Circuits For Analog System Design

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Lecture No. # 16

Error Budgeting for Constant Current Sources

Today's class, we will see how to make current, how to make a current transmitter which is much better than what we have discussed in the previous class. In the previous class, current transmitter, we had many issues like the ground potential; the one side goes to near to the ground potential and so on. So, let us relook at the earlier circuit, and then, see what are the disadvantages we had in that and how to overcome that, in this class.

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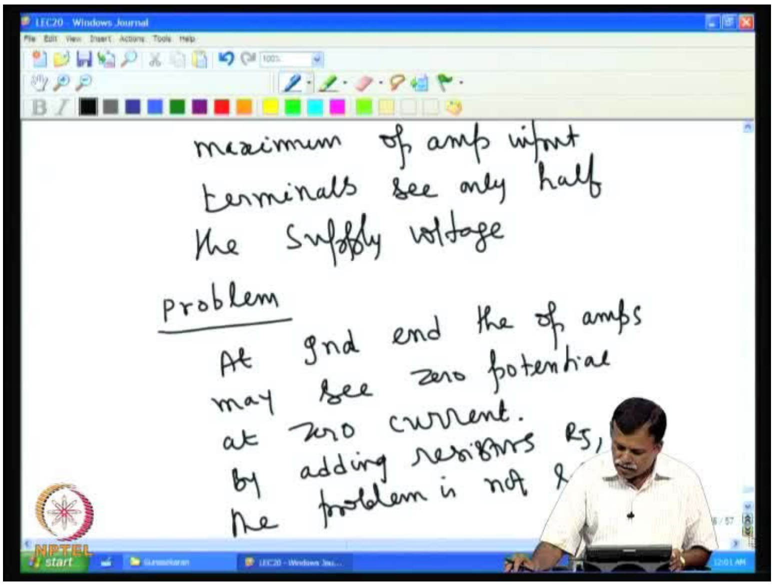

So, we had the resistance measuring circuit based on current transmitter. That was like this. So, we had operational amplifier, and then, we had the resistance is fixed up here. This is the sense resistance R, and then, we had the load resistance here.

We had the load resistance here, and then reference voltage was fit effectively with respect to this. For example, we can have example one convert into resistance then we can have voltage drop across this. Zener voltage can be fixed here and then this can act as a variable resistance. For example, if we want to make a current transmitter based on potential meter resistance variation, then this circuit is useful. This is actually current transmitter varying in the reference resistance is here, and the current I is actually given by this is V z that is the voltage across this is V z then V z by R is coming as a current. This is one of the circuits that we are discussed earlier, and then, from here, we went the ground referenced current transmitter, that is this type of circuit. Where in, what we are done is that we had shifted the resistance, reference resistance to the ground side. That is what we are done is we had shift at.

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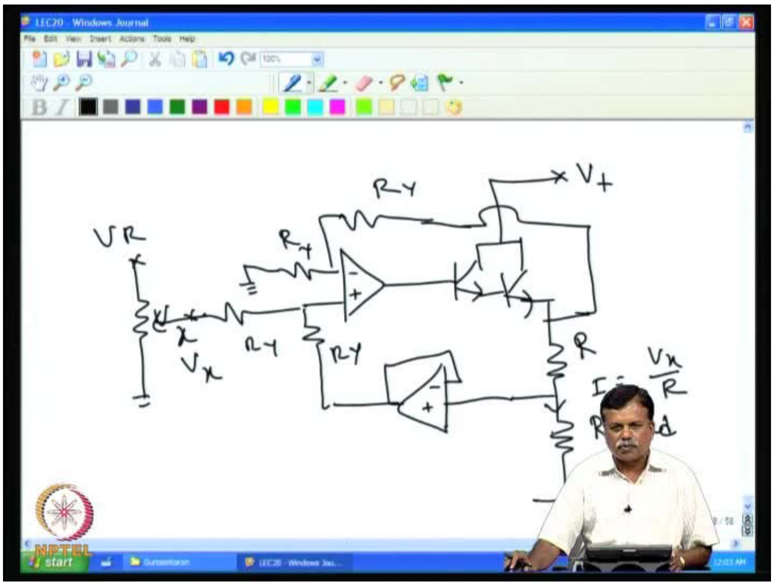

So, in the previous class circuit, what we are done was we shifted the, this is a supply voltage, and then, we are kept this as a resistance, reference resistance, and this is R load, and then we are taken this, and then, utilized this is V x, and then, this point. So, if this resistance are equal, say R y, all resistance are equal, then x one that the current I is actually V x by R. So, V x is the applied voltage in this case we can have. For example, V reference here, and then, this can be a variable voltage. So, the voltage at this point V x divided by this R gives you the current.

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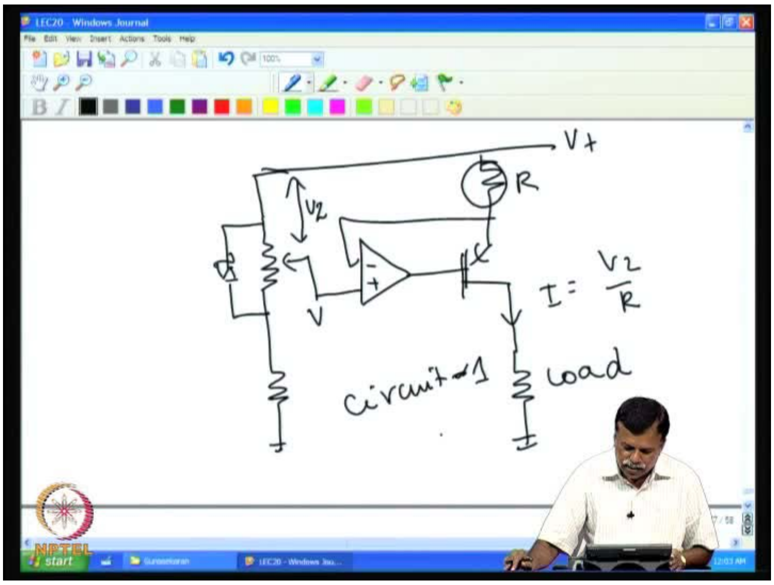

So, these are the two different types of current sources that we have discussed. One is with reference resistance hanging at the V supply voltage. This acting as a reference voltage, and in this case, this we call circuit 1, and then, we have the second circuit, where in, the reference resistance is this, and then, applied voltage is this V x.

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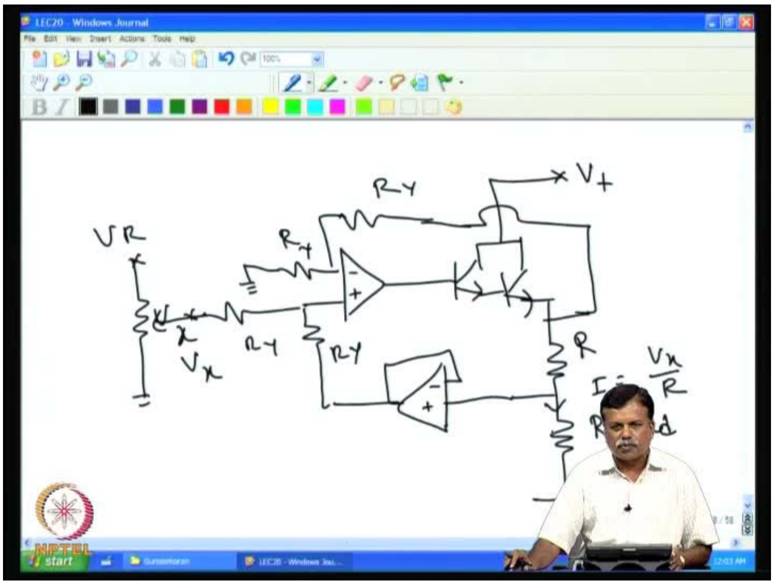

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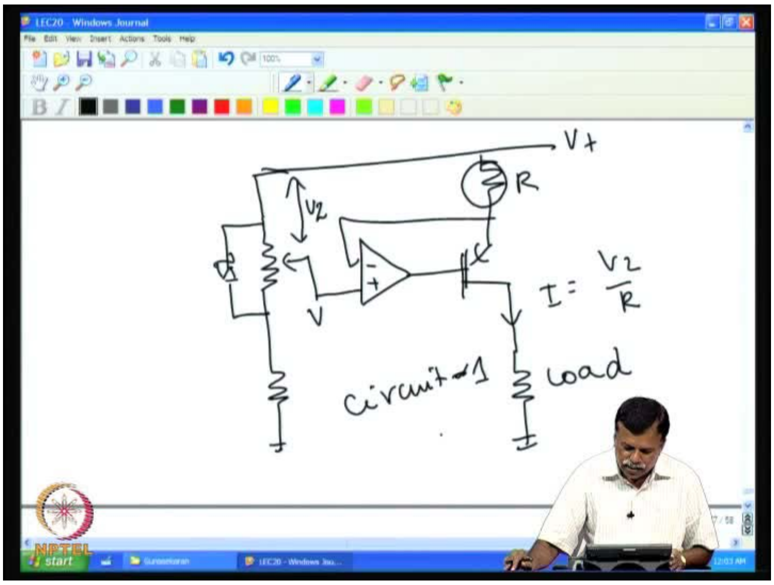

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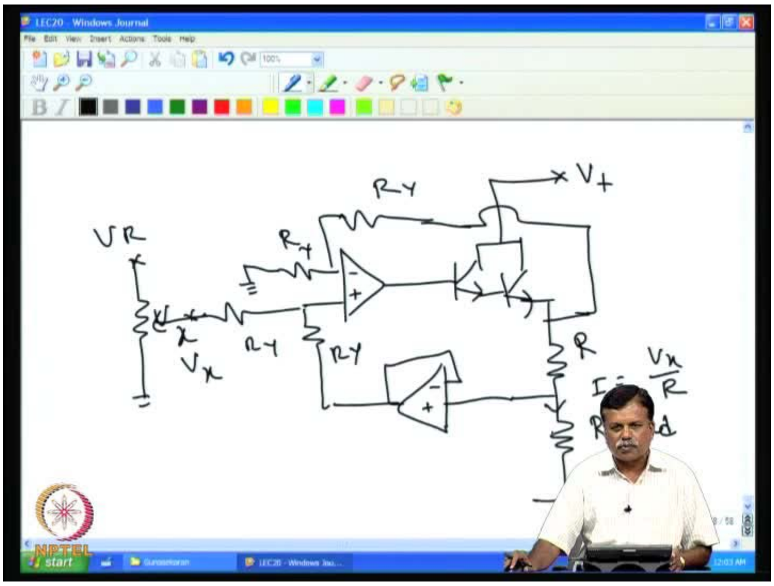

Now, this is, if you compare these two circuits, these two circuits, this circuit, the circuit number one have the input voltage with respect to supply voltage, that is we are measuring the input voltage V z with respect to the supply. Whereas, in the circuit number two that is on this circuit, the input voltage is with respect to ground V x divided by R is the current. So, this is the, this is the basically these two different circuits actually behave in a different manner. For example, if you take this circuit, this has advantage that our input voltage can be with respect to ground, and then, that makes it easier to design a current source, and the load is also with respect to ground and this ideal to use this.

