Electrical Measurement And Electronic Instruments
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Lecture - 61
Schmitt Trigger (Contd.)

Hello and welcome. We are studying frequency meter, digital frequency meter and so, it essentially counts the number of rising ages or falling ages of a square or rectangular wave, within a pre specified time and if the input signal is not square, then we have to convert it into a square or rectangular wave. Like a sine wave, or triangular wave, is required to be converted into a rectangular wave, before we can count it and for that we need a Schmitt trigger.

Because, we could have used comparator, but comparator will not work if the signal is noisy, but Schmitt trigger will work that is what we have seen, we have seen what a Schmitt trigger does, I mean what is it is function, but we have not discussed the circuitry or how a Schmitt trigger is made. So, we will discuss that today using op-amps ok.

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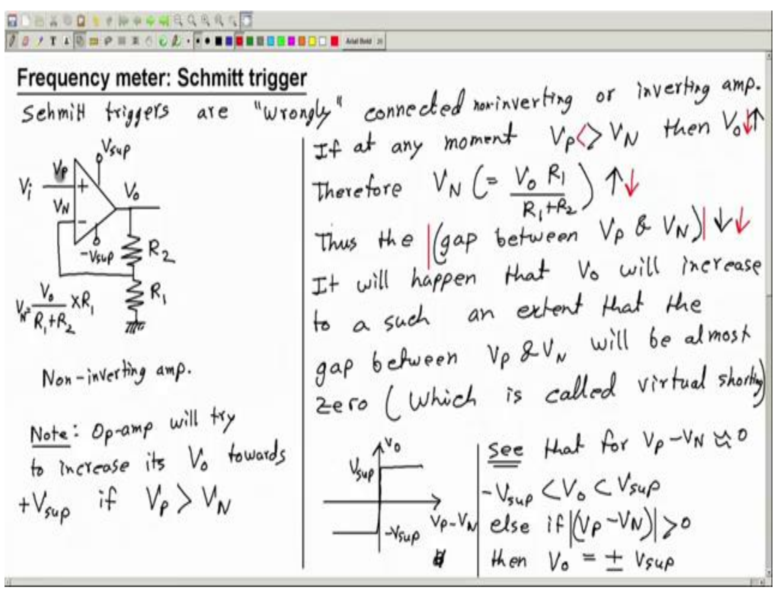

So, if you recall once we have mentioned that Schmitt triggers are wrongly connected amplifiers inverting or non-inverting amplifiers, non-inverting or inverting amplifiers. So, let us see it how it works. So, let us start with a non-inverting amplifier. So, this is a non-inverting amplifier, where a fraction of the output voltage V o, a fraction of the output voltage is fed back to the inverting terminal or minus terminal and here you give the input call it V i.

So, input is here and if I call this as say R 1 and R 2 then this voltage which is fed back is of course, $\frac{V0\ R1}{R1+R2}$ this is nothing but the current which flows in this branch multiplied by R 1 is the voltage across this resistance which goes back here.

Now, this is non-inverting amplifier ok. Now, let me just tell you a small observation about the this circuit. So, we know that the op-amp increases it is output voltage towards the positive supply value, if this input; that means, V P call it V P call it V N, if this voltage is higher than V N, then op-amp will increase it is output towards the positive supply value. So, this is the positive supply voltage and this is the negative supply voltage the rule err note.

So, this has also seen in static characteristic that op-amp in will increase will try to increase, it is output V o towards V supply positive V supply if V P is greater than V n. So, what happens? If, you give say a positive voltage here ok, which is higher than say V N whatever the value of V N is at this moment. If, you give a voltage here, which is higher than the value of current value of V N, then it will increase it is output towards the V supply and if this is increasing then of course, this voltage will also increase, because this voltage is nothing, but V o multiplied by some constant so; that means, this V N will also increase.

Therefore, the gap between V P an V N will reduce. And, if the gap between V P and V N is reducing is going towards 0, then the op-amp will not require to increase it is output towards supply voltage V supply ok. So, so, let me just continue this note ok. So, if at any moment say V P is greater than V N ok, then V o increases towards the positive supply voltage.

So, with this symbol with this short hand I mean V o increases goes up ok. And, if this goes up then you see this value is V N, which is same as a fraction of V o ok.

So, therefore, V N which is same as a fraction of the output voltage also increases right and thus the gap between V P and V N reduces ok. So, gap between V P and V N reduces and it will happen that op-amp will increase, it is output V o to such a extent. So, that the gap between V P and V N is almost 0 ok. And, it will happen that V o will increase to such a extent that the gap between V

P and V N will be almost 0 will be almost 0. In fact, this is what is called virtual shorting between V P and V N ok. So, this which is so, which we called before which is called virtual shorting ok.

So, a summary of the story is that, if ever V P is higher than V N, then op-amp will increase it is output until and unless this point this potential is almost equal to V P ok. And, then at that value of V o the op-amp will stay happily ok. Because, then V P and V N are equal almost equal and you know that from the static (Refer Time: 09:57) characteristic from an from the ideas almost idea is static characteristic. If, V P and V N is almost close to each other; that means, this is V P minus V N, if this is close to 0, then output V o will remain can remain anywhere between these two ranges that is V supply and minus V supply ok.

