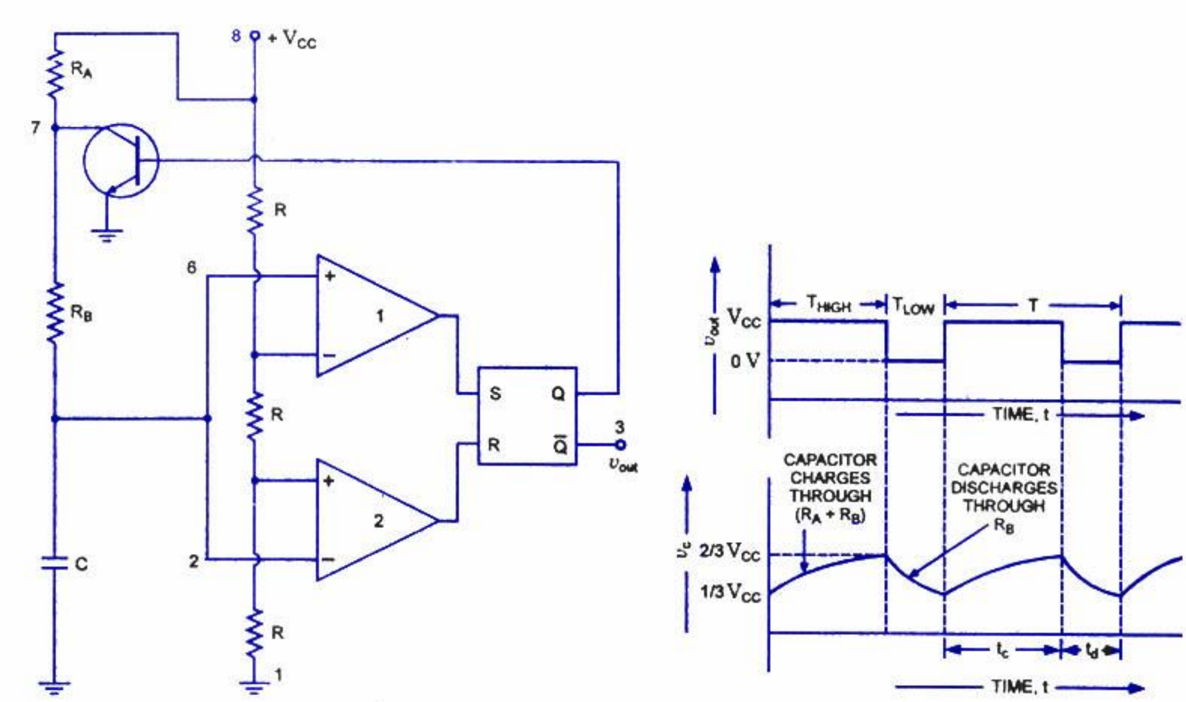
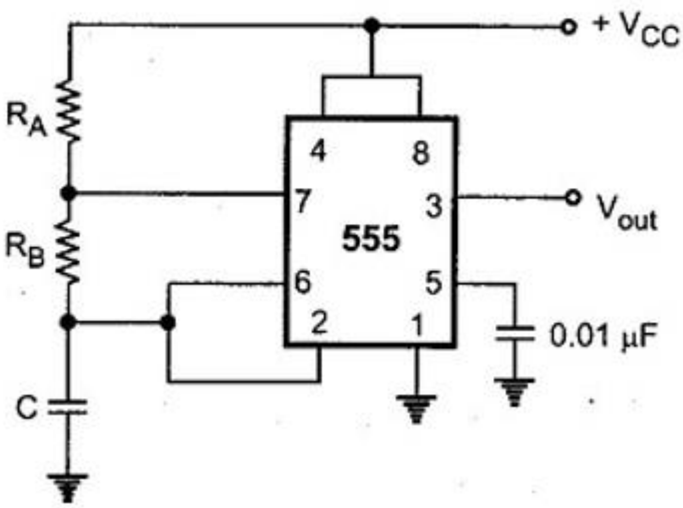
555 Timer Astable multivibrator

An astable multivibrator, often called a free-running multivibrator, is a rectangular-wave generating circuit. Unlike the monostable multivibrator, this circuit does not require any external trigger to change the state of the output, hence the name free-running. An astable multivibrator output consists of two quasi-stable states, that is it has no stable states in either HIGH or LOW states. Figure below shows the functional diagram of IC 555 used in astable mode of operation.