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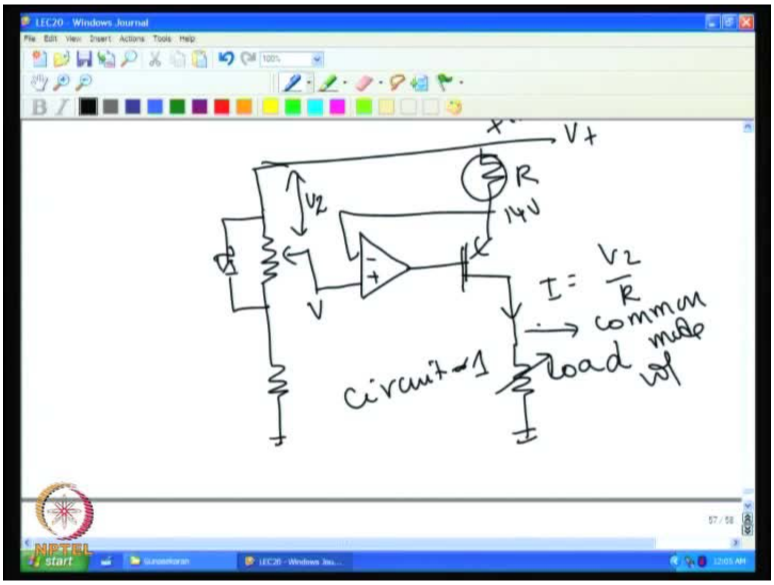

Whereas, if you take this, the, our circuit number 1 that the voltage is not respect to ground. So, but this had additional, this has one advantage that if I change the load resistance, for example, if I change the load resistance, then voltage at this point and at this point, there not varying. Where this is always at supply voltage, say this is plus fifteen volt, if it is a plus 15 volt and this may be 14 volt, depending upon the current, that is flowing and the resistance that we have.

So, whatever may be the resistance change here, the voltage across this changing is only very small amount. So, voltage at this point and at this point is changing only very less. So, net result is this voltage across the load change will not induce a current error. So, this we call is the common mode voltage for the op amp.

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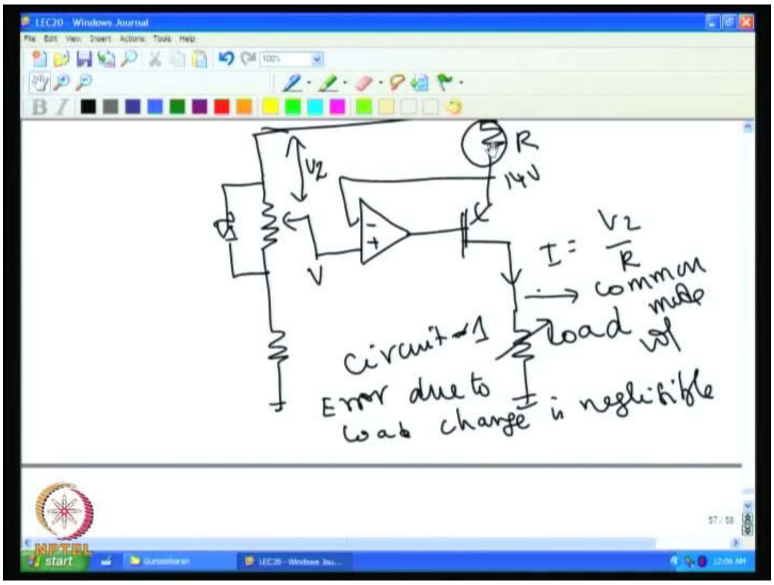

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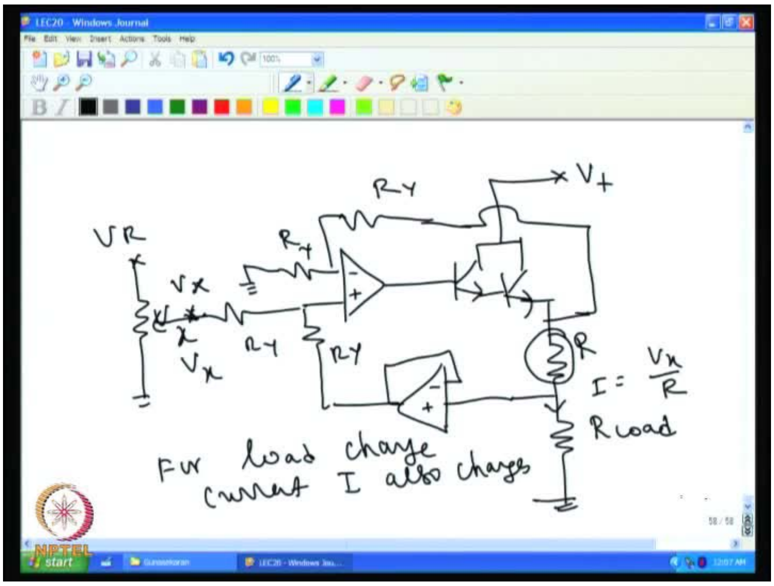

So, the load voltage is a common mode voltage. So, the common mode voltage changes with the loads variation when load changes. So, the common mode voltage will not give any error in this circuit. So, error due to load change is negligible. There is the, this is because the actual change that the op amps sees that its input due to load change is extremely small, that is only about 1 or 2 volt. Whereas, now, if you look at the second circuit, the load change here, so, load changes, then voltage at this point changes accordingly linearly.

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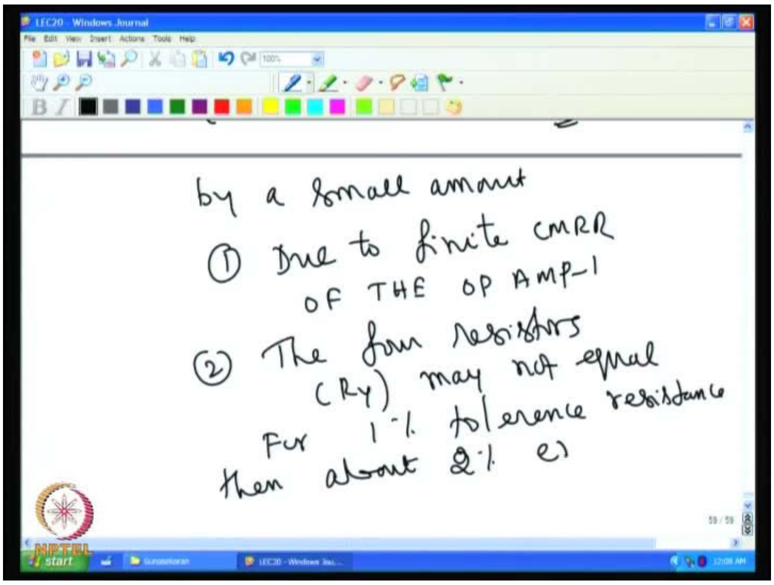

So, voltage at this point also changes and that makes the, that look at the voltage at this point, it changes, the common mode voltage of this amplifier is changing, and that makes this voltage produce a error. So, the input and output differs because of this change in voltage. So, this is known for common mode voltage error that is even load changes the current changes. So, this circuit for load change, current I also changes by a small amount. That is the reason is one is due to due to finite C M R R of the op amp. So, the C M R R of this op amp, say I call op amp one, C M R R of the op amp 1. So, that produces an error. Then there is one more much serious problem: if these two resisters R y, we said, there must be equal, these four resisters, this, this, this, this must be equal, but in reality, that we cannot get exactly equal resistance, there can be a change.

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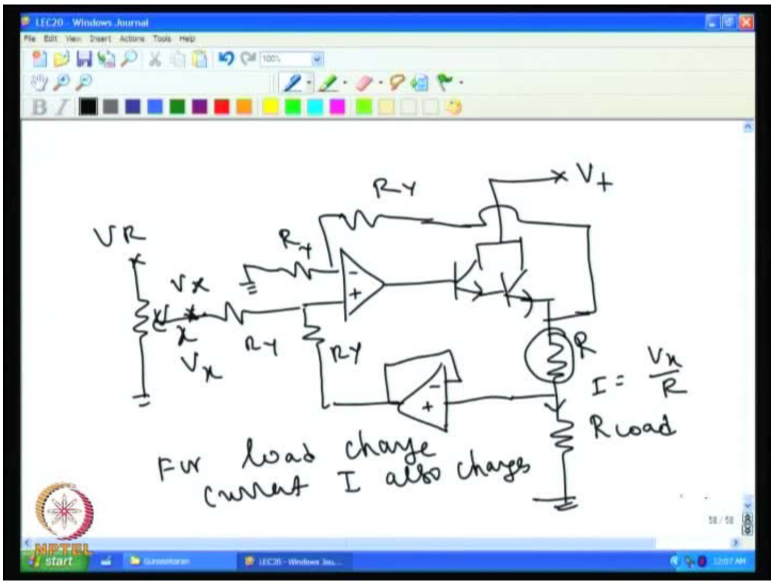

So, the error, as I said, second problem would be the four resistors. That is R y must be, may not be equal and may not be equal for 1 percent tolerance resistance. Then, about 2 percent error is expected; error in current is expected due to common mode voltage. That is these resistance are not equal. If they have one percent difference, then when load changes, this voltage changes, and that induces error in the current because we see that this voltage is divided by 2 by this resistance, and this resistance, and if these two are not exactly equal then division will not be exactly by half similarly. If this resistance is not equal, that is may not be exactly half.

