Analog Electronic Circuits
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Lecture – 23
Op-amps, OTAs

Welcome back this is analog electronic circuits and today's lecture 23 and, we were discussing Op-amps and OTAs in the last class. So, we are going to continue with the same the Op-amps and the OTAs and, we are also going to look at how negative feedback is going to be used with these Op-amps and OTAs. That is pretty much the topic for today's lecture ok. So, in the last class we were talking about possibly your favorite Op-amp circuit.

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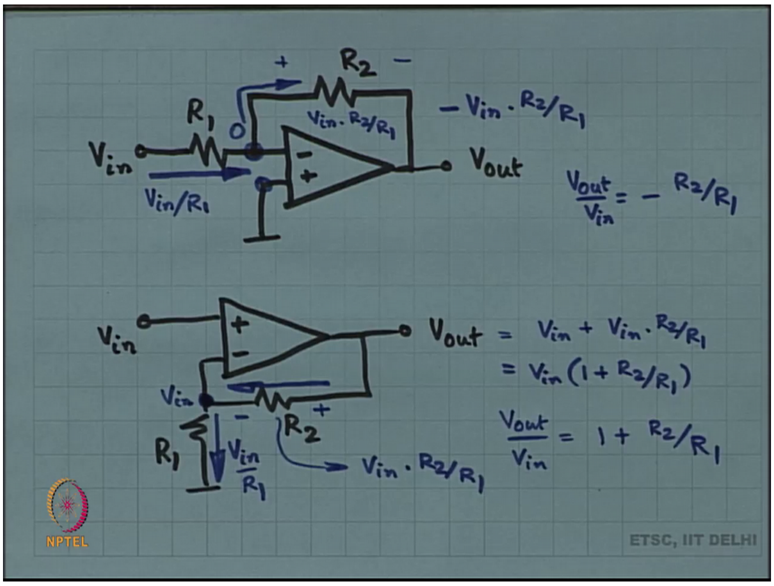

So, one was this and the other was variation of that and, the analysis of these circuits is very straight forward, all you have to remember is that, if you are drawn the circuit right, then the voltage at minus terminal is going to be equal more or less equal almost equal to the voltage at the plus terminal ok, which means that the voltage at the minus terminal in this particular circuit is 0.

In the other circuit once again the voltage at the minus terminal is more or less going to be equal to the voltage at the plus terminal, which means in this circuit the voltage is V in all right. So, this is all that you have to remember this is one more thing that you need to remember, that is the current going into the plus and minus terminals is always 0. So, remember this is the gate, I mean the Op-amp inside the Op-amp there are MOSFET's and these are gates of the MOSFET's ok.

So, the current going into the gate is 0, which means that the current going into the minus terminal is 0 the plus terminal is 0. So, whatever this current is by the way what is this current this side is V in the other side is 0. So, this current is V in by R 1 naturally, all of this current is forced to go the other way because no current can go into the minus terminal, which means that the drop across the R 2 resistors is going to be the current times R 2, which means that the drop across the R 2 resistor is going to be V in times R 2 by R 1 ok. You start from 0 so, the potential on the plus side is 0; that means, the potential on the minus side is going to be minus V in times R 2 by R 1.

And that is going to be your V out and automatically; that means, that V out by V in equal to minus R 2 by R 1. So, this is the standard analysis this is the short cut analysis, that you need to know because these circuits are going to come often and you need these are all very famous circuits, which are favorites of a lot of people. In the second circuit what happens this is V in so, the other terminal is V in and therefore, the current over here is V in by R 1. And clearly this current has to come through R 2 it has to no other way.

Right because the current going into the minus terminal is 0 so, that current has no other way, it has to come through R 2 which means the drop across R 2 is V in by R 1 times R 2 ok. So, you start from V in that is the voltage at the minus terminal. So, the voltage at the plus terminal of R 2 is going to be V in by R 2 by R 1 more than V in, which means V out is going to be equal to V in plus V in times R 2 by R 1, you can take V in common and that is your V out by V in all right. So, this is the standard way of analyzing this. Now, we have one important issue over here, this is what we were discussing in the last class. The issue that we have is that the Op-amp what we made is not really and Op-amp, what we made is an operational trans conductance amplifier.

