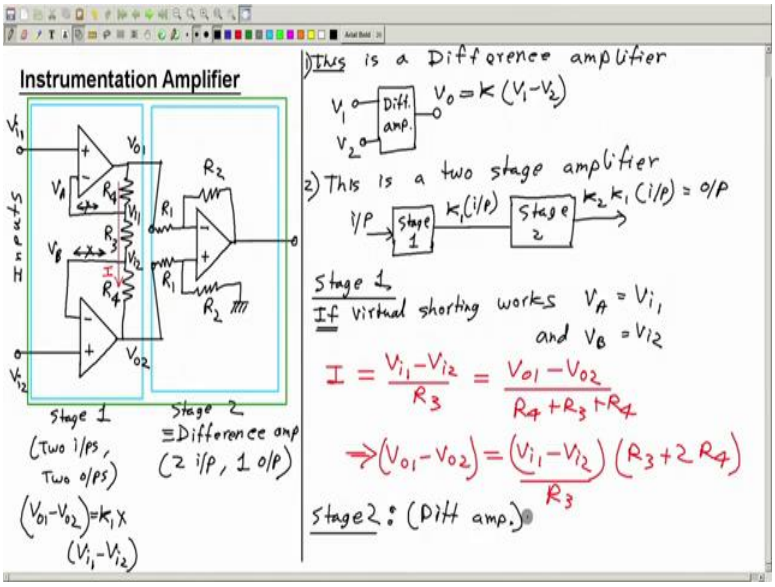
Electrical Measurement and Electronic Instruments
Prof. Avishek Chatterjee
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 75
Instrumentation Amplifier

Hello, previously we have studied inverting, non-inverting and difference amplifier using op amp. Today we will see an Amplifier which is made up of op amp, but it is bit complicated at least apparently complicated, but once you understand it then it is very easy ok. It is complicated because it is made up of not just 1 op amp, it is made up of 3 op amps ok.

(Refer Slide Time: 00:59)



So, let me first tell you how it looks like. So, it is made up of 3 op amps 1. 2 and 3. And this is a two stage amplifier ok, let me just first write a few words before I draw this circuit. Number 1 this is a difference amplifier. What is a difference amplifier? A difference amplifier is an amplifier which takes the difference between 2, values 2 voltages and amplified ok.

So, it is like this; so, if I draw it like a black box, so, this is a difference amplifier diff amp it has 2 inputs not 1 V 1 and V 2 and the output call V o = k(V 1 - V 2) this is how a difference amplifier behaves. So, this amplifier which we are making this instrumentation amplifier is also a difference amplifier, this is point number 1.

Now, point number 2 this is a two stage amplifier; this is a two stage amplifier. What do I mean by a two stage amplifier? It is basically 2 amplifiers in series or in cascade like this ok, stage 1. So, you give the input, from here you will have some constant multiplied by this input this will go to stage 2 and from this we will have this k called k 1.

Then we will have k 2 times k 1 times the input, this is equal to output ok. So, this is what a two stage amplifier is. So, we have 1 input which is amplified once and then amplified again. Now, let us come to this circuit, as I said it is a two stage amplifier. So, let me draw two stages this is this once this is going to do one stage and this is going to be other stage; first stage will have 2 op amps next stage will have 1 op amp.

Now, the way to connect it I will just tell you now how to do it later when I do more derivations I when we understand it is function, then you see you do not have to remember it, you can make it on your own right, now I will just tell you how to remember it.

So, let us put plus minus signs, plus minus plus from their output you take a potential divider with 3 resistances 1 2 and 3. Join them join the outputs from, here give a feedback negative feedback give a negative feedback; that means, this potential will be feed back to the negative input.

Similarly, here also you give the negative feedback that is why I do you minus here because I wanted to join it like this ok. Feedback should be negative should not be positive. So, this in these 2 inputs are connected now 2 more inputs are left 1, 2, these two I will use as the 2 inputs of my overall amplifier. So, these two are going to be 2 inputs call them V i 1 input 1 and V i 2 input 2. So, these are inputs ok.

And these two will be 2 outputs from these 2 op amps. So, this you call V o 1 V output 1 and this V output two. So, this is the stage 1, which has two inputs, two outputs; two inputs, two outputs ok. And this is a difference amplifier. So, the difference between the two inputs will be amplified and that will get reflected in the difference between the two outputs ok. So, this is a two input two output amplifier.

So, the difference of these two outputs call it Vo1- Vo 2 this is the difference between two outputs will be equal to some factor call it k 1 multiplied by the difference between two inputs V i1 - Vi2. This is how it will work ok, this is stage 1.

