Electronics

Prof. D C Dube

Department of Physics

Indian institute of Technology, Delhi

Module No. # 07

Differential & Operational Amplifiers

Lecture No. #04

Operational Amplifiers in Open Loop

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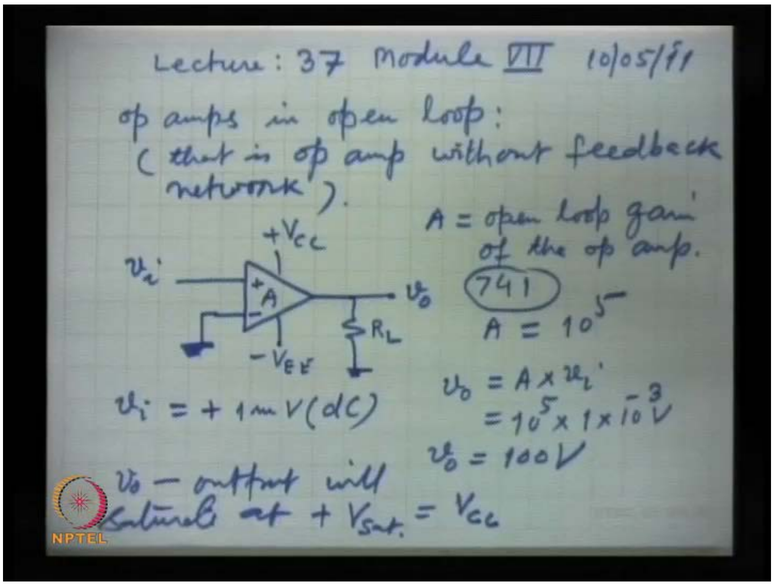

I have been discussed the basics of operational amplifiers, we continue to study them for example, how they can be used, and what are their circuit applications. First we take op amps in open loop, by open loop we mean that there is no feedback involved in it; that means, that is op amp without feedback op amp without feedback network. How will it behave, just let us consider a op amp with the two inputs as we have said. So, let us take that in open loop this is non inverting input to which we apply a input signal and let this inverting input b grounded.

Now, this A is the open loop voltage gain and v out we take from here R L, and this is v out. Now this A is the open loop gain, always remember open loop gain gain of the op amp and the 741 op amp, 741 which is a general purpose op amp and that we are taking as the model just a sample we used. So, this 741 has A around 10 to the power 5 its 100000 is the voltage gain. Now let us see what will happen if we apply A for example, a positive signal v i is plus 1 mill volt let us say this is d c.

Now, mathematically what will be the output, the output is gain into input that is, this v out will be A into v i gain is 10 to the power 5 ten to the power five and this is 1 milli volt. So, 1 is to 10 to power minus 3 volt. So, the simple mathematic says that v out will be 100 volts. Now very fundamental thing that in a circuit this v out the output voltage cannot exceed the maximum d c voltage is available or applied to the circuit. Therefore, this instead of 100 it will saturate at V sat output v out that is output we will saturate at plus V sat.

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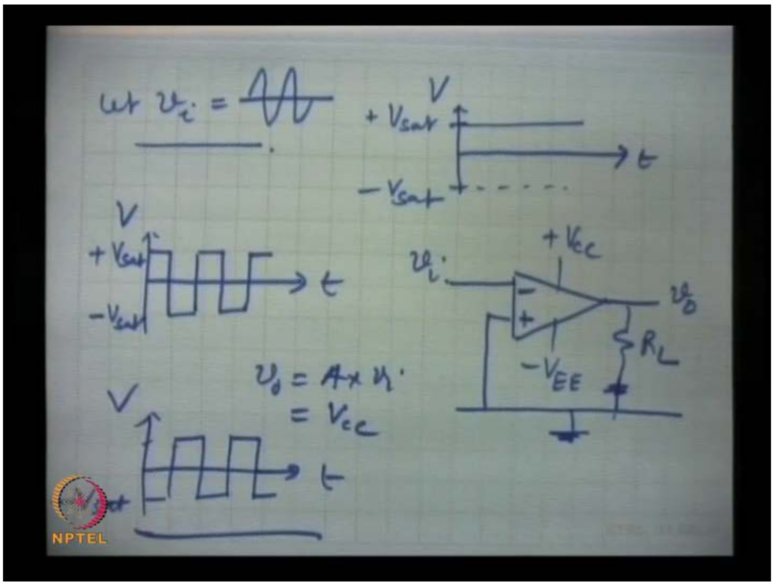

And V sat normally will be slightly low,, but of the order of V c c, the V c c is 15 volts then plus V sat will be roughly 14 or 14.5 volts. So, it will saturate. So, what we will get with the inverter non inverting signal the output will be like this, this is a time, this is a voltage and this is V sat this is minus V sat. So, if the voltage is positive it will just saturate here and if it is negative voltage here, if this voltage is negative then without change of polarity it will appear n output and it will saturate A.

