# Circuits for Analog System Design

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**Module No. # 03**

**Lecture No. # 14**

**Error budgeting for temperature Indicator**

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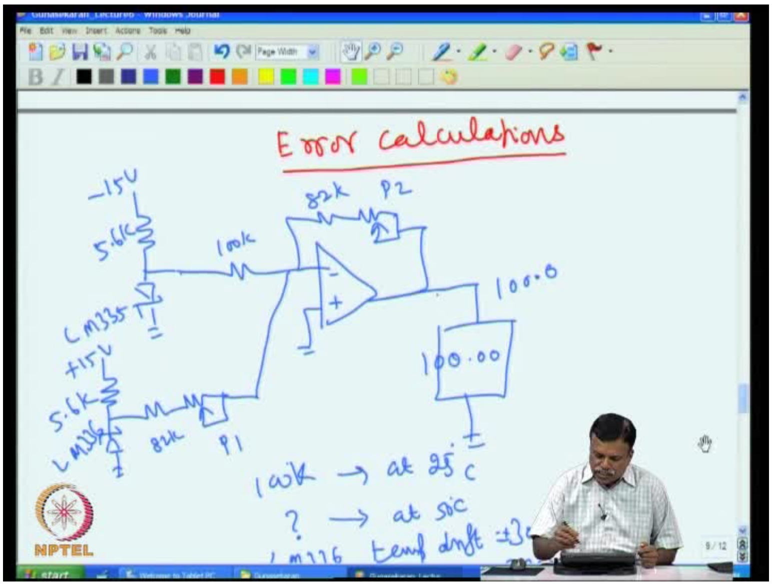


We discussed about temperature indicator, and this is the circuit that we have used in the previous class to construct a temperature indicator. Now in this class, we will discuss about how to compute the various errors involved in this, because in analog circuit error computation is very important, because whatever we construct that should give a accurate result.

So this class we concentrate more on error calculations or we call generally in analog domain, we called this error budgeting, the error budgeting has to be done. So, this is the circuit that we have used in the previous class here actually we had used this L M 335 as a temperature sensor. L M 336 is a 2.5 volt reference zener since this L M 335 gives at 0 degree c 2.73 volt to compensate that 2.73 volt we have put this L M 336 which is giving 2.5 volt and then we adjusted this resistance to make sure that at zero degree c this is giving 2.73 at that time output comes zero because this polarity and this polarity are opposite you know this is minus this is plus. So this voltage actually subtracts that 2.73 volt which was coming there, so net result is at zero degree c it gives you zero volt 100 degree c it is giving you 1 volt that is what we had seen in the last class. And we also explained how to calibrate this using ice and boiling water because you keep this one at ice and then adjust the adjust this P 1 to get zero degree c and then keep this one at boiling water adjust P 2 to get 1 volt. So, this is to be repeated three four time P 1 P 2 adjustment to be done three four time that is first you keep in ice adjust this then keep it at boiling water adjust P 2 then again go to ice adjust P 1 again go to boiling water adjust P 2 like that three four times if you repeat then you will get at zero degree c zero volt at 100 degree c you will get one volt this is what we had discussed in previous class and then we also said that what are the errors involved.

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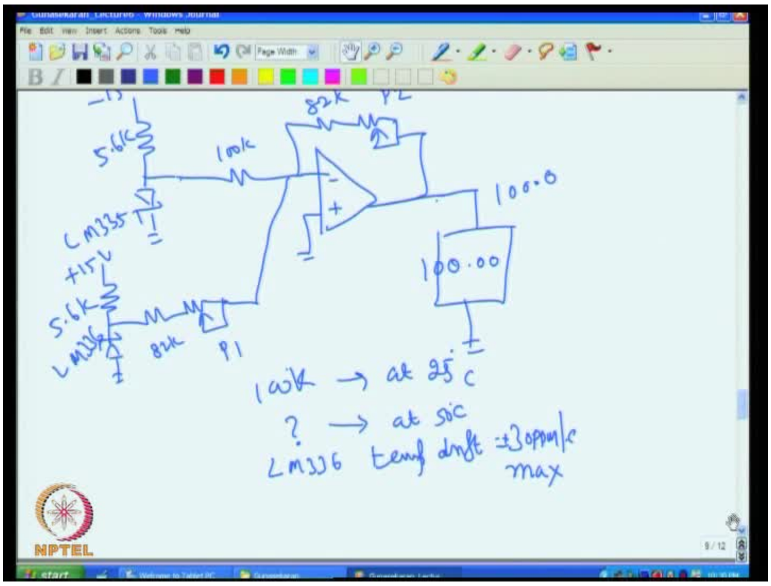