And stage 2 this will be just a normal difference amplifier which we have studied this will be same as a normal difference amplifier with an with a single op amp difference amplifier ok. So, how does that look like? It looks like this put minus plus give negative feedback.

So, you know this minus connected to output into output and plus P to ground g n o P g, then we have 2 more resistances and these 2 are going to be the input of this difference amplifier and this is the output of difference amplifier ok. So, this is a 2 input 1 output amplifier, normal difference amplifier ok. And you have to join these 2 stage 1 and stage 2, how? Connect this output to this input and connect this output to this input, right this is just a normal difference amplifier.

And you know in a normal difference amplifier we should have these 2 resistances equal call it R 1 and R 1 these 2 resistances equal R 2 and R 2, let me give this resistance some name, call this R 3 this also should be symmetric normally you can call it R 4. So, you call these also R 4 this is how it looks like the instrumentation amplifier. So, finally, then it is this which has 2 inputs 1 output. This is the overall amplifier inside it we have 2 amplifiers; one is this another is this the first 1 is a 2 input 2 output second 1 is a 2 input 1 output. Now, how does these 2 stages work? Ok.

So, stage 1 let us do the analysis first quickly list rigorously and then I will do more rigorously. Now, this potential is V i 1 e virtual shorting works then this potential will also be V i 1 ok. If virtual shorting works then this potential call it V A this you can call V B then V A = Vi1. If virtual shorting works let us assume it works for now.

And similarly, for this op amp V B = Vi2. So, this is same as V i 2 this is same as V i 1. Now, no current can flow here right, no current can flow here and no current can flow here right. So, the current can only flow in this branch like this ok. If a current start from here it will flow continuously like this and will stop, I mean we will come up to this no branching is possible here or here ok. So, this current will be a common current continuously.

So, let us call this current as I; I is the current which starts from here and goes there. Nothing can come branch out from here or here ok, that is obvious for op amp that is obvious ok. Therefore how much is this current? Now,

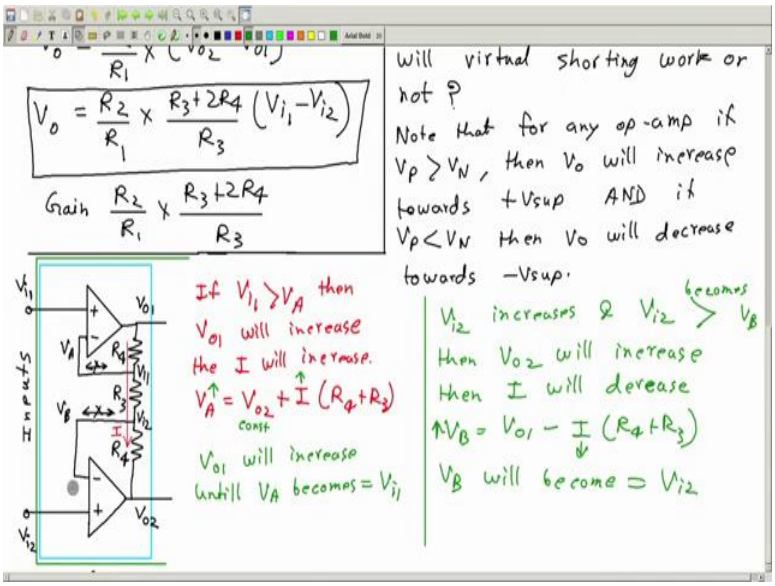
$I = \frac{Vi1-Vi2}{R3} = \frac{Vo1-Vo2}{R4+R3+R4}$

$Vo1-Vo2 = \frac{Vi1-Vi2}{R3}$ (R3+2R4)

Now, so, ok; so this is. So, here as we say that output will be proportional to the in difference of input difference of output proportional to difference of input yes that is what we have yeah and the derivation is simple you just observe same current flows from here to here ok. So, and this potential difference between these 2 is same as the input difference and this is the output difference simple.

Now, for stage 2 this is just a difference amplifier and we have done the derivation for it in a lot detail. So, we will not do it again. So, this is just a difference amplifier. So, therefore, we can write directly that this voltage call it V o final output.

(Refer Slide Time: 15:51)



$Vo = \frac{R2}{R1}$ (Vo2-Vo1)

$Vo = \frac{R2}{R1} \frac{Vi1-Vi2}{R3}$ (R3+2R4)

Output is proportional to the difference of the 2 inputs just like it has to be for a difference amplifier. So, we say difference amplifier takes the difference of 2 quantities and amplifies it this is same thing is happening and the gain in this case.