Now, if we apply a sinusoidal signal let v i b sinusoidal like this, this is the input signal and the if this is say of the order of a milli-volt then same thing will happen here. It will just saturate at plus V sat and here it will saturate at minus V sat. So, if this is the input the output will be this. This is the output voltage time plus V sat and here this is minus V sat, this is highly distorted this is not the replica of the input. Therefore, does in open and loop A op amp amplifier is a rarely used almost never used as an amplifier because output will be a kind of square wave for a sinusoidal signal.

So, this is highly distorted when we compare the two. The same thing will happen when we apply the input instead of a the non inverting input if we apply at the inverting input, all voltages are always with respect to ground. When we say v i this is like this actually here this is the ground level and this is grounded and here we apply a voltage this is the inverting input and v i and this is the output which is a gain with respect to ground this is v out this is the load. So, this is not shown, but in a statement we cover it that all voltages output and input voltages are with respect to ground.

So, here when we apply it the sign will be inverted if it is d c if we apply a positive voltage it will saturate at a minus V sat and if it is negative voltage, it will saturate at plus V sat and we apply a sinusoidal signal and if this exceeds the limit A into v i more than V c c, then it will produce a signal at output A square wave with inversion. That means, the it will be like this, this is time, this is minus V sat plus V sat and this is voltage. So, this is n if we apply use it as a differential amplifier.

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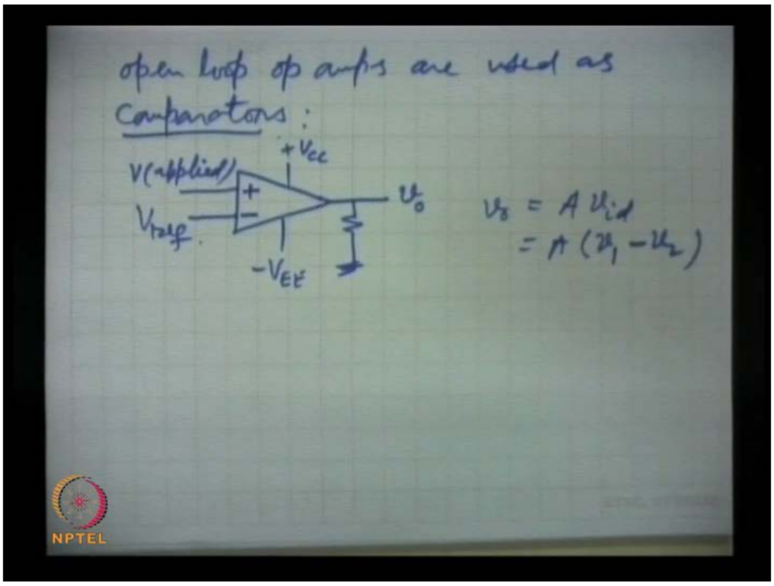

Then the difference of the two will be will appear will again normally, it will saturate. Unless the difference is in say micro volts then of course, amplified signal will appear.

Now, what how we summarize this? That normally as an amplifier in open loop op amps are not used; sometimes they can be used as comparators open loop op amps are used as comparators; comparators is a circuit which compares two voltages. So, here for example, we give here a, one is the reference this is a reference voltage.

And this is the applied voltage, we applied to be compared applied means the one which you want to compare. Now the output when we take, then as soon as this will exceed this, the output will saturate accordingly and a signal will be available. So, this way the three configurations in open loop the inverting amplifier, non inverting amplifier and as a difference amplifier this is a not used as an amplifier, but one of the applications for open loop is as comparators where v 0 will be A v i d and A into v 1 minus v 2, where one of these can be a reference voltage.

So, this can be used as an as an comparator,, but the use of op amps as an amplifier is very wide very wide as I said there are a large number of applications of op amps. But most of these applications are with the using proper feedback and the amplifier realization that is construction of a amplifier is simplest with a op amp. We can choose how much gain we will see we are coming to that that, we can choose how much gain for the amplifier is required and what is the input impedance we want. Then we have choose just two, three resistances of a rap appropriate value they are to be attached with the op amp.

