Triangular Wave Generator

Recall that the output waveform of the integrator is triangular if its input is a square wave. This means that a triangular wave generator can be formed by simply connecting an integrator to the square wave generator. The resultant circuit is shown in Figure 1. This circuit requires a dual op-amp, two capacitors, and at least five resistors. The frequencies of the square wave and triangular wave are the same.

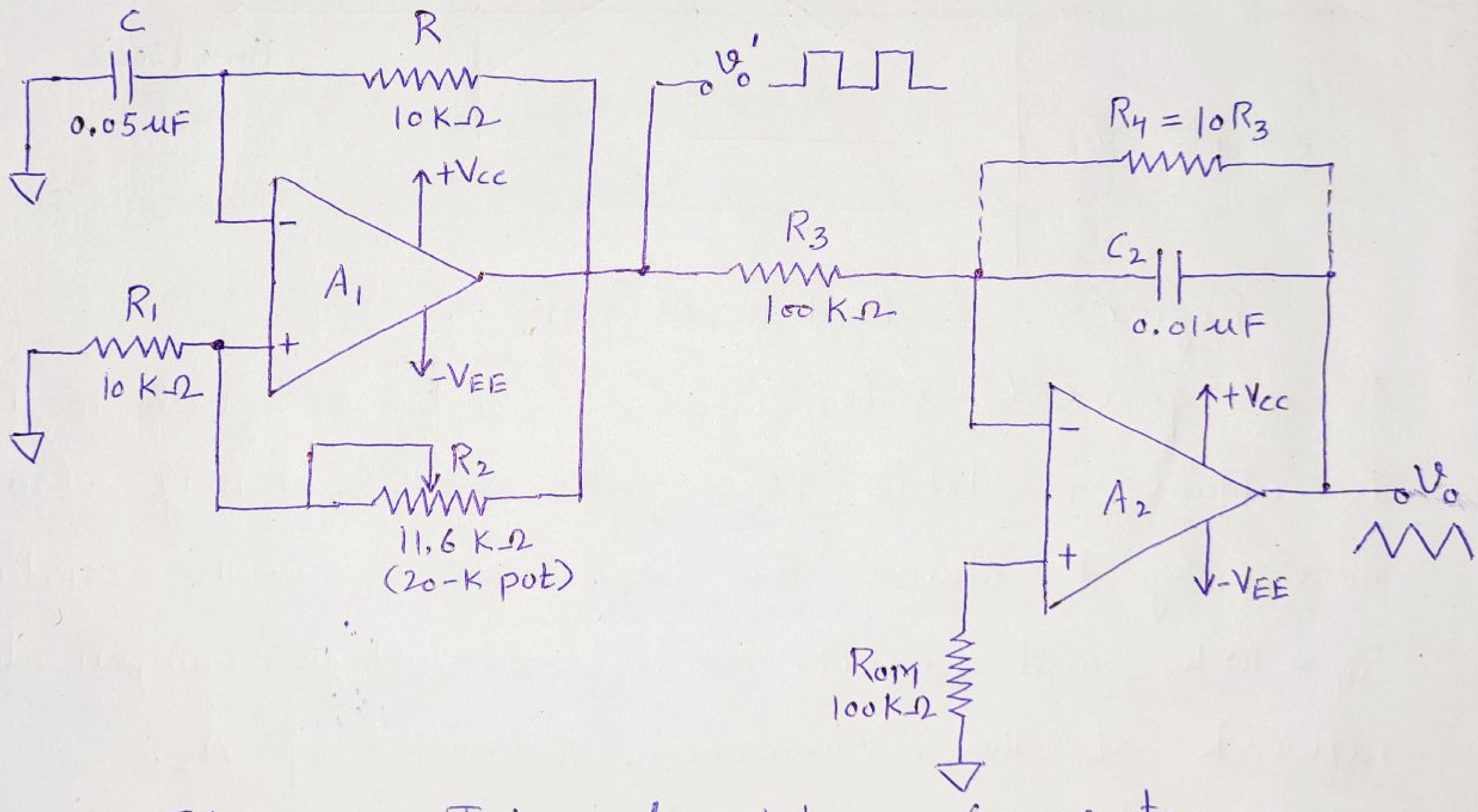

Figure 1. Triangular Wave Generator

For fixed R_1, R_2 and C values, the frequency of the square wave as well as the triangular wave depends on the resistance R. As R is increased or decreased, the frequency of the triangular wave will decrease or increase, respectively. Al-though the amplitude of the square wave is constant ($\pm V_{sat}$);

the amplitude of the triangular wave decreases with an increase in its frequency, and vice versa. For the output of A_2 to be a triangular wave requires that $5 R_3 C_2 > T/2$, where T is the period of the square wave input. The output wave forms of triangular wave generator of Figure 1 are shown in Figure 2.

