Op amp Practical Applications: Design, Simulation and Implementation.
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Lecture – 20
Op-amp with Positive Feedback: Non- Inverting Schmitt Trigger

Hi, welcome to this module. In this module, we will see a non-inverting Schmitt trigger circuit. Now, if you remember in the inverting Schmitt trigger circuit, we have seen how the hysteresis voltage is dependent on the regenerative feedback right. So, here if I want to understand how the non-inverting Schmitt trigger circuit works, then what are the parameters that I have to look for right?

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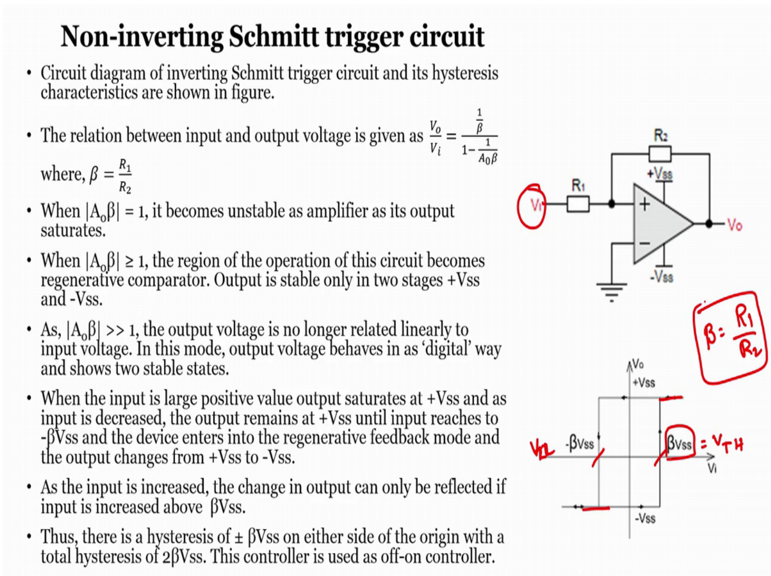

So, let us see how we can understand the non-inverting Schmitt trigger circuit. As you can see here right the input voltage is applied to the non- inverting terminal, there is a regenerative feedback, positive feedback. And the hysteresis characteristics of this particular circuit are shown here ok. So, the relation between input and output voltage, if I want to find the relation between output voltage and input voltage, then it can be given by V o by V i equals to 1 by beta divided by 1 minus 1 upon A o beta, where beta is nothing but R 2 R 1 by R 2 beta is my R 1 by R 2.

Let us consider the same thing that we have consider for the inverting Schmitt trigger where first is mod of A o into beta is equal to 1. So, in this case, the circuit becomes an unstable as an amplifier and its output saturates. In case of mod of A o into beta greater than equal to 1, the region of operation of this circuit becomes regenerative comparator. And output is stable only in two stages plus V s s and minus V s s right. Third, as, mod of A o into beta is greater than greater than 1, the output voltage is no longer related linearly to the input. And this mode, output voltage behaves as digital way and shows two stable states. This is similar operation if you understand inverting Schmitt trigger circuit, but what are the changes there are very few changes in terms of only circuit diagram.

So, when the input is large positive output saturates to plus V s s as the input is decrease output remains at plus V s s until input reaches to beta V s s the device enters into regenerative feedback mode and output changes from plus V s s to minus V s s right. So as the input is increased the change in output can be reflected, if input is increased above plus beta V s s right. So, what is the hysteresis, hysteresis is plus minus beta V s s. And on either side of origin, there is a hysteresis total hysteresis of beta V s s minus beta V s s which is like two times beta V s s right. So, this controller can be used as an on-off controller.

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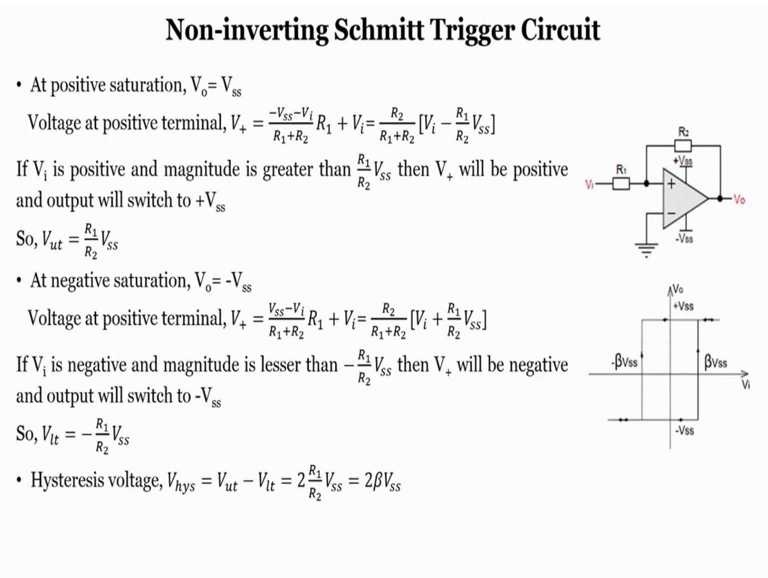

So, at positive saturation what will happen V o equals to V s s right if it saturates it can go to the maximum value which is plus V s s. Voltage at positive terminal V plus equals to minus V s s minus V i divided by R 1 plus R 2 into R 1. When I say maximum V s s does not mean that it will reach to plus 15 volts. Suppose, I apply plus 15 I apply minus

15, you guys know that, if I if this goes saturation does not go exactly plus 15 volts, it is less than plus 15 volts. And how much is it is your homework. It never reaches to plus 15 volts all right. So, understand that when you talk about saturation, it is not exactly plus V c c plus V s s, it is less than plus V s s or less than minus V s s ok.