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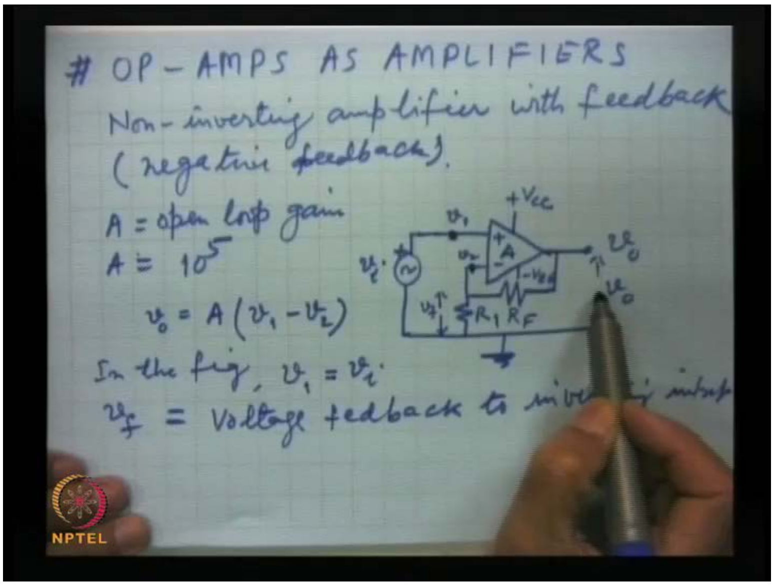

And the design will be extremely simple you need not to bother about biasing network this and that, that is all everything has been taken care of by the manufacturer and designing the op amp. So, we take the applications of amplifier of op amp as amplifier first. So, op amp as amplifier op amps as amplifier there are three amplifiers and all three we will take one by one. First, we take non inverting amplifier non inverting amplifier with feedback and this feedback is negative feedback, in amplifiers we always use negative feedback.

This point was stated and made clear when we were discussing a feedback in amplifiers negative feedback. First, let us see what will be the simple circuit and then we analyze this amplifier. This is v out and this is the input and the feedback is this R F this resistance is R F and this is R 1 look at the simplicity of the circuit and of course, these sources are there plus V c c and minus V c c. Even if we do not show these two d c supplies it altimeters it is implied no electron circuit will work with a without a d c supply.

Because, d c voltages are needed for biasing the transistors which is too important for biasing is too important for the operation of any transistor. So, this is the circuit and this we analyze and since the input signal has been connected with the non inverting input which is indicated by plus sign. So, this is a non inverting amplifier with a proper feedback now we analyze it and remember A many times written here, A is the open loop gain open loop gain, gain without feedback. This is the feedback amplifier how much will be the gain that we will estimate and evaluate for this, but this is provided by the manufacturer open loop gain.

And for most of the amplifiers particularly 741 this is A is 100000, 10 to the power 5. Now the v out this v identify this is v 1 and this is v 2, now v out this v out simply this is gain and the difference of two voltages v 1 minus v 2, whatever is the voltage here that is v 1 and whatever is the voltage here that is v 2. So, the difference of this will be will be multiplied with the gain will be the output, if we take in this figure, in the figure in the figure v 1 this v 1 is equal to v i this two are identical. So, v 1 is v i and v 2 v 2 will be the voltage here feedback voltage.

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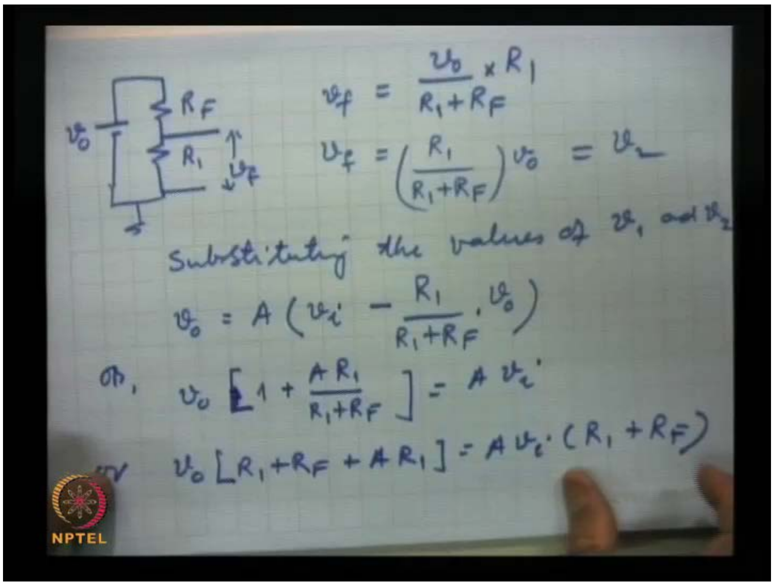

This is we write v f, v f is voltage feedback to inverting inverting input and this is simple, this we have talked several times, but anyway I do this. Voltage here is v 0 and these are two resistance and what will be the voltage drop here, this is voltage divider circuit, which I can drawn like this actually this is R F R 1 and whatever is the voltage drop here, this is v f the feedback voltage and this is v 0 see here v 0 and this resistance these two resistance is they are dividing this voltage.

