Op-Amp Practical Applications: Design, Simulation and Implementation

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Lecture – 21
Op-amp with Positive Feedback: Astable Multivibrator

Hi, welcome to this module. In this module, we will see different multivibrator. So, what is that different multivibrator? Different multivibrator I mean by astable multivibrator ok. So, what is astable multivibrator right? We have seen multivibrator that can if I apply a positive feedback system right that oscillate between high state and low state to produce a continuous output, then that kind of circuit is called what? That kind of circuit is called a multivibrator. It vibrates multiple right multi directs multiple points like on and off, on and off, on and off right. So, it is an astable multivibrator. Let us let us see in detail, do not worry about it.

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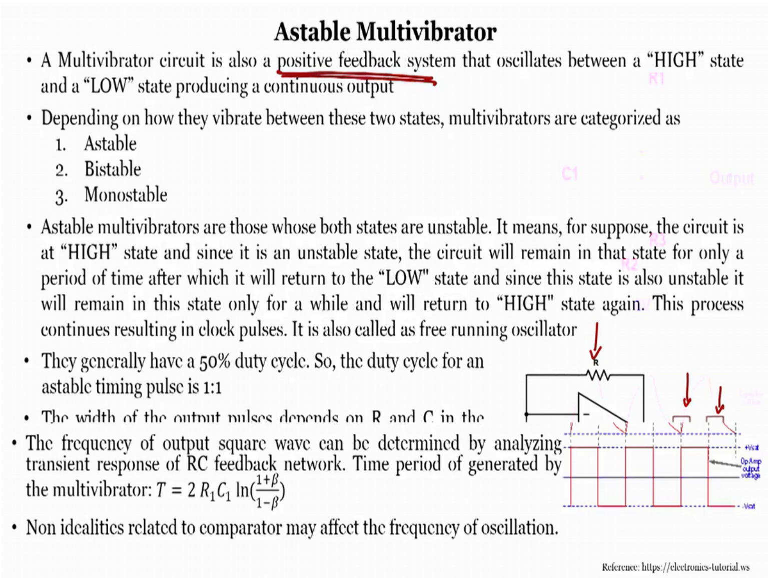

Ah If you come to the slide, a multivibrator circuit is also a positive feedback system right. It is a positive feedback system. Now, when you apply positive feedback? When you want to use the circuit as an oscillator. When you apply negative feedback? When you want to use the circuit as an amplifier. So, a multivibrator circuit is also positive feedback system. So, if there is a positive feedback system, what will happen? It will oscillate; it will oscillate between a high state and a low state to produce a continuous output. You can say high state, you can say low state, it (Refer Time: 01:39) high and low to produce a continuous output.

Depending on how they vibrate between two states, multivibrator can be classified as astable, monostable, bistable. But, if they in the case of astable multivibrator, what is that astable? Both the states are unstable; both the states are unstable right. So, it means for the circuit if the circuit is at high state, and since it is an unstable say the circuit will remain in that state only for a period of time after which will return to the low state right. So, and since this state is also unstable, it will again return to the high state. This process of continuously changing the high state to low state, low state to high state right, results in clock pulses. And thus astable multivibrator is also called free running oscillator right.

So, a multivibrator is a positive feedback system, it oscillates between high and low. If how they vibrate between two states according to them, they can be classified; we have seen bistable, we how they are classified, astable bistable, monostable. And astable are those both states are both states are unstable right. So, since it repeats switches from high to low and low to high, it results in a clock, and you also called free running oscillator.

They generally have a 50 percent duty cycle. So, the duty cycle for a astable timing pulses 1 is to 1. The width of pulses depends on R and C right. Astable multivibrators are used as clocks and the timers right, because it has it continuously generates output signal with 50 percent duty cycle right. It can be used the timer, it can be used the clock right. And thus these astable multivibrators are used for applications such as pulse position modulation PPM, and frequency modulation, these are the application of the astable multivibrator.

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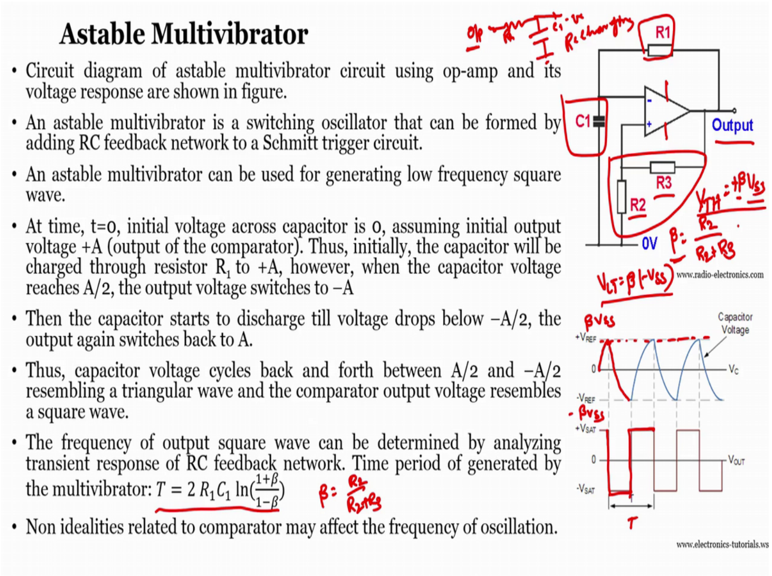

So, if you see here, this is the circuit for the astable multivibrator, this is the capacitor voltage, and this is the output voltage. So, what is shown, a circuit diagram of astable multivibrator using op-amp and its voltage response are shown here. An astable multivibrator switching or an astable multivibrator is a switching oscillator that can be formed by adding R and C right is a feedback network to the Schmitt trigger. An astable multivibrator can be used for generating low frequency square waves. You can here see, we can generate low frequency square waves.

At time t equals to 0, initially the voltage across the capacitor is 0 right, assuming initial output voltage plus V A the thus initially, the capacitor will charge through resistor R 1 to plus A right. So, voltage is plus A or plus V i set plus A, which is the output of the comparator. The capacitor, since it is at 0, it will start charging 2 plus A. However, the capacitor voltage reaches A by 2, the output switches to minus A, as soon as A reaches to A by 2 right, the output switches back to minus A you see. So, from 0, you starts here, it reaches to A by 2, and the output goes to minus A.

