Integrated Circuits and Applications
Prof. Shaik Rafi Ahamed
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

555 Timer
Lecture - 29
Astable operation

So in the last lectures we have discussed about the monostable multivibrator and its applications using 555 timer. The second mode of this 555 timer is astable mode. So, this is the circuit diagram of 555 timer in astable mode. You can see some differences between this astable mode and monostable mode. So, one difference is in stable mode we have only one resistor whereas, here we have two resistors R_A and R_B. Another important difference is in astable mode there is no trigger signal.

So, the trigger input 2 will be connected to 6 pin and that will be connected to the capacitor C. Now, using this astable mode also we can generate the square wave at the output. So, in order to explain the operation initially without applying V_{CC}. So, the voltage across the capacitor will be 0.

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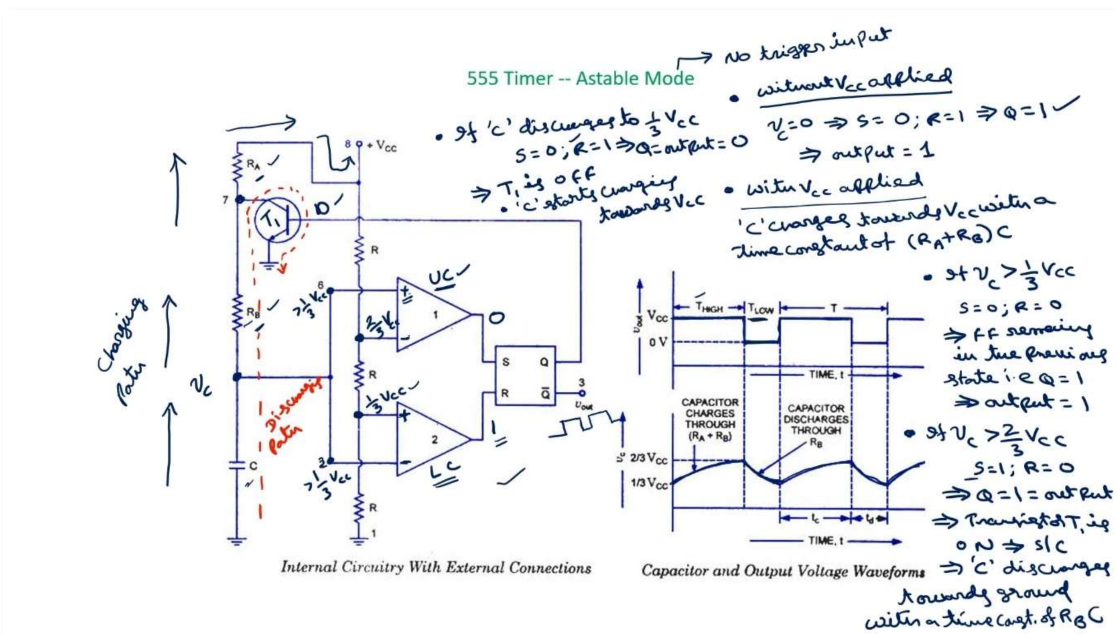

Let us call this voltage as v_C, v_C is 0 and v_C is the voltage at 6^{th} terminal as well as 2^{nd} terminal okay. So, for this operational amplifier which will acts as a upper comparator this voltage is $\frac{2}{3}V_{CC}$ which we have already discussed in the earlier lectures. For the lower comparator this voltage is $\frac{1}{3}V_{CC}$. Observe that here $\frac{2}{3}V_{CC}$ is applied to the negative terminal whereas, this $\frac{1}{3}V_{CC}$ is applied to the positive terminal. Now, the voltage across capacitor will be applied to the positive terminal of upper comparator negative terminal of lower comparator.

So, if this voltage is 0 what happens to this output of upper comparator because the voltage at positive terminal is 0 negative terminal is greater than 0. So, output will be logic 0 implies S is equal to 0 whereas, for the lower comparator the voltage at inverting terminal is 0 non-inverting terminal is positive value which is greater than 0. So, as a result of that R becomes 1. So, because reset input is 1 implies Q is equal to 1. So, that Q itself will acts as the output of the circuit implies output of stable multivibrator is 1.

Now, if I apply the V_{CC} also this will remain ON only with V_{CC} applied then what happens the capacitor will charges towards the V_{CC}. So, this is the charging path this will charge towards this V_{CC} this is charging path capacitor C charges towards V_{CC} with a time constant of RC but here R is sum of R_A and R_B. So, $(R_A + R_B)C$. Now, capacitor voltage may reach a value which is slightly greater than one third V_{CC}. If v_C is slightly greater than $\frac{1}{3}V_{CC}$ what happens to the output? You can see that if this voltage is slightly more than $\frac{1}{3}V_{CC}$ what will be output of upper comparator and what will be output of lower comparator?

So, here this positive voltage is less than negative voltage for the upper comparator so 0 whereas, for the lower comparator negative terminal voltage is greater than positive terminal voltage so this is also 0. So, S is equal to R is equal to 0 implies flip flop remains in the previous state. What is that previous state? Q is equal to 1. Implies output is also 1.

