Electrical Measurement And Electronic Instruments
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Lecture - 53
Inverting amplifier versus Schmitt Trigger

Welcome. So, in our last class we have studied and did a thorough analysis of inverting and non-inverting amplifiers using op-amp. So, next thing we should do is of course, an analysis on difference amplifier, but before that let us ask a question, what happens. If, we by chance or by mistake swap or change the plus minus terminal of the op-amp in either of this circuits.

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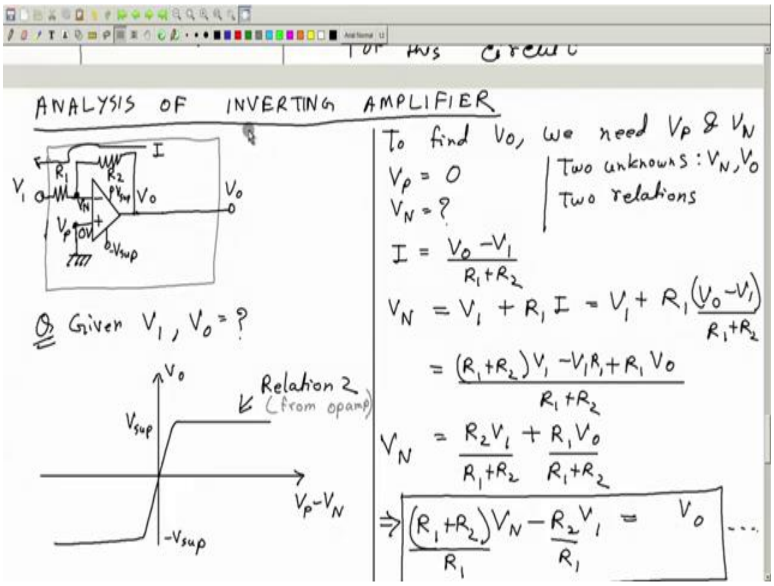

So, say see consider this circuits, this is a inverting amplifier let me copy it.

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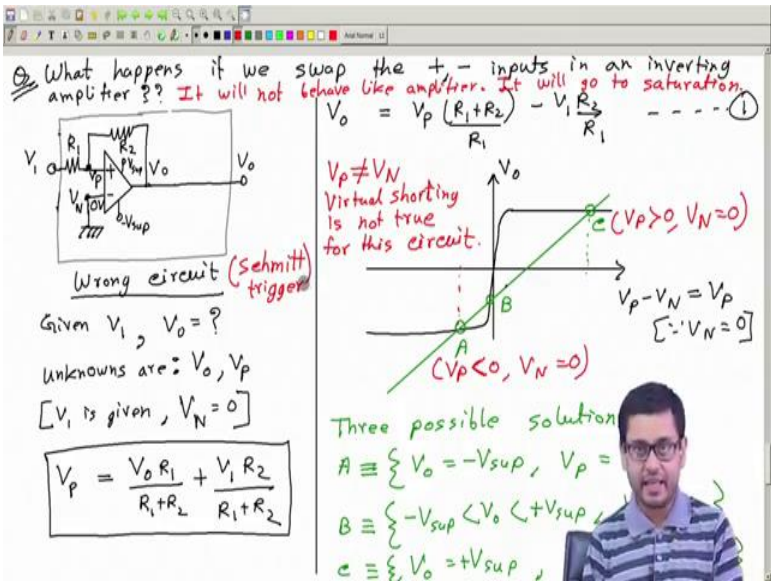

So, this is the correct circuit of an inverting amplifier. Now, what happens, if we by chance or by mistake make this as plus and this one as minus ok. So, the question is what happens, if we swap the inverting and non-inverting terminals plus and minus inputs, in an non this is a this is inverting amplifier. Originally, it was inverting amplifier in an inverting amplifier.

