

## ECE 214 - Lab #5 — Schmitt Trigger and Oscillator Circuit

23 February 2016

**Introduction:** Two TL082 Operational Amplifiers (OpAmps) are used to design an oscillator. The first OpAmp is configured as a Schmitt trigger using positive feedback. The second OpAmp is configured as an inverting integrator. The scope is used to examine the signals from the oscillator in both the time domain and the frequency domain. Powering the OpAmps using a single power rail is investigated.

### Pre-Lab:

1. There are many ways to implement a Schmitt trigger. A simple implementation is shown in Figure 1.

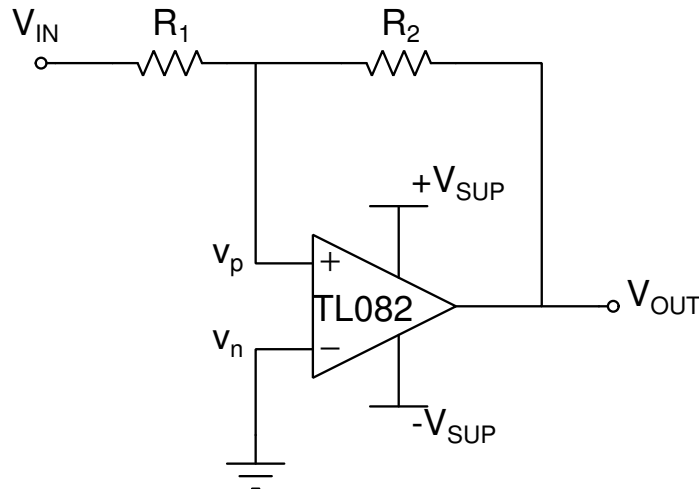


Figure 1: Schmitt trigger circuit.

This circuit uses positive feedback -  $V_{OUT}$  is connected, through resistor  $R_2$ , to the non-inverting input of the OpAmp. Note: when an Op Amp is configured with positive feedback:  $v_p \neq v_n$ . Rather  $V_{out}$  takes on one of only two values:  $+V_{SUP}$  or  $-V_{SUP}$ .  $V_{OUT} = +V_{SUP}$  when  $v_p > v_n$ , and  $V_{OUT} = -V_{SUP}$  when  $v_p < v_n$ .  $V_{OUT}$  transitions between  $-V_{SUP}$  and  $+V_{SUP}$  when  $v_p = v_n$ .

- (a) Assume the OpAmp in the above circuit is ideal.
- (b) Analyze this circuit and explain how the circuit functions when  $V_{IN}$  is varied between  $-V_{SUP}$  V and  $+V_{SUP}$  V.
- (c) Sketch the transfer characteristics as  $V_{IN}$  increases from  $-V_{SUP}$  V to  $+V_{SUP}$  V
- (d) Sketch the transfer characteristics as  $V_{IN}$  decreases from  $+V_{SUP}$  V to  $-V_{SUP}$  V

Make sure all axes on your graphs are properly labeled.

2. The circuit shown in Figure 1 can be modified to operate from a single rail voltage as shown in Figure 2. In this circuit,  $-V_{\text{SUP}} = 0 \text{ V}$  and the inverting input,  $v_n$ , is biased at  $+V_{\text{SUP}}/2$ .

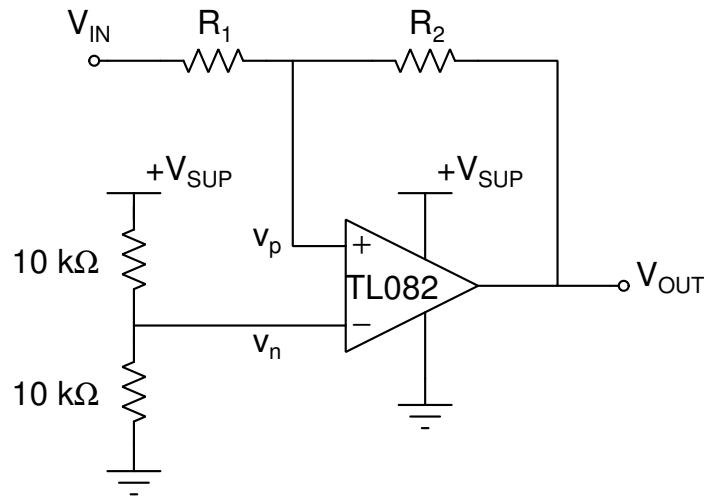


Figure 2: Modified Schmitt trigger circuit using a single rail voltage.

