Circuits for Analog System Design

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Lecture No. # 21
Output Resistance Calculations for op-amp

In the previous lecture, we were discussing about input resistance of the op-amp and we had shown how to compute the input resistance. And also, we had discussed what are the errors associated with the input resistance and so on, and we have also given an example with respect to PH measurement.

So, in this class, we discuss about output resistance of the op-amp and the errors associated with the output resistance, and then how to tackle this output resistance issues in the op-amp. This output resistance is also an important issue, which is often ignored by most of the designers.

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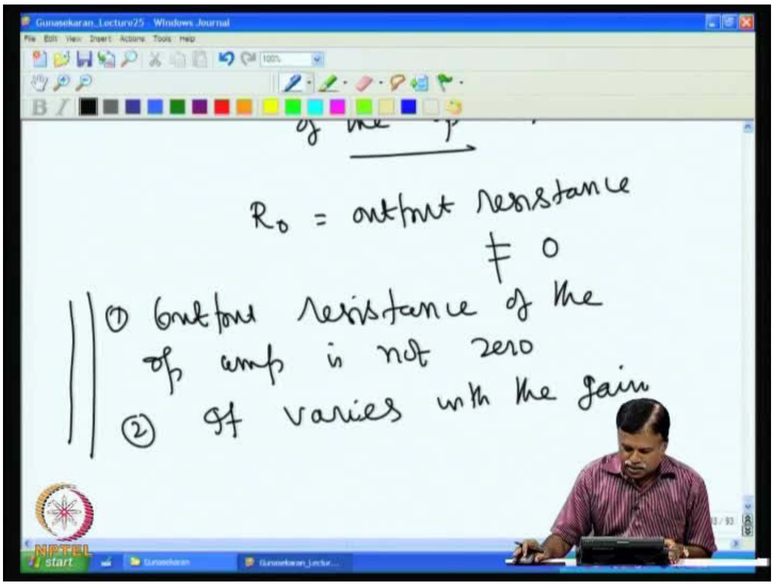

R_o = output resistance $\neq 0$

① Output resistance of the op amp is not zero

② It varies with the gain

So, today, we discuss about output resistance of the op-amp. The first thing is that conventionally they think that, you know, output resistance of the op-amp, which I called as R 0, output resistance of the op-amp, that conventionally it is taken as 0; but actually it is not 0; this is the thing that we want to sell, the that is, output resistance of the op-amp is not 0. And the second point is, it varies with the gain. It varies with the gain, because even for the given op-amp, the output resistance is not 0 and also it is not constant; it varies with the gain; and this must be understood actually clearly and the changes that is coming, because of that it is to be applied carefully.

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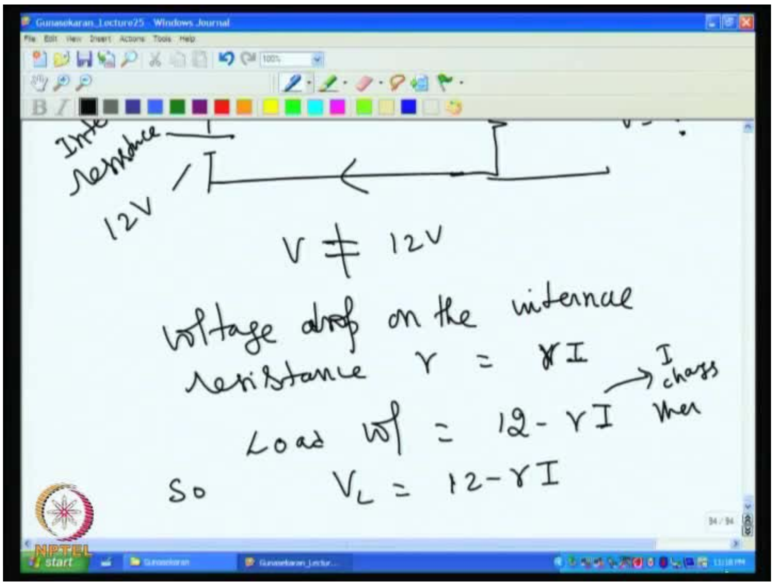

$V \neq 12V$

Voltage drop on the internal resistance $r = rI$

I changes then

Load vol $= 12 - rI$

So $V_L = 12 - rI$

So, let us see, what is the, what do you mean by output resistance first. Because, we want before getting into what is the output resistance op-amp, let us see what is the output resistance; because, if I have a source - for example, if I have a source, now, we have a resistance here; we call this is the internal resistance - for example, this is a battery; it has its own internal resistance.

Now, this battery is a source now, say, say 12 volt; so, battery is source, it has its internal resistance, and then I have a load here. Now, if I look at the voltage across this, that is the… What is the voltage across this? This voltage is actually not 12 volt, this V is not equal to 12 volt because, there is a current I in this, that current actually goes through this internal resistance r - I call this is r, small r; so, there is a voltage drop on the internal resistance. So, voltage drop on the internal resistance r - r is equal to r into I; because, I is the I is the current that is flowing so, if I take I is the current, then the internal voltage drop is V r into r into I. So, the output load voltage is load voltage; load voltage is 12 volt minus r into I; so, the output voltage actually changes with the load, and that depends upon what is in the internal resistance of the internal resistance r of the battery.

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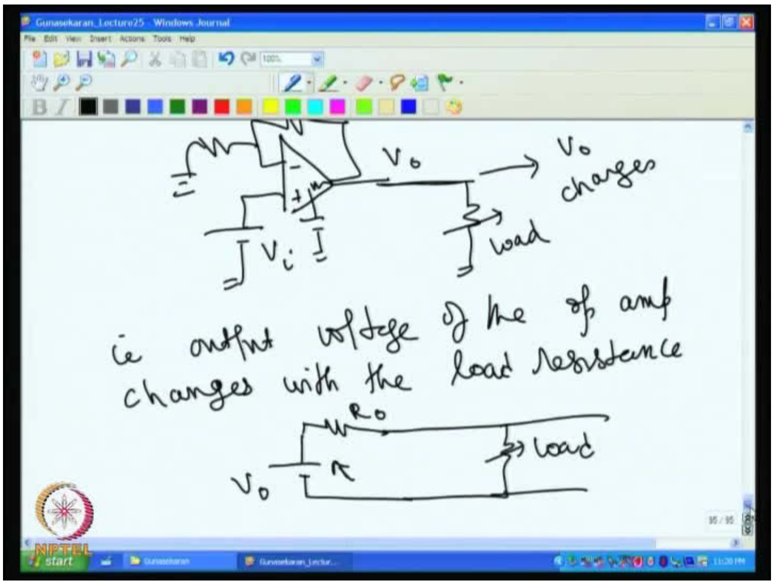

ie output voltage of the op amp changes with the load resistance

So, output… Because, when I changes, when I changes, then load voltage, that is, we called V load is equal to 12 minus r into I; then, if the current, the load voltage changes; so, with current, with load current, output volt, load voltage changes. This case, we had taken a battery and r is taken as an internal resistance. Now, this is true for any source, because, if not only for the battery, for example, if I take operational amplifier, then we have, say, some input voltage, and then some… I have given some input voltage here, then I get the output voltage here V I, V 0; and then, the output voltage - if I change the load here, I change the load here, this output voltage changes, V 0 changes; that is, output voltage output voltage of the op-amp changes with the load resistance.

Now, the this is because we have to draw the equivalent circuit as this, that is, we have op-amp is a voltage source that I have put this here like this, this is the voltage source; that voltage source has its own internal resistance, and that is the internal resistance there and that is the load; this is the load; this is the load and this is the equivalent internal resistance here R 0; this the output voltage that is supposed to be present at the output; this is the V 0; and this is the actual voltage that is supposed to come across their load.

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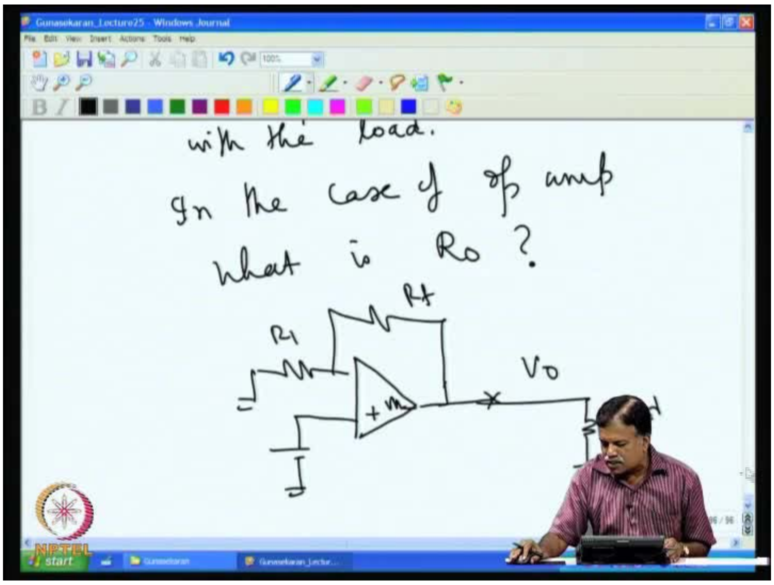

with the load.

In the case of op amp what is Ro ?

So, similar to the discussion that we had earlier, that in the case of battery, we had an internal resistance R naught; here also, the op-amp also has shown internal resistance, and then when you change the load, then voltage across this will change depending upon the internal resistance that it is having. So, this is true for any voltage source; for any voltage source, there is a finite internal resistance so, output voltage will change with the load.

