Basic Electronics

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Lecture - 69
555 Timer

Welcome back to Basic Electronics. In this lecture we will look at a very useful IC the 555 timer. In particular, we will see how it can be used for mono stable and a stable application. So let us begin.

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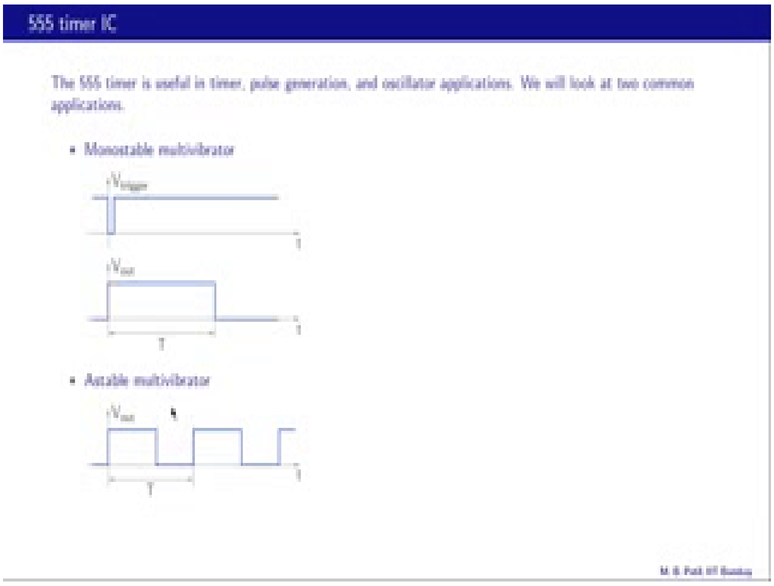

We now look at the 555 all right timer IC which is useful in timer pulse generation and oscillator applications. And we will look at 2 of these applications. One mono stable multi vibrator, for this circuit we have a trigger pulse in this case it is a negative going trigger it is 1 then becomes 0 for a short time and then it goes back to 1. As a result of this trigger pulse the mono stable multi vibrator produces a pulse at it is output, and that pulse has a fixed duration T, which is given by the component values that we use for the circuit and we will see what those are all right. So that is the first application we will look at.

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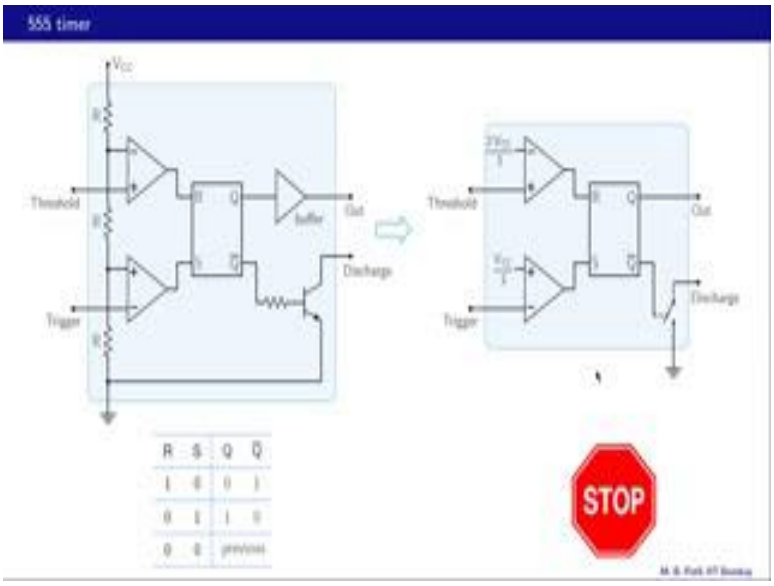

Second application is a stable multi vibrator. Now this is essentially an oscillator circuit and it oscillates between high and low values. And this time period depends on the component values that we use in this circuit. Here is the 555 timer IC given by this box here, and inside the IC we have several components, registers, comparators and RS deadlock, a buffer and a BJT switch. Let us look at the connections now. This is the ground for the IC and that is the V CC power supply, typically 5 volts. And these comparators of course, do not draw any current. So this current is 0 this current is also 0. Then we have simply these 3 registers in series R R and R. And because of voltage division with respect to this ground this potential is V CC by 3 and this potential is 2 V CC by 3.