The net result is when this resistance changes, we have the change in voltage and that will induce voltage, that is equivalent, telling some voltage added along with V x or decreased V x and net result is the current would be changing with respect to load.

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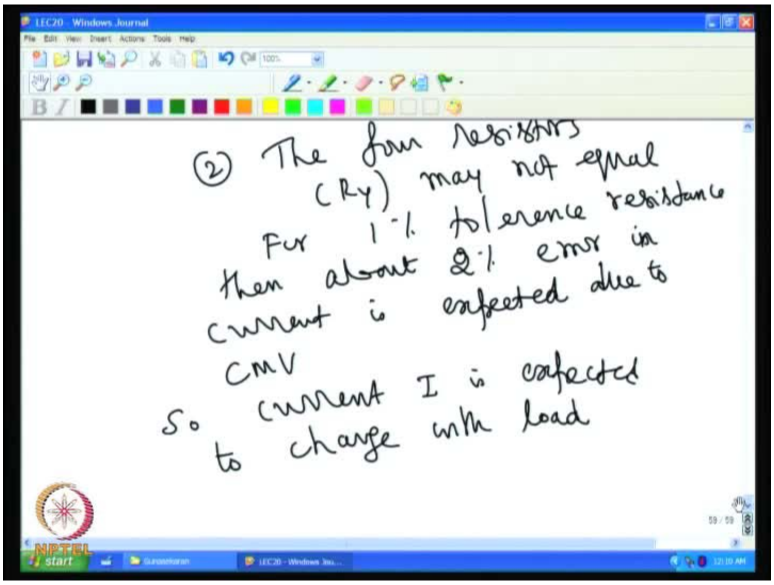

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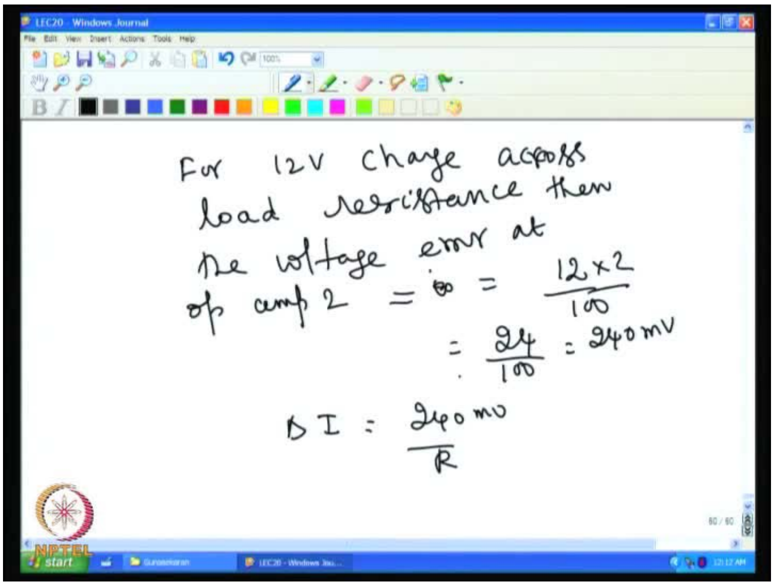

So, the current is expected; so, current I is expected to change with load. This is another major error which was not there in the earlier circuit. For example, 2 percent, if the load resistance changes, for example, 600 ohms, then 12 volt changes expected at this point; then 2 percent of that 12 volt will be, will be 2 percent of 12 volt, for example, if you work out for 12 volt change across load resistance, load resistance, then the voltage error, the we call name it op amp 2. Voltage error at op amp 2 is equal to 12 volt divided by 2 percent.

That is, that will be 24 divided by 100 will be 240 milli volt. This is quite a large error, and then, the current change would be delta I; delta I would be 240 milli volt divided by R. So, R is the reference resistance.

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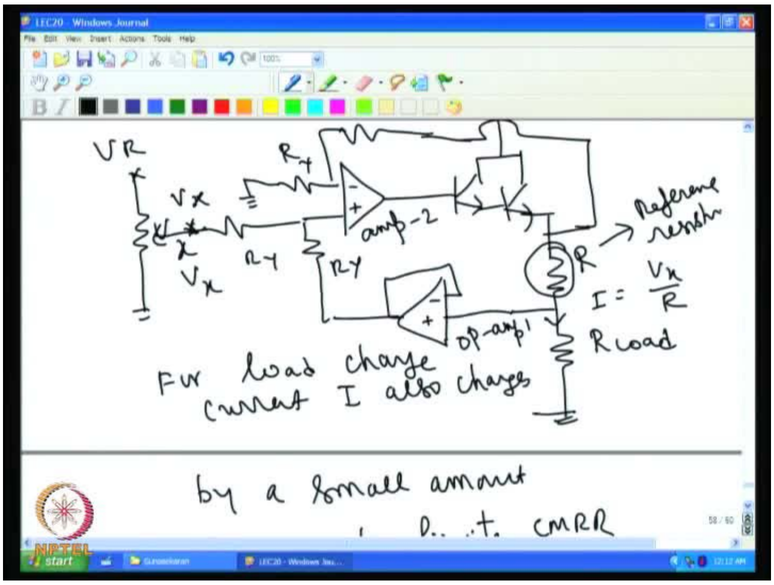

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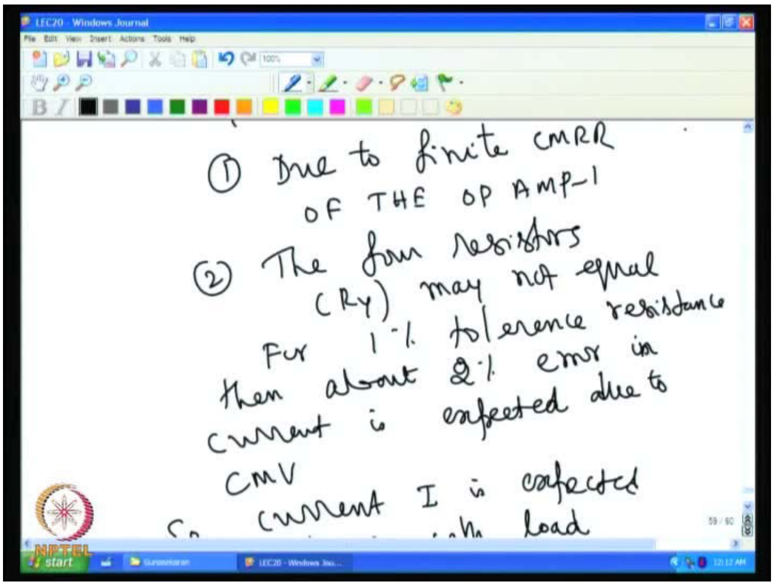

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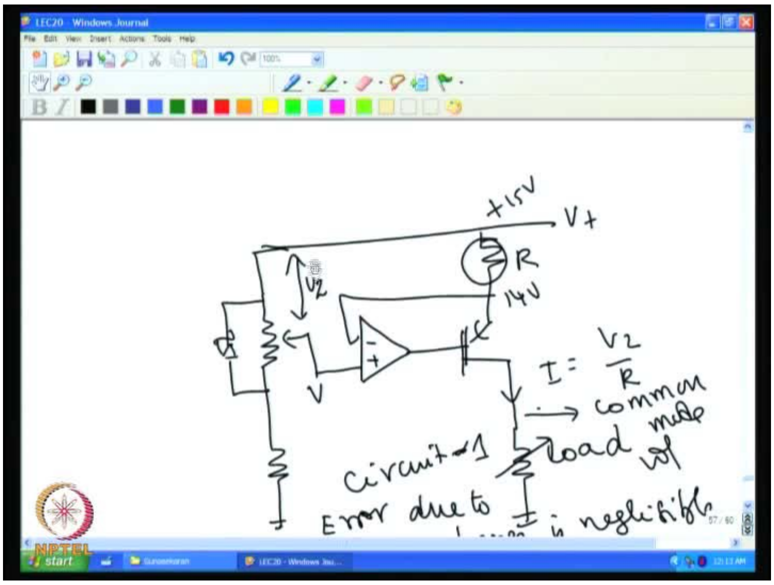

So, this is one of the major error in this circuit, and this circuit, even though is good because the input voltage, signal voltage with respect to ground, and the load also with respect to ground, because of that, this is, this has many advantages, but still this produce a huge error and it calls for matching of these resistance, that is this ratio must be match to this, then only this error can be solved. That is why people prefer to use this circuit. Wherein, that common mode voltage problem is not there in this. However, this calls for voltage with respect to supply not with respect to ground. That input voltage should be this is refer to supply rather than to the ground.

So, if one can combine the goodness of this circuit, this circuit number 2 with one, then you will be better off in designing our circuit, because the constant current source and the current based and the current transmitters are extensively used in the industry, and this error needs to be addressed, and this problem to be solved.

So, one can think off circuit which is mixed of circuit 1 and 2, so, that is we refer the load to the ground, and then, we want refer the input voltage also with respect to ground. At the same time, we do not want this common mode voltage problem that was coming in the second circuit. So, the approach that we can take for that would be we can have circuit in the following manner.