The same thing happens in the op-amp, the question is - how much is the change? So, for in the case of op-amp, in the case of op-amp, what is R naught (internal resistance)? That is the question actually, and then - why it should change with load, and also it changes with gain? What is R 0? So, we look it this, we can see this carefully in the following manner. What we can do is, we take a operational amplifier, then I apply some input voltage; assume I, give some gain g and assume it has as known internal resistance.

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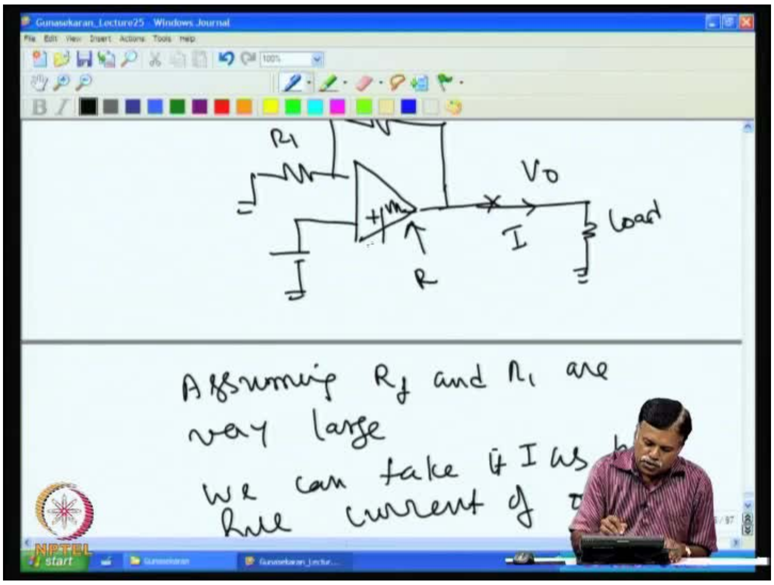

Assuming R_f and R_1 are very large

We can take it I as the current of

Connect this, then, that is the output voltage. Assume that I have a load here - this is a load; assume this resistance here - R f R 1 are very high, that is, there is no essentially, not much current is flowing; negligible current is flowing through R f an R 1. Assuming R f and R 1, R 1 is large, very large. We can assume we can assume R large, we can take it as, take I as the actual current, I as the full current of op-amp. So, we assume that I as the full current of the operational amplifier. Now, if you look at the operational amplifier, what is the actual resistance involved inside this R? There is a… Because, it is acting as a source and has it is own resistance

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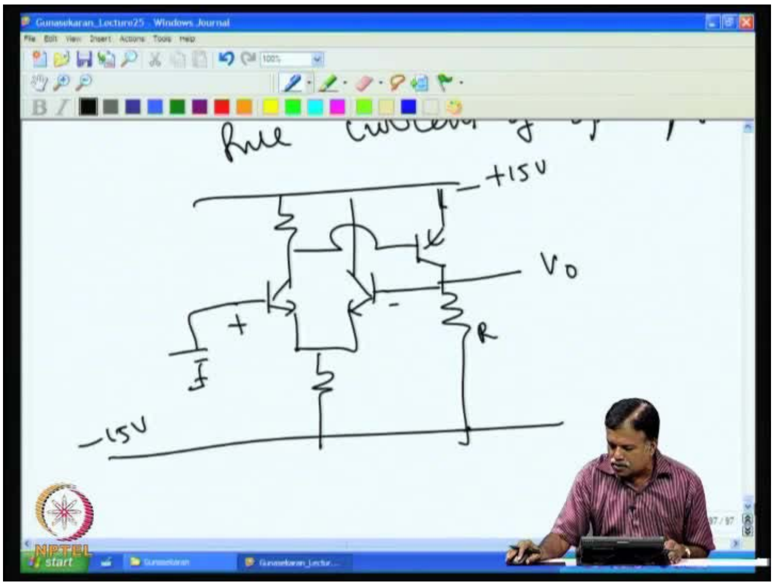

This actually, if we look at our earlier op-amp circuit that you know, we have this; for example: in this case, our classical op-amp circuit, if we take; this is V 0. Now, for example, this resistance will be the output resistance of the op-amp, because we give here plus 15 and minus 15 volt, and we have, of course, assume that I give you some input voltage here; then the output the in this case, this resistance R, the resistance resistance R, the resistance R is acting as a internal resistance. But the output volt, if I load this one, I load this - this is the load - the output load … In this case, R acting as an internal resistance, but the effective output resistance is not R.

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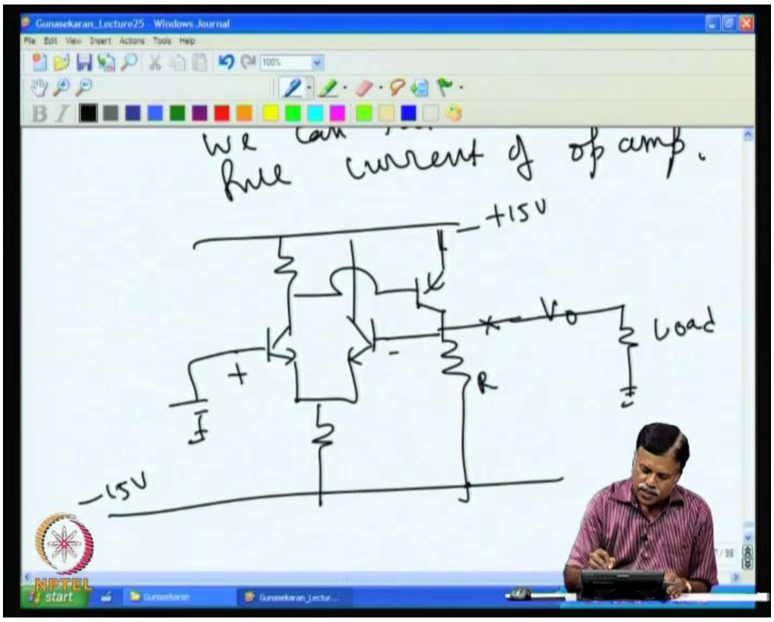

This is because, suppose, if I load this; if this voltage changes, then effectively, for example, if I load this, then if this voltage decreases, then this voltage also will decrease, this also will decrease, and that then this also, this voltage also will decrease. Then, since this is this decreased, and so, this, this current will increase. So, if this decreases and this decreases, it will increase this current, and that will increase the output voltage. Because of the feedback, op-amp compensates most of the voltage loss that is taking place because of the current flowing in the internal resistance R.

So, the effect… So, the effective output resistance is not really R; it is much smaller than the R; this because you have a current I flowing here, then we expect R into i is the voltage drop, but then, that reduction in voltage that, you know, the current flowing through this, reduces voltage here, and that reduces voltage at this point, and that makes more current flow here, and more voltage appears here to compensate.

So, most of the loss that is taking place of the internal resistance op-amp is compensated because of the feedback action; because of the closed feedback action, most of the loss is compensated; because of the closed loop feedback, most of the voltage that is loss, is compensated; but not fully, but most of the voltage that we have loss, is put back, is put back because of the feedback action. This is because of the closed loop feedback action; that is the reason that effective resistance is not R, it is much smaller than R. So, the effective output resistance, the effective output resistance is much smaller than R; this is because of the closed loop feedback.

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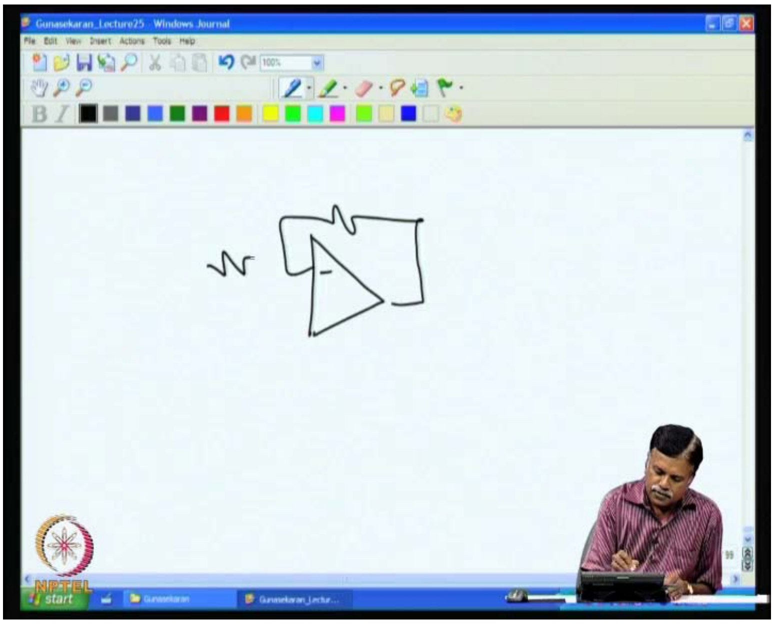

So, the same thing happens in the case of operational amplifier also. So, if I have the circuit here, then if I give the input voltage and if I put the load here, then if I change the load here, I change the load, then current flowing through this changes I, and then the current flowing through this also I so, voltage across this the voltage drop - voltage drop across this resistance also changes - voltage drop changes. If the voltage across this changes, then we expect output voltage to change here; then, when the output voltage changes, that change is reflect at here and that corrects it back; that basically, it increases this voltage. For example, if I increase the current I, then the voltage decreases here, that decreases voltage here, and that increases this voltage, such that, this voltage is put back to the original value, so that the loss in the internal resistance is partly compensated. So, effectively, you see very small change in the output voltage due to the current change; this is because of the feedback. So, effectively, we say that the effective output voltage change is, the effective output voltage change is, much smaller.

