Electronics.
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Module No. 07
Differential and Operational Amplifiers (Contd)

Lecture No. 5
Operational Amplifiers in Open Loop (Contd.)

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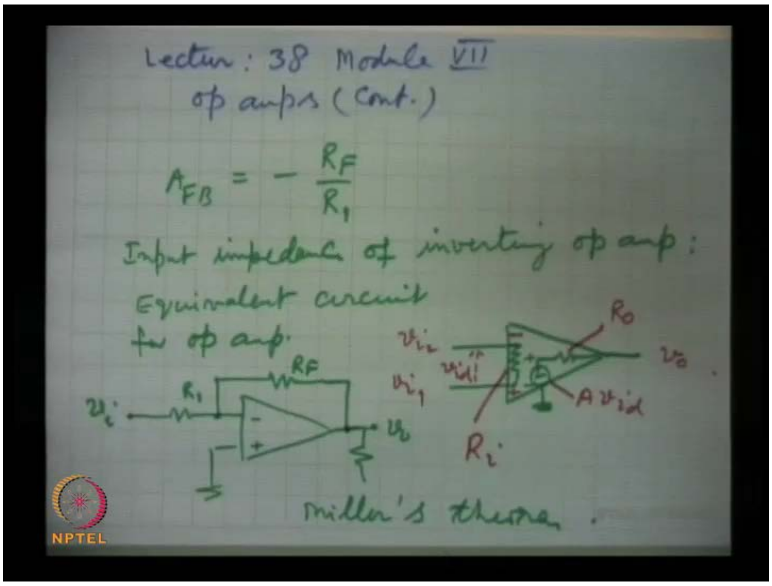

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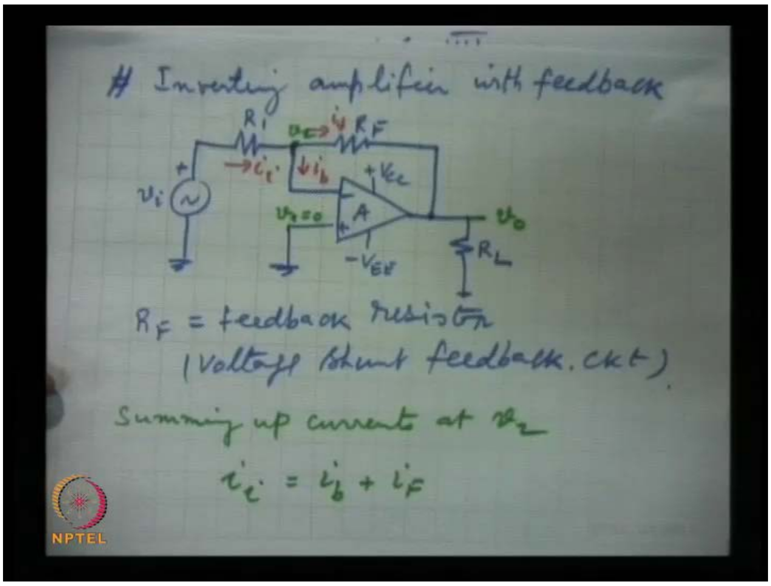

We were discussing the inverting amplifier, and two things which we did; one was that the practically used expression for voltage gain with feedback amplifier. This was minus R F by R 1; that is the ratio of these two resistances R F and R 1 that gives the voltage gain. We can choose these resistances in the clom range to get a particular ratio, and that will be the gain. This was the point which we discuss. Another important point was that v 2 was at zero potential; that means, it was at ground potential, and this is called virtual ground. Ground, because which is at ground potential and virtual ground, because actual ground can observe almost any amount of current, but this is a small signal device. So, hardly fraction of ampere will be the current, which this will be able to handle. So, these two points we discussed. Another feature as it was pointed out, that inverting non inverting amplifiers. These are both very widely used amplifiers. So, let us look for other important features of this amplifier. Next parameter is the input impedance, input impedance of inverting amplifier. For this we first draw a simple equivalent circuit for op amp.

Simple it is this, this is the voltage source, where this is v i d, and this resistance is R O the output resistance. And this is the inverting input and this is the non inverting input, and here we give this signal v i 2, v i 1 and we take v out here. So, this is the equivalent circuit, and amplifier we remember that the basic amplifier is this. This R F this is R 1 and here is the input for the inverting amplifier. Now this resistance r i is quite high. Here this resistance we have been saying, that input impedance first stage of op amp is a differential amplifier, and differential amplifier has very high input impedance. So, this is r i and it is more than one mu ohms in general. So, we can apply Miller's theorem which we have used earlier. Miller's theorem is applicable to find out the equivalent resistance of this R F at input and output, because this is in Miller's configuration, what is Miller's configuration. One end of the resister is connected at the input and the other end is connected at output. So, this is in Miller's configuration, and we can apply Miller's theorem.

