EXPERIMENT .NO.6
DATE:--/--/--

TRIANGULAR AND SAWTOOTH WAVEFORM GENERATORS USING OP-AMPS

AIM

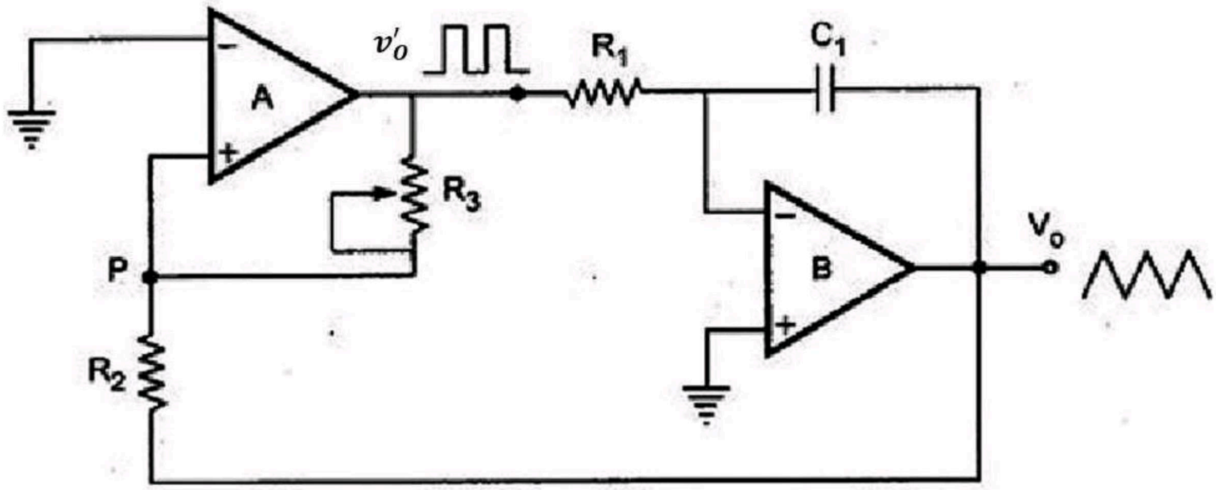
To design and setup,

1 An op-amp based triangular waveform generator with frequency of $200Hz$
2. An op-amp based sawtooth waveform generator with rise-time $7ms$ and fall-time $1ms$

THEORY

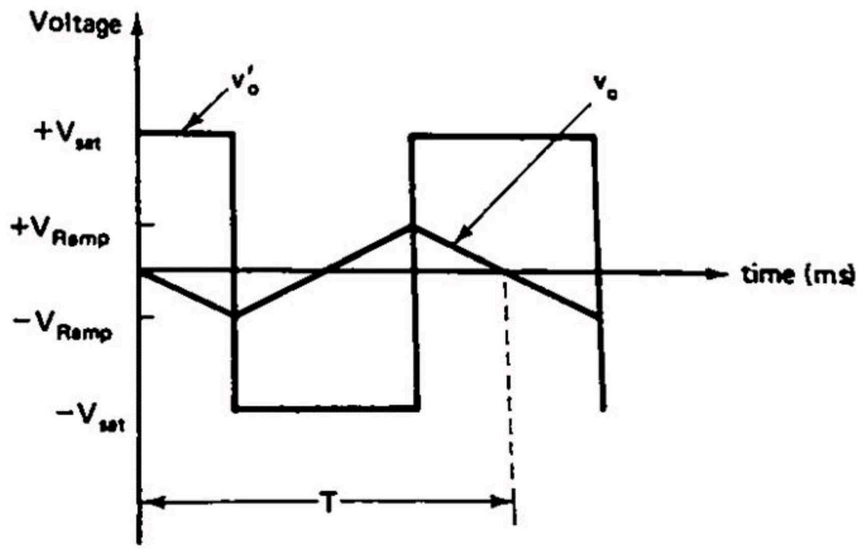
Triangular waves have equal rise and fall times. Sawtooth waves have unequal rise & fall times.