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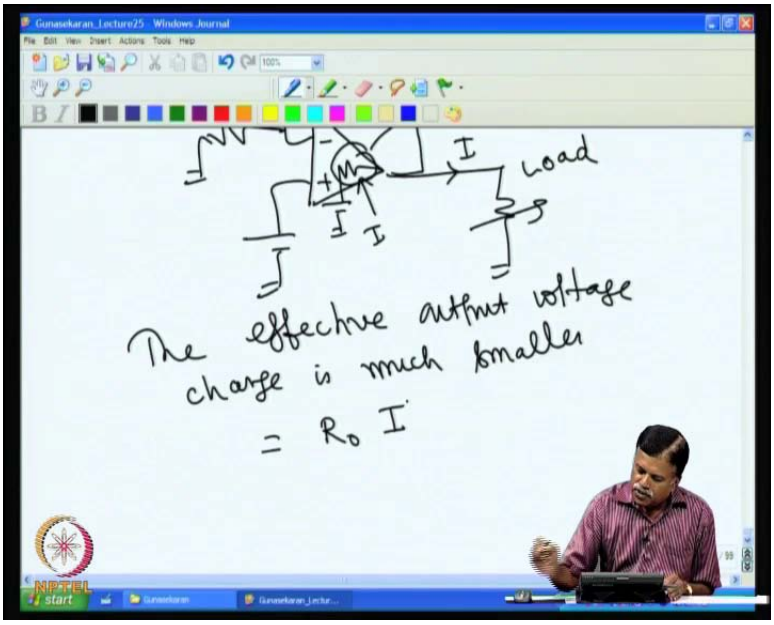

The effective output voltage change is much smaller

$= R_0 I$

This, we will represent with the new internal resistance - the effective internal resistance. So, and then, we call these effective output voltage changes, much smaller, that is equal to R 0 into I, where we call R 0 is the effective internal resistance or simply we call output resistance of the op-amp; where R 0 is effective output resistance of the op-amp, where R 0 is much smaller than R. For example, in a typical op-amp, in a typical op-amp circuit, in a typical op-amp circuit, R actually equal to around 100 ohms, but R 0 is few milliohms.

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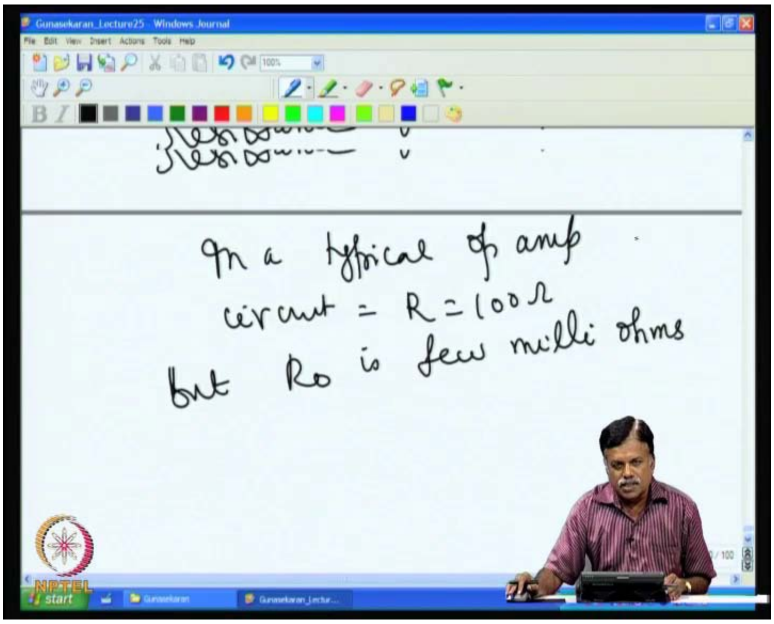

In a typical op amp circuit = R = 100 Ω

but Ro is few milli ohms

So, this computation is not difficult; that, we can really do that, assuming that, you know, the current I is the output current; then if I is the output current, then I can find out what is the voltage drop here - that will be R into I; but then, we know that this voltage is not, the change here is not R into I, because this change, whatever, if that much change occurs, then that will change this voltage, and immediately this will be increase, and again this will try to come back to the original value.

But then, we know that without load, this voltage is less; with load, this voltage have to increase, because, suppose, if I reduce the resistance, the current will increase; that increase in current, actually, increases the voltage here; that that will actually reduce the voltage here; then that will reduce the voltage and that will increase this voltage. So, eventually, this voltage will be increased to get back this; but then, this increase takes place, because there is a decrease in voltage here and there is a decrease in voltage here. So, eventually, voltage at this point, you know, if I look at the voltage at this point, with and without this load; then you will find with load - the voltage at this point, say, I call it is in non-inverting terminal the inverting terminal so, at inverting terminal the voltage have to decrease with load.

So, in the typical op-amp, it is around 100 ohms, for example - if I have above 10 milliampere current flowing here through this, then 100 ohm into 10 mill ampere that will give you about 1 volt drop across this; that means, if it is originally 10 volt, it will drop to 9 volt, then this voltage will decrease and that will make this voltage to go up to close to 11, and then, this you will get back to 10 that is what in real life happens. So, in real life, when load resistance is decreased, when load resistance is decreased, the voltage at the inverting terminal decreases, inverting terminal decreases, so that output voltage is put back.

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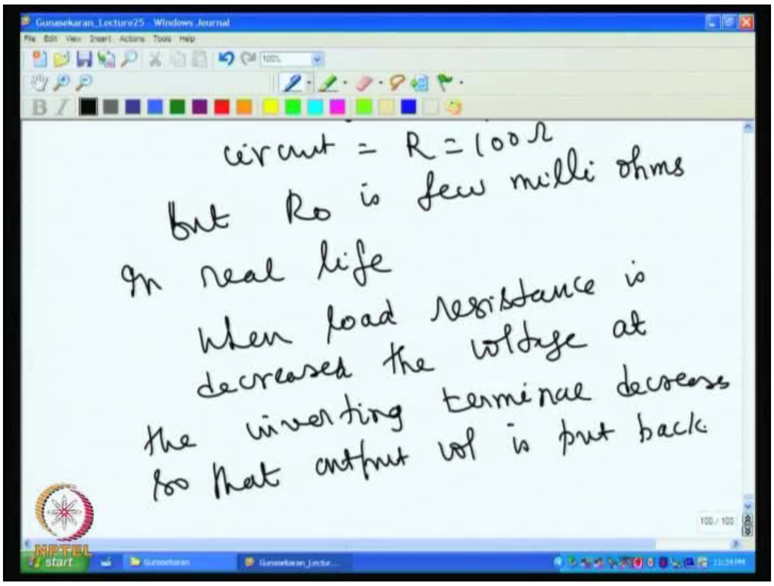

circuit = R = 100 Ω
but R_o is few milli ohms
In real life
when load resistance is
decreased the voltage at
the inverting terminal decreases
so that output vol is put back

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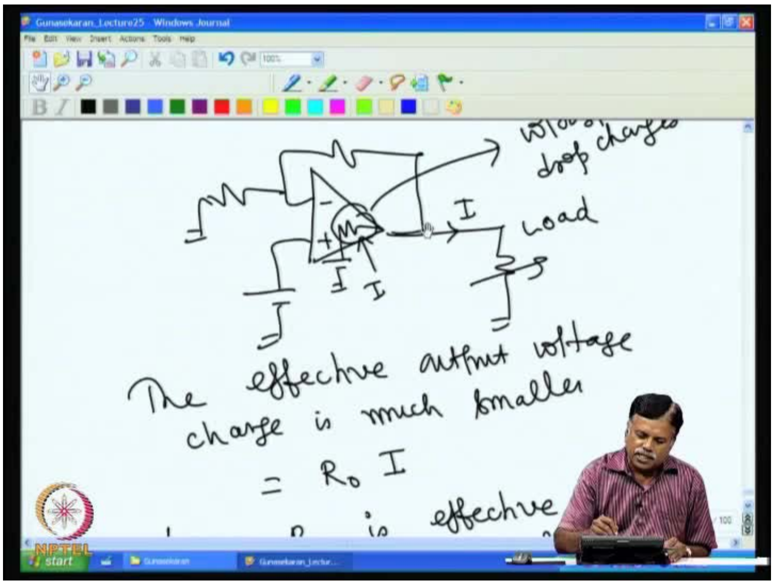

The effective output voltage
change is much smaller
= R_o I
is effective

So, that means, assume that the voltage change at put back; but there will be some voltage, but output voltage will not be equal to the original value, so, but output voltage will not be equal to original value, because output voltage - if the voltage at inverting terminal have to change, then output voltage also has to change, because output voltage change only, changes the voltage at the inverting terminal.

So, when you load the op-amp, this voltage has to change, and that also have to change, and this voltage has to increase so, this is what happens; but some small change the in output is expected; so, if we can write the equation for this, then we can write the, you can quantify - what is the change that is expected?