So, this is the network. How much will be v f the current will be v 0 R 1 plus R F, this is the current through these resistance is which are in series and the voltage drop across R 1 will be the current, this is a current actually this is the current and multiplied with R 1 becomes the voltage. So, v f is R 1 by R 1 plus R F v 0 simple voltage divider circuit and this we have talked several times. This is the current which will be flowing and what will be the voltage drop across this multiplied with R 1 that is this voltage v f. So, we substitute the value of v 1 substituting the values of v 1.

And v 2 this v f this is a equal to v 2 the voltage here with respect to ground is the same as voltage v f. So, this is v 2 and v 1 we already have this. So, when we substitute v 1 and v 2 we get v 0 is a v 1, v 1 was v i minus v 2, v 2 is this. So, R 1 R 1 plus R F into v 0; so this is simply v 0 equal to a into v 1 minus v 2, we have substitute the substituted the values of v 1 and v 2 and this we can write or we take this term here or v 0 is v 0 into 1 plus A R 1, R 1 plus R F this is a v i let us 0 r across multiplication.

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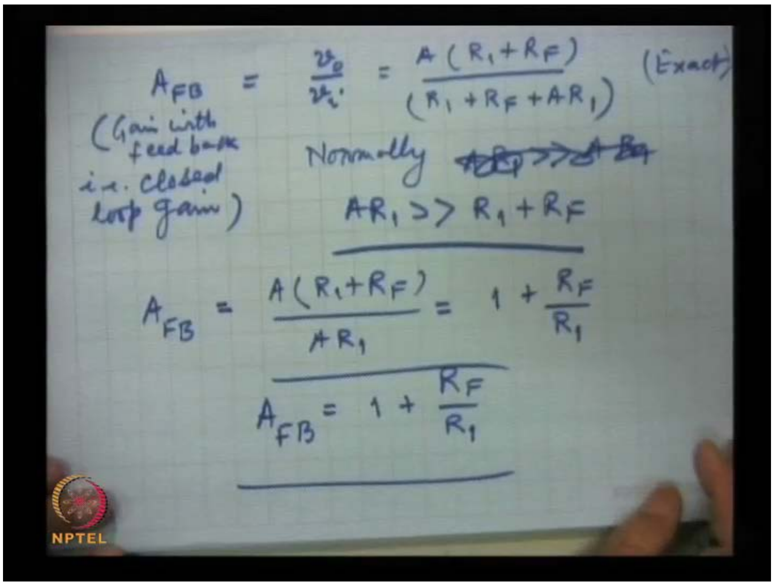

We will give A ~~0~~ R 1 plus R F plus A R 1 this is equal to A v i R 1 plus R F and now form here, we can get the close loop gain from this the expression we will get A with feedback. So, normally we write with F or F B with feedback gain gain with feedback, that is A F is closed loop gain closed loop closed loop gain this is equal to v 0 by v i here input signal was v i output v 0. So, ratio of output voltage to input voltage is the gain this is the op amp in open loop and this is the feedback network.

So, this whole amplifier is A and amps which feedback this is amps which feedback for that, this is the gain and which from this equation v 0 by v i, this becomes equal to A R 1 plus R F R 1 plus R F plus A R 1, this is the exact expression we write here exact. This is the exact expression for the voltage gain,, but when we see the practical situation it gets drastically simplified and the situation is that normally and normally means most of the time A R 1 is very, very large as compare to R 1 plus R F, R 1 into A, A is 10 to the power 5; so, 100000 times R 1, while this resistance is made differ early by effect of 2 or 3 or 5. So, this is this condition will be mostly ~~a~~ available and applicable. So, this we can or this can be neglected and then gain which feedback becomes equal to A R 1 plus R F by A R 1 or simple 1 plus R F by R 1. This is the gain of the non inverting amplifier with feedback is 1 plus R F by R 1, how simple you choose the gain how much you want 10, 20, 30, 50, 100 accordingly choose these two resistances if for example.

Now, because this is a amps is a small signal device. So, resistance is normally will be ohms because ratios suppose we want a gain of 20. L let A F B desired is 20 and for that from this expression, we want R F by R 1 ratio be to 19. Now 19 you can have for example, R F you can choose a say 190 into 2; so many ohms and R 1, because this is to be 20 this ratio as to be 20. So, this becomes 380, 380 divided by 20.