Gain = $\frac{R2}{R1}\frac{R3+2R4}{R3}$

So, the derivation is very simple and now once you know the know the derivation you can now remember this circuit because the second stage is just a difference amplifier which we have studied many times and the first stage is like this with just 2 inputs take a potential divider connected between the 2 outputs and from the middle point feed it back negative feedback here also negative feedback. Once you know the derivation you can remember the circuit.

Now, let me ask a more involved question which is here we have assumed the virtual shorting works. Does it really work? That is a more interesting question. So, the question now we are asking is will virtual shorting really work or not? Ok. So, for this we can get rid of the second stage because second stage is a difference amplifier which you understand very well, the first stage is something new where in the derivation we have assumed the virtual shorting without justification ok.

So, let me get rid of this part for clarity. So, I will say that in an op amp from it is static characteristic you just absorb that the output of an op amp can take 3 different values. So, let us check with up these what happens if these voltages are increasing or decreasing slide and then how will the op amp behave ok.

So, just note that for any op amp if V P > V n, then V o output will increase towards plus V supply and similarly if V P < V n then V o will decrease towards - V supply this is the rule of an op amp. If V P is higher than V n then output will go towards positive V supply to try to go towards the such respond plus V saturation and if V P s lower then output will go down to the negative the supply.

Now, we see in this circuit what happens because of the negative feedback mainly if at any moment say V i > V A ok. So, let us say if V i1 > V A then this is higher than this then what will happen output V o 1 > V o 1 will increase ok.

Now, assuming that everything else in this circuit remains unchanged assuming that like this voltage is not changing this voltage is not changing for simplicity then what will happen this is increasing then this current I will increase, then I will increase and if i is increasing right then.

VA = Vo2 + I(R4+R3)

So, now if i this i you see is increasing this i is increasing V o 2 this is constant assuming then VA will also increase right. And how long will it increase? It will increase until and un unless VA reaches V i1 ok. So, V A will; so V o1 will increase until V A becomes equal to V i1 and then the op amps output will take that particular value which had made these 2 equal ok.

And even if say if you change the output further if you increase sorry input further if you increase it this will cause the output to increase and it will make the V A also increase and get equated to V i1.

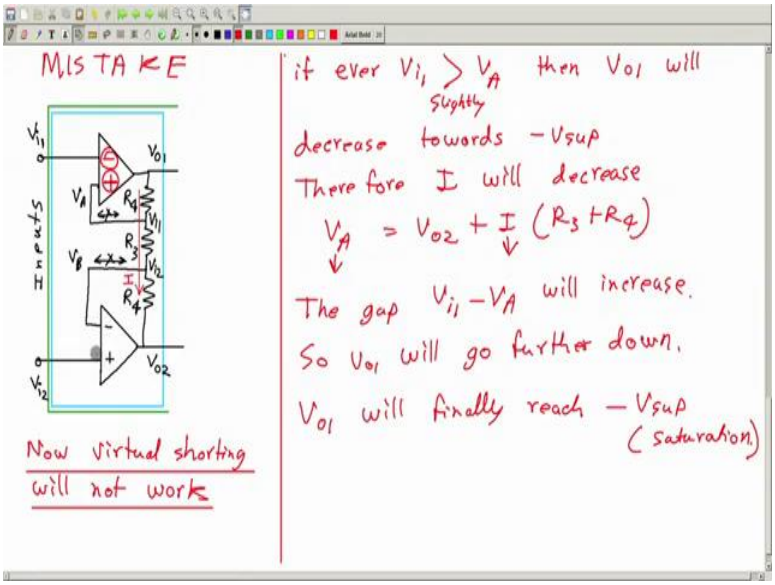
Similarly if you decrease this just think it on your own if you decrease it then this positive input is decreasing and if it goes down below V A, then V o1 will come down if V o1 comes down then this current i comes down, if i comes down then this potential also comes down. In this way what happens if you change V i1 op amp will change it is output and will make in make as long as possible this V A = V i1 until this goes to saturation ok.

So, virtual shorting works this is because of this negative feedback similarly in this op amp also you do the analysis yourself say if V i2 increases; if V i2 increases and if it goes above V B and V i2 > V B, then what will happen? Then V o; so this is greater than this. So, V o 2 will increase, then V o 2 will increase assuming everything else now remains same. So, V o 1 is same. So, this is increasing. So, current I will decrease ok.

Then I will decrease and if I decreases. So, then this potential will go up because

V B = V o1- I (R 4 + R 3), now I is decreasing this debt let us assume this is constant this is decreasing. So, this will go up this is going down this is going up. So, then V B will become same as V i 2 once again and then the op amp will stay steadily ok. So, this way once again the virtual shorting between these 2 points will work, but now note of caution is that if you by chance by mistake swap this plus minus symbols ok.