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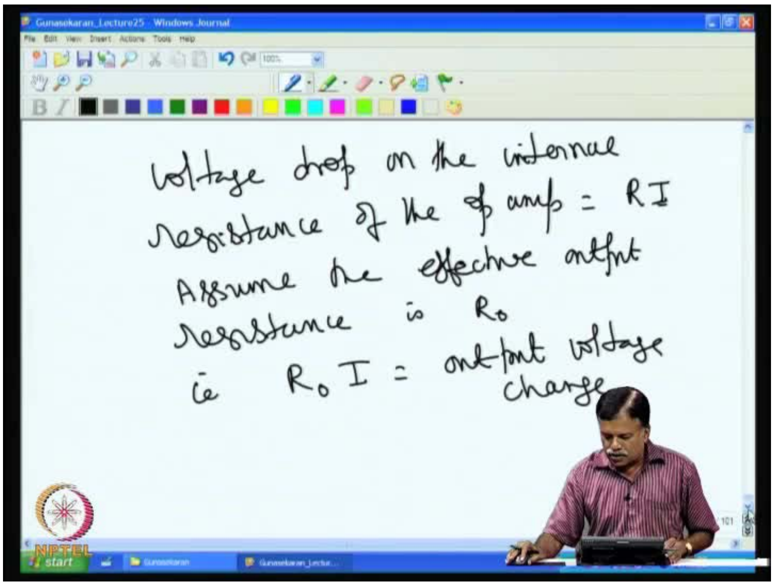

Voltage drop on the internal resistance of the op amp = R I

Assume the effective output resistance is R_0

ie $R_0 I$ = output voltage change

And then, we can also write down - what is the expected output voltage change? So, we assume that, you know, current is I and actual resistance of the op-amp is R so, voltage drop on the internal resistance of the op-amp, op-amp is equal to R into I; this is because, the current has to go through the internal resistance. Assume, assume, the effective output resistance is R 0; this is, after compensation, the effective output resistance R 0, that is, R 0 into I is the output voltage change with feedback - with everything, that if I load with current I, then output of the op-amp changes by this much amount, then I take that R 0 as a output resistance. Equal to output voltage change… Because, that is how the internal resistance defined, that is, the output voltage change must be equal to R 0 into I; so, R 0 is the effective output resistance, I is the load current. So, effective output resistance is R 0 so, output voltage change is I so, we now got the output voltage change which is R 0 into I; if the output voltage changes, then what is voltage change at the inverting terminal of the op-amp?

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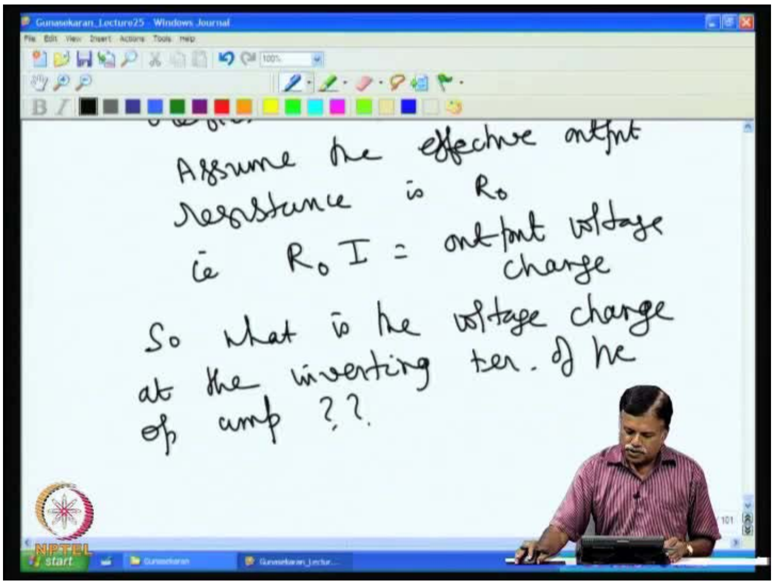

Assume the effective output resistance is R_o

ie $R_o I$ = output voltage change

So what is the voltage change at the inverting ter. of the op amp ??

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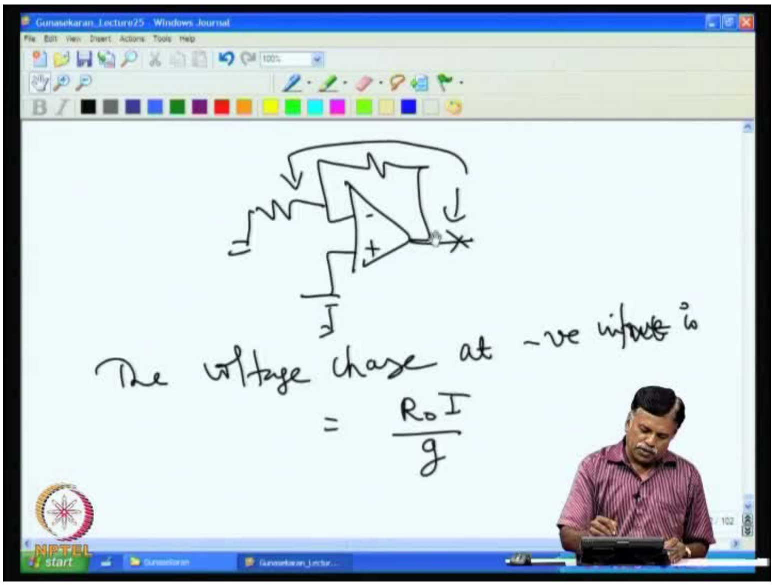

The voltage change at -ve input is

$$= \frac{R_o I}{g}$$

So, what is the voltage change at the inverting terminal of the op-amp? That actually, that section is divided by gain, because, whatever voltage change that is happening at the output of the op-amp, and that should be reflected to the inverting terminal; so, the we have the gain resistance here. So, whatever changes that is taking place here, that has to make a change here by the gain times so, if the voltage change at negative input is R 0 I divided by g; g is the closed loop gain because, the if you find that you know that this voltage divided by the ratio of the these 2 resistors, because output voltage divided by the ratio of the these resistance and which is nothing but the gain.

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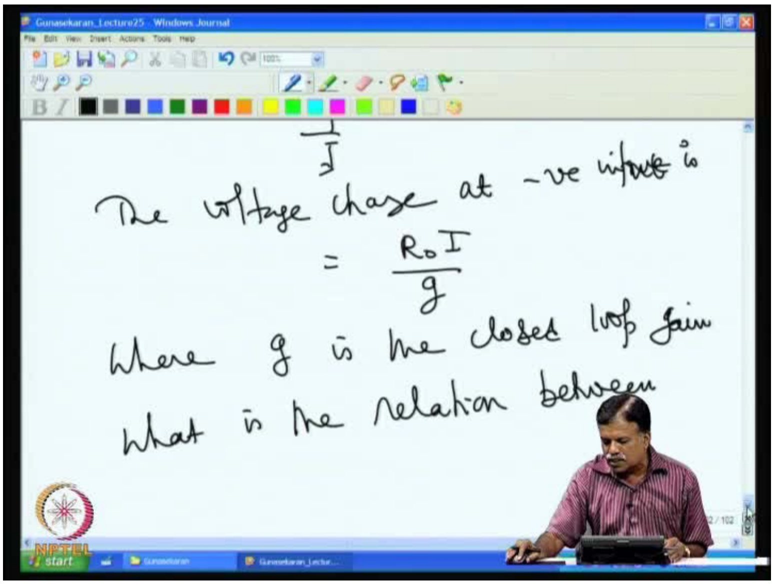

$\overline{\;\;}$
I

The voltage change at -ve input is

$$= \frac{R_o I}{g}$$

Where g is the closed loop gain

What is the relation between

So, the output, the voltage change at minus terminal is R 0 I by g so, where g is the closed loop gain. Now, so, the we got a voltage change at the inverting terminal; if inverting terminal voltage change is this much - R 0 I by g – then, what is the change at the output? Whether we can find if the minus terminal change occurs by R 0 I by g, then output w have to change by a d; because, in any in an op-amp, the difference between these two voltages amplified by the open loop gain is the output voltage. So, if this point changes by some x, then output will change by x into a d, so, where g is the open loop gain.

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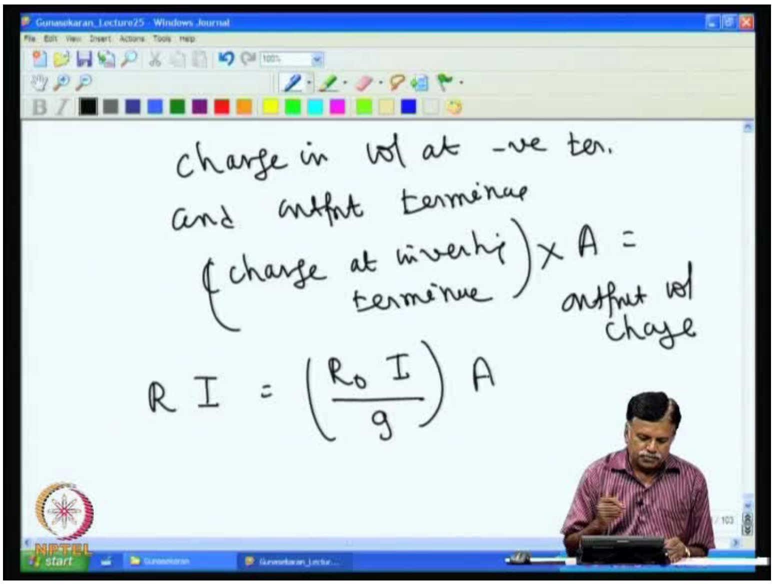

change in vol at -ve ter.
and output terminal

(change at inverting terminal) × A = output vol change

$$R\,I = \left(\frac{R_0\,I}{g}\right) A$$

Now, next question is - what is the relation between change at the minus terminal and change at the output? Between change in voltage at minus negative terminal and at output terminal, that is actually, change at inverting terminal into A is output voltage change, because the change here, that has to happen at the output so, I can write like this. So, if I take R as output, then R into I is the change that is taking place at the… We have written down already this one. There is the output voltage change that is actually equal to R 0 into I divided by g, that is the input voltage at the negative terminal change into A, because, A is the open loop gain and this term this term gives - what is the change at the minus terminal? And that, multiply by the A gives you the output voltage change actually. So, that is actual voltage drop across the op-amp’s internal resistance.