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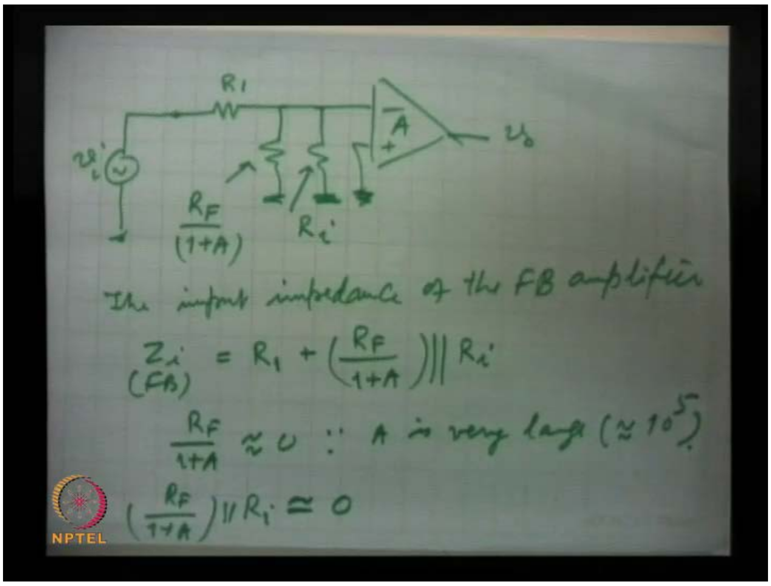

So, in that case the impedance which we will be getting is this. This is R 1, and this resistance this is the Miller's equivalent at the input, and this is equal to R F by 1 plus a where a is the open loop gain. And this is that r i the input impedance here. This r i and this is in Miller's form, so we transform it to its equivalent at the input. And this is R 1 and of course here, this is v i. So at the input, the net resistance of feedback amplifier; this one. The input impedance of the feedback amplifier becomes z i with feedback, so feedback amplifier. This is R 1 plus this combination in parallel. So, R 1 plus R F 1 plus a in parallel with r i. Now, here a is very large. So, this R F will be very close to zero. R F by 1 plus a is closed to zero, because a is very large, of the order of ten to power five. So, this is almost zero and any smaller resistance in parallel with high resistance, the result in case, the smaller one. So, R F 1 plus a in parallel with r i is almost zero. Therefore, input resistance is only r i.

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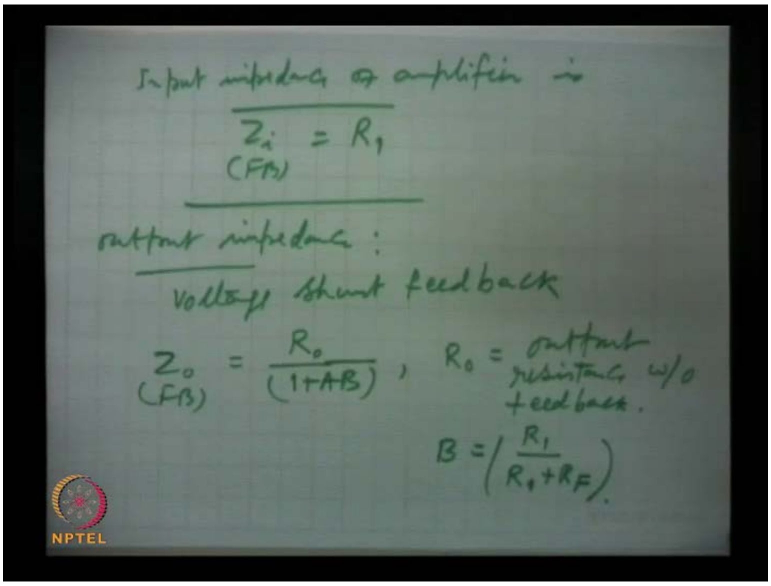

Input resistance or input impedance, input impedance of amplifier is R 1, this is. Whatever value we choose in the inverting amplifier, the value of r one that will be the value for input impedance how; simple, it is if you want to have a inverting amplifier with input impedance of say five kilo ohms and gain twenty and tape this R 1 as five k and because gain is twenty. So, twenty times of this; that means, hundred k hundred kilo ohms R F and five k r one will give input impedance of five k and gain of hundred. Very simple design and that is one reason of the popularity of op amp. And from a similar consideration also, the value comes out to be R 1. The similar consideration is, that this point is at ground potential, v 2 is virtual ground. So, what is the impedance which you expect between these two points.

