Integrated Circuits, MOSFETs, OP-Amps and their Applications
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Lecture – 19
Operational Amplifier Configarations

Welcome to this module and here we will see the application of operational amplifiers. So, until what we were learning in the previous lecture were the characteristics of an operational amplifier. So, when you talk about the characteristics; we have seen several characteristics operational amplifier including its input impedance it is out impedance high gain.

And then we have seen how offset voltages comes into play? What is input bias current? And then we have seen how CMRR comes into play? And what exactly CMRR is? And how the CMRR should be if it is very high? How it is useful to get the actual output voltage of our desired value and we can reduce the common mode voltage if the CMRR is extremely high; we have seen that example as well.

We have also seen how can we use the operational amplifier? And what kind of circuits we can use to nullify the effect of the offset? How can be offset the output voltage such that our output would be nullify? Or output should be 0; that means, that when we apply ground to both the terminals our output should be 0; so, what we can do?

So, we have seen that circuit that we can connect between terminal 1 and terminal 5; a potentiometer and by changing the value of the potentiometer, we will be able to see the output voltage equal to 0. Then we have also seen the input effect of input bias current, input offset current and how we can determine given the values of input offset and input bias current? Or input currents when you are given then how can you determine those values? So, once we have understood and we have also seen about the virtual ground.

Very important concept of virtual ground we have also seen; now using all these things that is our basic how we can implement the different operation on the fire circuits? That is the idea that is today’s lecture. So, this lecture is our class 10 and our lecture 10 and it is divided into several modules; so, to help you out to understand how the Op-amp circuits can be designed.

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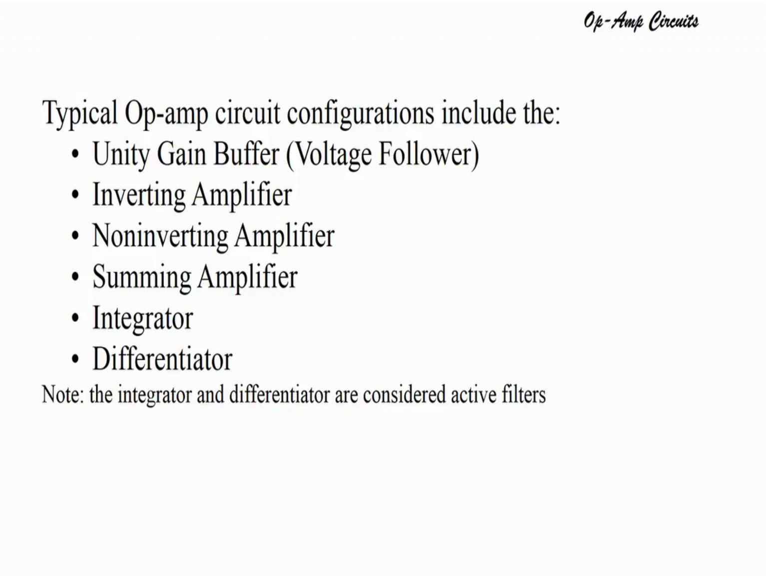

So, when you talk about operational amplifier circuits; what we see? We see that the operational amplifier circuits configuration includes several different applications starting from the unity gain amplifier or unity gain buffer; then we have seen inverting amplifier, then we will see inverting amplifier non inverting amplifier, then we will see summing amplifier, we will see integrator, we will see differentiator and not only that we will also see filters.

So, that is would be this filters would be our next lecture, for this particular lecture we will see the following amplifiers, we will take few problems and we will try to solve it. So, we understand how we can design operation amplifier based circuits.

So, like we have seen there are several kind of circuits we should start understanding the first one; which is the voltage follower circuits.

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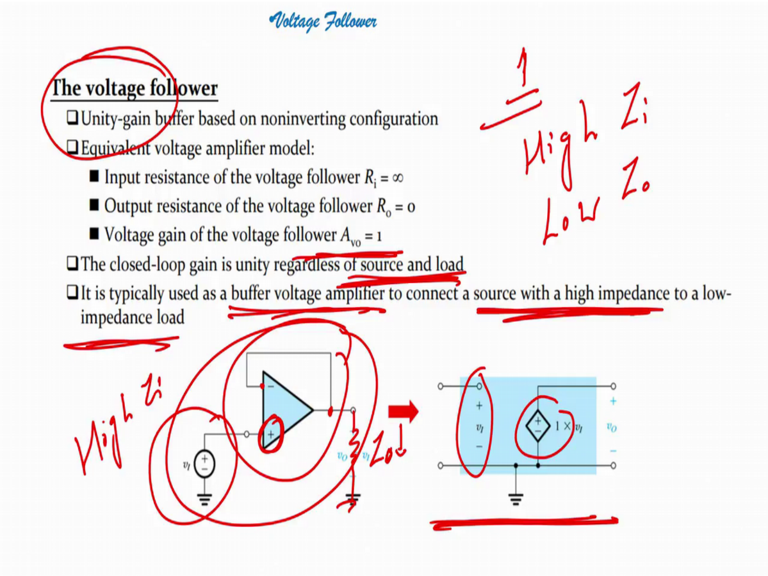

So, if you can see on the screen; what we see is a unity gain buffer based on non inverting configuration; what does that mean? That if I apply a voltage at the non inverting input and I have a feedback to the inverting; the output is feedback to inverting here. This becomes our unity gain buffer based on non inverting configuration because we are applying voltage to the non inverting amplifier.