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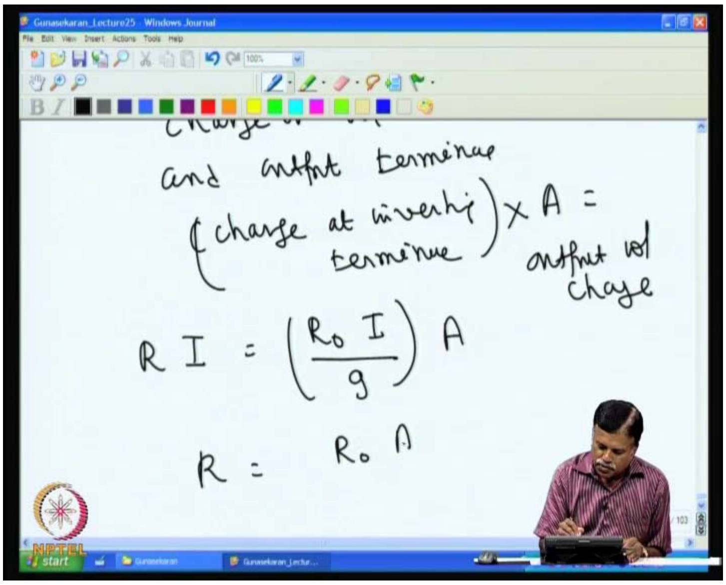

and output terminal

(change at inverting terminal) × A = output vol change

$$R\,I = \left(\frac{R_0\,I}{g}\right) A$$

$$R = R_0\,A$$

Now, if we remove I, then you will get that R, actually coming as R 0 A by g, where R 0 is coming as a output resistance; so, if I can, write that one, change this one, that comes R into g by A; so, output resistance is related by because related by closed loop gain and open loop gain. So, output resistance, output resistance output resistance, R naught R into g by A R, or, for example, for most of the op-amp, R is equal to 100 ohms. So, what is R naught comes, for example - if it is 100 ohms, and if we have a gain of 100 g 100 and open loop gain of 20000 - this is open loop gain, then this is closed loop gain, and this is the internal resistance of the op-amp. So, that actually, if you compute this, it comes; so, R naught, actually, here comes; you have a 10 power 4 divided by 2 into 10 power 4 that comes 0.5 ohms. So, that is the output resistance op-amp - it is not 0.

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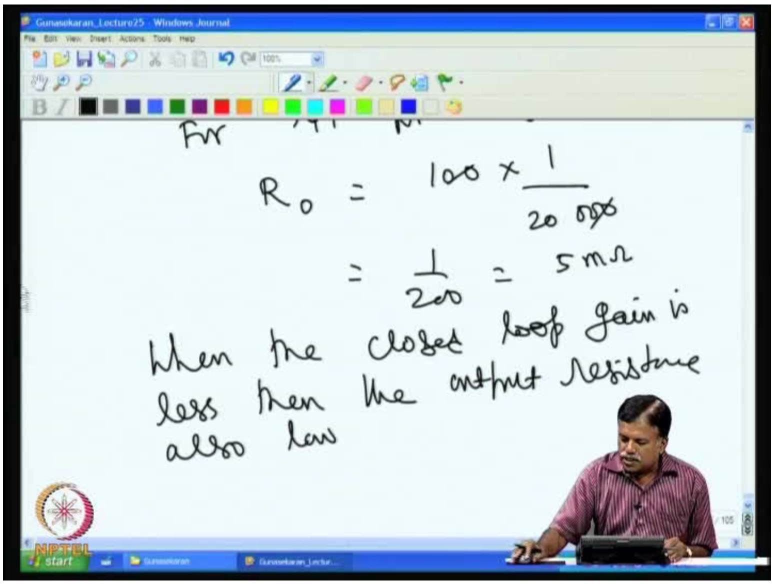

For

$$R_o = 100 \times \frac{1}{20\,000}$$

$$= \frac{1}{200} = 5\,m\Omega$$

When the closed loop gain is less then the output resistance also low

Now, this is actually, for the 741, we have taken typical values; because for 741, the typical value, this is around 100 ohms; and then, we are given 100 gain and open loop gain is around at 20000; for same 741, for example - if I give a unity gain for voltage follower, for voltage follower for 741 for voltage follower, R naught actually is becoming 100 into 1 divided by 20000, which actually makes 1 by 200, and that is equal to 5 milliohms.

So, when the gain is when the closed loop gain is less, then output impedance also comes down; when the closed loop gain is low, when the when the closed loop gain is less, then the output resistance also low; that is why voltage follower gives the lowest resistance. So, voltage follower voltage follower voltage follower gives lowest output resistance. Similarly, we had seen earlier, if the gain is less then input resistance also less, that is, the closed loop gain is less, then the input resistance also very high.

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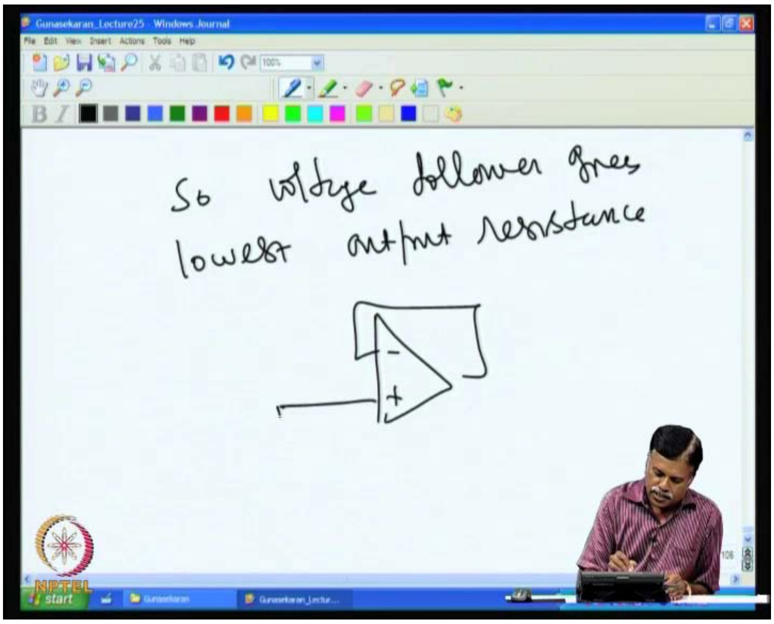

So voltage follower gives lowest output resistance

So, if I have voltage follower, then this has so lowest output resistance and highest input resistance; so this is must voltage follower voltage follower voltage follower gives highest input resistance highest input resistance, then second one is the voltage follower, gives you the lowest output resistance. Because, this, one has to realize, that is, why very often at the input stage, we use voltage follower to get highest input resistance, and then, also, it gives you the lowest output resistance; and, if we increase the gain, then the output resistance will go up, for example - if I take 741 and I find try to find out what is the R naught, for say, 1000 gain, then if the is the 100 ohms is the internal resistance, if I go for 1000 gain and with 20000 closed loop gain, you will have 5 ohm as a output resistance; for 1000 gain, for g is equal to 1000 then, output resistance goes up to 5 ohms - this is very large actually.

So, one should not think that always the output resistance of op-amp goes to 0 and it is constant; it can be very high, if you try to get more gain; and then, what is the kind of error that this output resistance gives? Because, we had seen that output resistance op-amp is not 0 and it varies with gain. If you want highest gain, then reduce the closed loop gain.

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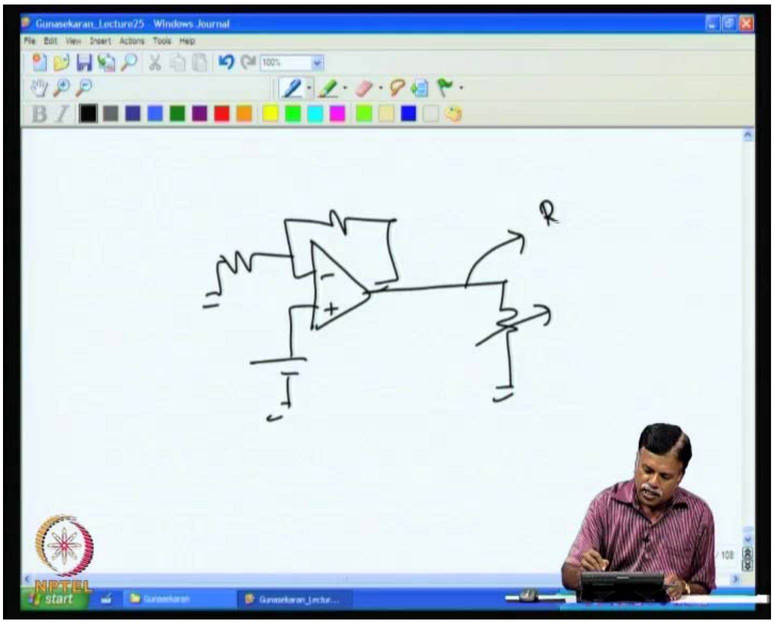

Now, let us see, what is the error in the, what is the problem because of this output resistance. Because, we remember, that if I have op-amp circuit, then if I am loading, it if I am loading it, we have the load, then if I change this, then I can this output voltage will be changing. How much it will be changing? That will be R 0 into delta I, that is, the change that one should look at this point. This is uncompensated error, that is, this is after compensation this is the change that has occurred.

