UMass ECE 210 – Fall 2023

Lab 6: Function Generators with RC op-amp circuits

GOALS:

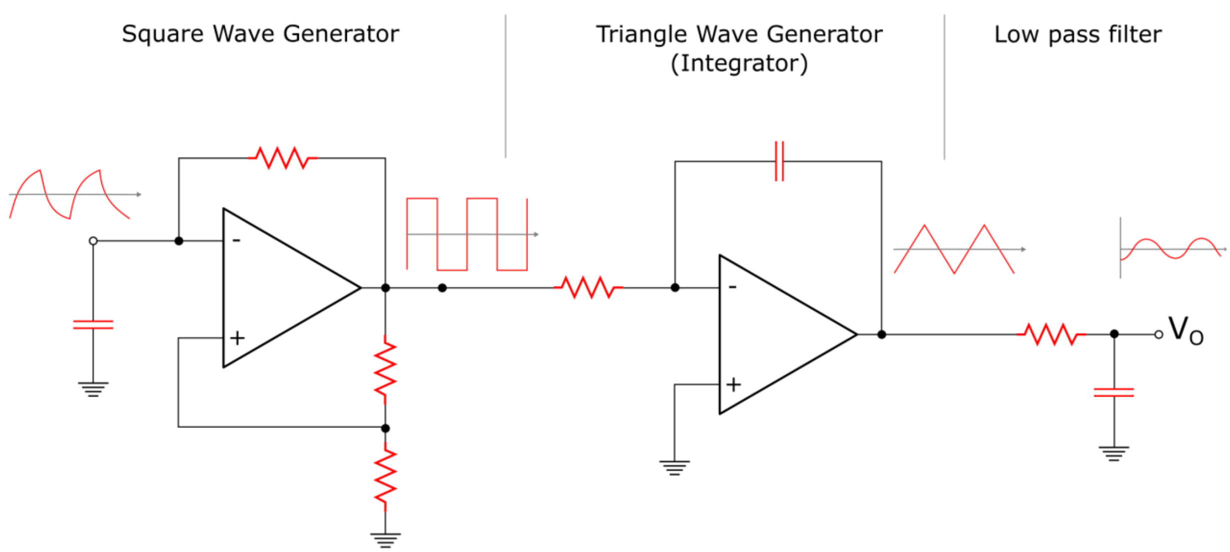
- Build Op-amp circuits for generating functions
- Create a low pass filter with RC components

DATA required for Lab report:

PLOT – Output of Square wave circuit
PLOT – Output of Triangle wave circuit
PLOT – Outputs of Sine wave circuit (filtering triangle wave)

<u>Introduction:</u>

Op-Amps can be combined with capacitors to create dynamic circuits based on the charging and discharging time of the capacitors. As an example, we will create a square wave generator in which a capacitor on the input charges and causes the output to invert very quickly to its maximum due to the very large gain, creating a square wave. Then we will add another op-amp to act as an integrator of the first stage's square wave using a capacitor on the feedback. Finally, we will filter the triangle wave with a low pass filter to create a sinewave.



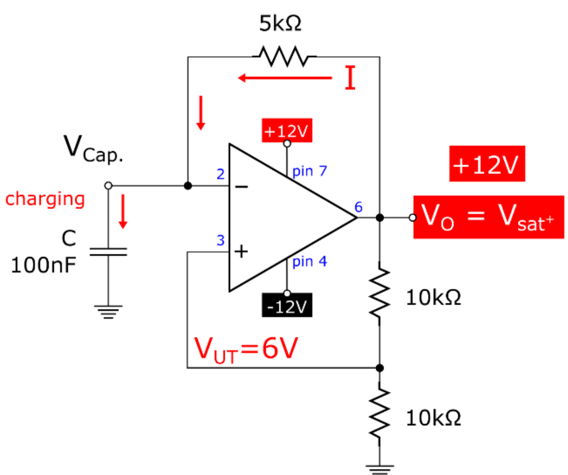
1. <u>Square wave generator:</u>

We will **NOT** use the signal generator for this lab.

