Circuits for Analog System Design

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Module No. # 04

Lecture No. # 17

Error Budgeting for Thermo Couple Amplifier

Today, we will discuss more about error budgeting in analog circuit, because we had seen how to apply operational amplifier for resistance measurement; then various transient signal conditioning like infinity also we had seen. But, we also worked out errors associated with operational amplifier.

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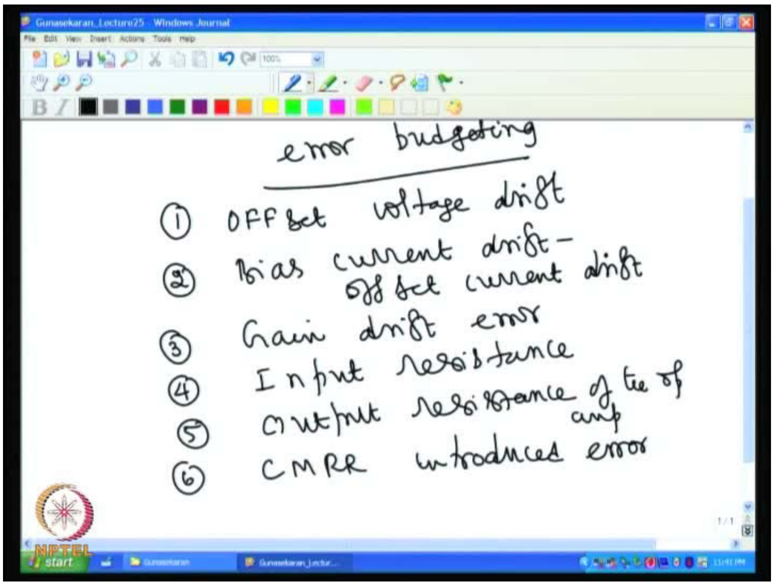

We see in the consulted manner, what are the errors that are the coming in the operational amplifier and how to compute them in the real instrumentation design? We look at the operational amplifier errors in today's lecture. Errors and error budgeting.

We will see the errors involved are actually offset voltage drift. This we already discussed, we will see more about this. Then, we will have bias current drift or offset current drift, both we will look it together. We have actually gain drift error, this we have not discussed so for. Then, we have input impedance, input resistance error; input resistance of the op amp that we should find out. Then, we had output resistance of the op amp. Then, we had the errors due to call mode rejection ratio, introduce error. Then, input resistance gain error. So, these are the various errors, which is there as per the D C signal is concern. There are other errors, which associated with AC signal processing that will see separately at some other time, when you are dealing with AC applications of the operational amplifier.

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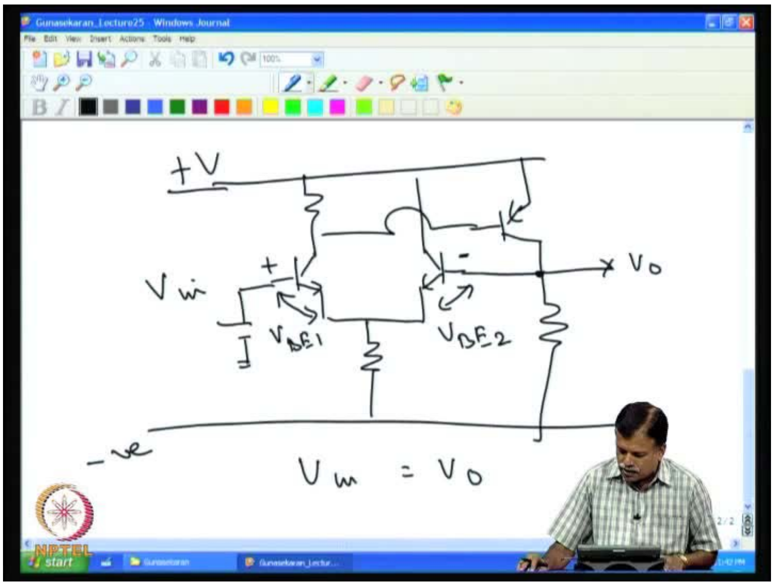

Now, we will see offset voltage drift error, then why it is coming, how to compute and make error budgeting. Introduce in the error budget, the errors related to the offset voltage drift. Now, if you look at our original op amp circuit configuration that basically see our three transistor op amp that this is the circuit that we had. This outing is an output, this is a power line, is a plus voltage and minus voltage; the two inputs, plus input and minus input. So, we want to apply and amplify the voltage, we give the input here. For example, if it is the voltage forever, we directly connect this to the output. This is a voltage follower that is whatever voltage input is given the same thing appears at the output. So, v input is equal to v output.

Now, in this case, basically the operational amplifier was working with the assumption that the voltage drift; the base emitter voltage here and the base emitter voltage here, V B

E 1 and V B E 2 are same, with temperature also they are tracking always equally. So that is one of the basic assumptions that are made in the operational amplifier design.

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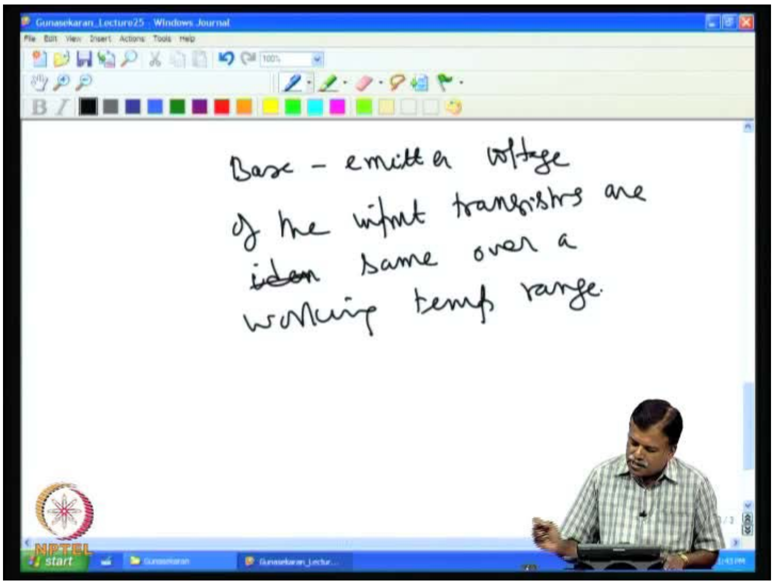

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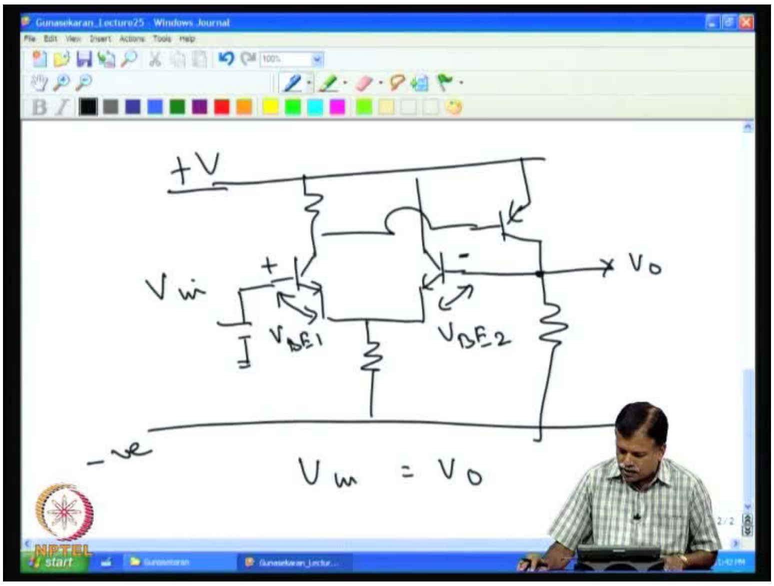

The base emitter voltages of the input transistors are identical, voltages are same results that they say over a working temperature range. But, in reality, base emitter voltages may not be equal; if they are not equal at that temperature, we called as offset voltage, but then the difference also not constant, the difference varies with the temperature that we refer it as offset voltage drift.

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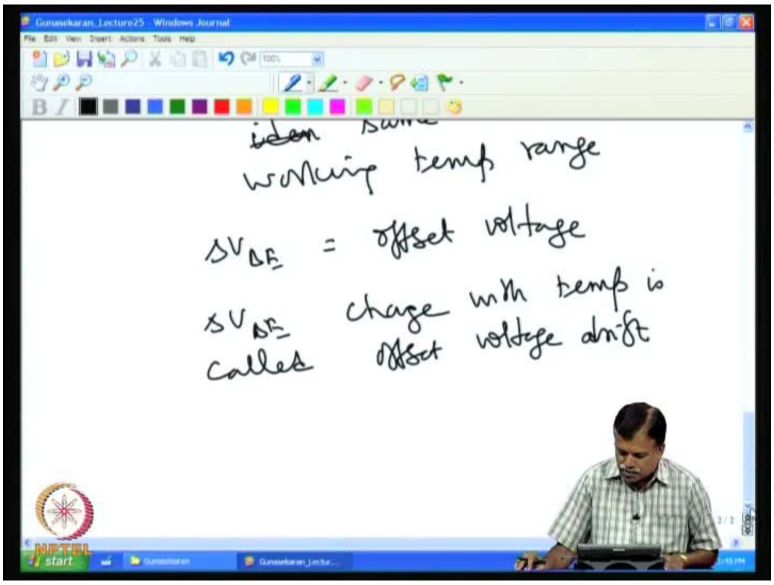

The delta V B E is considered as offset voltage; offset voltage is not a serious issue that can be compensated out. Then delta V B E change with temperature - change with temperature is called offset voltage drift.