So, we write that this is the change. This is that I realized - if this is change after compensation, after compensation after compensation. After compensation, this is the change that is expected in the op-amp terminal. So, one can find out what is the R 0 from the manufacturer data sheet because R 0 can be found out by the R value; the actual R value is given by the manufacturer in the data sheet in the data sheet. So, once that is known, then closed loop gain and open loop gain also have… Closed loop gain, you will know, and open loop gain also, we find from the data sheet; and then, one can find out the output resistance; and once output resistance R 0 is known, one can find out - the what is delta I; and then, the multiplication of that gives you the actual output voltage change.

Now, this error is to be taken into consideration in addition to other errors that we have discussed. Other errors what we have discussed is - what is the bias current error, then what is the input resistance error, what is the gain drift error? All those have to be considered in this case. Now, one more aspect is that, this current that is flowing here through the feedback resistance, also comes from the output. So, if I put this resistance… so, this also is load for the output only, so, feedback resistance… Because, we had original shorted, we assuming R f is large; in actual case, R f also acts as a load for the op-amp; in real use, in real life, in real case, R f also acts as a load.

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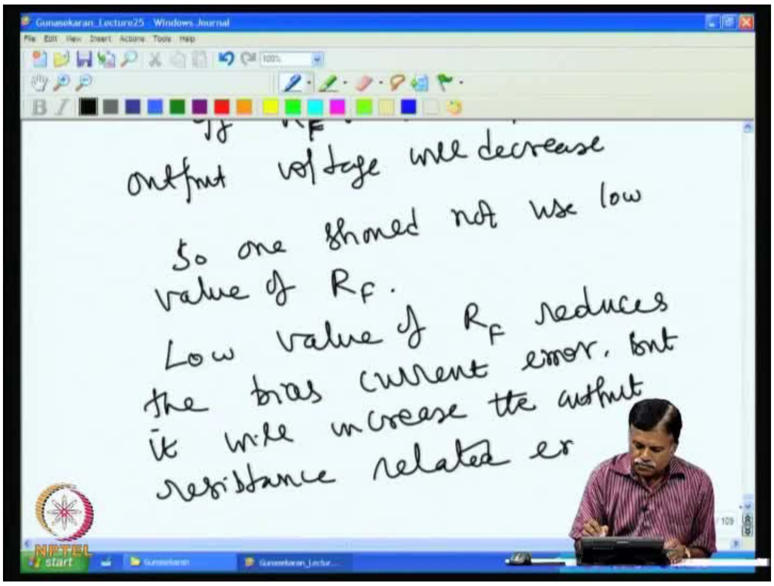

output voltage will decrease

So one should not use low value of R_F.

Low value of R_F reduces the bias current error, but it will increase the output resistance related er

So, if R F is small, then output resistance also, if R F is small, then output voltage will decrease, that is why we should not use small/ low value of R F; if we use low value of R F, then output resistance induced error will increase. So, for that is so, one should not use low value of value of R F; particularly, low value of R F is tempting, because, if I use a low value for R F, bias current error will be small. It should not be low value R F because, because, low value of… So, and it is a low value of R F; low value of R F reduces the bias current error, but it will increase the output resistance related error. Normally, one cannot take more than 10 milliampere current; even if you are put 2 low value of output resistance

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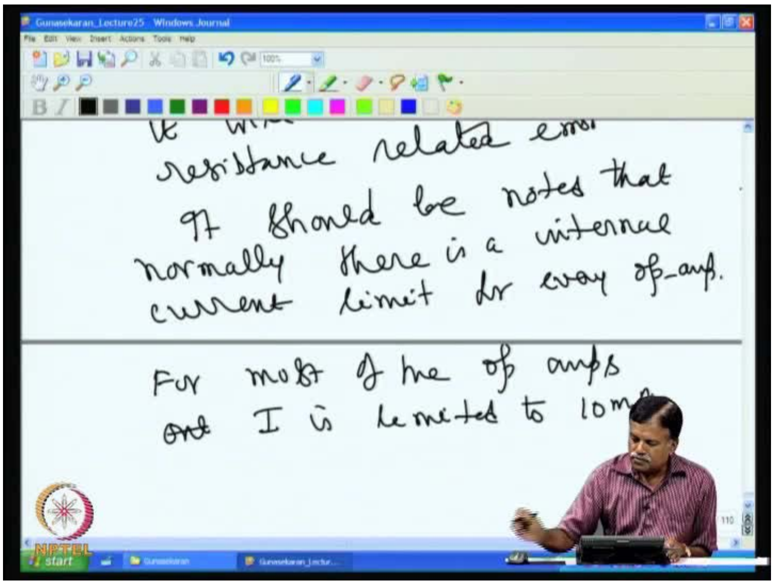

resistance related error

It should be noted that normally there is a internal current limit for every op-amp.

For most of the op amps out I is limited to 10m

So, normally, the output related error is somewhat related, somewhat less only compared to the bias current error, because one cannot take more than 10 milliampere current from the output of the op-amp, most of the op-amp. Some op-amps are capable of giving up to 20 milliampere, but nevertheless, you cannot take too much current from the output of the op-amp. It should be noted that output current normally, there is a internal current limit for every op-amp; for most of the op-amps, the output current is limited to 10 milliampere, most of the op-amps output I is limited to 10 milliamps.

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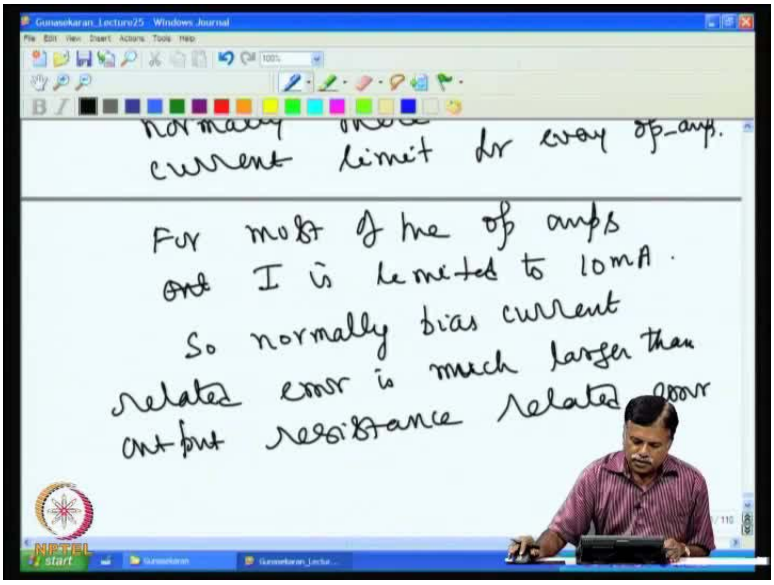

current limit for every op-amp.

For most of the op amps out I is limited to 10mA.

So normally bias current related error is much larger than output resistance related error

So, normally, the output related error is not very high compared to the bias current error; so, normally, bias current error bias current limited error is much more than the output current bias current error introduced error bias current related error much larger than output resistance related error. So, normally, we are not much worried about the output resistance error, but in the some cases, when the current drawn is much larger, then this error is a problem; for example - if I want load heavily at the output, then since current also limited so, normally, what we do is we will bias this, we will, we reduce the output current using the transistor

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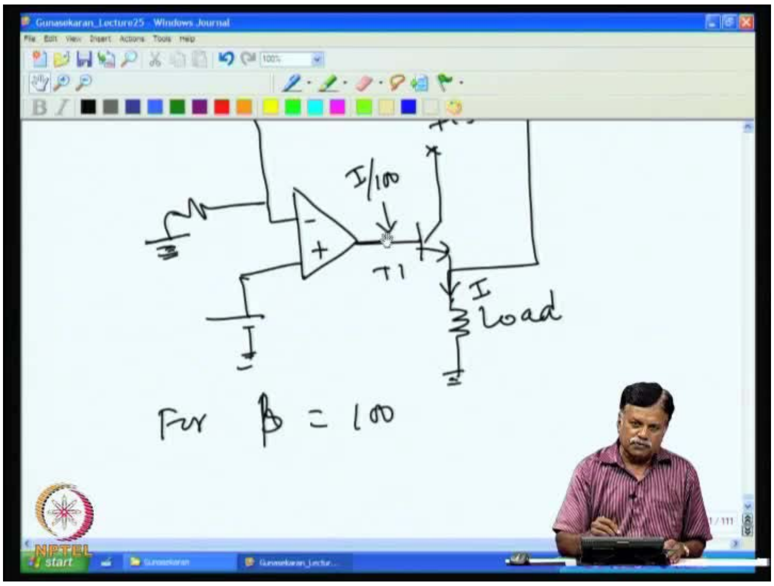

For example, if I need very high current, the normal practice is that you take op-amp and put the transistor, for example - I can have this arrangement, then return the emitter to this and give the input to this; so, you have the transistor t 1 and then your load can be now very high; this is load. For example - the HFE of transistor is 100, assume for HFE, for beta of the transistor is to be 100; if beta is 100, then we know that load current - this current I and this current output current of the op-amp related by beta so, I by 100; so for load current of I, then the output current of the op-amp is very small, 100 times lower.

So, now, the output voltage error - we have to compute only for this reduced current, not for this current. For example - if I have a 1 ampere current here and if HFE is 100, then you will have only 10 millampere current, which the operational amplifier can give. So, we have to compute the output error, current only for 10 milliampere; and remember, that we are taken a feedback from the output here; you should not take a feedback from this to this. For example - I should not connect in the following manner ,then you will not get the correct voltage.