So, we have V plus equals to minus V s s minus V i divided by R 1 plus R 2 into R 1 plus V i which is equal to R 2 by R 1 plus R 2 in the bracket V i minus R 1 by R 2 V s s bracket over say, if V is positive or input voltage is positive and magnitude is greater than R 1 by R 2 V s s, what will happen and V plus will be positive, now output will switch to V s s right. That means, if I V i input voltage is positive and magnitude is greater than R 1 by R 2 into V s s; then may V plus will be positive and output will switch to plus V s s; so, V u t equals to R 1 by R 2 into V s s right, which is my upper trigger point.

At negative saturation, this is a positive saturation, at negative saturation my V o equals to minus V s s right. So, in this case what will happen voltage at positive terminal V plus equals to V s s minus V i by R 1 plus R 2 into R 1 plus v i. So, if I solve this I have R 2 divided by R 1 plus R 2 into V i plus R 1 by R 2 into V s s, if my V i is negative and magnitude is less than minus R 1 by R 2 into V s s, what will I have? I will have V plus will be negative and output will switch to minus V s s right. So, my output is switching plus plus V s s to minus V s s, when my voltage V i is greater than R 1 by R 2 into V s s or is less than minus R 1 by R 2 into V s s right. So, in this case my upper voltage was V u t equals to R 1 by R 2 into V s s, my lower voltage is minus R 1 by R 2 into V s s that is my hysteresis voltage will be V hysteresis V u t minus V l t V u t is R 1 by R 2 into V s s minus R 1 by R 2.

So, we have written like R 1 by R 2 V s s minus of R 1 by R 2 into V s s, this will be nothing but plus 2 times R 1 by R 2 into V s s. And what is R 1 by R 2 R 1 by R 2 is our beta S 2 times beta V s s right. This is what we called here that total hysteresis of two times beta V s s right. So, this is how you are non-inverting Schmitt trigger circuit works right in case of inverting and non-inverting circuits. So, Schmitt trigger application we will have the output which is in on and off condition.

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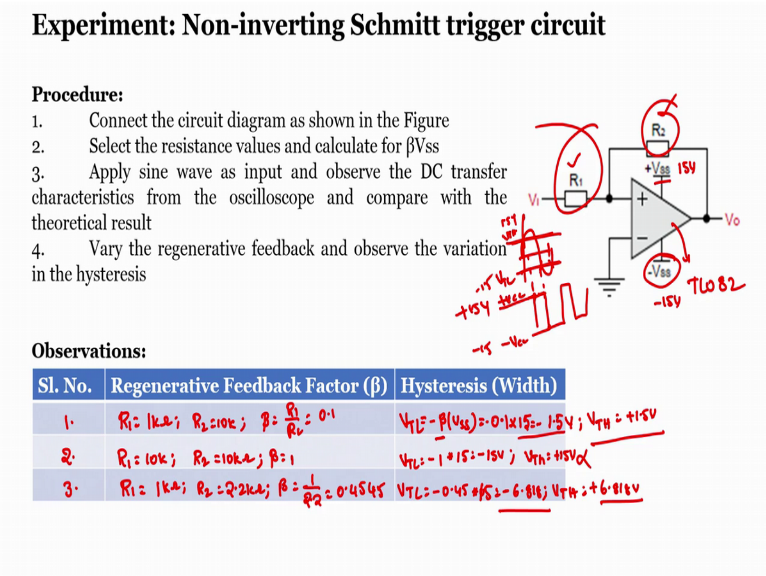

So, let us see, if I want to perform an experiment right to design the Schmitt trigger circuit, then non-inverting Schmitt trigger circuit is shown here where you have to connect the circuit as shown in the diagram. Then you have to select the resistance R 1 and R 2 and calculate beta into V s s, apply sine wave at the input voltage and observe the DC transfer characteristics on the oscilloscope and compare with the theoretical results vary the regenerative feedback and observe the variation in the hysteresis. So, the observations are still the same you apply a regenerative feedback, you look at the hysteresis. All right guys.

So, what we have done here is we have understood non-inverting Schmitt trigger circuit. Now, to design the circuit using multi sim, again we will ask your friend Sita Ram who will show us how to perform the experiment using multi sim.

Now, we are going to work on non-inverting type Schmitt trigger, when it comes to the circuit, if we observe there would not be much difference between a inverting type of Schmitt trigger and non-inverting type of Schmitt trigger, but only difference is that rather than giving input to an inverting terminal the input will be provided to the non-inverting terminal. But the feedback should always be a positive feedback. The reason is in Schmitt trigger the op amp has to be operated in saturation mode. So, it is also some kind of a comparator, but comparators only have a single threshold. If input is higher, it goes to plus V c c; if input is lower than the threshold value, it goes to minus V c c, but whereas Schmitt trigger, you can select when to go high, when to go low based upon the resistance that you choose and you can decide the that you know the width of here hysteresis or the lack between on and off of your system.

Now, as we already seen as a professor already discussed about non-inverting type Schmitt trigger, we will see what experiment that we are going to do, how the connections of an non-inverting type of Schmitt trigger, how what is the difference between inverting and non-inverting when it comes to circuit connections everything. Then later on we will use the simulation first one is the theoretical we will take different resistance values, we will calculate beta and we will all also calculate lower threshold value as well as a higher threshold value for the chosen resistance.

And theoretically we will calculate what is the high threshold and lower threshold. Then we will compare with a simulation we will analyze the relation between input and output, how the output is varying it depends upon the change in the resistance. And we will also experimentally verify using TA kit as we have already seen in similar it is similar to that of what we have seen for inverting type of Schmitt trigger. Now, we will look into the non inverting type Schmitt trigger circuits, we can see that the major difference is that the connection. So, as we remember in case of an inverting type the input is connected to the negative terminal and this particular point was connected to ground.