(Refer Slide Time: 28:13)



So, mistake if you by chance say swap this you make it minus and make it plus ok. Then let us see what happens virtual shorting will not work anymore. Now, virtual shorting will not work. Why? Let us see. See if V i 1 increases from V A slightly if ever V i 1 becomes slightly greater than V A slightly, then what will happen? V o 1 will become negative we will try to go towards negative because this is higher, then V o 1 will decrease will go down towards minus V supply right. So, this value is decreasing.

Now, once again assuming everything else in this circuit is not changing for simplicity of analysis, if this is now going down what will happen to this current? Therefore, I will decrease assuming everything else like V o 2 is unchanged. So, this is unchanged this is decreasing, so this current will decrease. Now, if this current is decreasing then what can we write about V A; V A =V o2+ I (R3 + R 4). Now, I is going down this we have assume not changing, so this will also go down ok.

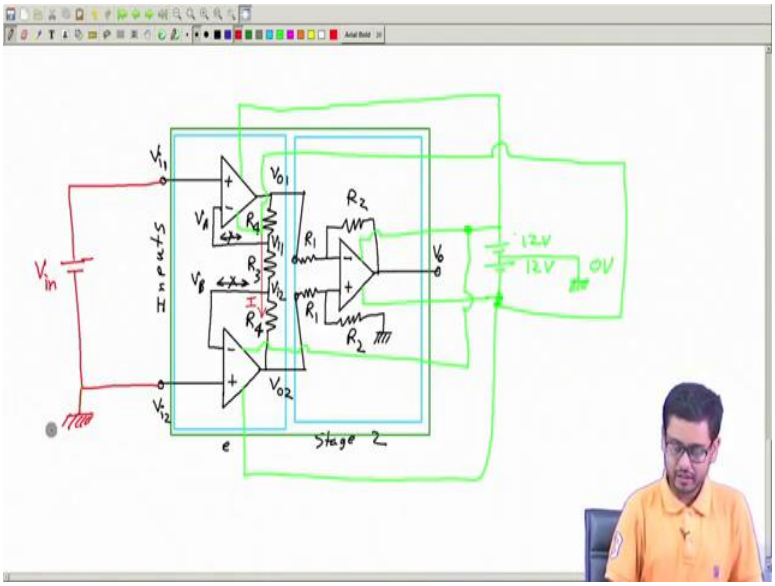
So, V A is going down and therefore, the gap of V i1- V A will increase because V A was already less than V i 1 and now V A is going down; V A is going down further. So, this gap will increase and if this gap is increasing then V o 1 will go down further ok. So, V o 1 will go further down I mean this way a chain reaction will happen this is going down which will cause current I 2 go down which will cause V A 2 go down and if V o goes down the gap between these 2 increases. So, V o and will go down and then this way a

chain reaction will happen and finally, V o 1 will finally, reach the lowest possible value which is minus V supply saturation ok.

So, output will go to saturation and you see this gap as we said in the chain reaction continue to increase ok. So, this gap increased continuously in a chain reaction. So, there was no chance that this gap will be go down to 0. So, virtual shorting in this case will not work. Similarly if you swap these 2 terminals if you make this plus this minus then for this op amp virtual shorting will not work and then you cannot do this derivation you cannot write these equations ok.

So, this will no longer act as an amplifier like the way we are expecting. So, plus minus symbols correct plus minus symbols is very essential otherwise your circuit will not work your answer will be wrong ok. And last thing that I will finish with one statement is that when you connect the inputs suppose you ok, let me say it in a different slide ok.

(Refer Slide Time: 33:47)



Suppose you have a battery which has a voltage call it V in small battery and you want to say amplify this voltage and then you possibly will measure it ok. So, what do you will do? You can connect it like this ok, but also do not forget to connect to me create a common ground to these input ok.

So, what is this ground? This ground means this is the same ground as this one here or you actually have the power supplies let me also draw all these power supplies in our different

color. So, all these will have their power supplies say like plus minus 12 volt. So, this is 12 volt, this is also 12 volt. So, this is connected to minus 12 this is connected to plus 12 this center point can be grounded and this is the reference 0.0 volt to which this terminal is also connected ok.

So, similarly this you can connect here this power supply you connect to the positive side like this ok. All negative sides you have to connect to the minus side here also this will go to the minus side like this ok. Although the diagram is ugly, but I think the idea is clear I hope and this ground the this should be common do not leave it floating like this, please do not leave it floating like this ok. This is how to use a instrumentation amplifier.

Thank you.