Now, if it charges to a value which is slightly more than $\frac{2}{3}V_{CC}$, if $v_C > \frac{2}{3}V_{CC}$ what happens? Now, this voltage will be greater than $\frac{2}{3}V_{CC}$. So, for the upper comparator the voltage at positive terminal is more than the voltage at negative terminal. So, output becomes 1 whereas, for lower comparator the voltage at negative terminal is greater than voltage at positive terminal as a result of that this remains 0 only. So, what happens S becomes 1, R becomes 0 implies set input is 1 means Q is equal to 1 that itself is output.

Now, what happens we will see. Now, if Q is equal to 1. So, this Q is connected to this transistor T_1. If this Q is equal to 1 this will on the transistor T_1, it will act as short circuit. Now, the capacitor has a path to discharge through this short circuit to the ground.

Now, what will be the discharging path of the capacitor? So, this is the discharging path because this transistor is short circuited this will go to the ground this is discharging path. Implies capacitor discharges towards ground with a time constant of R_BC because in the discharging path you can see this red dotted line. So, this R_B is there this C is there. Now, when it discharges to a value of $\frac{1}{3}V_{CC}$ it has to actually discharge up to the ground, but when it discharges to a value of $\frac{1}{3}V_{CC}$. What happens now this voltage is again $\frac{1}{3}V_{CC}$ this is $\frac{1}{3}V_{CC}$.

So, what happens you can see. So, for the upper comparator positive terminal voltage is less than negative terminal voltage. So, output becomes 0 and for the lower comparator negative terminal voltage is greater than positive terminal voltage. So, output of the comparator becomes 1. So, S is equal to 0, R is equal to 1 implies Q is equal to output is equal to 1.

Now, what happens to transistor T_1? Q is equal to 1 means $\overline{Q}$ is equal to 0, S is equal to 0, R is equal to 1 means output is equal to 0 because reset input is 1. Now, this input is 0 for this transistor T_1. So, what happens to T_1? T_1 is OFF. So, there is no path for the capacitor to discharge. Now, the capacitor starts again charging towards V_{CC} with the time constant of $(R_A + R_B)C$.

Again, when it charges to a value which is $\frac{2}{3}V_{CC}$ output again goes to HIGH. So, what happens is the voltage across the capacitor switches between $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ and the output also switches between HIGH to LOW. So, you can see from this figure that. So, when it charges from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ output is HIGH and when it discharges from $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$, LOW. Again, when it comes to a value which is $\frac{1}{3}V_{CC}$.

So, this transistor will be OFF and again the capacitor will charges this cycle will repeat. As a result of that at the output of this 555 timer will get a rectangular type of the output. Because this discharging time constant is less charging time constant is $(R_A + R_B)C$ discharging time constant is R_BC. So, this $T_{LOW} < T_{HIGH}$. Now, this is the total time period $T_{HIGH} + T_{LOW}$.

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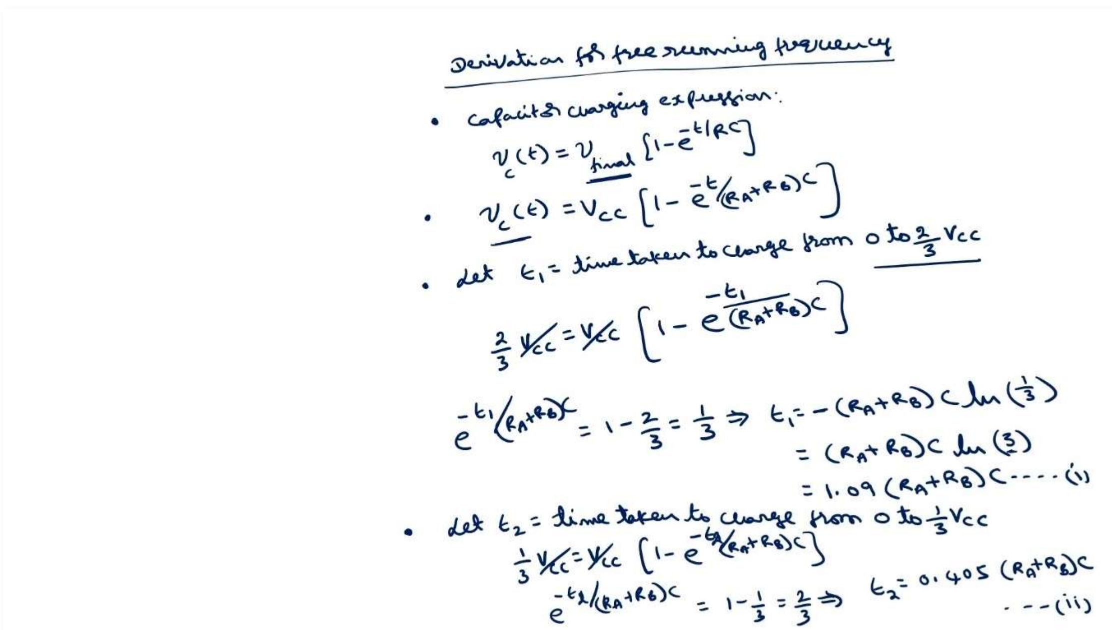