Offset voltage drift is one which is very serious, because this cannot be compensated normally without using additional circuit. Because, offset voltage, it can be compensated, by adding a reverse voltage to the op amp that problem can be solved. But, if the offset voltage change with the temperature, then output changes and that creates a problem that is what we had seen earlier in the case.

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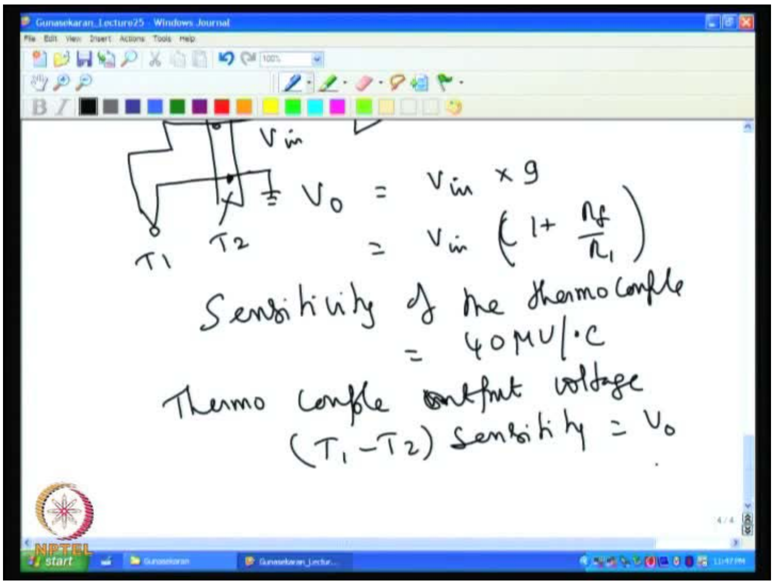

Now, we take a simple circuit, for example, thermocouple amplifier I want to make with the operational amplifier. Then, for example, we have a single junction thermocouple connected to this, then we have a gain that we said we have a gain R f by R 1. So, this gives us this is v in and then this is v out, then v out actually is given by v in into gain that actually we are shown as 1 plus R f by R 1. This equation I live it to you that we can find in a very many text books, how to drive this equation. We get gain in this, for example, if we take thermocouple, this is single junction thermocouple. Sensitivity of the thermocouple is 40 micro volts per degree C.

In this case, it produces temperature difference depending upon - I redraw this, so that it is convenient to look at it. For example, we can have a sensor terminated in a block like this and then this is grounded. Now, the temperature difference between this junction and this block, this is T 1 T 2. Thermocouple produce a voltage corresponding to temperature difference between T 1and T 2, so T 2 is the terminating block (Refer Slide Time: 08:24).

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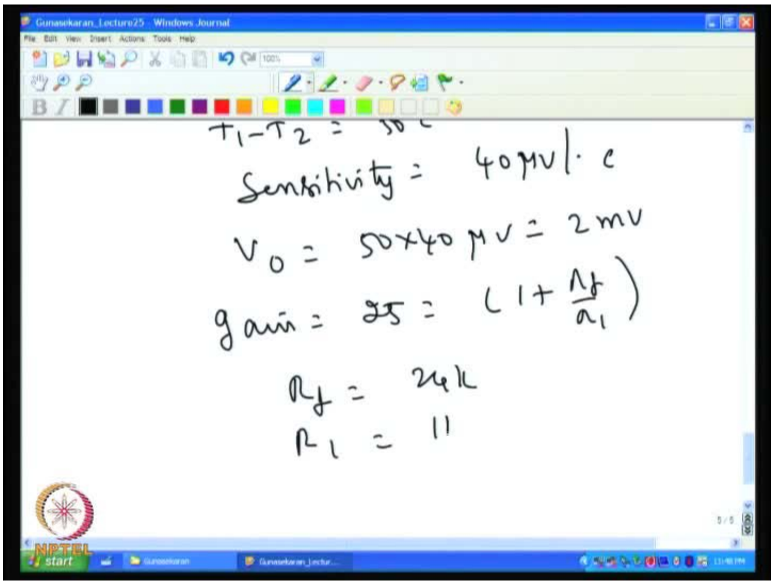

The thermocouple output voltage is T 1 minus T 2 into sensitivity that is v 0. By taking that difference in temperature, we can get the output voltage. For example, if T 1minus T 2 is a 50 degree c, then sensitivity is actually - for most of the thermocouple, this is roughly 40 micro volt per degree c, then v out actually comes 50 into 40 micro volt that comes 2 milli volt.

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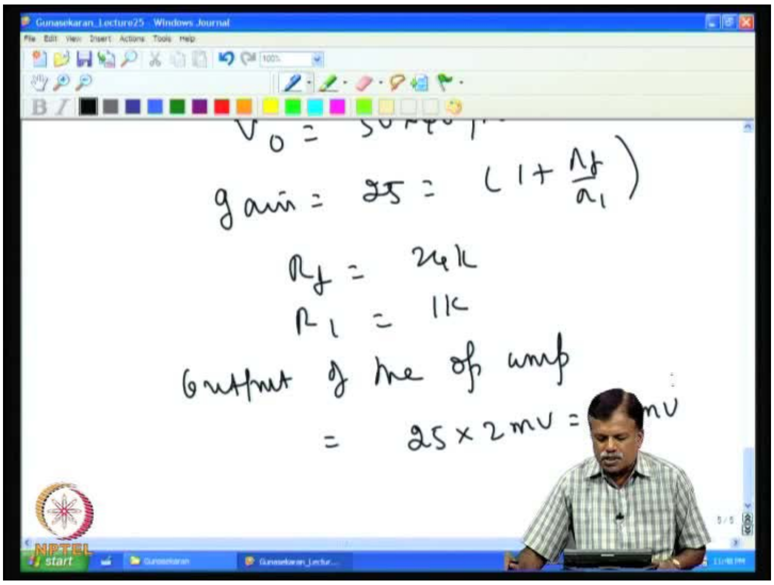

For 50 degree temperature difference, then we will have 2 milli volt as a input, then if we take gain as 25 that is equal to 1 plus R f by R 1. By taking R f is equal to 24 k and r 1 is equal to1 k, one can get the gain of 25. So that will give v output of the op amp. So, output of the op amp will become actually 25 into 2 milli volt that actually become 50 milli volts. So, this what one can expect in the ideal op amp case.

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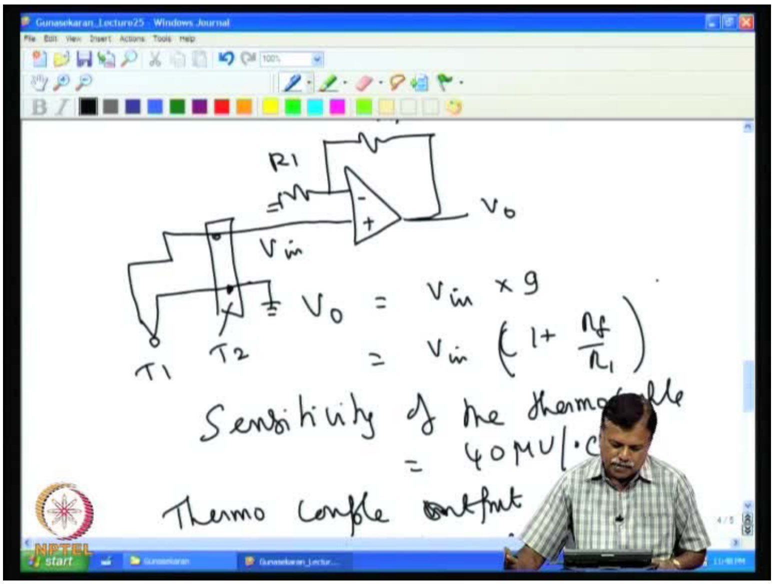

If it is ideal op amp, then if this is for example at room temperature 25 degree c and this is of 75 degree c, then the temperature difference is between this and this is 50 degree. Corresponding to 50 degree, this will put 2 milli volt, 2 milli volt multiply by 25 that expected to give 50 milli volt output here. This is what expected, 50 milli volts supposed to be stable over the operating temperature of this op amp (Refer Slide Time: 10:55).

It is assumed that the operational amplifier is kept in the working environment, this is kept at the temperature where temperature to be measured; this junction is kept at the place where the temperature to be measured. The op amp is probably kept in the room temperature, because this is inside the instrument, but the room temperature changes, so the operational temperature also changes. That actually makes this output to drift, because offset voltages of the op amp drifts with the temperature, because offset voltage changes with the temperature. Yes, we discussed that base emitter voltages are not matched exactly for the two input transistors.

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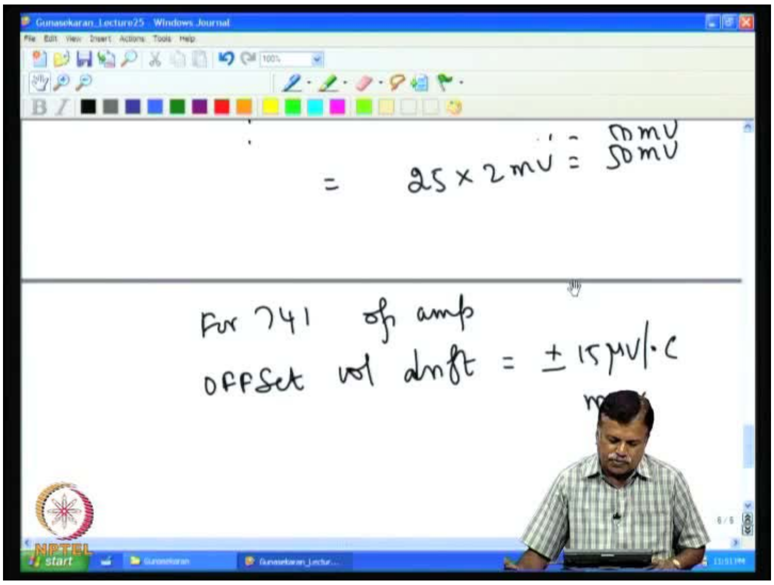

Net result is we get offset voltage drift. For example, if you take 7 4 1, then we have for example, for 7 4 1 op amp offset voltage drift is given as plus or minus 15 micro volt per degree c max. That is the maximum drift expected to be 15 micro volt per degree c. It is not exactly 15 micro volt, the polarity also not known, it can be plus or it can be minus of or some of, it can be even 0 within 7 4 1 I C itself.