Now if we see this this is a zener voltage this L M 336 gives you 2.5 volt fixed at all temperatures it is supposed to give only 2.5 volt and the voltage here should not vary with temperature. But, L M 336 zener voltage varies with temperature that we had shown in the previous class as even if we look at the data sheet of L M 335 that gives the L M 336 L M 336 is the zener this temperature called as 30 P P M per degree c maximum that is the rating that was given for this.

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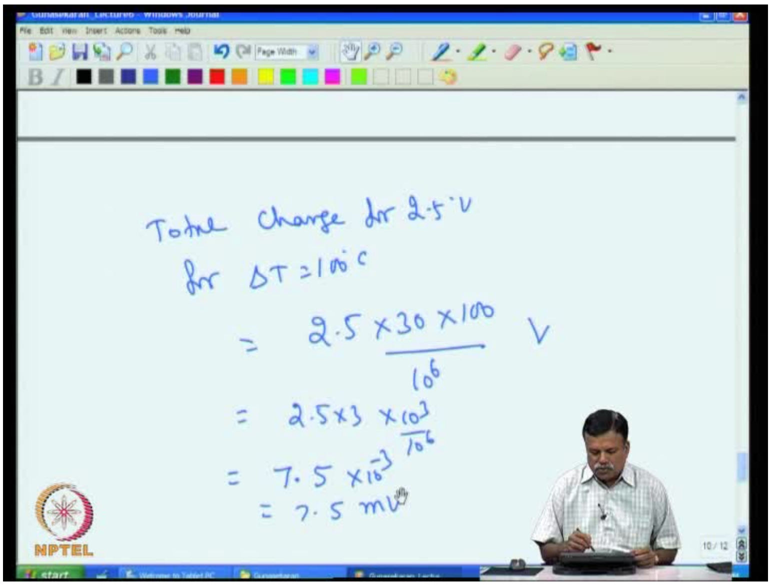


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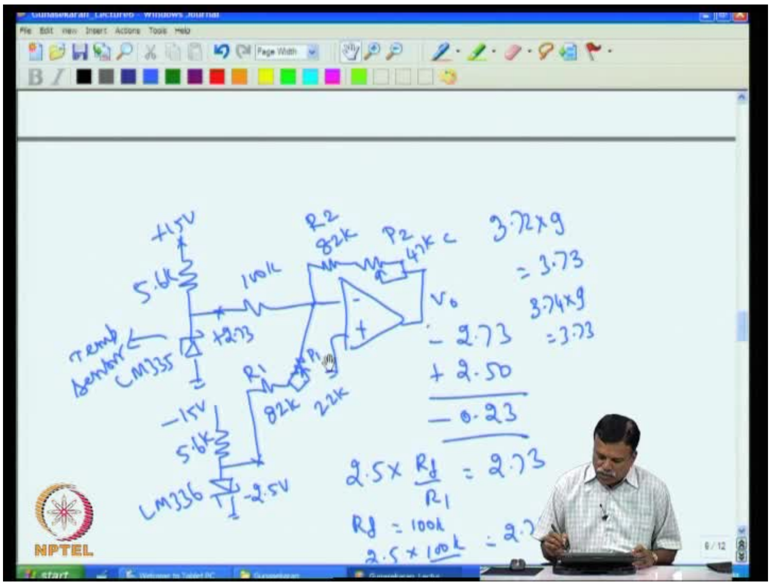