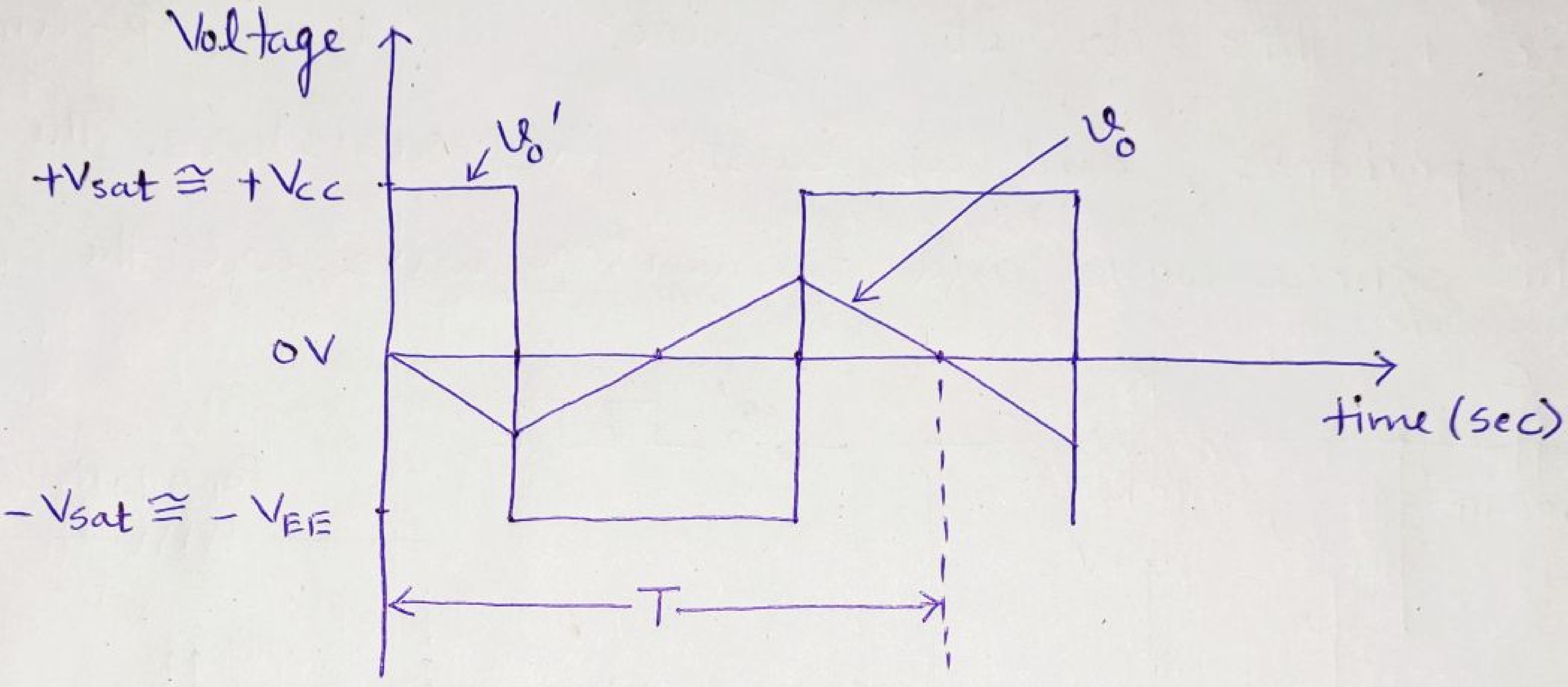

Figure 2. Output wave forms.

As a general rule, $R_3 C_2$ should be equal to T. To obtain a stable triangular wave, it may also be necessary to shunt the capacitor C_2 with resistance $R_4 = 10 R_3$ and connect an offset voltage - compensating network at the noninverting terminal of A_2.

Another triangular wave generator, which requires fewer components, is shown in Figure 3. The generator consists of a comparator A_1 and an integrator A_2. The comparator A_1 compares the voltage at point P continuously with the inverting input that is at 0 V. When the voltage at P goes slightly below or above 0 V, the output of A_1 is at the negative or positive saturation level, respectively.