Let us look at the comparators now. For this comparator V plus is equal to V CC by 3 and that is compared with the potential at this trigger input or the 555 timer. If V plus is higher than this output is 1 otherwise it is 0. For this comparator V minus is 2 V CC by 3, that is compared with the potential at this threshold input of the 555 timer. If this input is higher than V minus then this output is 1, otherwise it is 0. The comparator outputs are applied to the R and S inputs of this RS flip flop. And here is the transition table for the RS flip flop. If R is 1 S is 0 then Q is 0 if R is 0 S is 1 then Q is 1, and if R and S are both 0 then Q retains it is previous value. So that is how this flip flop works. The Q output goes through this buffer and that brings us to the output of the 555 timer.

The purpose of this buffer is to provide sufficient current to the external circuit that they might connect over here all right. Now this Q bar drives this BJT switch. If Q is 0 then Q bar is 1 and the BJT turns on, and the base current is sufficiently large so that the transistor enters saturation. So this voltage is very small like 0.1 or 0.2 volts. When Q is 1 then Q bar is 0, and the transistor is then off. Now one end of the transistor the emitter end is connected to ground like that, and the other end is brought out and that is called the discharge terminal of the 555 timer.

So that is how the 555 internal circuit works. And let us now replace it with a simplified picture which is sufficient for our purposes. Now in this diagram the BJT has been replaced with an ideal switch. If Q bar is 1 then the switch turns on, this discharge terminal gets connected to ground. If Q bar is 0 then the switch is off and we have an open circuit here. The other difference is that we have dropped these resistances and that is because the only purpose of these registers is to provide these voltages V CC by 3 here and to V CC by 3 over here. So it is not necessary to show the resistors in this simplified picture, but we should remember that for the lower comparator V plus is V CC by 3 and for the upper comparator V minus is 2 V CC by 3. So that is the purpose of the registers, all right.

Now, at this point it is a good idea for you to draw this simplified picture because that will help you to understand the applications better. And it is not that hard to remember we can start with this RS flip flop RS Q Q bar. Q is the same as the output terminal of the 555. And here we are not showing the buffer, but we understand that it is there. Q bar controls this ideal switch, one end of the switch is connected to ground and the other end is brought out as the discharge terminal of the 555 timer all right. So that was the output side of the flip flop. And the input side we have R and S R comes from the upper comparator and S comes from the lower comparator. And for the upper comparator we remember that V minus is 2 V CC by 3 and other terminal that is the plus terminal is brought out as the threshold input of the 555 timer.

For the lower comparator, V plus is V CC by 3 and other input that is the minus input of the comparator is brought out as the trigger input of the 555 timer. So once we remember these features it is not difficult to draw this circuit. So now, the stop sign has come and that is telling you that you should turn off the monitor and practice drawing this circuit and then continue.

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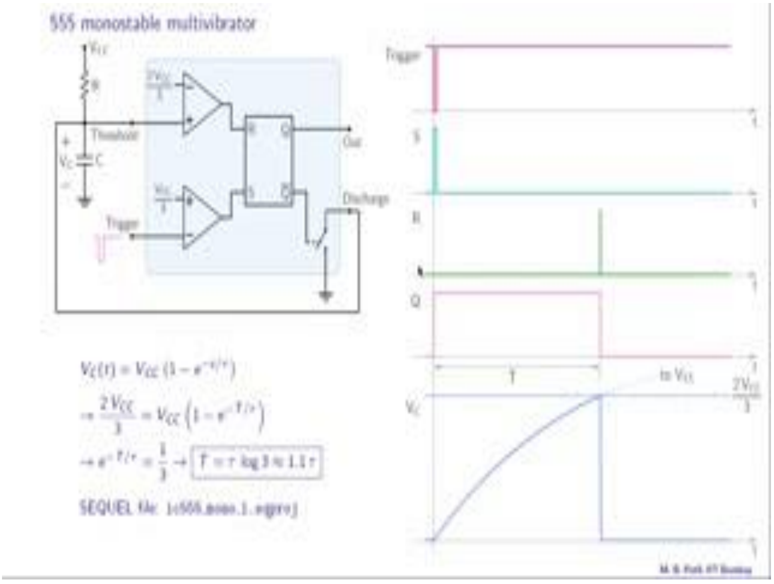

Let us look at the 555 mono stable multi vibrator now. Here is the circuit. This is our 555 the internal circuit. The threshold input is connected to capacitor going to ground and a register going to V CC. And the threshold and discharge are connected together. Add the trigger input you have a negative growing pulse; that means, it is 1 let us say 5 volts then it goes to 0 a 0 volts and then comes back to 5 volts.