So, just see that for V P - V N close to 0, V o lies between plus minus V supply ok. So, let me rather write minus V supply less than V o less than V supply ok. So, this is in this small region, else if V P - V N is slightly greater I mean significantly greater than 0. So, if this is sufficiently greater than zero; that means, it is outside the resolution than then, then V o is equal to plus or minus V supply depending on whichever is higher ok.

So, here what we observe that we are still you once again, because this is very important that if ever V P is higher than V N, then output will increase until and unless this potential is almost equal to this potential, when these two will be almost equal then add that value of V o op-amp will stay happily ok.

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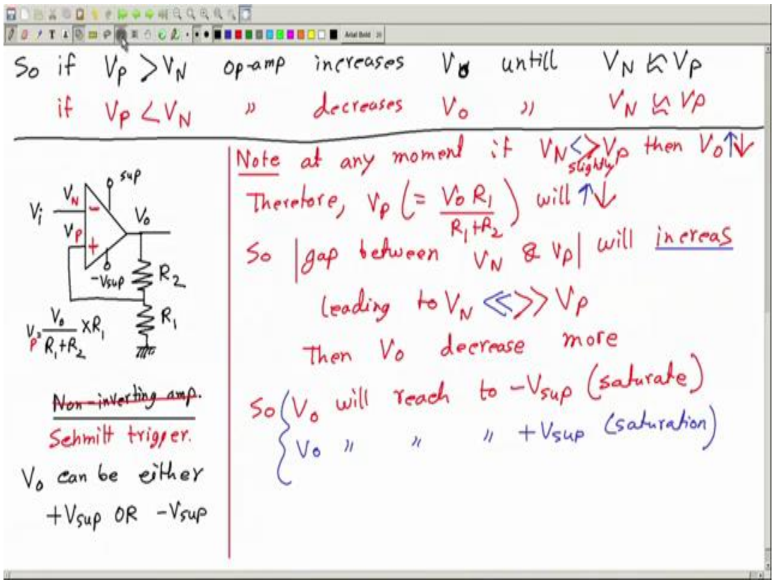

So, what is (Refer Time: 12:11) in if V P is greater than V N op-amp increases V o until V N is almost equal to V P. Similarly, similarly very similarly if we see this circuit once again, if ever this potential is lower than V N ok, if ever this potential is lower than V n. So, in this same statements we can write with a different color, that if at any moment V N is less than V N then output will decrease ok.

So, I am writing with a different color and therefore, this value will also decrease. and thus what will happen once again the gap between this V P and V N will also decrease because if this is lower than V N, then output will decrease therefore, V N will also decrease and thus V N will come closer to V P ok.

So, here I write with the red color, if V N not, V N; V P is less than V N then op-amp decreases V o until once again V N and V P are almost equal. This is how it works? Ok. So, this is how the equilibrium establishes? You can try to increase this voltage op-amp will also try to increase this voltage and thereby make these two equals.

Similarly, if you try to decrease this voltage op-amp will also decrease this voltage and thereby will make V P and V N equal. This is how a how one can understand this non-inverting amplifier.

Now, let us see what will happen, if we change this plus and minus terminals. So, instead of connecting this to plus I connect it to minus and here I connect it to plus. So, then I should also call this, V N and this as V P this circuit is no longer non-inverting amplifier ok. This is called a Schmitt trigger ok. So, how will it work?

So, now, you note that what will happen if say ever V N > V P at any moment. So, at any moment if say V N is greater than V P ok, this potential is greater than this potential, then output will decrease towards minus the V supply, then V o decreases towards negative supply voltage ok.

Now, this potential is decreasing. Therefore, what will happen to this potential which is coming from here ok. So, this is not N this is P. This is a fraction of output potential divider rule. So, therefore, V P which is same as $\frac{V0\ R1}{R1+R2}$ will also decrease because V o is decreasing right.

So, if ever this so, we started with the assumption V N is higher. So, if ever this value is higher, then V P will decrease. So, if V N is higher V P will decrease that is what will happen then the gap between V N and V P will increase further. So, gap between V N and V P so, this gap will increase. So, leading to V N becoming more and more greater than V P, because V P is decreasing.

Therefore, V N will become more and more larger compared to V P because V P is decreasing right. So, this gap increases. And, if this gap increases then output will decrease further. So, then V o decreases more and this way it will continue to happen. So, if I start with that V N is slightly. So, this greater than is slightly greater than, slightly greater than V P, but due to this chain reaction you can say loosely speaking. Due to this chain reaction the gap between V N and V P will be more and more V N will become larger compared to V P as time progresses and V o will keep going down towards minus V supply, how long until and unless it hits minus V supply.