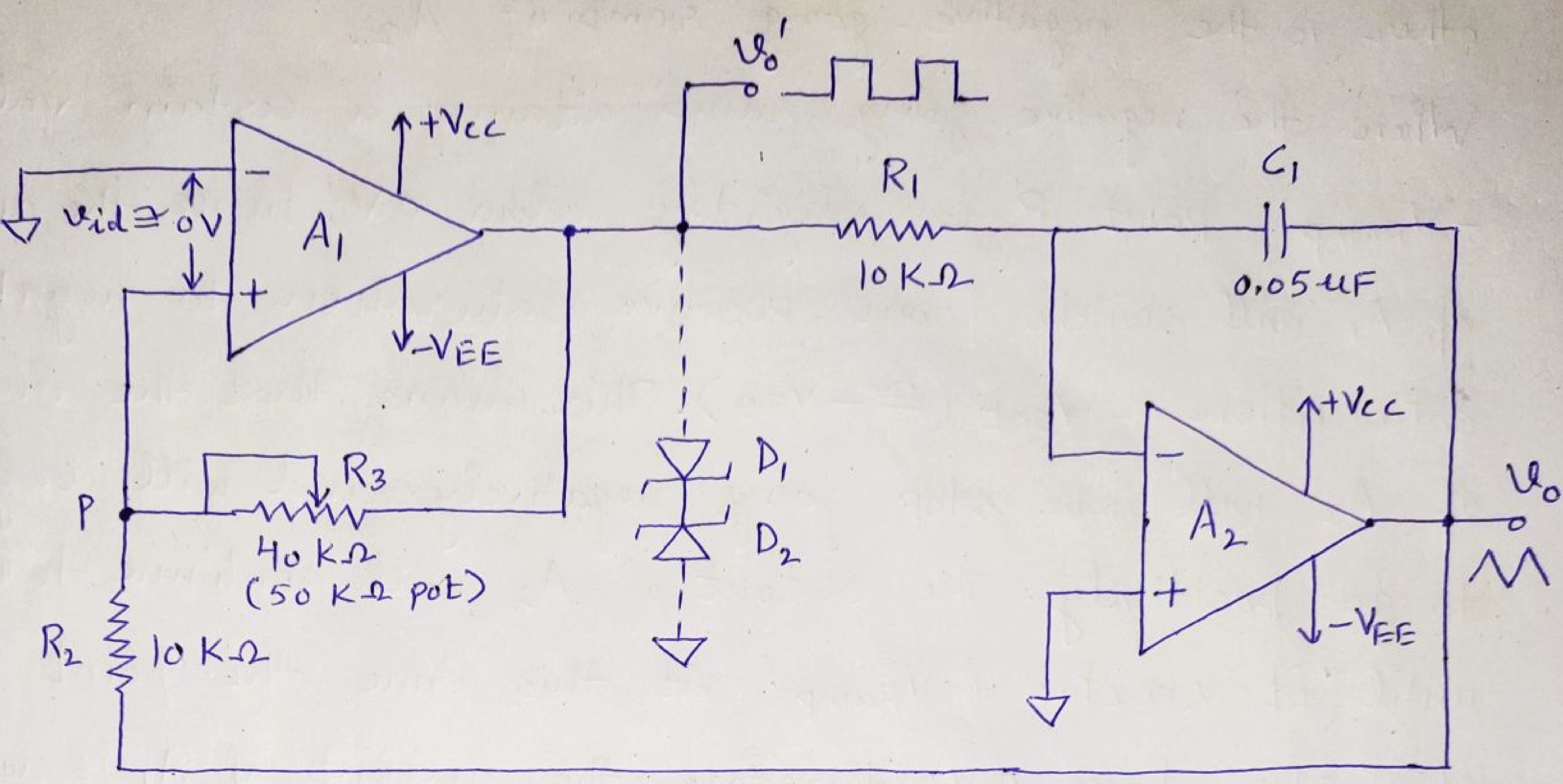

Figure 3. Triangular wave generator.

The output waveforms of triangular wave generator shown in Figure 3 are illustrated in Figure 4.