We did not really make an Op-amp; because it is output impedance was large ok. So, either the output node is a drain it is got to be a drain drain of some MOSFET right either it is a cascode drain, or it is an ordinary drain whatever it is the output impedance is somewhat large. And large output impedance automatically means that the circuit is going to behave like a current source. So, instead of a voltage controlled voltage source, which the Op-amp should be what we have unfortunately made is a voltage controlled current source and, the question that I was trying to answer is that is this going to affect anything.

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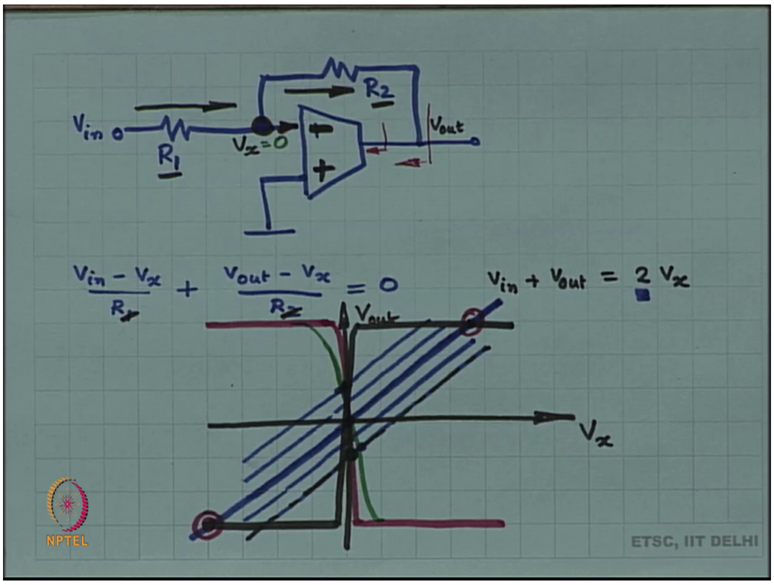

If I place a voltage controlled current source by the way it is drawn like a trapezium not a triangle, this voltage controlled current source ok.

If I make the same circuit with an OTA instead of an Op-amp will it work, what is going to happen all right so, this was what we were thinking about in the last class. Now, first things first what is the current going into the plus terminal oh sorry, this has to be the minus terminal, this has to be the plus terminal, what is the current going into the minus terminal, this is made up of MOSFETs so, it is got to be 0 perfect. So, the current going into minus terminal is nothing, but 0 which means whatever is this current all of that current has to go through R 2 ok. Now, all that I need to establish is, what is this voltage all right.

That's all that I need to establish. Now, what we are going to do is we are going to do a brief analysis ok, before I discuss what this voltages is one more issue at hand, you saw that I corrected this from plus minus to minus plus right, why did I do it; obviously, the plus minus is a wrong a is a mistake ok, what is the mistake over there question 1, question 2 we have been I am leaving a lot of things unsaid right now.

I am trying to ask those questions. So, from the last discussion from this discussion one thing that I missed out, or rather did not really tell you is why are these 2 voltages more or less equal, that is question 1, next is there a problem, if I draw plus minus instead of minus plus.

Question 3 what is the voltage over here actually in the in the OTA case, what is the voltage right, what how does it work out ok. So, these are my questions right now and, I am going to try to answer these questions all of these questions with one analysis. So, the idea is this, if you if you think long back a long time back towards the first or second class, we had studied the load line ok, when we talked about diodes when we talked about the MOSFET initially we talked about the load line ok.

So, we are going to bring the load line back cover back into the picture and do our analysis all right. So, the way it works is let us say let us call this voltage something, we what do you want to call it V x ok, since we do not know what it is let us call it V x all right. Now, imagine this OTA is not there.

Let us for once through it out of the circuit, let us not worry about the presence or absence of this OTA ok, let us not worry what is over here, there is something over there clearly I do not want to know, what it is can I write some KCL KVL, we can write the KCL at this node and, that KCL will look like V in by R 1 plus V out sorry V in minus V outs by R 1 plus V out minus V x by R 2 is equal to 0.

