Quadrant II – Notes

Programme: Bachelor in Science (Third Year)

Subject: Physics

Paper Code: PYC 106

Paper Title: Analog Electronics (Sec-I)

Unit: 3

Module Name: Waveform generator- Square wave, Tri-angular wave and Pulse generator.

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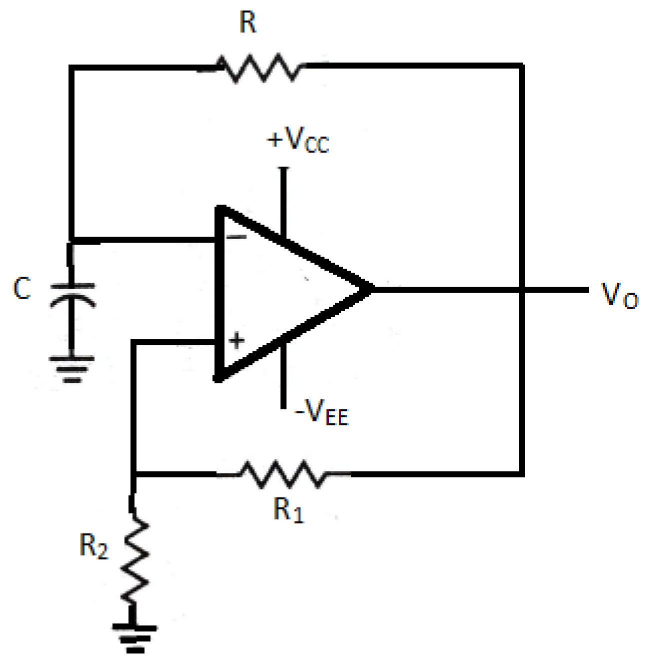
Notes

Op-amp as Square wave generator (Relaxation Oscillator):

The Op-amp as square wave generator is as shown in the figure below:



The circuit generates an output signal with no input signal applied. The output can be either $+V_{sat}$ or $-V_{sat}$. The output is fed back to the non-inverting input through a voltage divider network in the form of R_1 and R_2.

When the output is in positive saturation: $+V_{sat}$,

The feedback voltage is:

$$V_f = \frac{R_1}{R_1 + R_2} V_o$$

The feedback factor is:

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

And the reference voltage at the non-inverting is:

$$V_{ref} = +\beta V_{sat}$$

The capacitor is expected to charge to $+V_{sat}$, but however, does do so as it encounters the UTP $+\beta V_{sat}$. Hence when the capacitor voltage hits the UTP, the error voltage is zero which means that when the capacitor voltage goes greater than the UTP, the error voltage becomes negative and the output switches to $-V_{sat}$. The reference is now $-\beta V_{sat}$ (LTP). The capacitor is now forced to charge in the opposite direction (discharging). When the capacitor reaches the LTP, the error voltage is once zero which means that when the capacitor voltage is greater than the LTP, the output switches back to a high state i.e $+V_{sat}$. On account of the continuous charging and discharging of the capacitor, the output is a Rectangular wave.

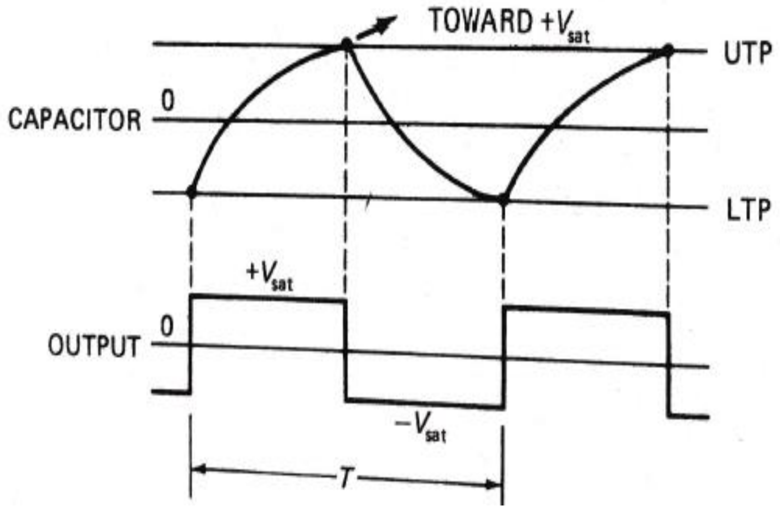
If β is the feedback factor then:

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

The UTP is $+\beta V_{sat}$ and the LTP is $-\beta V_{sat}$. For any RC circuit, the capacitor voltage can be expressed by the relation:

$$V_C = V_i + (V_f - V_i)(1 - e^{\frac{-t}{RC}})$$

Where V_c is the instantaneous capacitor voltage, V_i is the initial capacitor voltage and V_f is the final target capacitor voltage.