Like plus 15, connect this, connect this and connect the input V input R F R 1; now, this is the if you are taking this output, then this R F should not - if the gain R F by R 1 - this resistance should not be connected here. So, this circuit is wrong; this connection is wrong; this is not acceptable. So, if you want to boost the current, the resistance of the R F must be terminated to this point, to the output; not to the output of the op-amp, that is, terminate this resistance to the output, not to the output here, but to the output. So, what is normally done is, you connect this one to here. This is okay, but this is not acceptable.

So, one has to… Because, once you connect this resistance here, that is, if I connect this here, the base emitter voltage change, you know, the anyway base current will very small only, because the loading effect is very small, because this base current is small, because the HFE of the transistor takes their most of the current, and most of the current is coming from here and the base current is small. Nevertheless, that base emitter voltage change which is the 0.6; that is not compensated by the closed loop, because this 0.6 voltage loss will be there if this is connected. So, base emitter voltage drop will be a loss - V BE. V BE is a loss and this also, V BE changes with temperature; V BE changes this is a loss and V BE changes with temperature; that is why one should not connect like this. So, if you want connect, then connect the R F directly to the output.

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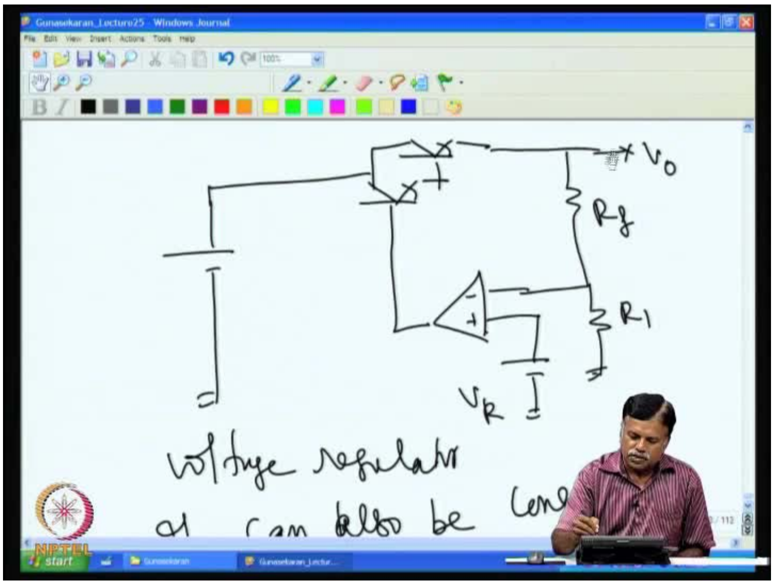

Now, this actually, we can see, even in the our voltage regulator circuit, which we have seen this type of output resistance reduction circuit only; because we can see, if we look at the voltage regulator circuit, we will get like this, that is, we have a unregulated voltage here, then we will connect the op-amp circuit; in fact, we put a Darlington, if we want very high current so, we connected this, I connect it to this here.

So, we have connected the output of that this; for example - I connect this here, this is a, we call this is a voltage regulator, this is V reference and we are discuss already this one. These are voltage regulator circuits; voltage regulator actually, it is not a voltage regulator; it can also be considered as, it can also be considered as, non-inverting amplifier, because you see, if I look at it, I do not see this voltage regulator; if I see as a non-inverting amplifier, what actually happens? We see V I will give we… Instead of calling V reference, we call this as the input voltage; and these two are the feedback resistances that I call as R f and R 1 - feedback resistances. So, this voltage, whatever you are giving, input voltage is multiplied by this R f by R 1 1 plus R f by R 1 is what at appears at the output.

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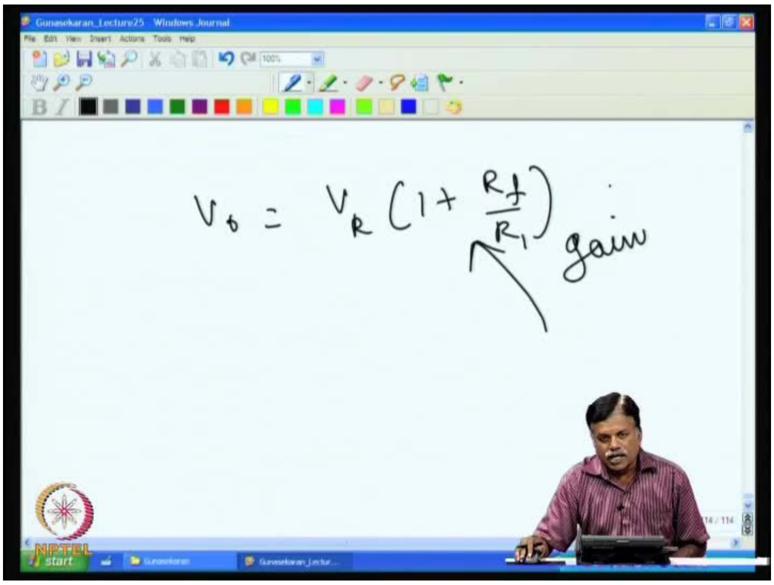

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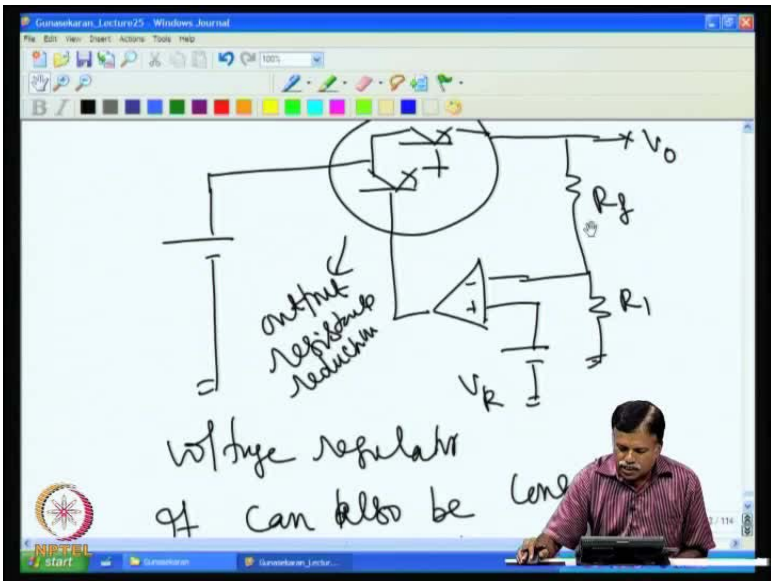

So, V output, I can write it as - V output is equal to V R into 1 plus R f by R 1 so, this is acting as a gain, and the reference is acting as input voltage. So, input, I can call, this is the voltage regulator, is nothing but an inverting amplifier with low output resistance, that is, the output resistance reduced by using the Darlington pair. So, here, Darlington pair acts as a output resistance reduction and also, to boost the current so, the op-amp cannot give too much current, you know, it cannot give more than 10 milliampere current. So, this multiplied by beta, multiplied by beta is what the output current comes.

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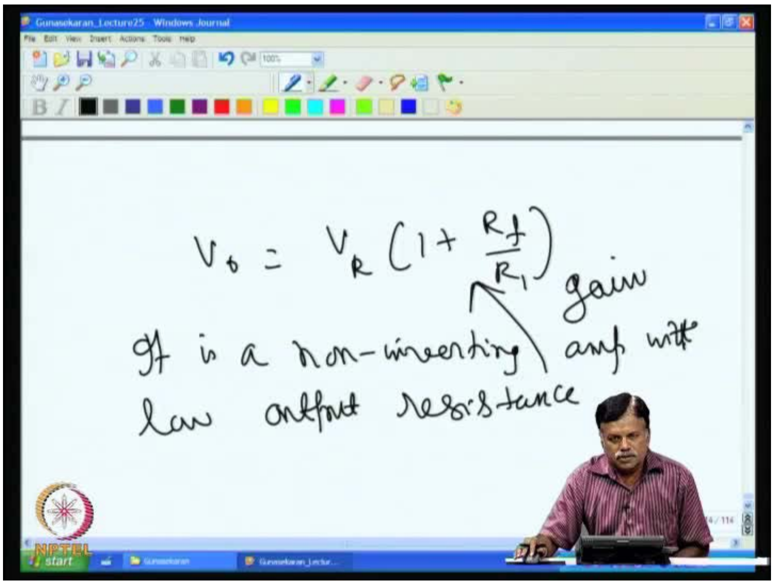

$V_o = V_R \left(1 + \frac{R_f}{R_1}\right)$

It is a non-inverting amp with low output resistance

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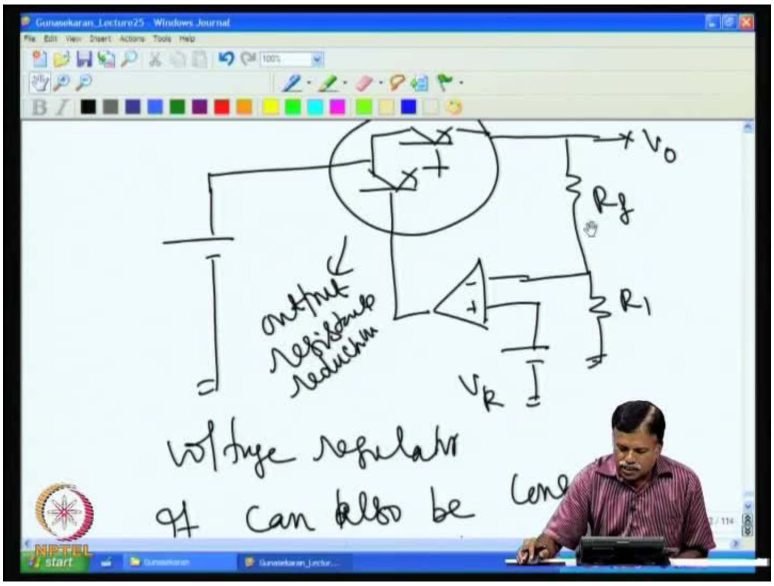

voltage regulator

It can also be con

So, I can say this is the inverting non-inverting amplifier with low output resistance. So, it is a non-inverting amplifier with low output resistance. Now, assume that you know - what is the output resistance of, the, this circuit? So, if I have here for example 10 milliampere current. Then, if I have 100 ohm resistance here, then one can expect 1 volt drop across this, or, I can say the output at the op-amp output - what is the output resistance? At the output of the op-amp, then we can write R 0 into I, that is, 10 milliampere is the expected change.