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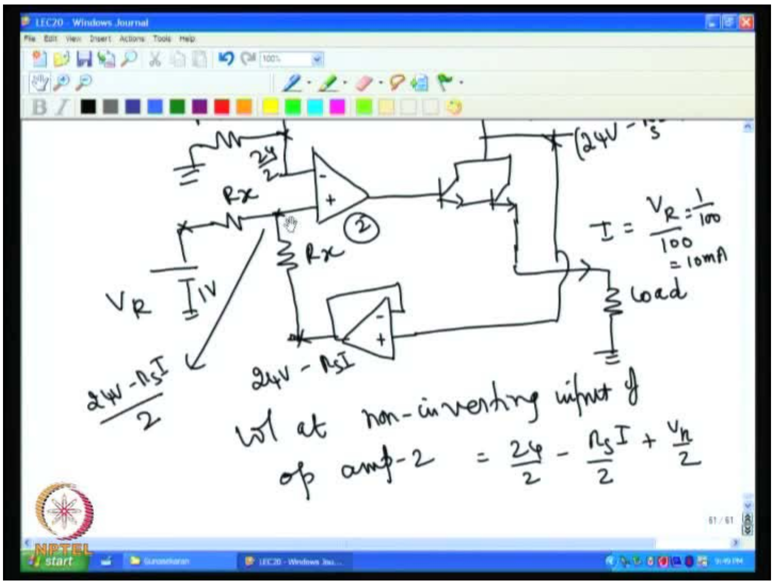

So, we will start that. Actually, what we do is we will take the operational amplifier. Then, current driver, we put with the Darlington so that the base current is very small. So, we had run by current driver. Then, we put our sense resistance here and connect the supply here V plus, say may be 24 volt or whatever it is or 15 volt. Then, this is going to the load, for example, this is the load resistance, this is R since.

Now, what we do this we will take this as a sense resistance. Now, I will connect from here the voltage divider arrangement that what we are done in the earlier case. So, will have a equal resistance, say R x and R x equal resistance I put. So that whatever voltage is here, which is nothing but a supply voltage. So, this is V plus and we will get actually V plus divided by 2; this is basically our voltage divider by a factor of 2, that is done.

Now, we at apply the voltage at the plus input. Now, this actually we do it in a different way. So, I take this, then I will put a follower here, then I do apply this voltage through the, and then, apply my V reference here, this also R x; this also R x.

So, this basically all these 4 resistors are equal values are put. Now, if you see, how the circuit is working that is essentially, for example, if I apply, for example, say 1 volt here, and if I have, for example 100 ohms here, then the current through this I actually is given by V reference divided by 100 ohms. In this case, it is one volt divided by 100 that will be equal to 10 milli ampere.

So, the current that is flowing through this is now given by this and this. This is what we had earlier. Only thing is we are changed the position of this resistance which was in the lower side, we are shifted to the power supply end. Instead of referring this resistance to the ground side, V reference now, we had shifted the reference to the power supply end.

Now, basically the working is similar to what we had in the earlier case. So, if this is say 24 volt, and then, if there is a current that is flowing through that, then this will automatically come to 24 volt minus R into I, where this R s into I. So, where, this is R s and current I is flowing through that, so, that is the voltage drop that comes across this. So, voltage at this point, voltage at this point is actually, slightly less 24 volt, and then, this as, this is coming the voltage at this point again comes 24 volt minus R s into I. That is the voltage that comes at this point.

This voltage is now half of that is applied here. So, will have this one, voltage at this point will be 24 volt minus R s into I divided by 2, and we know that this point is at 24 volt by 2 because this is half, this 24 volt, and then, this is divided by 2. So, this is actually half of that. So, essentially we know that this point and this point must be equal plus and minus must be equal. So, if we do that then automatically we will get that voltage at this point must be equal to this voltage that means at this point has to be 24 by 2.

So, voltage at this point is given by 2 contributors that is one from here and another from V reference, both of them are half of that. So, we can write now voltage at plus terminal. Voltage at in non-inverting input of we call op amp 2, this is op amp 2, that would be 24 divided by 2 minus R s I by 2 plus V R by 2 because this voltage also half of that is applying and that is to be equal to 24 by 2.

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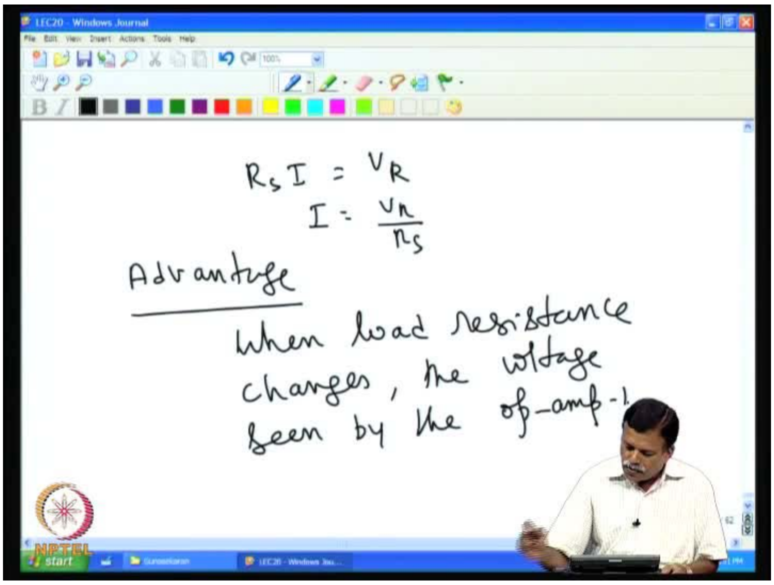

So, because voltage at plus must be equal to minus. So, V plus that is equal to V minus. By taking that then we will get automatically R s by into I is equal to V R. So, that gives us I as V R by R s.

Now, this is the same equation what we got, when the, when this resistances was connected at the ground side, but now, what is the advantage that we are getting in this circuit? That advantage is that, if the load is short at or even if it is load resistance because the load resistance is at the customer end and you may put whatever resistance that he wants.

So, depending when the current is fixed, when the load changes, the voltage at this point changes, and that voltage change is not affecting this because voltage at this point is always supply voltage minus R s into I. So, voltage at this point is not at all changing, even if you change this, the actual change is taking place across the transistor, which makes that this circuit is not prone for common mode voltage; that is the main advantage of this circuit compared to the other circuit.

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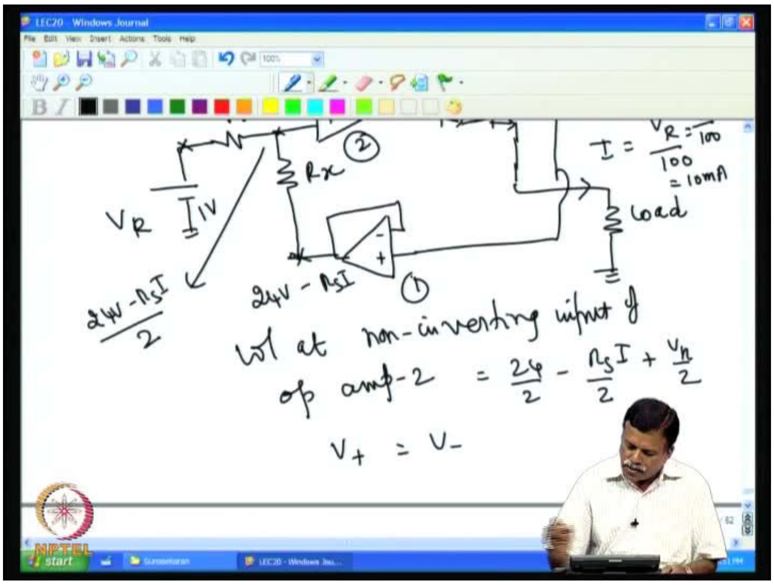

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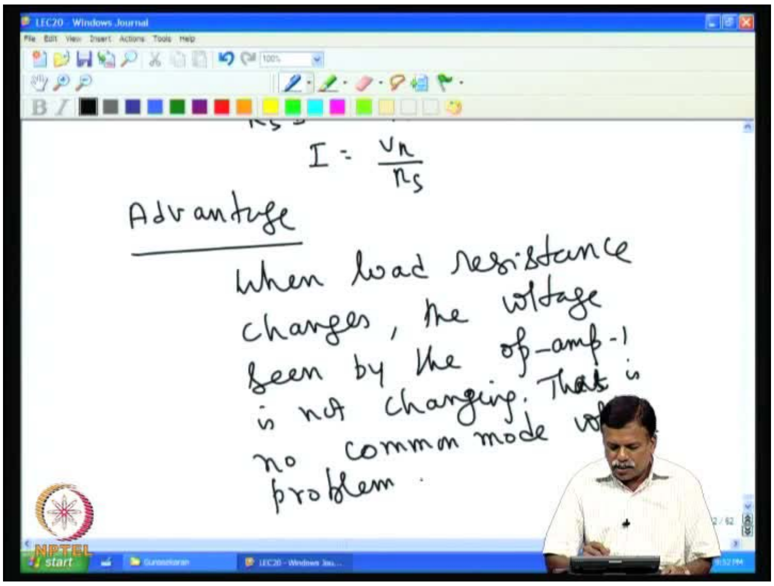

So, actual advantage is, when load resistance changes, the voltage seen by the op amp 1. That is this, I put this as op amp 1 op amp one is not changing. this

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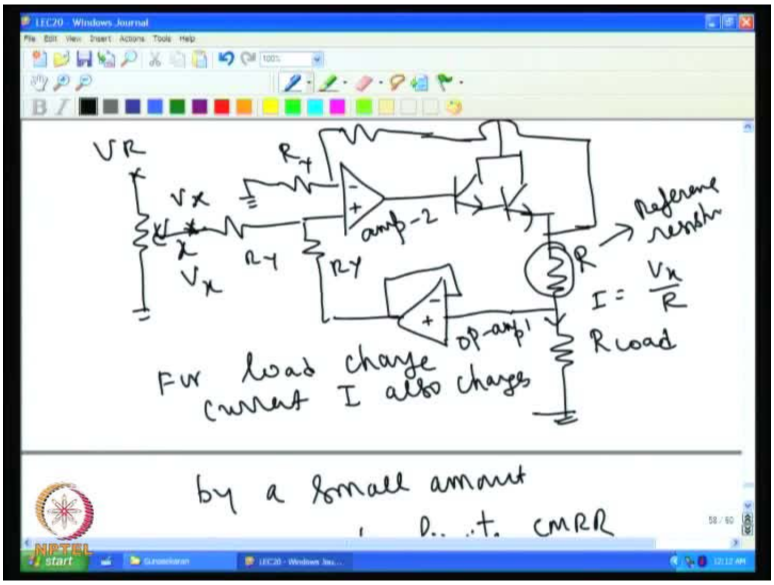

That is no common mode voltage problem. This is a major advantage because the common mode voltage change is a major issues in the earlier circuit, because if you go back to our earlier circuit and see, that, if we go back and see our earlier circuit, when the load resistance changes, then voltage at this point changes, and voltage at this point changes, and that makes that the applied voltage at this point change, of course, voltage at this point also changing, when the load changes. (Refer Slide Time: 23:55)

Then, this voltage is actually divided by 2 by the these 2 resistors and whatever voltage is also divided by these 2 resistors by half, but then, these division may not be equal mainly because the resistors are not exactly equal .Even though we have put all equal values, because of that tolerance, they are not equal and that gives enormous amount of error, when load changes. Whereas, that problems is not there in this new circuit. That common mode voltage has no effect because common mode voltage is not at all applied to the op amps.