Here is our initial situation. The capacitor voltage is zero; that means, the capacitor is initially uncharged so V C is 0. The flip flop output Q is 0 initially the value of the trigger is 5 volts before t equal to 0. And if that is 5 volts; that means, V minus V is 5 volts. V plus is 5 volts by 3, so therefore, S is 0. What about R? We have V plus equal to 0 V minus equal to 2 V CC by 3 and therefore, R is also 0. So that is our initial situation. All right now, the trigger goes low for a short time and when that happens, we have V CC by 3 over here as V plus and V minus is now 0 so therefore, this has become equal to 1 as shown over here. What about R? Our V C has not really changed yet so therefore, R is still the same that is 0, as shown here. And because we have S equal to 1 and R equal to 0 the flip flop output will now get set to Q equal to 1 like that, and when that happens Q bar becomes 0 the switch is an open circuit and therefore, all we have now is this capacitor and this resistor connected in series and going to V CC.

So, now V C starts rising towards V CC with a time constant of R equal to R times C as shown over here. Notice that our trigger has now gone back to 5 volts, and when that happens this V minus here is greater than V plus and therefore, S becomes equal to 0 as shown over here. So now, we have S equal to 0 R equal to 0 and therefore, Q does not change. In the meanwhile, V C is rising towards V CC. And we will see that it does not quite reach V CC and let us see why. So this is what actually happens V C does not reach V CC when it crosses 2 V CC by 3 things change and let us see why? When this V C becomes larger than 2 V CC by 3 what happens is V plus becomes greater than V minus making R equal to 1 and we now have R equal to 1 S equal to 0.

So, therefore, Q gets reset to 0. When that happens Q bar becomes 1 and now the switch closes. When the switch closes this capacitor gets discharged through the switch. And that of course, happens very quickly because the switch has a very small resistance. So our Q has gone from 1 to 0 at this point, and R goes momentarily high, because the comparator output has become high, but as soon as that happens, we have seen that the switch closes and V C becomes 0, because the capacitor gets discharged. When V C becomes 0 our V plus is now lower than V minus, and therefore, R becomes equal to 0 as shown over here. And now we are back to where we started, our V C is 0 as across in the beginning, Q is 0 R is 0, S is 0, as we had in the beginning Q equal to 0 R equal to 0 S equal to 0, and our trigger is high.

So, now the circuit is waiting for another trigger to come along, and then it will produce another pulse and the output. Let us now calculate the output pulse duration denoted by T over here. And we will start with this charging process the equation that describes this charging process is V C of t equal to V CC times 1 minus e raised to minus t by tau. When t becomes equal to T we are talking about this point now this is our t equal to 0 this is t equal to T capital T and that happens V C becomes equal to 2 V CC by 3. So that gives us an equation for capital T. And we can solve this equation we get e raised to minus t by tau equal to 1 by 3, or t equal to tau times log of 3. This is log to the base e not log to the base 10. And that is about 1.1 times tau. So that is the duration of the output pulse. The circuit file for this simulation is available. You can run the simulation and look at all of these waveforms.

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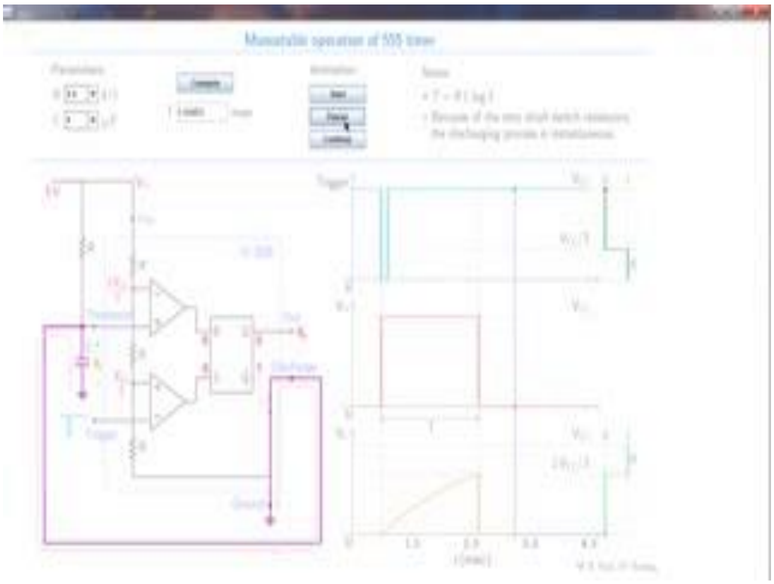

Let us now look at an animation of the mono stable operation of the 555 timer. Here is our circuit this is where the trigger pulse is applied. And the components which control the output pulse duration as we have seen are this resistance and this capacitance, are can be chosen from here it can be 1 k or 1.5 k or 1.8 k. C can be chosen over here either 1 micron or 1.2 micron or 1.5 micro all right, let us compute the waveforms, when we do that we also get this number for the duration of the output pulse, 1.648 milliseconds and that comes from this formula here which we have already seen.