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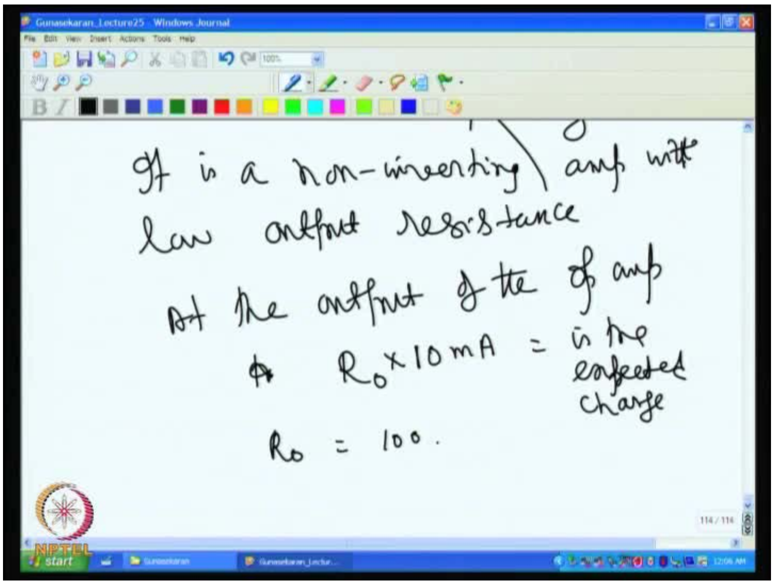

It is a non-inverting amp with low output resistance

At the output of the op amp

$R_0 \times 10$ mA = is the expected change

$R_o = 100$.

Now, for a typical case if I take - what is the R 0? R 0 actually, in this case, is a 100 ohms; and then, we have closed loop and open loop gain - if we calculate, for example, if I have… In this case, you know, if I take at this point, then I say that it is a open loop circuit, or, if I take this as my output, that is what we are doing, then this can be taken as suppose, if there is equal, then the gain is actually, closed loop gain is 1; so, in that case, 1 plus 1 2; so, the output resistance becomes 2 by 20000, that actually become 200 by 20000, which actually becomes 1 by 100 is 10 milliohm.

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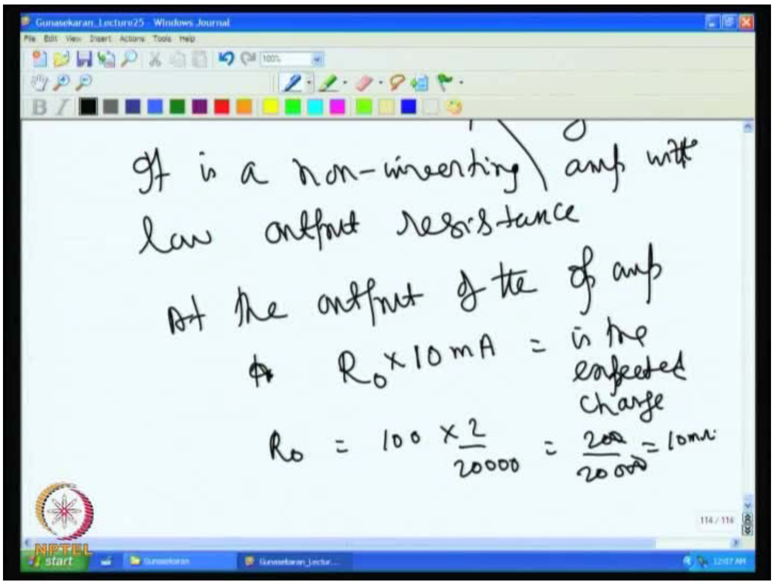

It is a non-inverting amp with
low output resistance

At the output of the op amp

$R_o \times 10\,mA$ = is the expected change

$R_o = 100 \times \frac{2}{20000} = \frac{200}{20000} = 10 m\Omega$

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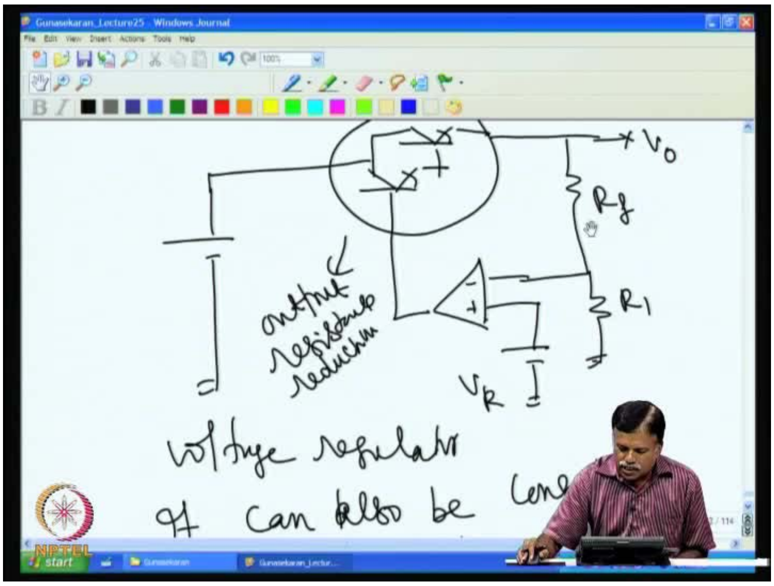

voltage regulator

It can also be con

So, output resistance will be 10 milliohms and then, at output of the op-amp, then we can expect 10 milli ohm into 10 milil ampere current, that is, 100 micro volt change expected, because of the output resistance itself. Of course, output voltage changes here are due to many other reasons; that is, when normally, when you make a voltage regulator instead of the battery, we will feed an unregulated voltage; then, this voltage itself drops with load current; then, the supply voltage also changes; then, the current flowing through this changes. All these contribute for output voltage regulation.

So, which we are not which we have already discussed earlier, which we need not repeat it here; so, the voltage regulator circuit, what you see is, a kind of circuit which actually is having a reduced output resistance circuit, is nothing, no need we called as a voltage regulator. It is only a question of how we look at the circuit and different angles. So, what is the other affects of output resistance? For example, sometimes, we will connect the circuit like this - for example, if I have an operational amplifier circuit.

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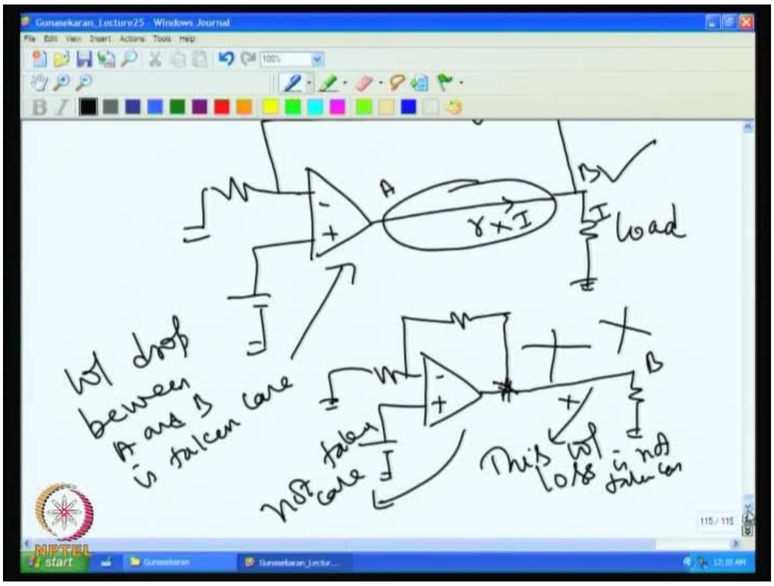

Now, I give the input; assume I have a load here, which is, assume it is quite low; I am not using any this thing, that is, any transistors to boost the current so, this is the load, then I put the resistance here - this one - in other resistance, I can do like this, I can connect it to this point, and I can also connect it to this. Other way of doing this would be here itself, I draw that, that is, I can connect this way; I can connect it, this is a I can have a load; I have this, then connect this at this point.

Now, compare these two circuits. If I take these two circuits, this is a good circuit, this is the practice to be followed; this should not be followed. The reason is, if you look at this, that this voltage drop, the current that is flowing here, you know, this as a resistance r and current I is flowing, and the load current is I, is very substantial; then, there is a voltage drop of R into I; this R into I also compensated by the closed loop action, the feedback action compensates this loss to extend R into I by AD into g.

So, that is not there in this case, for example - here, you have a voltage - this voltage loss, this voltage loss is not taken care. So, one has to use only this type of circuit in the actual usage so, the actually the I will call this A and B so, voltage loss between A and B is taken care; voltage drop between A and B is taken care in this circuit, it is not taken care in this circuit. not taken care So, the first circuit only to be used for this purpose.

We will close the, this discussion with this. We will see in next class, the consolidated application of all these errors and then we move on to the AC applications. Thank you.