EXPERIMENT .NO.5
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ASTABLE AND MONOSTABLE MULTIVIBRATOR USING OP-AMPS

AIM

To design and setup,

1 Op-amp based Astable multivibrator circuits for
   a. 50% Duty Cycle and time period= $1ms$
   b. 75% Duty Cycle and time period= $1ms$
2. An op-amp based Monostable multivibrator circuit for producing a time delay of $10ms$

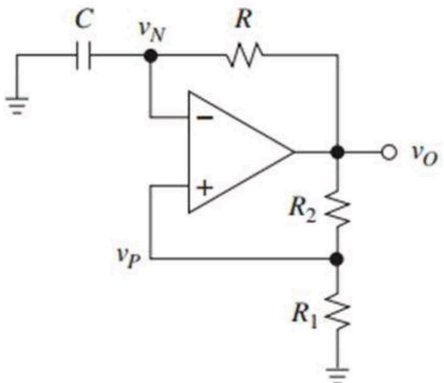
THEORY

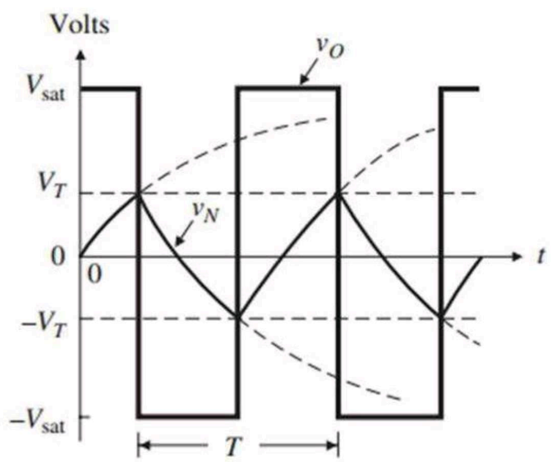
OPAMP BASED ASTABLE MULTIVIBRATORS

Multivibrators are regenerative circuits used for timing applications.

An Astable multivibrator (free-running multivibrator) toggles spontaneously between one state and the other, without any external commands. Its timing is set by a suitable timing network.

The circuit diagram for an op-amp based Astable Multivibrator is given below.





The circuit is an op-amp comparator with positive feedback forming an inverting Schmitt Trigger. If V_{sat}'s are symmetric, the Schmitt Trigger thresholds are also symmetric at $\pm V_T = \pm V_{sat}.\frac{R_1}{R_1+R_2}$

The signal in the inverting terminal is provided by the op amp itself via the RC network

At power turn-on ($t = 0$) v_O will swing either to $+V_{sat}$ or to $-V_{sat}$. Let us assume it is $+V_{sat}$ so that $v_P = +V_T$

This will cause R to charge C toward $+V_{sat}$, leading to an exponential rise in v_N with the time constant $\tau = RC$

As soon as v_N catches up with $v_P = +V_T$, v_O snaps to $-V_{sat}$, reversing the capacitance current and also causing v_P to snap to $-V_T$

Now v_N decays exponentially toward $-V_{sat}$ until it catches up with $v_P = -V_T$, at which point v_O again snaps to $+V_{sat}$, thus repeating the cycle

Once powered, the circuit can start and sustain oscillation, with v_O snapping back and forth between $+V_{sat}$ and $-V_{sat}$, and v_N slewing exponentially back and forth between $+V_T$ and $-V_T$. After the power-on cycle, the waveforms become periodic

The time period of Oscillations:

Assuming V_{sat}'s are symmetric, v_O has a duty cycle of 50%

We have,

The time taken to charge or discharge a capacitor C from V_0 to V_1, $\Delta t = \tau.\ln\left(\frac{V_\infty - V_0}{V_\infty - V_1}\right)$

Hence, $\frac{T}{2} = RC.\ln\left(\frac{V_{sat}+V_T}{V_{sat}-V_T}\right)$

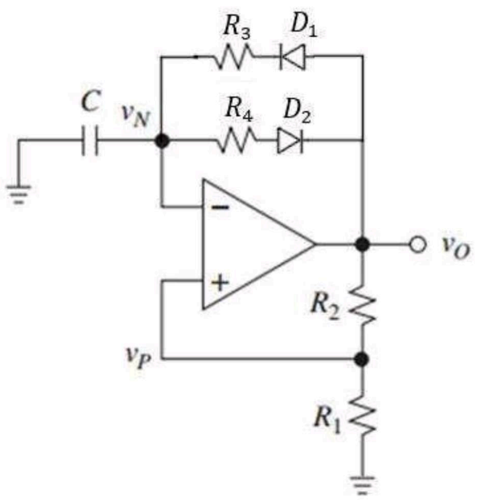
Substituting $V_T = V_{sat}.\frac{1}{1+R_2/R_1}$ into the above equation we get,

$$T = 2RC.\ln(1 + 2R_1/R_2)$$

Hence the frequency of oscillations, $f_0 = \frac{1}{T} = \frac{1}{2RC.\ln(1+2R_1/R_2)}$