So, this is the swapped the circuit with swapped terminals. So, this is so, this is the wrong circuit ok. You should have minus here and plus here, but I have the wrong circuit, I have plus here and minus here. So, what will happen? How do you analyze it? Ok. So, let us study that. So, once again I mean what we have to do is find the co answer to the question, what will be the value of output V o, if we know the value of input V 1. So, given V 1, V o will be how much?

So, this is what we have to find out for this wrong circuit, but the process that we will follow is once again same, we will find out the first we have to find the unknowns, that you have to solve for. So, the unknowns are of course, V o output and here V N ok. V 1 is given and V P = 0. So, these are knowns V 1 is given and V P = 0.

So, we have two unknowns. So, now, to find or solve for these two unknowns, we need two relationships. Now, these two relationships one of course, will come from here from this part of the circuit, which is the series combination of R 1 and R 2.

$$VN = \frac{V0\ R1}{R1+R2} + \frac{V1\ R2}{R1+R2}$$

So, it is a weighted average of V o and V 1 and the weight with V the weight associated to V o is proportional to R 1. So, V o is further from R 1 and closer to R 2 therefore, we have V o multiplied by R 1, the resistance which is further. And, with V 1 we have R 2; that means the resistance which is further from V 1. So, this is new rule for V N. So, this is one relation, you can also derive it by finding the current and then adding the voltage drop here, the way we did it in the last class here we did that ok.

So, and you see we have the same pretty much the same result. So, this is a quick way of doing it ok

$$V0 = \frac{VN\ (R1+R2)}{R1} - \frac{V1\ R2}{R1}$$

So, this is relationship number 1 and the second relationship will of course, come from the static characteristic of the op-amp. So, I will do this now a bit quickly because we have done this all already twice and we have we are now a bit more matured.

So, we can do it little quicker ok. So, the second relationship is this static characteristic, which is here we have V P - V N, here we have V o and the characteristic looks like this for an ideal op-amp this line goes very close to the y axis like this. So, this is a static characteristic ok. Now, there is a mistake; the mistake is that, what I mean small mistake. So, V N is now the voltage at the plus terminal ok. And, V P is now the voltage at minus terminal ok, because, I have changed the sign. So, let me change this name, let me make V N = V P, V P = V N.

So, that N stands for negative and P stands for positive. So, everywhere now I have to make this N and this P, this is P, this is P, anywhere else yeah here this is P ok. So, because this is now V P, this is now V N ok. V N 0 V P is this much yeah, I guess if it is correct ok. So, now, V N is equal to 0 here. So, therefore, this I can write simply as equal to V P. Since, V N is equal to 0 therefore; this is the curve relation between V P and V o.

So, this is one relation, which comes from the static characteristics of the op-amp and the other relationship is this which comes from the external circuit, potential divider kind of potential divider rule here.

So, now, let us plot them together. So, this is the static characteristic and let me draw this curve ok. So, this curve is V o or y axis y is equal to this is called is x the x axis x multiplied by N minus some constant, because V 1 is given. So, this is y = N x- C ok. So, that curve will look like this N x - C. So, this slope will be positive, but the intersect will be negative like this ok. So, the intersect is negative, because this is negative assuming V 1 positive and this is the slope here is of course, positive because resistances are positive.

So, now, what will be the suggestion you see these 2 curves intersects at 3 points 1 2 3; that means, there are possibly 3 solutions. So, this is one, this is one solution, this is another solution and this is another solution. So, we have so, three possible solutions ok, you can call them as give there some names this point as A, this point as B, this point as C ok. So, we have three possible solutions for the unknown V P and V o. If, this solution is this then output V o will be minus V supply ok.

So, let me write them A, B and C; for a we have output V o = - V supply, this is minus V supply and V P is equal to a something V P is this much ok. Something, I am not writing this something, and here for point B we have V o equal to something between minus V supply and plus V supply. So, here let us write this minus V supply, less than V o, less than V supply and V P this is 0 almost 0 V P is equal to almost equal to 0. And, for points C we will have V o output equal to V supply plus V supply and V P is again something.