The above figure shows the output and capacitor waveform.

When the capacitor starts from $-\beta V_{sat}$ and ends at $+\beta V_{sat}$, the target voltage is $+V_{sat}$ and the charging time is T/2. Hence, in the above relation:

$$\beta V_{sat} = -\beta V_{sat} + (V_{sat} + \beta V_{sat})(1 - e^{\frac{-T}{2RC}})$$

$$\therefore \frac{2\beta}{1+\beta} = 1 - e^{\frac{-T}{2RC}}$$

$$\therefore e^{\frac{-T}{2RC}} = 1 - \frac{2\beta}{1+\beta} = \frac{1-\beta}{1+\beta}$$

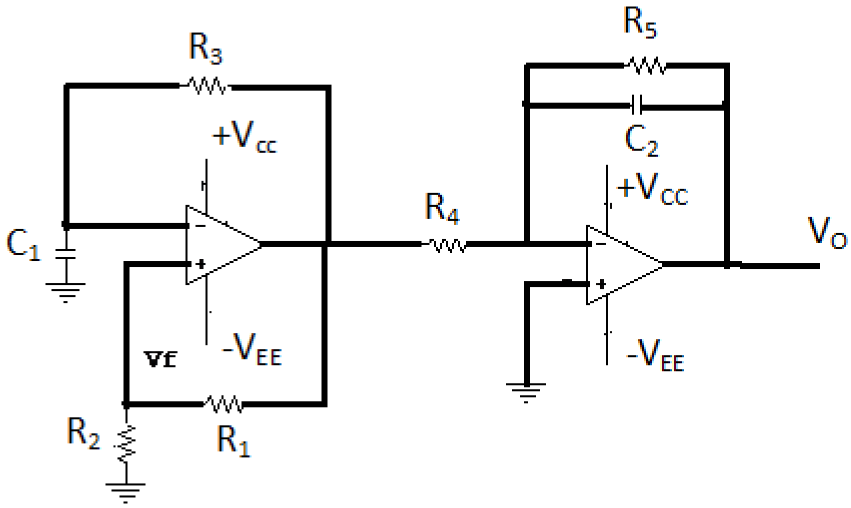
$$\because \frac{1+\beta}{1-\beta} = \frac{R_1 + 2R_2}{R_1} = 1 + 2\frac{R_2}{R_1}$$

$$\therefore T = 2RC\ln(1 + 2\frac{R_2}{R_1})$$

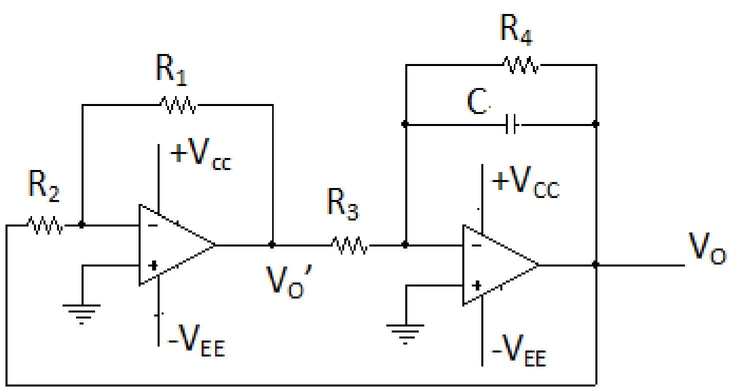
The circuit is a relaxation oscillator as it generates an output signal whose frequency depends on the charging or discharging of a capacitor.

Tri-angular wave generator:

A Tri-angular wave generator is obtained when a relaxation oscillator is cascaded with an integrator. The rectangular wave output from the relaxation oscillator serves as an input to the integrator which then produces a tri-angular waveform. The rectangular wave swings between $+V_{sat}$ and $-V_{sat}$. A circuit for a relaxation oscillator in conjunction with an integrator is as shown below:

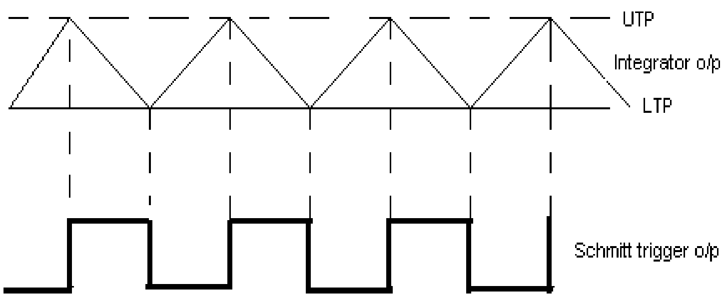


A second way of generating a triangular wave is by cascading a Schmitt trigger circuit along with an integrator. Since, a non-inverting Schmitt trigger produces a rectangular wave, it can be used to drive a Schmitt trigger to produce a triangular wave. This triangular wave is then fed back and used to drive the input of the Schmitt trigger. Thus, the first stage drives the second and the second drives the first as seen in the figure below:



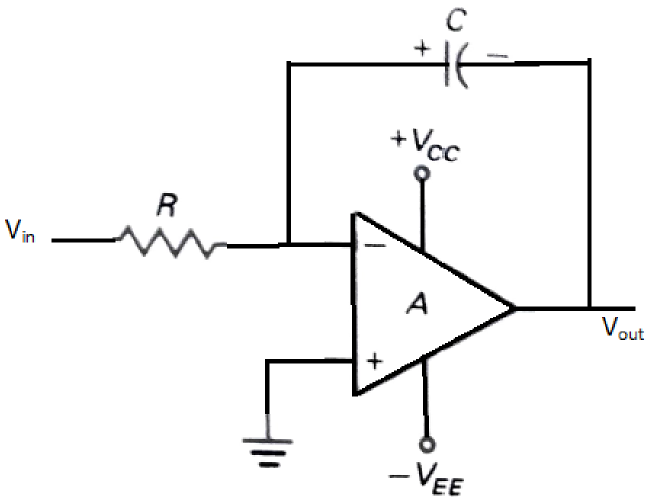
When the output is low, the input must increase to the UTP to switch the output to high. Similarly, when the output is high, the input must increase to the LTP to switch the output to low.

When the Schmitt trigger output is low, the integrator produces a positive ramp. This positive ramp increases until it reaches the UTP. At this point, the output of the Schmitt trigger switches to the high state and forces the triangular output to reverse direction. The negative ramp decreases until it reaches the LTP as seen below:



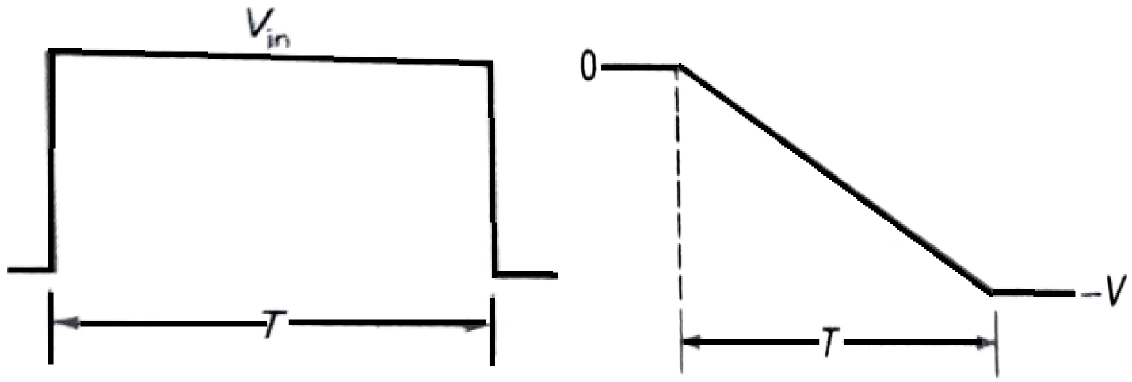
Ramp generator:

The op-amp as a ramp generator is as seen in the fig below:



The input to the circuit is in the form of V_{in} at the inverting terminal of the Op-amp while the output is V_{out}. The input is in the form of a rectangular pulse with a constant voltage Vin during a pulse time T. The input current is hence constant and all this current flows through the capacitor.

With C = Q/V, V = Q/C. Since the current flowing through into the capacitor is constant, the charge Q increases linearly and hence the capacitor voltage increases linearly with a polarity as seen in the circuit. On account of the phase reversal of the op-amp, the output voltage is a negative going ramp as seen in the figure below:



At the end of the pulse period, the input voltage returns to zero and hence the charging stops.

Since V/T = (Q/T)/C and the charging current being constant, we have:

V/T = I/C and V = IT/C where:

V is the capacitor voltage

I is the charging current

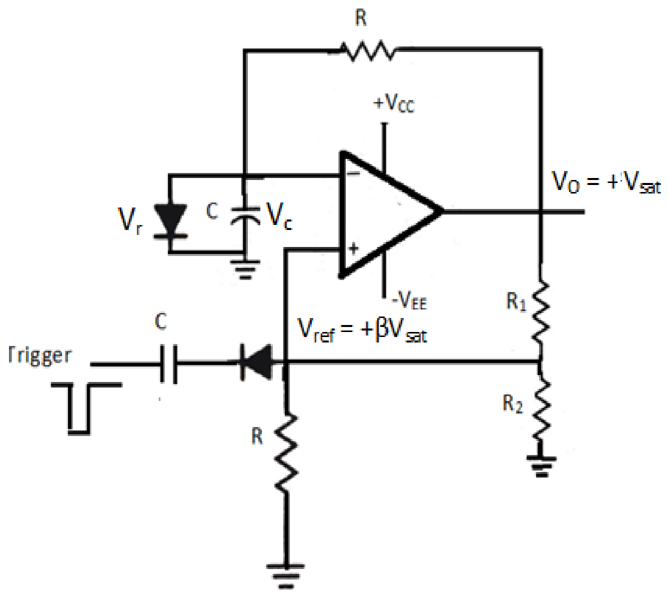
T is the charging time and

C is the capacitance.