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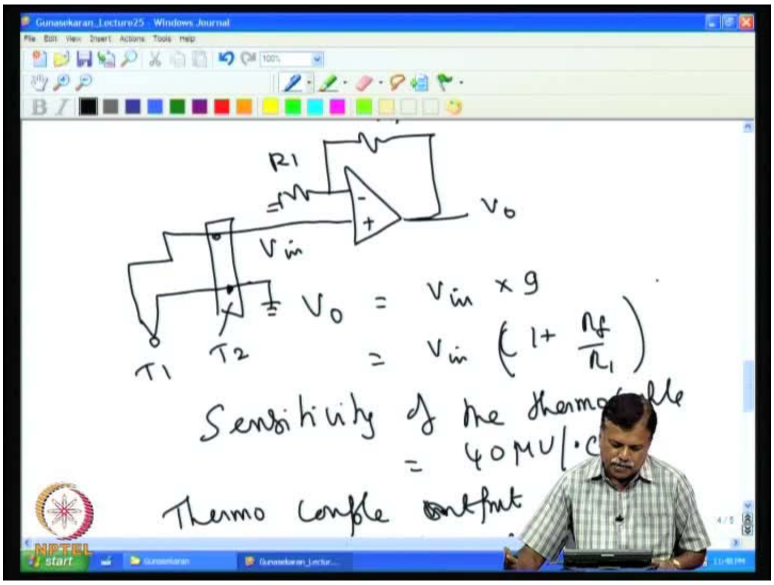

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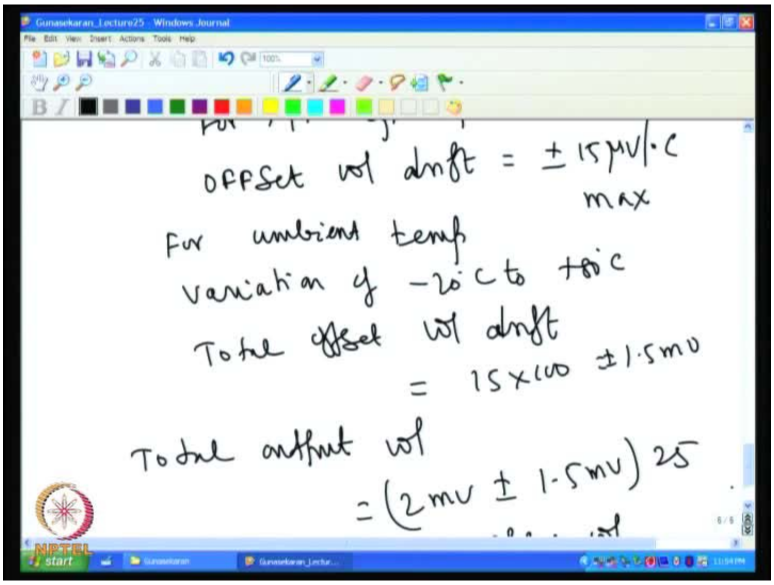

When we make this instrument, we do not know what is the drift of the op amp that what we are using? You know, we are using 7 4 1, then it is not known - particular piece of 7 4 1 which I am using has how much temperature? It is not known. One had to take always the maximum value. In this case is 15 micro degrees per C, so for ambient temperature variation of minus 20 degree to plus 80 degree c, this is the range at which industrial grade equipment supposed to work.

The room temperature will be anywhere from minus 20 to plus 80 degree, this is coming because these instrument in industrial environment might be installed straight away in the open air, where sun light falls or the ice also drops over the instrument. That is why industrial grade instrument supposed to work in these temperatures. If you are using for industrial application, then I had to assume at 100 degree variations that temperature change. In that case, if the 100 degree variation is expected, then total offset voltage drift to be calculated, to be 15 into 100 micro volts. So, total offset voltage drift would be 15 into 100 that will be 1.5 milli volts, which will be plus or minus.

At the input, we can expect 1.5 milli volt changes, because of the offset voltage change. That means, at this point, you can expect 1.5 milli volt changes due to offset voltage drift alone. So that we put the uncertainty, because that offset voltage suppose be added with the input voltage and then we should calculate what be the output. If I add the signal is 2 milli volt, offset voltage drift is 1.5 milli volt, then the total output voltage will be 2 milli volt plus or minus 1.5 milli volt into gain, which is 25.

We will have that means the error introduced by that is error due to offset voltage drift. Drift works out to be plus or minus 25 into 1.5 milli volt, which is 37.5 milli volt plus or minus 37.5 milli volt.

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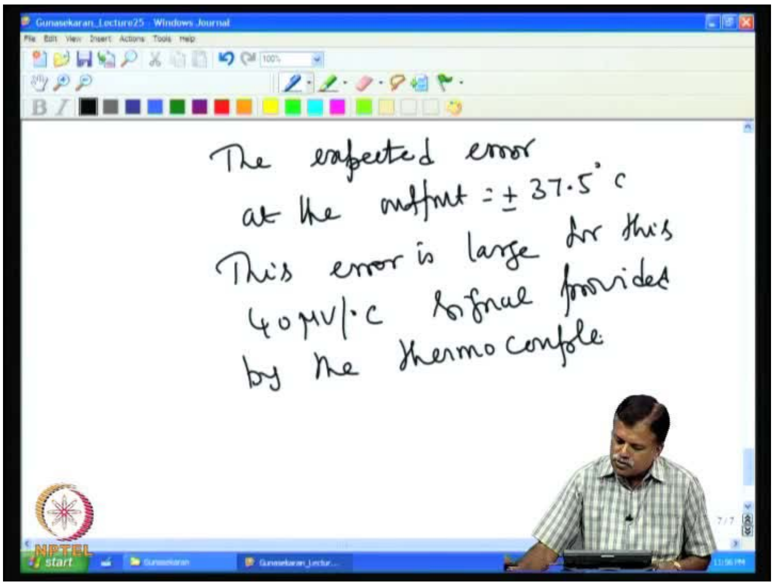

Now, if we look at this error, at the output of the op amp 1 milli volt is 1 degree c, because we had seen it is coming 50 milli volt for 50 degree temperature difference. At v 0 1 milli volt, is correspond to 1 degree error that means, if you use 7 4 1 for this application, we will have error of plus or minus 35 degree, 35 milli volt that is corresponding to plus or minus 37.5 degree error.

The expected error at the output is equal to 37.5 degree c plus or minus 37.5 degree at the output of the op amp. This is quite large, because our signal is very big that means offset voltage is a serious issue when the input signal is very low. That case one have to go for low drift operational amplifiers; for example, we have l m 7 1 4, we have L m 0 7 and so on that various operational amplifier, the class of operational amplifier meant for low level D C amplification, so one will have to go for low drift op amp. So, this error is large for this 40 micro volt per degree c signal provided by the thermocouple.

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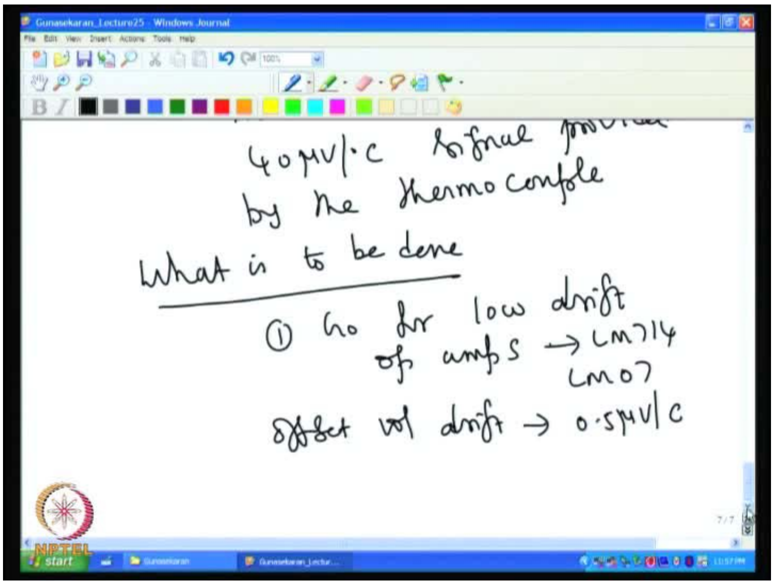

What is to be done? One had to reduce the error, then one has to go for low drift op amps; for example, we have a op amps drift as well as - for example, we have L m 7 1 4 is there, l m 07 is there, they provide offset voltage drift as low as 0.5 micro volt per degree c.

