EXPERIMENT No. 10

WAVEFORM GENERATOR USING OPAMP

AIM

To set up and study square waveform, triangular waveform and sawtooth waveform generator using Op-Amp.

THEORY

Square wave oscillator

The basic square wave oscillator is based on the charging and discharging of a capacitor. Op-amps inverting input is the capacitor voltage and the noninverting input is a portion of the output fed back through resistors R_1 and R_2 (refer figure 1). When the circuit is first turned on, the capacitor is uncharged, and thus the inverting input is at 0V. This makes the output a positive maximum, and the capacitor begins to charge towards voltage at V_O through resistor R. When the capacitor voltage reaches a value equal to the feedback voltage (V_f) on the non-inverting input, the op-amp switches to the maximum negative state. At this point, the capacitor begins to discharge from $+V_f$ towards $-V_f$. When the capacitor voltage reaches $-V_f$, the op-amp switches back to the maximum positive state. This action repeats and a square wave output voltage is obtained.

Expression for period is

$$T = 2RC \ln \frac{1+\beta}{1-\beta} \qquad \text{where } \beta = \frac{R_2}{R_1 + R_2}$$

If $R_1 = R_2$, the equation for period reduces to $T = 2RC \ln 3$

The frequency of oscillation, $f = \dfrac{1}{2RC \ln 3}$

Triangular-wave oscillator

This circuit (figure 2) uses two operational amplifiers. Op-amp A_1 functions as a comparator and the op-amp A_2 as an integrator. Comparator compares the voltage at point P continuously with respect to the voltage at the inverting input; which as at ground potential. When the voltage at P goes slightly below zero, the output of A_1 will switch to negative saturation. Suppose the output of A_1 is at positive saturation $+V_{sat}$. Since this voltage is the input of the integrator, the output of A_2 will be a negative going ramp. Thus, one end of the voltage divider R_1-R_2 is at $+V_{sat}$ and the other at the negative going ramp. At time $t = t_1$, when the negative going ramp attains value of $-V_{ramp}$ the effective voltage at point P becomes slightly less than 0 V. This switches output of A_1 from positive saturation to negative saturation level $-V_{sat}$. During the time when the output of A_1 is at $-V_{sat}$, the output of A_2 increases in positive direction. At the instant $t = t_2$, the voltage at point P becomes just above 0 V, thereby switching the output of A_1 from $-V_{sat}$ to $+V_{sat}$. The cycle repeats and generates a triangular waveform.

At $t = t_1$ $\qquad \dfrac{-V_{ramp}}{R_2} = -\dfrac{+V_{sat}}{R_1} \qquad$ ie. $\qquad -V_{ramp} = -\dfrac{R_2}{R_1}\left(+V_{sat}\right)$

Similarly, at $t = t_2$ $\quad +V_{\text{ramp}} = -\frac{R_2}{R_1}\left(-V_{\text{sat}}\right)$

The peak to peak output of the triangular wave is

$$V_{\text{O(pp)}} = +V_{\text{ramp}} - \left(-V_{\text{ramp}}\right) = 2\frac{R_2}{R_1}V_{\text{sat}}$$

During the period 0-t_1, The integrator functions as below.

$$V_{\text{O(pp)}} = \frac{1}{RC}\int_0^{T/2}\left(-V_{\text{sat}}\right)dt = \left(\frac{V_{\text{sat}}}{RC}\right)\left(\frac{T}{2}\right)$$

Then, $T = 2RC\left(\frac{V_{\text{O(pp)}}}{V_{\text{sat}}}\right)$

Substituting for $V_{\text{O(pp)}}$ $\quad T = \frac{4RCR_2}{R_1}$

Then, frequency of oscillation, $f = \frac{R_1}{4RCR_2}$

Sawtooth-wave oscillator

The difference between the triangular and sawtooth waveform is that the rise time of the triangular wave is always equal to its fall time while in sawtooth wave generator, rise time may be much higher than its fall time or vice versa. The triangular wave generator can be converted to a sawtooth wave generator by injecting a variable dc voltage into the non-inverting terminal of the integrator. This can be done by using a potentiometer as shown in figure 3. When the wiper of the potentiometer is at the centre, the output will be a triangular wave since the duty cycle is 50%. If the wiper moves towards $-V$, the rise time of the sawtooth becomes longer than the fall time. If the wiper moves towards $+V$, the fall time becomes more than the rise time.