Thus, capacitor starts to discharge till the voltage drops to minus A by 2, and output switches back to A. So, again A starts charging to A by 2, and again output change switches to minus A. This will call capacitor voltage cycles back and forth between A by 2 minus A by 2 resembling a triangular wave, which you can see here right, and the comparator output voltage resembled a square wave right, because it is charged on discharge of again charged, again on, again discharge, it is off right. So, it is like a square wave.

The frequency of output square wave can be determined by analyzing the transient response of RC feedbacks network. And the time period of the signal generated by the multivibrator is given by T equals to 2 times R 1 C 1 log natural log of 1 by beta 1 plus beta divided by 1 minus beta. So, no idealities related to comparator may affect the frequency of oscillation right. So, you did understand how the astable multivibrator works.

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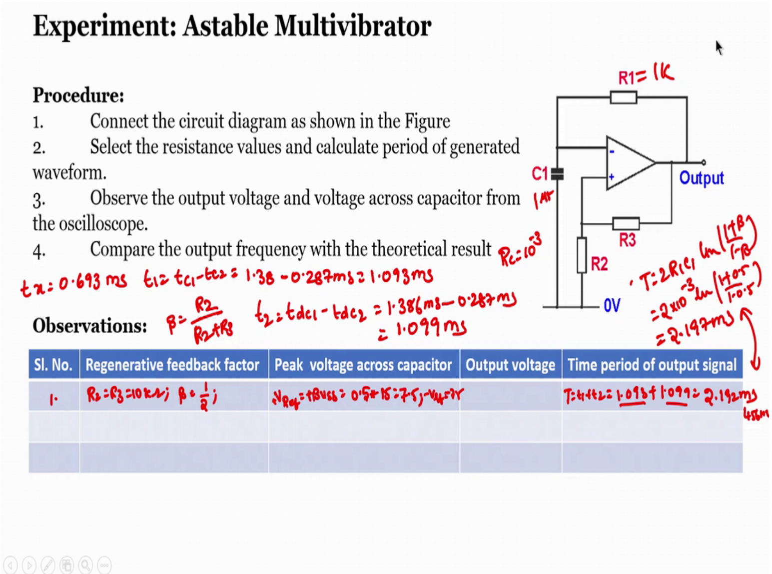

Now, if you want to go perform the experiment, then you have to connect the circuit as shown here, which is write over here. Select the resistance values and calculate the period of generated waveform. Observe the output voltage and voltage across capacitor; you can observe the voltage across capacitor from the oscilloscope. Compare the output frequency with the theoretical result. So, regenerative feedback factor, you see what is the peak voltage across capacitor, what is the output voltage, and what is the time period of the output signal. This is the experiment that you need to perform. We will see if you can also perform the experiment, to show it to you how thus the astable multivibrator works.

Now, to do that the things that we have seen a particularly about circuit designing by t a Sitaram and Suman, they will also discuss about the circuit design and perform simulation. Then they will discuss about how the circuit operates, we have seen in theory in detail, but we just need to have a quick recall of house circuit operates, they will show you about that circuit operation, and compare it with the simulation. So, simulation we use Multisim, and then we do not stop at simulation, we also go further and perform experiments. So, we will compare theory with simulation, to compare theoretical results with our experimental research. So, this is the complete idea.

And now what I will do is I will request Suman and Sitaram to join us and show us how the experiment procedure can be carried out. Guys, you need to focus, we have designed this thing after lot of brainstorming, and this experiments I feel that, if you learn, it will be good for lot of other applications right. So, I will request now t a to help us with the circuit experiments, and I will request him to join us.

Now, we are going to see an astable multivibrator. So, we will start with an astable multivibrator now. So, similarly to our previous modules even in this module, we will briefly look into the design of operational amplifier as a mono astable multivibrator, how it works, and we will do it some theoretical calculations, we will also discuss of the connection of the circuit.

Once the theoretical part is done, we will design the same circuit in circuit simulation software. So, we are using Multisim. So, we will use Multi-stimuli to design, and verify whether the theoretical output as well as the expected output is similar or not. Then the functionality, we will discuss we will verify it. Once that is done, we will look into the experimental you know connections of the same circuit in using a TI board and we will compare the results that we are getting from experimental and simulation as well as a theoretical. So, as in theory, we have already discuss as professor has already discussed about an astable multivibrator, we will briefly look into the design, we will discuss that, and we will go back to our processor in a similar way.

Now, when we look into the stable multivibrator circuit, if you remember correctly our inverting and non-inverting Schmitt trigger circuits, we can see here that one part when you observe, it is also following similar kind of some part of design is similar to our inverting type Schmitt trigger, is not it? When you observe our when you look recall our simuli you know Schmitt trigger circuit, it the Schmitt trigger circuit is using a positive feedback. Even in this case, you have a positive feedback connected with resistance R 3 and one more resistor R 2 whereas, for inverting Schmitt trigger, the input is being connected to the negative terminal.

Even in this case, forget about this R 1 resistor and the C 1 resistor, but when you clearly observe that, when we remove this R 1 and C 1, we can see that input. Input is connected to the negative terminal of here that means, when you observe even from astable multivibrator, we require some part of some part of our Schmitt trigger circuits 2.

Now, if you recall, what we discussion in our inverter you know inverting Schmitt trigger, we remember that the thresholds, the thresholds required for Schmitt trigger depends upon the positive V SS and negative V SS. The supply voltages of the operational amplifier, and the resistance that we are using the feedback resistance and input resistance connected to the positive terminal of your op-amp.

And we have also seen the calculations like the higher threshold value write V TH the higher threshold value is equal to plus beta into V SS that means, positive supply voltage into the beta, where beta is nothing but in this case R 3 R 2 divided by R 2 plus R 3 right. If you recall, just look into ourlook into the previousyou know module on inverting Schmitt trigger, so beta is nothing but R 2 by R 2 plus R 3 right.

And we have also known that if you recall our inverting Schmitt trigger, when the input voltage is greater than the higher threshold, we will get minus V CC. When the input voltage is lower than lower threshold value, we will get a positive V CC. So that means, that the lower threshold value is beta into minus V SS right, where beta is nothing but again R 2 by R 2 plus R 3.

But, in case of an astable vibrator, so we have another component like R 1 and C 1. So, it is a combination of R 1 and C 1, and the input to this RC filter is coming from the output of your op-amp, is not it. And we know that since it is an positive feedback, op-amp can only can only be in two states, either in a positive V CC state or negative V CC state, because it always operates in plus or minus V CC state or in a saturation region, is not it, so because of that reason, the input apply to your RC filter.