TRIANGULAR WAVEFORM GENERATOR



- It consists of a comparator (A) and an integrator (B)
- The comparator compares the voltage at P with the inverting input (-) which is at 0V

- When voltage at P goes slightly below 0V, the output of A is at $-V_{sat}$ and when it is slightly above 0V the output of A is at the $+V_{sat}$
- Assume the output is initially at $+V_{sat}$. This is the input for the integrator B. Then B's o/p will be a negative going ramp
- Thus, at one end of the voltage divider, $R_2 - R_3$ we have $+V_{sat}$ of A and at the other end we have the negative going ramp of B
- When the negative going ramp attains a certain value $-V_{ramp}$, point P becomes slightly below 0V. Then output of A becomes $-V_{sat}$. Hence output of B will begin to go in the positive direction. Output of B will increase until it reaches $+V_{ramp}$
- At this point, P is slightly above 0V and hence output of A becomes $+V_{sat}$
- This cycle then repeats



To determine the amplitude & frequency of the triangular wave:

Amplitude :

$$\frac{-V_{ramp}}{R_2} = \frac{-V_{sat}}{R_3}$$

$$\Rightarrow -V_{ramp} = -\left(\frac{R_2}{R_3}\right)(+V_{sat})$$

Similarly $+V_{ramp} = -\left(\frac{R_2}{R_3}\right)(-V_{sat})$

⇒ The **peak-to-peak o/p amplitude** of the triangular wave is, $v_O(pp) = 2\left(\frac{R_2}{R_3}\right)V_{sat}$

Time Period :

The time taken by v_O to swing from $-V_{ramp}$ to $+V_{ramp}$ = $\frac{1}{2}$ the time period = $\frac{T}{2}$

This time can be calculated by substituting, $v_i = -V_{sat}$; $v_o = v_o(pp)$ in the integrator o/p equation,

$$\Rightarrow v_O(pp) = \frac{-1}{R_1C_1}\int_0^{T/2} -V_{sat}dt = \frac{V_{sat}}{R_1C_1}\frac{T}{2}$$

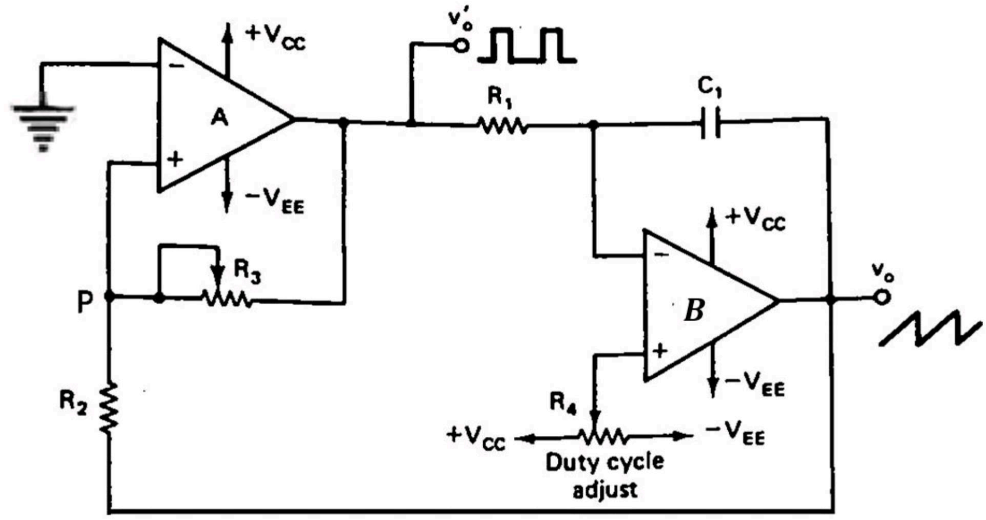
$$\Rightarrow T = 2R_1C_1\frac{v_O(pp)}{V_{sat}}$$

Substituting for $v_O(pp)$, we have $T = \frac{4R_1C_1R_2}{R_3}$ $\Rightarrow f_0 = \frac{R_3}{4R_1C_1R_2}$

Where f_0 is the frequency of oscillation.