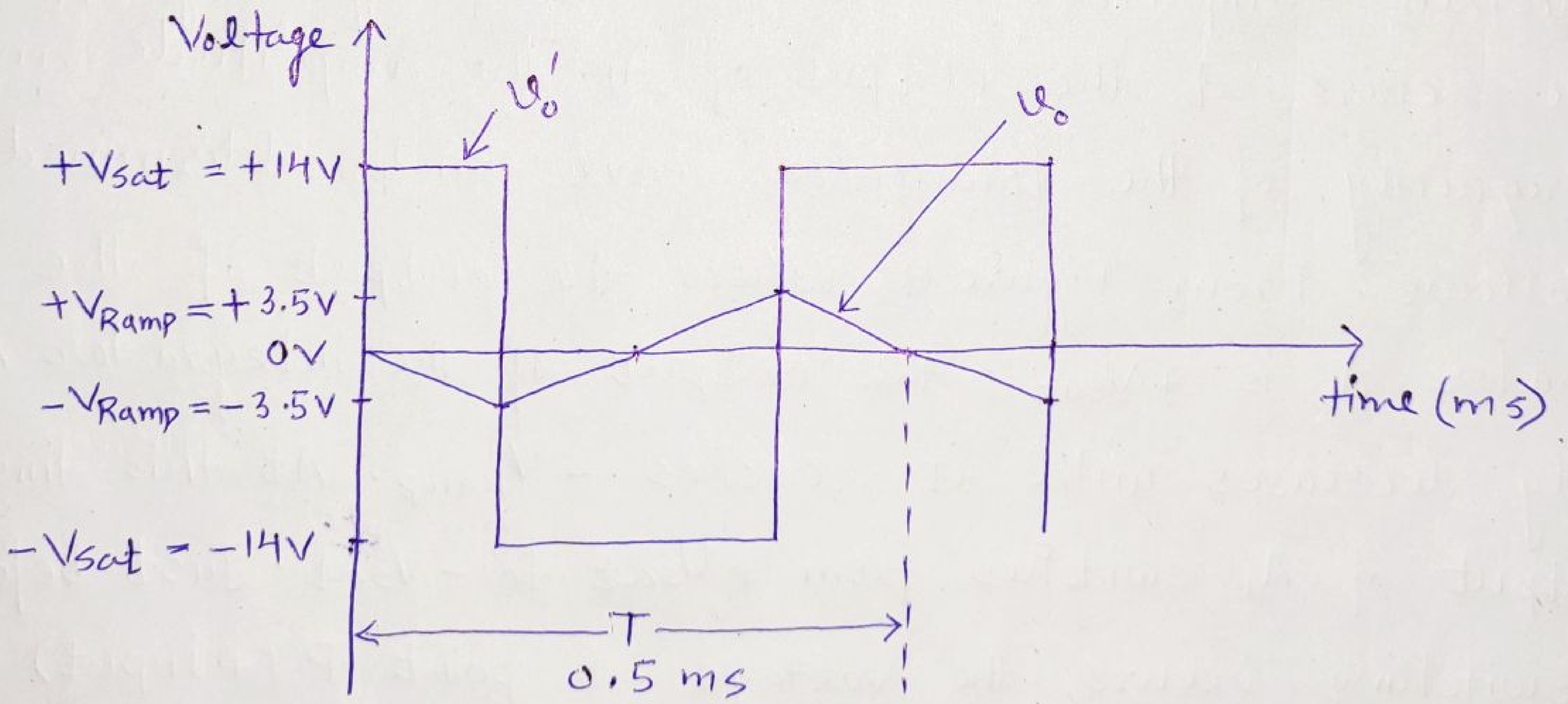

Figure 4. Output waveforms

If the output of A_1 is set at positive saturation $+V_{sat}$, then $+V_{sat}$ is an input of the integrator A_2. The output of A_2, therefore, will be a negative-going ramp. Thus one end of the voltage divider $R_2 - R_3$ is the positive saturation voltage $+V_{sat}$ of A_1 and the other is the negative-going ramp of A_2.

When the negative going ramp attains a certain value $-V_{Ramp}$, point P is slightly below 0 V; hence the output of A_1 will switch from positive saturation to negative saturation $-V_{sat}$ ($\cong -V_{EE}$). This means that the output of A_2 will now stop going negatively and will begin to go positively. The output of A_2 will continue to increase until it reaches $+V_{Ramp}$. At this time the point P is slightly above 0 V; therefore, the output of A_1 is switched back to the positive saturation level $+V_{sat}$. The sequence then repeats. The output waveform is as shown in Figure 4.