We have seen this application earlier also equivalent voltage amplifier model. So, if I make a equivalent voltage amplifier model; how can I use it? You can see that the input resistance of the voltage follower; input resistance is infinite; output resistance is 0.

Voltage gain of the indicate amplifier that is why this is called unity gain. Unity gain means what? Gain is 1; so, to have gain equal to 1, we have A vo voltage gain equal to 1; the closed loop gain is unity regardless of source or load.

So, this is our indicate amplifier; it is also used as a buffer voltage amplifier to connect a source with high input impedance to a low input impedance load; why? Because the indicate amplifier has a high input impedance and it has a low output impedance; that means, it can be connected to a source. Suppose the source is this one, which has extremely high input impedance; then we can connect the unity gain amplifier. And the load will have extremely low output impedance.

Then we can connect the unity gain amplifier, unity gain amplifier is also used as a last stage of most of the amplifying circuit because it is a voltage follower and will it can be connected to any load which will draw lot of current, but the voltage at the input will be same at the output.

The voltage will follow; whatever voltage is at input it will follow at the output. So, output voltage follows the input voltage that is why it is also called voltage follower; the gain is 1 that is why is it is also called unity gain amplifier. So, these are the characteristics of operational amplifier particular as a voltage follower; this is how we can use operational amplifier as a voltage follower.

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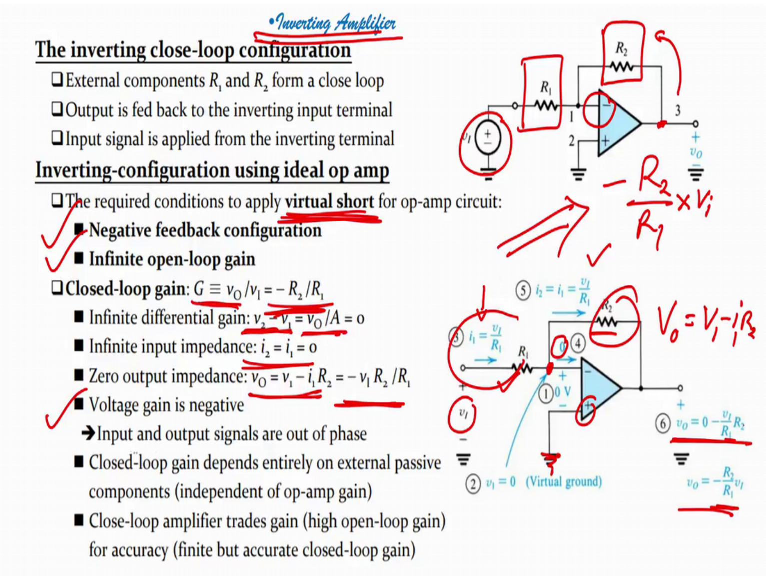

Now, let us see further; the inverting amplifier; so, how we can design a circuit of an inverting amplifier using a Op-amp? So, the inverting close loop configuration external components R 1 and R 2 form a close loop; here you can see R 1 and R 2, this forms a closed loop because you are feeding back a R c here and input signal is applied from the inverting terminal. So, we are applying the input to the inverting terminal.

So, three things we have to understand external components R 1 and R 2 that forms closed loop, second output is fed back to the inverting input and third is that input signal is applied to the inverting terminal. Now, the required condition to apply virtual shot up on circuit is negative feedback and infinite open loop gain; these are the requirements is not it? So, what if there is a closed loop gain? So, close loop gain G equals to v o by v i which is nothing, but minus R 2 by R 1.

See if I see here; you see at this point it will be virtual ground; we have seen the concept of virtual ground because this terminal is grounded, our inverting terminal is grounded that is why the point at non inverting terminal will also be considered as ground; the virtual ground. So, if I have register R 1; I apply voltage V 1 then the current flowing through my register R 1 would be nothing, but i equals to v 1; by R 1.

Similarly if I want to measure the current flowing through R 2; it will be nothing, but i 2 equals to i 1 equals to v 1 by R 1. So, what will be my output voltage? It is 0 here; here voltage is 0 because nothing will flow here it is a infinite input impedance and a very high input impedance and the difference voltage is also 0 volt. So, if I want to measure v o; v o is nothing, but 0 minus v 1 by R 1 into R 2. So, what will be v o? v o will be nothing, but minus R 2 by R 1.