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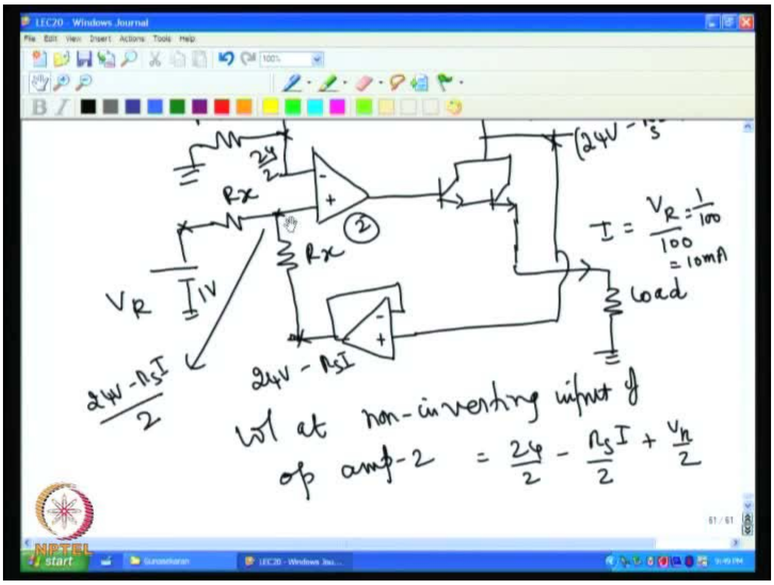

So, this is a excellent thing to happen, and this circuit, that is why is very popular and one you need not worry about common mode voltage. Particularly, when the load resistance is not in your hand and the user going to change means, that the load the, effect of this voltage the change in voltage is not going to put any error at all, and that way these 4 resistors now need not be matched. Even if there is a tolerance, and that is not going to introduce error because of load change.

The mismatch of these resistors can give an error because of line voltage change, but line voltage change, one can regulate, and then, make it to a constant. In that case, the mismatch of this resistance is not a problem. So, one need not struggle hard to make the resistance equal.

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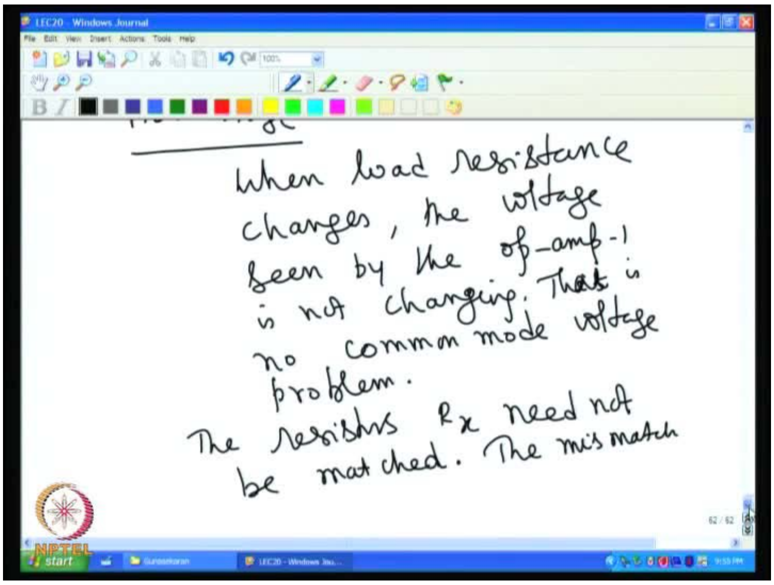

So, the other advantage is the resistors R x need not be matched. The mismatch, gives error mismatch, gives error only for a small amount if input supply changes.

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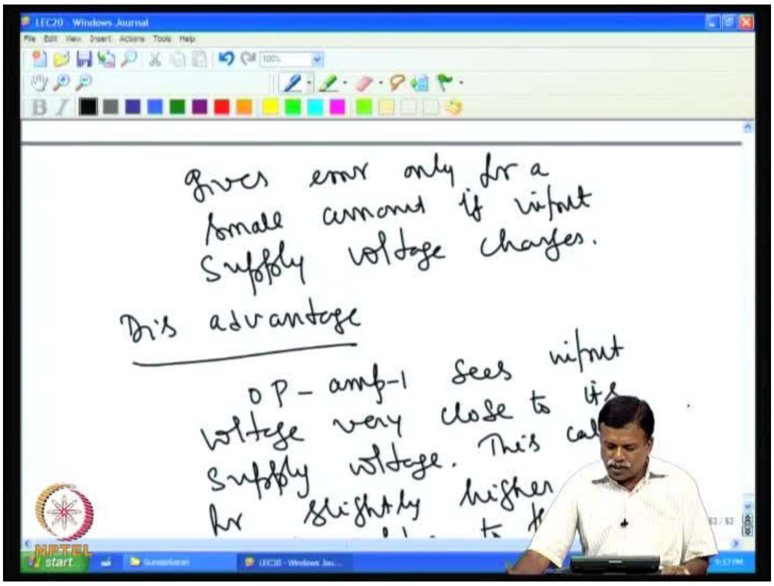

So, this is a major relief. Of course, there is one drawback in the circuit, that is this when the current is very small, for example, if this current is very small, then current flowing through this very small, then this voltage and this voltage are at the same potential. That is this will be at the supply potential, and this operational amplifier is operated with the supply voltage which is same as 24 volt, then 24 volt is supply voltage, and the input also 24 volt. In that case, this will not work.

So, this is one of the drawback of this circuit that calls for either this voltage has to be this supply voltage would be little higher or this voltage has to be little lower. So, any one of them has to be done.

So, the main drawback is the op amp 1 sees the voltage very close to the supply voltage. This happens in the single supply operation. So, the disadvantage: op amp sees input voltage very close to its supply voltage. This calls for slightly higher supply voltage to the op amp.

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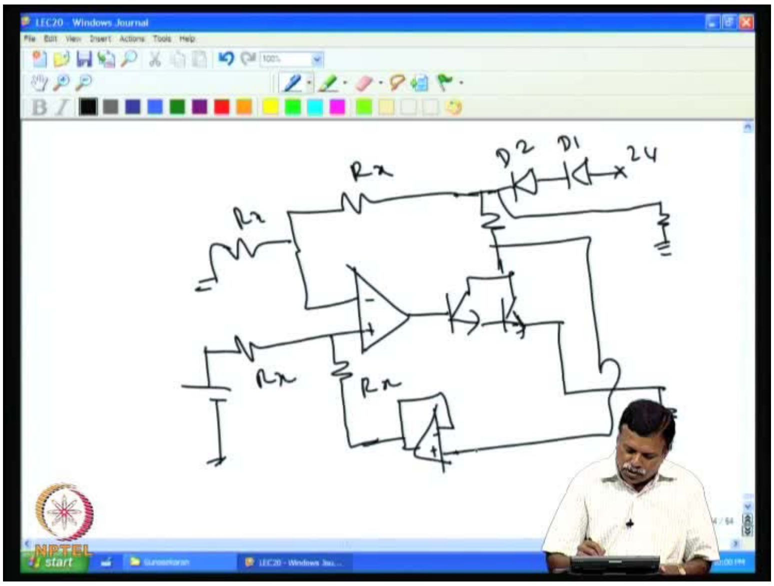

So, this can be achieved by adding the diodes at the input. What can done is that, we can add 2 diodes to reduce the input supply voltage, say for example, we can have two diodes, and give the, say 24 volt here, and then the rest of the circuit can be remain same that we can have. Now, the output load is can switch here, and then, the other part of circuit can remain same.

So, these resistance R x can made equal or even if they are not equal, there is a tolerance, thus not going to error, and we not going to produce any error, and these two diodes D 1 and D 2 are added, such that, now, because of these two diodes, there will be voltage drop of 1.2 volt. That means, even at the worst case, the input will be 1.2 volt lower than the input supply. That will make this op amp work without any problem even in single supply.

So, that problem of input voltage by very close to the supply voltage can be solved by adding the diodes in the actual circuit, and that very low current, the diode drop cannot be 1.2 volt. That problem can be solved by adding a very small resistance here to the ground, and that resistance can be select such that only fraction of milli ampere current is flowing, and that is ensured all the time. So, there will be always 1.2 volt drop. If require, you can also add one more diode if you want more voltage drop to this input.

So, this circuit works very well without having any problem, and the resistance change here, I will change the voltage at this point and that not going to affect the accuracy of the circuit. That way it is a good.

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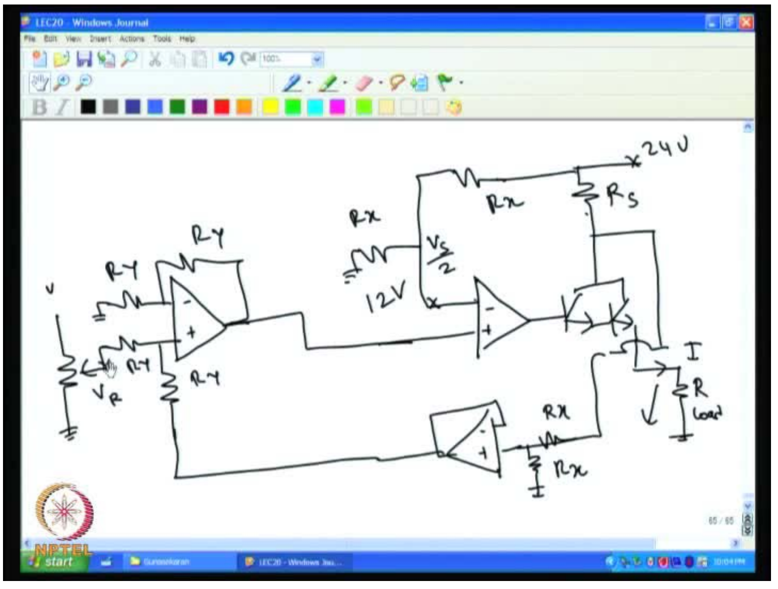

Now, we can also solve this voltage problem without adding the diode, because, now, we added these two diodes to solve the voltage that is appearing at this point. This can be solved by using another slightly difference circuit, and that will be like this. So, what we can do is we can we can add a circuit similar to the other one, but now, what you do is, we will not connect the diodes, connect this 1 to 24 volt. Now, at this input, we need by factor of 2 division that I can achieve from here. This is similar to what we had. Then, this is our load resistance. Then, we can take this. We can have a follower. This is similar to what we had.