So, if I clearly write it down here ok, so what we will do is that here we will see, this is a resistor, and this is a capacitor. So, this is R 1 ok, this is R 1, and we are saying this is C 1, and the output of op-amp is being connected here. The output across the capacitor C 1 is connected to the negative terminal. And we also know that the op-amp input impedances are really higher. So, since those are all really higher right. So, now current will flow that means, R 1 and C 1 are in series. So, how does the circuit looks like? it is nothing but our integrator or your RC charging RC charging circuit.

But, but what is our you know charging of your RC filter, so at what voltage it will charge, so it charges up to it charges up to the input apply to RC filter. In this case, the input applied to the RC filter is nothing but the output of your op-amp that means, when your output is at positive state, the capacitor will try to charge to plus V CC state right. And again when the output is at minus V CC state, whatever the value is store at your you know capacitor will discharge to minus V CC state or it is a negative charging of your capacitor, so that means, the capacitor will always try to charge till plus V CC and discharges from plus V CC to minus V CC, when the input of RC filter is at minus V CC.

But, when we see here, we also have another component like R 3 and R 2 because of that reason, it create some thresholds to our astable multivibrator. So, those thresholds are nothing but your V TH higher threshold and lower threshold value. So, if you recall what are the thresholds, the thresholds here is nothing but V reference in this case, so it depends upon the resistance value that we choose that is nothing but beta into plus V SS and beta into minus V SS. So, these are the two thresholds that we are setting that means, whenever so whenever depends upon the R 3 and R 2 resistors, the capacitor will charge only up to that particular value.

Then, since the input voltage since the capacitor is keep on increasing, whenever the capacitor reaches the voltage of beta V SS value. When the input voltage is that means, beta V SS value is greater than is greater than our sorry input voltage. The charging voltage of the capacitor C 1 is greater than beta V SS, which is the threshold value, then the output goes to minus V CC. So, here we can observe that the output is going to minus V CC.

Since, the output is going to minus V CC, whatever the energy been stored in our capacitor will again discharge back to minus V CC state. So, we can see that it goes it is discharging, but it is not going till minus V CC, because we have another threshold is the negative side, so that threshold is minus beta V SS. So, whenever the capacitor voltage is again lower than beta V SS, the output state goes to plus V CC again starts. So, this continues, so that so, if I want to calculate, the frequency of the frequency of our astable multivibrator what frequency it is being oscillating that entirely depends upon our beta value and V SS value right.

So, as we have already seen in a theory class, how do we calculate as a professor discuss in the theory class, how do we calculate our T value. And we also know that the relation is the T relation is 2 into R 1 C 1 into log 1 plus beta by 1 minus beta, where beta is nothing but R 2 by R 2 plus R 3. We will theoretical verify, we will also do the simulation verification with along with an experimental verification two right.

So, when we go to our experiment, so the same thing we are using given in the experiment. So, what we are doing is we will connect in the same passion. So, in this case, let us consider let us consider R 1 as so, I will consider R 1 as 1 kilo ohms, so we will consider R 1 as 1 kilo ohms, and C 1 as 1 microfarad. So, if it is a case, what is a time constant tau is nothing but RC. So, RC meaning so, time constant RC, which is nothing but 1 kilo into 1 micro. So, 1 kilo into 1 micro is how much, 10 power minus 3 that is RC value. Now, but do we require RC along with an tau component, we also know we have to understand how what is the time duration, we require to know what is this one, and what is this one. The addition of these two give us t value.

Now, how do we calculate that how do we calculate that. So, in order to calculate that first we should understand the beta value, and we should understand the thresholds plus we the higher threshold value and lower threshold value. So, now we will see, so we will consider in order to understand that first we will consider different R 1, R 2, and R 3 values. So, as we have seen in the last experiment, we have considered R 1 and R 2 as in one case we can consider as 10 kilo ohms, so that when I say R 2 is equal to R 3 is equal to 10 kilo ohms, then the beta value is nothing but 1 by 2 right. So, beta is nothing but what R 3 R 2 divided by R 2 plus R 3 10 divided by 20, this is 1 by 2.

Now, since it is 1 by 2, what is the peak voltage across a capacitor that we can see, it is nothing but one peak voltage that it is going to plus peak voltages or plus reference right or plus beta into V SS is nothing but 0.5 into right 1 by 2 is 0.5. And V SS is 15 that we are using it, it is nothing but 7.5 that means, we can we are making the capacitor to charge only till 7.5 volts. Even though even though input voltages the output of your op-amp is nothing but the input of your RC filter is making it as 15, but because of the threshold, the capacitor can only charge up to 7.5.

When the capacitor is high the capacitor in voltage the charging value of a capacitor is greater than 7.5, it allow it makes your Schmitt trigger value to it makes the op-amp output to go to minus VCC. So, it is starts again discharging, is not it. Now, what about minus V reference value? It is nothing but minus 7.5, so that means, the output the capacitor voltage will always charges and discharges plus from plus 7.5 to minus 7.5 volts that is what even we have seen right.

Now, based upon that, how do we calculate our time period? So, if we recall our basics on charging and discharging of a capacitor, if we recall our charging and discharging time constants of our capacitor. So, the charging of a capacitor right if I say this is my capacitor charging rate right, this is voltage across capacitor, and this is the time right. So, if I want to know what is the time it takes, so we know the equation for this is nothing but voltage across a capacitor is the supply voltage into 1 minus e power right 1 minus e power minus t by RC right. Now, now but here, the scenarios are little different right.

So, now what is the threshold? The threshold is we are charging only up to 7.5 volts, we are not allowing the capacitive charge more than seven point 7.5 volts, because when the input voltage of a capacitor is greater than 7.5, the input connected to RC filter is going to minus V CC right because of that the maximum voltage is 7.5. So, I want to know what is a time taken for the capacitor to reach from 0 to 7.5 volts right from 0 to 7.5 volts. Now, when I say 0 7.5 volts right, so what is now what like how do we calculate how do we get a time value, so that means, we should understand the T.

So, what we are trying to find out now is what is the time duration from here to here, let us say t x I am calling it, from here to here, what is the time duration right. So, how do we calculate? So, V C is nothing but 7.5. In this case, V S is from 0 to V S, it is nothing but 15 1 minus e power minus tau by RC. So, I will say t x, so rather than saying minus t, I will say minus t x right.