Internal Circuitry With External Connections *Capacitor and Output Voltage Waveforms*

Astable Operation



Operation When the flip-flop is set, Q is high which drives the transistor in saturation and the capacitor gets discharged. Now the capacitor voltage is nothing but the trigger voltage. So while discharging, when it becomes less than (1/3) V_{CC}, comparator 2 output goes high. This resets the flip-flop hence Q goes low and Q goes high. The low Q makes the transistor off. Thus capacitor starts charging through the resistances R_A, R_B and V_{CC}. Total resistance in the charging path is ($R_A + R_B$), the charging time constant is ($R_A + R_B$) C. Now the capacitor voltage is also a threshold voltage. While charging, capacitor voltage increases i.e. the threshold voltage increases. When it exceeds 2/3 V_{CC}, then the comparator 1 output goes high which sets the flip-flop. The flip-flop output Q becomes high and output at pin 3 i.e. Q becomes low. High Q drives transistor in saturation and capacitor starts discharging through resistance R_B and transistor. Thus the discharging time constant is R_BC. When capacitor voltage becomes less than (1/3) V_{CC}, comparator 2 output goes high, resetting the flip-flop. This cycle repeats. Thus when capacitor is charging, output is high while when it is discharging the output is low. The output is a rectangular wave. The capacitor voltage is exponentially rising and falling. The waveforms are shown in above the figure.

Derivation for the frequency of oscillations

At the output the waveform is not symmetric due to the fact that the charging time constant is greater than the discharging time constant. The high output remains for longer period than low output. The ratio of high output period and low output period is given by a mathematical parameter called duty cycle. It is defined as the ratio of ON time i.e. high output to the total time of one cycle.

The ON time and OFF time of the astable multivibrator circuit can be calculated by taking the charging and discharging time of the capacitor C. The ON time of a cycle is equal to the charging time of the capacitor from 1/3Vcc to 2/3Vcc and the OFF is equal to the discharge time from 2/3Vcc to 1/3Vcc.

V(t) is the voltage value across the capacitor at a particular instant of time t.

$$V(t) = V_{Final} – (V_{Final} – V_{Initial})\, e^{-t/RC}$$

During charging, the capacitor is charging towards the source voltage Vcc which is the final voltage. And the initial voltage is 1/3Vcc which has across the capacitor during the beginning of each cycle.

$$2V_{cc}/3 = V_{cc} – (V_{cc} - V_{cc}/3)\, e^{-T1/(RA+RB)C}$$

T1 is the time required to charge the capacitor C through resistance R_A+R_B from the voltage 1/3Vcc to 2/3Vcc by the source V_{cc}.

$$2V_{cc}/3 = V_{cc} – 2V_{cc}/3\, e^{-T1/(RA+RB)C}$$

$$V_{cc} – 2V_{cc}/3 = 2V_{cc}/3\, e^{-T1/(RA+RB)C}$$

$$V_{cc}/3 = 2V_{cc}/3\, e^{-T1/(RA+RB)C}$$

$$1/2 = e\,\text{^}(- T_1/(R_A+R_B)\, C)$$

Applying natural log function at both sides of the equation.

$$\ln(1/2) = \ln(e^{\wedge}(-T_1/(R_A+R_B)\,C))$$

$$-\ln(2) = -T_1/(R_A+R_B)\,C$$

$$\boxed{T_1 = 0.69 * (R_A + R_B) * C}$$

Similarly, for the OFF calculate the time period for discharge of capacitor from the voltage $2V_{cc}/3$ to $V_{cc}/3$.

$$V_{cc}/3 = 2V_{cc}/3\ e^{-T_2/R_B * C}$$

T_2 is the time required to discharge the capacitor C through resistance RB.