So, V o will reach to minus V supply; that means, it will saturate, you know from the static characteristic output cannot go below minus V supply. So, therefore, it will go to only minus V supply. Similarly, if I start with the assumption that V N is ever slightly less than ok. So, let me write it with a different color, if ever V N is slightly less than V P, then V o output will increase and if the output is increasing then this will also increase resulting into that and to the fact that the gap between them will increase further, it will continue to increase. So, this will remain same ok.

So, here then I should write this will become more and more less than and ok. And, in that case V o will reach to plus V supply, once again saturation ok. So, when you say read this note read all the red colored things together or you read blue colored things together ok.

So, this in this circuit we observe that output will either go to positive saturation or it will go to negative saturation, positive V supply or negative V supply. So, V o can be either plus V supply or minus V supply, that is the only two stable value that the output can take ok. Now, let us see so, let us continue with this circuit ok.

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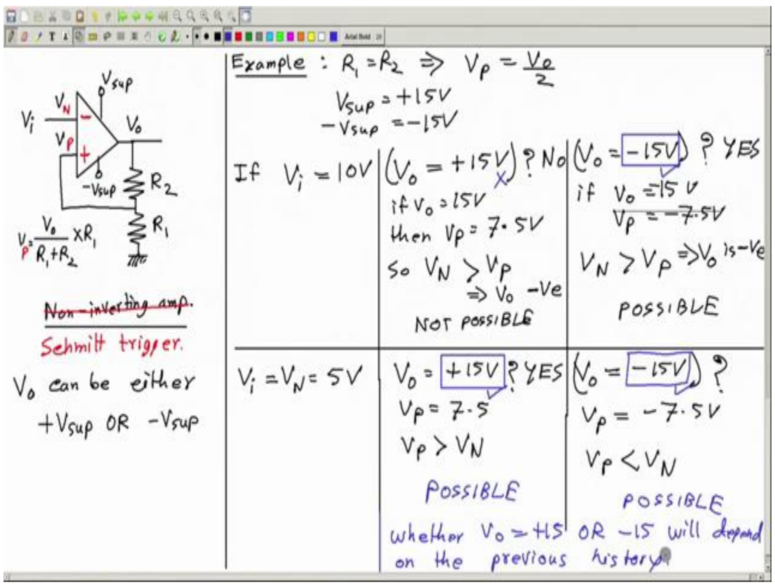

So, now let us take some concrete example. So, let us take an example say R1=R2 right. Therefore, this V P will be half of V o right. And, say this V supply is equal to say plus minus 15 volts plus 15 volt and minus V supply is equal to minus 15 volt right these this two are plus minus 15 volt.

Now, if I write V i input equal to say 10 volt, what will be the output. So, input is 10-volt output what will be the value of output. So, you know output can be either plus V supply or minus V supply. These are the only two stable values we have seen this in many different through many different logics ok.

Now, let us see is it possible that V supply is equal to plus 15 volt, because it can be only plus 15 or minus 15 let us see whether this plus 15 is correct answer or not ok. So, let us check question.

So, if V o equal to plus 15, then V P equal to half of that ok, then if V o = 15 volt, then V P is 7.5 volt ok. Now, this 7.5 volt is here, which is less than, V i which is 10 volt.

So, VN = V I > V P. So, output must be negative, output cannot be positive. If, V N > V P then output cannot be positive. So, the answer is no, this is not possible ok. Now, so, let us check can the output be equal to minus 15 volt yes is it possible let us check.

So, if it is if V o = - 15 volt, then V P = - 7.5 volt and then V N, which is 10 volt ok. V N is 10 volt is greater than V P fine and if V N > V P then V o should be negative ok. So, V o should be negative yes V o is negative. So, this is possible answer is yes. So, this is possible. So, this is the answer, but this is not possible, because in this case when V N becomes V P this implies output should be positive, but sorry output should be negative, but output is positive. So, this is not possible ok. So, this is the answer.

Now, let us take another case where input is V i or which is same as V N = 5 volt ok. Now, let us ask is V o = 15 volt possible ok. Let us check, then if V o is 15 volt, then V P is 7.5 and in this case V P > V N, because V N is 5 volt. So, output should be positive. So, it is possible yes.

So, output can be plus 15 volt ok. So, this is possible, this is correct. Now, let us check is it possible that V o is equal to minus 15 volt is it possible ok, let us check. If, V V o is minus 15, then V P should be minus 7.5 and then V P is less than V N, because this is 5 volt and this is minus so, this is less than.

So, output should be negative and yes, the output is negative. So, this is also possible, surprisingly this is also possible you see. So, both are possible both are correct answer. So, this is possible, this is also possible. So, output can take both the values plus 15 or minus 15, when the input is 5 volt, but the output cannot take two values at the same time. So, which value will it take that will depend on the previous history ok.

So, so, whether V o equal to plus 15 or minus 15 will depend on the previous history ok. Now, I request you pause the video at this moment or even close it and think about it what is happening I mean there are two answer possible just think and convince yourself for a while and then come back ok.