But in this case, it is input should be given to non-inverting terminal that is why it is called non-inverting Schmitt trigger. So, the negative terminal is connected to ground apart from this everything look same. So, when you see the characteristics the output curve, the relation between an input and output. It was also inverted of your previous output are of your inverting type Schmitt trigger when you if you recall what we have seen in our inverting Schmitt trigger circuit, when the input is greater than the upper threshold the output will be minus V c c right.

But whereas, in this case when the input is greater than lower threshold value the output is minus V c c, but whereas, in the previous case in inverting type when the input is lower than lower threshold value the output is plus V c c, but whereas, in this case it is minus V c c. And similarly when the input is greater than beta V s s which is your higher threshold value, so, I am saying this is called lower threshold value. I will say V t l and this is nothing but V t h higher threshold value. So, when your input is greater than this V t h, then the output will be plus V c c apart from this the operation was everything same, but what how would the relation between the resistance and beta in a previous case, if you recall what we have discussed the beta is nothing but R 1 by R 1 plus R 2.

Whereas, in this case, the beta is R 1 by R 2; I hope this we have professor has already covered in the theory session. Now, when we look into the experiment what we are going to do we will choose different resistance value we will take t l 082 in an experiment. So, it is a dual op amp that we have already seen in the last session two and we will consider different R 1 R 2 and we will connect accordingly right. And for the chosen resistance value of different R 1 R 2 we will calculate beta and then we will calculate the higher threshold and lower threshold values too.

Then so, for that case what I will do is that initially we will choose resistance as 1 k and 10 k. So, I will say R 1 is equal to 1 kilo ohm R 2 is equal to 10 kilo ohm. So, if it is a case what is the beta value. So, as we know that beta is nothing but R 1 by R 2. So, the beta values 1 by 10 which is 0.1, right then what about the lower threshold. So, V t l which is nothing, but our lower threshold; that is what we are doing the nomenclature for that which is beta minus I will say minus beta into V s s; nothing, but what is our negative supply voltage into what is the beta value.

So, since beta is depends on R 1 and R 2 and from the calculation we can see it is a 0.1 value and we will be operating our V s s and minus V s s with plus 15 volts and minus 15 volts. So, this V s s will become 15, since it is minus V s s it is minus. So, which is nothing but 1.5 minus 1.5 volt is the lower threshold value right. So, similarly higher threshold value V t h I am representing as plus 1, 5 volts. So, if you recall how the output characteristics of a non-inverting amplifier, we know that when the input voltage whatever the input that we are applying when this particular input voltage is greater than this V t h.

In this case, it is nothing but 1.5 volts, then we will get high right. Then again till what time it will be high when our negative when our lower threshold value V t l, if the input value input voltage is lower than this V t l. Till then it will be higher see in our case it is minus 1.5 right. So, when the input voltage value is lower than minus 1.5 or here minus 1.5, till then it will be higher right and it keep one continuous. Right and what will be this voltage value this will be plus V c c and minus V c c the reason why it will be always in plus V c c and minus V c c.

Because, since op amp open loop gain of an op amp itself is almost very very higher, since the op-amp is also connected in a positive feedback manner, when we look into the transfer function of a positive feedback, the overall gain will be even more higher than the open loop gain as a result, since the gain is higher even small input voltage is enough to make the op amp to operate in a saturation region, because of that reason the op amp output will be always in either in plus V c c state or minus V c c state.

And in this case, we have operating the op amp at 15 volts and minus 15 volts, so that is the reason the higher value output will be plus 15 and the lower is minus 15. But when to switch on when to switch off will be decided by the thresholds; that means, it depends upon the resistors that we are using it ok. Then we will take another resistance values too we will see for different resistance value and we will calculate.

Once we calculate our lower threshold and higher threshold value, we will do the simulation of by considering the same resistance connecting. The similar way as we have seen in the circuit, and we will compare the theoretical and simulation, once both are done we will also look into the similar experimental thing. So, all three will compare and will finish this experiment. So, now, I will consider R 1 as 10 k and R 2 also as 10 k. So, when you see the beta will be 10 by 10 which is 1 right. So, so V t l will be what V t l will be minus 10 into 15 right, so which is nothing but sorry 1 beta is 1 minus 1 into 15 which is minus 15 volts.

And whereas, V t h is nothing but V t h is plus 15 volts, but since in a simulation we can easily see, because since in a simulation, there are no restrictions of the input voltage we can easily see. But this is very difficult to visualize with our experimental, because our source when you see the maximum peak to peak value you can get is a 20 volts, so that means, the peak value will be only of 10 volts. So, since in this case we require a peak of more than 10 volts this cannot be used in our application. So, but in simulation will see how to how exactly it works, whether it is working as per expected or not.

Next, what about other resistance value I will take R 1 as 1 kilo and R 2 as 2.2 kilo 1 kilo and R 2 as 2.2 kilo. So, what will be the beta value 1 by 2.2. So, 1 by 2.2 is 6.818 volts sorry. So, 1 by 2.2 we will take a calci 1 divided by 2.2; so, 0.4545 this is the beta value.

Now, what about V t h, V t l? So, V t l is minus 0.45 into 15, so which is nothing but into 15 so, 6.818 minus. So, the lower threshold is minus 6.818. And similarly the higher threshold will be plus 6.818 volts right. So, we will verify the same thing using simulation first. Now, when I look into the simulation will open in a multi sim right. So, when my when we see first thing is we have to take an op amp. So, I will go to the op amp and this is a analog pallet. So, in this, if I look into that you have 5 terminal op amp I am placing 5 terminal op amp here.