In any case even after you plug the Op-amp or OTA back in over there this current is going to be 0 ok. So, my KCL is still going to be valid, with or without the Op-amp or OTA whatever it is all right. Now this R 1 and R 2 they are just causing extra stress over here, let us assume R 1 and R 2 are equal without any loss of generality.

For now I am going to assume R 1 and R 2 are equal just for this analysis because, I do not want to write too much nothing much is going to change, just that the equations will look a little simpler. The ideas remain exactly the same, if you do not like it you can keep R 1 and R 2 in your notebook, I am going to remove R 1 and R 2 and call it 1 general R ok. So, if I call it R, then the R can safely cancel out because on the other side there is 0 that is why I made it R. And we are going to get V in plus V out equal to 2 times V x fine.

Now, what I am going to do is V out is an unknown I do not really know what is going to be V out, all right V x is the input terminal to my device let us call this the device, V x is the input terminal to my device, V out is the output terminal of the device. Let us make a graph with x axis as V x and y axis as V out ok.

So, note clearly the choice of access, the choice of access is the input terminal to the device and the output terminal of the device, where my device is the Op-amp or the OT whatever it ok. So, I have an equation over here V in plus V out is equal to 2 V x and, I would like to plot this equation on this graph, where the x axis is V x and the y axis is V out.

What is it going to look like a straight line lovely? So, this is going to look like a straight line with the slope of 2. And if V x is 0 V out is going to be minus V in for example, ok. So, it is going to cut the x axis sorry the y axis it is going to cut at minus V in. So, whatever V in is I do not know right. So, if V in is let us say plus 0.5, then it is going to cut the y axis at minus 0.5, if V in is plus 1 then this line is going to cut the x axis sorry the y axis at minus 1.

If V in is 0 then this line is going to cut the y axis at 0, if V in is minus half it is going to cut it at plus half if V in is minus 1 and, it is going to cut it at plus 1 so, on and so forth ok. So, you get a family of curves for different values of V in you can draw different curves and, all of these curves are straight lines which are parallel to each other clearly right. They are all straight lines with slopes of 2 my drawing is very bad over here, it looks like it is 45 degrees, it is not 45 degrees it should be something with the slope of 2.

So, far so good what have I done by the way, I have not done I have not bothered with the device at all, I have only done one KCL and this KCL is valid. Whether this device is an Op-amp, or this device is an OTA, or there is no device at all it does not matter even if there is no device it is the KCL is still valid.

Find not a diode, diode would not work because it is going to take current we took this equal to 0 right. So, it should not be that this current start smattering right it should not matter this current should be 0. So, it should be a device such that that current is 0 ok. So, Op-amp OTA air these are valid devices for us right now.

All right so far so, good the next thing that I am going to do it. Now, we go to the market purchase the Op-amp, or the OTA right you set at the drawing board design the OTA. And then you plus it in over here so, before you plug in you need to ask the question, what is the characteristics of this OTA, what is the input output characteristics of this OTA remember.

The input terminal is V x the other input terminal is at ground ok. So, we do not worry about the other in input terminal, the output terminal is V out all right. Now, the way and Op-amp or an OTA is going to work is that if the minus terminal is positive, then the output is going to become negative.

If the plus terminal is positive in this case the plus terminal is ground ok, if the minus terminal is negative, the output is going to become positive ok. So, this is the inverting terminal basically, then the OTA you design the OTA for a large voltage gain, which means that you know let us say you designed it for a large voltage gain of let us say 10000 ok. So, if my input is 1 milli volt, the output is going to if the input is minus 1 milli volt, the output is going to shoot up try to shoot up to plus 10 volts ok.

Now, it depends on what the power supplies of this OTA R, if your power supply is only 2 volts then of course, you cannot shoot the output up to plus 10 it is going to stop at 2 volts ok. If the power supply is 1.2, it is going to stop at 1.2. If the power supply is 12 volts than 10 volts is all right. So, this is what is going to happen this is the kind of characteristics.

So, let me draw it for you, the drawing is going to look somewhat like this and, let us choose a different color to make it clear, that what I am drawing is the characteristics of the device ok. And the gain of this that is the slope of this in this transition region is minus 10000 in this case this slope is going to be minus 10000, in case of this graph that I have drawn because, you have designed the OTA or the Op-amp whatever, it is with the gain of 10000 all right so far so, good.