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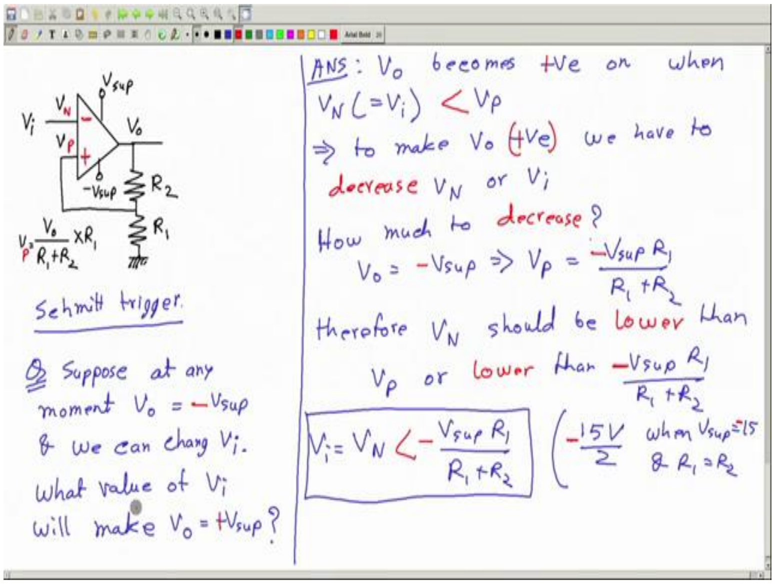

So, now this is our Schmitt trigger. Let us ask a question. So, the question is suppose at any moment V o = + V supply, V o can be either plus V supply or minus V supply. So, let us assume V o =+ V supply at any moment. And, we are changing the input we can change the input ok. So, we can change V i and we want to make V o = - V supply. So, the question is what value of V i will make V o = - V supply so, this is the question of.

So, now answer so, first observation is that if I want to make a V o negative, when can it be negative it can be negative only, if this value is higher than this value right so; that means, I have to increase V i ok. So, let us write V o becomes negative only when V N, which is same as V i in this circuit is greater than V P. So; that means, to make V o negative we have to increase V N or V i we have to increase V N or V i ok.

Now, how much what is the minimum value of V N or V i, which will surely make I mean which will make a output negative ok. So, now, how much to increase the answer is as follows? So, you just observe that V o equal to plus V supply therefore, this point is at a value V supply multiplied by this factor.

So, V P this value I can write V P = $\frac{V0\ R1}{R1+R2}$, now V o we know is equal to V supply. So, here we write V supply right. So, this is V P and we have to make V N higher than V P. So, therefore, V N should be higher than or at least slightly higher than V P or which is same as higher than, $\frac{Vsupply\ R1}{R1+R2}$ because this is the value of V P ok.

So, V N > $\frac{Vsupply\ R1}{R1+R2}$ ok. So, this is what we have to do we have to increase V N, which is same as V i higher than this value. If, we increase this higher than this value ok, then the output will become negative. So, for example, if I take this equal to plus 15 and R 1 = R 2 then this becomes 15 volt by 2 when V supply is 15 volt and R 1 = R 2 for example, ok. So, this is the condition, this is the boundary condition where the output will change I have to increase input by this amount ok.

Now, similarly you can ask the same question that if at any moment the output is negative, how can I make it positive ok. So, let me ask the completely opposite question, copy next page paste ok. So, now, let me ask the completely opposite question that suppose at any moment V o is negative ok; and we can change V i the and what value of V i will make V o positive ok.

So, answer will be again similar V o becomes positive only when V N < V P. So, to make V o positive we have to decrease V N or V i. Now, how much to decrease? So, you just observe that once again this is equal to minus V supply. So, this is minus V supply. So, you have to make V N should be lower than V P and; that means, lower than this value ok, this value ok. And, if this is minus 15 volt then this is minus 15 that is as is as it is so, now, what happens let us see. Let us go to the next slide ok.

And, so, let us see how the input and output changes ok.

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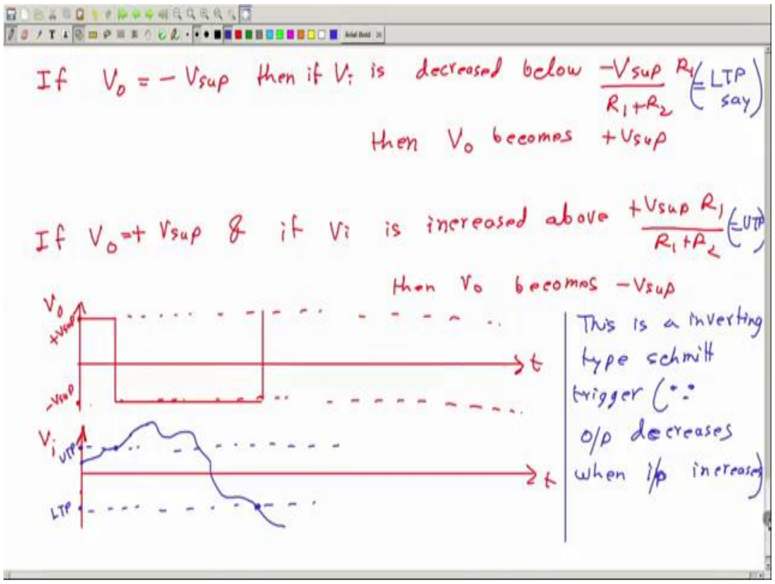

So, if output is equal to is negative, then V i less than this if V i is decreased, then if V i is decreased below this $-\frac{V0\ R1}{R1+R2}$ am I right, yes. If, it is decreased below this then V o becomes then V o becomes plus V supply. Similarly, if V o is plus V supply and if V i is increased above $\frac{+V0\ R1}{R1+R2}$, then V o becomes negative ok.