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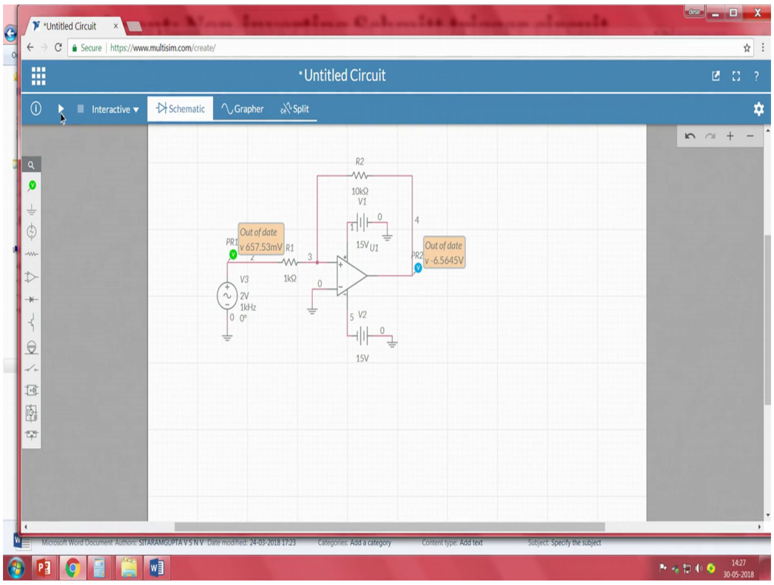

Now, I have to provide the plus V c c and minus V c c to the op amp. So, I will take I will go to source pallet, here I will go with a dc voltage. And I will rotate it. I will connect from here to here right. And similarly I need a ground, I will put a ground later on I will connect it. And again I need one more supply voltage here to power it the negative bias power, then again the ground right. What else we require we also require resistance value. So, I will take a resistor. So, should be is it a negative or positive, so it is a positive feedback. So, I am taking a positive feedback. Then what about negative? Negative should be connected to the ground, so I will take on more ground I place it near the negative terminal.

Now, where the input to be applied and where to measure the output input should be applied at R 1 resistor. So, what I will take a sinusoidal wave. So, ac voltage, I will place it here with respect to the ground. We have to measure with respective to the ground.

After replacing everything I will connect to the wiring. So, how to do connection simply wherever you want to create a wire, just go to the end tip press left of mouse left mouse click, automatically the tool will be converted to wiring tool then move your mouse. So, wherever there is a connector, it automatically shows you know zoom out function. So, when you click it, automatically it will connect it right. Similarly, from here, here just go here and click it here.

And again from resistor to the positive terminal, and this resistance to this positive terminal; and the other end of the resistor has to be connected to V out this is my V out. And the negative terminal should be connected to the ground. And the positive input bias input voltage should be connected to positive source, and negative terminal should be connected to the ground. The voltage that I have to apply is 15 volts right that is what we have done in the calculations too. If you would have done the calculation using 10 volts then you can apply 10 volts here too, so then the output will be fluctuate from plus or minus 10 volts, but thresholds will change beta into V c c or beta into V s s.

Similarly, even here, so I have to connect negative to the negative terminal, so that since the voltage source 12, so I have to be changed with 15. Since, it is a 15, since a negative terminal connected here; that means, the voltage that we are applying is minus 15 volts right. Then so is everything is ready, yes, our circuit is done now. But we have to do the comparison, we have took see the relation between the input and output until unless we connect scope. The circuit will be working, but it is very difficult for us to visualize it.

So, what we do is that I will go to the analogue and annotation pallet here we have voltage you know indicators or kind, kind of a graphers props, those are called props. And we can take one more prop and connect at the output voltage terminal right. Now, I have already created the props wherever I want to see the input and output. So, input will be in green and output will be in blue color, but is this resistance for me. If I use this resistance value it is nothing but beta values of 1, so beta into V s s V s s is 15, then this is a second case, but right now first we will go with the first case.

So, for that I will take R 1 as 1 kilo R 2 as 10 kilo. So, I will change R 2 to 10 kilo ohms right. Now, what is the input voltage, when we look into the presentation we remember that the threshold values 1.5 plus 1.5 and minus 1.5. When we recall what is an expected output, if you remember, when my input voltage is greater than the higher threshold value meaning in this case when the input voltage is greater than plus 1.5 volts, I should get an output as plus V c c meaning it is 15 volts. Similarly, when the input voltage is lower than minus 15 volts or sorry minus 1.5 volts, it is a lowest threshold value I should get an output as minus V c c

Now, is my input to measure both whether I am getting plus V c c as well as minus V c c? No, the reason is the input voltage below than the higher threshold value itself. Since, it is lesser than the higher threshold it will be in one saturation it will be in plus V c c, sorry, it will be in a minus V c c we can also simulate and we can see ok. So, we need to apply we need to apply more than more than threshold voltage. So, I will go peak value as 2 volts. So, I am going peak value value as 2 volts. And I am going to run the value going to the grapher.