Now what we do is instead of directly applying these two, this here, what we can do is, we can divide this voltage by a factor of 2 here. For example, I put this by equal values, say again R x and R x. Now, I have to apply this voltage to this point along with the reference voltage. So, the reference voltage sets the current. To achieve this, we use one more operational amplifier here, and then, this I can use as a difference amplifier. So, this I ground it, then I have my potential meter, this is V reference.

So, here, this output can be connected to this, and this can be connected to this. This circuit solves all the problems that we had earlier, that is we had a issues with respect to common mode voltage; we had issues with respect to supply voltage appearing at the input, almost entire supply voltage appearing in appearing at the input; both these problems are solved in the circuit.

If we carefully analyze this, we will see that voltage at this point is supply voltage. So, that is actually almost equal resistance output. So, we will get this point, supply voltage by 2. So, this is V s by 2, for example, if it is 24 volt, this sitting at 12 volt.

Now, this is our load resistance R; this is our reference resistance R, that is R s, and this is the load resistance, and this is the current that we are talking of. For the current equation is same as what we had earlier. That is, if this is V reference, say V v, I will call fraction of reference voltage or we call this itself as a V reference and this has to be equal. So, I will put this one as R y and this also R y. So, this is actually a difference amplifier with 4 equal resistors are put here.

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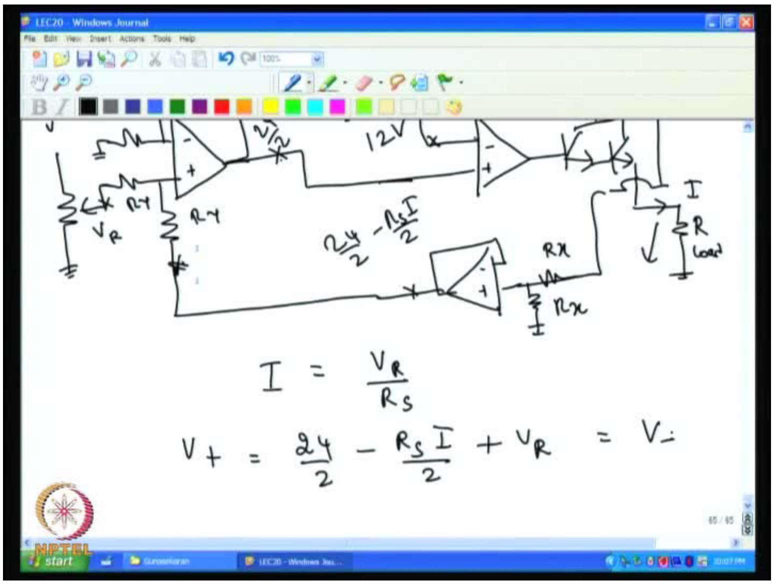

Now, even this resistance need not be matched that is one advantage with the circuit. So, even if the not match, they are not going to produce the error due to the common mode voltage that going to appear because of the changing load. Now, if we analyze the circuit, if this is V R, then we will show you that the current that is flowing here is nothing but V R by this fixed resistance that is R s that is the current that is actually flowing through this.

Now, that we can show like this that is, if this is R s and current I is flowing, then voltage at this point become 24 minus R s into I; I is the current that is flowing and R s resistance. So, you get this, and then, this is actually divided by 2 here division by 2. So, voltage at this point, voltage at this point actually becomes 24 by 2 minus R s I by 2. That is the voltage achieved get at this point, and this is a difference amplifier. So, whatever voltage that is applied here, whatever voltage is here, that going to appear as it is at this point plus the contribution because of this also will be appearing. If this 2 resistance are equal, so, output voltage at this point, output voltage at this point is this applied voltage plus this applied voltage. That is voltage at this point is nothing but this voltage plus this voltage because this resistance are equal. So, voltage at this point actually becomes 24 by 2 minus R s into I by 2 that is the voltage at this point. The voltage at this point is 24 by 2 minus R s I by 2.

So, if we take the voltage at this point, that is 24 by 2 minus R s I by 2 plus this V R as it is coming at this place. So, we will get the voltage at this point as V R. So, all 3 voltages will be appearing at this point some of this. So, we get this voltage plus this voltage appearing at this point.

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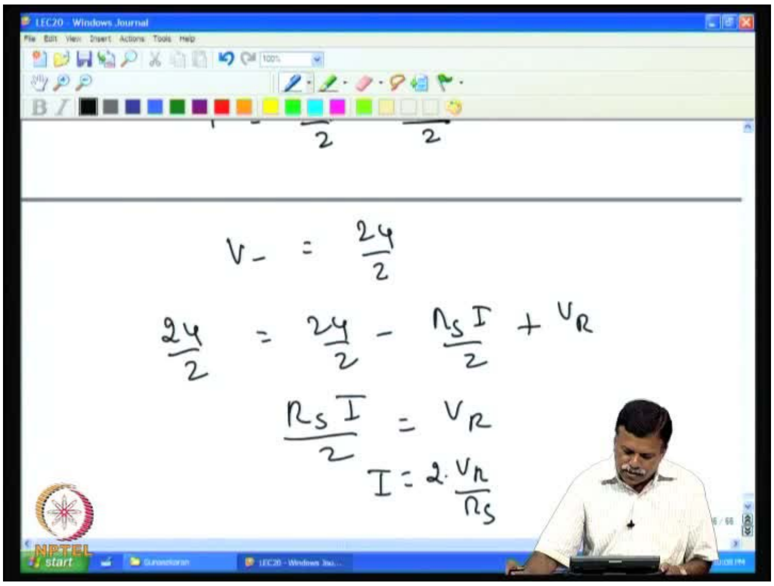

Now, this must be equal to V s by 2, so, because voltage at plus terminal must be equal to minus terminal. So, voltage at plus terminal is V plus as coming as 24 by 2 minus R s into I by 2 then plus V R, and that must be equal to voltage at minus V minus, and that voltage at V minus, similarly, already known V minus V is already known. So, V minus is 24 by 2. So, that makes if both are equated that we can write 24 by 2 that will be equal to 24 by 2 minus R s into I by 2 plus V R.

So, that makes R s into I by 2 equal to V R. So, that is the small change that is that a factor of 2 differences that had come. That is not serious issue because we can always adjust the V R to the required value. So, the I is actually become not V R by I s V R by R s that is I actually become V R by R s into 2.

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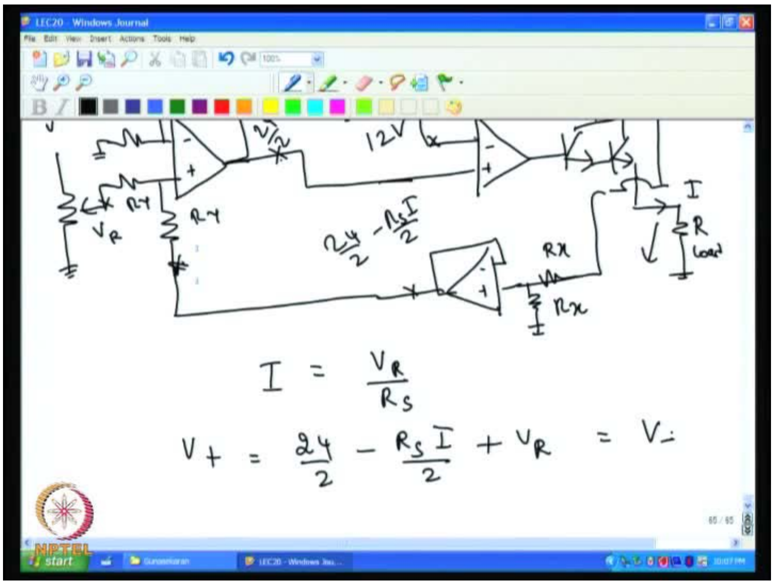

So, that is actually factor of 2 as coming in. This are coming mainly because of that divide voltage appearing as it is, but then, this voltage is not actually, this voltage, whatever is there, will appear as it is at the output because of this difference amplifier which was not there in the earlier case. So, the current value is now is known by this.

Now, this circuit as the has advantage, many it has, many advantage mainly because the voltage at this point is not close to the supply voltage, this almost half of the supply voltage. So, need not struggle hard to see that the op amp works very close to the supply voltage; that problem is not there, and then, even if the resistance changes, this voltage will change, but this voltage is not changing, and so, this voltage is not changing. So, common mode voltage is not a problem of this op amp.

Similarly, this voltage is also not changing with load. Net result is, even if there is a mismatch here, there is not going affect the accuracy of the circuit. So, the both the problems, that is the op amp input going very close to the supply voltage, and then, the common mode voltage change affecting the current. Both the problems are solved very effectively. Even if these 2 resistance, if these 2 resistance are not exactly one is to 2, and then, this also not one is to 2 is not a problem because more time this voltage and this voltage is changing, and whatever change that is occurring here is very small, and that is only due to the current variation, that gives much lesser problem. So, this circuit works extremely well for constant current applications.