Note that, f_0 depends only on external components and not on V_{sat}

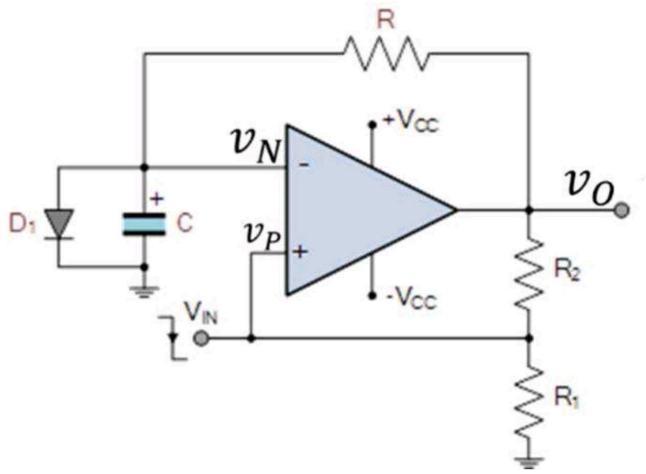
To obtain a different duty cycle other than 50%, we can use two different charging and discharging resistances using diodes in the negative feedback path as shown below.



T_{ON} = charging time from $-V_T$ to V_T $= R_3C.\ln\left(\frac{V_{sat}-(-V_T)}{V_{sat}-V_T}\right) = R_3C.\ln(1+2R_1/R_2)$

T_{OFF} = discharging time from V_T to $-V_T$ $=R_4C.\ln\left(\frac{-V_{sat}-V_T}{-V_{sat}-(-V_T)}\right) = R_4C.\ln(1+2R_1/R_2)$

OPAMP BASED MONOSTABLE MULTIVIBRATORS



At initial power on(t = 0), the output (v_O) will saturate towards either $+V_{sat}$ or $-V_{sat}$

Assume it is $+V_{sat}$. Then, $v_P = \beta V_{sat}$ where $\beta = \frac{R_1}{R_1+R_2}$

$v_N = 0.7V(= V_D)$ due to the forward biased diode D_1. This diode prevents v_N from going any more positive. i.e., $v_N \ll v_P$. Hence the output voltage v_O remains stable at $+V_{sat}$

At the same time, the capacitor C charges up to 0.7 volts and is held there by the forward-biased voltage drop of the diode

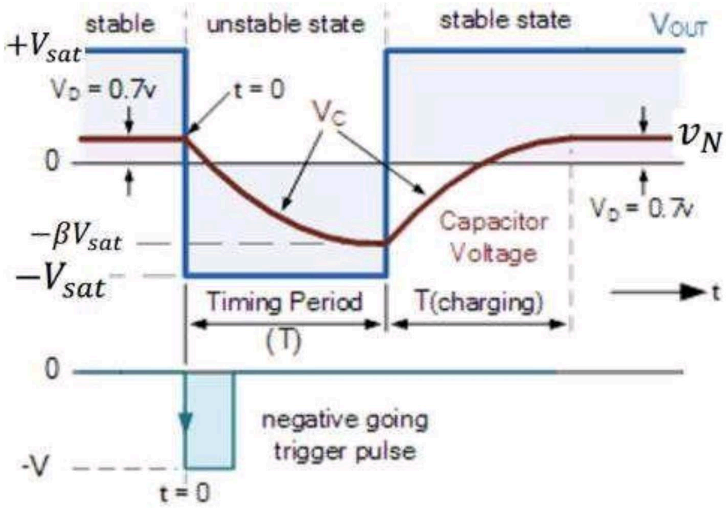
Suppose we apply a negative going pulse to the noninverting input terminal. v_P is now less than $v_N(= 0.7V) \Rightarrow v_O$ switches state and saturates at $-V_{sat}$. This is the metastable state of the Monostable Multivibrator. Now, $v_P = -\beta V_{sat}$

This temporary meta-stable state causes the capacitor to charge up exponentially in the opposite direction through the feedback resistor, R from +0.7 volts down to $-V_{sat}$ with time constant $\tau = RC$. Now the diode is reverse biased and has no effect on the capacitor voltage.