If we calculate the value 7.5, 15 2s right, 7.5 2s is 15, so that is nothing but when I take in this direction, it becomes 0.5 is equal to 1 minus e power minus t x by RC right. So, when we calculate it, it becomes I will take this to this direction, this to this direction, it will it will become e power minus t x by RC is equal to 1 minus 0.5, which is 0.5 right. So, minus t x by RC is log 0.5 right. So, what is the value of log 0.5, we will calculate it, log 0.5 is minus 0.693. So, t x will become this minus, this minus cancel, it will become RC into 0.93. What is RC? So previously we have seen R 1 is 1 kilo, C 1 is 1 micro, so RC value is 10 power minus 3 right. So, we will say 0.693 millisecond.

So, what we got now? When we see theoretically, we understood that the time taken from here to here is 0.693 millisecond. So, we will keep it that is t x, but what we required, we require complete T. So, it is not from 0 to here, we require from here to here, from plus 15 to minus 15, because it has to go from plus 15 to minus 15, the intermediate changes are plus V reference and minus V reference right. But, actually the capacitor has to charge from discharge from plus 15 to minus 15. Similarly, charging is also in the same way plus 15, it has to charge from plus 15 to minus 15, but intermediate changes are plus V reference and minus V references.

Now, if it is a case, since we are looking into the charging state charging state, so let us consider now we will do this, so that we will get this t 1. So, later on we will see the discharging the t 2, this is t 2. I can say t 1 plus t 2 gives our complete T. Now, so since one we have calculated, let me erase everything, except this value, so everything we are erasing. So, I hope these values are clear. So, the first one is 693 millisecond. So, somewhere, I will note it down. So, t x we got it as 690 sorry 0.693 millisecond 0.693 millisecond.

Now we are calculating what, we are calculating for t 1, because this is t 1, we are saying t 1. What is the value of t 1? So, if you want to understand the value of t 1 theoretically, now we have to make we have to understand our again the charging circuit how. Now, in this case, the charging is not happening from 0, the charging is happening from minus 15 volts minus 15 volts ok, so I will draw here. The charging is happening from if I say this is minus 15, and this is plus 15 volts, when I have a capacitor and input voltage is 15 and the ground value is minus 15 if I say, the charging will happen from here to here right, but because of our beta V SS plus or minus beta V SS or our higher threshold and lower threshold values the charging can go only up to plus 7.5 minus 7.5.

So, we require to know what is the duration of this. So, we required to know the duration, but how do we calculate it. Suppose, suppose if I can consider what is the time taken for the capacitor to go from minus 15 to minus 7.5, and that means, this particular value. And if I also calculate the time required for the capacitor to go from minus 15 to plus 7.5 that means, from here to here, subtract this value with this value, I will get the time duration of this right.

Understand once again, what I mean to say is that, so I will write the bigger picture of this. So, this is the capacitor charging completely, this is minus V SS and this is plus V SS, in this case minus 15 and plus 15. But, I need the capacitor at plus 7.5 and minus 7.5, this is minus 7.5, if I say. So, I need to know what is the time required for this capacitor to charge from minus 7.5 to 7.5, is not it? When we recall back this was not completely discharge that means, some amount of voltage is already there that is minus 7.5. From minus 7.5 to it is started charging, but it suppose to charges till 15, but it is charged only till plus V reference, which is nothing but 7.5 in this case.

Now, if I do that, that means, I need to know the time duration from minus 7.5 to plus 7.5 volts. So, how do we calculate? we cannot directly put it, it is not a linear circuit at all, it is a non-linear, capacitor charging rate is a non-linear. We can see e power minus 3 by RC because of that first we have to know what is a time required, I need this voltage this time period by the by this time period. So, in order to find out what we have to do, first we will calculate what is a time taken for the capacitor to go to from minus 15 to 7.5 right as t c 1, and we will calculate what is the time required from minus 7.5 minus 15 to minus 7.5 as t c 2. So, the difference between t c 1 minus t c 2 gives our T 1. So, I write it down again, this is not so clear. So, the difference between t c 1 minus t c 2 is nothing but T 1 that is what we are looking, we are interested in.

So, how do I calculate t c1 and t c 2? So, the same formula, because this is a charging of a capacitor right, but t in this case is t c 1. So, what I will do is that V c is equal to or V c 1, so this is V c reference 1 positive reference is equal to V s into 1 minus e power minus t c 1 by RC right. This is the formula for the capacitor charging. Now, now what is V c 1, V c 1 is from minus 15 to 7.5. So, what is the complete voltage or we can also say how much percentage in our complete V SS right, how much percentage of complete input voltage? Input voltage range is plus 15 to minus of minus 15, which is 30 volts, and seven point minus 15 to plus 7.5 that is the complete voltage that I have here right. So, I can say 15 plus 7.5 is equal to 15 plus 15 30 into 1 minus e power minus t c 1 by RC right.

So, if I calculate this value 15 plus 7.5 is nothing but 22.5 divided by 30. So, the value is 0.75. This is 0.75 is equal to 1 minus e power minus t c 1 by RC. When we do complete calculation, we will get t c 1 as so, I am taking this to this direction, this to this direction minus t c 1 by RC is equal to log l n right 1 minus 0.75. So, what is the value of log 1? 1 minus 0.75 1 minus 0.75 is 0.25, so log 0.25 right. So, the value is minus 1.38629. So, t c 1 is equal to RC into minus, minus cancel, RC 1 into RC into 1.3869. RC we have seen, it is nothing but 10 power minus 3 is RC right here, so it is nothing but 1.38 millisecond. But, is it what t 1? No, it is t c 1. We also have to calculate t c 2.

How do we calculate t c 2? I am writing it down. So, now V c R 2 is nothing but V s into 1 minus e power minus t c 2 by RC right. So, V c R 2 is how much V c R 2. So, minus 15 to 7.5 what is the difference? So, 15 minus 7.5 is equal to total input voltage we are applying is 30 1 minus e power minus t c 2 by RC. So, when we calculate the value of this, we will get it as so, 15 minus 7.5 is 7.5 right 7.5 by 30 divided by 30, it is nothing but 0.25 0.25 sorry 0.25 is equal to 1 minus e power minus t c 2 by RC.

When we do the complete calculations similar to this to this side, this to the side, I can say minus t c 2 by RC is equal to 1 minus 0.25, which is 0.75 right log 0.75 by the by log 0.75, the value of 0.75 right. Log 0.75 is minus 0.2872. Now, minus, minus, I can cancelled it down, t c 2 is nothing but I am writing it down up t c 2 is nothing but 0.2872 into 10 power minus 3 RC is 10 power minus 3 millisecond that is t c 2.