So, 20 ohms and 380 ohms if we take ratio will be 19, but these resistance is will draw it large current and the currents will exceed the maximum current which is recommended for the op amps and op amps will be burn. So, instead of in ohms these are taken in clones. So, we can choose the this in clones and ~~a~~ we can have this ratio 19 then gain will be 20. For example, let R F be 19 clones and R 1 v 1 ohm then gain A F B will be 1 plus 19 k by 1 k. So, this is 20 gain will be 20 how simple it is to construct a non inverting amplifier with a desire gain.

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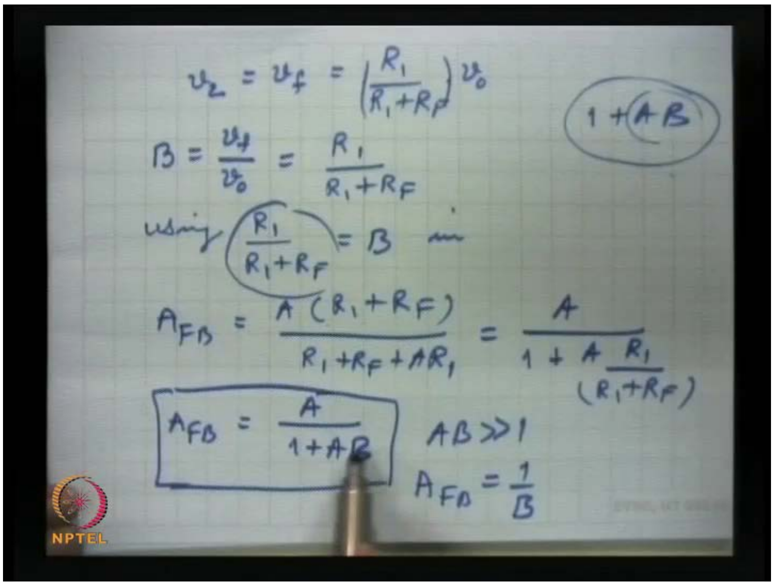

Now, let us go further to show that non inverting amplifier with amps is a very close to an ideal voltage amplifier. It is an ideal voltage amplifier and this we can show by using the concepts of feedback. Now from this equation v 2 equal to v f which was equal to voltage divider R 1 plus R f into v 0 this is v f, you remember that in the feedback networks 1 plus A B, where A B is the close loop gain and beta A factor. So, beta is v f by v 0 the fraction which is written 2, this is the input of this is the feedback network the input.

Here was v 0 this v 0 is the input to the feedback network and output we are taking here. So, the gain of of of feedback network is output divided by input v f by v ~~0~~ which from here we write as a R 1 by R 1 plus R F. This is the the gain of the feedback network and then using this expression using R 1 R 1 plus R F equal to B, in the A F the exact equation, which was A R 1 plus R F R 1 plus R F plus A R 1. If we use this then this can be written as a A F B is A 1 plus A B just substitute like this.

And this becomes this we divide by R F actually. So, this is A by 1 plus A R 1 R 1 plus R F which this is B. So, this is this expression which was the expression for a voltage amplifier with the negative feedback and this term A B will be very large in comparison to 1. So, 1 can be drop. So, the gain A F B is 1 by B that is highly stable. The gain of the feedback amplifier op amps does not depend on variations in a which may vary because of aging or temperature or noise in the surroundings whatever may be the reasons, but the gain of the feedback amplifier the of the no inverting operational amplifier with feedback is stable.

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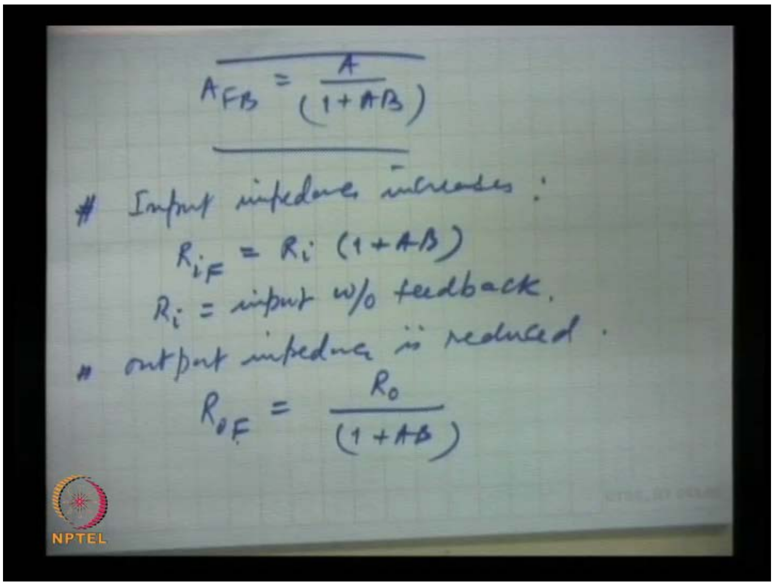

And it simple depends on the B, the B network is normally few resistances. So, with this expression every quantity will vary with the you remember we said this which feedback that because, the gain is A 1 plus A B and all qualities will vary either increase or decrease by a factor 1 plus A B. If we increase we have multiply by this factor and if they fall will have to divide it. So, this is this amps here the sacrifices what we are doing that gain falls from A to this, the gain of the non inverting amp with feedback is much reduced it is reduced by this factor 1 plus A B and this factor may be 100.