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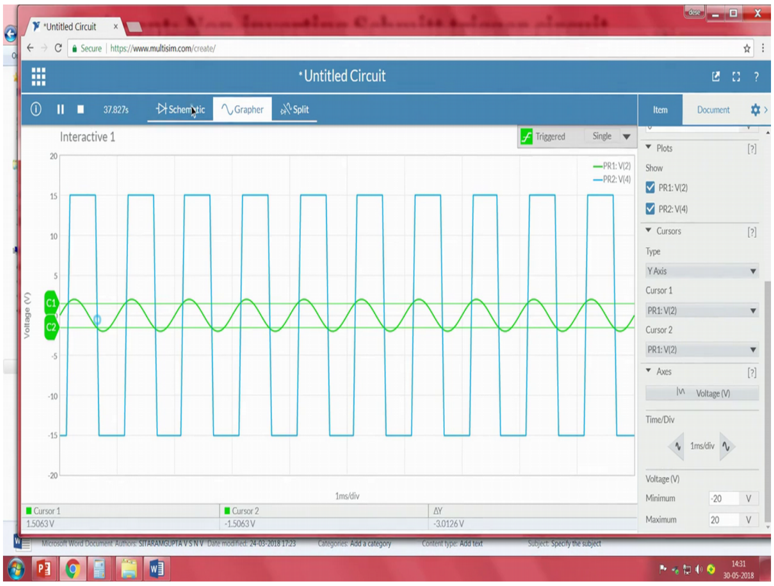

Yes, going to settings and change scaling it. So, here we can clearly observe that this is my input, the green color line is my input and the blue color line is my output. So, for our understanding ok, what is the peak value, it is some around 2 volts. Now, what we have to create cursor, so that easy for us to understand. What I will do is that I will go to y axis cursor, one cursor should be at 1.5 volts right. So, when will when you look into this particular point, we can see where exactly the cursor is at right. Cursor one is somewhere around 1.8. So, I have to make it as 1.5 right, oh, So, just lightly cross 1.5. So, I will just move towards 1.5 also, so somewhere around 1.5.

Now other cursor should be at where minus 1.5, because that is a threshold that we have created where do you I have to see at this point. Now, I will go slowly little down up ok, 1.59 yes minus 1.5 approximately minus 1.59. Now, when I see, so the triggering I will make it as a single so that I cannot see any fluctuation. Now, when we observe it, what we have understood, when we see that the output voltage will go to plus 15 volts when the input value is greater than V t h. In this case, V t h is 1.5 volts.

So, when we see when this cursor is when this green line is greater than C 1 which is the cursor one, we can see the output is moving to plus V c c right. And similarly when it goes to minus V c c, since it is not a comparator when our input is lower than C 1, it will not go to V c c it will go to minus V c c only when the input is lower than C 2 value. Now, observe that when I see the input is decreasing sorry this should be 1.5 ye. This is 1.5, ye. Now, when you observe, when our the input is lower than minus cursor two which is minus 1.5 which is lower threshold value, then the output is move towards minus V c c.

So, everywhere it is happening in the same way. But what is the difference that you observe from inverting and non-inverting type, in case of inverting this would have been in a reverse way meaning when the input is greater than C 1, I would have get minus V c c, but when the input is lower than C 2, then the output would have been plus V c c, but in this case it is a completely similar to the input similar to the threshold, threshold input is greater than first higher threshold go to plus V c c right.

Now, now we will go to the schematic we will change our resistance values and we will observe whether it is also affecting for other whether the output expected output is same for the second case also. So, in a second case, the resistance both resistance should be of 10 k is it not that is the case that we have considered. So, look into the slide when we see that R 1 is also 10 k R 2 is also 10 k. So, the beta value is 1. Now, the threshold id minus 15 and plus 15. So, when I go here, I will change it to 10 k. this should be 10 k right. Now, both resistors are 10 k as a result the beta value is 1.

Now, when I go back to our ye grapher, now one more important thing, what the input value. Now, the threshold values are not below the 2 volts right, the peak value of the input is 2 volts right. But the thresholds are even higher than the 2 volts. So, we cannot see that operation right. So, in order to see the operation what we have to do, we have to increase the input voltage greater than 2 volts right sorry greater than the V t h. Now, in this case the V t h is 15. So, what I will do is that I will make it as 20 peak that means, peak to peak is 40 right. Now, the input is more than 20 volts, even the negative input is minus 20 volts.

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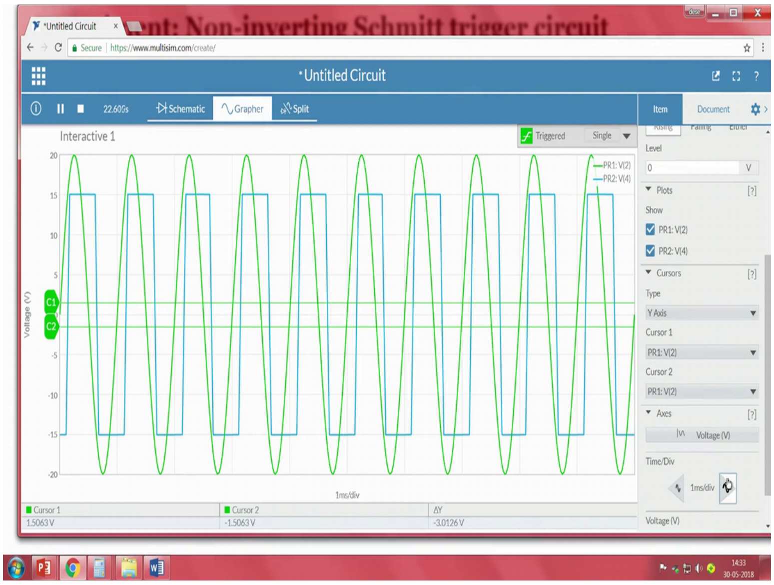

So, when I look into the grapher, I have to make it as auto, yes, auto. So, it is updated, then I am making it as a single. Now, if you observe it here, so what I will do is that I will increase I will decrease the time duration, so easy for us to understand.

