Band Reject Filters

The band-reject filter is also called a band-stop or band-elimination filter. In this filter, frequencies are attenuated in the stopband while they are passed outside this band as shown in frequency response of the band reject filter. The band-reject filters can also be classified as (1) wide band-reject or (2) narrow band-reject.

Wide Band-Reject Filter

Figure 2. shows a wide band-reject filter using a low-pass filter, a high-pass filter, and a summing amplifier. To realize a band-reject response, the low cutoff frequency f_L of the high-pass filter must be larger than the high cutoff frequency f_H of the low-pass filter. In addition, the passband gain of both the high-pass and low-pass sections must be equal. The frequency response of the wide band-reject filter is shown in Figure 1.

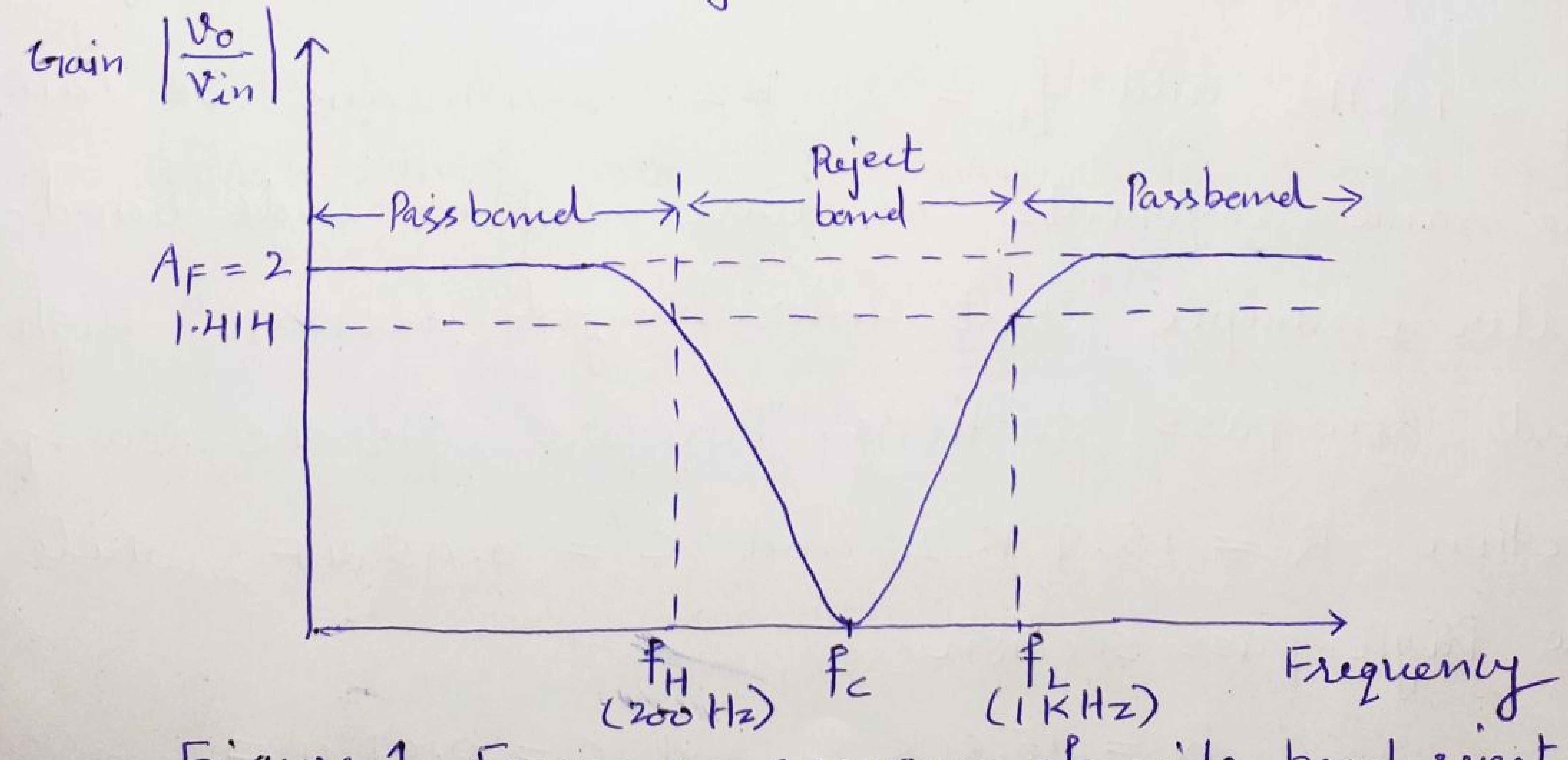

Figure 1. Frequency response of wide band-reject filter

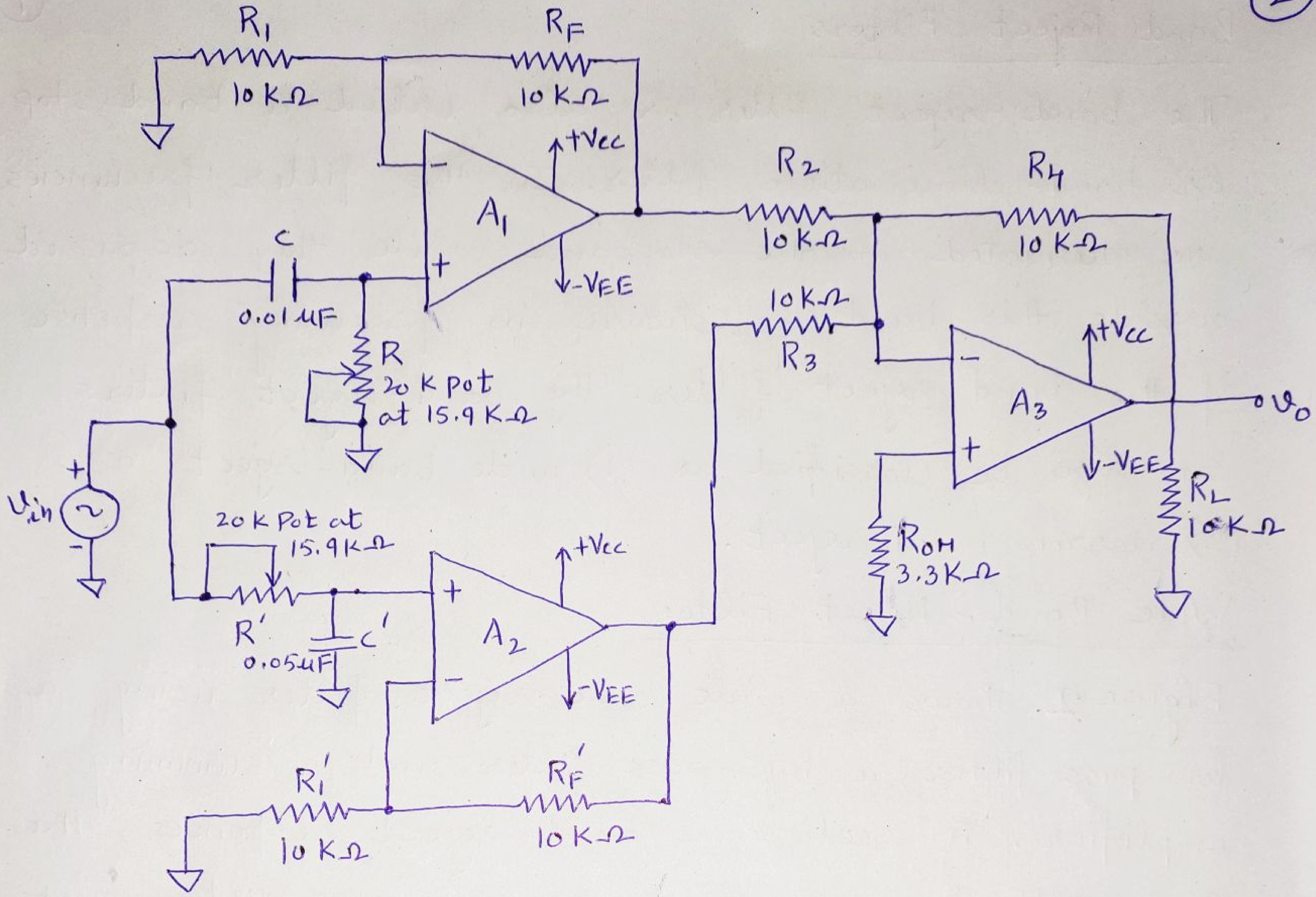

Figure 2. Wide band-reject filter.

Q1. Design a wide band-reject filter having $f_H = 200$ Hz and $f_L = 1$ KHz.