DESIGN AND CIRCUIT DIAGRAMS

Design of square wave generator

Let the frequency of oscillation be 1 kHz

Take $\beta = 0.5$ and $R_1 = R_2 = 10$ kΩ.

Frequency, $f = \frac{1}{2RC\ln 3}$ $\qquad$ Assume $C = 0.1$ µF

Then, $R = \frac{1}{2Cf\ln 3} = \frac{1}{2\times 0.1\times 10^{-6}\times 1000\times \ln 3} = 4.55$ kΩ

Select standard value of 4.7 kΩ for R.

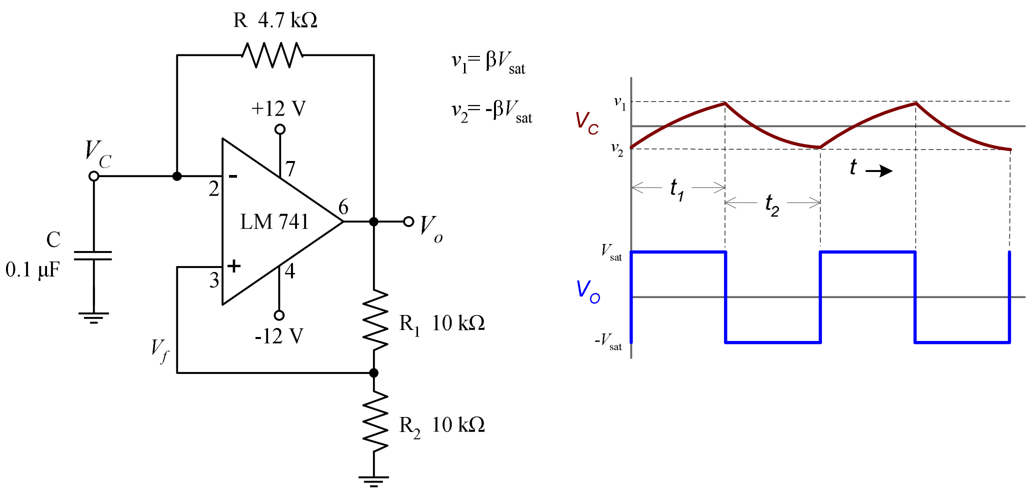

Fig 1. Square wave generator and waveforms

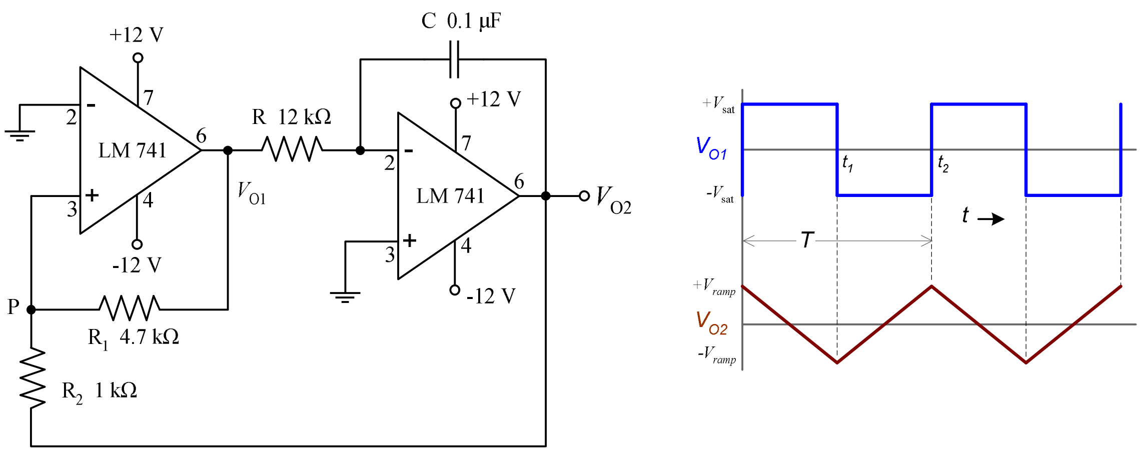

Fig 2. Triangular wave generator and waveforms

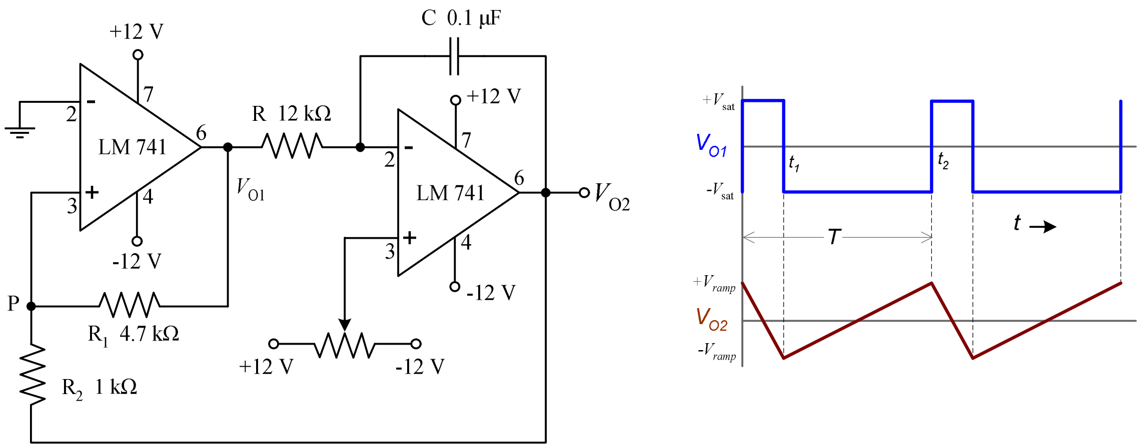

Fig 3. Sawtooth wave generator and waveforms

Design of triangular wave generator

Let the frequency of oscillation be 1 kHz

We have $f = \dfrac{R_1}{4RCR_2}$ and $V_{O(pp)} = 2\dfrac{R_2}{R_1}V_{sat}$

Since supply voltage is ±12 V, V_{sat} will be approximately 10 V

Let $V_{O(pp)}$ be 5 V; Assume R_2 = 1 kΩ.

Then $R_1 = \dfrac{2V_{sat}}{V_{O(pp)}}R_2 = \dfrac{2\times 10}{5}\times 1\times 10^3 = 4\text{ k}\Omega$

Select standard value, R_1 = 4.7 kΩ

Assume C = 0.1 μF

$$R = \frac{R_1}{4fCR_2} = \frac{4.7\times 10^3}{4\times 1000\times 0.1\times 10^{-6}\times 1\times 10^3} = 11.7\text{ k}\Omega$$

Select standard value, R = 12 kΩ

Design of sawtooth wave generator

Design is similar to that of triangle wave generator.

Select R_3 = 47 kΩ potentiometer to vary the reference voltage of second op-amp.

PROCEDURE

1. Set up the circuit after testing the components.
2. Set up the square wave generator as shown in figure and observe the output waveform and note down their amplitudes and frequencies.
3. Set up the triangular wave generator as shown in figure and observe the variation in frequencies of output waveform by varying the values of resistances R_1, R_2 *and* R_3
4. Set up the sawtooth wave generator as shown in figure and note down the rise time and fall time.
5. Move the wiper of the potentiometer in both directions and observe the changes taking place in the waveform.

RESULT

Circuits of square wave generator, triangular wave generator and sawtooth wave generator are designed, setup and waveforms observed.