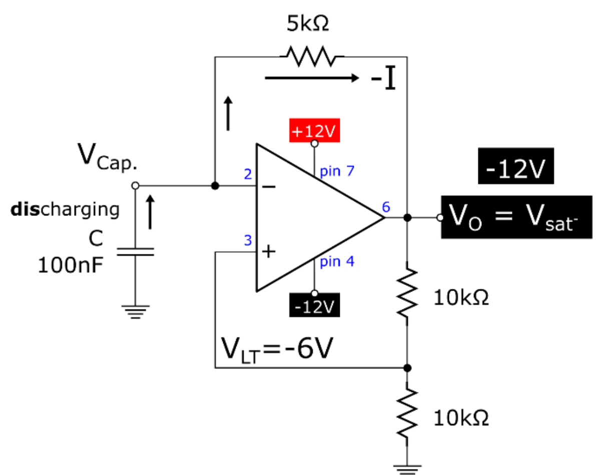
Instead, we will GENERATE a square wave with an op-amp, almost like how we tested the open-loop gain of the op-amp last week in Lab 5.

However, now we will use the charging and discharging of a capacitor on the input of the op-amp to set the period of the oscillations (not the signal generator).

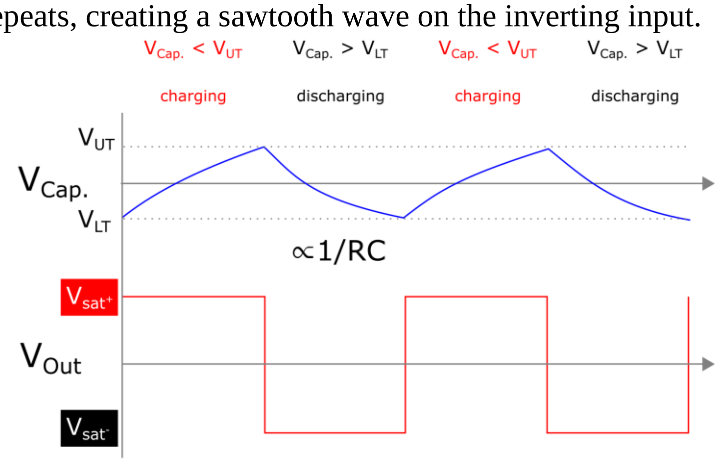
If $V_{Cap.} < V_{UT}$, feedback current charges capacitor
Increasing the voltage until it reaches
the upper threshold voltage (V_{UT}=6V)



If $V_{Cap.} > V_{LT}$, feedback current **dis**charges capacitor
Decreasing the voltage until it reaches
the lower threshold voltage (V_{LT}=-6V)



The circuit is designed to reverse the charging and discharging of the input capacitor.
If the capacitor on the inverting input is not charged, then $V_{cap} = Q/C$ will be small.
The output will be $V_{out} = A\left(\frac{V_{out}}{2} - V_{cap}\right) = V_{power}$. Saturating at the positive power supply voltage when $V_{cap} < \frac{V_{out}}{2}$, and charging the capacitor, slowly increasing its voltage.
Then when $V_{cap} > \frac{V_{out}}{2}$, the output quickly flips to the negative power supply voltage and starts slowly discharging the capacitor until it is negatively charged enough that $V_{cap} < -\frac{V_{out}}{2}$ and then the whole process repeats, creating a sawtooth wave on the inverting input.