Here are the waveforms, this is the trigger that is the output pulse, output of the flip flop, that is the pulse duration the output pulse duration t that is the capacitor voltage V C starts off at 0 then starts going towards V CC, but when it reaches 2 V CC by 3 things change as we have seen all right. Now in addition we have also shown the S and R inputs of the RS flip flop here. This is S that is 1 and that is 0 when the trigger value falls below V CC by 3 S becomes equal to 1 otherwise it is 0. Here is the R input of the flip flop, that is R equal to 0 and that is R equal to 1, when V C is below 2 V CC by 3 then R is 0 otherwise it is 1.

Let us now start the animation. And in particular we should look for the charging and discharging of the capacitor and the position of this switch. Start now the switch is closed because a trigger is high now, switch opens capacitor charges that is the charging path and note that both S and R are 0 during this interval, and now the switch closes again.

Let us now look at a stable operation of the 555 timer. This is an oscillator so we are going to have a square wave as the output. This is our internal circuit of the 555 timer. Now the threshold and trigger inputs are tied together and we have a capacitor going to ground from there.

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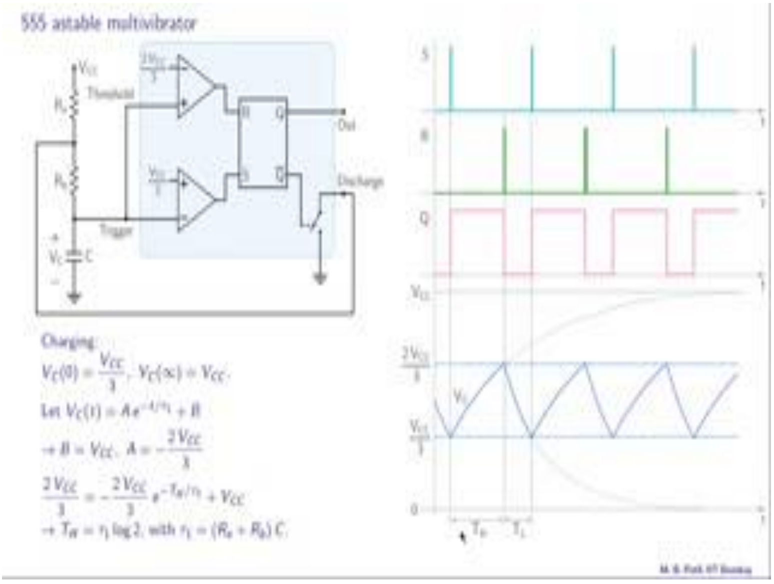

And now we have R a and R b, and the node between these 2 is connected to the discharge pin all right. Here are the waveforms S R Q the output of the flip flop and this is the capacitor voltage V C. So let us try to figure out what is happening.

Let us start somewhere here, so we have S equal to 0 R equal to 0 Q is high, and our capacitor voltage each say this value. Now if Q is high; that means, Q bar is 0 and this switch is open and therefore, this capacitor will start charging toward V CC and the time constant will be R a plus R b times C. So that is shown by this trajectory over here. Now the capacitor voltage does not quite reach V CC, because when it crosses 2 V CC by 3 things change now let us see how.

Let us look at the R and S inputs of the flip flop, S is 1 if this V plus is higher than V minus and what is V minus, V minus is the same as the capacitor voltage, which we are plotting over here. So when the capacitor voltage falls below V CC by 3 S becomes equal to 1, otherwise it is 0 so; that means, if V C falls below this line, here then S becomes equal to 1 otherwise it remains 0, and that is what we are seeing over here. What about R, R becomes 1 if V plus exceeds to V CC by 3 and once again V plus is the same as V C here, so therefore, if V C exceeds to V CC by 3; that means, if V C it is in this region then R becomes equal to 1 otherwise R is 0 as we have shown over here.