Now if you see infinite differential gain; infinite differential gain is v 2 minus v 1 is nothing, but v o by A is nothing, but 0; infinite differential gain would be 0. Because the infinite differential gain, the value here is 0 infinite input impedance we know that it has infinite input impedance; that means, my i 1 equals to i 2 equals to 0, then you have 0 output impedance; that means, my output voltage will be nothing, but v o equals to v 1 minus i 1; R 2 that is correct, v o equals to what? v 1 minus i 1 into R 2 because you see here is same this R 2. So, I have v o equals to nothing, but v o equals to V 1 minus i 1; R 2

So, if I substitute the value what will I have? Output equals to minus V 1; R 2 by R 1. Now if I take voltage gain is negative because my inverting amplifier my voltage gain is minus R 2 by R 1; my gain is minus R 2 by R 1, voltage gain then we can multiply by input. So, voltage gain is what? Negative.

Input and output signals are out of phase; this is another concept and we have seen this concept. Let us see when you talk about out of phase; out of phase is nothing, but when we apply the input to the inverting terminal which is over here.

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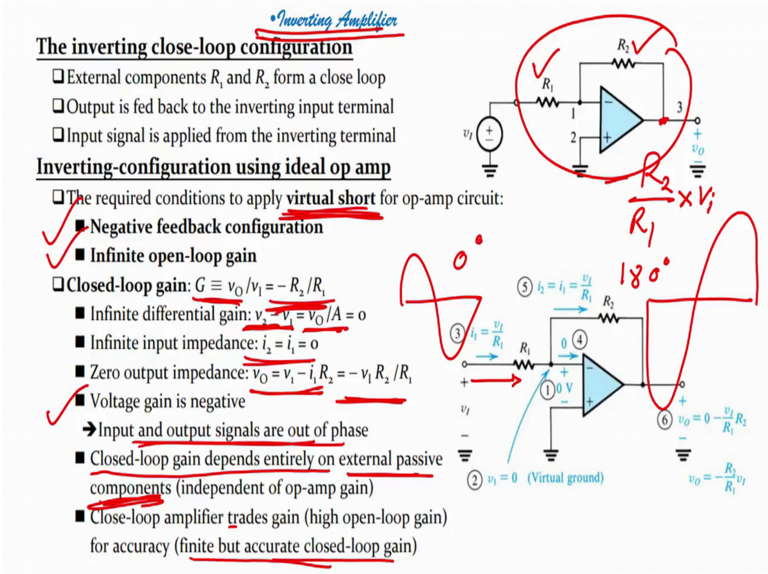

It is applied to the inverting terminal input is signal like this, output will be multiplied or amplified version of the input. Output would be amplified version of the input and that amplification depends on the value of R 2 by R 1.

But is it in phase or out of phase? This is in phase signal, but in case of inverting; you will see that the output would be amplified, but out of phase; it will be magnified, but generally 180 degree out of phase; if this is 0 degree, it is 180 degree out of phase. So, that is what is written here that input signals and output signals are out of phase.

Next closed loop gain depends entirely on external passive components; why? Because we have R 2 and R 1; so, this is external passive component, R 1 is register, R 2 is register; these are externally connected to the Op-amp that is why they are external passive; passive components. And our gain, this is a closed loop if you see this amplifier it is in close loop configuration. Now closed loop gain depends on the value of R 2 and R 1 and that is why we can say that the close loop gain depends entirely on external passive components.

Close loop amplifier trades gain for accuracy; that means, that here we do not have extremely high gain, but we can change the gain and we can have finite, but accurate closed loop gain. So, accuracy is better here, but we have finite closed loop gain, but in case of no feedback you will have infinite gain, this is the inverting amplifier.

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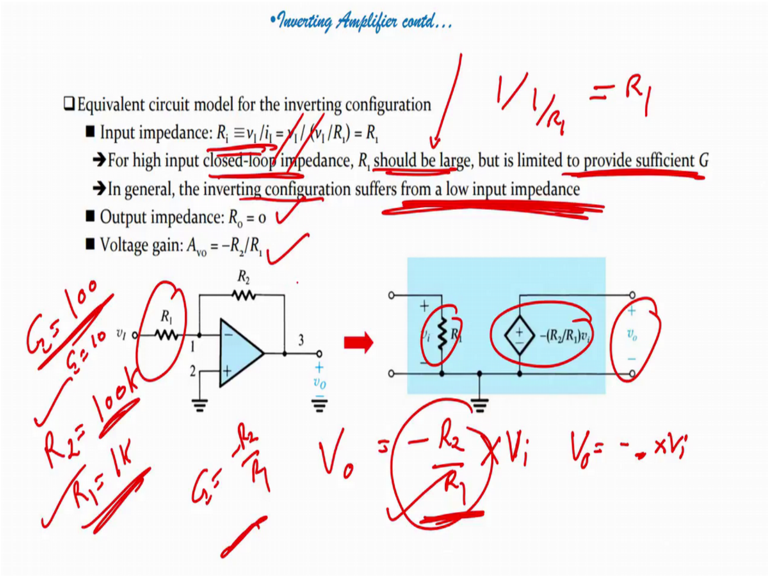

Now, if I draw equivalent circuit model of inverting configuration; what will I have? I have R 1, my gain is minus R 2 by R 1 into v i; I have output voltage v o, input voltage v i. So, input impedance is nothing, but R i equals to v i by i I or v i by i 1 equals to v i divided by v 1 by R 1 that is correct; which is nothing, but v v cancel or this value will be cancelled. So, it is nothing, but 1 divided by 1 by R 1 which is equal to R 1; that means, my input impedance will depend on the value of register R 1.