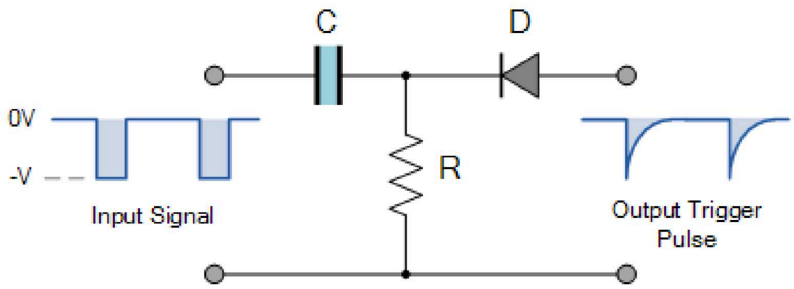
As soon as the capacitor voltage(v_N) reaches the same potential as $v_P(= -\beta V_{sat})$, the op-amp switches back to its original permanent stable state with $v_O = V_{sat}$

Once the timing period is complete and the op-amp's output changes back to its stable state($+V_{sat}$), the capacitor tries to charge up in reverse to $+V_{sat}$ but can only charge to a maximum value of 0.7V($= V_D$)

<u>Summary</u>: *A negative-going trigger input, will switch the op-amp monostable circuit into its temporary unstable state. After a time delay, T set by the capacitor, C and the feedback resistor, R, the circuit switches back to its normal stable state*



Triggering Circuit for Monostable Multivibrator



An RC differentiator circuit with a negative going input pulse is usually employed to provide a negative trigger to the monostable multivibrator. When the input suddenly goes from 0 to $-V$ a negative spike is produced at the output of the differentiator which will trigger the monostable multivibrator. The diode ensures that the trigger pulse arriving at the op-amp's non-inverting input is always negative.

As a general rule-of-thumb, for an RC differentiator circuit to produce good sharp narrow spikes its time constant should be less than one-tenth of the input pulse time period.

Op amp Monostable multivibrator Time Period

The time delay period (T) of the rectangular pulse at the output(the unstable state time) is calculated as:

T =time taken for C to discharge from 0V to $-\beta V_{sat}$ through R;

$$\Rightarrow T = RC.ln\left(\frac{-V_{sat}-0}{-V_{sat}-(-\beta V_{sat})}\right) = RC.ln\left(\frac{1}{1-\beta}\right) = RC.ln(1 + R_1/R_2)$$

When $R_1 = R_2 \Rightarrow T = RCln(2) \cong 0.693RC$

The charging recovery time for Monostable multivibrator is the time taken by the capacitor to charge again from $-\beta V_{sat}$ to v_D(≅0.7V). During this time, the MSMV may not respond to a second negative trigger pulse

$$T_{recovery} = RC.\ln\left(\frac{V_{sat} + \beta V_{sat}}{Vsat - V_D}\right) = RC.\ln\left(\frac{1+\beta}{1 - V_D/V_{sat}}\right)$$

DESIGN

OPAMP BASED ASTABLE MULTIVIBRATORS

For 50% Duty Cycle:

$T = 2RC.\ln(1 + 2R_1/R_2)$.

Let us take $R_1 = R_2$ so that $T = 2RC.\ln(3)$

$1ms = 2RC.\ln(3) = 2.197RC$

Choose $C = 0.1\mu F \Rightarrow R = 4.5k$. Choose $4.7k$ std.