$$T_2/R_B * C = \ln(2)$$

$$\boxed{T_2 = 0.69 * R_B * C}$$

DUTY CYCLE = T_1/ T_1 + T_2

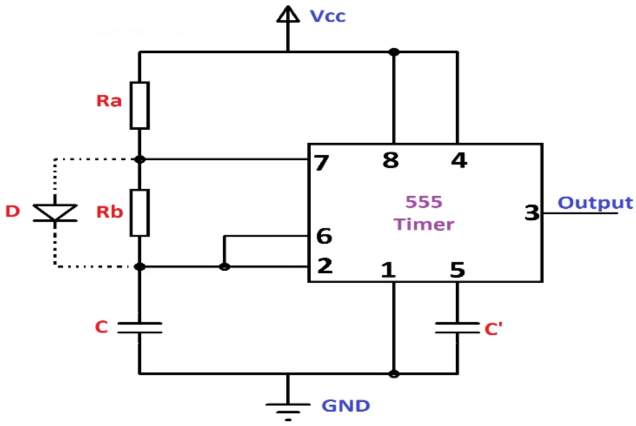
From the above formula of T1 and T2, the duty cycle can be calculated as,

$$D = (R_A+R_B)/(R_A+2R_B)$$

$$\textbf{\% Duty cycle, D} = (R_A+R_B)/(R_A+2R_B) * 100$$

Astable multivibrator using 555 timer with diode:

The above 555 astable mutivibrator circuit can only generate an output which has a duty cycle above 50%. Because as the charging resistance is RA+RB and discharging resistance is RB, the T1 or the ON period will be always greater than the OFF period. Thus a duty cycle below 50% is not possible with the normal 555 astable circuit.



So in order to charge and discharge the capacitor through different resistors, a bypass diode is added in the below circuit. Hence, during charging the Diode D bypass the resistance RB and the charging current flows through RA and D. And the discharge as same as normal circuit through the RB.

Astable multivibrator with diode formula derivation

Here the charging and discharging is done through two independent resistors the formula derivation is same as the above 555 astable multivibrator circuit except for the charging resistor.

ON time Formula, T1 = 0.69 * RA * C

OFF time Formula, T2 = 0.69 * RB * C

The total time period, T = T1 + T2 = TON + TOFF

T = 0.69 * RA * C + 0.69 * RB * C

T = 0.69 * (RA + RB) * C

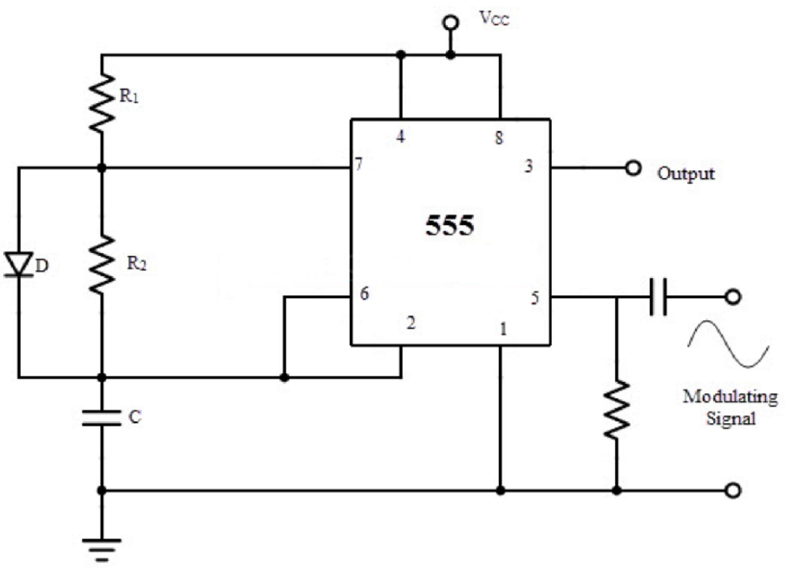
Here we get a

Duty cycle, D = RA/(RA+RB)