So, the time taken for the capacitor to charge from minus 15 to minus 7.5 volts is 0.287 milliseconds, and the time taken for the capacitor from minus 15 to plus 7.5 volts is 1.38 millisecond. But I need the time taken for the capacitor from minus 7.5 from here to from here, this time. So, if I if I want to do that, it is nothing but t c 1 minus t c 2, which is 1.38 milliseconds minus 0.287 milliseconds right, the values also makes sense. So, low voltage, lower time it takes; higher voltage, higher time it takes for the capacitor. 1.38 minus 0.278 sorry 287, which is nothing but 1.093 milliseconds that means, the time taken from here to here is 1.093, approximately 1.1 milliseconds right. This also we will keep it a keep it aside.

Now, so we got one value, this value right; t 1 we got. Now, what we need to do, we need to understand about discharging right, is not it. Now, I am erasing everything. So, I hope this is clear. But, when we observe carefully, the discharging and charging rate of capacitor equations are not same right.

So, what is if you recall our RC discharge filter, where we would have studied in our previous physics or electronic circuits right, the discharge the relation we can write it down as V c. The discharge rate of capacitor we can say if I say this is V s, and this is time, and this is V c, this is V c. V c, I can write it down as V s into e power minus t by RC right that is our discharge rate of capacitor right. So, V c is equal to V s into e power minus t by RC, is our discharge rate of capacitor.

Now, I can directly implement this, and I can calculate to know, because this is from full 15 volts to 0 volts, but in our case, our capacitor is not fully charged to 15 volts, our capacitor somewhere here, somewhere around 7.5 volts, when I compare with the previous cycle right. When I see here, the capacitor is discharging from plus V reference, plus V reference in this case is 7.5 volts right 7.5. And again, is it discharging completely to minus 15 volts, see is it completely discharging it to minus 15? No, it is only discharging up to minus V reference that means, somewhere in between. And I want to calculate the duration from this reference value to this is reference value, this time duration I want, this I am saying it is as t 2 right.

How do we calculate it? If I want to calculate, first I have to calculate, what is the time duration required for the capacitor to discharge from plus 15 volts to this reference value? This reference I am saying it as plus V reference, this reference I am saying it as minus V reference right. So, I am saying it as again t d c 2 discharge 2 previous one is t c 11, we consider d c 1 from plus 15 to minus V reference right. And again, if I can calculate the time duration from plus 15 to plus V reference, meaning plus V CC to plus V reference as t d c 1. Since, I want to know t 2, so t 2 I can write it down as t d c 1 minus t d c 2 make sense right.

Now, how do I calculate t d c 1 and t d c 2 right? If I want to calculate, substitute the same thing in the equation. So, I will write it down below V c is equal to V s into e power minus t by RC. So, in this case t, I am calling it as calling it as t d c 1 right. What is V s V. What is V s? V s is from minus 15 to plus 15 that is 15 minus of minus 15 30 volts. Now, what is V c, now since it is t d c 1, I want to consider only till minus V reference. What is the discharge time taken for the capacitor to discharge from 15 to minus V reference, minus V reference is 7.5 right, it is minus 7.5 right minus V reference.

What is the time? So that means, minus 15 15 minus 7.5 15 minus 7.5, so 15 minus of minus 7.5, I want to know the voltage across the capacitor sorry. So, voltage across the capacitor is minus 7.5 right minus 7.5, which is 30 right into e power minus t d c 1 by RC. So, if I calculate 7.5 by 30, so 7.5 divided by 30, which is 0.25 right. So, minus 0.25 is equal to e power minus t d c 1 by RC, I can say t d c 1 is equal to RC into log and minus 0.25.

So, sorry, this is not 7.5, I am discharging from 15 to if I see this, I am discharging from 15 volts to minus 7.5. That is when I when I convert into 30 volts, it will become total 30 30 minus 7.5; or I can say how much? What is the percentage of V s in complete 30 volts V s right? What is the percentage of minus V reference in complete 30 volts?

If I want to do in that way, I can note it down as, so this is complete 100 percent right. 100 percent is nothing but 30 volts, now 7.5 minus 7.5 which is so, this is 50 percent, then 7.5 volts is how much, 7.5 into 100 by 30 7.5 into 10 divided by 3, so it is 25 percent. So, 25 percent; so, this is nothing but 50. So, this is 25 right and whereas, the 7.5 is 75 right. Now, this is 25 percentage of complete V CC is minus V reference 75 percent right. Now, 0 to 25, 25 percent; so, 7.5, 50 percent 0, minus 15 to 25 percent is seven point minus 7.5 minus 7.5 to another 25 percent is 0. And again, from 0 to plus V reference is another 7.5, which is 25 percent; again another 25 percent is yeah.

So, I can say this I can say the relation between V c and V s as 25 percent of V s is nothing but V c right. So, V s, V s if I cancel, I it should be 0.25 some calculation mistakes 0.25, then it will become RC into log 0.25, so which is nothing but 10 power minus 3 ok. I will write it down, so that this phase I can use it for t d c 2 minus 10 power minus 3 into log 0.25 is how much, log 0.25, so which is minus 1.386. So, minus, minus I can make it positive, so 1.386, which is 1.386 milliseconds. So, the time taken for the capacitor to discharge from plus 15 to minus reference minus 7.5 volts is 1.386 right make sense. So, t 2 note it down as t d c 1 minus t d c 2, so I got it as 1.386 milliseconds.

Now, logically if I see, based upon our logic if I see, so time taken for capacitor to discharge from plus 15 to plus 7.5 should be even smaller than this, is not it. We will see, we will also calculate that. So, I will say V c is equal to V s into e power minus t d c 2 by

R 2 RC. What is V c? Now this is seven 75 percentage of our full value. So, I can say 0.75 75 percent right, so 0.75 of V s is equal to V s into e power minus t d c by RC.

So, when I calculate t d C 2 should be equal to ok, I will write it down right side t d c 2 should be equal to minus RC into log 0.75 right, so which is nothing but t d c 2 is RC is nothing but 10 power minus 3 log 0.75. So minus 0.287; minus 0.287 minus, minus cancel, so this becomes 0.287 milliseconds. So, make sense, is not it. See when I see the time taken for the capacitor to discharge 2 minus points minus 7.5 value is 1.36 right, it takes longer time to discharge right. Whereas, the time taken for the capacitor to discharge to only 25 75 percent of voltage that means, plus 7.5. We will takes very lesser time right 0.287. So, the difference value will be 0.287 milliseconds. So, t d c 2 is 1.386 minus 0.287, which is nothing but 1.099 milliseconds right.