Take $R_1 = R_2 = 10k$

For 75% Duty Cycle:

$T_{ON} = R_3C.\ln(1 + 2R_1/R_2)$

$T_{OFF} = R_4C.\ln(1 + 2R_1/R_2)$

$$Duty\ Cycle = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

For 1ms period, and 75% Duty Cycle, $T_{ON} = 0.75ms$ and $T_{OFF} = 0.25ms$

Take $R_1 = R_2 = 10k$ and $C = 0.1\mu F$

$T_{ON} = 0.75ms = R_3C\,.\ln(3) \Rightarrow R_3 = 6.8k$

$T_{OFF} = 0.25ms = R_4C\,.\ln(3) \Rightarrow R_4 = 2.2k$

OPAMP BASED MONOSTABLE MULTIVIBRATORS

When $R_1 = R_2$ the time period of the output pulse is given by

$T = RCln(2) \cong 0.693RC$

Desired $T\ = 10ms$

Choose $C = 0.1\mu F$; $\Rightarrow R = 144k$. Choose $150k$ std

Take $R_1 = R_2 = 10k$

Design of triggering circuit:

The charging recovery time: $T_{recovery} = RC.\ln\left(\frac{1+\beta}{1-V_D/V_{sat}}\right) = 150k \times 0.1\mu \ln\left(\frac{1.5}{1-0.7/13}\right) =$ $6.9ms$

The second trigger should not be applied within $6.9ms$ after applying the first trigger.

Hence, we choose a $\pm 5V$ $(5Vpp)$square wave with 50% duty cycle and 50ms total period(20Hz) and apply it to an RC differentiator circuit to produce positive and negative spikes at the rising and falling edges of the square wave respectively. We use a diode at the output of the differentiator to remove the positive going spikes.

Since the input pulse duration is 50ms, we take $R_dC_d \ll 50ms$ for proper differentiator operation

Take $R_dC_d = 50ms/10 = 5ms$

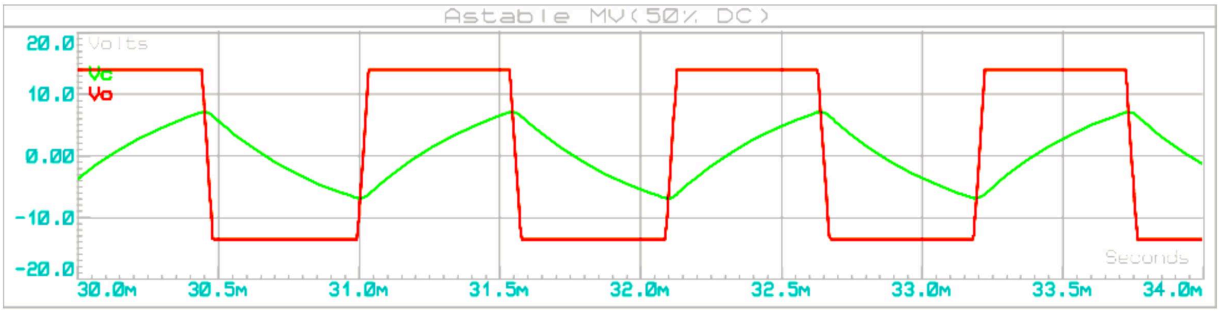
Choose $C_d = 0.1\mu F$; $\Rightarrow R = 50k$ Use $47k$ std.

PROCEDURE

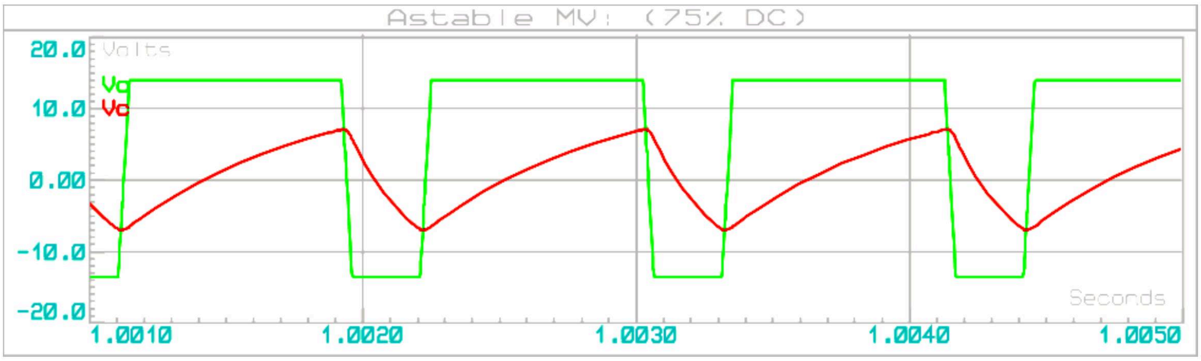
OPAMP BASED ASTABLE MULTIVIBRATORS(For both circuits)

- Setup the circuit and apply supply voltages to the op-amp terminals
- Observe the capacitor waveform v_C and the output waveform v_O simultaneously on the CRO
- Draw the observed waveforms and note down the timing values. Measure the observed on and off time periods of the output square wave and compute the duty cycle