For high input close loop impedance; R 1 should be large, but is limited to provide sufficient G; what does that mean? That if I have A v equals to what is my gain here? R 2 by R 1; isn't it? And if I say output voltage; v o is nothing, but R 2 by R 1 into input voltage v i. Now what we are saying here? That for high input closed loop impedance, what we should have? We should have R 1 extremely high; R 1 value should be extremely high. So, if I put R 1 extremely high; what will happen? My output would be similar to my input.

Let us say if R 1 is infinite or closed infinite; this R 2 value R 2 by R 1 will be extremely small into v i into v i. So, I cannot do that R 1 can be extremely high, this is not possible otherwise this will not work properly. So, what is written? But is limited to provide sufficient gain, we have to use very high value of R 1, but we have to also understand what is the gain of our amplifier? For example, if I want to have gain of amplifier to be 100; then I can have R 2 which is 100, but R 1; I cannot have 100, I can only have 1.

So, if I have gain of; so, I can have R 2 equal to 100 K; R 1 equal to 1 K; you see. So, it is limited by this gain; even we want higher. If I put like 10 K here, my gain will not be 100; my gain will become 10 because gain is nothing, but minus R 2 by R 1. So, it is limited to provide sufficient gain; this is an example which we have seen.

Now in general, the inverting configuration suffers from low input impedance; you see her why? Because you see here only R 2 by R 1; if I want to have gain of 100; my R 1 would be 1 K; if I select R 2 equal to 100; a 1 K is extremely small, but in reality we should have R 1 or in input impedance extremely high.

So, in case of inverting amplifier the low input impedance is a problem or in another terms inverting amplifier configuration suffers from a low input impedance. Output impedance is 0; voltage gain is nothing, but minus R 2 by R 1 easy? Super easy right?

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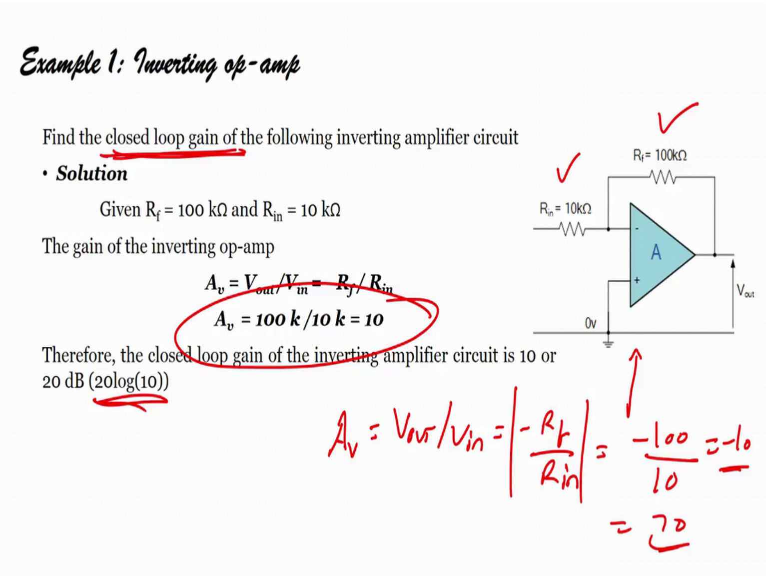

So, let us solve an example. So find the closed loop gain of following inverting amplifier circuit. You are given a circuit and you are asked to find the closed loop gain; now we are already given R in 10; R F 100, then what is our A v? A v is nothing, but V out by V in or we can write minus R F by R in 100 by 10 both is kilo ohms; so I do not write itm that is fine. So, what I have? Minus 10, but gain cannot be minus, so we always write is equal to 10; gain is equal to 10.

So, if I want to understand the closed loop gain; my closed loop gain of the inverting amplifier circuit is 10 or 20 dB or 20 log 10. So, this is how I can understand my inverting amplifier.