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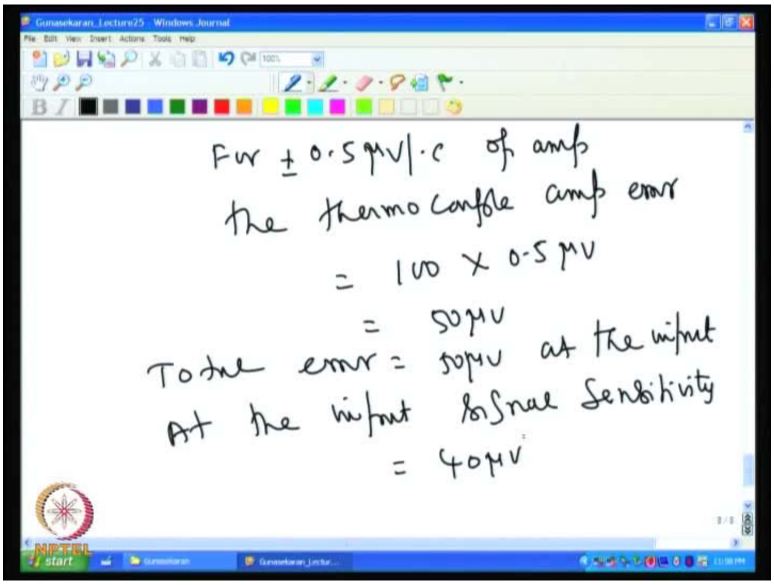

For example, if I had used this, then for hundred degree variation the total input drift would have been only 50 micro volt. For 0.5 micro volt per degree c op amp plus or minus op amp the thermocouple amplifier error is equal to 100 degree ambient temperature variation into 0.5 micro volt that actually gives you 50 micro volt error at the input.

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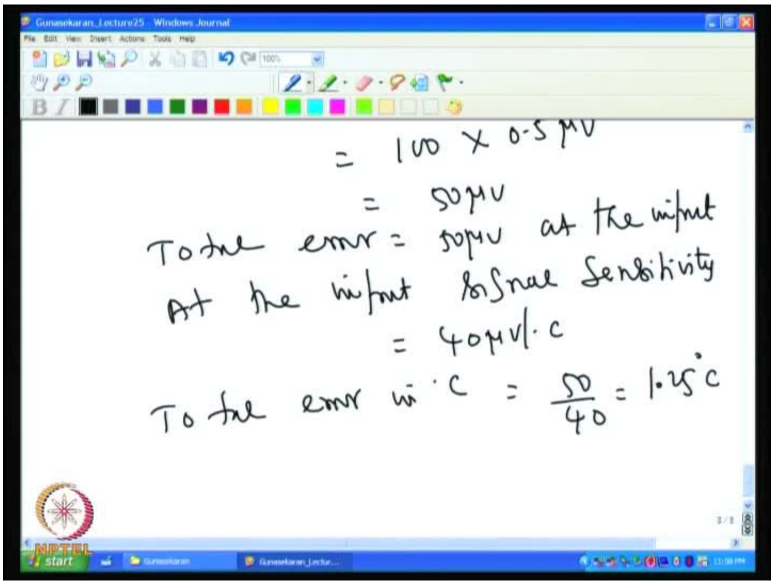

So, total error is equal to 50 micro volt at the input, but at the input, signal sensitivity is 40 micro volt per degree c. It is equal to 40 micro volts per degree c, so the total error in degree c would be 50 by 40 micro volts that comes 1.25 degree c error. If I use an L m 7 1 4, then I will get error of only 1.25 degree due to offset voltage drift. So that is why we have a class of amplifiers called a low drift operational amplifier and this very important thing one have to consider when you are designing a DC circuit. Because, one has to see what is the actual drift that is coming because of offset voltage drift?

This can be reduced only by going by the low drift op amp, because when you are making 100 of units, each op amp that you are using will have different amount of drift. One cannot say what is the actual drift for a given particular piece, so one have to take the worst case drift and then assume that is the worst error that I will get out of all these instruments.

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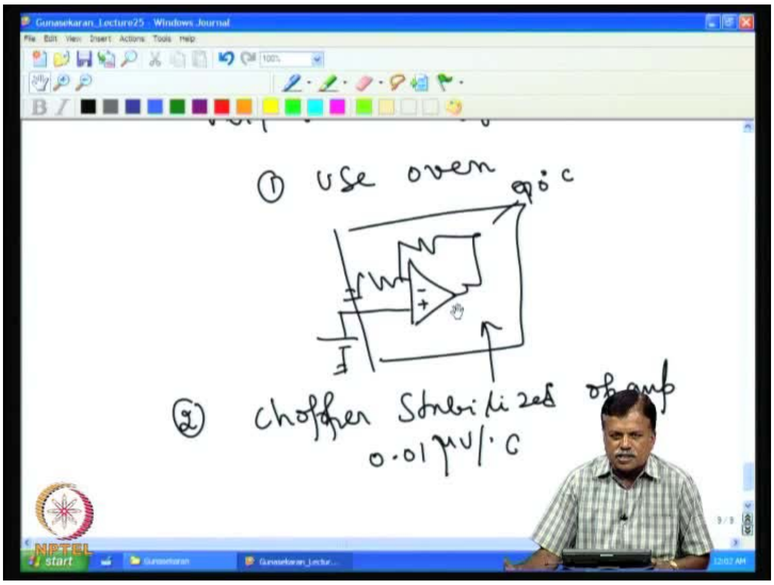

One has to go only for a low drift op amp, thus no other thing that can be done to reduce the offset voltage drifts. Of course, there are serious cases, where the temperature if the input signal is very low; for example, if I were using a sub micro volt DC signals that is to be amplified, still we do not want the DC drift to be a employed, then this can be allow oven. For very low DC signals, then the option available is use oven - small oven like crystal ovens we can have very small size ovens available, the front and alone can be housed in that.

So, what are the circuit that you have, for example if you are putting a input stage, this input stage alone can be housed, kept inside the oven, so that the temperature of this oven is maintained constant 70 degree or if it supposed to work at 80 degree ambient, then I go and keep it at 90 degree c, so the oven is kept always at 90 degree. The ambient temperature will have almost no effect on the op amp and the output of the op amp will not drift. This is one way of solving the drift problem if the signal is sub micro levels, because we do not have directly op amp, which have very low drift, like maximum you can get would be 0.1 micro degree per c drift, beyond that we do not get op amp in the low drift category. Other possibilities that are, go for chopper stabilized amplifier, where you can expect the drift as much as 0 .01 micro volts per degree c.

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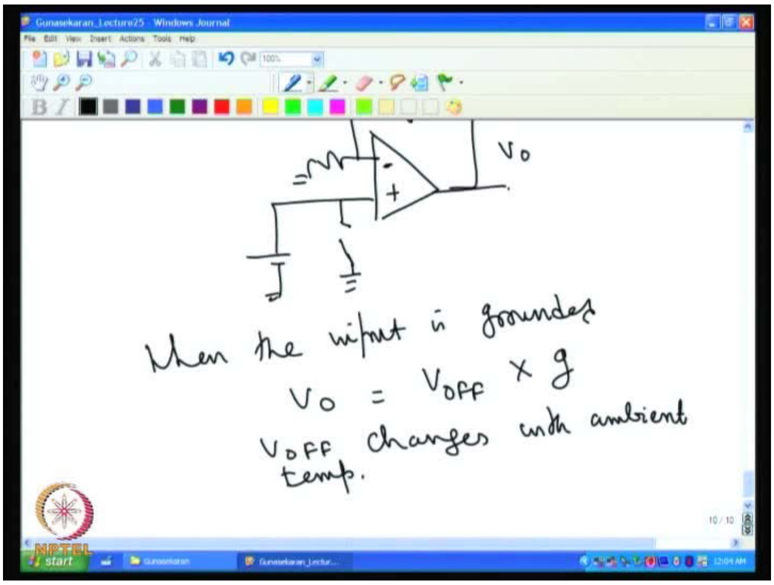

Here, offset voltage drift will be very small; these amplifiers can be used alternatively for dealing with low level signals. Operational amplifier introduces a lot of noise; we see more about this little later. The option, we have to incase handle at very low level signal, is use oven and compensate it. But, there are other techniques also being used namely that we can have auto zeroing amplifiers. That is third optional, would be to go for auto zero method.

In this method, what is done is that you have an input signal; example, the inputs signal is there connected here and then connect this. Normally, what is done is that offset voltage with the op amp, you before - for example, if you want to make measurement of this output voltage, what can be done is, we can have a switch here. For example, I can have a switch, I can start this and make it a ground, so I expect 0 volt here. But, then normally you do not get 0 volt, you will get the input is 0, when the input is grounded, v 0 is actually v offset into gain that offset voltage - v offset changes with ambient temperature.

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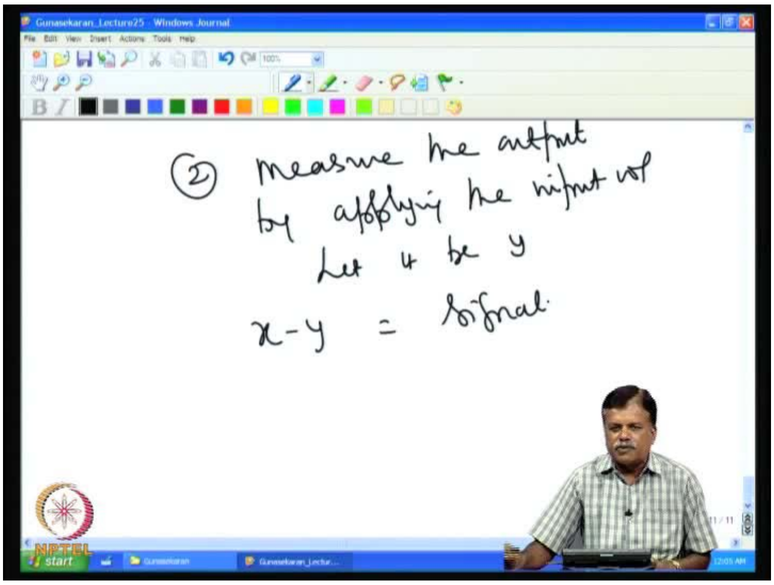

Before making measurement, initially you start this one to 0 and take this voltage. This voltage can be stored x, then open the switch s and then make the measurement, let that voltage by y. So, difference between these two x and y gives you the input voltage. What is done is that step one is measure the output by grounding the input, let it be x. Then, second step is measure the output by opening the, by applying the input voltage, let it be y. So, this is done all that time, so that x minus y gives you the signal.