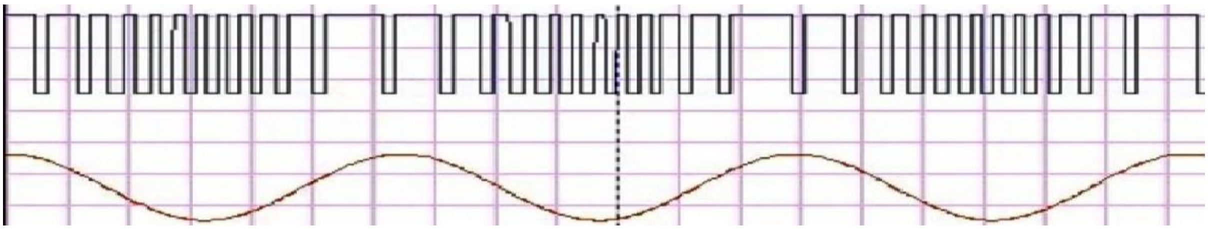
Duty cycle in %, D = RA/(RA+RB) * 100

Frequency Modulation using Astable Multivibrator

Astable multivibrator can be used to generate frequency modulated signals. A modulating signal is given to the pin 5 (control voltage). The circuit of Frequency Modulation using astable mode of operation of the IC 555 is shown below.



A diode is connected in parallel to the resistor R2 in order to generate a pulse output with duty cycle ≈ 50%. The modulation signal is applied at pin 5 through a high pass filter consisting of a capacitor and a resistor. According to the modulating signal applied at pin 5, the output will be frequency modulated. If the voltage of the modulating signal is high, the time period of the output signal is high and if the voltage of the modulating signal is low, the time period is low. The waveforms of the modulation signal and the frequency modulated signal are shown below.

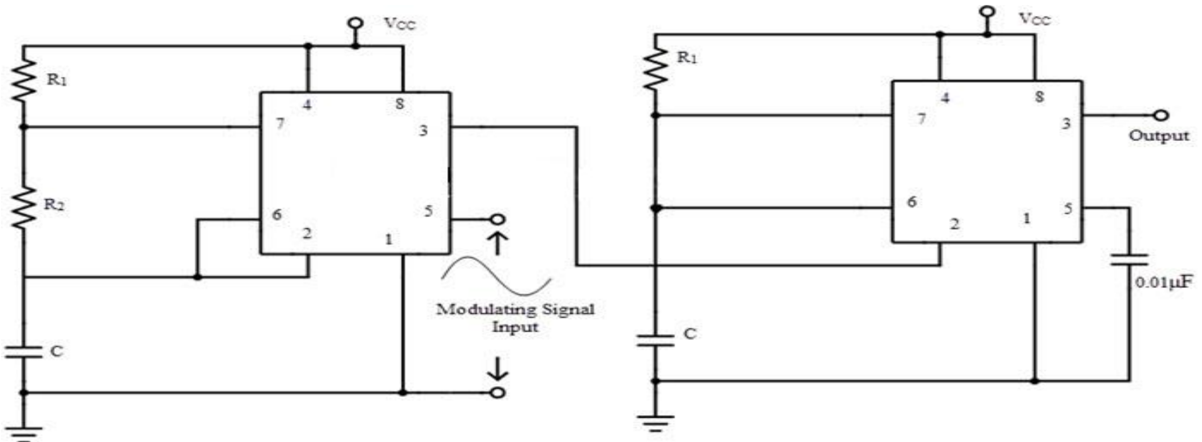


Pulse Position Modulation:

In pulse position modulation, the position of the pulse varies according to the modulating signal while the amplitude and the width of the pulse are kept constant. The position of the each pulse changes according to the instantaneous samples voltage of the modulating signal. In order to achieve Pulse Position Modulation, two 555 timer IC's are used in which one operates in astable mode and the other in monostable mode.

The modulating signal is applied at the Pin 5 of the first IC 555 that is operating in astable mode. The output of this IC 555 is a pulse width modulated wave. This PWM signal is applied as the trigger input to the second IC 555 which is operating in monostable mode. The position of the output pulses of the second IC 555 changes according to the PWM signal which is again dependent on the modulating signal.

The schematic of the Pulse Position Modulator using two 555 timer IC's is shown below.



The threshold voltage for the first IC 555, which is determined by the control voltage (modulating signal), is changed to UTL (Upper Threshold Level) and is given by

$$UTL = 2/3\ VCC + VMOD$$

As the threshold voltage changes with respect to the applied modulating signal, the width of the pulse changes and the hence the time delay is varied. As this pulse width modulated signal is applied to the trigger of the second IC, there will be no change in either amplitude or width of the output pulse but only the position of the pulse is changed.

The waveforms of the pulse position modulated signals are shown below.