So, you have got this blue lines are because of Kirchhoff the red curve is because of the device, the circuit has to obey both the blue as well as the red, what is that going to imply that the output voltage V out. So, it implies that it is going to operate at the point of intersection of the 2 curves right. So, suppose your V in value is plus 1 volt, if V in value is plus 1 volt it is going to choose, this particular line let us say right, which cuts the y axis at minus 1 all right. Now, you have now that you have chosen that line the point of operation is going to be the intersection point of that line that blue line and the red curve.

Which happens to be this green point ok, now if I change the import to minus 1 volt, it is going to choose this is point, if I chose the input to be 0 volts, where you are ok. So, depending on the value of the input you are going to choose the value of the, you are going to get a value of the output.

And clearly what is going on over here, the one thing that you should be able to see visually over here is that V x is going to be very close to 0, I mean it does not matter what is V out, but V x over here has got to be equal to 0, because your cutting so, close to the y axis even, if it is not 0 it is something very small because the gain of the Op-amp is so, high or the OTA.

Now, if V x is equal to 0 does it matter if this is an Op-amp or an OTA because, this current goes in no current goes into the OTA. The same current goes out automatically I have declared the value of V out, it is the same analysis whether it is an Op-amp, or if it is an OTA all right. So, it should not matter right now it should not matter, you do not really need to make an Op-amp and OTA will do just fine ok.

But take a look at it be careful right think about it before declaring victory. So, it looks as if V x is equal to 0, then the result is the same whether it is an Op-amp or an OTA is the answer is V x going to be equal to 0 is the question and, that question is answered by this graph right. If my gain is indeed high if the gain of the Op-amp is indeed high, then there is no problem ok.

Now, there is a slide problem over here, the slide problem is as follows. The gain of the Op-amp might the gain of the OTA not Op-amp the gain of the OTA, there is a chance that it is going to reduce, because of the support why is it going to reduce, remember the gain of the OTA was the trans conductance times the output impedance trans conductance, you have got something output impedance.

Looking over here you had some output impedance and, you got that output impedance trans conductance times that output impedance was the gain, but if you look at V out and look at the output impedance, you will have the output impedance of the OTA and, also

R 2 because R 2 is right to ground ok. So, looking into the output of the OTA you see some impedance but you also C R 2 ancient with it all right.

So, the gain of the OTA is going to be now the trans conductance, times the original output impedance in parallel with R 2 ok. So, there is a chance that the gain of the OTA is going to reduce all right. So, this is a worry how worry some this is depends on how small the value of R 2 is, if the value of R 2 is very large, then there is no it is not a problem because, the large resistance is ancient nothing much is going to happen, but if the value of R 2 is small compared to the output impedance of the original OTA, when we will have a problem the gain of the OTA is going to reduce. And then what is going to happen, if the gain of the OTA reduces what happens to my curve, the curve becomes a little weaker right.

Of course this is a highly exaggerated curve instead of a slope of 10000, you might have a slope of 1000 your g m is still large. So, you will still have some gain right instead of gain of 10000 may be your new gain is just thousand ok, in which case this green curve does not look like green, I mean it will still look like the red curve 1000 slope is still very large ok.

But in any case what you are going to see now is that you are slightly off from your answer slightly off, but you are still more or less over there, you are still going to follow the pattern that V x is almost equal to 0 ok. Just that you are a little words off, how much words off will have to do numerically quantitatively, you will have to assess graphically it looks like you are still not that much words off V x is still something which is very close to 0 ok.

So, this answers of few things, first of all it answers the question why are the two terminal voltage is more or less equal, this graph should answer that, number 2 you should be able to understand now, why an Op-amp and OTA are very similar and what is the difference. The Op-amp has a low output impedance to start with it is a voltage controlled voltage source. So, the output impedance is very low, it is not doing g m times R out ok.

In case of an Op-amp it is a voltage controlled voltage source, with a very low R out all right. Now, if R out is low, then putting an additional R 2 ancient with it is not going to change anything it is going to continue remaining low ok.