Before each and every measurement, you have to ground it and see the output voltage, then open the switch and see the voltage. That means two measurements are to be carried out each, every point in every time we want measurement, one have to do this. Then, the offset voltage can go off, this helps us to certain extend. If the drift is too high even this technique will not work, either drift is reasonable then this technique works.

Obviously, you can see that in analog circuit, you will be fighting most of the time against this offset voltage drift. This is one of the important problems or one of the difficult problem one to crack in analog circuit design, particularly when you are dealing with the low level DC signal. One has to be aware how to calculate this offset voltage drift.

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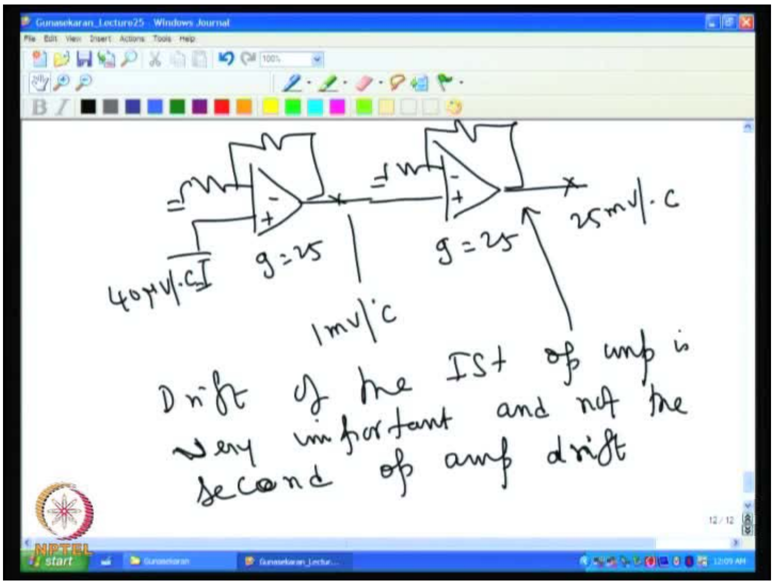

Now, if you are having multiple stages, then most of the input stage are the one you have to vary. For example, if I am amplifying a small signal, if we have a several stages of the amplifier, second stage for example thermocouple amplifier, then second stage again, if I am putting a another gain of 25, here gain 25, another stage which gain 25, then if this is 40 micro volt per degree c, I can expect here one milli volt per degree c signal. Here, actually you will get 25 milli volts per degree c signal, where again here is 25, here 40 micro volts becomes 1 milli volt, then 1 milli volt becomes 25 mill volts here (Refer Slide Time: 29:00).

Now, the drift of this op amp - second op amp is not a big concerned, the drift of the first op amp is very important, but not the second op amp drifts. This is because, for the second op amp, the signal is now 1 milli volt per degree c. So, the maximum offset voltage drift, even if I take 7 4 1, the maximum offset voltage drift expected it is 1.5 milli volt at this point. Signal is one milli volt and drift is 1.5 milli volts that mean the error expected here is only 1.25 degree. Here, I can use 7 4 1, whereas if I use 7 4 1 here, the expected drift is 1.5 milli volt at the input and the signal is 40 micro volt per degree c, this will equivalent 37.5 degree error that as we calculated.

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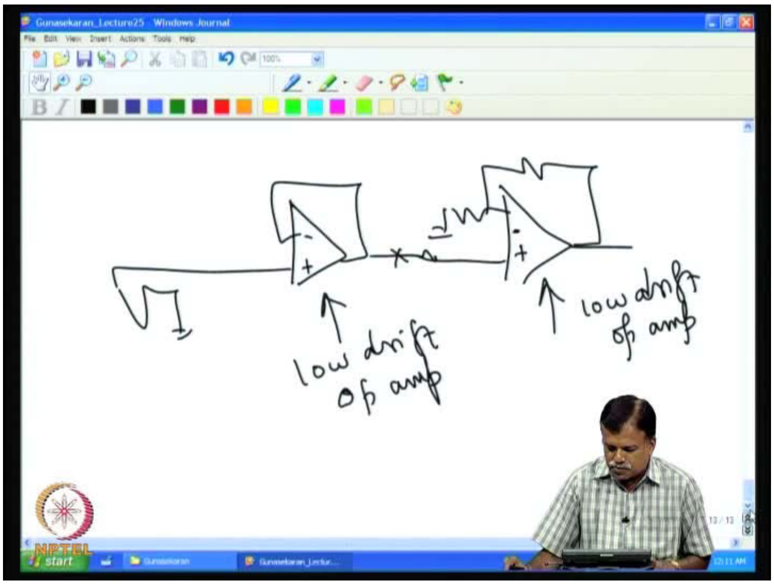

Since the signal is amplified here, the second op amp drift is not a serious issue and again, you have to see how much the signal is amplified. If you use the first op amp as a voltage follower, then even for the first, second one drift matters. For example, if I had used a first voltage follower, then we have to pay the price, because now the drift of both op amps comes in to the picture, because here signal is not amplified at all at the first stage. So, the drift of this should be low, so low drift of op amp is required for this, as well for this.

Both has to have low drift characteristics, then only the error can be controlled, so one had to be careful that whenever using a voltage follower that use the D C case, only if it is essential we have to use, otherwise we will be adding of the drift of this plus this or we look for low drift of op amp for this well as this. Because, low drift of op amp comes with the price that it cost more, so one have to be careful in looking for low drift of op amp.

Once you are able to calculate for any given circuit, what is the total error due to the offset voltage drift? This is an important aspect, one had to work out to various circuit models and see how much error that it is coming. For example, I can put one small circuit, for example constant current source which have discussed, for that we can find out what is the error due to the offset voltage drift.

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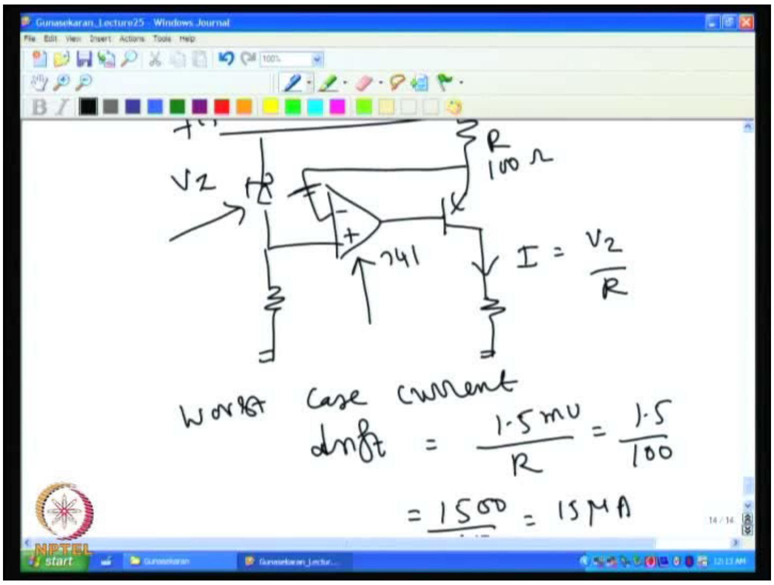

Like for example, if I have the circuit like this, in this case, offset voltage drift of this op amp will give error. This drift of this zener will give a current error, there is a current source, this is V z, this is plus 15, this is R, so you get this current I is actually V z by R.

The drift of this will directly effect this one, similarly if the offset voltage of this op amp drifts that is to be assumed as V z is drifting, because offset voltage can be added like this, either plus or minus. So, offset voltage drift directly gives a error; for example 7 4 1, then if it is 100 ohm, then worst case current drift would be 1.5 milli volt divided by R, whether if it is 100 ohms. Then that will come, as you know, if we convert into micro volt, then will have 100 that will be 15 micro amperes current drift, is expected because of the offset voltage drift. You may think that one can compensate this while putting the diode that is not possible. As we said that this offset voltage drift is not known for the particular piece, 1 7 4 it can be even 0, another one it can be even plus 10 micro volt per degree c, then third one it can be minus 10 micro volt per degree c. So, the compensation is not possible for the offset voltage drift.

One have to make an error budget and make sure that the total error that is coming due to offset voltage drift is within the acceptable limit. That is the only solution that one can think of as per as offset drift voltage is concerned. By now it would have been very clear that offset voltage drift is a big bottle neck in the analog circuit design, for DC circuit, this is the major source of worry for any analog circuit designer.

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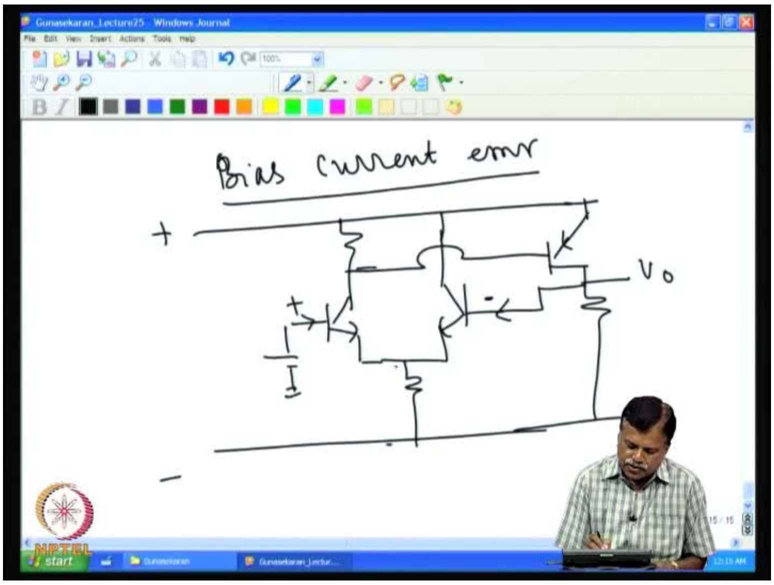

Next, we see the other error that is namely offset current drift error or bias current error. Now, the bias current error is coming, if you look back our original simple op amp circuit that we had this and then we had this. This are output, then this is plus, this is minus, we have plus input here and then this minus; for example, I connect this to this. Now, if you look at the base currents of this, this base current here and there is a base current here; this is a voltage follower (Refer Slide Time: 36:00).