The virtual ground and this point R 1. So, R 1 ends from a more rigorous simple analysis, though we have found that input impedance is R 1. Now the output impedance, output impedance can also be derived from similar considerations, but we are using another concept. Since it is a voltage shunt feedback, which we are using with the inverting amplifier, then you recall from what has been said earlier when we were discussing feedback in amplifier, that voltage shunt feedback brings the output voltage down be a vector of 1 plus a b, that is the output impedance as shown in this equivalent resistance is r o. This r o, because of that feedback it will be reduced, and this is R O with feedback. This is sorry Z O with feedback is R O, 1 plus A B.

And so this is drastically reduced here, R O is the output resistance or impedance same thing, at a small frequencies. So, output resistance without feedback, and A is the open loop gain, and B is equal to R 1 by R 1 plus R F. So, this way this is drastically reduced, which is again which goes in fever of a voltage amplifier. Inverting amplifier is a voltage amplifier, which has a high input impedance. We can choose the value of R 1, and gain is high we can choose the ratio R F by R 1, and the output impedance is low as given by this equation. So, this is about the output impedance. Now we have done non inverting amplifier, we have done inverting amplifier, and we have evaluated the basic parameters of the amplifier. And the next is the differential amplifier.

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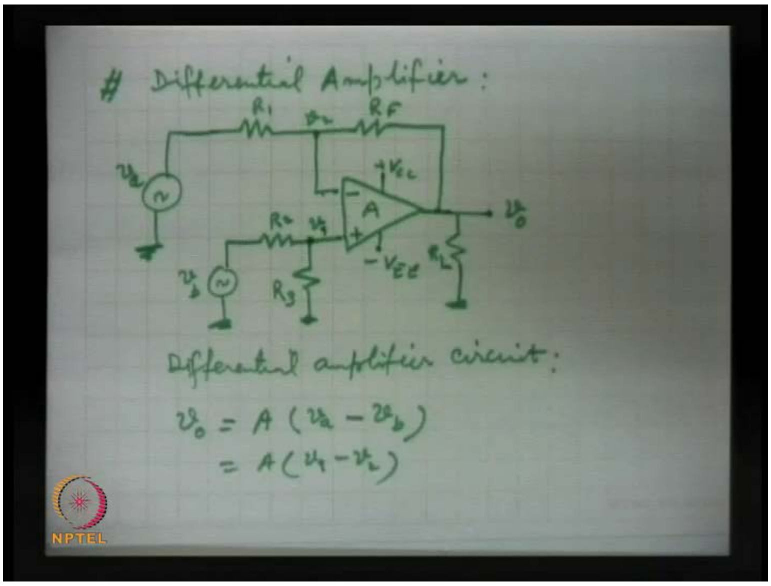

We have a studied differential amplifier using a two transistors q 1 and q 2 in connecting any particular way, and when we collect the outputs we take the outputs from the two collectors, then a differential amplifier can be constructed. That is the basic design and that was investigated for various basic understanding. Actually, instead of using, the transistors discreet transistor units, and then providing a constant current and all that. Actually the differential amplifiers are realized, by using a operational amplifier and using it in a differential mode. So, this is the basic circuit, gain open loop gain is A. This is inverting and this is non inverting input, the batteries, and now, here we connect R 3 R 2 and this input is the voltage is v 1, and here we apply the signal source v b. Similarly, here R 1, this is v 2 and this R F, and here is the other input signal v a. v a v b and this is one and two, so this is the differential amplifier circuit.

And v out, as we have studied in the differential mode gain into v a minus v b. This is the, whatever is the signals which will be available here. We actually I should have written v 1 minus v 2 for this, but anyway the difference here that will be amplified; whatever is the voltage at a v 1 and v 2 the difference will be amplified. Now to study these two signals, again we take help of the super position theorem. In such cases, it also phase to apply the super position theorem, and we will take one input signal active at a time, the other will be grounded. We will see what will be the output of that, and then the other will be activated and the first one will be in grounded. Again we will take the output and net output will be the. This is super position theorem, that algebraic of the two will be the net output of the differential amplifier. So, remembering this design this of course, we will be needing in our discussion further, that the relationship between input and output voltages can be obtained.