Now, we got we got t 1, as well as t 2. So, when we will go back to our circuit, the complete T is nothing but t 1 plus t 2. So, time period T is equal to t 1 plus t 2; t 1 is nothing but so, I am saying this is t 1, this is t 2 or t 2 plus t 1 anything is fine. So, t 1 is 1.093 and milliseconds, and t 2 is 1.099, so which is nothing but 1.099 plus 1.093, which is 2.192 milliseconds. So, if I want to convert into frequency, it is nothing but 1 divided by 2.12 milliseconds. So, it is 2.192 milli answer inverse, I will get 456 hertz right. We will also see with our experiment, and we also have formula here, 2 is equal to 2 R 1 C 1 into log 1 plus T is equal to 2 R 1 C 1 into log 1 plus beta by 1 minus beta.

So, how do we calculate? We can calculate in the same way, rather than taking the values, we can substitute into as we have already seen as professor explain in the theory class, so we can we can see the same thing. So, if I substitute beta here, beta value is nothing but how much, it is beta is half right 0.5 by 1 minus 0.5. So, it is nothing but 1 by 2 minus 1 1 by 2 and 3 by 2 sorry 1.5. So, when I calculate the value 2 into 10 power minus 3 into log 1.5 log 1.5 divided by 0.5, so the value is equal to 2.197 milliseconds right. The value is equal to this, but this cannot gives us what is t 1 and t 2 period, but with our logical sense, when we calculate, we also got our t 1 and t 2 values, we will compared with the simulation right. I hope this everything is clear.

Now, we will see we will do the same thing in our simulations, so will open our Multisim right. And we have also calculate t x right. We can also see the t x value 2. This is 1 kilo, this is 1 microfarad right. Now, just go to our simulation in a Multisim live, let me create a circuit. Now, as we have already seen how to create a circuit in our even old lectures, in our previous sessions. Now, we will not see about that, but we have to we have to create the circuit. So, this is the circuit right.

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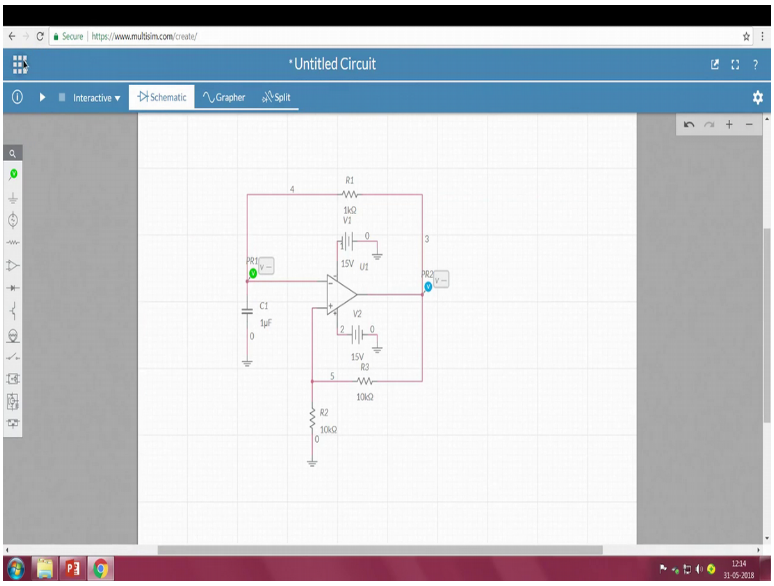

So, first I have to take our op-amp. So, I will take 5 terminal op-amps, so that we can even provide plus V CC or minus V CC, and I will swap the values sorry swap the positive and negative just by flipping it just by flipping the circuit. Then, so we have to consider R 2 and R 3. So, I need two resistors; one resistor for R 1, and other resistor for capacitor right sorry another capacitor I will revise the capacitor. Then I need resistor values, which is R 2, this is my R 2, then other resistors value R 3 right, then what else? Do we need any power supplies? Yes, we need a power supply only to provide voltages to op-amp, not to activate our circuit right.

So, astable multivibrator once you switch on once you provide a supply to our operational amplifier, it starts charging, discharging, charging, discharging, charging discharging; we do not required to give any triggering pulse right. So, they should be negative. So, I am connecting it to negative value ok, and ground this should be connected to ground. Then I also need one more voltage source to provide to the positive. I am giving it, then I have to rotate, so I will rotate it, then this should be connected to again ground.

Now, we made a calculation of beta, and reference values, plus V reference, and minus V reference by considering the supply voltage is as 15 and minus 15. So, if I want to cross verify with the simulation results with our theoretical calculations, we should we should change the supply voltages, otherwise it changes complete value. So, this goes to 15 and 15. So, this is minus 15, we have applied at this point, positive 15 is applied at this point.

Then what next, R 1 and C 1 has to be connected 1 kilo farad. Yes, this is 1 kilo ohms sorry and 1 micro farad, those are right. So, this has to be connected to this one, and this should be connected here. Whereas, the negative terminal of an op-amp has to be connected here, so that the charging and discharging of the capacitor can be compared with our positive value, then this will be ground right. Then after that, in order to provide our saturation sorry our plus beta V references values plus and minus V reference thresholds values; we have to connect R 2 and R 3.

Now, what values of R 2 and R 3 we have considered, so we have consider 10 k and 1 10 k and 10 k. What will be will there be any difference, if I take 1 k 1 k? No, because the beta remain same, whether it is 1 k or 10 k right. So, as per theoretical calculation, beta values is R 1 sorry R 2 divided by R 2 plus R 3 1 k divided by 2 k, again it becomes 1 by 2. So, whether it is 10 k 10 k or 1 k 1 k or if as long as R 2 and R 3 are same, this calculations remain same 10 kilo ohms, so we have change everything, so everything is done.

Now, what we have to see, we have to see the time period, we have to see the capacitor charging and discharging, and we have to see the output voltage right. So, I will put one at this point capacitor charging, another one at this point. So, green indicates our green indicates our the capacitor charging and discharging, blue indicates our output. Now, let me save the circuit save, I am saving the circuit as astable multivibrator. Now, just go to the graph, run the circuit.