So, suppose let me draw the some timing diagram like this, this is time versus V o and this is time versus V i ok. Now, V i say let us say let us assume that V o is initially plus V supply, this is plus V supply and this point is minus V supply ok. And, let us call this point on the V i line is equal to this ok. So, this let me just give you the name ok, because I cannot write this big expression in the small space. So, let me give it a name let me just give it a name LTP call it LTP and this you call as UTP, lower trigger point and upper trigger point ok.

So, here I write this UTP and here I write LTP. The value of LTP is same as this and value of UTP is same as this. Now, you see that if the output is positive and if you increase V i above UTP ok. Say, if you increase V i from some initial value we do not know what the initial value is. So, may be here if you increase it, increase it and cross this point, then the output will become negative. So, at this point output will become negative and then it will stay negative as long as you keep the input here or actually as long as you keep it above LTP ok.

But, if you bring the in input below this value; that means, this value like this here at this point output will become positive again. So, this is how it works? This is exactly like a Schmitt trigger right. This is the upper trigger point of a Schmitt trigger lower triggers point of a Schmitt trigger.

The only observation is that it is a inverted Schmitt trigger you can call, because when you see input increases output decreases and here input decreases output increases. So, this is this is a inverted or inverting type Schmitt trigger, since output decreases when input increases ok.

So, this is called a inverting type Schmitt trigger. And, one small fact we have started this by changing the plus minus sign of a non-inverting amplifier. So, if you start with a non-inverting amplifier and change the plus minus sign it becomes a inverting amplifier, inverting Schmitt trigger. So, start from non-inverting amplifier and change the plus minus sign, it will become inverting amplifier just you can note this point ok.

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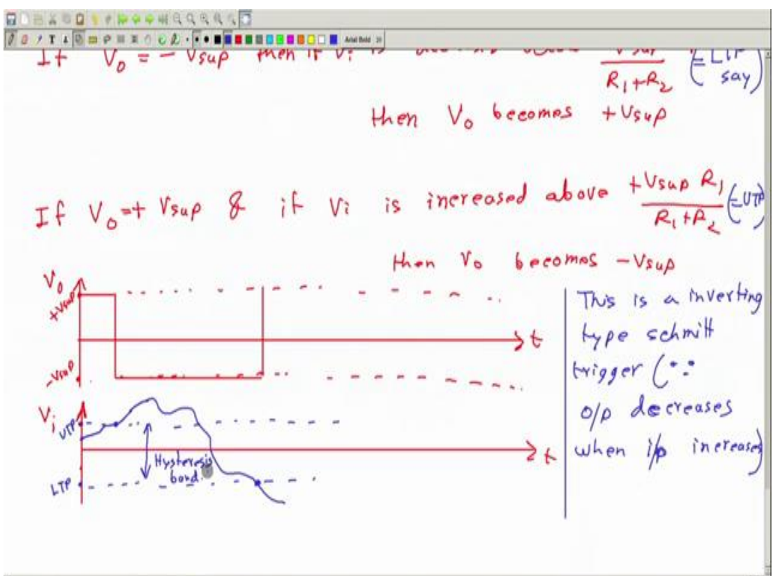

And, this is otherwise just like a Schmitt trigger only thing is that it is a opposite, but there is still a upper trigger point, there is still a lower trigger point and this is the hysteresis band hysteresis band or hysteresis gap. So, this is like a Schmitt trigger, but it is inverted ok.

So, now let us quickly see another type of Schmitt trigger, which is non-inverting type.

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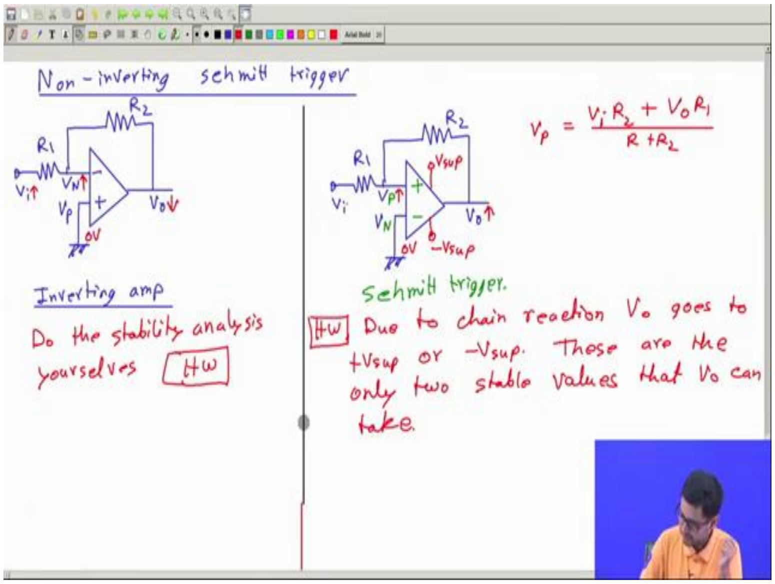