So, this will this if we drop a vertical line this will be the value of V P. Once again here in this case for A, if you drop of vertical line here this will be the value of V P something let me write this something ok. So, there are three possible solutions because we have 3 intersects inter intersections so, but output cannot take 3 values at the same time output can take only 1 value. So, which value will we take will it take A, or will it take B, or will it take C.

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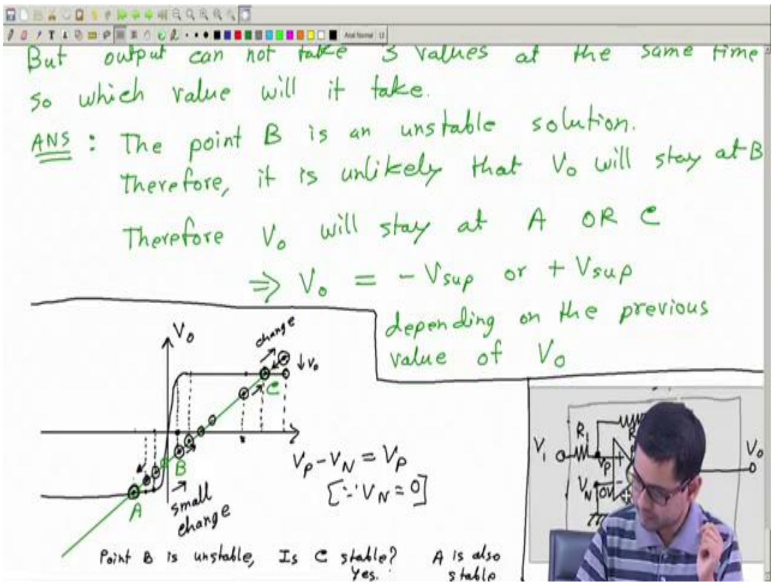

So, its right, but output cannot take 3 values at the same time. So, which value will it take let me tell you the answer, the answer is that we will show you or justify you that the point B. The point B which is this point is an unstable solution; the point B is an unstable solution. Therefore, it is unlikely that the solution will be or V output will be at this value ok. So, therefore, it is unlikely almost impossible that V o will stay at B, so, the output cannot take the value which is suggested by this solution B.

So, it will then take. So, therefore, V o will stay at or I should I may say the solution will stay at A or B not B C A or C; that means, V o will be equal to minus V supply or plus V V supply minus V supply or plus V supply, still we have 2 2 possibilities which one. So, which one will the output take? And, the answer is it will depend on the past history of V o or the previous value of V o ok, depending on the previous value of V o ok.

So, this is what I am going to justify. So, first let me justify why point B is not stable. So, for that, let me just copy this ok. So, let me first tell that why point B is not stable or unstable. For that assume that at some moment the output I mean if the solution is here is at point B ok, at some moment say this is here, but then due to some disturbance due to whatever the reason is say the output V o changes a bit ok.

It can go up a bit slightly or go down slightly, due to whatever it is you can think of I mean this op-amp is an IC so, with the output may depend also on nibs of this voltage supplies and see also if the voltage supply have some noise, that will also bit V o or whatever the reason is whatever the reason is V o can fluctuate a bit it can go up a bit or go down a bit. Now, what will happen if V o goes up a bit if this point this value is increased a bit then the value at V P will also increase assuming V 1 is constant, it is not changing. Say, if this increases slightly then of course, V P is some sort of average of V 1 and V o.

So, if V o increases V P will increase also here, you can see if this increases this is constant then V P will increase ok. So, V P I mean V P must lie on this line V P must lie on this line. So, I mean the V o versus V P point that must lie on this line. Because, this R 1 and R 2 and V 1 none of them are changing, because this line is defined by R 1 R 2 R 1 V 1 all these values all these values are not changing. Therefore, this line will remain same, now if V o increase a bit V P will also increase a bit. So, this if I start from here, I will move slightly here ok, like this ok, but I must lie on this line ok. So, I can go a bit like this.