Expected Waveforms: Astable multivibrator (50% Duty Cycle)



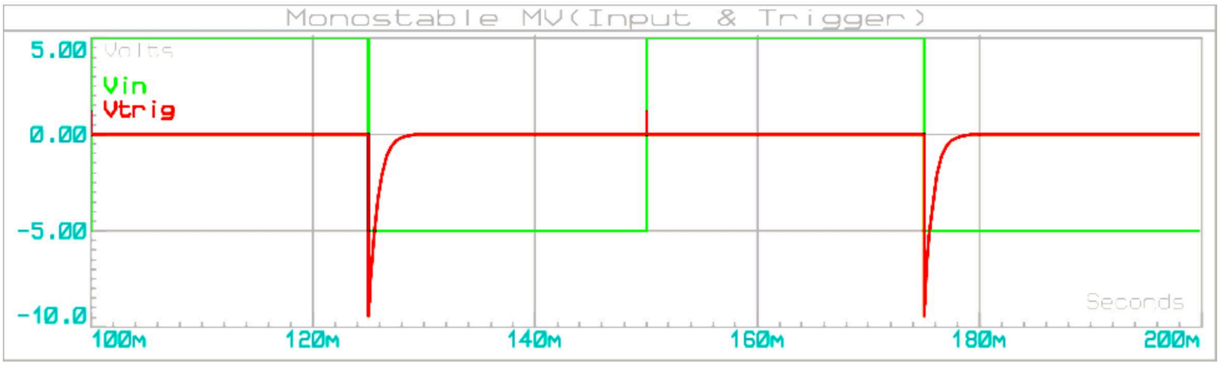
Expected Waveforms: Astable multivibrator (75% Duty Cycle)

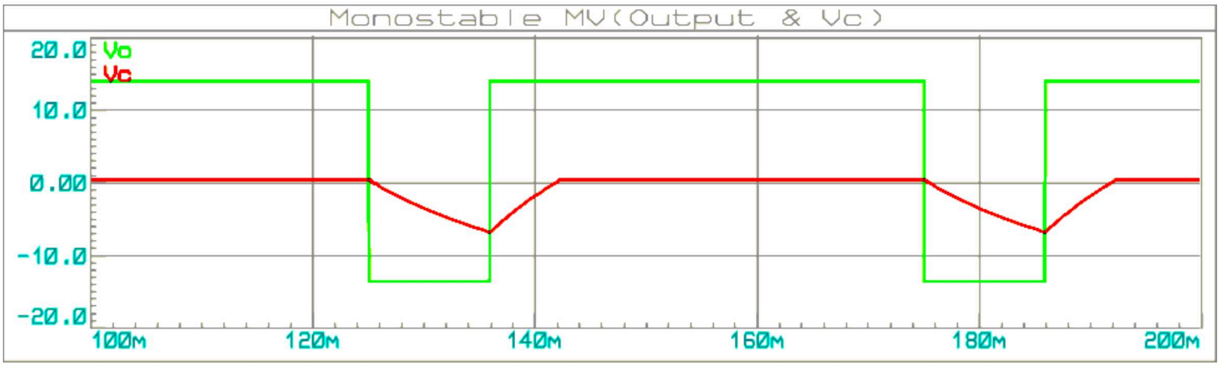


OPAMP BASED MONOSTABLE MULTIVIBRATOR

- Setup the circuit and provide supply voltages to the op-amp terminals
- Apply a square wave of 20Hz frequency as the input to the RC differentiator and connect the output of the differentiator to the non-inverting terminal of the op-amp
- Observe the input square wave v_{in}, the differentiator output v_{trig}, the capacitor waveform v_C and the output waveform v_O simultaneously on the CRO
- Draw the observed waveforms and note down the timing values. Measure the time period of the output pulse.

Expected Waveforms: Monostable multivibrator





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RESULTS

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

1 An Op-amp based Astable multivibrator circuit for 50% Duty Cycle and 1ms time period
   - Observed Time period =___
   - Observed Duty Cycle =___
2. An Op-amp based Astable multivibrator circuit for 75% Duty Cycle and 1ms time period
   - Observed Time period =___
   - Observed Duty Cycle =___
3. An Op-amp based Monostable multivibrator circuit for producing a time delay of $10ms$
   - Observed time delay =___