is the input of the bandpass filter while node C is the output. Node D is the input to the limiter while node A is the output. Insure that there is ONLY ONE GROUND for the entire circuit. The op-amps share the same ±15 V supplies.

2. LIMITER TESTING. Remove the connections marked AB and CD. Apply a f_0 sine wave of $2\ A_1$ volts peak-to-peak between node D and ground. Display the voltages at nodes D and A on the oscilloscope. Get a hard copy. Record the peak-to-peak voltage of the square wave observed at node A and compare to the design value. Check that the square wave is 180 degrees out of phase with the input sine wave. Discuss any discrepancies with the instructor.

3. BANDPASS FILTER TEST. Disconnect the function generator and oscilloscope from the limiter. Apply a f_0 square wave with an amplitude of $\frac{\pi}{36}\ A_1$ volts peak-to-peak between input node B and ground. Display the voltages at nodes B and C on the oscilloscope. Get a hard copy. Check that the output is a f_0 sine wave of approximately $2A_1$ volts peak-to-peak and 180 degrees out of phase with the input. Discuss any discrepancies with the instructor.

4. "LINEAR" OSCILLATOR TEST. Turn off the power. Disconnect the function generator. Replace the previously removed connections between nodes AB and CD. Connect the oscilloscope to node C. Turn on the power. Verify that a f_0 sine wave of approximately $2\ A_1$volts peak-to-peak is displayed on the oscilloscope. Get a hard copy. Discuss any discrepancies with the instructor.

5. DO NOT DISASSEMBLE YOUR CIRCUIT UNTIL THE INSTRUCTOR HAS VERIFIED YOUR RESULTS.

6. ASTABLE OSCILLATOR CIRCUIT. Assemble the circuit of Figure 3. Display the voltages v_O and v_C on the oscilloscope. Verify that v_0 is a one millisecond square wave. Get a hard copy. Discuss any discrepancies with the instructor.

7. DO NOT DISASSEMBLE YOUR CIRCUIT UNTIL THE INSTRUCTOR HAS VERIFIED YOUR RESULTS.

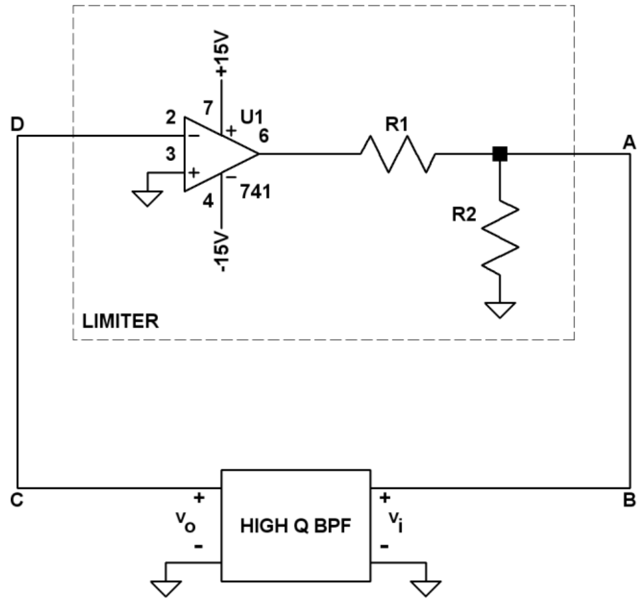

Figure 1. Active-Filter-Tuned Oscillator. See section 18.2.4 of [1] for a discussion.

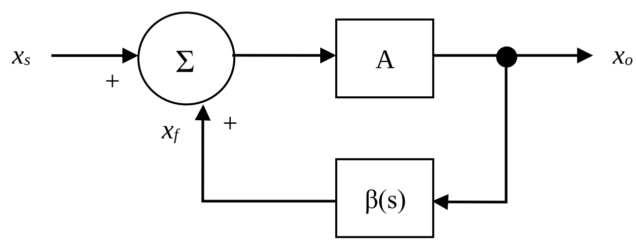

Figure 2. Linear System with Positive Feedback. See Figure 18.1 of [1] and related text for a discussion.

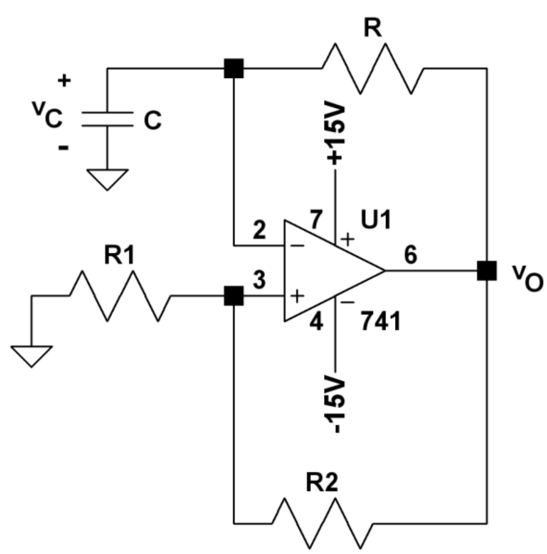

Figure 3. Astable Oscillator Circuit. See Figure 18.26 of [1] and related text for a discussion.

1. Complete the exercises in your lab notebook during lab as time permits.

Exercises

1. LIMITER OSCILLATOR QUESTIONS. Explain the origin of the $\frac{\pi}{72}$ factor that relates the size of the sine wave and the square wave. (HINT: Use a Fourier series analysis.)

2. Explain the operation of the limiter. Why must the limiter provide a phase reversal for the circuit to oscillate?

3. When the limiter output is 15 V, calculate the current flowing into the series combination of R1 and R2. Given that the output resistance of the 741 op-amp is 75Ω, what is the power dissipated in the op-amp output resistance due to the previously calculated current? Compare to the maximum rated power dissipation of the 741 (50 mW).

4. Why is the word LINEAR in "LINEAR" oscillator in quotes?

5. ASTABLE OSCILLATOR CIRCUIT QUESTIONS. Prove the following relation:

$$T = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

   where T is the period of the square wave and $\beta = R_1/(R_1 + R_2)$.

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