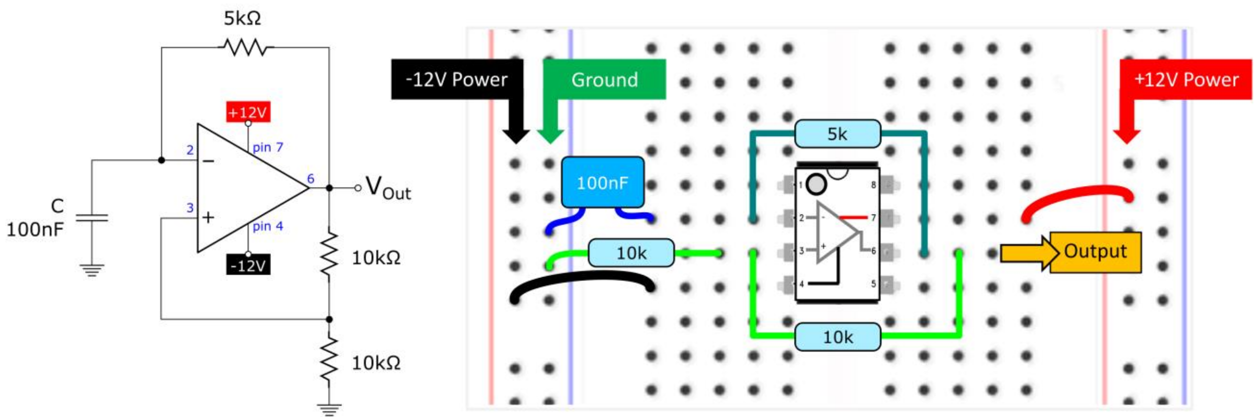


1. Square wave generator:

1. Draw the circuit diagram

2. Draw the breadboard layout of the circuit including the pins of the op-amp.

3. Assemble the circuit on the breadboard (like the op-amp circuit for Lab 5)
   (For 5kΩ, you can use 4.7kΩ or 5.2kΩ)



4. Measure and RECORD - Input waveform at $V_{Capacitor}$ (V_-, the sawtooth wave on pin 2)
   a. Voltage peak to peak?
   b. Frequency?
   c. Shape?

5. Measure and RECORD - Output waveform at V_{Out}
   a. Voltage peak to peak?
   b. Frequency?
   c. Shape?

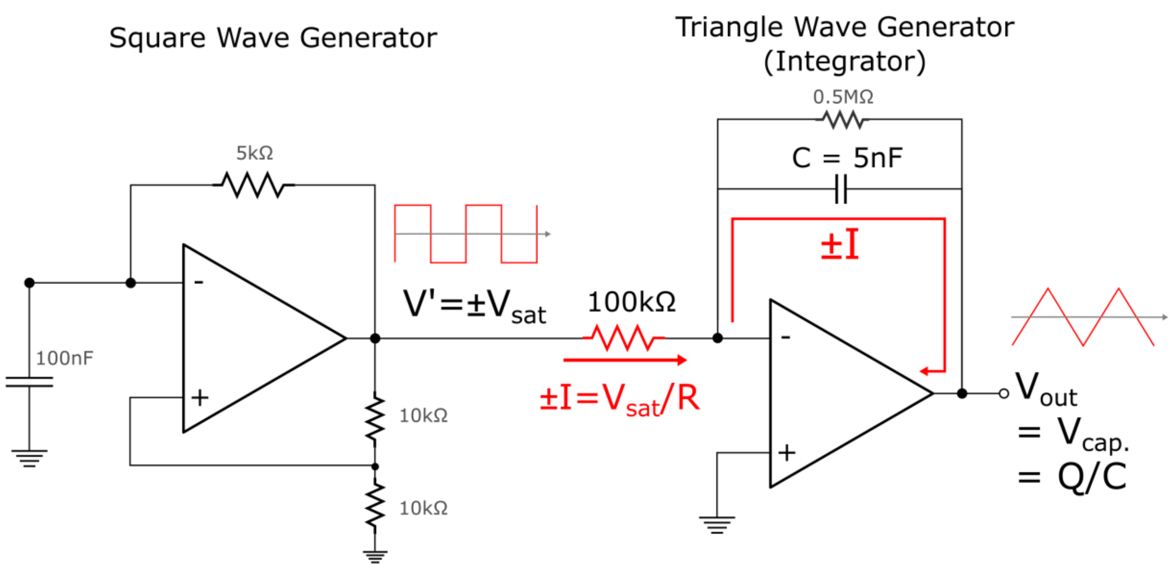
6. Measure and RECORD the very small amount of time it takes for the <u>output voltage</u> to switch from positive to negative (i.e. How sharp is the square wave???)

   Zoom in on the trace and use the cursor or estimate with the TIME/DIV

   Recall that the feedback can cross directly over the op-amp on the breadboard.
   Don't forget to connect the power supply to provide power to the op-amp.