Solution: In this example, as compared to wide band-pass filter, band frequencies are interchanged, that is, $f_L = 1$ KHz and $f_H = 200$ Hz. This means we can use the same components as were used in wide band-pass filter example, but interchanged between high-pass and low-pass sections. Therefore, for the low-pass section, $R' = 15.9$ KΩ and $C' = 0.05$ uF, while for the high-pass section

$R = 15.9$ KΩ and $C = 0.01$ uF

Since there is no restriction on the passband gain, use a gain of 2 for each section. Hence let,

$$R_1 = R_F = R_1' = R_F' = 10\ K\Omega$$

Furthermore, the gain of the summing amplifier is set at 1; therefore

$$R_2 = R_3 = R_4 = 10\ K\Omega$$

Finally, the value of $R_{OM} = R_2 \| R_3 \| R_4 \cong 3.3\ K\Omega$. The complete circuit is shown in Figure 2 and its response is shown in Figure 1. The voltage gain changes at a rate of 20 dB/decade above f_H and below f_L, with a maximum attenuation occurring at f_c.

All-Pass Filter

As the name suggests, an all-pass filter passes all frequency components of the input signal without attenuation, while providing predictable phase shifts for different frequencies of the input signal. When signals are transmitted over transmission lines, such as telephone wires, they undergo change in phase. To compensate for these phase changes, all-pass filters are required. The all-pass filters are also called delay equalizers or phase correctors. Figure 3 shows an all-pass filter wherein $R_F = R_1$. The output voltage v_o of the filter can be obtained by using the superposition theorem:

$$v_o = -v_{in} + \frac{-jX_C}{R - jX_C} v_{in}(2) \quad \text{--- (1)}$$

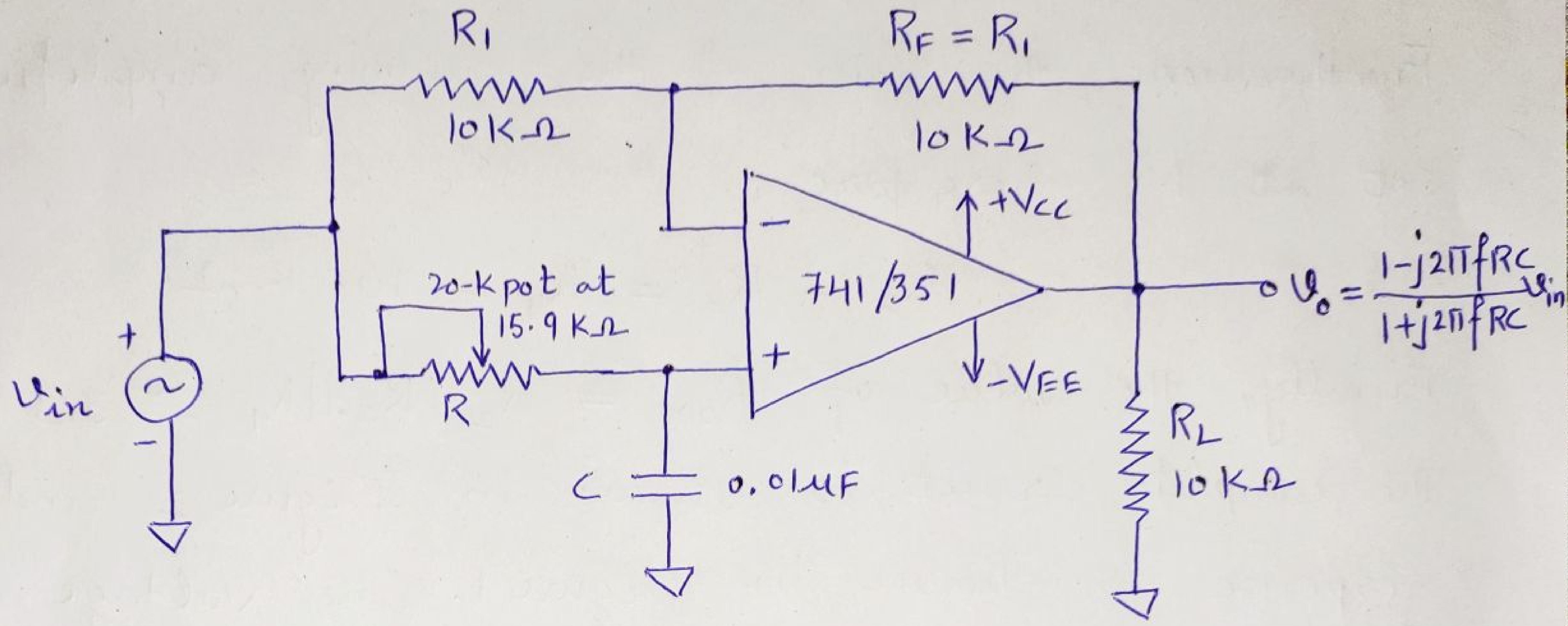

Figure 3. Circuit of All-Pass Filter.