The desired amplitude can be obtained by using appropriate zeners at the output of A_1. The amplitude and the frequency of the triangular wave can be determined as follows: From Figure 4, when the output of the comparator A_1 is $+V_{sat}$, the output of the integrator A_2 steadily decreases until it reaches $-V_{Ramp}$. At this time the output of A_1 switches from $+V_{sat}$ to $-V_{sat}$. Just before this switching occurs, the voltage at point P (+ input) is 0 V. This means that the $-V_{Ramp}$ must be developed across R_2, and $+V_{sat}$ must be developed across R_3. That is,

$$\frac{-V_{Ramp}}{R_2} = -\frac{+V_{sat}}{R_3}$$

or

$$-V_{Ramp} = -\frac{R_2}{R_3}(+V_{sat}) \quad \text{——— (1)}$$

Similarly, $+V_{Ramp}$, the output voltage of A_2 at which the output of A_1 switches from $-V_{sat}$ to $+V_{sat}$, is given by,

$$+V_{Ramp} = -\frac{R_2}{R_3}(-V_{sat}) \quad \text{——— (2)}$$

Thus, from equations (1) and (2), the peak-to-peak (PP) output amplitude of the triangular wave is,

$$v_o(PP) = +V_{Ramp} - (-V_{Ramp})$$

$$v_o(PP) = 2\frac{R_2}{R_3}(V_{sat}) \quad \text{——— (3)}$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$. Equation (3) indicates that the amplitude of the triangular wave decreases with an increase in R_3.

The time it takes for the output waveform to swing from $-V_{Ramp}$ to $+V_{Ramp}$ (or from $+V_{Ramp}$ to $-V_{Ramp}$) is equal to half the time period $T/2$. This time can be calculated from the integrator output equation by substituting $v_i = -V_{sat}$, $v_o = v_o(PP)$, and $c = 0$.

$$v_o(PP) = -\frac{1}{R_1 C_1}\int_0^{T/2} -(V_{sat})\,dt$$

$$v_o(PP) = \frac{V_{sat}}{R_1 C_1}\left(\frac{T}{2}\right)$$

Hence,

$$\frac{T}{2} = \frac{v_o(PP)}{V_{sat}}(R_1 C_1)$$

or,

$$T = (2R_1 C_1)\frac{v_o(PP)}{V_{sat}} \quad \text{——— (4)}$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$. Substituting the value of $v_o(pp)$ from equation (3), the time period of the triangular wave is,

$$T = \frac{4R_1C_1R_2}{R_3} \quad \text{—— (5)}$$

The frequency of oscillation then is,

$$f_o = \frac{R_3}{4R_1C_1R_2} \quad \text{—— (6)}$$

Equation (6) shows that the frequency of oscillation f_o increases with an increase in R_3.

Q1. Design the triangular wave generator so that $f_o =$ 2 KHz and $v_o(pp) = 7$ V. The op-amp is a 1458/772 and supply voltages $= \pm 15$ V.

Solution: For 1458, $V_{sat} = 14$ V. Therefore from equation (3),

$$\frac{R_2}{R_3} = \frac{7}{(2)(14)}$$

$$\left[\text{Note}, \quad \frac{R_2}{R_3} = \frac{v_o(PP)}{(2)(V_{sat})} \right]$$

$$\therefore \quad R_2 = \frac{R_3}{4}$$

Let $R_2 = 10$ KΩ; then $R_3 = 40$ KΩ.

Now from equation (6),

$$2\text{ KHz} = \frac{40\text{ K}\Omega}{(4)(R_1C_1)(10\text{ K}\Omega)}$$

Therefore, $R_1C_1 = 0.5$ ms. Let $C_1 = 0.05\ \mu F$; then $R_1 = 10$ KΩ.

Thus, $R_1 = R_2 = 10$ KΩ, $C_1 = 0.05\ \mu F$, and $R_3 = 40$ KΩ.

Sawtooth Wave Generator

The difference between the triangular and sawtooth waveforms is that the rise time of the triangular wave is always equal to its fall time. On the other hand, the sawtooth waveform has unequal rise and fall times. The triangular wave generator of Figure 3. can be converted into a sawtooth wave generator by injecting a variable dc voltage into the noninverting terminal of the integrator A_2. This can be accomplished by using the potentiometer and connecting it to the $+V_{CC}$ and $-V_{EE}$ as shown in Figure 5.