Pulse generator:

The monostable multivibrator is a one-shot multivibrator that has one stable state. The circuit remains in its stable state until a triggering signal causes a transition to the quasitable state. After a time, T, the circuit returns to its stable state.

One such monostable multivibrator is as shown in the figure below:



When the output is at positive saturation $+V_{sat}$,

Feedback voltage is :

$$V_f = \frac{R_1}{R_1 + R_2} V_o$$

Feedback factor is :

$$\beta = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

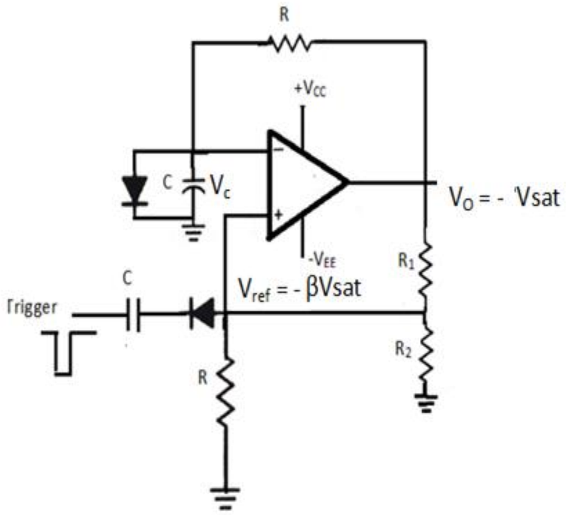
The reference voltage at the non-inverting is:

$$V_{ref} = +\beta V_{sat}$$

The diode goes ON and the capacitor is clamped at the diode voltage Vr=0.7V.

The error voltage is positive and the comparator output switches to a high state, positive saturation + V_{sat}.

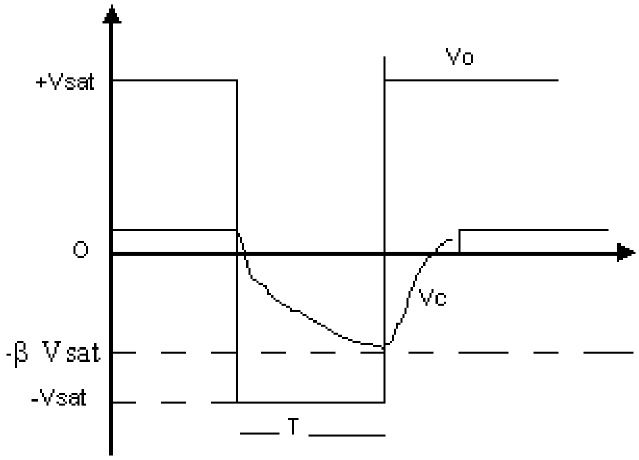
If the trigger amplitude is greater than (βV_{sat} – V_r), it will cause the output to switch to negative saturation, - V_{sat} as seen in the figure below:



The capacitor now charges to -V_{sat} with the diode off, the reference voltage is:

$$V_{ref} = -\beta V_{sat}$$

When the capacitor voltage becomes more negative than -βV_{sat}, the comparator output switches back to a high output. The output is as seen in the figure below:



Output and Capacitor waveforms

When the triggering pulse occurs, the capacitor charges from an initial value V_r towards a final value $-V_{sat}$. From the equation for an RC circuit, we have:

$$V_C = V_f + (V_f - V_i)(1 - e^{\frac{-t}{RC}})$$

$$V_C = V_r + (-V_{sat} - V_r)(1 - e^{\frac{-t}{RC}})$$

$$\therefore V_C = -V_{sat} + (V_r + V_{sat})\, e^{\frac{-t}{RC}}$$

$$-\beta V_{sat} = -V_{sat} + (V_r + V_{sat})\, e^{\frac{-T}{RC}}$$

$$\therefore \frac{V_{sat}(1-\beta)}{V_{sat} + V_r} = e^{\frac{-T}{RC}}$$

$$\therefore T = RC \ln \frac{V_{sat} + V_r}{V_{sat}(1-\beta)}$$

$$T = RC \ln \frac{1 + (\frac{Vr}{V_{sat}})}{1-\beta}$$

If $V_{sat} >> V_r$ and $R_2 = R_1$, then $\beta = ½$ and

$$T = RC \ln 2 = 0.69RC$$