Now, $-j = 1/j$ and $X_C = 1/2\pi fC$. Therefore, substituting for X_C in (1) and simplifying, we get

$$v_o = v_{in}\left(-1 + \frac{2}{j2\pi fRC + 1}\right)$$

or,

$$\frac{v_o}{v_{in}} = \frac{1 - j2\pi fRC}{1 + j2\pi fRC} \quad \text{--- (2)}$$

where f is the frequency of the input signal in Hz. Equation (2) indicates that the amplitude of $\frac{v_o}{v_{in}}$ is unity; that is $|v_o| = |v_{in}|$ throughout the useful frequency range, and the phase shift between v_o and v_{in} is a function of input frequency f. The phase angle ϕ is given by

$$\phi = -2\tan^{-1}\left(\frac{2\pi fRC}{1}\right) \quad \text{--- (3)}$$

where ϕ is in degrees, f in hertz, R in ohms and C in farads. For fixed values of R and C, the phase angle ϕ changes from 0 to $-180°$ as the frequency f is varied from 0 to ∞. In Figure 3, if the position of R and C are interchanged, the phase shift between input and output becomes positive. That is, output v_o leads input v_{in}.

Square Wave Generator

In contrast to sine wave oscillator, square wave outputs are generated when the op-amp is forced to operate in the saturated region. That is, the output of the op-amp is forced to swing repetitively between positive saturation $+V_{sat}$ ($\cong +V_{CC}$) and negative saturation $-V_{sat}$ ($\cong -V_{EE}$), resulting in the square-wave output. The circuit of square-wave generator is shown in Figure 4. This square-wave generator is also called a free-running or astable multivibrator.