So, now non-inverting Schmitt trigger ok. And to make the circuit what we have to do we have to start from a inverting amplifier and change the plus minus sign ok. So, we will start say from a inverting amplifier minus plus give a negative feedback, this is R 2, R 1, I ground it this is the input, this is what this is inverting amplifier ok.

Before proceeding I request you that you do a stability and equilibrium analysis of the circuit on your own I just tell you very quickly that if ever say this, this is V N this is V P, if ever say you increase V i which will cause V N to increase ok. So, if ever I just give some symbols, if V i is increased then of course, V N will also increase because V N is some sort of average of this V i and V o. So, if you increase V i then output then V N also increases and if V N increases this is at 0, if V N is trying to increase output will try to decrease right, because negative input is increasing. So, output will decrease.

Now, if output is decreasing this will cause V N to go down right. So, you are increasing V i and op-amp is decreasing V o. And, therefore, you are trying to increase V N op-amp is trying to decrease V N. So, op-amp will increase it is output until and unless V N is again brought back to the same value as V P, which is 0 volt ok.

So, I am not writing these details things which I did for the previous 1 due to lack of time, you do it yourself if you need any help I will be happy to assist you no problem ok. So, do this stability analysis yourselves homework ok. So, now, let us start with this inverting amplifier and let us switch this plus minus signs ok. So, I will make this plus with a different color to highlight it and this minus ok. So, now, I should also call this as V N and this as V P right. So, this will become a Schmitt trigger a Schmitt trigger ok.

Now, I request you that you do the stability analysis or equilibrium analysis of this circuit on your own, because we already have done that for the previous circuit. So, I will not write it in detail, but I will just briefly mention. See at if at any moment, if say V P is let me first it is it, say if at any moment V P is higher than V N. Then, what will happen then the output will increase if V P is higher, then output will increase which will cause the V P increase further. Because, V P depends on V o like this,

$$Vp = \frac{Vi\ R2 + Vo\ R1}{R1 + R2}$$

So, if I have V P higher output will increase ok. If, output increases here V P increases further, and if V P increases output will increase even further, and then due to this chain reaction loosely speaking, informally speaking, due to this chain reaction output will keep increasing and will go to positive supply voltage ok, plus V supply. Similarly, if V P is lower at then V N at any moment, then output will decrease which will cause V P to decrease further and with this chain reaction output will go to minus V supply ok.

So, homework you just convince yourself thoroughly that due to chain reaction V o goes to plus V supply and or minus V supply and these are the only two stable values that the output can take that V o can take ok; and so, output can take only these two values. Now, I will request you to play another small game the game is like this.

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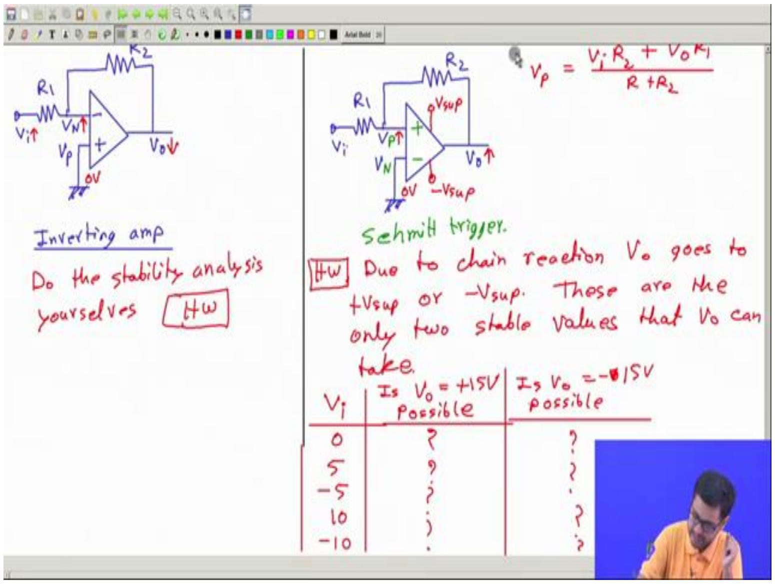

So, you take say different values of input make a table like this V i you choose the value of V i as 0 volt, 5 volt, minus 5 volt, 10 volt, minus 10 volt etcetera and ask is V o = + 15 volt possible yes or no ask this question ok, for all these given values. Similarly, ask is V o = - 15 volt possible see is it possible or not and we will see that for some input only 1 output is possible and for other input both outputs are possible ok. Let us see it is a nice fun it is a nice game you just play with this ok, like we did for the previous circuit this time you do it yourself ok.