So, nothing much is going to happen all right, the gain is going to remain pretty much the same, because the gain is relying on g m not on R out. So, g m is very large R out is very small in case of the Op-amp, in case of the OTA g m is all right g m is a nominal value R out is very large because, it is a current source all right. So, this is pretty much the difference between the Op-amp and the OTA. So, two questions answered, the third question was that what happens, if I interchange the minus and plus terminals ok, what happens if I make a mistake, what is going to happen at the blue curves going to remain all are they going to change.

The blue curve I had nothing to do with the device, it was the blue curves where made when the Op-amp was thrown out of the picture. So, they will do fine they will remain exactly where, they are no change in the blue curves. The only change is going to be in the red curve the curve for the Op-amp, because now that you have interchange the minus and plus terminals right.

The polarity of the red curve is going to change. So, instead of the weight is it is going to start looking the other way ok, just the polarity is going to change because, now if V x is slightly positive, imagine this is plus this is minus if V x now is slightly positive then V out is going to be positive ok.

So, that is what happened all right so, this is the only change that takes place. And then what happens, we have to establish the point of interaction between the blue curve and the device curve ok. So, the blue straight line let us say we pick the straight line V in let us say 0, where does it intersect the device curve. Earlier it was intersecting at the origin.

Now, it still intersecting at the origin, but there are two more points of intersection. So, you have got two extra two new points of intersection, so, this straight line is crossing the device curve at three points of intersection not 1 all right and, this is a disaster ok. So, the weight works is it is either going to be at this stop point, or it is going to be at the bottom point it is never going to show up at the centre point all right.

It is almost like you have plays the stone on top of a hill not a stone, you have placed football on top of a hill and, you expect the football to remain right on top of the hill and not rolled down any one of the two circuits ok. And once it is rolled down on one side it is going to stay there all right. So, when you make such a circuit if you happen to interchange the plus and minus terminals, the circuit is going to remain at either the positive supply voltage or the other supply voltage right.

And it is never going to move from there notice the gain the DC operating point gain, the small signal gain at this point of operation is 0, the small signal gain at this point of operation is 0 ok. So, the Op-amp has no gain which means, if I now apply a small input signal nothing is going to change the output is going to remain exactly where it is ok.

So, this is totally flat over here all right. So, this circuit does not work basically if you flip the plus and minus terminals, you will either be stuck at this point, or at this point you will never come in the middle all right and, that is the reason why the plus and minus terminals are important ok.

So, you have to draw it correctly, if you do not write correctly, if you make a mistake the circuit does not work. The circuit is not unstable a lot of peoples come back and say, the circuit is unstable it is not unstable; it is a very stable right there is no stability issue over here. The circuit is rock stable, once the football has rolled down on the other side, it is not even going to bother trying to come back to the other side of the hill it is their it is going to remain there forever now ok.

So, the circuit is very stable there is no instability it is just that there is no gain and, this is not the point the operating point that you are looking forward to all right. So, what is the, is the mechanism to make sure that the operating point of the Op-amp is correct, this mechanism is called negative feedback.

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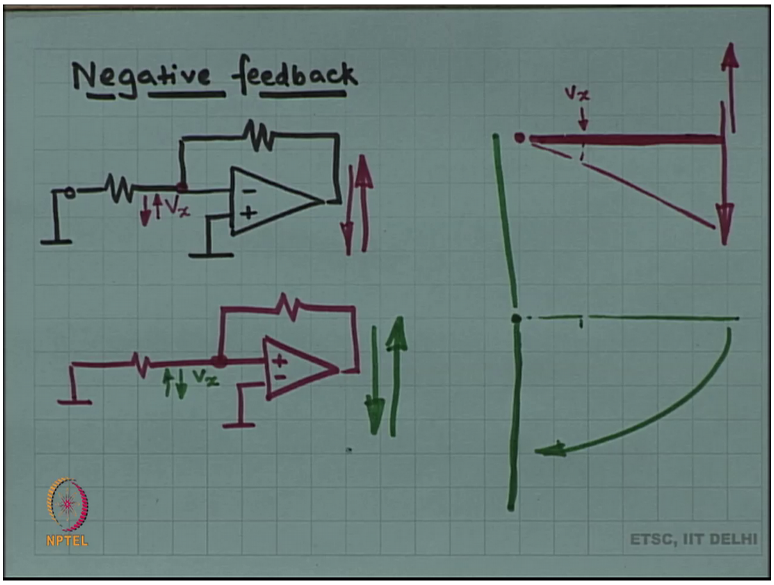

All right, so this is the mechanism by virtue of which the operating point of the Op-amp was set nicely for example, in this circuit so, let us now imagine, we just have Op-amps I am going to I am using right. Now, I am using this triangle and the trapezium interchangeably and do not worry too much about it, whether it is a triangle or a trapezium right now.