All right let us now come back to this charging process. When the capacitor voltage crosses 2 V CC by 3, then R becomes equal to 1. Now we have R equal to 1, S equal to 0 and therefore, the flip flop gets reset to Q equal to 0. When that happens Q bar becomes equal to 1, the switch closes and now the capacitor starts discharging following this path. And what is the time constant for this process it is R b times C. So that is what is shown over here. And notice that when the capacitor voltage starts falling, it is once again in this range between 2 V CC by 3 and V CC by 3 and therefore, RS again become 0. All right now when V C crosses V CC by 3, S becomes equal to 1, as we commented earlier and now we have S equal to 1, R equal to 0, the flip flop gets set, Q becomes equal to 1 Q bar becomes 0, the switch opens and now the charging process starts again so the capacitor starts charging toward V CC, with a time constant of R a plus R b times C, and that is shown over here and this cycle repeats and that is how we get oscillations.

Let us now calculate T H and T L, T H is the interval of high output and T L is the interval of low output. Let us start with T H, and that corresponds to the charging of the capacitor it starts from V CC by 3, and would go eventually to V CC. So here are the conditions on V C during the charging process. We will take this as t equal to 0 so at t equal to 0 we have V C equal to V CC by 3, and V C at infinity is V CC, that value. Now let we see p A e raised to minus t by tau 1 plus B, during this interval. And what is tau 1? Tau 1 is the time constant associated with the charging process, that is R a plus R b times C all right.

Now, we use these conditions and get B and A, b turns out to be V CC, A turns out to be minus 2 V CC by 3. And with A and B known our V C of t is completely determined during this interval. What is the next step? We have t equal to 0 here this is t equal to T H at t equal to T H, our V C is 2 V CC by 3. So we can use this condition to obtain T H. So for V C we substitute 2 V CC by 3, for t we substitute T H and then we obtain this equation. And A and B have also been substituted here. We can solve this equation note that V CC cancels out and get T H equal to tau 1 times log of 2 to the base e where tau one is R a plus R b times C, so that is the first interval of interest.

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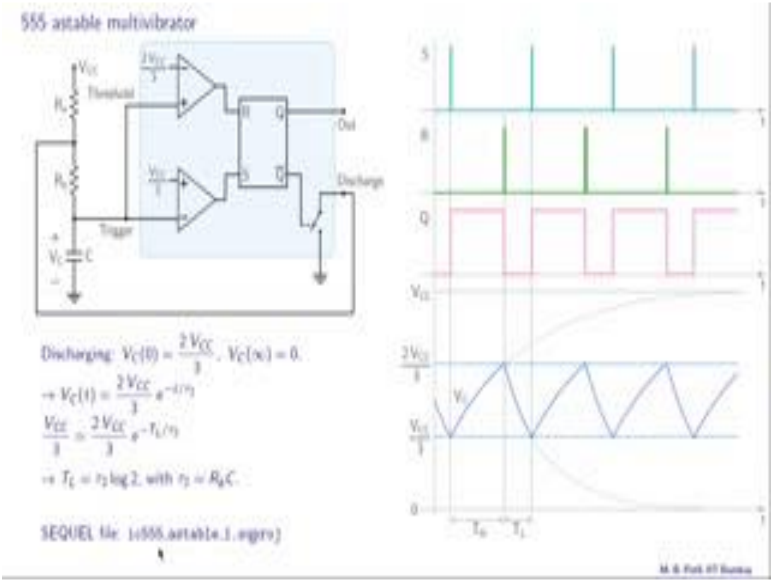

Let us now consider the discharging process to obtain T L. We will take this time as t equal to 0. So this time is t equal to T L, what is V C at t equal to 0, that is 2 V CC by 3 and V C at infinity is 0, so those are the conditions we have for V C, and using these conditions we can now write the equation during the discharging process namely V C of t equal to 2 V CC by 3 times e raised to minus t by tau 2, and tau 2, here is the time constant associated with the discharging process, what is our discharging path, it is this the switch is closed during this time, so therefore, that is our path. So the only resistance in the circuit is R b and therefore, tau 2 is R b times C all right.

The next step is to use the fact that at t equal to T L, V C is V CC by 3. So let us substitute for V C, V CC by 3. And for T L and that gives us an equation for T L. V CC cancels out and we get T L equal to tau 2 times log of 2 to the base e where tau 2 is R b times C. So now, we have T H and T L and now we can calculate the total time period and therefore, the frequency. Here is the sequel file and you can try out this simulation try to change component values R a, R b, C and see what happens.