So, now, if I go a bit this if I come here say then at this value of V P so, at this point ok.. Let me show this the same thing in this diagram without making that clumsy ok. So, if I move from here to here at this point, slightly this is slight move movement small change, although I am not, I am drawing a significant among, but assume this is a small change. Now, what happens this static characteristic or the property of the op-amp that says that at this value of input ok? So, now, this is the value of V P or V P - V N because V N = 0. So, now, at this point by dropping a perpendicular from this new point so, at this point the output of the op-amp should be this this much ok.

So, therefore, the op-amp will now try to increase it is output and and match this characteristic, because op-amp believes or believes on this property, this static characteristic. So, the op-amp finishes the input V P - V N is here it will try to increase it is output to this value. Therefore, V o will increase further. So, what will happen this point will move towards the right further ok? And, say now if it comes here let me zoom it ok.

So, now, if it comes here then it will see the output should be this much V o should be here ok. So, the op-amp will try to increase it is output further. So, this may what will happen this point will move gradually like this and will come here, at this point C, then the op-amp will see ok. Now, I am simultaneously on this green line because I am not allowed to move away from a green line, but I am also on this black line this static characteristic.

So, then the op-amp will be happy, because for this value of input this is exactly what the output should be from the static characteristic. So, this is where the op-amp will stop, this is where the op-amp will become happy. So, if I start from this point and by any chance move a bit towards the right, by a slight increment of the output V o, due to whatever reason that will cause further increment of output and this will go on in a chain until and unless I it is this point.

Similarly, if I have a small change in the opposite direction say output is reduced by a small amount, then from this point I come here. I am not allowed to leave this green line ok. I must always stay on this green line, because that is the relationship which I obtain from the potential divider rule here. So, if output decreases I will come here.

And, now at this value of input so, now, S this is the input to the op-amp. So, this is input to the op-amp. Now, for this input the output of op-amp should be here, which is less than the current V o. So, what will happen the output will decrease further? So, I will move down further here and then once again for this input, this should be the output of the op-amp. So, op-amp will try to decrease it is output further. So, I will keep moving like this until I come at this point A, where the op-amp will be happy again, because now this point lies on the static characteristic of the op-amp.

So, the op-amp will be happy. So, if I move slightly towards the right or slightly towards the left, I will go and go and go and hit this point C or in the opposite direction and hit this point A. So, this point is unstable ok. So, that so, this is why this point B is unstable. Now, let us see are this points A and C stable ok. So, let us check are these points so, point B is unstable, but now I will let us ask is C stable? Ok.

So, let us focus on this part now say I start from this point and by some chance I move a bit away from this see the output is increased V o is increase therefore, I come here ok, only in a small change. So, I come from here to here and then at this point. So, this is the value of V P - V N and the static characteristic of op-amp will say that for this value of V P- V N, the output of op-amp should be here. So, the op-amp we now try to decrease the value of V o why, because it has higher value of output than it should have according to the static characteristic.

So, now V o will decrease, V o will decrease means what now I will come back in the opposite direction and I will come back to point C. Similarly, if I move a bit in this direction say I come starting from here, I come to this point due to a small change in V o I cannot leave this green line. So, now this is the value of V P - V N. So, at this value of V

P - V N this should be the output of the op-amp, but the actual output is here. So, the op-amp will take no I have to increase my output. So, it will increase the output and therefore, I will go back once again towards the point C.

So, if I move away from here to here, I will go back if I move away from here to here, I will go back therefore, this is a point which is stable, because if I move away, I will go back ok. So, is point C stable yes? Similarly, you can show that point that A, this point is also stable ok. Now, so, I have tried to justify why this point B is not stable and these 2 are only stable solutions A and C, A and C ok.

Now the next question is so, what will be the output will the solution be A or will it be C ok. Until you will it depends on the previous value of the output the history of the output.