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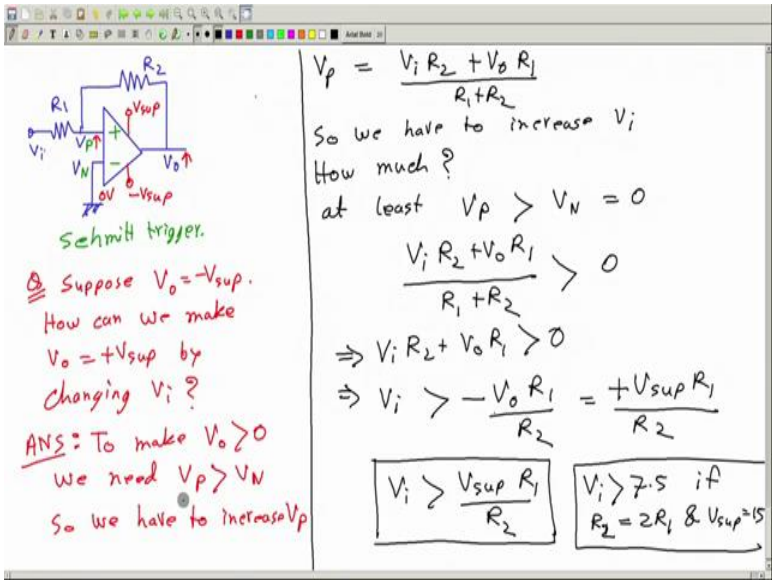

Now, let us ask a question that suppose so, the question is suppose V o is negative at some moment and we can change V i. So, the question is how we can make output positive by changing input ok. How can we make V o = + V supply by changing V i this is the question of. So, let us see what is the answer?

So, first question is do we have to increase V i or decrease V i. The answer is we have so; we want to make output positive, when can the output be positive only if V P > V N. So, we have to increase V P ok. And, we can increase V P by increasing V i ok. So, to make V o greater than 0, we need V P greater than V N ok.

So, we have to increase V P right. And, how can we increase V P; by increasing V i, because V P is nothing but $\frac{Vi\ R2+Vo\ R1}{R1+R2}$ ok. So, we have to increase V i, because if V i increases then V P increases, but how much at least as much. So, that V P becomes higher than V N and V N is equal to 0. So, at least V P should be greater than slightly greater than V N which is same as 0 ok.

Now, V P is this. So, let us write $\frac{Vi\ R2+Vo\ R1}{R1+R2}$ this should be greater than equal to 0 and from this we this goes away. So, from this we can write Vi R2 + VoR1>0 from which we write Vi > - Vo R1/R2. Now, in case of V o we can write the current value of V o which is same as minus V supply this is the current value.

So, it becomes minus minus plus plus Vsupply R1/R 2 ok. So, this is the condition Vi should be greater than this is the boundary value if I increase V i > V supply R1/ R 2 then output will go to positive value ok. So, this is the condition. So, you can take an example like this is equal to 15 volt and say R2 = 2 R 1 then we have to increase V i > 7.5 ok.

So, like V i > 7.5 if R 1 if R 2 = 2 R 1 and V supply = 15 volt ok. So, this is an example you can take ok. Similarly, you can ask the same question that if V o is negative sorry if V o is positive then what should you do to make it negative ok. So, copy next page paste.

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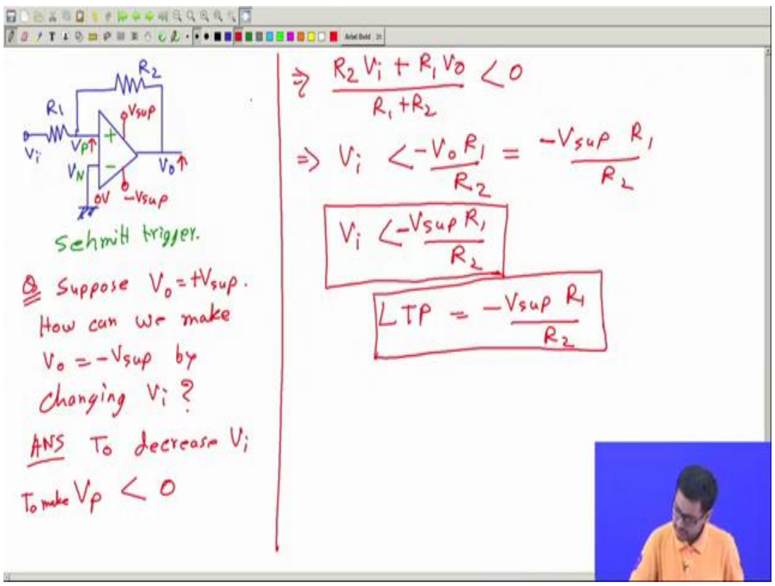

So, if this is positive how can we make it negative? So, you see that to make it negative we have to bring this value down lower than 0 and that is possible by bringing V i down sufficiently. So, answer we have to decrease to decrease V i now how much at least we have to make it make V P equal to or sorry less than 0 volt ok.