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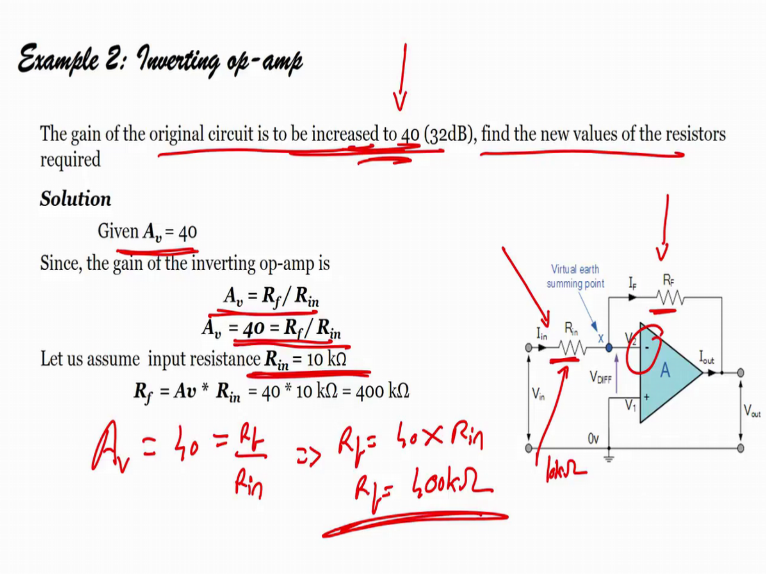

Let us see one more example; so, the inverting amplifier, the gain of the original circuit is to be increased by 40 dB. Find the values of resistors; see we are not given the values of register. Now, what is given? That we have to increase the gain to 40 dB or 40 or 32 dB; so, what will be value of resistors? That is the question.

So, given A v equals to 40; it is already given, gain is 40. Now since it is an inverting Op-amp; is it inverting Op-amp? Yes because we are providing input to the inverting terminal. So, what will be my A v? A v will nothing, but A v would be R F by R in. So, 40 equals to R F by R in; so, if I assume that my R in; let us say it is 10 kilo ohm; then my R F would be what? See I have this formula, I have A v equals to 40, equals to R F by R in implies R F equals to 40 into R in.

If I assume R in to be 10 kilo ohm, my R F would be 400 kilo ohms; very easy super easy. If I consider R in as 1 kilo ohm; then my R F would be 40 kilo ohms, if I assume my R in equal to 10 kilo ohm; R F would be 100 kilo ohms. So, this is how we can solve the question for the inverting amplifier.

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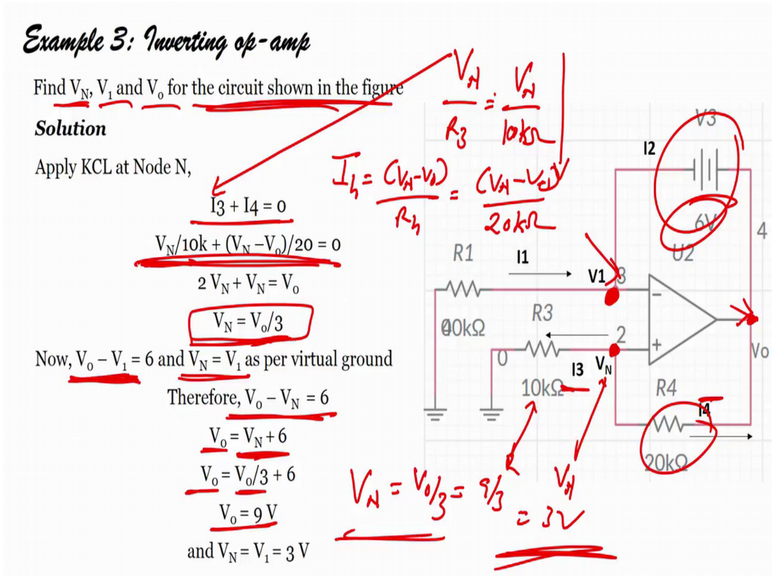

Let us see one more example; I am giving you more example, so that you can understand when you are given a circuit; how can you solve the problem? So, find V N; V 1, V o for the circuits shown here; for this particular circuit, we have to find lot of things; so, let us see. So, if I use the circuit first at node N; I have to here, I have to find. So, I will use Kirchhoff current flow at node N and what will I have? I will have I 3 and I have I 4 here. So, that will be I 3 plus I 4 equal to 0; according to Kirchhoff current this will be I 3 plus I 4 equals to 0.

Now, what is I 3? I 3 is nothing, but V by R; what is V? V is my V N; what is R? R is my 10 kilo ohm; V N 10 kilo ohm. So, I substitute these value correct; plus I 4 what is I 4? I 4 is here, I 4 is nothing, but you see here, you see here. So, it is like V N minus V o divided by R 4 correct V N; so, from here I 3 is what? I 3 will be my V N by 10 kilo ohm, which is my R 3; I 3 will be V N by R 3 which is V N by 10 kilo ohm. And I 4 equals to V N minus V o by R 4 equals to V N minus V o divided by 20 kilo ohms.

This is what I have written here, so from here when you solve it; you will find that V N equals to V o by 3. Now V o minus V 1 equals to 6 and V N equals to V 1; as per virtual ground, V o minus V 1 equals to 6. Because here see; what is the bias voltage? 6 volt; that is applied across the 3 and V o; so, if I say V o minus V 1; V o this voltage minus this voltage is nothing, but 6 volts.