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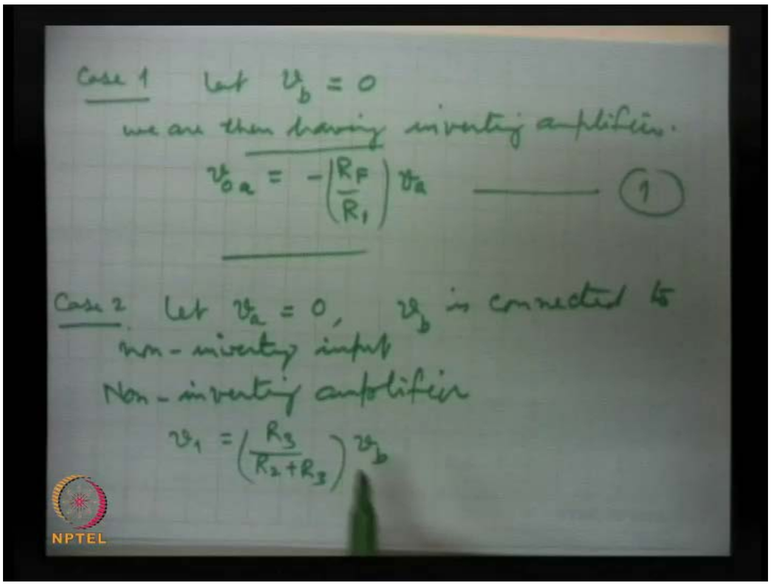

Let us take case one, and case one is, let v b be grounded. This is grounded on we are investigating the output, because of v a, v a as you will see if this is a grounded. This is a inverting amplifier. So, we are then having inverting amplifier, so the output v o, because of a, will be minus R F by R 1 into v a. This is the gain, gain is v o a by v a, which is equal to the ratio of that two resistances. These resistance R F by R 1, this is what for inverting amplifier, this is the gain. So, this is because of the first signal source v a active and v b is grounded. We take case two; case two is let v a be grounded and v b is connected to non inverting input, with resistance R 2 and R 3 this is implied. So, then we are dealing with a non inverting amplifier. And here what is this voltage v 1, this will be, this signal source will send the current, and that current will be v b by R 2 plus R 3 and when this current passes through this resistor R 3, whatever is the voltage developed here that will be v 1. So, v 1 obviously is, v 1 is R 3 R 2 plus R 3 into v b, voltage divider. This network is acting as a voltage divider for this voltage. So, what is the voltage which will be available at R 3 is this, and output due to v b, because of this input signal.

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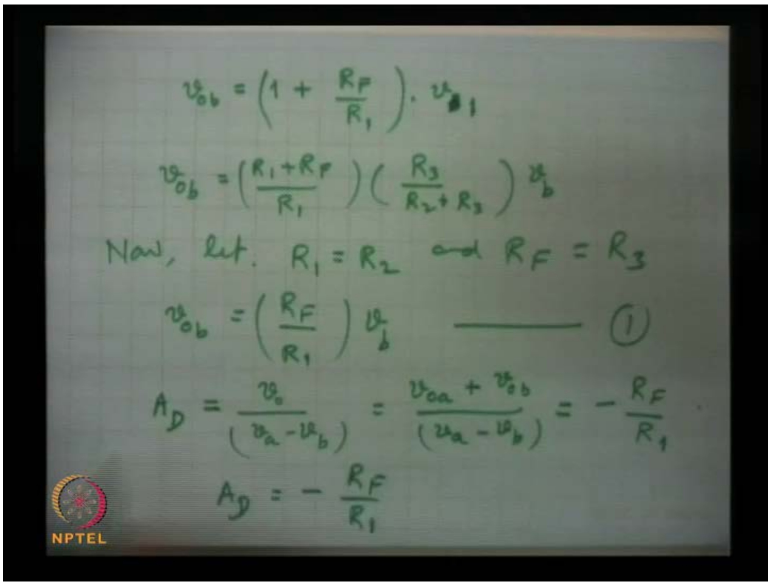

Because of this input signal, the output then will be v o b this is equal to 1 plus R F by R 1, this is the gain which we have still, which we have arrived at earlier for non inverting amplifier this is the gain, and into the input signal. This v o b by v is the gain of the non inverting amplifier, which is equal to this and hence v o b is equal to this. Now we substitute for sorry v 1. This v 1 and what will, it appear at output this is this, and now we substitute for v 1, as a we have got here this is the value of v 1, which we substitute. And then v o b is equal to R 1 plus R F by R 1 into R 3, R 2 plus R 3 into v b. This is the output and. Now, let resistance R 1 is equal to R 2, R 1 R 2 we take identical and R 3 and R F we take identical. So, let R 1 is equal to R 2 and R F equal to R 3, then when we substitute this, this will cancel and we are left with v o b equal to R F R 1 v b. This is the contribution under this condition, from the second input source v b.

Now we apply the differential or the effective super position theorem, and then it will be A D differential gain, which is equal to v 0, v a minus v b, and this is v o a plus v o b, v a minus v b. This is the general expression for the differential amplifier, and when we substitute these values of the two, by super position theorem then it comes out to be this, and which obviously, is using one and two it comes out to be R F by R 1; that means, the gain A D is equal to minus R F by R 1, this is under the condition. When in this design, we have taken R 1 equal to R 2 and R F equal to R 3, which is a symmetrical design which is normally used, and then this gain is this much.