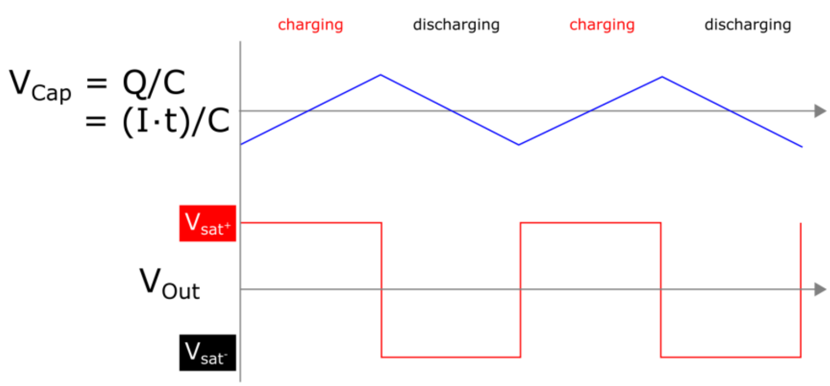
2. Triangle Wave Generator:

The next stage is an 'integrator', with a capacitor placed on the inverting feedback that charges and discharges linearly as a constant current passes through it, equal to the current passing through the input resistor. When the input changes sign the process reverses and the capacitor discharges linearly as the constant current changes sign. Note that the charging is linear due to the input resistor and not exponential, creating a triangle wave.

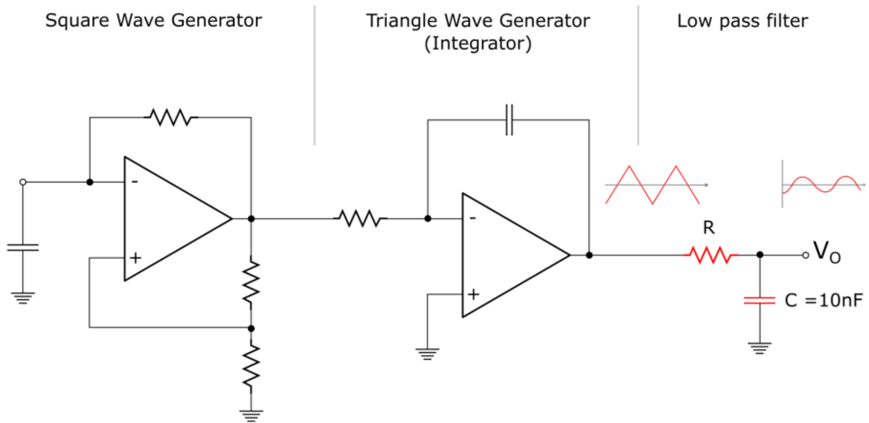


Reference: https://www.ti.com/lit/pdf/snla140 (Fig. 1-11 pg. 8, Fig. 2-4 pg. 16).
Animation: https://www.falstad.com/circuit/e-triangle.html

1. Assemble the circuit by adding another op-amp to your breadboard
2. Use a 100k resistor to send current to the 2nd stage
3. Add the ~500kΩ resistor and 4.7nF capacitor in parallel to create the integrator
   (The large resistor is needed to 'center' the integrator at long times and prevent offsets)
4. Measure and RECORD - the voltage at the input of the 2nd stage ,V' (output of 1st stage)
5. Measure and RECORD – 2nd stage output (V_{output}) including Vpp and frequency
6. In your report, work out the KCL for the integrator at the inverting input

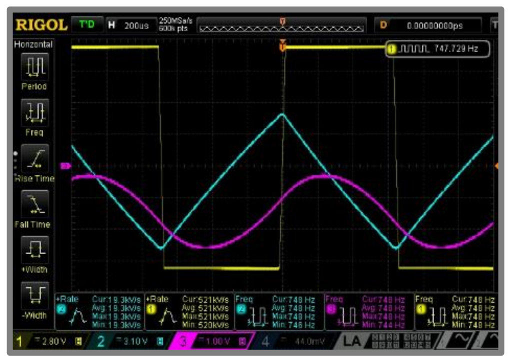


3. <u>Sinewave with low pass filter:</u>



Lastly, we will build a low pass filter to convert the triangle wave to a sinewave.