So, we have to make it V P to make V P less than 0 volt which implies V P is nothing but once again $\frac{Vi\,R2+Vo\,R1}{R1+R2}$ < 0 from this you can write Vi <$\frac{Vi\,R2+Vo\,R1}{R1+R2}$, which is same as let us put the current value of V o. So, we have to bring it down V supply R1/ R2 ok. So, this is the boundary condition V i < V supply R1 / R2. If, you bring it below sorry minus there is a minus there is a minus this minus ok, if you bring it down below this then the output will change ok.

So, very quickly so, this value I will call as lower trigger point LTP =- Vsupply R 1/ R2.

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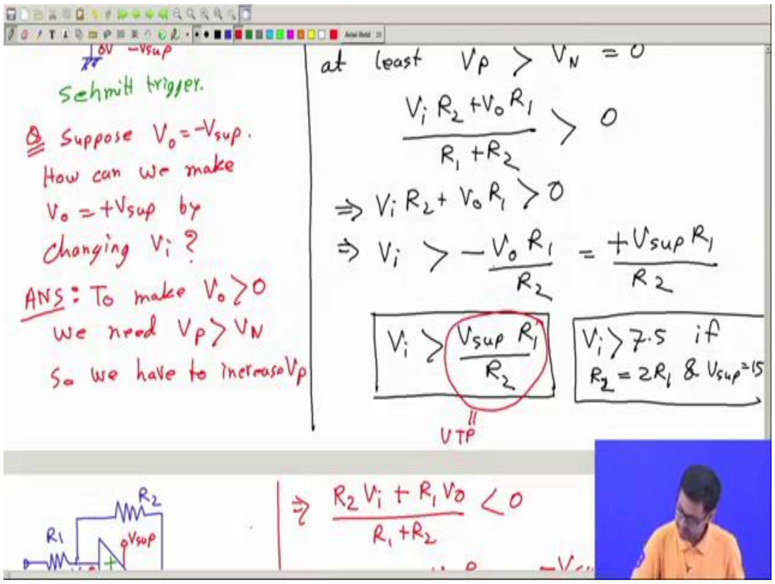

And, this value I will call upper trigger point.

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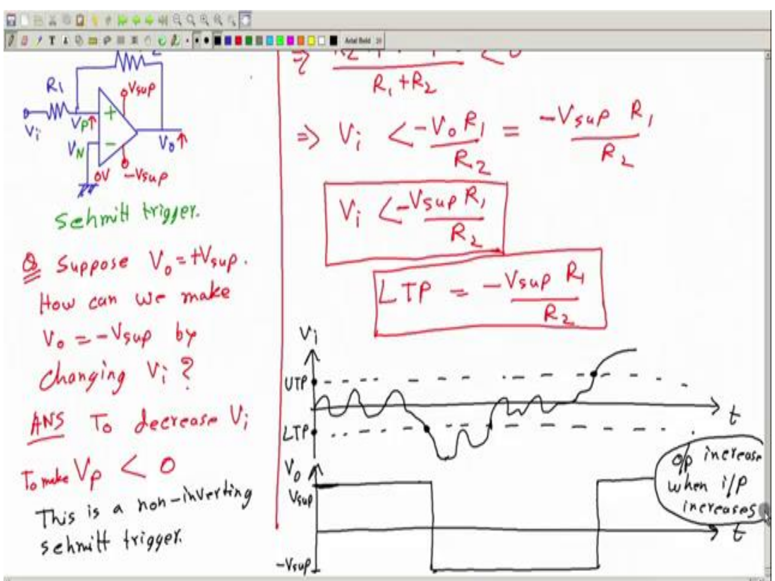

So, now you can do a timing analysis take time versus V i and time versus output, output can be either V supply or -V supply and V i on V i axis mark these two values LTP, which is this and

UTP, which is the negative of this so, this is the UTP. So, mark these two points (Refer Time: 60:33) start with the assumption say output is initially positive here and then input is changing ok.

So, the input is changing when will the input when will the output becomes negative to a for the output to be negative, you have to bring the input below lower trigger point. So, say here it goes down below lower trigger point then the output at this point will go to minus V supply.

And, then say input is again changing when will it make the output positive, the moment when the input goes above upper trigger point. So, say here. So, here output will become positive ok. So, this is how it works and you just see this is just like a normal Schmitt trigger, when input decreases, output decreases, if input increases output increases.

So, this is not a inverting Schmitt trigger this is a normal Schmitt trigger non-inverting Schmitt trigger. So, this is a non-inverting Schmitt trigger. Since, you observe that output increases when input increases and vice versa if input decreases output also decreases. So, this is a non-inverting Schmitt trigger, although we have just started this from an inverting amplifier. So, if you start with an inverting amplifier and switch the plus minus sign it will become a non-inverting Schmitt trigger ok.

Thank you.