And V N; this V N this voltage V N should be equal to this voltage V 1; why? Because by the concept of virtual ground. So, what we have? V o minus V 1 equals to 6 and V N equals to V 1; so, therefore, V o minus V N equals to 6. So, V o will be V N plus 6; so, V o would be V N plus 6; V N is what? V N is V o by 3. So, I will put V o by 3 plus 6; so, V o would be nothing, but 9 volts.

Now, I know that V N equals to V 1 equals to 3 volts; how? Because I know V N equals to V o by 3 equals to 9 by 3; equals to 3 volts. V N equals to V o by 3; this is 3 equals to what is V o? V o is 9 volts; so, 9 Volts by 3 which is nothing, but my 3 volts. So, this is how I can find; what is the V N, V 1 and V o for a given circuit; when you are given a circuit of an inverting amplifier.

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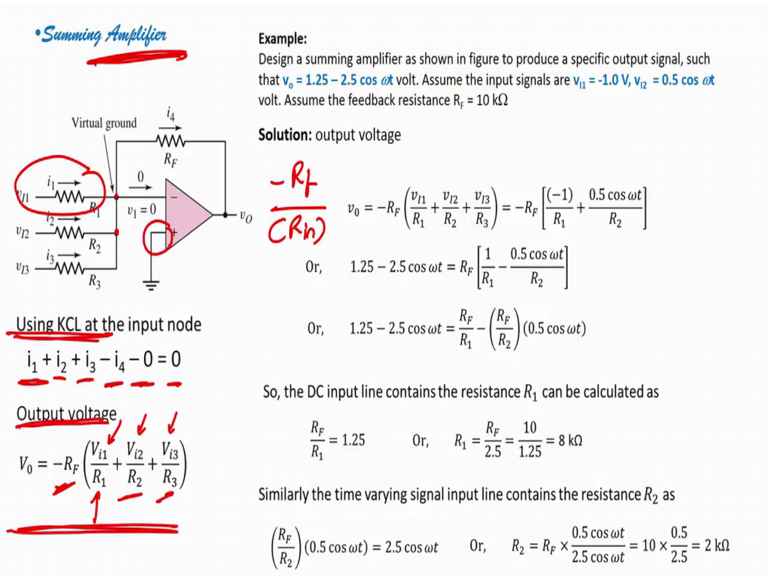

Now, let us see an example of a summing amplifier. So, what is summing amplifier? Let us see the circuit; so, when you see the circuit; what do you find is that when you use inverting amplifier; if you come back on the screen, you will see that we are using a inverting amplifier, we have a feedback register, but instead of one input register; you have three; you can have n input registers. So, n inputs and the output will be summation of all the inputs. So, how can you do that? It is written over here, if you are given this circuit; then using Kirchhoff current law what we can find? We can find, i 1 these values i 1, i 2, i 3 three values I get. So, i 1 plus i 2 plus i 3 minus i 4; here and here you see this configuration minus 0 equals to 0

So, output voltage would be what? V o equals to minus R F; am I right? Why? Because it is inverting amplifier; this is the inverting amplifier. So, inverting amplifier our formula is R F by input resistance R in; here first is V 1 by R 1; why? Because R F into V 1 here' V 1 by R 1 plus V 2 by R 2 plus V 3 by R 3 ; that means, output voltage is the summation of the input voltage and you can change the gain with the help of R F and input registers.

That means, it is not only providing a summation; it is also providing the amplification, and that is why; what we say is this is an; summing amplifier. Now here you can see very easily that the concept about virtual ground will come here, here and here this is nothing, but because the non inverting terminal is grounded; the voltage at the inverting terminal is also considered as 0 which is your virtual ground.

Now, if you are given an example which is over here in front of you; this example a design a summing amplifier as shown in figure to produce a specific voltage such that v o equals to this; assume that v 1 is this, v 2 is this and feedback register R F is of 10 kilo ohm value.

Now, if you see closely; you are given v in 1; you are given this voltage which is your v in 1 here; you are given v in 2, but you are not given anything about v I 3 here; are you given anything about v I 3. So, we do not have to assume there is v I 3 or v I 3 equals to 0. Now we can just; we know this formula which is similar to here; this formula for summing amplifier, we will substitute the value; so, minus R F remains as it is here.

What is V i 1? V i 1 is minus 1 volt divided by R 1 plus what is V i 2? V i 2 is nothing, but 0.5 cos omega t by R 2; now what is V o? V o is given as 1.25 minus 2.5 cos omega t; equals to R F into this value.

So, if I further solve it; what will I have? 1.25 minus 2.5 cos omega t equals to R F by R 1; minus R F by R 2 into 0.5 cos omega t. So, the DC input line contains resistance R 1 and that can be calculated as nothing, but R F by R 1 equals to 1.25; this is very easy; here you see this value R F by R 1 or R 1 equals to R F by 2.5; what is R F? R F is given 10 kilo ohm; so, R 1 equals to 8 kilo ohm.

