Electrical Measurements And Electronic Instruments
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Lecture – 77
555 – Timer circuit

Hello and we will come back again. So, this week we are starting function generators and oscillator circuits. We have seen one function generator; we shall take of couple of more examples popular examples and you shall see that there is a common underlying similarity in all these circuits. So, if you understand them one of one or few of them well, you can generate you can make your own circuits, not very difficult.

So, today now we shall take up a popular circuit called 555 timers. This also comes in a compact integrated circuit for this IC 555 timer you can also make it I mean these you can also realize this circuit using op-amps once we study it is very simple.

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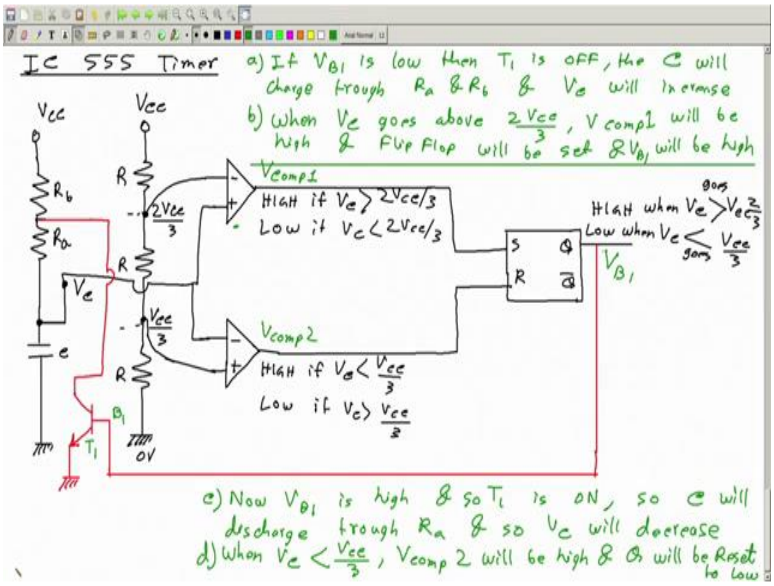

So, the topic is IC triple 5 or 555 timer. This is what this is a oscillator circuit I mean this can be used as a oscillator circuit and we can generate a square wave using this just like the previous function generator we have talked about using this circuit also we can also generate square wave or rectangular wave to be precise. So, let us see.

This is made up of mainly two comparators. Do not once again do not please try to memorize it, try to understand it if you understand it you can always recall and reproduce it on your own you do not have to memorize it. So, just I will take two comparators and one potential divider. So, let us take two comparators these are op-amps they will have two inputs plus minus plus minus one output and a potential divider which divides which has three equal voltages equal resistances 1 2 and 3 this side is 0 volt this side is positive. We call it V cc this is a positive voltage applied and this is 0 volt, this is R, this is R, this is R.

So, what is the voltage here? The voltage this voltage will be Vcc/ 3. this voltage will be 2 Vcc/3, two third of this voltage. The task of these two comparators is to compare another voltage which I have not drawn or let me just draw it. So, another voltage calls it V c. So, there will be another voltage coming from somewhere something; this voltage will be compared against these two levels ok.

So, we have to compare this voltage whether it is higher than this two third of Vcc or is it lower than this level. This is what we have to do and to compare with this we have this comparator and to compare with this we have this. So, this comparator will tell me if the Vcc is lower than this. So, what we can do let us connect this to the plus terminal and let me connect this to the minus terminal. So, this voltage will tell me if this is higher or lower than this Vcc/ 3 ok. So, now, this will be high.

So, let me write this will be high, this output will be high if when this will be high, if this is low if negative input is low; that means, if V c < Vcc/3 and that means, also this will be low if Vc > Vcc/3. This is what this will tell me ok. Similarly I will connect this comparator so that this comparator tells whether this is higher than this or not. Say I want that the output to be high if this is what I want I want this is to be high if Vc > 2 Vcc /3 and low if V c < 2 Vcc/ 3.

So, what I have to do then, I have to connect the plus terminal to the Vcc and the minus terminal here. So, if this V c is this V c goes high then the output will be high right. So, I mean once I compute this circuit after that we will see that you actually do not have to remember anything; you could have taken all these opposite logics. You would have taken that this is low, if this is greater this is high if this is and so on and accordingly you can complete this story and complete the circuit. So, make your own choice think and choice do choose ok.