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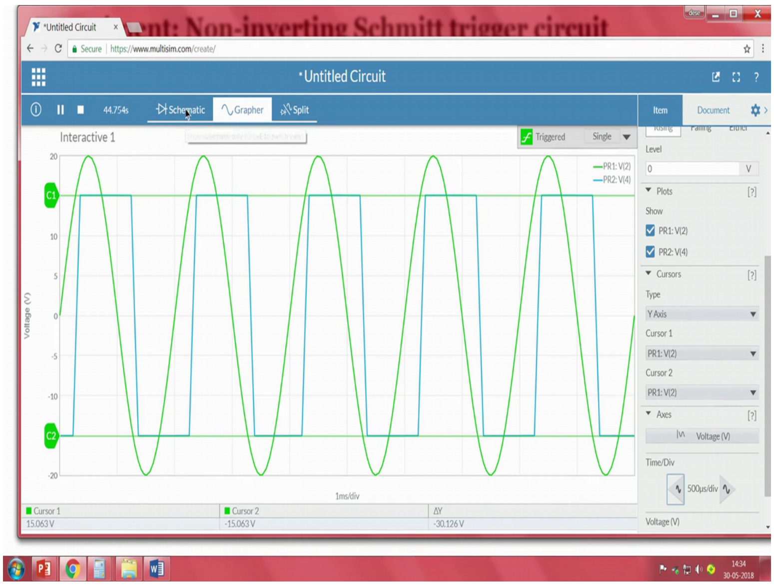

Now, what is my C 1 and C 2, meaning C 1 is higher threshold, and C 2 is the lower threshold. C 1 is plus 15, C 2 is minus 15. So, I will set C 1 as plus 15. So, you can see it at this point, so C 1 is somewhere around right now at 10, so I will go to 15 volts moving to 15 right. And C 2 should be minus 15. So, C 2 value we can see it here right.

Now, the output is as per expected, why do not we check. Now, when we observe, when the input is greater than this value input is greater than value, it started to change right. But, why the output is not greater than, the previous case if we observe, the input signal is smaller, output voltage is higher. But, why in this case it is not, because the saturation voltage of the op-amp is plus or minus 15, but the input is higher than that right, so that is why, we can see this is already at plus V c c. Now when it is going to minus V c c, whenever the input just crossed just cross your minus V V l t or by V t l, where threshold value, then it has gone to minus V c c right, make sense clear right.

Now, we will look into other case also what is the other case, R 1 has 1 kilo, R 2 has 2.2 kilo ohms. So, go back to the schematic, then I am just stopping it, replace this with 1 k, and this with 2.2 k right. Now, now do we need this value, may not be. Even if it is the case, we can visualize it. Even if it is smaller than that, smaller than the thresholds values is also good enough. Now, what is an unexpected output here it will be, whenever the input is greater than higher threshold. So, what is the higher threshold at this point, it is 46.818 right when our input is greater than 6.8 approximately of 6.81 or 82 right, it it it will be at plus 15 volts; lower than that value, it will be at minus 15 volts volts. Otherwise, it will follow in between; it will always follow the input.

Now, in this case, if I see if I run system and I will change, so we do not need this value, I will go with a 10 volts. Peak value is 10 volts; peak to peak is 20 volts. Going back to the grapher yes, here we can see C 1 should be 6.8 something. So, I will take 6.8 slowly decreasing 86, and C t is also 6.86 minus 6.8 right, now observe. When the input is greater than this particular value, so it started moving towards this value, is it not observe right or track, I will see, where the input is right ye.

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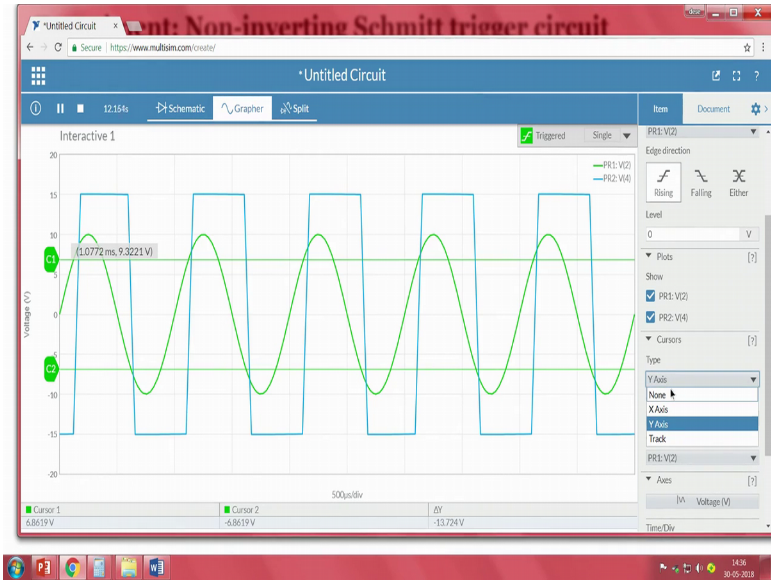

Now, if I observe it here, when the input is greater than C 1, I can see when I plot it here, started moving to minus plus V c c right. And when it is going to minus V c c, when the input is lesser than C observe. This is my C 2, which is minus 6.86. Whenever the input is lower than this value right at this point, it is started moving from plus 15 to minus 15 volts. So, we can understand that, the difference between an inverting and non-inverting, and the simulation is working as per expected to as per the theoretical calculation. We will also see the same results, whether we get the same results, when we do it in a in our experimental in with actually taking our op-amp, and connecting these resistors, providing an input, and observing the output voltage right.