Similarly, time varying signal input line contains R 2; you can see here, you see the point here you have to understand is; when you are considering DC input line, then you can see DC input line; it contains this value, but point varying signal; this contains this value; point varying signal which is this one; it will have 2.5 cos omega t. So, I can write R F by R 2 into 0.5 cos omega t is nothing, but this particular equation or R 2 is nothing, but this value or further if I solve it; R 2 would be 2 kilo ohms.

Thus I have found the value of R 1, I have found the value of R 2 and now I can put this value and design a summing amplifier; it is very easy; let us quickly once again see what we have done with summing amplifier. Summing amplifier is nothing, but an inverting amplifier connected in a way that you have a lot of input voltages; more than one input voltage.

So, here you can see; so, this is you can take a summation of those input voltages; it can be N numbers; like this it can be until N, this is R N; i N; V i N; N times. So, point is that the formula is very easy v o equals to; feedback register R F since this is inverting. So, minus R F by R 1 we have seen.

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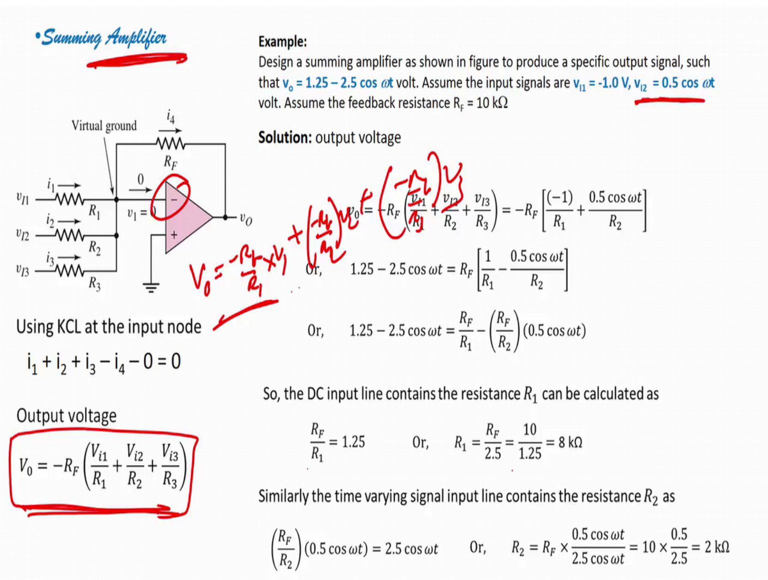

V o equals to minus R F by R 1 into V 1; this is inverting amplifier. Now here we have minus R F by R 1 into V 1 plus we have or minus plus we can also write minus R F by R 1 into V 2 plus; again we have minus R F by R 3; this is R 2 into V 3.

So, if I solve this; I will have this equation once I know this equation, if I am given a problem which is shown here; that for the given output voltage, if you have two signals;

input signals and you have feedback registers, then we can solve the value of R 1 and R 2 because there are only two because there are only two voltages V 1 and V 2.

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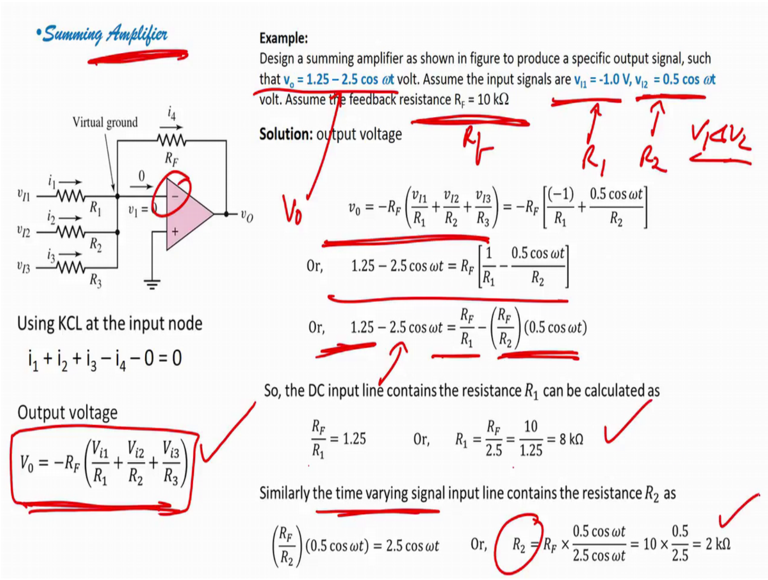

So, we have to find R 1 and R 2; we are given the value of R F, we are given the value of v o. We are given the value of v 1 and v 2; everything is given. So, this becomes; life becomes very easy because we have to just substitute the value and solve it and then we know that this is the DC input line, this is the resistance R 1; that is the feed would line contains. And then we see the time bearing signal, this is the time bearing signal and it is rated with this particular signal; so, then you can find the value of R 2. Thus R 1 and R 2 is very easy to find.