Now, what I will do take I will take a flipflop; S-R flipflop. S-R these are the two inputs, it I can take two outputs Q and Q bar. This is S-R flipflop. Let me connect this to the two inputs ok. Once again you could have connected this to reset and this to set there is nothing quite secret about it. You can still complete this story in that way you have to add just things accordingly ok. So, I connect this to S and R arbitrarily.

So, then what can I write about this? Let us say when this will go high, when Q will be high? Q will be high if I have a set signal coming here. And when I will get set signal? I will get set signal if this is high and this is high if V c goes above this. So, this will be high when V c goes above Vcc x 2/3 ok. If V c goes above this then this will be high and this will be low if I have a high reset signal; that means, this should be high and that this will be high only if Vc goes below this threshold this below this point. So, this will be low when V c goes down. So, goes down Vcc /3 ok.

So, if this voltage is changing with time and if it goes above there are two levels you can see there are two voltage levels. If this goes above this level above this level then here the output will be high and if this falls below this level then the output will be low here ok. So, this is ok. So, these are the main ingredients of these flip-flop two comparators, one potential divider.

Now, what I will do is this. I essentially want a oscillating voltage. So, I will also take this voltage changing with time for that what I will do, I will take a capacitor, call it c I will take some resistances few of them you can take call them Ra Rb and this side I will connect to Vcc positive voltage this side I will connect to ground.

So, therefore, what will happen the moment I make this connection the moment I make this connection current will start to come start to flow in through this resistance and charge this capacitor. Therefore, this potential will increase and this I will connect to V c. Now, you possibly know why I got in Vc this is the capacitor voltage Vc. So, the moment I complete this circuit this potential will start to increase. Therefore, this potential will start to increase also.

And, what I will do? I will take a kind of switch a transistor-based switch and I will connect that to this like this let me draw it in a different color. So, I will have a switch let me first write like this. So, if you see if I keep this switch open, if this is open like this then it will just charge the capacitor current will come like this from top to bottom and it will increase potential will increase.

But, if I close this switch then what will happen then this is connected to ground, this is at 0 potential. So, if there is any charge in this capacitor that will discharge and go to ground. So, this potential will drop ok. So, if I connect this switch the capacitor will discharge to the ground and if this is open then current will come from V c and will charge this capacitor.

Now, I cannot take a manual switch like this, I will take a electronic switch let us take a transistor base switch ok. So, if I give a positive or high voltage here at the base then this transistor will act like a short circuit and so, this switch will be on, so, current will flow like this, capacitor will discharge. And, if I give nothing at the input or low voltage at the input, then if the input is low this base voltage is low then this will act like a open circuit. So, this is not connected. So, the capacitor will charge.

Now, what I will do is this I observe that this voltage increases. So, this is off, then this voltage will increase which will make this output high after a while ok. So, I will connect it to this because you see say initially this is off if it is 0, then current is coming and these voltage is increasing if this is increasing according to this logic when V c goes above this level two third of this voltage then this output becomes high. So, this is this will be connected to this and then this transistor will be short circuited.

So, therefore, this switch will be on and the capacitor will discharge through this potential will start to drop and this V c will start to go down, and as it goes down at some point you know at some point this comparator will tell me that V c is lower than this threshold. So, so this will trigger the reset and this output will be low. And, once this is low this will be off this transistor will be off and if this is off then it will start to charge again. So, this way it will keep oscillating between charging and discharging ok.

So, let me just write the essential story in few words, say if call this transistor T 1 if and call this voltage base voltage B 1 ok. So, this is B 1. So, this is this voltage is V B 1 ok. Say, if V B 1 is low then T 1 is off, then capacitor C will charge through R a and R b these two resistances and therefore, V c will increase. Then, when V c this voltage goes above this level when V c goes above this level 2V cc/3 call this comparator 1. So, call this V comp 1 ok; then V comp 1 will be high and flip-flop will be set and Q will be high and then what will happen

So, now Q I mean the output V B 1 because this is the same thing. Now, V B 1 is high. So, T 1 is on. So, C will discharge through R a only discharge through R a; R b will not be there the current will directly go to ground through R a discharge through R a and so, V c will decrease and the last thing when V c goes. So, this is now decreasing. So, when V c will decreases below this level V c by 3 V cc by 3 when this goes below this by 3 divided by 3 then call this V comp 2. V comp 2 will be high and if this is high then reset will be triggered Q will be reset Q will be reset to 0 or reset to low ok. This way it will oscillate forever.

I hope the functionality is clear and so, next thing what we can do we can talk about the frequency of this circuit.