So, what is the expression for this total time period of the output signal generated by astable multivibrator? For that I will consider derivation for free running frequency of astable multivibrator. We know that the charging expression of the capacitor is v_C of course function of t is equal to $v_{final}[1 - e^{-\frac{t}{RC}}]$ where RC is the time constant. So, in the present case of the astable multivibrator what will be $v_C(t)$? is equal to the final value to which it charges is $V_{CC}[1 - e^{-\frac{t}{(R_A+R_B)C}}]$. Now, let t_1 is equal to time taken to charge from 0 to $\frac{2}{3}V_{CC}$. Then what will be expression for t_1? So, if you substitute this here this v_C is $\frac{2}{3}V_{CC}$ should be equal to $V_{CC}[1-e^{-\frac{t}{(R_A+R_B)C}}]$ becomes $V_{CC}[1-e^{-\frac{t_1}{(R_A+R_B)C}}]$.

So, this V_{CC} V_{CC} will get cancelled. If I take this term to other side $e^{-\frac{t_1}{(R_A+R_B)C}} = 1-\frac{2}{3}$ which is equal to $\frac{1}{3}$ or $t_1 = -(R_A+R_B)Cln(\frac{1}{3})$ or this is equal to $(R_A+R_B)Cln(3)$. This negative sign if you take inside the logarithm then you have to reverse this $\frac{1}{3}$. So, this becomes 3. So, $\ln(3)$ value is approximately equal to $1.09(R_A+R_B)C$. This you call as equation (i). Now, let t_2 is time taken to charge from 0 to $\frac{1}{3}V_{CC}$. Then what happened to this relation this $\frac{1}{3}V_{CC} = V_{CC}[1-e^{-\frac{t_2}{(R_A+R_B)C}}]$. So, this V_{CC} V_{CC} will get cancelled. So, you will get the same expression except for that here instead of 3 you will be having $\frac{2}{3}$ because $e^{-\frac{t_2}{(R_A+R_B)C}} = 1-\frac{1}{3}$ this is equal to $\frac{2}{3}$.

So, the only difference is here instead of 3 you will be having $\frac{3}{2}$. So, only if I calculate in a similar manner you will get t_2 as this is t_2 $0.405(R_A+R_B)C$. Now, we have one expression for the capacitor to charge from 0 to $\frac{2}{3}V_{CC}$ another from 0 to $\frac{1}{3}V_{CC}$. But what is interested is here the time taken to charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ and $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$.

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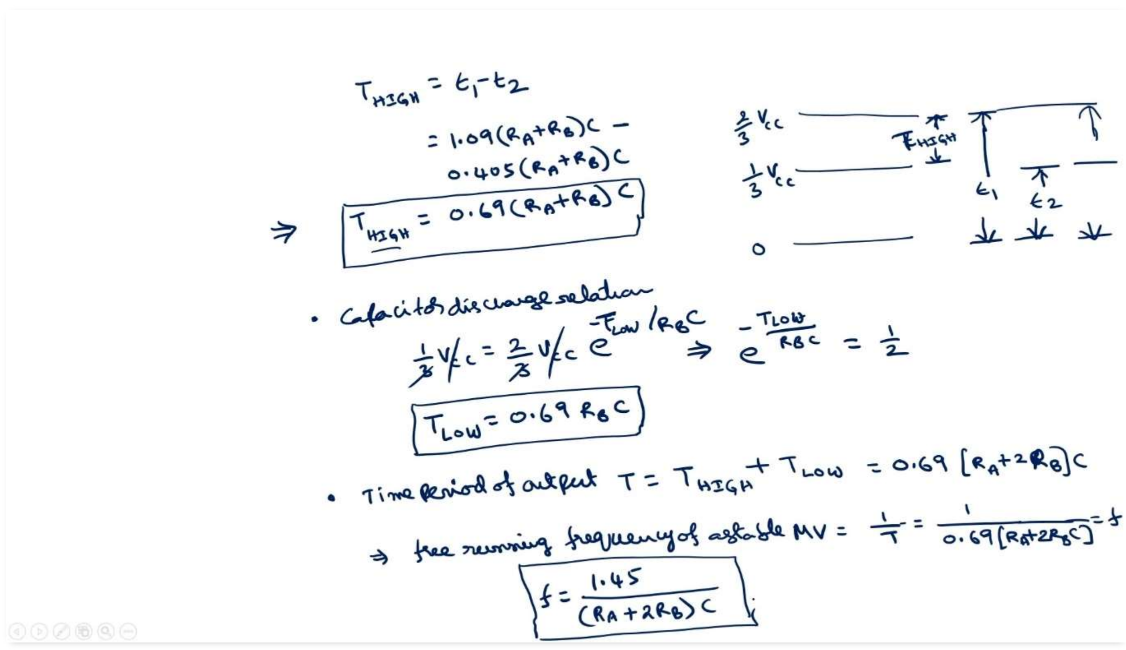

Because from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ we will call as $\frac{2}{3}$ time and $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$ will call as T_{LOW} time which is clear here. So, T_{HIGH} time is charging from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$ and T_{LOW} time is $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$. What we have computed is from 0 to $\frac{2}{3}V_{CC}$, 0 to $\frac{1}{3}V_{CC}$. Now, to get T_{HIGH} and T_{LOW}, these are the three values this is $0, \frac{1}{3}V_{CC}, \frac{2}{3}V_{CC}$. 0 to $\frac{1}{3}V_{CC}$ we called as t_2. So, this time taken for this one is t_2 and 0 to $\frac{2}{3}V_{CC}$ we called as t_1. Now, what is the time taken to charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$? This is T_{HIGH} this is T_{HIGH} $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$. So, T_{HIGH} is equal to this t_1 is the total time from this if I subtract t_2 we will get T_{HIGH}. So, $t_1 - t_2$. So, what is t_1? $1.09(R_A + R_B)C - 0.405(R_A + R_B)C$. So, what is the difference between 1.09 and 0.405? This will comes to $0.69(R_A + R_B)C$ this is the expression for T_{HIGH}.