- (a) Assume the OpAmp is ideal. With  $+V_{\text{SUP}} = 10 \text{ V}$  determine values of resistors  $R_1$  and  $R_2$  such that:
    - i. The Schmitt trigger levels are separated by more than 3.5 V but less than 4.5 V.
    - ii. The maximum current through any resistor is less than 10 mA.
  - (b) With the chosen values of  $R_1$  and  $R_2$ , what are the two Schmitt trigger levels?
3. An oscillator is formed by connecting the output of the Schmitt trigger to the input of an inverting integrator, and connecting the output of the inverting integrator back to the input of the Schmitt trigger. This circuit is shown in Figure 3.

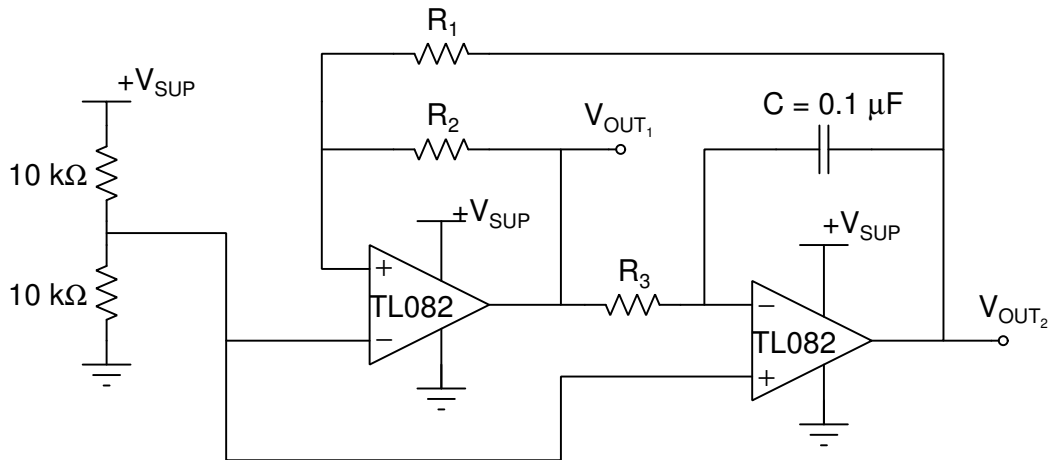


Figure 3: Oscillator circuit using a Schmitt trigger and an inverting integrator.

For the oscillator circuit shown in Figure 3:

- (a) Analyze this circuit and explain how it works.
- (b) Sketch the shape of the expected output signals  $V_{OUT1}$  and  $V_{OUT2}$  as a function of time.
- (c) Using the values of  $R_1$  and  $R_2$  calculated in Pre-Lab step 2(a), determine the value of  $R_3$  to produce an oscillation frequency of 5 kHz when  $+V_{SUP} = 10$  V.
- (d) Derive a formula that relates the oscillation frequency to the values of the components  $R_1$ ,  $R_2$ ,  $R_3$ , and  $C$ . Make sure the formula and derivation are recorded in your notebook and there is an entry in the table of contents indicating the page where the derivation and formula are located.