Now, this base current always is flowing into the operational amplifier; for example, this is a NPN transistor and that is always a base current. So, unless base current is there, the operational amplifier is not going to work that in this case transistor is not going to work. There is always a base current, the base current of this, base current of this, they need not to be equal and even if they are equal at one temperature, they need not be equal at another temperature. So, we can define this base current as a bias current.

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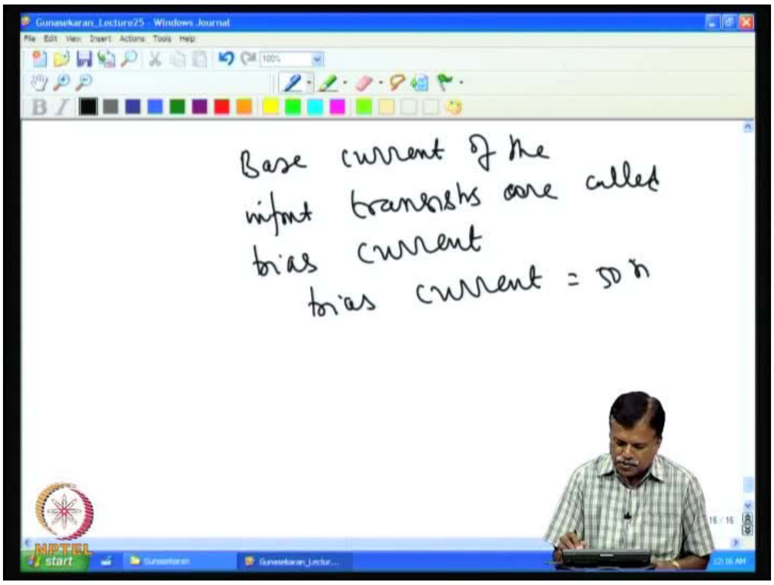

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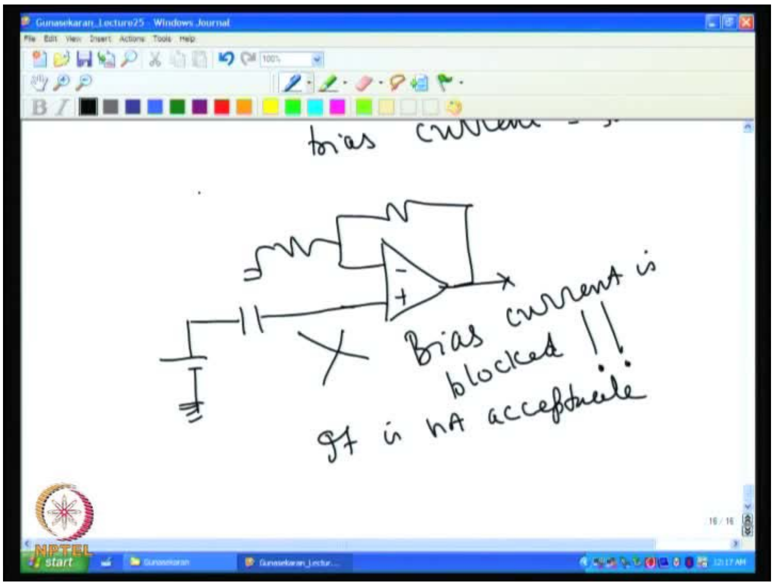

The base current of the input transistors are called bias current; for example, if you take 7 4 1, we say the bias current, where can you say 50 by gamma nano ampere. There is a current that is flowing through the base, is in nano ampere range. This current is must and it is not been blocked, if it is blocked, the operational amplifier will not work. For example, if I have a circuit, the operational amplifier circuit like this, you have the input, for example if I have one gain, so I put the circuit like this, which should not to be done, connect this, then I put one capacitors and connect like this (Refer Slide Time: 38:36).

This circuit will not work, because the capacitor will block the bias current that is flowing to this. The output will be always be saturated, because through leakage resistance, the current will flow, on this point will claim up to a large value and that will force output to saturate. So, this bias current is blocked and it is not acceptable.

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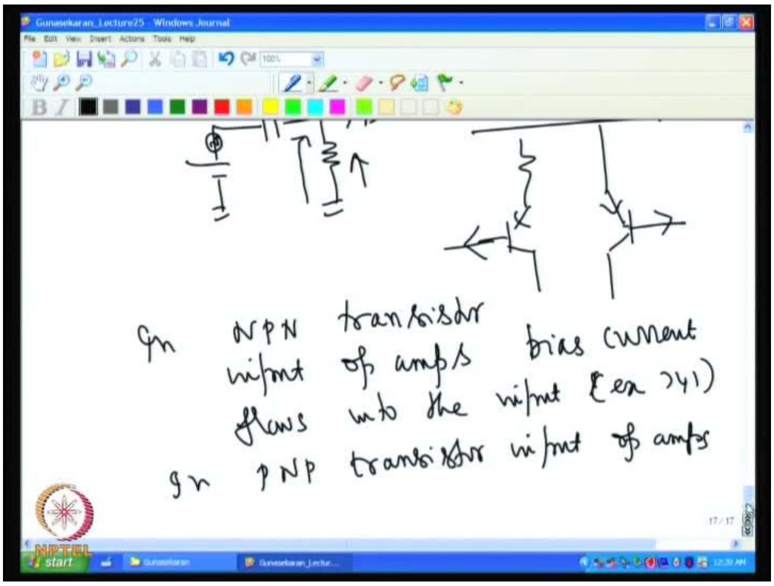

If I want to do this, then we have to offer a fast further resist bias current. If you want you can do like this, if you want, you can have the input voltage. If you want to apply for some reason, you want to block the DC component going here; for example, I may have DC and AC, you want to block the DC, there I should use the resistance here for the bias current to flow. In this case, the bias current actually flows through this, then to the base of the transistor and then to the ground, so the bias current actually now flows through this (Refer Slide Time: 40:10).

Similarly, the bias current for this, for example, the output is plus, then the bias current actually goes like this, then it goes and then into the ground. There are two types of op amp that is if the inputs are N P N, then you have the bias current always flowing in; so if the bias current in this cases always flowing in. If it is the P N P transistor in the input, then the bias current will be always flowing output; for example, you may have system like this, the input for example, L m 3 2 4 is having this kind of configuration that input stage is, actually is a P N P transistor, in that case, bias current is flowing out actually.

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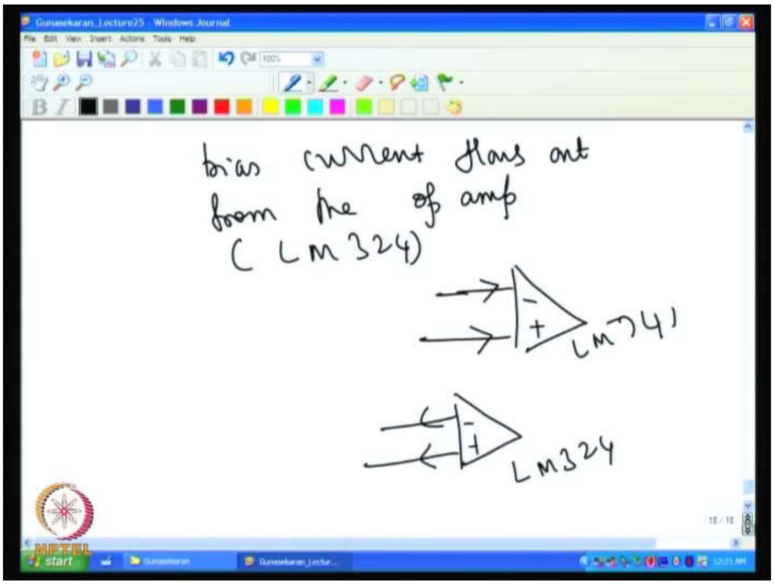

In N P N transistor input op amps, bias current flows - bias current flows into the input. Most of the op amps are like this; for example, 7 4 1 and so on; 7 4 1, 7 1 4 all this kind of most of the op amps are actually N P N type and the bias current actually flows in. In P N P transistor, input op amps bias current flows out from the op amp, for example, L m 3 2 4. So, the direction of the current - bias current depends on the type of the op amp, it may be flowing like this or it may be other way round. You may have minus plus and bias current may be flowing out like this; this is L m 3 2 4, this is L m 7 4 1.

Now, the question is what is the problem with this bias current? Because, bias current is essential one, without that the op amp will not work. So, there is always a bias current and the bias current always flows either into the op amp terminal or it flows out of the op amp input terminals.

Now, the question is what is the effect of this bias current? It is another major worry for analog circuit designer as for as accuracy is concern. Because of the bias current also introduced lots of DC error similar to offset voltage drift that we have to seen so for. So, one have to be careful listening the op amp circuit, then one should make error budgeting considering the bias current introduced errors.