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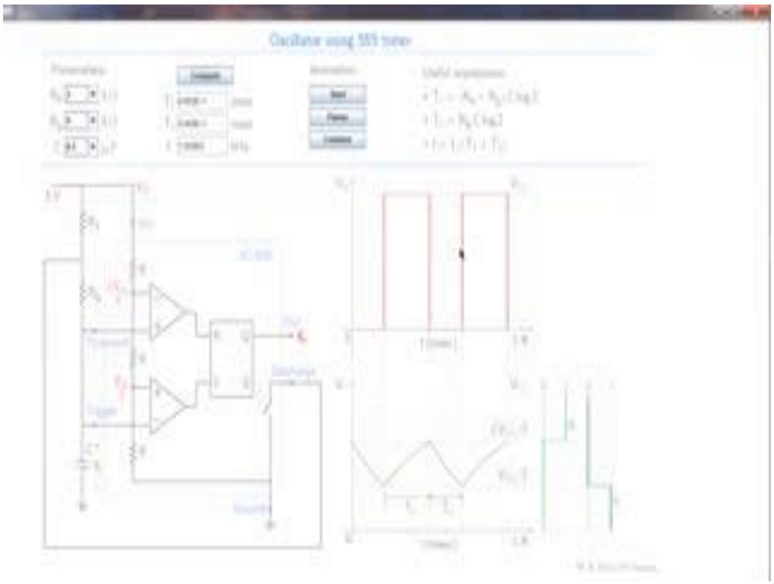

Let us look at an animation of the 555 oscillator which we have just discussed. Here are some useful expressions which we have derived earlier. This t 1 is the same as T H that is the interval of the high output. T 2 is the same as T L, that is the interval of low output and the frequency is 1 over t 1 plus t 2. The component values R a R b and C can be selected over here. R a can be 0.05 k or 2 k or 5 k, R b can be all right 5 k. Or 2 k or 5 k and C can be 0.1 micro and 0.15 micro or 0.2 micro, all right.

Let us now compute the waveforms. So that is what the waveforms look like. This is our output voltage versus time. This is 0.6 milliseconds here. So this is 0.1, 0.2, 0.3, 0.4, 0.5 0.6 milliseconds. That is our capacitor voltage. This is V CC by 3 and that is 2 V CC by 3 and as we have seen earlier V C oscillates between these 2 values. This is our T H in this case 0.2 milliseconds and this is our T L and this is 0.069 milliseconds. And we can see that T H, from the plot is also 0.2 millisecond. This is 0.1 millisecond so that is 2 divisions. And T L is 0.069 or 0.07 millisecond, all right.

Now, also shown in this plot are the R and S inputs of the RS flip flop. This is R, this is S this is R equal to 1 this is R equal to 0. This is S equal to 1. This is S equal to 0. Now when V C exceeds 2 V CC by 3, R becomes equal to 1, otherwise it is 0, and when V C falls below V CC by 3, then S is equal to 1 otherwise S is equal to 0, as we have mentioned earlier R and S remain equal to 0, most of the time because our V C always remains confined to this range, except we have very short spikes in R and S when V C exceeds to V CC by 3, there is a short spike in R, that is R goes to 1 momentarily and comes back to 0.

Similarly, when V C falls below V CC by 3, S goes to 1 momentarily, and comes back to 0. Let us now start the animation and in particular we should pay attention to the position of the switch whether it is on or off and also the charging and discharging paths for the capacitor. That is the charging path as we have seen earlier, and this is the discharging path like that. Let us start, now the switch is closed the capacitor discharges, the switch opens the capacitor starts charging, that is the charging path now the switch closes again, the capacitor discharges, opens again and the capacitor starts charging again and so on. You can also play with these component values R a R b and C.

For example, suppose we change R b from all right 5 k to 5 k. What do we expect R b is here in the T H formula, R b is also here in the T L formula, so therefore, both T H and T L are going to increase, and also the ratio of T H and T L is going to change; that means, the relative difference between these 2 is going to change. So the duty cycle of the V o waveform is going to change. So let us see if that happens, compute all right. So now, the times have increased. Note that the time scale here is 1.8 millisecond now. So T H has become 0.48 milliseconds. T L has become 0.35 milliseconds. And we also notice that the duty cycle of the output waveform has changed.

To summarize we have seen the internal circuit of the 555 timer and how it can be used for mono stable and a stable application. At this stage you know enough about digital circuits to be able to design and build a digital clock. So give it a try we will meet in the next class.