SAWTOOTH WAVEFORM GENERATOR

The above triangular wave generator can be converted to a sawtooth generator by injecting a variable dc voltage at the noninverting terminal of the integrator B



Here, the noninverting terminal (+) of the integrator is driven by the voltage set between $+V_{CC}$ to $-V_{EE}$ by the potentiometer R_4. Depending on the R_4 setting, a certain dc level is added in the input of the integrator ***B***

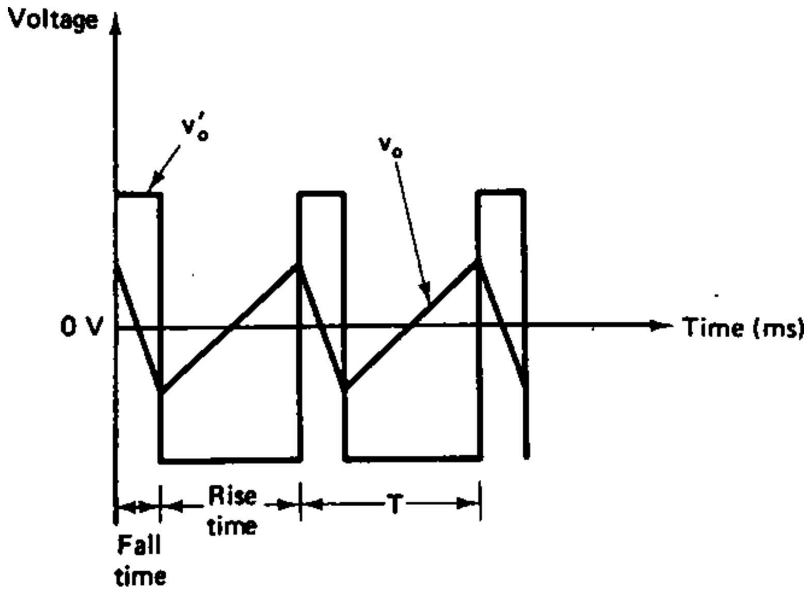
The duty cycle of the square wave is determined by the polarity and amplitude of the dc level inserted at B's non-inverting input. A duty cycle other than 50% can cause the output of B to be sawtooth.

When voltage at the noninverting input of B is negative (*i.e.*, when the wiper is moved toward $-V_{EE}$), the duty cycle is less than 50% resulting longer rise time than fall time

When voltage at the noninverting input of B is positive (the wiper is moved toward V_{CC}), the duty cycle is greater than 50% and rise time is less than the fall time

i.e., with the wiper at the center, the output of the integrator will be triangular and for any other wiper setting its output will be a sawtooth.

The frequency of the sawtooth decreases as R_4 is adjusted toward V_{CC} or $-V_{EE}$. However, amplitude is independent of R_4 setting.



DESIGN

TRIANGULAR WAVEFORM GENERATOR

Desired rise-time=fall-time= $2.5ms$

Total Time Period= $5ms \Rightarrow f_0 = \frac{1}{5ms} = 200Hz$

<u>Design of the integrator</u>:

$f_b = \frac{1}{2\pi R_1 C_1}$ the unity gain frequency of the basic integrator

Choose $f_b = 100Hz$

Let $C_1 = 0.1\mu F \Rightarrow R_1 = \frac{1}{2\pi f_b C_1} = \frac{1}{2\pi\times 100\times 0.1\mu} = 15.9k\Omega$; Use 15$k\Omega$ std

<u>Design of R_2 and R_3</u>

We have $f_0 = \frac{R_3}{4R_1C_1R_2} = 200Hz$

Take $R_2 = 10k \Rightarrow R_3 = 200 \times 4 \times 15k \times 0.1\mu \times 10k = 12k$; Use $10k\ pot$ in series with $6.8k$ Resistor

Expected peak-to-peak amplitude of triangular wave:

$$v_O(pp) = 2\left(\frac{R_2}{R_3}\right)V_{sat} \cong 2 \times \frac{10}{12} \times 13 = 21.7V$$