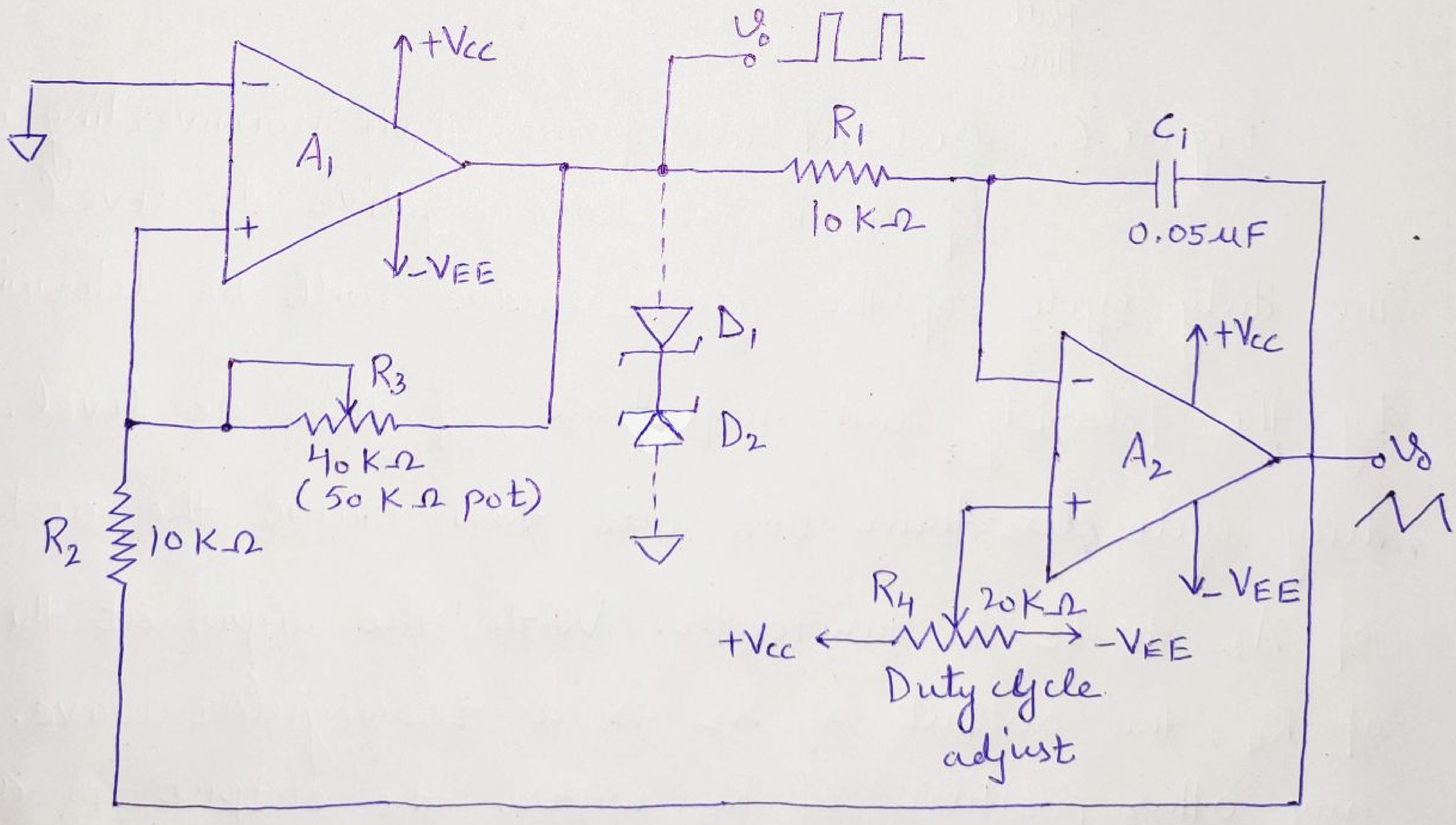

Figure 5. Sawtooth wave generator.

Depending on the R_4 setting, a certain dc level is inserted in the output of A_2. Now, suppose that the output of A_1 is a square wave and the potentiometer R_4 is adjusted for a certain dc level. This means that the output of A_2 will be a triangular wave, riding on some dc level that is a function of the R_4 setting. The output waveforms are shown in Figure 6.