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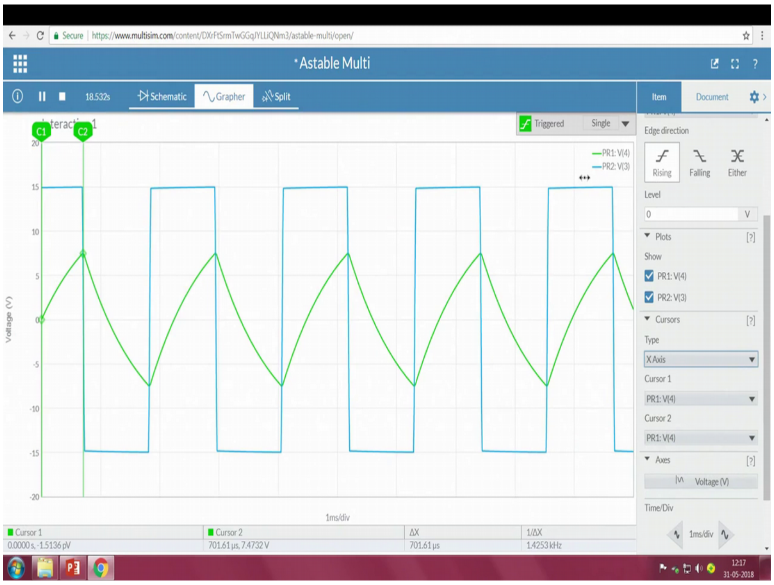

Yes, so I am going to settings, voltage right. So, I am making it to single trigger, not auto, single, so that only one cycle I can see right. Now, whether it is right or wrong, how do we know? One thing is when your input voltage is greater than plus V reference; we should get minus V CC. Now, observe here, when you see here, when the green is the input capacitor voltage goes go more than 7.5 right, see the value 7.48, approximately 7.5, the output is going to minus V CC right. So, it is similar to our inverting Schmitt trigger.

And again, when the input is when the input value is minus 7.5, the output goes to plus V CC right output is going to plus V CC that is clear. But, is this the what we require in our astable multivibrator know, we require to know we required to understand what is the frequency of your signal output signal. That frequency of the output signal entirely depends upon depends upon beta R 1 and R 2, and here RC what is the capacitor and resistors charging rate of your capacitor everything. So, in order to see that I have to create some cursors; so, one thing is clear, it is working fine.

Now, if I want to compare with our results theoretical results, let me create let me create X axis cursors. Now, if I look into the X axis one, I will make it connect at 0 right; and other, I will connect at plus V CC 7.5. So, you can observe cursor 2 value here; somewhere close to 7.47 somewhere close.

Now, what is delta x, delta x we got 701.61 microsecond. The time duration from the capacitor to charge from 0 to 7.5, this is 7.5. We can see here, 7.47 volts is 701 microseconds. What we got compare with our result, so go to this what is our t x value, t x if you remember 0.693 millisecond that is 693 microseconds 693 microsecond 701 microseconds almost close, the difference might be because of because of this value too right, because it is not exactly at 7.5.

Now, what is other one, other one is the time taken for the capacitor to charge from minus 7.5 to plus 7.5 right. So, help make the cursor to be at 7.47 volts or I can zoom it too, but fine this is fine. So, cursor 1, I am placing at minus 7.5 7.48, so approximately minus 7.5. So, now when I see the time taken for the capacitor from here to here this time, which we considered as t 1 in our case is 1.1243 right 1.1243 millisecond.

Just go to our presentation, what is t 1? If you observe, this is t 1 right. This is the time taken for the capacitor charge from minus 7.5 to plus 7.5. How much we got t 1?0 t 1 we got as 1.093 milliseconds right wait 1.093 millisecond. See 1.1243 millisecond that deviation maybe because of the values, or let me do okfrom here sorry, I have to do from here to here, so 1.48 right approximately 1.12 1.093, approximately 1.1. So, if I if I set it properly, since we do not have such a precision in this, you cannot exactly see the value right.

Then what is other one, we have to know we have to know what the time is taken for the capacitor to discharge from plus 7.5 to minus 7.5, the time duration. When we theoretically calculate, we got 1.1 millisecond; so this one. From plus 7.5 7.47 7.468 7.48 close to 7.5 to minus 7.48 right 1.12 milliseconds, we also got 1.1 milliseconds. The complete frequency, when we see the frequency is nothing but from here to here. So, what I will do is that I will make I will take the cursors on this, so I will keep it.

So, now the cursors are in C 1, I will see from 0, whether we get or not ok, I am not getting it that is fine to C 2 ok, so 2.241 milliseconds. What is the theoretical value we got, 2.192 milliseconds 2 4 the difference because of we have not exactly placed right, so which we is at our theoretical and our simulation results are almost the same almost same. Now, we will do the same thing using our board too using our t i board. We will connect the same thing we will connect the same thing, and we will see whether we are getting the responses in our board too right.

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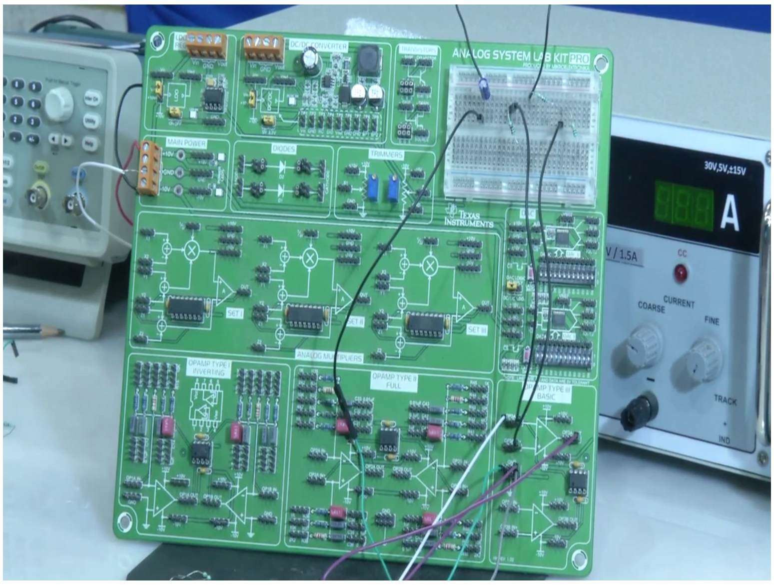

So, now we go back to our TI board. When we look into our TI board right, when we see here, so as we have already working on this board from our previous experiments itself. So, even now, we are going to use this particular operational amplifier this op-amp sorry, so this particular op-amp. And we know there are different bug connecters connected to the op-amp right. And we use this platform, this multi sorry breadboard platform to connect our R 1, C 1, R 2, R 3, resistance value, which decides that.