$$f = \frac{1}{2\pi RC}, \qquad \frac{1}{2\pi \cdot 150k\Omega \cdot 10nF} = 100\text{Hz}$$



1. Use a 10nF capacitor.
2. Calculate the resistance to create a low pass filter at the frequency of the input triangle wave *(Check what resistors are available in lab)*
3. Draw the breadboard layout of the circuit
4. Add the resistor and capacitor to create the low pass filter at the output of the triangle wave.
5. Measure and RECORD the input triangle wave and the output sinewave of the low pass filter. *(Note how there is still some 'triangle-ness' to your 'sinewave')*
6. Next, calculate the resistance needed to create a low pass filter at HALF the frequency of the input triangle wave.
7. Swap the resistors to create the lower low pass filter.
8. Measure and RECORD the output sinewave of the lower low pass filter. *(Note how this sinewave is purer than before but also more attenuated)*
9. Questions for Lab report discussion:
   a. Which low pass filter creates a better sine wave?
   b. What is the impedance of the capacitor at the triangle waves frequency?

REFERENCE: https://www.ti.com/lit/pdf/snla140 (Figure 2-1 page 15)

<u>LAB REPORT DUE NEXT WEEK</u>

Start outlining report. Do you have all the data you need?
Do you need to take pictures of your circuits?

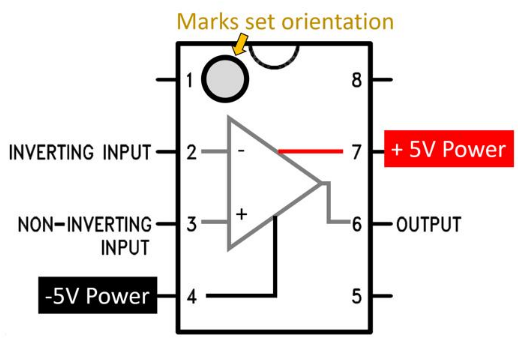
Lab Report 6 – Rubric

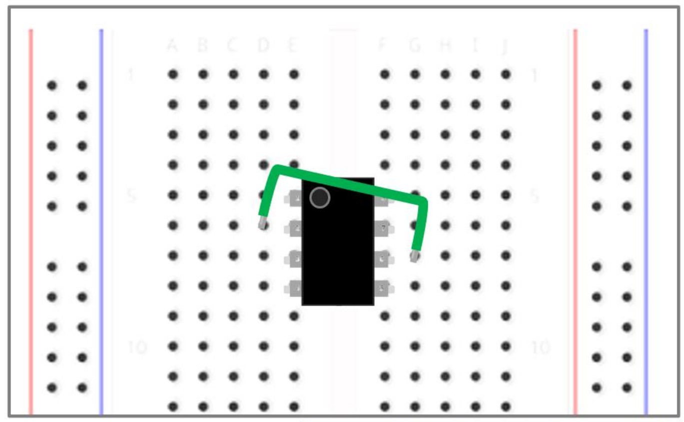
2,000-word limit   1 report/group

		Points	Grade
	Introduce and define concepts (with citations)	5	
	Motivation for experiment	5	
1	Experimental Diagram (drawing + PICTURE with labels)	5	
	PLOT – Output of **Square Wave Circuit** **(With input sawtooth wave from capacitor**)	5	
	Analysis (remember to show your work for calculations)	5	
2	Experimental Diagram (drawing + PICTURE with labels)	5	
	PLOT – Output of **Triangle Wave Circuit** (with input)	5	
	Analysis (remember to show your work for calculations)	5	
3	Experimental Diagram (drawing + PICTURE with labels)	5	
	PLOT – Output of **Sinewave Circuit from triangle wave**(with input)	5	
	Analysis (remember to show your work for calculations)	5	
	Conclusion	5	
		60	

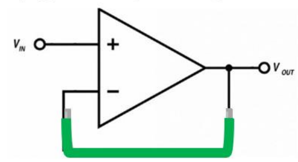
LM741 PIN DIAGRAM

LM741 PINOUT





Unity gain amplifier (Follower)



Use Header pins to make connections with clips