Similarly, we can obtain the expression for the T_{LOW}. So, in order to obtain for the T_{LOW} we have to consider the discharging capacitor expression because during this two-third to one-third capacitor discharging. So, we cannot use this relation capacitor discharging relation will be $\frac{1}{3}V_{CC}$ is equal to $\frac{2}{3}V_{CC}e^{-t}$ we call this as $\frac{T_{OFF}}{R_B C}$ because the discharging time constant is $R_B C$ which we have already discussed earlier. So, you see the discharging expression. So, what is the expression for T_{OFF}? This V_{CC} V_{CC} get cancelled, 3 3 get cancelled therefore, e to the power of $-T_{OFF}$ divided by T_{OFF} or T_{LOW} it is up to you because you have used HIGH here I am using LOW.

So, $\frac{T_{LOW}}{R_B C} = \frac{1}{2}$ or T_{LOW} after simplification you will get expression as $0.69 R_B C$. Therefore, the total time period of the output signal $T = T_{HIGH} + T_{LOW}$. So, it will be equal to $0.69(R_A + 2R_B)C$. So, what is the free running frequency? Multivibrator, MV stands for multivibrator is equal to $\frac{1}{T}$ is $\frac{1}{0.69(R_A+2R_B)C}$. This is the free running frequency f or if I take 0.69 to the numerator this will be $\frac{1.45}{(R_A+2R_B)C}$ this is the important expression for the free running frequency.

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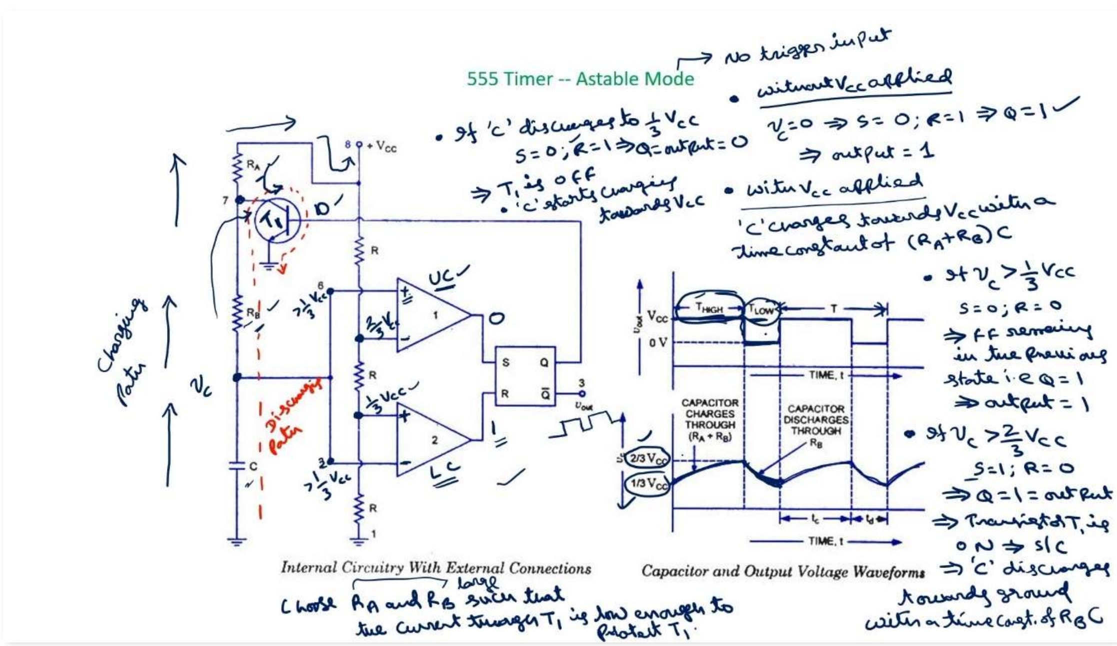

But here what should be the choice of R_A and R_B? If we consider the circuit diagram again we can see that when this transistor T_1 is ON. So, this will acts as short circuit and the current flows from this R_B as well as R_A also. As a result of that if R_A and R_B are low values more current will flow thereby it may damage the transistor T_1. So, you have to properly choose R_A and R_B such that the current flow through this T_1 is less which can protect the T_1 from the damage. You have to choose this R_A and R_B such that current through T_1 is LOW enough to protect T_1. So, normally you have to choose this R_A and R_B large values. This is one important observation and another thing is here we can see that this is not the square view this is rectangular view because ON time or HIGH time is more than LOW time.