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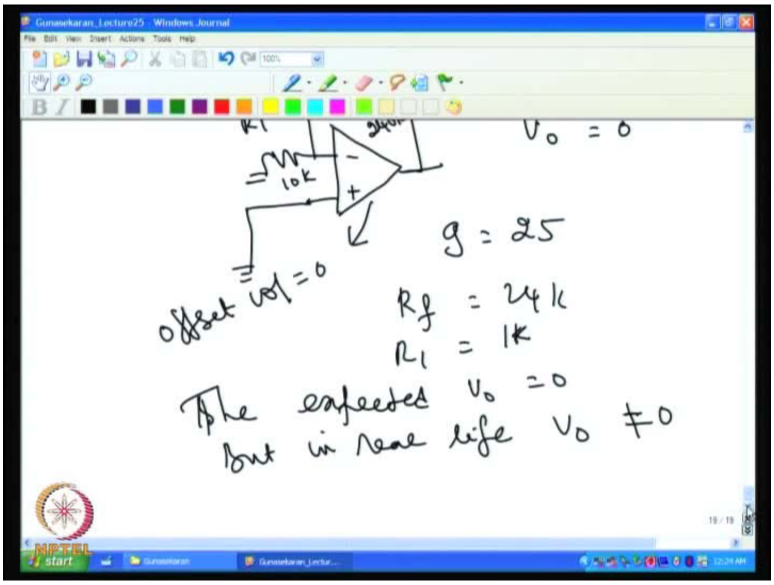

Let us take a simple circuit and see what effect bias current is creating. You have plus minus here, then for example, I have low input signal, I have grounded the input straight away, then I have connected the two resistors to give a gain here. For example, here R f and R 1, I need a gain of say 25, then we put R f is 24 k and R 1 is equal to 1 k, then I will get a gain of 25.

Now, for example, I had put here 240 k resistance and here I put 10 k, then I have a gain of 25. Assuming that offset voltage is 0, there is no offset voltage, then the input is 0, so v in is 0, so the expected v output also equal to 0. There is no offset voltage, but in actual case, even though there is no offset voltage and even there is no signal, the v 0 will not to be equal to 0, but the expected v output is 0, but in the reality, the real life, v 0 is not equal to 0. This is because that if you see, the bias current for this op amp have to go, now the bias current it comes like this, the input from the output it goes to the resistance, then it goes through this and then goes flows into the ground. That means through this 240 k resistance the bias current is flowing; for example, if it is a 7 4 1, the bias current is 50 nano ampere.

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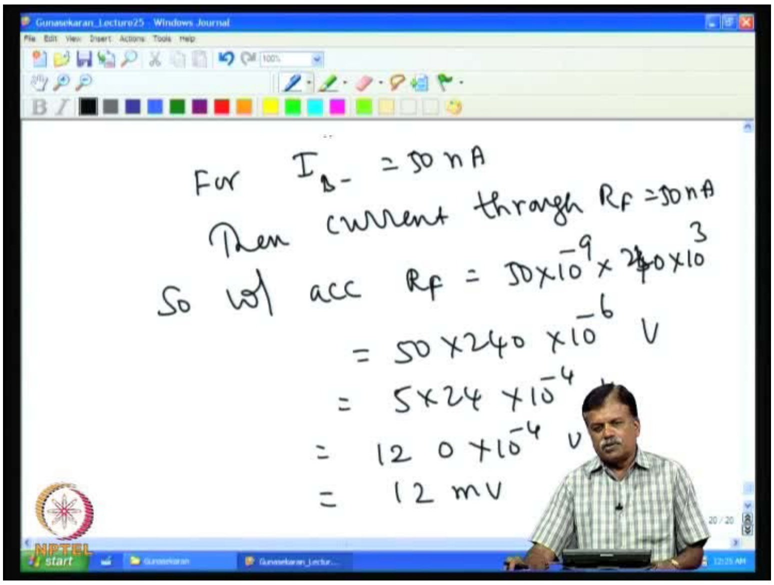

For I b minus equal to 50 nano ampere, then current through R f is equal to 50 nano ampere. So, voltage across R f that is equal to 50 nano amperes into 240 k that comes 50 into 240 into 10 to the power minus 6 volt. That comes 5 into 24 into 10 to the power minus 4 volt, 120 into 10 to the power minus 4 volt that is equal to 12 milli volts. That means, even though there is no offset voltage, it can take the op amp which has 0 offset voltages, still I will get the output 12 milli volt. This is because bias current has to go through this, without the bias current op amp is not going to work. So, the error introduced by this, with the offset bias current is 12 milli volts.

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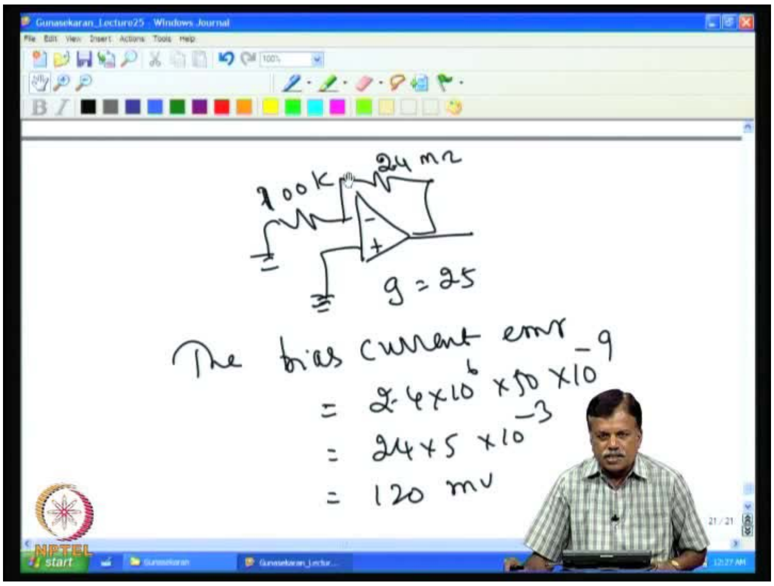

The error due to bias current is 12 milli volt; for example, if I had used the resistance - much higher resistances, for example, for this same 25 gain if I had used - for example, here, I can also go 2.4 meg, then 2.4 meg divided by 24 that comes 100 k. This also gives me gain of 25, because that again is equal to 25.

Now, the resistance what you use is 2.4 meg, now the bias current error becomes 2.4 meg into 50 nano ampere, which actually if you work out and see, you soon you will get 120 milli volt, because, you will get 24 into 5 into 10 power minus 3 that comes 120 milli volt. So, the bias current error becomes more as soon as increase in the resistance value.

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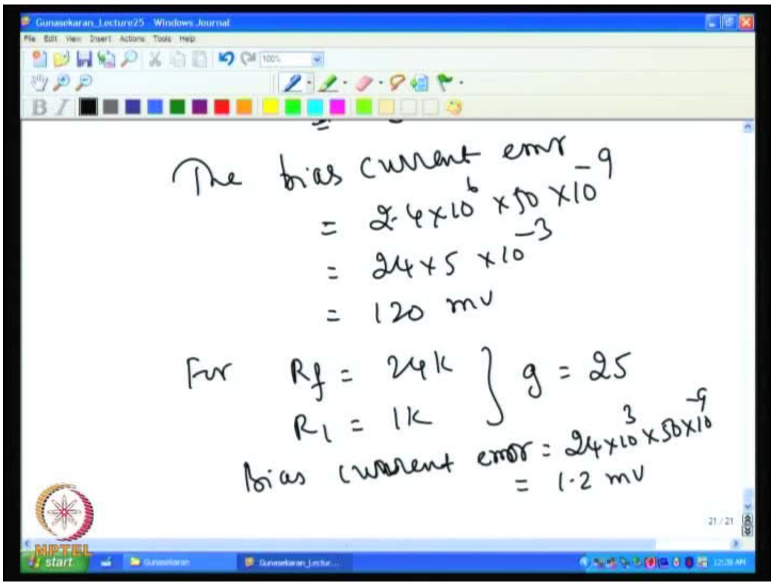

If I want to set the gain, then I should not put any resistance like. Higher the resistance that they put at the feedback, then higher will be the error. This error is irrespective of the offset voltage and offset voltage drift. This error is coming purely because of the bias current, whereas if I use very low resistance, for example if I use for R f is equal to 24 k, then R 1 is equal to 1 k, then the gain comes 25 - same gain 25.

Now, the error will become bias current error, actually you will have 24 k into 50 nano amps that will come 1.2 milli volts. So, smaller the resistance, then bias current will be lower. Now, we may wonder that why we worried only about one bias current that is only the current that is flowing through the minus may alone worried, then never worried about the bias current that is flowing through the plus terminal.

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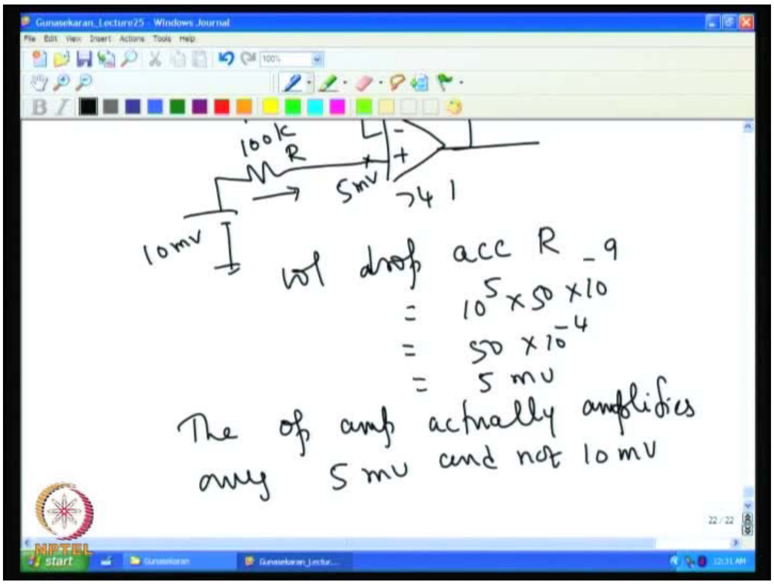

Now, actually in this case, the current is here also flowing through this, but there it is not developing any voltage, because there no resistance here, because of that we are not worried about the plus error. But, if you have a circuit like this, for example, I have a circuit like this, then for example, I have an input and I have a resistance here. Then, for the plus terminal, bias current actually goes through this. For example, if it is having 10 milli volt signal, if I have a 100 k resistance, then if it is 7 4 1, then the bias current actually goes through this. The bias current actually flowing through that will produce the voltage drop across this. So, as long as this is 10 milli volt, now the voltage drop across this R - across R would be 100 k 10 power 5 into 50 micro amps 50 nano ampere. So that will come 50 into 10 to the power minus 4 volt that is equal to 5 milli volt (Refer Slide Time: 50:58).