So, when we look into the board, when we look into the board, now we will do all the three test case scenarios. First test case scenario, I will take R 1 as 1 k, R 2 as 10 k right, and I will apply input as sinusoidal signal. And we will see, so since we have already calculated beta values, whether the output is going to plus V c c and minus V c c, when greater than plus beta V s s are going to minus V c c, when it is lower than minus beta into V s s, we will see that.

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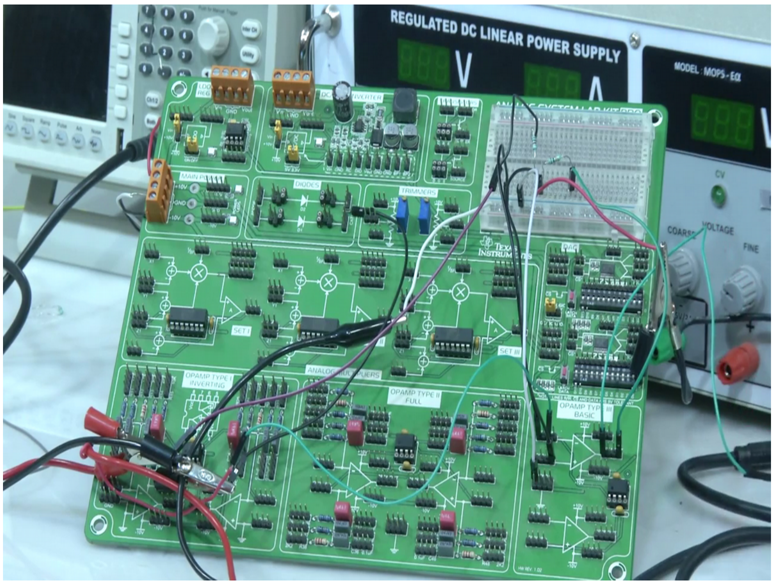

Now, when we come back to the circuit board, yes when we see; so, even in this case, we are going to use this particular subsystem right, similar to what we have done. And we will be using the same op-amp and we have already seen negative positive terminal as well as output voltage, and the powering is already done here right. Only thing is, if I switch on my power supply, if I switch on this power supply right, if I switch on this power supply, I can provide a power to the operational amplifier, and I will be connecting.

Since, this particular system does not have any resistors; we will be using this breadboard to connect the resistors. And in our design, we are using different varieties of resistors, all the resistor will be connected here. And we will be wiring it through this jumpers to the board, we will power we will provide input from this function generator, and we will visualize output from the oscilloscope.

Now, now we will take 1 kilo ohm resistor and 10 kilo ohm resistor. So, 10 kilo ohms should be connected to feedback, and 1 kilo ohm should be connected to positive input terminal to the input source right. Now, if you observe, so we are connecting a resistors, this is 1 kilo ohm resistor, so one resistor should be connected to the positive terminal. So, if I see, this resistor is connected with this wire jumper, this we are connecting it to the positive terminal, so that is a positive terminal bug connector bug state.

Now, what about the other terminal of the resistor, this should be connected to input. So, input is from the function generator. We are taking a function generator right, the function generator the function generator will be input will be connected to this particular point right. So, we are connecting it now right, input is done. Now, what about another resistor, yes we also need R 2 resistor, which is a feedback, so we will take 10 kilo ohms. So, we will take a 10 kilo, you will connect across positive terminal and the output right, so which is the positive terminal, this junction this particular junction is a positive terminal junction right. So, to other side of the breadboard other column of the [blood/breadboard] breadboard, we will be connecting this resistor. And other end, we will connect it to the output voltage.

Now, in this case, if I see the green color wire, this green color wire is one end is connected to the output right, and other end we are connecting it to this other end of the resistor right. Now, so we made we made connections to the positive terminal, we also made a connection to the feedback resistor, what about the negative terminal of an op-amp, the negative terminal of an op-amp is should be connected to the ground in this case right. So, we will take one more jumper, the ground is just below that, is it not.

So, from the negative terminal, we are connecting ground or we can also connect it at this point too, so because we already connected this ground using a white jumper wire to this board right. Now, where do we have to measure output where do you have to measure output, output has been measured at this particular point. So, by using one more channel of an oscilloscope, the second channel of an oscilloscope right, it is connected to the output terminal, and the negative is connected to ground.

So, when we see that when we see completely from the function generator, we provide supply to the board as an input as an input; and from the oscilloscope sorry from the voltage source, we provided plus 15 and minus 15 volts to the operational amplifiers. And one channel of an CRO is connected to the function generator input at the resistor input right at the resistor input. Whereas, whereas other channel is connected to the output ok.

Now, we will focus on function generator, we will switch on the function generator, we will set input value. So, since the in this particular case, the threshold values are so, threshold values are plus or minus 1.5 volts. So, what we will do is that, we will set a value of somewhere around 2 volts peak. So, we will go to amplitude, and we will set the peak value as 4 peak to peak right. We have set a value as 4 4 volts peak to peak, we can see the peak values 2 volts, the negative peak is minus 2 volts, so that is more than enough for us to visualize it.

Now, I will switch on the board, I just switched on the board, and I am also switching on CRO. When we switch on the function generator, we can see the signals here. So, what I will do is to just I will change the voltage values, time scale right also. What I will do is that, I will slightly increase the scale of the input right. When I see that, the scale of the input is 1 volt, whereas the scale of output is 5 volts let us say. Since it is the scale is 5 volts, one the box is nothing but 5 volts 1, 2, 3 boxes. So, why it is not completely 15, the reason is that saturation voltage will be slightly lower than plus V c c value right that is the reason, it is somewhere around 14 approximately 14 volts right.