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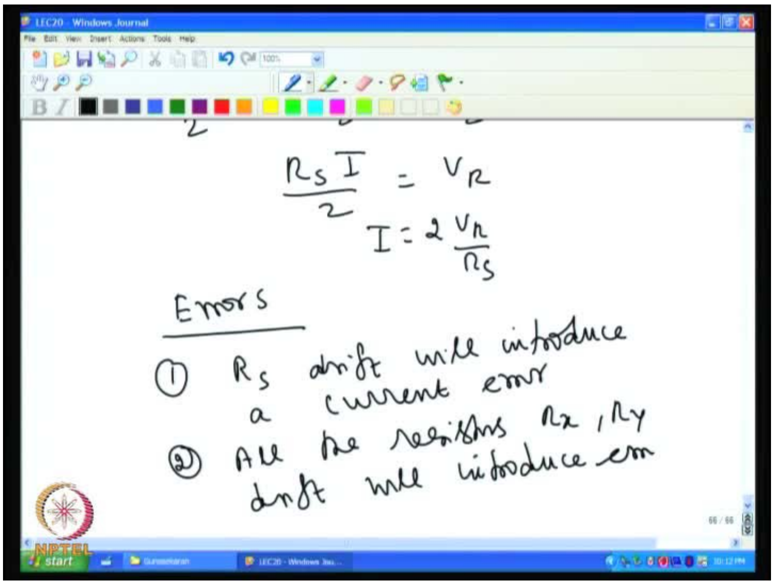

Now, if you look at the error budgeting for this circuit, we have some issues here. So, we will see what are the two problems, one will encounter in the circuit. So, we will see the merely list what are the errors expected in the circuit. So, errors in the circuit. Now 1, this is similarly, similar to the problem that we had in the earlier circuit that, if this resistance drifts due to temperature, then current will eventually change. So, only is the resistance R s drift, that will produce a error.

So, R s drift will introduce a current error. Now, then, second one: the resistance drift of this, the resistance drift of this, this, this, this R y R y R y, all will add, all will introduce a drift actually. (Refer Slide Time: 42:34) So, all the resistors R x R y drift will introduce error.

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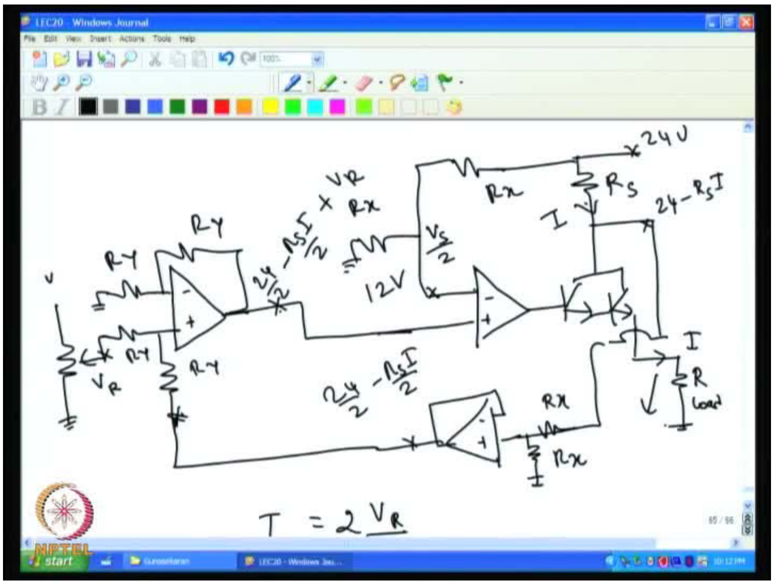

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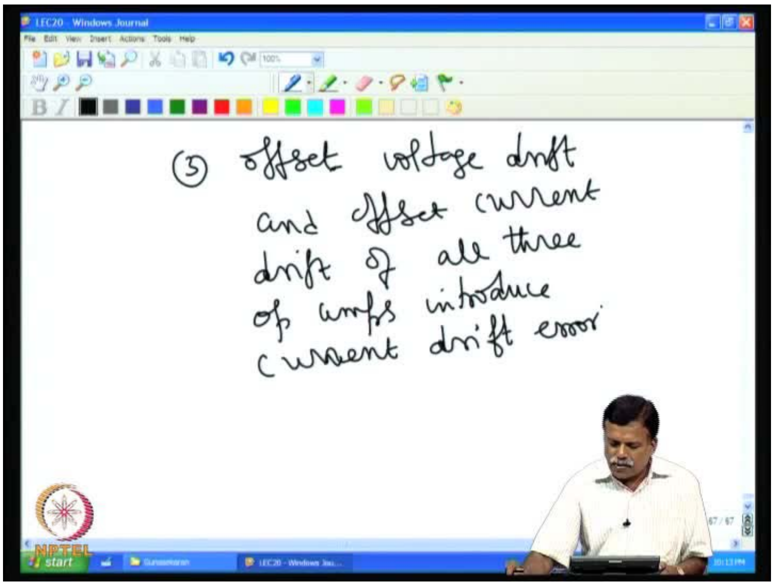

This is the major problem in the circuit, because now, we have eight resistors, and the drift of all this eight resistors will contribute for the error compare to the earlier circuit where we had only four resistors. So, the drift of all the eight resisters will introduce some error. Then, offset voltage drift of this op amp, this op amp, and this op amp, all three will introduce an error. (Refer Slide Time: 43:34) So, offset voltage and offset current drift of all the op amps, all three op amps will introduce an error.

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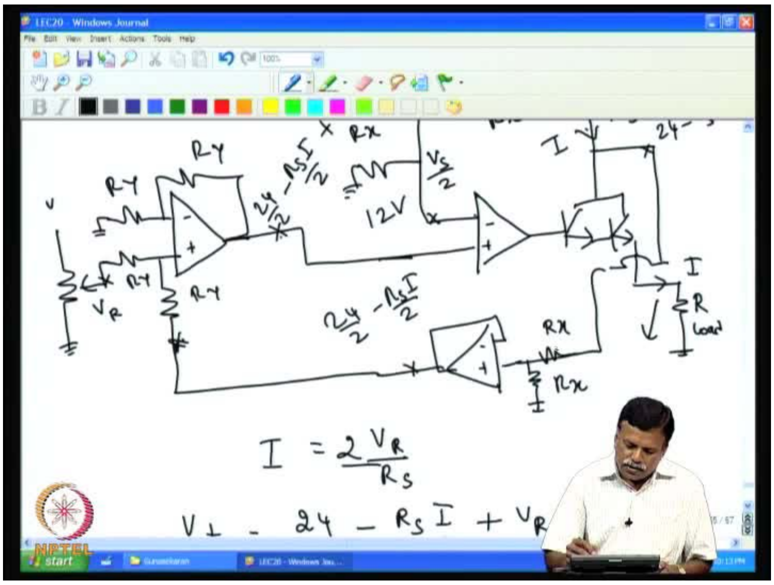

So, third error is offset voltage drift, and offset current, offset voltage, offset voltage, of drift, and offset current drift of all three op amps introduce current drift error, and this is also considered be large mainly because the resistors that we have to use here must be high, because what happens is we do not want, for example, the loading to take place here. So, the resistor that we used here has to be higher in value. These resistors need not be higher and that can be lower. So, this current of drift of this the offset current of drift of this op amp can be made small.

Similarly, these two resistors need not be higher because the current is directly coming from the supply, and that is not going to affect the working of the circuit. So, the, this need not be very high; maybe we can have 10 k level of resistors is good to reduce the offset current drift. This also can be a ten k level. Of course, this has to be higher value mainly because we do not want the current flow in this, and then, whatever current that is flowing here is adds the, that the current is added to this that gives a current error. So, to avoid that, this is to be kept high, and that will produce more offset current drift related error.

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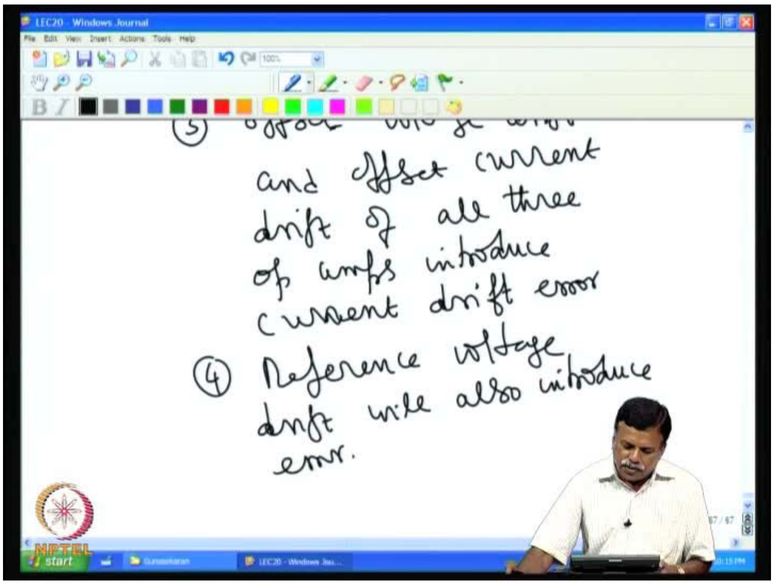

Then V reference drift that is if you take the reference voltage as this, say V I is the reference voltage applied, then the offset voltage drift of the reference voltage drift also will introduce an error. So, reference voltage drift will also introduce error. So, these are the errors that can be calculated like what we have done in the earlier case that to find out how much current will be drift because of the temperature drift.

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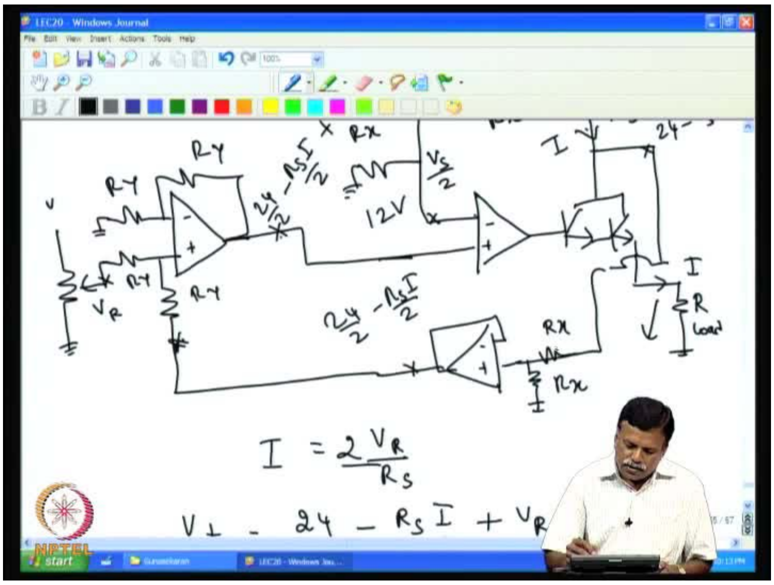

So, one should consider 0 minus 20 to 80 degree temperature change if we are considering industrial grade equipment. The supply voltage change here will not introduce any error. If the small change in supply voltage will not create much problem that will create small error, if these two resistors these and this are mismatched. So, as long as supply is constant, one need not worry about the ratio between this and the ratio of ratio mismatch between this and this is not a issue at all as long as supply voltage changes small which is normally the case because supply voltage always regulated and given.