### Lab Procedure:

1. Build the Schmitt trigger circuit shown in Figure 2 with the resistor values you calculated in pre-lab step 2(a).
  - (a) Set the power supply to 10 V and measure the voltage before connecting it to the circuit.
  - (b) Set the function generator to produce a 10 V peak-to-peak triangular signal with a 5 V DC offset at a frequency of 500 Hz. Again, check the signal on the scope before connecting it to the circuit.
  - (c) Determine if the Schmitt trigger works by measuring  $V_{OUT}$  and  $V_{IN}$  on the scope. Record in your lab notebook what you observe on the scope and make sure to measure the trigger levels that cause the output to change.
  - (d) Do your results agree with your pre-lab calculations? If not, adjust the values of  $R_1$  and  $R_2$  so that the trigger levels are separated by at least 3.5 V but not more than 4.5 V. Record the final values of  $R_1$  and  $R_2$  in your notebook.
2. Build the oscillator circuit by adding the inverting integrator as shown in Figure 3 with the resistor value for  $R_3$  you calculated in pre-lab step 3(c).
  - (a) Measure  $V_{OUT1}$  and  $V_{OUT2}$  on the scope. Is the signal what you expected? Is the frequency what you expected? Is the duty cycle what you expected?
  - (b) Include a sketch or photograph of  $V_{OUT1}$  and  $V_{OUT2}$  in your notebook.
  - (c) If your calculations in the pre-lab were correct, this oscillator circuit should generate a  $5 \pm 0.5$  kHz output signal. Redesign the circuit if necessary to meet this specification. What was the final value of resistor  $R_3$ ?
  - (d) Use the FFT function of the scope to examine the output signal in the frequency domain. Include a sketch or photograph of the frequency response of  $V_{OUT1}$  and  $V_{OUT2}$  in your notebook.
  - (e) Do you observe both even and odd harmonics in the frequency spectrum? Do you expect both even and odd harmonics? Explain your results?

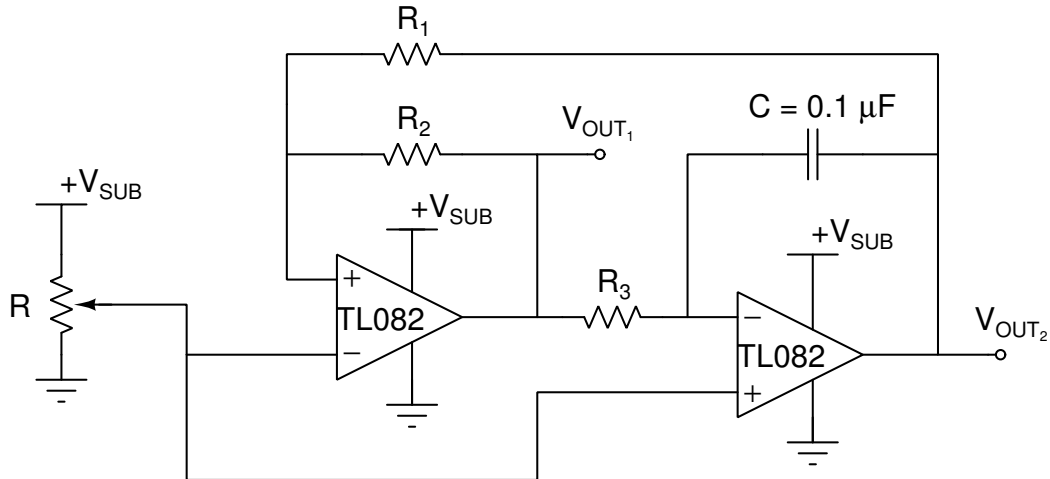


Figure 4: Oscillator circuit with an adjustable duty cycle using a Schmitt trigger and an inverting integrator.

3. If you observe even harmonics in the output signal, this is likely due to the non-ideal saturation levels in the OpAmp which results in an output signal with a duty cycle  $\neq 50\%$ . The duty cycle can be adjusted by changing the DC reference voltage at the non-inverting terminal of the inverting integrator as shown in Figure 4.
  - (a) Add the variable resistor to your circuit as shown in Figure 4.
  - (b) Adjust the DC reference voltage while observing the FFT signal on the scope. Determine the value of resistance needed to minimize the even harmonics.
  - (c) Record your final output spectrum in your notebook.
  - (d) Measure the magnitude of the first five harmonics for both the triangular- and square-wave outputs and record the results in a table in your notebook. Reference this table in your table of contents.