Now, what about the cursors? So, we will go to the cursors, I will set cursors here. So, what is the resistance we have used, 1 k and 10 k. The gain the higher threshold value is 4 point sorry 1.5 and minus 1.5 is a lower threshold. So, I will take a cursorsit is of amplitude cursor, I will take I am setting amplitude cursor. So, we can see two cursors; one here this yellow, and other one this yellow right. So, what I will do is that, I will change the cursors values. So, channel 1 if I see here, I have to make it as 1.5 volts right. So, I am going to 1.5 slightly yes 1.52. Now, channel 2, I will select channel 2, I will go to minus 1.5 right. Now, is it correct or not? How do you understand, whether it is correct or not, whether it is working as per our expectation or not. Our expectation was or as per our theoretical or simulation results, we have seen that, when the input voltage in this case the yellow color sinusoidal input is greater than the higher threshold in this case plus 1.5, I should get plus V c c, which is nothing but 15.

So, now if I see, this is my input, this is the higher threshold value, when I have observe here, when the input is greater than this higher threshold, the output is gone to plus V c c, is not it meaning. The circuit is working as per our expected in the high threshold, what about in the lower threshold, look it look into this. When the input voltage is lower than this yellow line right this yellow line, which is the lower threshold value right, it has gone to minus V c c, everywhere it is following the same thing right, which means that which means that with the resistance value, the theoretical as well as experimental both are same right, here we can see right 15 minus 15.

But, I am not going to do this case in experimental, the reason is that input voltage. When you see, I require input voltage to be greater than 15 volts, but the source, it cannot provide more than 10 volts as a peak value, so that is why, I will not consider this. But, if you have any source, you can also connect this and we can visualize, we can also do the experiment in your labs.

Other one is I will take R 1 as 1 kilo, R 2 as 2.2 kilo. And in that case, the threshold values are minus 6.818 and 6.818, and we will see. Rather than taking the second case, we will go to the third case directly. Now, we will replace R 2 resistor as R 2 register with 2.2 kilo ohms, previously it was 10 kilo, we will replace with 2.2 kilo. When we look in to the board, which is R 2 in this case, which is R 2, R 2 is this one right. This is the feedback resistor. So, we switched off the power supply, and we are replacing this with 2.2 kilo ohms right. So, now we replace the feedback resistor with 2.2 k, remaining circuit remain same, I am not even changing any point, then switched on.

But, what about the input voltage, the input voltage, previously we have set at when we look in to the function generator, the peak value when we look into this function generator, the peak value is 2 volts right ye. Now, this value is 2 volts. Now, I will I will change the value to more than 7 volts, so I will be connecting plus or minus or peak to peak as 15 volts or 20 volts anything is fine. So, we are connecting peak to peak as 15 volts right.

Now, how what should be my output before looking into the CRO? we will understand how the output should look like. When the input value is greater than 6.8, I should get plus V c c. And again, when the input value is lower than minus 6.8, I should get minus V c c. Now, so we are connecting the input to the system to the op-a[mp] to the circuit at the respected place. Now, when we will look into the output in the CRO, so when we focus on the CRO, we can see here. Now, the input box is also 5 volts, output box is also 5 volts.

Now, what we are doing is, we will place the cursors the both higher threshold cursor, lower threshold cursor to their respective places. In this case, the value is 6.8. So, I will see, whether I can exactly place at 6.8, if not approximately near that value, yes this is the ye 6.8 right. Again, I will make the lower cursor is also at minus 6.8 right. So, the both the cursors the higher cursor, lower cursor are connected. Now, is it switching on when the input is greater than plus V c c sorry; when input is greater than 6.8, higher threshold value (Refer Time: 49:55) why do not we check.

See the yellow line, this is our higher threshold, this is lower threshold, this is the input voltage. Now, when the input is greater than this particular value observes here this value, it has gone to plus V c c right. Again, when the input is smaller than lower than the minus V t l right, it has gone to minus V c c. So, it is following the same everywhere, so that means, whatever the result that we theoretically up time for different resistance values also using the simulation, whatever we have seen, even it is matching with our experimental values too.

But, when you compare with a normal comparator in these cases, we are by using two resistors, we are providing two threshold values; higher threshold, and lower threshold values. And the threshold values entirely depend upon your R 1 and R 2. And what type of circuit that you are doing or where you are applying the input voltage, weather applying it to the inverting terminal or non-inverting terminal. But, in realistic way, how do we understand, where do we use this particular circuit. So, why do not you consider the same example, we have discussed. Consider a water heater right, so day to day life, we will always use the water heater.

Now, when I see, I want to switch on the water heater, only when the temperature is lower than 50 degree, but when the water temperature is greater than 50 degrees sorry greater than 70 degrees, I have to switch it off, understand the scenario. When the temperature is greater than 70 sorry when the temperature is greater than 70, the output should be low, but when the temperature is lower than 50, then that the system should switch on.

If I want to design using a comparator, it is not possible. With a comparator, I can only put either one threshold either at 50 or at 70. So, when the temperature if it is a comparator, if I set it as 70, when that input is temperature is greater than 70, then switch on. Input temperature lower than 70, then it will switch on sorry lower than 70, it will switch on; if it is greater than 70, it will switch off, but in this case, it is not like that. When the temperature is lower than 50 degrees, then the heater will switch on; and the temperature is greater than 70, the heater switch off.

So, there is a time there is a lag between switching on and switching off your sensor sorry here heater. So, such a cases or in case of on off controlling, so that is why, Schmitt triggers are also called on off kind of controller, such cases wherever you require some kind of hysteresis some lag between when to switch on, when to switch off, this type of Schmitt triggers can be really useful right. I hope, you understood the difference between inverting as well as a non-inverting, and how it can be used in practical applications. So, we will see another example another experiment in our next session.

Thank you.