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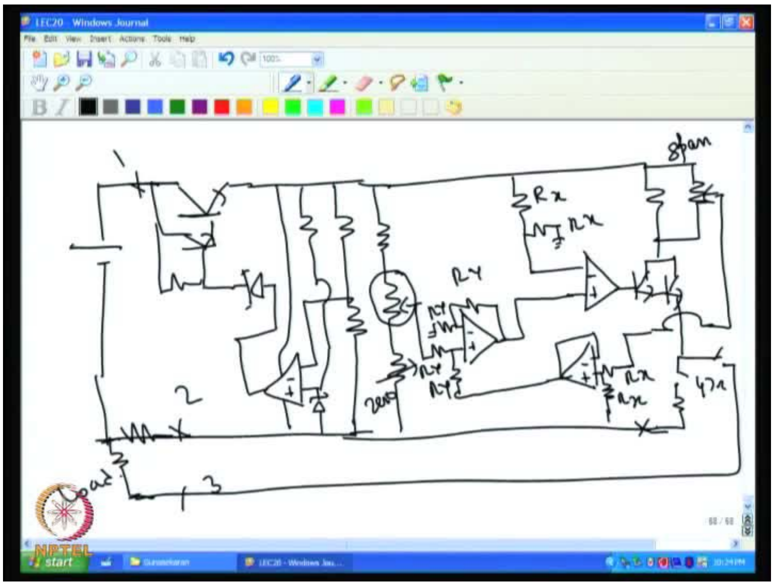

So, if you look at the circuit now, the entire circuit for two wire current transmitters, we can draw like this using the input power supply. We can add the input power supply and complete the whole current transmitter circuit by adding the regulator part. So, the entire circuit looks like this. We have a regulator at the input that this is supply from the, so, we will have this, and the simple regulator can be this.

So, we can have a Zener diode, and then, voltage regulator part of it connected to this then, feedback is given to this, and the reference to the regulator can be given from here, and the supply for the op amp can be taken from here. So, this gives you the regulated output voltage. This voltage can be now given to the current converter. So, the current converter part now consists of these three op amps which we have discussed so far. So, you will have this, that is connected to this, and then, our load resistance can be connect at here, then the input circuit, the current can be connect at here. Then, our potentiometer, which supposed to play a role in deciding can be added at here, and this can be given to the difference amplifier, which, this has to go to the other way round. So, you will have difference amplifier connected here, and the output of that is given to a voltage for lower, and the divider. This output can be given to this, and then, that completes the entire current transmitter part.

So, this is the current transmitter including the voltage regulator that is added here. So, we have, now this is acting as a load resistance. This is sense resistance R s, and they are supposed to be equal that R x and R x, they all 4s should be equal, and these all 4 resistances should be equal. So, the working of this circuit was already explained, that we are already explained how this is working, except that we are added this now. Instead of getting a reference voltage, we added the potentiometer. So, the potential meter variation changes this voltage that changes this current.

So, now, if the potentiometer is attach to the wall or any other system, then when the mechanical system moves, then the potential meter also moves and then current changes. One can make it one end 4 milli ampere and other end 20 milli ampere that can be achieved suitably by adding 0 one span, one can add 0 one span either here, for example, I can add a 0 here, and the span variation potentiometer can be added here. For example, I can remove this, put as span varying potentiometer here can be connected to this.

So, one can vary the span here, that is keep the potentiometer at one end, adjust this to get 4 milli ampere current through this, and then, move the potentiometer in the other end, adjust this span to get 20 milli ampere. So, by doing that one can get 4 to 20 milli ampere current transmitter circuit this way. Now, this circuit as we said, many advantage compare to the earlier circuit, namely: common mode voltage and the supply voltage change will not have any problem, and particularly this is suited, if I want to use the same thing for two wire as well as three wire system, because whatever shown here is the regulator plus this current transmitter which is has 2 wire system. Now, for example, if I want use this for a 3 wire system that one can do like this, for example, if I want 3 wire system, I remove this. Then, I will give this as output to the external use. I can connect output for the external use so that the user actually, normally what is done is he actually take this and connected it at the other end.

So, this act as the load resistance, and then, this because 3 wire system, because you have input 1 then 2 and 3 wire. So, you have 1 2 3 and these resistance can go up to 600 ohm.

So, this will become a 3 wire system. Suppose, if I want use it as a 2 wire system, then the same circuit can be change with little change. One can get a 2 wire system, for that what we can be done is we can remove this one, and then connect here. Instead of high resistance, will put small resistance 47 ohms, and then, the sense resistance can be added here, that is the load resistance can be added here, and you put only a smaller value of resistance at this point.

For example, I can have 47 ohms, or so, we can put here, and then, if I want to use as a 2 wire system, 3 wire system, what I do this I will remove this, put one switch here. I have one hertz switch, this can be given here. if the customer wants to have use it as a 2 wire system, then you switch on this and you switch off this, and in that case, you will put the load resistance here for 2 wire system. If you want to use it as a 3 wire system, you will open this and close this, and then, put the load here, this is load.

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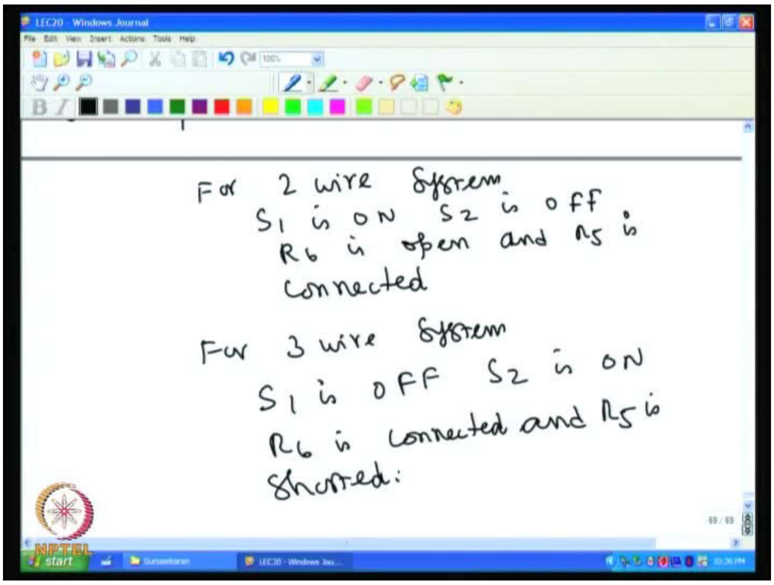

So, this can be used as 2 wire or 3 wire system that is, if I write it here, that is I name it switch s 1 and s 2. So, for 2 wire system, I will put the resistance as R five and this is R six 2 wire system, s 1 is on, s 2 is off; s 2 is off, and s 1 is on, and R 6 is open; R 5 open, and R 5 is connected. This will make the circuit as a 2 wire system, and if you want to use for 3 wire system, for 3 wire system, what can done is, we can have s 1, s 1 is off; s 2 is on, then R 6 is connected, and R 5 is shorted.

So, that the current actually goes, and 3 wire current actually comes through this. So, this way one can make 2 wire as well as 3 wire system in this model, which was not possible in the other cases, because in the other cases, that if you want make both 2 wire and 3 wire configuration, one have to see that the current actually flows through that, and making 420 milli ampere adjustment is not all that elegant compared to this circuit that provides.

So, one can design a 2 wire or 3 wire system using this. This one of the popular circuits that is used in the industry, put transmit the resistance value over a long distance.

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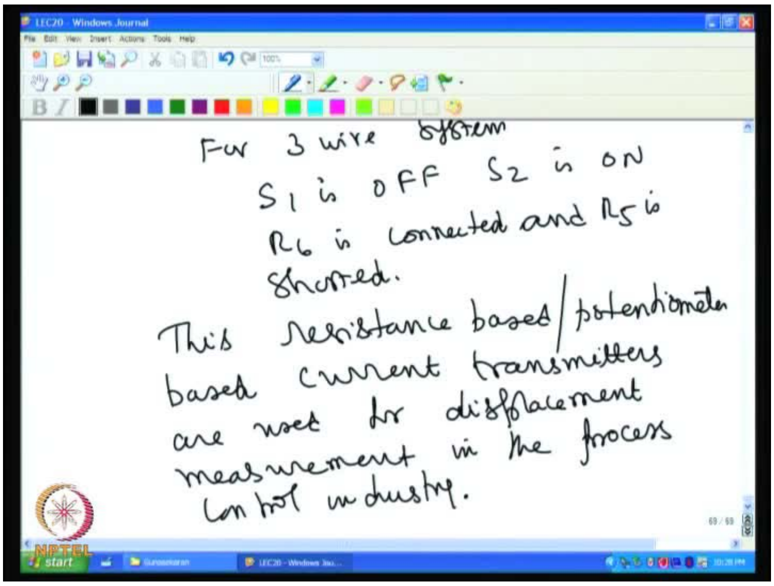

So, we had shown how to make 2 wire and 3 wire system for resistance based current transmitters. So, resistance based systems are used for displacement measurement in the industry. So, if you look at the industrial scenario, this 2 wire, this resistance based that is basically potentiometer based current transmitters are used for displacement measurement in the process control industry, in the process control industry. So, these are the 2 wire systems are made. Now, in the next class we will see in the consolidated manner, how to make the resistance measurement, and then, we continue our discussion in other topics later on. Thank you.