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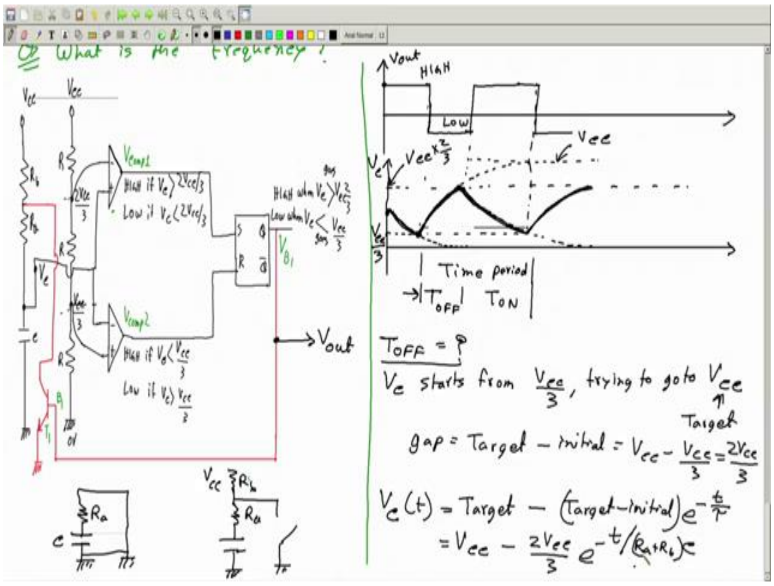

So, the question what is the frequency or what is the time period ok and we should be also able to draw the waveforms at different points this voltage this output etcetera. I hope you can still read this because you know now what they actually what actually is there ok.

So, now let us draw the waveforms. See let us start with this V b 1 and once again to start with we have to assume some initial value say this is initially high. So, this is initially high. So, we start with some high value and then let me take this as V c the capacitor voltage here ok. So, if this is initially high then the capacitor is discharging through R a. So, if the capacitor voltage is something in it is it has some initial value it is once again this is an assumption that this is the initial value then it will discharge and it will go towards 0 voltage ok.

So, so, I start from here and it will go towards the 0 voltage exponentially because this is a R c circuit. This is just like this right capacitor c then in series you have R a and then this is grounded; that means, this to here connect. So, this will discharge with the time constant R a c; this is going down toward 0, but will it reach 0? It will not because something different will happen at the moment when it reaches the level Vcc/3.So, this height is V cc/3.

If this is Vcc/3 then somewhere here I will have also let me draw it draw this level as Vcc into two third; this is Vcc into one third. Now, the moment the capacitor voltage comes here story will change why because this voltage is lower. So, this op-amp will be triggered this will say the out the output is here high, reset will be triggered. So, this will be low ok.

If this is low then this switch will be off ok. So, after this movement the switch will become off and if the switch is off then the capacitor will start to charge instead of discharging because this part is part is not connected. It is connected like this get this R a then R b R b, Ra this is no longer there it is open, but here I have the voltage Vcc and ground this will start to charge ok. So, it will charge again exponentially and it will try to go towards V cc.

So, let this height let this height be same as Vcc. So, it is trying to go exponentially asymptotically towards Vcc, but will it reach there? It would not because it will come up to 2 Vcc like this and then once again this story will change at this point why because at this point. So, at this point this voltage Vc is above two third Vcc. So, this comparator will get activated and it will trigger the set and therefore, this voltage will be high again, this will turn on this transistor again. So, it will start to discharge again.

So, it will start to discharge once again and will try to go towards 0 voltage, but it will not definitely reach that. It will reach only up to one third Vcc. So, it will come up to this and again this story will change. So, this is how Vcc will oscillate ok. So, it oscillates between these two levels two third Vcc and one third Vcc and how about this V b? Let me just call this V b as V out let this be the output voltage of the circuit which is also oscillating. So, let me call this V out ok. So, here in this part when the capacitor is discharging, why is the capacitor discharging? It is discharging only because this transistor is on and it is on only when this is high.

So, here definitely this is high and then here it will be low it is low and that is why this is off and therefore, the capacitor is charging and then here. Once again it will be like this once again this is not very low level I mean detain accurate diagram in a sense that or it is like somewhat schematic because you know we are not considering I mean what is meant by high or low to this which voltage is considered as high or logic or level one or which voltage is considered as level 0 for this flip-flop, what is the output voltage of this comparator, what is the voltage exact voltage that should be applied to get this transistor on-off, all this exact voltage levels we are not considering in detail.

We are only considering whether it is when it is high, when it is slow, how will it will oscillate. So, we are looking at it from a abstract level not somewhat abstract level not very detailed ok. So, I mean for example, the I mean the maybe the should be supply voltage to this op-amp be plus minus dual volt, is it? If so, then you know this output will be plus minus dual volt or, but for a digital circuit may be dual volt is not acceptable. So, those details you ignore right now so, fine.