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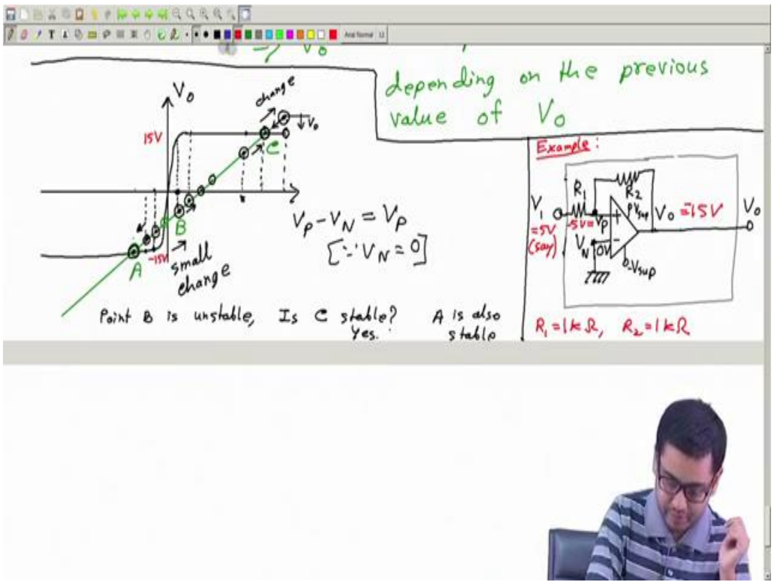

So, ok let me a so, let us now focus on this circuit ok. So, say at some moment the value of V o = + V supply ok. So, let us make a guess not guess say, at some moment this is equal to plus V supply at some moment.

Now, if say let me just take a concrete example, let me take a concrete example, let me call this V supply equal to 15 volt. So, this will be minus 15 volt ok. Let me choose the value of input V 1 equal to say 5 volt, example now this is so, this is equal to 15 at some moment ok. So, this is 15 volt, this is 5 volt, and let us take all this resistances is equal to 1 kilo ohm 1 kilo ohm R 2 equals 1 kilo ohm for ease of calculation.

Therefore, V P will be what V P will be just an average of V 1 and V o so, in this expression or here if I put 1 1 1, so, this is half. So, 1 1 1 this is also half, so, V P will be average of V 1 V 1, V o y 2 V 1 by 2. So, then V P will be equal to 10 volt, this is 5, this is 15, this will be average 10 volt. Now, if this is 10 volt V P is 10 volt, V N is 0 volt ok. So, this op-amps is that V N is 0 volt V P is 10 volt this is higher. Therefore, output will be of course, equal to positive this supply 15 volt. So, it will stay at that value happily it will not change it is output ok.

So, if I start from the value of 15 volt at the output then then; that means this is equal to 10 volt and this is higher than V N. So, therefore, output will remain at it is value 15 volt, because op-amp behaves like a comparator. What it does it compares V P and V N and if V P is higher it increases output if V P is lower it decreases output, that is what it does?

Now, let us take another example, another case where say we have say where we have this equal to minus 15 volt. So, this point is at minus 15 volt, but the input I am taking the same value 5 volt. So, what will be this value average of this and this so, then 5 and minus 15. So, so this will be average will be plus 5. So, this will be 5 volt, because 5 minus 15 is sorry it will be minus 5 5 minus 15 is minus 10 divided by 2 is minus 5 ok.

So, this will be minus 5. Now; that means, this is 0 this is minus 5. So, V P is lower and if V P is lower what will the op-amp do, op-amp will keep it is output at the minus V supply that is minus 15 volt. So, it will stay happily, there it is not going to change it is output. So, therefore, we see that in this example the output will depend on the previous value of the V o. If, we start from the assumption that V o is minus 15 volt, then it will stay at minus 15 volt. If, we assume that it starts from plus 15 volt it will stay at plus 15 volt it is not going to change.