You will have the 5 milli volt drop across this that this will be higher, this will be lower that means it is like this, because the current is flowing like this. So, this will be higher, this will be lower, so eventually what happens is, this voltage is subtracted. So, if I have here, this voltage now is 5 milli volt. Actually, what you get at this point is not 10 milli volt, 10 milli volt minus 5 milli volt you get only 5 milli volt at this point. The op amp actually amplifies only 5 milli volt and not 10 milli volts.

That means, the plus terminal bias current also introduce an error, this error also can be large if the source resistance - for example, this 100 k may be as source resistance itself.

If this source resistance is high, then the error also is high or sometimes we add this resistance for protection purpose, because we do not want some large current flow into this. So, we add this resistance, should limit the input current let's flowing to the op amp. So, in that case this resistance introduces an error.

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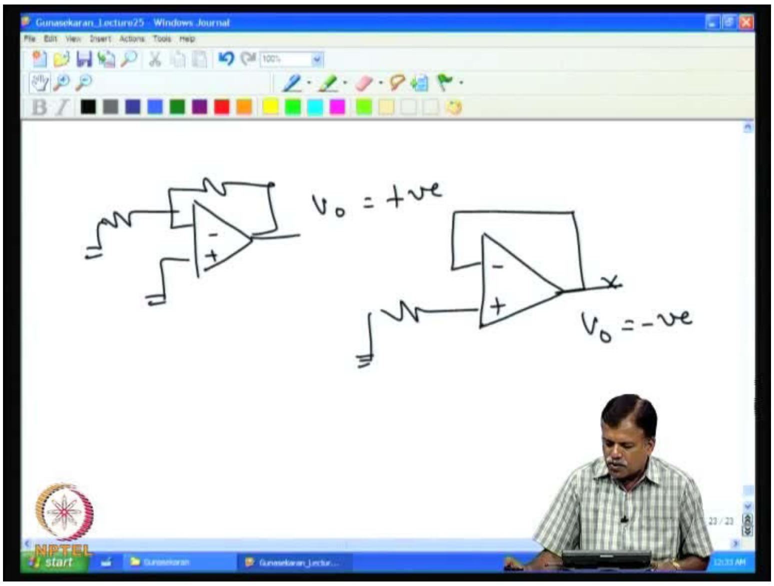

Now, you can see quickly that bias current at the plus input produce the minus voltage that is, whatever voltage that is developed is actually minus in the sense that the input voltage minus this is what is appearing here. Whereas, in the earlier case, when the current was flowing through the minus that output voltage comes plus, because the extra voltage is coming. That means the bias current at the minus terminal produce a plus voltage, the bias current at the plus terminal produce a minus voltage. That means, if I can show like this, for example if I have a two circuits, if I have this and then input is a ground, then I get V error V 0 is equal to positive; output will be positive. Whereas, if I have the same thing, then I have no signal, I connect at this and then I connect this here, now the v output is minus voltage.

The plus terminal voltage produce a negative error and the minus terminal bias current produce a positive, in the sense the output is positive in this case, output is negative in this case.

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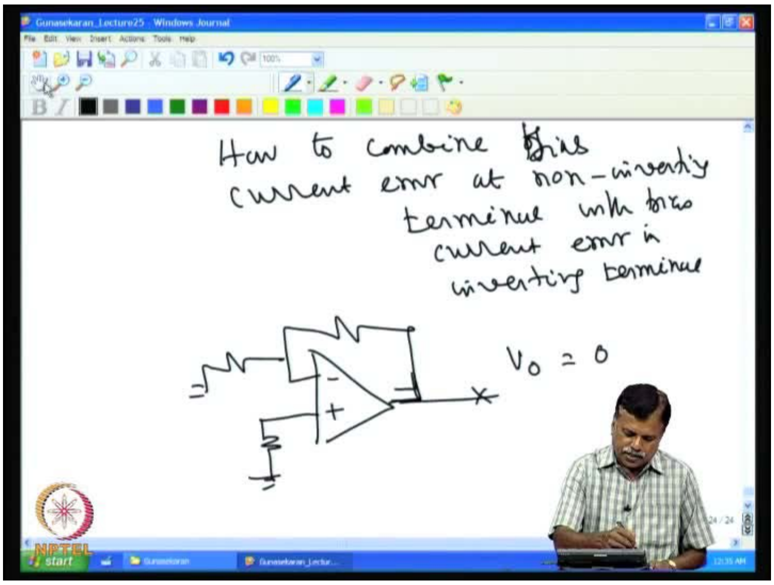

Now, one interesting thing is that from this can damage that - if we can combine in this positive and negative, if they are equal, then one can make the output equal to 0. That is the bias current error can be removed, provided the two errors are identical. One possible resistance for this would be like this; for example like have a circuit like this (Refer Slide Time: 55:40). How to combine both errors? How to combine the bias current error - current error at non inverting terminal with bias current error in inverting terminal? This kind of common sense is used very often in an actual circuit. Now, what can I do is that we can a put the circuit like this, I can have this and I can have this, I can have resistance here.

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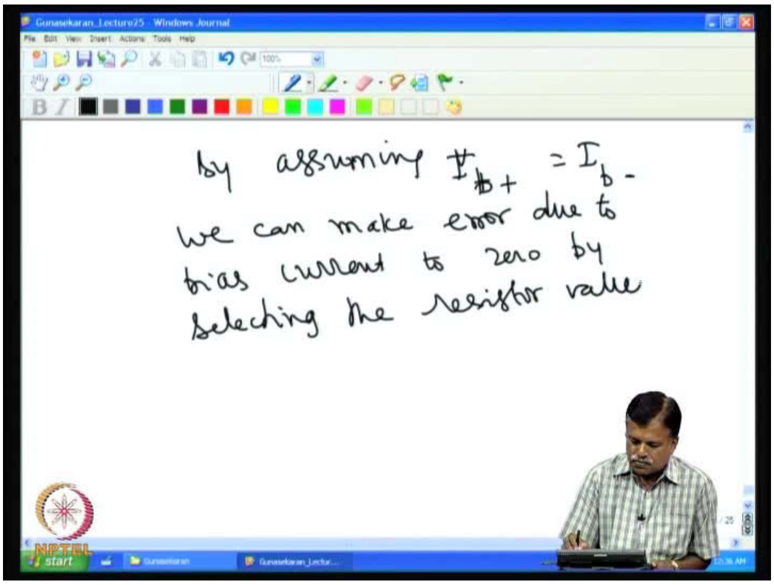

Now, I have no input voltage, assume the offset voltage is 0, then I can have the v output can be made 0 even though there is a bias current, because the bias current for the minus terminal is flowing like this and producing the positive voltage. Bias current for plus terminal is flowing like this and putting minus voltage at this point. The minus voltage amplified by this will be the output (Refer Slide Time: 56:54). If this resistance and this resistance are correctly selected, if these two bias currents are equal, this current equal to this current, then we can make the output goes to 0. So, this kind of adjustment has to be done. By assuming I bias current plus equal to I bias current minus, we can make error due to bias current to 0 by selecting the resistor values.

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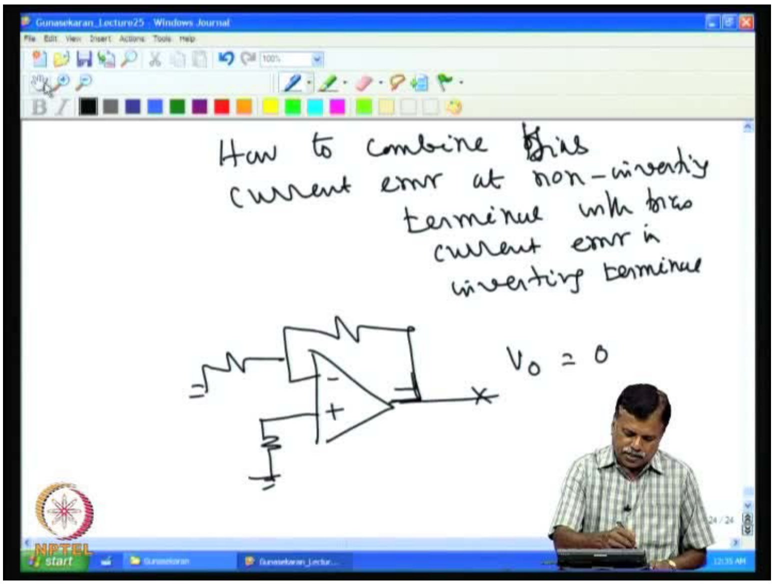

Now, for example, if I have a gain 25, then I can select this R f and I call this is R b such that this if they are correctly selected, then I can make the output voltage 0 and then the bias current error appears to be 0. We calculate these values correctly, but that we do in the next class.

One thing have to remember that this compensation works only at one particular temperature, because even if the bias currents are not exactly equal that is one problem; that is this current and this current are not equal (Refer Slide Time: 59:00). Even if they are equal at one temperature, they are not equal at all other temperatures. So, this compensation to be looked only with this approximation that they may not be exactly come to 0 to all temperatures, there can be an error. We discuss more about this in the next class, thank you.