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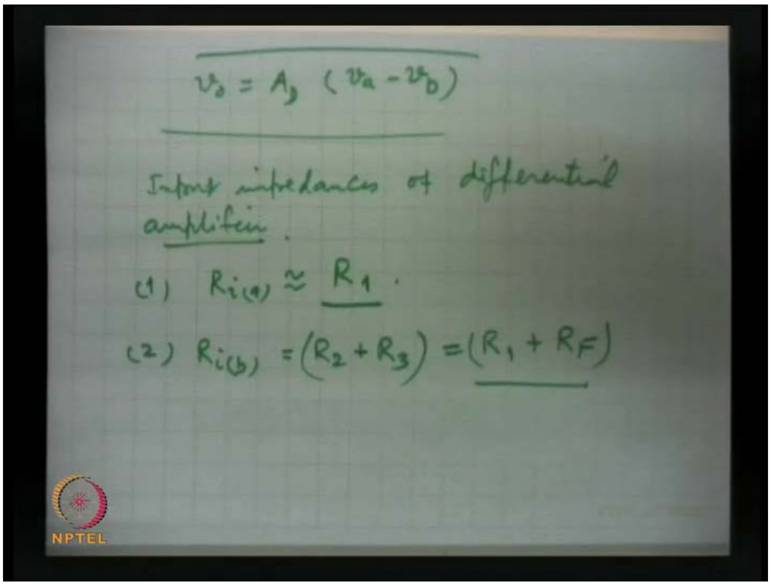

And the output will be with this gain, and two inputs v a minus v b. It is the difference of the two signals will be amplified, and whatever is common will be filtered out. Another important point is, that because the input impedance is different for inverting and non inverting amplifier. So, let us briefly talked about the input impedances of differential amplifier. The inverting part of it, that is R i a input impedance, because of the inverting amplifier, this we know, that this is equal to R 1. And for non inverting amplifier, what is the impedance which will be seen here, between this and ground these two in series. So, this is one, and two is R i b, because of this v what the b source will see as the impedance, that will be R 2 plus R 3, and because we have taken it R 1 equal to r 2. So, this is R 1 plus R F.

The inverting amplifier will see R 1 as the impedance, while the non inverting will see the impedance R 2 plus R 3, which is equal to R 1 plus r f. So, this is a important conclusion, that besides the magnitude the fact is, that the impedance is seen by two input sources, they will be different for a differential amplifier now. So, the major three amplifiers, which can be easily accomplished with the help of a operational amplifier we have completed; that is a non inverting amplifier, a inverting amplifier, and a differential amplifier. Now, there are some other forms of the amplifiers, which are a small modifications over this inverting and non inverting once, which are also widely used.

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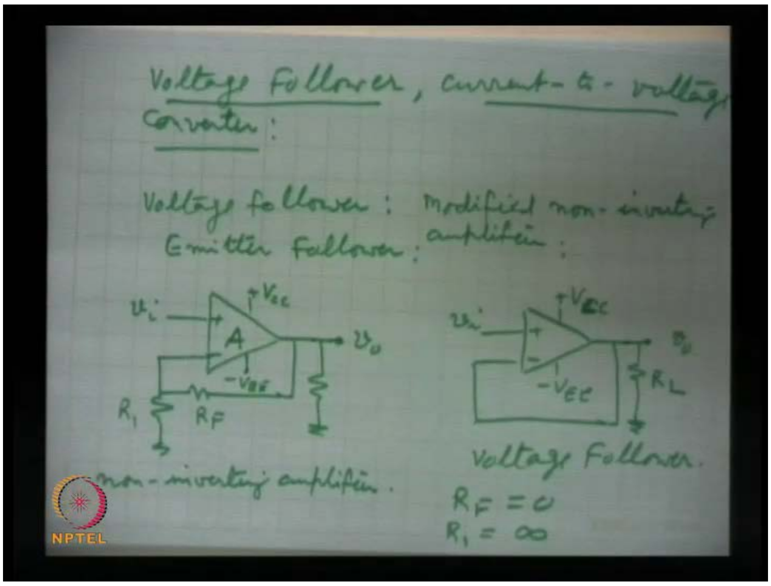

So, let us take one or two cases. The case of a voltage follower for example, voltage follower, this is one and another one which we can study, is current to voltage converter. These are both these amplifiers; voltage follower, and current to voltage convertor. Both these amplifiers have a good number of applications and they are used. So, let us see how the inverting and non inverting amplifiers, with little modification can give these functions, which find wide acceptability in systems. Let us first take voltage follower; voltage follower is synonym to what we have done, in emitter follower, and discreet circuits with b j t, we had emitter follower.