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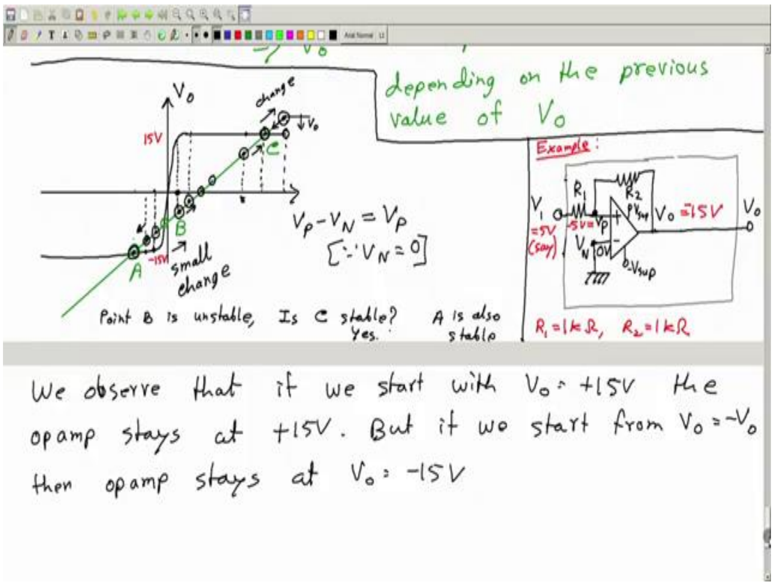

So, in this example so, we observe that let me write so, we observe that if we start with V o equal to plus 15 volt, the op-amp stays happily at the same value. But, if we start from V o equal to minus 15 volt, then op-amp stays at V o = - 15 volt. So, it depends on the previous value ok. So, let me just summarize what we have said so, a small summary. So, we have started with the question that sorry, what happens if we swap or altered by mistake the plus minus inputs of an in this is inverting amplifier original inverting amplifier should have minus terminal here and plus terminal here.

So, by mistake if we swap it what happens? The question is will it still behave like an amplifier will it be the case that V o = V 1 multiplied by some constant, like we had previously. For the original inverting amplifier it was minus R 2 by R 1 times V 1 will it be so, and in this detailed analysis we see no the output will not be equal to V 1 multiplied by R 1 R 2 sorry R multiplied by R 2 by R 1 it will not be so.

Instead output will be either positive supply V supply or minus V supply ok. So, this we will call the output will go to saturation positive saturation or negative saturation. And, which 1 will it go to that depends on the previous value of V O. So, if by chance let me say it in a other way, if by any chance output goes to plus V supply, it will stay there happily no problem, that is a valid stable solution if output goes to this point by any chance it will stay there again happily forever.

But, the output is not going to be input V 1 multiplied by at minus R 2 by R 1 no it is not an amplifier, it is not going to are like an amplifier, that is because this point is unstable it will not stay here ok. So, the answer let me write. It will not behave like amplifier, it will go to saturation plus or minus we have seen it with thorough analysis and also another observation very nice observation will virtual shorting the concept of virtual shorting be valid in this wrong circuit will V P equal to V N no why V N is 0, but, how much is V P.

So, suppose if I land up here at this point C, then V P is this much ok, then V P is this much which is here to here which is not 0 it is positive, but V N = 0 ok. So, here at this point V P > 0, V N = 0. Similarly, if I land up at this point I will have V P less than 0 this much ok. This is this will be the value of V P, but V N = 0. So, V P is not equal to V N unless at this point yes at this point V P will V N, because both are so, so V P V P is always 0, but this is not a stable point.

This is not a point that we are likely to have. So, virtual shorting is not true for this circuit ok. So, that is why I said virtual shorting is not a property of op-amp in general, it is a property of the circuit some special circuits not of all circuits, this circuit does not work with the concept of virtual shorting ok.

So, 1 small note you can if I give you this circuit and ask you the question, that V 1 is 5 volt what will be V o you cannot do the analysis with the assumption V P = V N so, V P = 0 no that method will not work ok. So, with that is because virtual shorting is not true for this circuit. We will come back to this circuit again later this is a very useful circuit. Although, this is a 1 circuit, but this is also very useful circuit, this has a name this is called Schmitt trigger, S c h m i t t, I guess this spelling is trigger we will come back to the circuit again and again.

Thank you.