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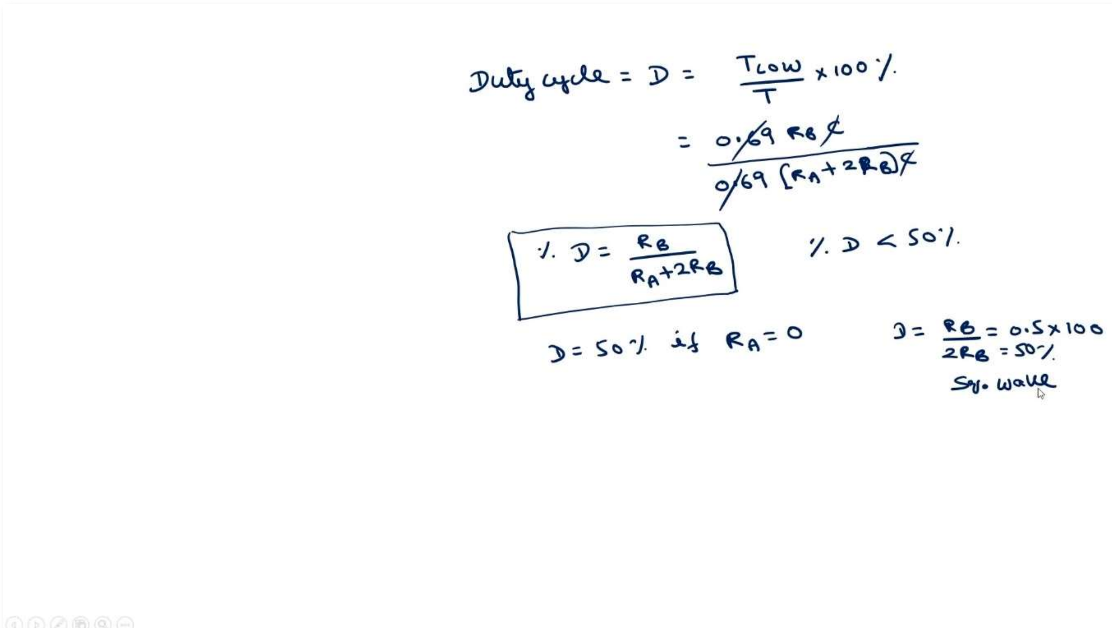

Here there is one important parameter called as duty cycle is defined as D T_{LOW} divided by total time T into 100 percent. So, what is the duty cycle of the astable multivibrator? T_{LOW} we have derived as $0.69R_BC$ and total time will be $0.69(R_A + 2R_B)C$. So, C C get cancelled 0.69 0.69 will get cancelled. So, therefore, percentage of D is equal to $\frac{R_B}{R_A+2R_B}$. Here because the numerator is less than the denominator this percentage of D is always less than 50%. If I want to make this duty cycle as 50% so, that you will get square view. So, how do you make this D as 50? If you make R_A is equal to 0, if R_A is equal to 0 what is D? $\frac{R_B}{2R_B}$ this is equal to 0.5 into 100 will be 50%. So, that you will get square wave instead of rectangular wave.

But that is not possible here why because here this if R_A is equal to 0 then the more current will flows through the transistor T_1 because resistance is 0 that may cause a damage to the T_1 thereby the entire stable circuit. So, as result of that this is not the feasible solution. So, in order to have a duty cycle 50% or more than 50% so, we have to use alternative circuit. So, now such circuit is this is your 555 timer 8 4 are connected to V_{CC}, 8 3 we are going to take the output 5 and 1 are connected to the ground this 5 will be connected to $0.1\mu F$. And here we are connecting R_A, R_B then capacitor C to the ground and this 2 also connected to 6 this is 7. So, initially charging time constant was $(R_A + R_B)C$ and discharging time constant is R_BC because of that we will not achieve this duty cycle 50%.

Now, in order to get the duty cycle 50%, I am going to connect a diode here. So, that what happens is during the charging cycle the voltage at the anode is more than the voltage at cathode as a result of that diode will be forward biased. And if you take the ideal diode it will acts as short circuit and because this is connected across the R_B, R_B also will be short circuited now the charging time constant becomes $R_A C$ previously it was $(R_A + R_B)C$ now because of the connection of this diode.