SAWTOOTH WAVEFORM GENERATOR

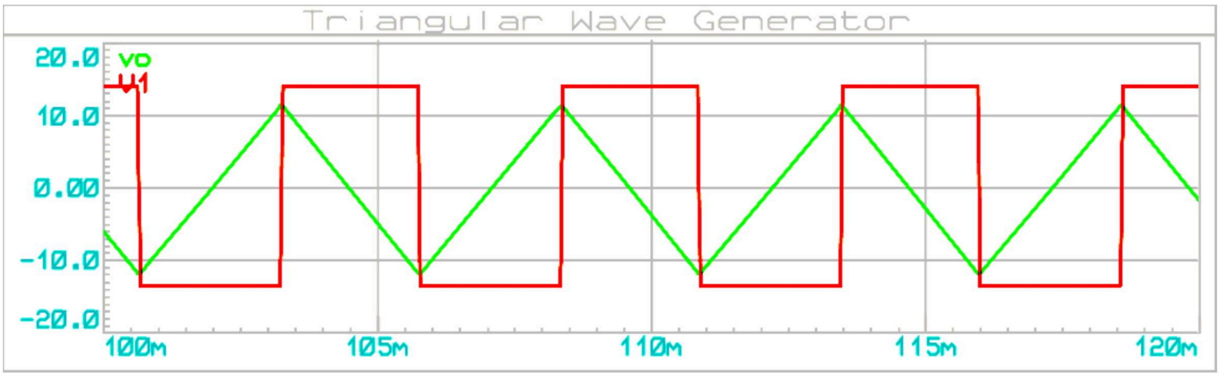
We will use the same component values as in the triangular waveform generator so that the peak-to-peak amplitude of the sawtooth wave remains the same ($\cong$ $21.7V$). Use a $100k$ pot in place of R_4. Potentiometer R_4 can be adjusted to obtain the desired rise and fall times.

PROCEDURE

TRIANGULAR WAVEFORM GENERATOR

- Setup the circuit and provide supply voltages to the op-amp
- Observe the waveforms at the output of the comparator v_O' and the output of the integrator v_O
- Adjust the pot R_2 to obtain the required triangular wave timings
- Note down the rise and fall times of the triangular waveform and the peak-to-peak amplitude

Expected Waveforms: Triangular Waveform Generator

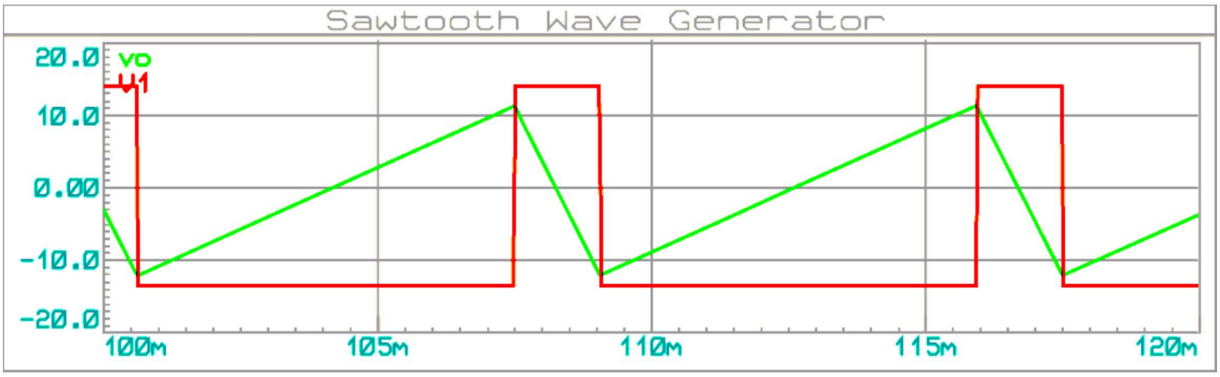


SAWTOOTH WAVEFORM GENERATOR

- Setup the circuit and provide supply voltages to the op-amp

- Observe the waveforms at the output of the comparator v'_O and the output of the integrator v_O
- Adjust the pot R_4 to obtain the required rise and fall times
- Note down the rise and fall times of the sawtooth waveform and the peak-to-peak amplitude

<u>Expected Waveforms: Sawtooth Waveform Generator</u>



OBSERVATIONS

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RESULTS

The following circuits were designed and setup using op-amp IC 741

1 An op-amp based triangular waveform generator for a frequency of $200Hz$
    - Observed Frequency =_______
    - Observed Rise-time =_______
    - Observed Fall-time =_______
2. An op-amp based sawtooth waveform generator with rise-time $7ms$ and fall-time $1ms$
    - Observed Frequency =_______
    - Observed Rise-time =_______
    - Observed Fall-time =_______