So, the original question was to find the frequency ok. So, we have to find the time period what which is the time period the time period is from here to here this is the time period. So, you have to find this time and for that we have to find this to time call it T OFF and call this T ON. T OFF is the time where now the output is off or low, T ON is the time when the output is on or high ok. So, let us find T OFF. Let us find how much is T OFF.

So, you see the capacitor is starting. So, V c starts from V cc by 3 and it is trying to go and trying to go to what value V c V cc this supply voltage. If nothing is stopping this capacitor from getting charged if this transistor is not there they need to go to the full value V cc ok. So, this is the target value target voltage, this is the initial voltage and then the. So, this is the target ok.

So, how far is the destination or the difference between the initial and the target? I mean this gap between this and this target an initial value target minus initial. So, this is V cc minus V cc by 3 is same as 2 V cc / 3 ok. This is how much it wants to go this is how much it wants to go and therefore, the V cc V c the capacitor voltage you can write it target minus this. So, what will happen finally, this term will be 0. So, final value no will be target value at as t tends to infinity.

Gap= target – initial =Vcc- Vcc/3 = 2Vcc/3

$$Vc(t) = \text{Target} - (\text{target-initial})\ e^{\frac{-t}{\tau}}$$

$$= Vcc - 2\ Vcc/3\ \ e^{\frac{-t}{\tau}}$$

This you could have also derived I mean formally like the way we do using differential equations etc, but this is how you can also remember and if you have not studied differential equations are you do not know this transient formulas you can remember in this way ok. So, finally, it will be the target value when this will be 0 and initially it will be this is this is 1. So, target – target cancels and this is how the voltage changes ok.

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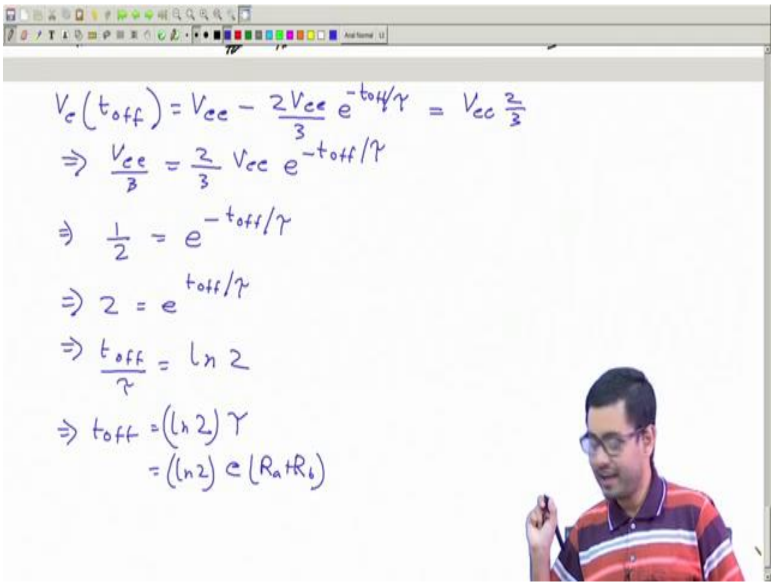

Now, now, we have to find how long will it take we are to go from initial value to this, two third V cc ok. Say, this time if this is this t = 0, this time is t = t off sorry, not this time this time if this is t = t off and this is t go to t 0 so, this is the time required for the capacitor voltage to go from one third V cc to two third V cc.

$V_c(t_{off})$ = Vcc- 2Vcc/3 $e^{\frac{-toff}{\tau}}$ = 2 Vcc/3

Vcc/3 = 2Vcc/3 $e^{\frac{-toff}{\tau}}$

½ = $e^{\frac{-toff}{\tau}}$

2 = $e^{\frac{toff}{\tau}}$

T_{off} = ln2 τ = ln2 C (Ra+Rb)

So, now we will similarly find the value of on time and then we will. So, on time is this time or this time then we will add t on and t off together to get the total time period [FL] ha [FL].