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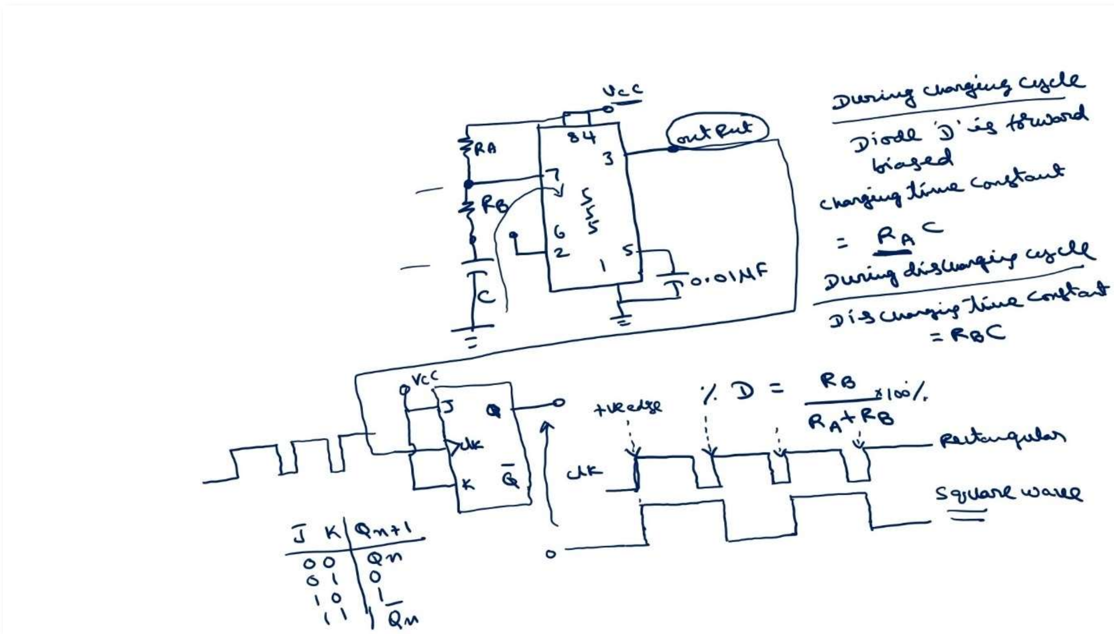

So, during the charging cycle this diode will be forward biased thereby it will act as short circuit this path will be short circuited this will effectively acts like short circuit. So, the charging time constant will be $R_A C$ whereas, during the discharging cycle the diode will acts as open circuit as a result of that the diode will be here the diode will be open circuited as a result of that the R_B whatever the resistance that we have connected here will be present, this we can remove. So, discharging path is this one through this transistor which is presented 7^{th} terminal to the ground which we have discussed in the earlier slide. So, what will be discharging time constant? is equal to $R_B C$ as a result of that what will be the percentage of duty cycle? So, we have $\frac{R_B}{R_A+R_B}$ only because here in the previous diagram without diode this was $R_A + R_B$ now this is R_A only.

So, because of that this will be $R_A + R_B$ into 100%. Now, by properly choosing R_A and R_B we can make this duty cycle 50% as a result of that the output now will becomes square wave instead of rectangular wave. This is one way to generate the square wave at the output instead of rectangular wave. Another way is we can connect this output of this 555 timer astable circuit to a flip flop you connect this output to the input of a flip flop. This is clock, this is J and K this is Q, $\overline{Q}$. Now we will take the final output here this J and K will be connected to this V_{CC}. So, this will acts as a T flip flop in toggle mode. Now, the clock signal is this. So, initially without diode and all this circuit will generate here rectangular type of waveform ON time is more, OFF time is less because here diode was not there without diode this is the output that will be generated, but I want to convert this into square wave okay.

So, if this type of input is connected to the clock, this is clock signal and J is equal to K is equal to 1 for J is equal to K is equal to 1 the output always will changes the state. If I take J K flip flop truth table $Q_n + 1$ is the present state Q_n is the previous state for 00 it will remain in the previous state 01 regardless of the previous state 0 10 regardless of the previous state 1 for 11 $\overline{Q_n}$. If previous state is 0 present state becomes 1, previous state is 1 present state becomes 0.

And if I assume that this clock is positive edge triggered clock. So, at the positive edge of this clock signal it will enable this is positive edge these are the positive edges. Say initially output is 0. So, at the positive edge because J is equal to K is equal to 1 0 becomes 1 and this will stay HIGH until the next positive edge. So, at this positive edge because J is equal to K is equal to 1 again it will goes to LOW it will continue up to next positive edge again HIGH up to next positive edge like that this will be a square wave.

This is the rectangular wave which is generated the output of 555 timer astable mode without a diode. So, to get a square wave one technique is you can connect the diode, second technique is you can connect the output of astable multivibrator to the clock of J K flip flop and make J is equal to K is equal to 1. So, you will get the output as square wave. So, this will be generated here. So, this is about this 555 timer in astable mode. So, using this astable mode you can generate a rectangular wave as well as a square wave.