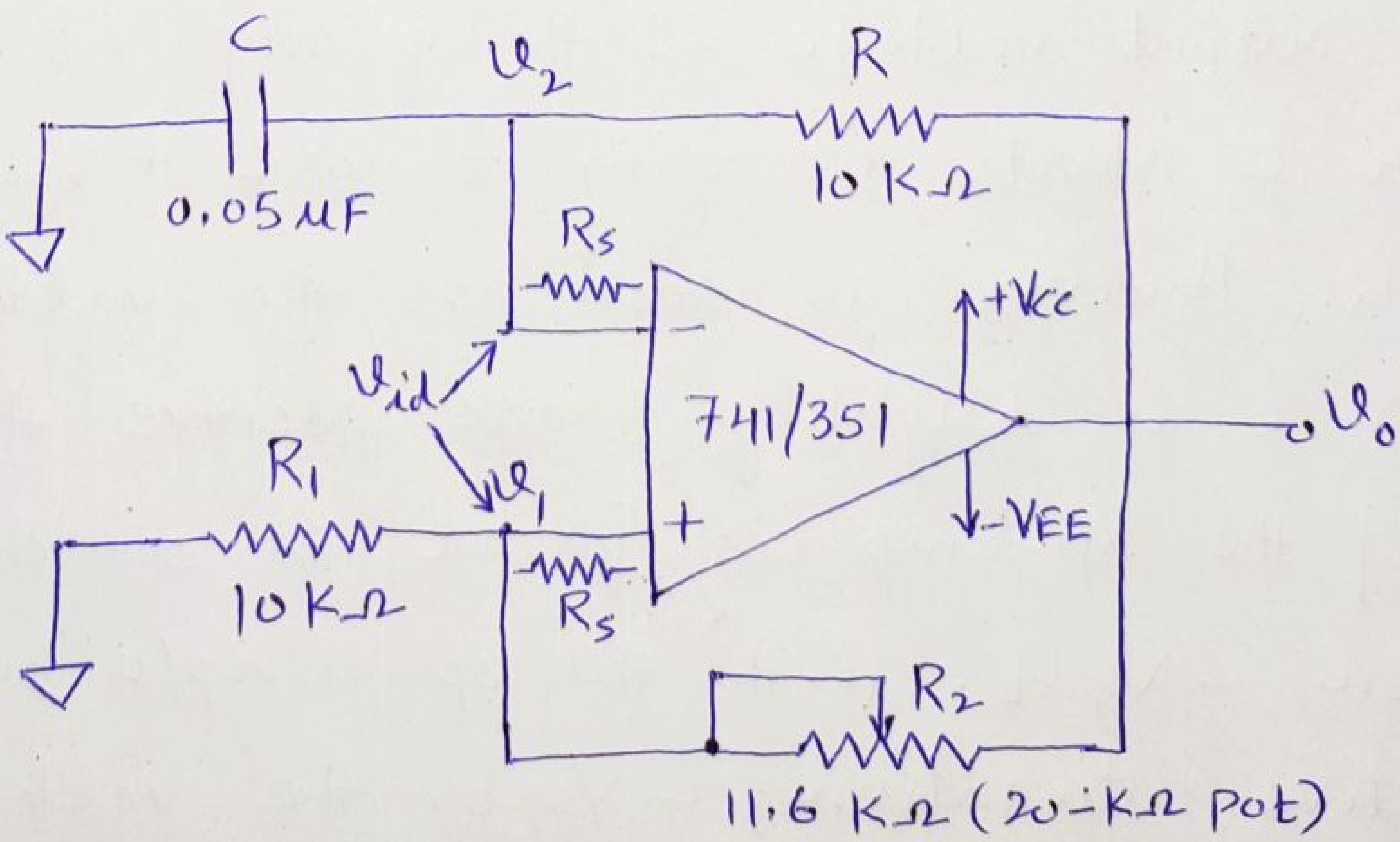

Figure 4. Square wave generator.

The waveforms of output voltage v_o and capacitor voltage v_2 of the square-wave generator are shown in Figure 5.