So, then the gain will fall by hundred 10 to the power 5 by 100 even 1000. So, if it is 1000 this factor is 1000 it will be just 100 may be less. So, now what are the quantities we recollect from our discussion in the feedback chapter which we finished that input impendence, input impedance with feedback that is R i F with feedback this is R i and it increases by this factors. If this is R i is the input without feedback then this is the input impedance it will increase by this factor.

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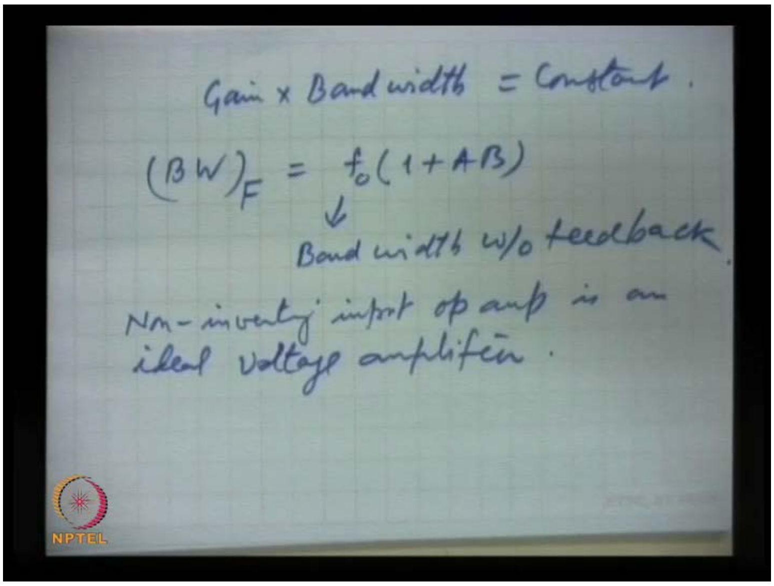

And this factor is for example, often 1000 10 and more see 1000 times the input impedance will increase and the output impedance, in this case we will reduced the output impedance is reduced is reduced and with feedback R F. If without feedback it is R o then this 1 plus A B, it will be reduced and a ideal or rather a good voltage amplifier is suppose to have high input impedance and low output impedance and band width will increase because you will recall that gain width product is constant gain voltage gain into band width product is a constant for a device in this case gain falls by a factor 1 plus A B.

Hence the band width increase by the same factor 1 plus A B. So, with feedback band width band width with feedback this is, if this is the band width without feedback, then it will be this is band width without feedback. So, we are seeing all through that non inverting op amp is a non inverting amp is a an ideal voltage amplifier, non inverting input op amp which is called actually non inverting op amp is an ideal voltage amplifier. So, this is the major things about a non inverting amplifier.

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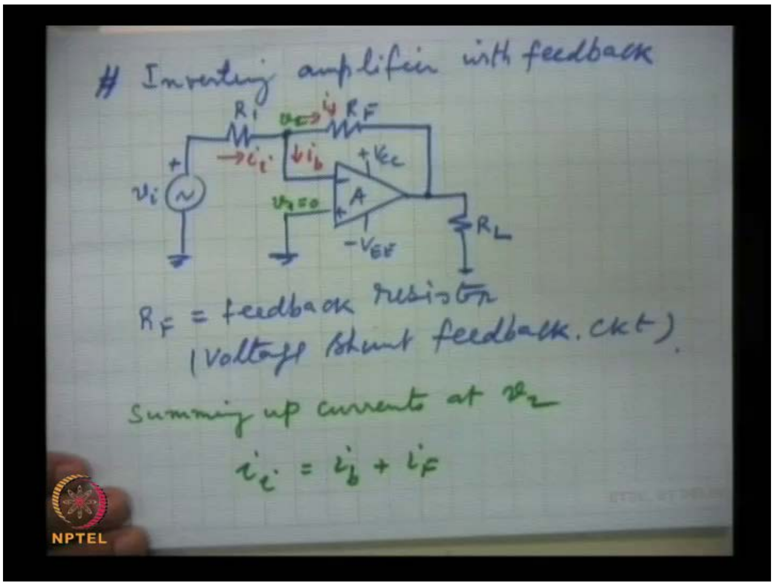

Next, we take inverting amplifier and how we known that whether the amplifier is inverting or non inverting simple. Where we are feeding the input signal as you have seen in this case the which we have studied the input signal was at as to a non inverting amplifier a non inverting input. So, it was a non inverting amplifier. Next is inverting amplifier inverting amplifier with feedback let us see the circuit, the circuit is this, this is the circuit for inverting amplifier just we connect two resistances R F and R 1.