So, suppose the input voltage is 0, now you can do the analysis of this with the help of these curves right, you choke choose the centre blue line because the input voltage is 0, and you find that the point of intersection is at the centre and glow and behold everything works out that is fine, what we are going to do now. So, you already understand that right that analysis you already understand.

Now, let us think of it in a slightly different way, let us think of this node V x, if V x is a little more than plus, if V x is a little higher than the plus terminal, then the output terminal of the Op-amp is going to be lot lower ok, because the Op-amp has it is at the minus terminal and the Op-amp has large gain. So, if V x is slightly higher than what is required, then the output is going to be a lot lower and, what is going to happen, when this voltage goes down it is going to pull down through this resistor ok.

Now, think of it this way this side is fixed at ground all right, this is at V x. If the other side goes drastically down, this is the resistive divider; it is automatically going to pull down the point in the middle like a lever right. So, the fulcrum is on one side right this is V, this point is Vx this is the fulcrum the fulcrum is ground ok.

If V x is a little higher what we are saying is V x is a little higher then, the output voltage on this side goes drastically down, if this goes drastically down then because of the resistive divider it is going to automatically bring the voltage at V x also is going to come down ok. So, if it is a little higher than required, then immediately the output of the Op-amp is going to respond and pull it back lower, if V x is a little lower than required, then what is going to happen the output voltage is going to go drastically up and it is going to pull it back to the right place.

So, this beam is going to be balanced right over here all right. So, this is your negative feedback. So, this principle is called negative feedback, if the voltage over here is slightly lower than required, then the output is going to go drastically up, if it drastically goes up then it is going to correct the mistake that happened at V x to start with all right.

So, this principle is called negative feedback, now imagine the situation where the Op-amp was connected the wrong way. Now, what is going to happen if V x was slightly lower than required, slightly lower than required. Now, it is connected to the positive terminal the output is going to go drastically low right, it is going to go drastically low and going to it is going to pull V x down even further, V x was a little low the output is going to go drastically down and, when it is going to pull V x down all the way ok.

When V x goes a little further down, again the output response by going further drastically down right. So, this beam is not going to be balanced at all right, you started from here V x was a little down immediately the output fell drastically down. So, this is eventually going to collapse it is going to look like this right, if you if you draw mechanical beam over there it is just going to collapse all the way.

If V x was a little up to start with, then it is going to push up. So, the beam is going to look like this ok, the output is if V x was a little up to start with, then the output is going to be drastically up and it is going to push it upwards all right. So, you would not get balance in this particular beam right, this action when the output is reinforcing the mistake right.

You started with an error, then you are reinforcing the error this is called positive feedback as opposed to negative ok. If I make a mistake while teaching and, you said point out to me that you are making a mistake right then, I will try to correct myself, if you say then no you are doing a great job continue right, then I am going to make even more mistakes right, on the more mistakes I make you start enjoying it even more and you appreciate me even more, then I am going to make even more mistakes right. So, the entire thing is going to go downhill whereas, every time I make a mistake, if you point it out and say, no this is not correct, then I will try to improve myself all right.

So, that is negative feedback right negative with the help of negative feedback, you will see negative feedback everywhere in real life right, it is there in all places right, just when you are trying to pick up an object. Suppose there is this object I keep it on the table, I close my eyes and now I do not know where the object is, I am looking for it I cannot find it ok. The moment I open my eyes I see where my hand is I see where the pen is and, I ask my hand to go a little bit forward by the error. The error that I committed I try to fix it right, this is also negative feedback all right. So, negative feedback is there everywhere.

This circuit over here is a negative feedback circuit all right and, here both terminals are at ground, now where you apply the input is irrelevant, you can apply the input in which case it becomes this circuit, you can apply the input at the other terminal at the plus terminal instead of over here right. You can apply the input over here, in which case it becomes the second circuit all right.