Now with op amp the circuit is voltage follower, and this is you remember this is the modification of a non inverting, modified non inverting amplifier. So, the basic amplifier was this. This is R 1, R F, v i, v o and this is the batteries, the d c sources, and the open loop gain is A. This is a non inverting amplifier, and this is modified to this form, and how this modification comes I will just talk, v i and here this is voltage follower, and how it has been obtained. Here we have made R F equal to zero in the basic non inverting amplifier. This R F has been made zero, so it is just a connector here. And R 1 is taken as infinitely large, very high value, so not there. A gap is infinite a resistance, so R 1 has been taken infinite, and R F has been taken zero. The circuit is reduced to this.

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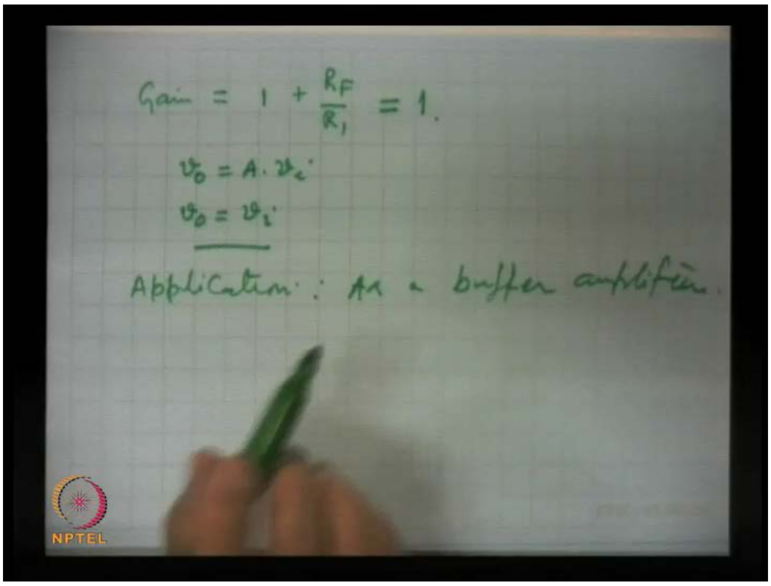

And the gain of the non inverting amplifier is 1 plus R F by R 1, when R F is a zero then this is reduced to one. When gain is one, and then v out is gain into v in. And since this gain is one, v out is equal to v i. This is what in emitter follower, why from where the name comes in emitter follower. The output voltage follows the ammeter. Here we are seeing that this output which will appear here, this will be of exactly equal magnitude as input, and the face will be in face; that means face is also same, so that is why the name voltage follower. Now you may question that if the same voltage appears and same a face appears, what is the function of a voltage follower.

The application of voltage followers is the same as for emitter follower; that is as a buffer amplifier. The input impedance is very high, output impedance is very low. So, this can be used to for matching purposes, matching impedance. So, the application is as a buffer amplifier. But it is preferred over emitter follower for two reasons that the input impedance is much higher in this case, in the case of voltage follower as compare to emitter follower. And here output is exactly equal to input. They are more equal than in the previous case. So, these are the two points, because of that a voltage follower, which is a modified non inverting amplifier, that can be realized and it is used as a buffer amplifier.

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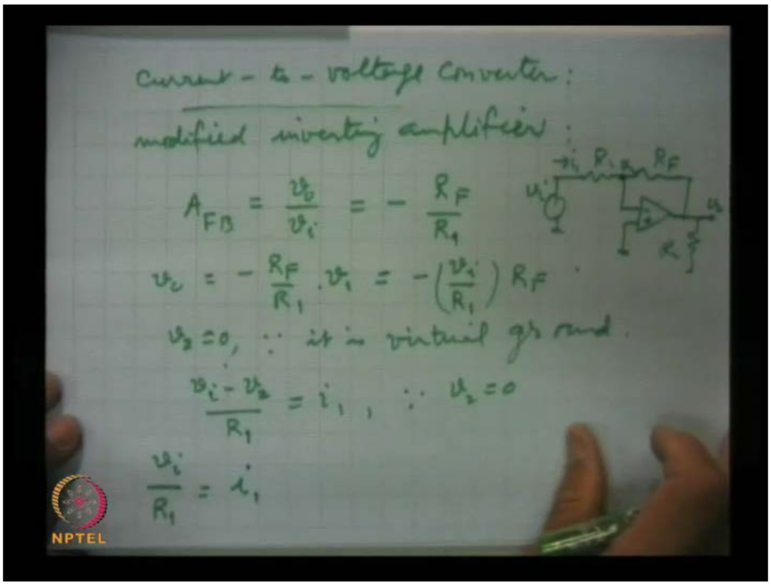

Another example let us take and that is of current to voltage convertor. This is a modification of the inverting amplifier; modified inverting amplifier, which can work as a current to voltage converter. There are many situations where such kind of application will be required. For example, in a photo sensitive devices photo divots. The currents are available which will be varying within ten stay or whatever it is. So, those currents have to be converted into voltage format for further processing. And so current to voltage convertor will be a requirement. Another other situations may be in a digital to analog convertors. There are several sensors which may give it different, which may give you the current, and we have to get the corresponding voltage. Now as I said it is a modified inverting amplifier.