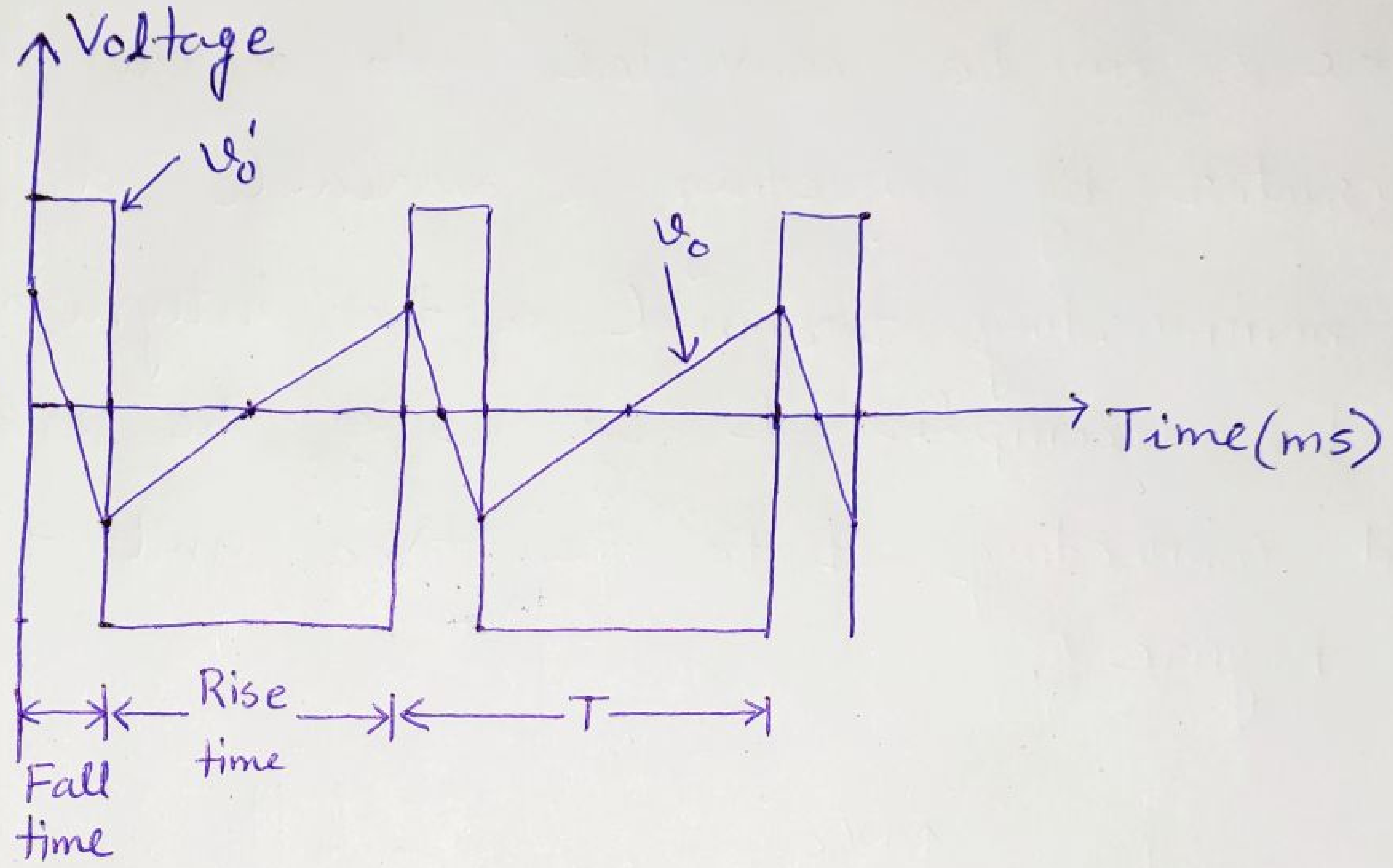

Figure 6. Output waveform when noninverting input of A_2 is at some negative dc level.

The duty cycle of the square wave will be determined by the polarity and amplitude of this dc level. A duty cycle less than 50% will then cause the output of A_2 to be a sawtooth. With the wiper at the center of R_4, the output of A_2 is a triangular wave. For any other position of R_4 wiper, the output is a sawtooth waveform. If the wiper is moved toward $-V_{EE}$, the rise time becomes longer than fall time. If the wiper is moved toward $+V_{CC}$, the fall time becomes longer than the rise time. Frequency of the saw-tooth wave

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