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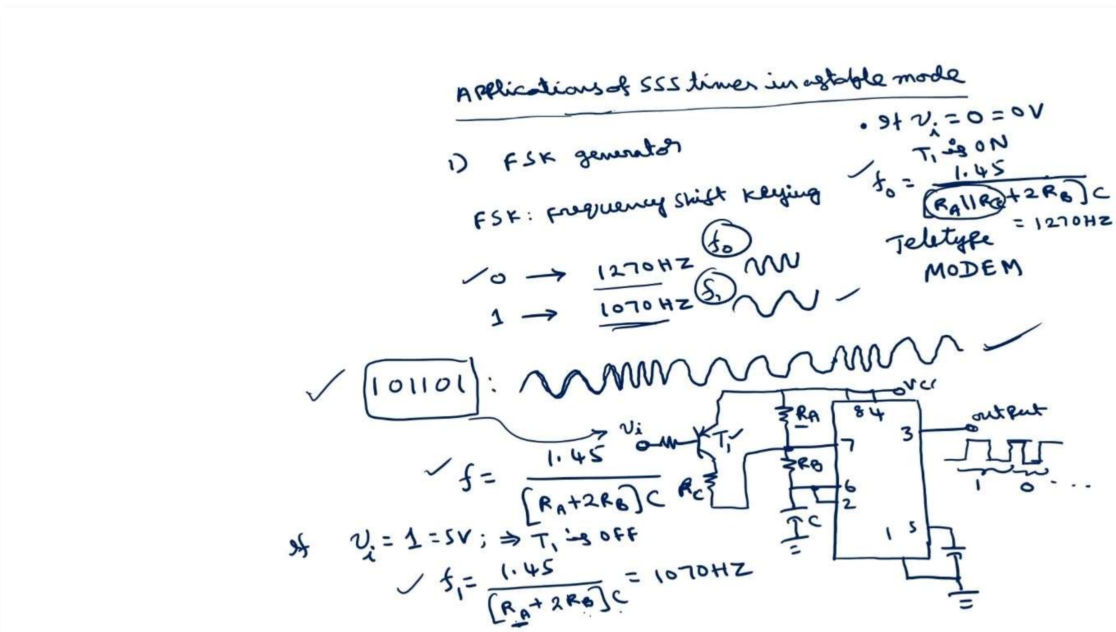

Now, there are some applications of this 555 timer in astable mode. We have discussed some applications of this 555 timer in monostable mode also. In astable mode also we have some applications. One application is FSK generator. FSK stands for Frequency Shift Keying. This is one of the digital modulation technique. So, in the digital modulation we are going to transmit zeros and ones. So, in case of FSK, 0 will be transmitted by 1270 Hertz signal. This is some high frequency signal and 1 will be transmitted by 1070 Hertz signal in teletype radar this is relatively larger. So, in order to transmit a bit of 101101. So, the waveform that will be for 1 this is high frequency and 0 high frequency for 1 this is low frequency for 0 high frequency. Again, two 1s two low frequency signals 10 high frequency signal then 11 low frequency signal. So, this will be transmitted in order to transmit this 101101.

So, basically here we have to generate the output with the two frequencies one is 1270 another is 1070 in case of teletype MODEM modulator demodulator. So, we know that the free running frequency of astable multivibrator is $\frac{1.45}{(R_A+2R_B)C}$. So, what you are going to do here is. So, I will connect this 555 timer in astable mode. This is circuit diagram of astable mode and we are going to do some modification here. This is R_A, this is R_B, this is capacitor, this 2 will be connected to 6 and 7. So, the extra modification is where we are going to give this bit pattern.

So, for that we need some input circuit here I am going to give this through the transistor. So, this transistor is connected here, this will be connected to R_C, this is input v_i that is bit pattern this bit pattern is connected here. Now, we can see that the output frequencies let us call this frequency corresponding to 0 you call as this as f_0 corresponding to 1 you call as f_1. So, if you apply a logic 1 if v_i is logic 1 which is 5 volts then what happens this transistor will be OFF, T_1 is OFF. This T_1 is different from the T_1 that we have used in the astable mode okay. So, T_1 is OFF as a result of that what happens this will be open circuited what will be the expression for the frequency of this one f_1 R_C will not come into the picture and the frequency this frequency itself $\frac{1.45}{(R_A+2R_B)C}$. So, now, we choose the values of R_A R_B C such that this will be 1070 Hertz.

On the other hand, if vi is logic 0 it is 0 volts then this transistor will be ON as a result of that what will be the frequency now this R_A will come in parallel with R_C this is short circuited. So, this expression becomes now f_0 expression becomes 1.45 divided by R_A becomes R_A in parallel with R_C $+ 2RB$ into C. Now, we have to choose this R_A R_B R_C and C such that these frequencies 1270 Hertz. We can see that this value is less than this R_A value because R_A are taking a parallel combination with R_C okay. So, in the denominator lower value means this frequency is larger than this frequency. So, like that here we will get FSK output of course, here I have explained for the sine wave, but here we will get square wave 0 means we will get large amplitude this is corresponding to 0 corresponding to 1 small frequency. So, 0 means large frequency so, less time period. So, this is 1 this is 0 and so on. This is how we can generate this FSK using 555 timer.

The second application of this 555 timer in astable mode is you can generate PPM signal also using astable multivibrator. PPM stands for pulse position modulation. Using a monostable multivibrator we can generate the PWM waveform which is pulse width modulation whereas using astable mode we can generate the pulse position modulation.

So, what is the difference between the pulse position modulation and pulse width modulation? If I take this modulating signal as sine wave this is modulating signal. There will be carrier signal which will be square wave. This is carrier. Then what will be the PWM modulated signal which we have discussed in the earlier lectures? The width of the signal is varied in accordance with the magnitude of a modulating signal. If I take the first sample here this magnitude will remains the same. If I take the second sample here this magnitude is more than that of the previous magnitude because this amplitude is greater than this amplitude. If I take here this will be highest and here this will be same as this almost. Again here 0 it is 0 this is same as this and for negative you will be having if I take here they will be having less magnitude less duration because of negative values. Here this will be again same less value like that this PWM will be generated.