For a inverting amplifier the gain with feedback your, which is the ratio of output v to input, this is equal to minus R F by R 1, this we have been saying on through that for inverting amplifier, gain is the ratio of the two resistance; the feedback resistance and the input resistance. And from here v out is simply minus R F, R 1 into v 1 or this is equal to minus, same v 1, R 1, v i R 1 into R F. Now v 2 is 0 here. This was the total amplifier, and now what we are seeing, this is the virtual ground v 2, v 2 was 0, because it was because it is virtual ground. This is v 2 is virtual ground, in that case the what will be this current, v i minus v 2 is divided by R 1 is i 1, but because this is zero. So, because v 2 is zero, as it is virtual ground. The v i R 1 this is equal to i 1, and this we can substitute, so this is the currents.

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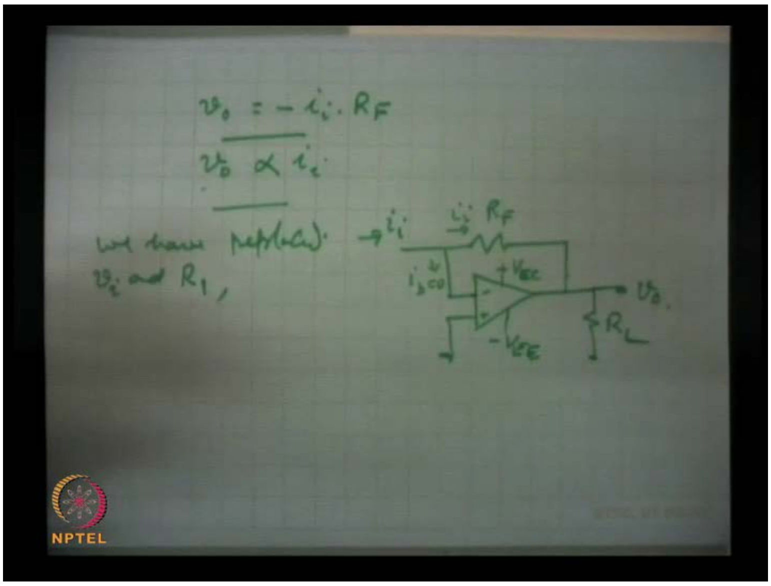

So, what we are getting. We are getting v out equal to minus i i into R F, that is output voltage is propositional to the current. This is what is expected out of current to voltage convertor, and what we have done, this is R F this is current i 1 and this is same as i i here, because this current i b is very close to zero. And we have replaced the voltage source v i and resistance R 1 by its current equivalent and we get this circuit, and here obviously, the output varies according to the input, and hence this is the current to voltage convertor. And here since the output as we have seen, output resistance of the inverting amplifier is very low. So, this current, this voltage is developed, because of this current variations; this will be independent of the load resistance. Because again the same thing, low and high impedances in parallel, the lower one dominates. So, because the input impedance is very low, this value of r l does not affect that and it works in a prefect manner. And applications I said photo detector that photo currents are converted into voltages and so on, so this is another application. Now moving further towards the application, now we go for amplifiers; that means operational amplifiers for mathematical operations.

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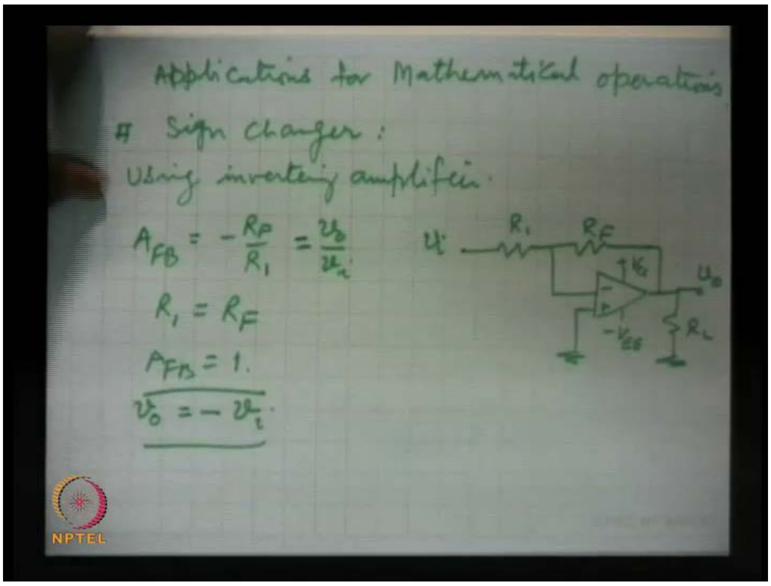