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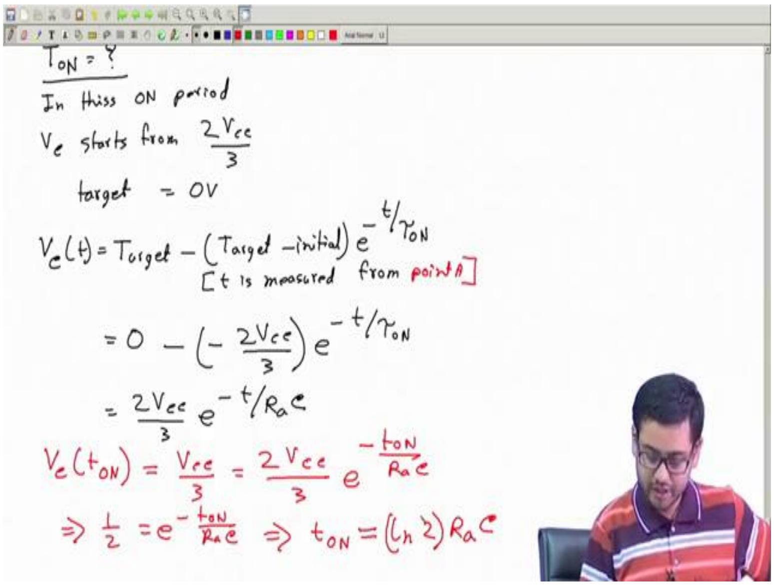

[FL] Ok. So, let us now find similarly this time t this is T ON. So, for this let us first write how this voltage changes in this period ok. So, it changes it starts from two thirds V cc ok.

Vc starts from 2 Vcc/3

Target = 0 V

$Vc(t) = \text{target} - (\text{target} - \text{initial})\ e^{\frac{-t}{\tau on}}$

$= 0 - (-2Vcc/3)\ e^{\frac{-t}{\tau on}}$

$= 2Vcc/3)\ e^{\frac{-t}{\tau on}}$

$Vc(t_{on}) = Vcc/3 = 2Vcc/3)\ e^{\frac{-ton}{Ra\,C}}$

$½ = e^{\frac{-ton}{Ra\,C}}$

$t_{on} = \ln 2\ Ra\ C$

So, then we can write once again V c t is equal to just use this idea target minus target minus target minus initial e to the power minus t by tau call this tau ON time this is the and this is for the ON pay ON time ok. Similarly, previous one I should better call it tau OFF, tau OFF, this is tau OFF, this is tau OFF, OFF, OFF, OFF, OFF time constant tau OFF and time constant tau ON here in this case ok.

So, and then let us put the values target value is 0 and this t so, this t is actually the time measured from this moment ok. So, I am re initializing the time and to 0 here to do the estimate son here or if you do not like that then if you still want to keep this as the origin for time. So, let me then subtract this previous value t OFF. So, you can write this t minus t OFF, but I think this is complicated.

And, now let us call this time let us call this time t equal to t ON starting from this value starting from this value. So, this is the time t equal to t ON; my target is to find this value because I want to find this gap this time of ON time and for that I have to find this time the instant when this goes down below V cc by 3 ok. So, if we assume that V c at t ON it goes to V cc by 3 then let me just write the value of this by putting the putting t ON in this expression this becomes e to the power minus t ON by R a c ok.

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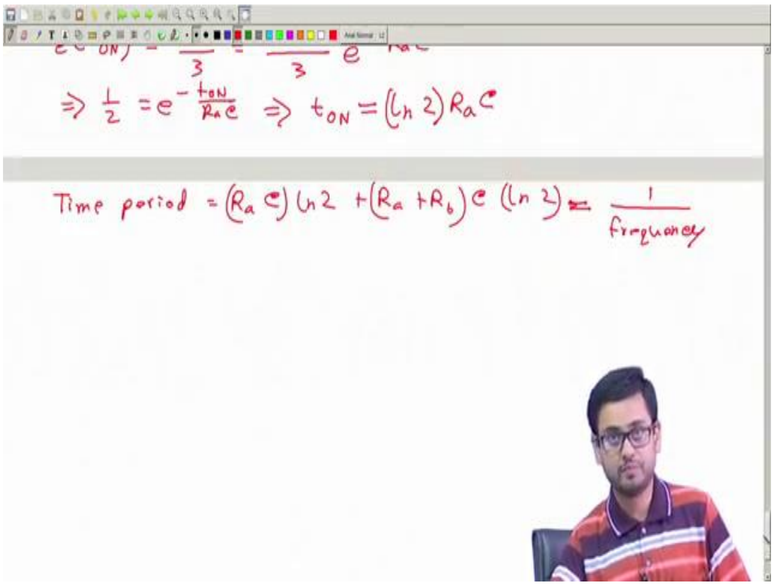

Time period = Ra C ln2 + (Ra+Rb) C ln2 = 1/frequency

Thank you.