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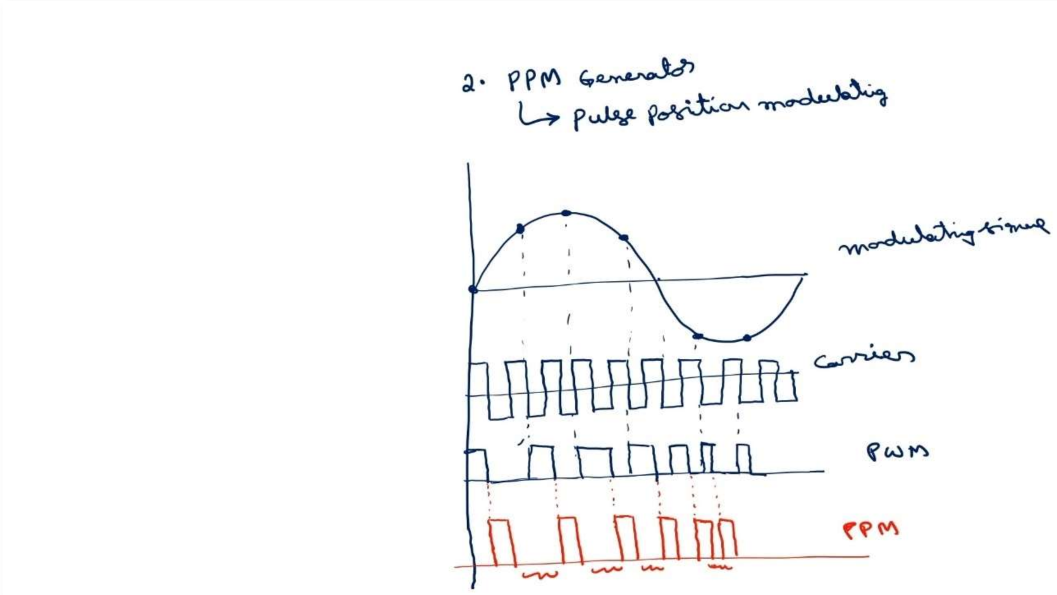

Now, PPM will be pulse position modulation. If we take this PWM at the end of this pulse, pulse width remains same this is the pulse width, but the position of this pulse will changes. Here the position is this, here the position is this, here the position is this. You can see that this distance is varied this is called pulse position. You can see that here the distance is reduced further here it will be reduced. You can see that here the distance between the two successive pulses is very less means position is reduced position is changed this is called PPM wave pulse position modulation.

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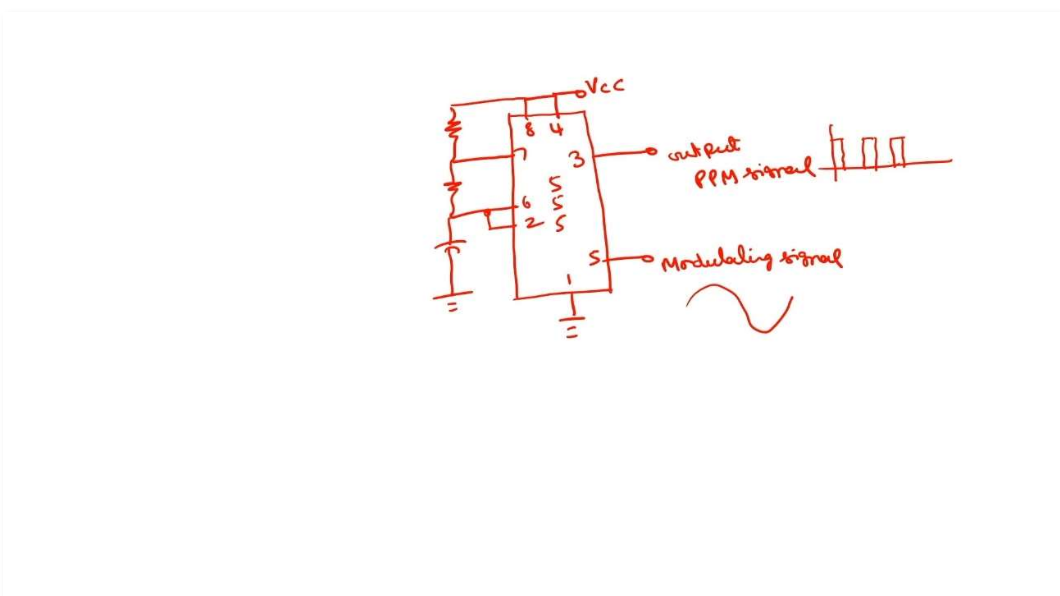

So, in order to generate this PPM wave the circuit diagram is instead of grounding this 5th pin of 555 timer you have to connect modulating signal. Here you have to connect the modulating signal that 3 will get output which is PPM signal and the remaining circuit is same. This is 555 timer circuit. So, if you apply this modulating signal here you will get the PPM signal here which positions will changes. So, these are the applications of this astable multivibrator. So, this is all about the 555 timer we have discussed about the operation of the 555 timer then we consider the monostable multivibrator operation, the applications of the monostable multivibrator, then astable multivibrator, applications of the astable multivibrator.

So, in the next lecture we will discuss another specialized IC called as PLL okay.

Thank you.