Now, we will connect the same circuit. We will connect we will take the resistance values, whatever we required, and resistance and capacitance value. So, R 1 what we consider, 1 k? So, we will take 1 k, and 1 microfarad capacitor. So, in this case, we may not require function generator, we need only power supply this power supply and CRO, we do not need this function generator. So, we will take 1 k resistor, now is connecting it. Then you will take 1 microfarad capacitor, so where so, we will connect it on the breadboard, then we will make the connections. So, 1 microfarad capacitor should be connected from negative terminal to ground right.

So, even you can see into our presentation 2 about the circuit, if you want, Then R 2 and R 3. R 2 and R 3 either 1 k 1 k or 10 k 10 k, we can consider. So, now in this case, since we have used 10 k, where going to use 10 k. One 10 k resistor should be across positive terminal to ground, and another should be should be parallel sorry across should be the feedback path that means, from the output to positive terminal of your op-amp. So, you can see the connections. So, we have connected capacitor as well as three resistors there right. One point is from capacitor to 1 microfarad capacitor to 1 kilo ohms, and other two resistors, which are on the right side are 10 k 10 k resistors right. Now, we will take jumpers, and we will connect it to our op-amp, so where we have to connect one the junction point of capacitor and the resistor should be connected to the negative terminal.

So, the jumper has been connected to one jumper has been connected to the positive terminal, and other jumper is being connected to the negative terminal, and that jumper is being connected to the negative terminal jumper is connected to the junction of R and C right. We can see here to the junction of R and C, then to the negative of our op-amp right it is connected. So, other one to the positive terminal, it should be connected to the junction of 10 k 10 k resistance. So, we can see here. So, to 10 k 10 k the junction of 10 k and 10 k resistor, the jumper has been connected to the positive terminal of op-amp, so that means, we made the connections required for that, but we have not even provided the ground terminals, so we have to give the ground terminals.

So, we will take one more jumper wire, so where is the ground terminal here in the op-amp, so we can take the grounding bug connector switch is on the board here. So to this ground, so we will connect this ground to the common point there right. Then, so we need to ground two common points ok. So, now the circuit is ready. So, now what we have to do, we have to provide plus V CC and minus V CC to operational amplifier, so that we are providing to using power supply to the main power.

So, we can see here end of the boards is plus 10 minus 10, since our calculation we uses plus 15 and minus 15, since op-amp can also work for plus 15 and minus 15. So, we are using we are using plus 15 and minus 15. And since, here are the connections, the same connections are being connected to the plus V CC and minus V CC of our or to the op-amp itself. So, we do not have to take another wires, (Refer Time: 70:25) connected there. Now, our connections are ready.

So, we have to see the voltage across the capacitor right, and the frequency of the output voltage. For that, we take two channels of oscilloscope, the first channel is being connected at so, the first channel, we will connect at the junction of R and C, which is the negative terminal to the negative terminal, and other terminal will be grounded. Whereas, other channel, we will take the other channel, we will connect it to output voltage. So, when we look into the oscilloscope, the yellow the first channel represents the voltages the charging and discharging of the capacitor, and the blue one represents the blue one represents our output voltages. Now, the circuit is ready right. So, now only thing is we have to switch on, we will switch on the oscilloscope as well as power supply right.

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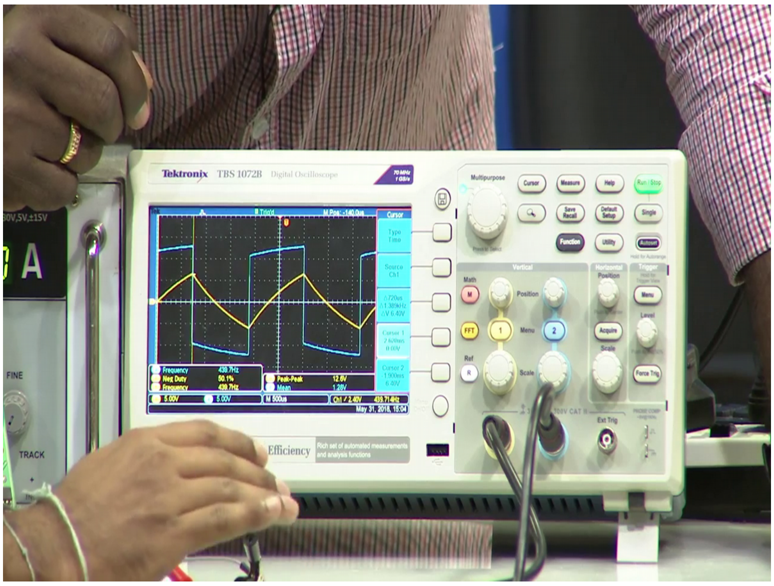

So, we got input as well as output too. So, we will keep both in the same plane, so that easy for us to understand. Now, so when we look into aside, we have seen t x has 0.693 milliseconds, which is nothing but from 0 to what is the time taken to go to go to plus V reference. And we have also seen t 1 and t 2 values, and we have also theoretically verified. Now, we will see in our experimental way.

So, we will create a cursors here, I am going to the cursors, so I will create type as time cursors, I need time cursors. And what I will do is that I will take the first cursor, and move across 0 line, so 0 is somewhere here right. So, cursor 1 if we notice the cursor 1 will be at 0 volts. So, let me zoom in little bit, so easy wait 2.2, so at 0 volts. What about the cursor 2, I will select cursor 2, so towards I am connecting it reference value, reference is somewhere around 7.5. So, when I when we see the difference, the difference is 720 microseconds right, so we got 693 milli microseconds.

Now, other thing is we have to see the complete frequency. So, how can we see the complete frequency, we can directly go to is a channel 1, I can say so, yeah, channel 1 frequency is already set, but I need for channel 2. Channel 2 frequency, I will enable it. So, when we see, we can see the frequency is 439 hertz. So, what we got, 456 hertz right almost equal, that difference is because of our tolerances due to our capacitance, probably due to the due to the capacitance resistances, as well as the plus V CC and minus V CC states also. So, since we have applied plus V CC or minus V CC as 15 volts, but op-amp can only go below that particular value that is a reason, there will be small offset variation right. We can also see t 1 and t 2, but as we have already seen in the simulation, even it looks the same way even in the CRO right.

I hope, so we got a complete understanding on how to calculate you know the time duration, the frequency of our output signal, and how do we compare with a theoretical and practical using astable. In case, what we can do is that, we can consider different other values of R 1 and R 2. And we can do the same calculation, and we can compare the results with our simulation and the theoretical. So, so you can have a look on the complete circuit once again. So, you can see here, so complete connections are made.

Thank you.