Applications for mathematical operations; we will take will good number of mathematical operations and the circuits for them, that how we can realize those operations, how those operations can be obtained electronically. Let us start with the simplest case, the sign changer; that means electronics understand the quantities in the form of voltage. So, if we can change the sign of voltage, then that is the sign changer, and this can be easily obtained by inverting amplifier, using inverting amplifier. This is inverting amplifier, in this the gain, you remember the gain is minus R F by R 1 and which is equal to v 0 output by input voltage. Now, if we choose here the two resistances is as of same magnitude. So, R 1 is equal to R F; then this term will be unit, and gain in this case will be one, and v zero will be minus v i. And these two will be of identical magnitude, because gain is one. So, the sign has been changed. If you want to change the sign, let us use a inverting amplifier with unit gain, then it can amputate sign changer.

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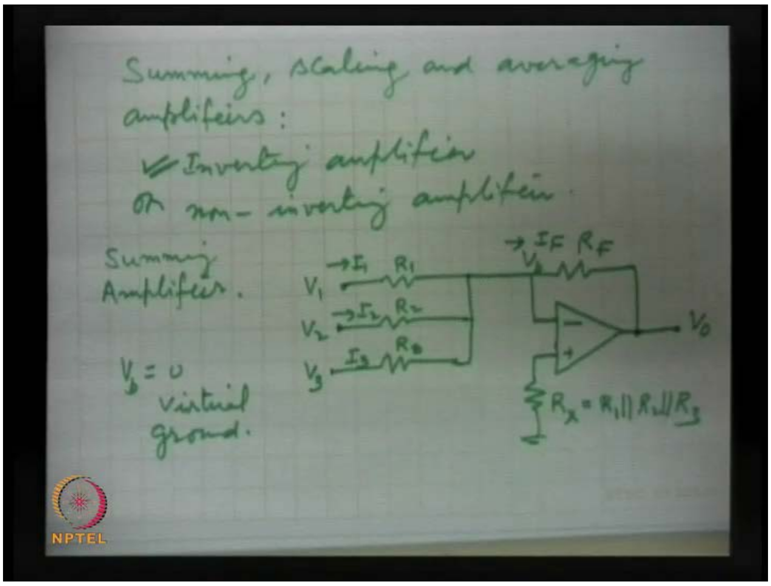

Now more important application, for applications of op amp, so we go for summing, scaling and averaging amplifiers. Summing amplifiers is the one, where there are more than one inputs, and the output will be the sum of all the inputs. If that we can achieve that will be is summing amplifier. And similarly is scaling and averaging amplifiers, we will take one by one. So, let us first take. Now, these amplifiers can be realized either in inverting mode and using inverting amplifier, or by using non inverting amplifier. To save time we will go for the case inverting amplifier. So, let us take first a summing amplifier using an inverting amplifier, what is the basic circuit. There will be more than one input two three four five six any number. So, for simplicity we take three inputs. This is v 1 v 2 v 3 and R F, and this is R 1 R 2 R 3 and this is the inverting input, and this is non inverting input. So, far we have being connecting it to ground, but now we introduce another concept.

Instead of directly connecting to ground, it has been shown that the, if we connect the resistance here R x, which is roughly equal to the parallel combination of all these resistance of R 1 R 2 R 3, it works batter. Here the zero errors for example, when there is no input signal the output should be zero, such conditions they are slightly battery achieved, and hence it is a common practice to use here, a resistance of appropriate value which is given by the parallel combination of these resistances, and that can be connected. So, this is the basic summing amplifier. And as I said we have taken for simplicity three inputs; voltages v one v two v three, output v zero and this is a inverting amplifier. Now, first I take the general expression, and then one by one we will go for summing amplifier, scaling amplifier, small modifications in the three now, but major thing is the same.

So, this voltage v b, remember v b zero virtual ground. Now, we will take this and we can write, that the currents here; this is I 1, this is I 2, this is I 3. Now, because this voltage is zero, what will be this current I 1, I 1 will be v 1 minus v zero by R 1. Similarly these currents, but this is zero. So, the current is actually v 1 R 1, this is equal to I 1, v 2, R 2 is I 2, so all these currents. And the sum up of the currents will be I F. We will continue that this simple circuit will give always, the output that will be the sum up input voltages, and if these voltages represent numbers two three five whatever, then the output will be the sum of these numbers. So, we will continue this analysis, that form the main analysis, we can arrive at scaling, averaging, summing amplifiers and that all operations, mathematical operations, then we will go for differentiator and integrator circuits and so on, we will continue .