So, both the circuits come from the same route, just where you apply your input. So, I apply the input over here, I get the top 1, I apply the input at this terminal I get the second circuit flip it round draw redraw it right, you apply input over here and redraw right, it is just a topological not even this is not too much topology.

It is just flip the circuit and draw it again this is the same circuit; all right this is understood ok.

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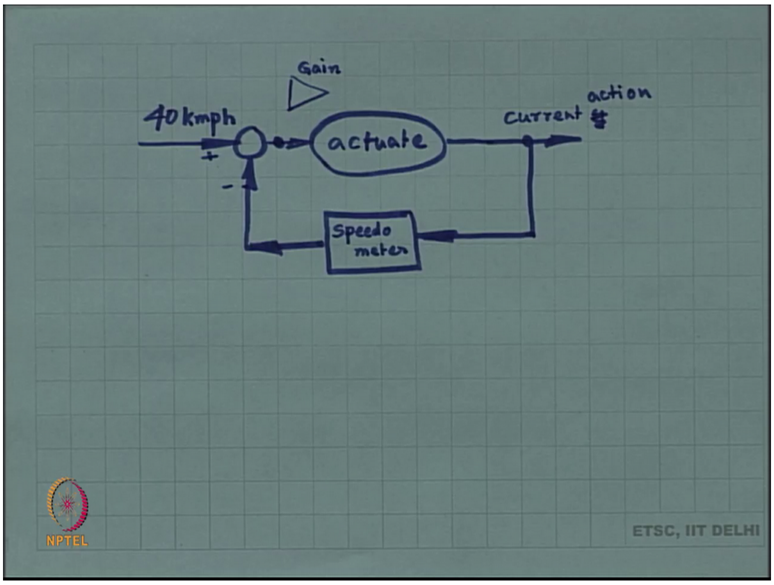

So, let us do one more. Suppose your I do not know do you know how to drive a car, some of you know how to drive a car ok, most of you know how to drive a bike. Suppose you have a hilly road the there are ups and downs on the road and you are told that, you have to drive your bike at a constant velocity no matter, what it it is straight road just that there are ups and downs all the way ok. You have to drive your bike at a constant speed. Now, the most important thing that you need, if you are given such a task you need a speedometer all right.

Something that is going to tell you your current speed, without a speedometer this is a no brainer you have to give up you say I cannot do it all right, you first thing you need most important thing you need to do this job this is speedometer all right. So, I am going to draw the speedometer. So, the speedometer so, I am going to call this arrow as the speed. So, this is the current speed or actually this is the current action and the speedometer is going to measure your current action and declare a speed a value for the speed.

So, this box over here is the speedometer all right, you have been asked travel at a constant velocity. So, I know the you have been told that this is the value 40 kmph all right, the speedometer is always declaring the current speed sometimes, when you are trying to go uphill your speed is probably coming down right, sometimes when you are trying to go downhill your speed is increasing and so, on and so forth. So, maybe this thirty nine maybe this is 41 some number is coming out over here, 38 whatever it is.

Now, what is going to be your job your job is going to be you to see that this was my target velocity, this is my current velocity what is the difference between the 2, what is the error what error am I making right maybe I am going downhill and my speed has become 41. So, the error in that case is minus 1 from the target, maybe I am going uphill speed has become 38. So, the error in that case is plus two kmph fine.

So, you are trying to measure the error and, then after measuring the error what you have to do, depending on the error you have to produce more action right, either you press your accelerator even more or you write your bicycle harder right you push more force on the pedals, whatever you want to do right. If you are driving a scooter you put more excel you put more petrol into the engine right, you press the accelerator term the accelerator in the scooter.

So, so, this is your actuate right you actuate whatever is to be done and, how you actuate depends how much you actuate depends on what is the error. If the error was 0 you do not actuate at all, if the error was minus 1, you have to break ok. So, depending on the error you have to actuate, you have to either accelerate or decelerate or keep your velocity just the same just t ok.

So, here we have a gain usually we have a gain all right. So, this is the general scheme of things, now this looks straight out of your control theory book right, this is the classic negative feedback schematic the Op-amp comes right here right the Op-amp is going to come right over here and, the job of the Op-amp is going to be to make sure that the two inputs are more or less equal all right.