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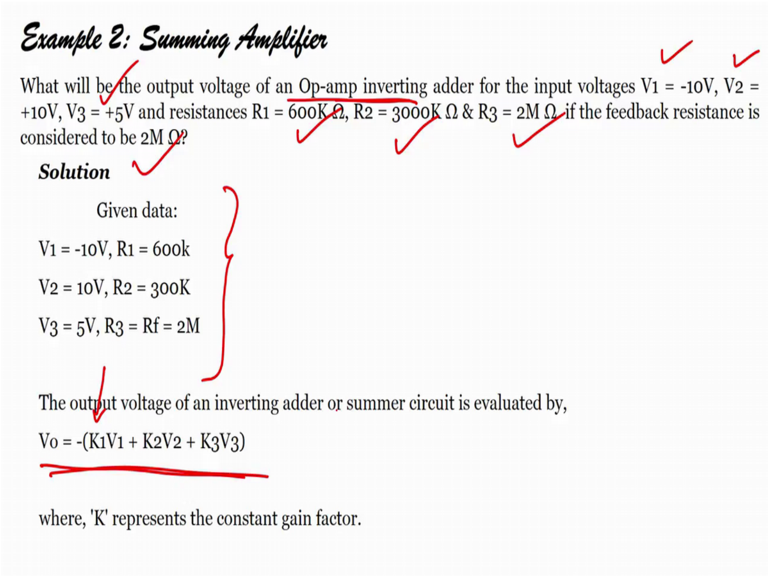

So, let us see one more example of summing amplifier. So, what will be output voltage of Op-amp inverting adder; it is also called inverting adder; for the input voltage is V 1 is given V 2 is given, V 3 is given. R 1 is given, R 2 is given, R 3 is given and feedback resistance considered to be 2 mega ohms; R F is also given; you see life is so, easy it is; so, easy question; everything is given V 1, R 1, V 2, R 2, V 3, R 3, R F; everything is given.

Now, output voltage is what? Output voltage is V o equals to minus K. So, K is nothing, but this is nothing, but gain factor; R F by R 1 that is the K, R F by R 2; K 2; R F by R 3 K 3; so, minus bracket K 1, V 1 plus K 2; V 2 plus K 3; V 3.

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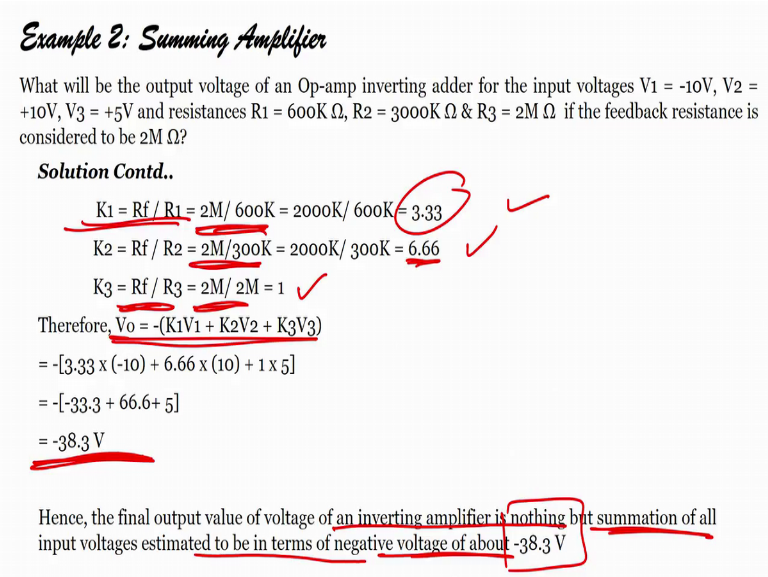

So, if I substitute the values then what will happen? K 1 is nothing, but R F by R 1. So, if I substitute values; 2 mega ohm via 600 kilo ohm, I will have 3.33 which is my R F by R 1 or K 1. Same way if I substitute value for K 2; that is R F by R 2; 2 mega ohm divided by 300 kilo ohm; I will have 6.66. And then finally, for K 3; R F by R 3; 2 mega ohm by 2 mega ohm is 1. ;

So, I have now 3 values if I substitute those values in this equation what will I have? V o equals to minus 38.3. Hence the final output voltage of a inverting amplifier is nothing, but the summation of all the input voltages estimated to be in terms of negative voltage of about 38.3 volts; about minus 38.3 volts; negative voltage is minus so 38.3 Volts; very easy, this is how the summing amplifier can be solved.

So, what we have seen in this particular module is that we have seen that we can use the operation amplifier; as an inverting amplifier and then we have solved few problems. Then we have also seen, the operational amplifier as a summing amplifier and we have seen a problem, how it can be used as a adder or as a summer or the summing amplifier?

Now, in the next module; let us see how you can use operation amplifier as the non inverting amplifier? Say there are several applications like we have seen the slide 1; that the Op-amp can be used as a inverting, non inverting, differentiator, integrator, summer. So, we will see few other circuits in the next module. Till then you just look at what I have thought, in this particular module and I will see you in the next module bye take care.