These two resistance is externally connected then it makes a inverting amplifier and now we investigate the important properties of this circuit. Here R F this is the feedback resistance feedback resistor and R 1 is a another resistance and we can see that this is the voltage shunt voltage shunt feedback circuit. Now the most important property of an amplifier is the voltage gain the other important property is input impedance and so on. So, first we take a voltage gain of this amplifier.

Let us see here this current is i i this is i b and this i f, this is the input current which is divided into two parts. So obviously, summation of currents at this point which is v 2 and this is v 1 this is of course, is 0 because, it has been grounded this terminal is at potential v 2 and this is with respect to ground of course, and this is at v 1, but v 1 is 0. So, summing up currents at v 2 gives i i this is equal to i b plus i f and i b you remember that the input impedance of A the op amp is a extremely large it is in wave ohms.

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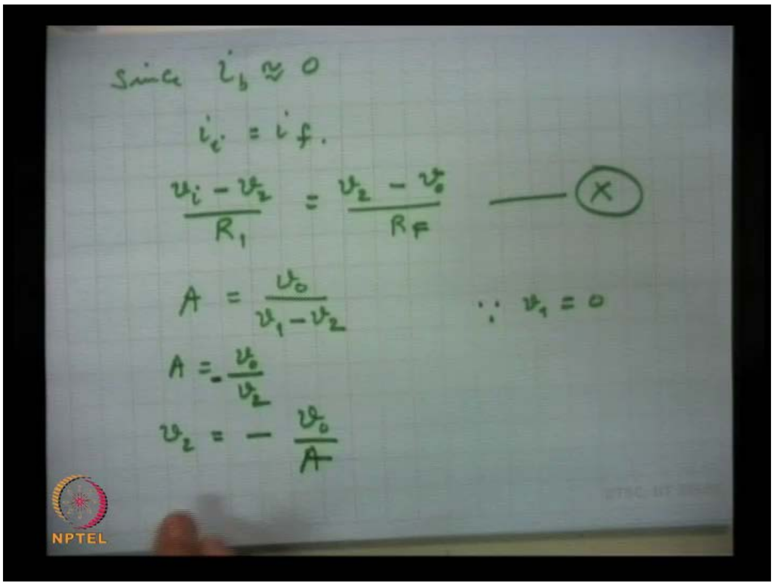

So, this current is very feeble. So, since i b is very close to because the input impedance of the amplifier is very high. Therefore, i i is simple equal to i f now what is the value of i i and this terminal one terminal is at the voltage v i the other terminal as v 2. So, what is the current flowing through this ohm law potential difference is v i minus v 2 divided by R 1. So, this is this current this is v i minus v 2 by R 1 this is equal to i f I mean i f the two terminals of i f 1 is at voltage v 2 other is at voltage v 0 output voltage.

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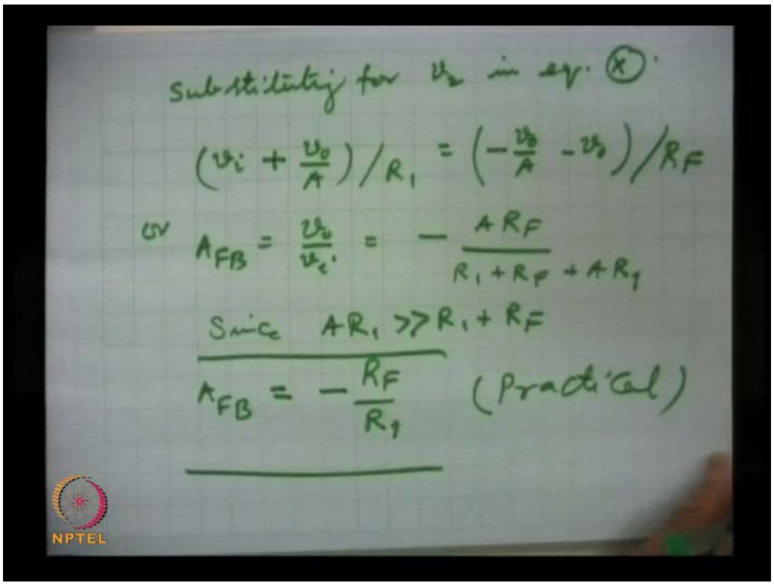