So, in any control system we are going to use the Op-amp to do this job all right. Let us go a little further, let us I do not know what you have done in your circuits or your circuits courses, but this would be the right time to introduce a few other of circuits with Op-amps, couple of popular circuits. So, you learnt the will be you already know the inverting amplifier the non inverting amplifier, you can do additions subtractions with Op-amps.

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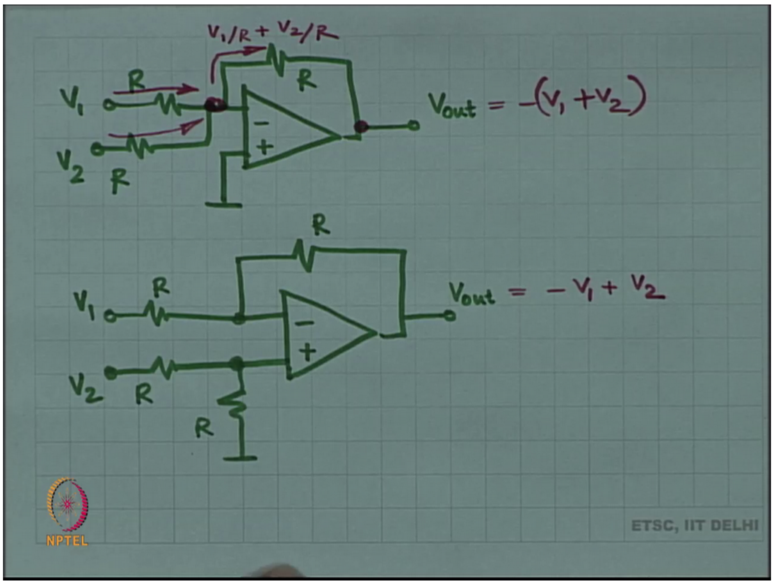

So, for example so, what is going to happen here, if there is negative feedback, then the minus terminal will be equal to the plus terminal that is the idea number 1. If there is negative feedback minus and plus are going to be equal, if they are equal in this case there is negative feedback.

So, the voltage here is going to be 0; that means, the current in this path is V 2 by R, the current in this path is V 1 by R and by KCL the current in the feedback path is V 1 by R plus V 2 by R. And this is the current going through the R resistor and therefore, the drop across the R resistor the feedback resistor is R times the current, which means the drop across the feedback resistor is V 1 plus V 2 and you started with a voltage of 0 volts on this side, that automatically means that V out is nothing, but minus V 1 minus V 2 all right.

And this is generally called an adder circuit; the reason why it is called an adder is because you did the plus operation with KCL over here ok. So, overall there is a minus, but no it is also you could also rewrite it has minus half V 1 plus V 2. So, that is why this is called an adder, the other classic circuit is this right and, whenever things get complicated like if this in this circuit looks a little complicated.

Whenever things get complicated, you start using superposition as opposed to your traditional analysis and, suppose position is going to work very well with Op-amps, you silence the voltage sources one by one. So, first you silence we do which means we to become 0 volts ok, V 2 is 0 volts than the plus terminal which is in between is also going to be 0.

And then it falls back to the same volt circuit plus terminal is at 0, I apply V 1 R R, which means that V out is just going to be minus V 1. And then in the next step you silence V 1, which means you make V 1 equal to 0 and apply voltage at V 2, if I apply voltage V 2 over here, then the voltage at the plus terminal is V 2 by 2 ok.

And now it is the other circuit, where are applied V 2 by 2 at the plus terminal and I have got R 2 ground R in feedback and, this has a gain of 1 plus R 2 by R 1 which is 2 in this case 1 plus R by R right, we are talking about the good old circuit, this good old circuit right over here, I have got V 2 by 2 and I have got R and R over here so, it has a gain of 2 and, if it has a gain of 2 then the output is nothing, but V 2.

Because V 2 by 2 through a gain of 2 becomes plus V 2 and because of superposition these two quantities come together add up all right. So, this is pretty much oral analysis, you do not have to do much right, you have analyzed orally visually you get your answer right away ok. So, this is called the subtractor, because it really does V 2 minus V 1, we are going to stop here and, then continue in the next lecture.