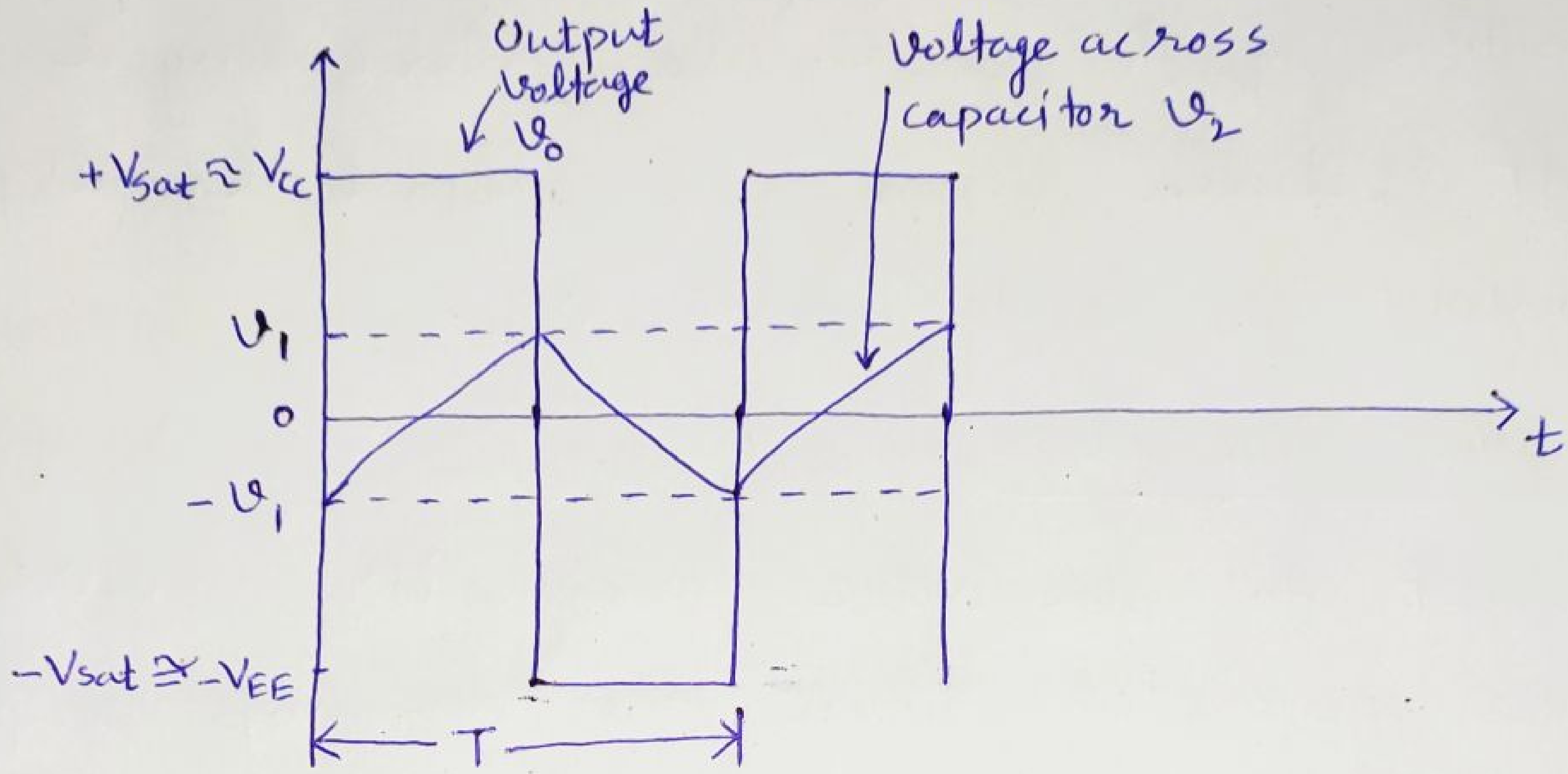

Figure 5. Waveforms of output voltage v_o and capacitor voltage v_2.

Suppose that the output offset voltage V_{OOT} is positive and that, therefore, voltage v_1 is also positive. Since initially the capacitor C acts as a short circuit, the gain of the op-amp is very large (A); hence v_1 drives the output of the op-amp to its positive saturation $+V_{sat}$. With the output voltage of the op-amp at $+V_{sat}$, the capacitor C starts charging toward $+V_{sat}$ through resistor R. However, as soon as the voltage v_2 across capacitor C is slightly more positive than v_1, the output of the op-amp is forced to switch to a negative saturation, $-V_{sat}$. With the op-amp's output voltage at negative saturation, $-V_{sat}$, the voltage v_1 across R_1 is also negative, since

$$v_1 = \frac{R_1}{R_1 + R_2}(-V_{sat}) \quad (4)$$

Thus the net differential voltage $v_{id} = v_1 - v_2$ is negative, which holds the output of the op-amp in negative saturation. The output remains in negative saturation untill the capacitor C discharges and then recharges to a negative voltage slightly higher than $-v_1$. Now, as soon as the capacitor's voltage v_2 becomes more negative than $-v_1$, the net differential voltage v_{id} becomes positive and hence drives the output of the op-amp back to its positive saturation $+V_{sat}$. This completes one cycle. With output at $+V_{sat}$, voltage v_1 at the noninverting input is

$$v_1 = \frac{R_1}{R_1 + R_2}(+V_{sat}) \quad \text{— (5)}$$

The time period T of the output waveform is given by,

$$T = 2RC \ln\left(\frac{2R_1 + R_2}{R_2}\right) \quad \text{— (6)}$$

or,

$$f_o = \frac{1}{2RC \ln[(2R_1 + R_2)/R_2]} \quad \text{— (7)}$$

Equation (7) indicates that the frequency of the output f_o is not only a function of the RC time constant but also of the relationship between R_1 and R_2. For example, if $R_2 = 1.16 R_1$, equation (7) becomes,

$$f_o = \frac{1}{2RC} \quad \text{— (8)}$$

Equation (8) shows that smaller the RC time constant, the higher the output frequency f_o and vice versa.

The highest frequency generated by the square wave generator is also set by the slew rate of the op-amp. An attempt to operate the circuit at relatively higher frequencies causes the oscillator's output to become triangular. In practice, each inverting and noninverting terminal needs a series resistance R_s to prevent excessive differential current flow because the inputs of the op-amp are subjected to large differential voltages. The resistance R_s used should be 100 KΩ or higher.

Q. Design the square-wave oscillator of Figure 4 so that $f_o = 1$ KHz. The op-amp is a 741 with dc supply voltages $= \pm 15$ V.

Solution: Use $R_2 = 1.16\, R_1$ so that the simplified frequency equation (8) can be applied.

Let $R_1 = 10$ KΩ, then $R_2 = (1.16)(10\text{ K}\Omega) = 11.6$ KΩ

Next, choose a value of C and calculate the value of R from equation (8). Hence let $C = 0.05\,\mu F$.

$$\therefore \quad R = \frac{1}{10 \times 10^{-8} \times 10^{3}} = 10 \text{ K}\Omega$$

Thus,

$R_1 = 10$ KΩ

$R_2 = 11.6$ KΩ (20-KΩ potentiometer)

$R = 10$ KΩ

$C = 0.05\,\mu F$