So, this is equal to v 2 minus v ~~0~~ by R F and from here we can what will be the gain. The gain of the amplifier, this is equal to v ~~0~~ and two voltages v 1 by v 2,~~,~~ but v 1 is 0 because it is grounded v 1 is 0. So, since v 1 is 0, A is v 0 by v 2 and of course, that is a minus sign here, from here v 2 is equal to minus v 0 by A and this we substitute let us call this equation x. In this equation we substitute this substituting for v 2 in equation x we get v i minus v i minus v 2, but because v 2 is minus v 0 by A.

So, this is v 0 by A by R 1 this is equal to minus v 0 by A minus v ~~0~~ by R F or the voltage gain with feedback. This is equal to v 0 by v i output is v 0 input is v i. So, this is the voltage gain of the total amplifier and this is equal to minus A R F just from here, it is simple manipulation and this is R 1 plus R F plus A R 1 and since A R 1 is very large as compare to R 1 plus R F. So, this we can drop and A F B gain with feedback this simply is minus R F by R 1. How simple it is the expression for the gain of this inverting amplifier this of course, sign shows the inversion as it is we expected, because it is a inverted input, so inverting input.

So, hence this sign indicates there and just choose the desired ratio R F R 1 required to obtain the the desired gain. If gain as to be 100 choose this 100 k this as 1 k the gain will be 100 how simple it is. You cannot think an simpler amplifier in which the you choose the gains several parameters will have to adjust and several parameters you have to calculate here simply two resistances you have to take of appropriate value R F and i R i and this will be the the case. So, this is the practical this is the exact expression for the voltage gain which is rarely used.

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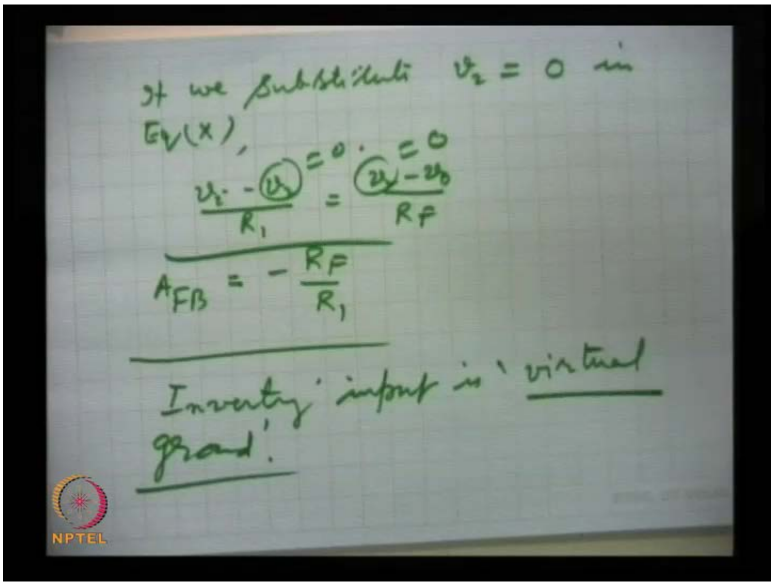

Because it does not make sense while this condition is very much satisfied hence this is the practical expression. So, practical expression for the voltage gain now one very important parameter about this amplifier and that is this expression can be obtained from this equation. If we substitute v 2 equal to 0 the same expression which we have arrived here, we get if we substitute v 2 equal to 0 in equation x in equation x, then we will get the same here, this equation x was this v i is v 2 R 1 v 2 v 0 R F.

And from here if we substitute this as 0, this is 0 then the gain A F B is equal to minus R F by R 1 same expression means sure, we have a obtained ever that is here we got the same thing if this consideration, but the same expression we get with v 2 equal to 0. What is v 2 equal to 0 this is v 2, v 2 equal to 0 means that v 2 is at the ground potential ground potential it is called virtual ground. The inverting input very important inverting input is virtual ground virtual ground. Why ground because at ground potential and why virtual because, actual ground can take almost any amount of current hundred thousand amperes whatever, but here you know only milli amperes can be observed in the device.

So, it is virtual ground this concept remember that inverting input is a virtual ground it is at ground potential this is a great hell in simplifying the analysis of more involved circuit like summing integrator differentiated, which we we are going to be studied. So, remember two things the gain of the inverting amplifier is just the ratio R F and R 1, choose these appropriate values for the desired gain, and the inverting input is a virtual ground and we will continue our discussion. This is very important point remember that inverting input is a virtual ground it is at ground potential.