So if you calculate that then we ended up in the previous class total drift zener voltage comes to be 7.5 volt for example, if you see this total change for 2.5 volt for 100 degree temperature variation 2.5 into 30 P P M into 100 degree c that works out to be 7.5 millivolt change. That means the zener voltage changes by 7.5 millivolt when temperature change of 100 degree occurs. Now, if that means if I go back to the our this circuit if this changes by 7.5 millivolt obviously this voltage also will change. Here for example, this and this more or less gain of one if you want to know exactly we have to find this divided by this resistance that will give you exact gain. But if you see rough estimate it is one is to one so here 7.5 millivolt change will produce nearly 7.5 millivolt change at the output, that means you will have with when the temperature of this changes or the temperature of the ambient temperature changes because ambient temperature can changes as I said for industrial grade equipment minus 20 degree to plus 80 degree if taking as 100 degree change you can expect 7.5 volt millivolt change here. But at this point 10 millivolt change is considered as a 1 degree c that means because of the ambient temperature change the zener voltage changes and the output voltage changes because of that and you have error of 0.75 degree plus 10 millivolt is 1 degree c 7.5 volt end up in having 7.5 degree error. So this this zener drift alone gives 0.75 degree c error at the output so this is a first error so if you then if you look at the other errors for example, this is the resistance that we are using the resistance value also will change with temperature this resistance also will change with temperature this also will change with temperature.

There is a another error that we can we have to worry about it because when these resistance change the output voltage will change as so even though the temperature of this is not changing the output voltage will appear to be the output voltage will change and that will appear to be a temperature change. And that is a significant error one have to look into this then to look in the operational amplifier by itself the operational amplifier is having offset voltage the that means that even when I give which for example, I give here zero here zero then I expect output supposed to be zero but, you will not get zero the you will get some output voltage and that voltage is coming because of the offset voltage and the offset voltage normally represented with respect to the input.

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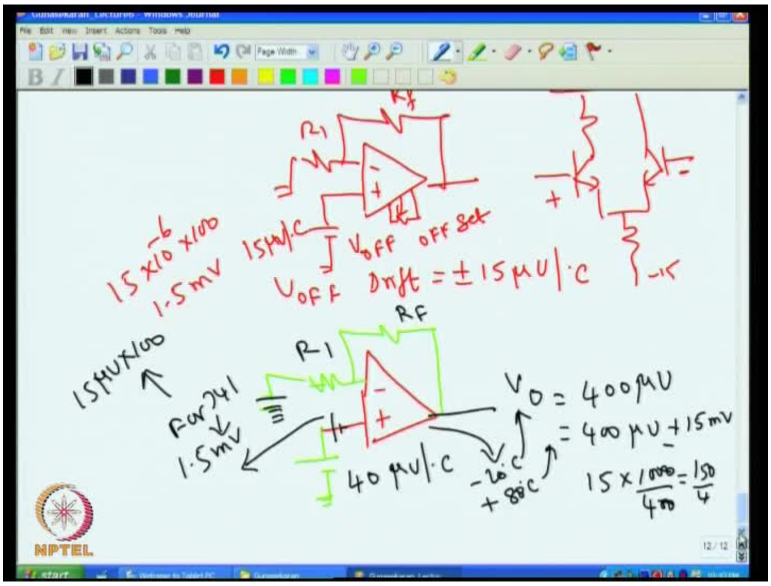


So now if you see the look into the operational amplifier the I can show like this, if I take the operational amplifier and then draw this we can show that it has a offset voltage and then if I have a gain that depends on this R F and R 1. Then this is v offset this is not the input voltage that I am applying this is the actually the offset voltage this is there internally the operational amplifier and if you look at our discussion the offset voltage is nothing but, the voltage base emitter voltage difference between the 2 transistors because now I redraw that operational amplifier circuit here that we look at the operational amplifier circuit that you have the 2 transistors at the input and that is connected to this recall our old circuit. You know plus 15 here and minus 15 here and this is coming plus terminal and this is coming as a minus terminal the base emitter difference between these 2 transistors that we have base emitter voltage difference. Here base emitter voltage this as a base emitter voltage this base emitter voltage difference base emitter voltage minus this base emitter voltage if both are equal then offset voltage is zero but, there is small difference between the two base emitter voltages this and this that is actually coming as a offset voltage in fact offset voltage itself is not a big problem because when if the offset is there you will get output voltage amplified by the gain and appearing at the output.

But there is a provision in the operational amplifier adjust offset that I can have if you see this one that is I call is offset voltage adjustment. One can adjust this and make it zero but, then that that does not solve the problem because that at one given this offset voltage is continuously changes with temperature because if the temperature of the op amp changes this will be and this will be you know this will be and this will be changing that means offset voltage changes with temperature that is at this voltage changes with the ambient temperature. That means even if you adjust this at one temperature the another temperature this is not going to be get adjusted that means it will be definitely going to be produce a output voltage because you cannot adjust each and every temperature. This offset voltage so offset voltage adjustment only solves partly the problem so the actual issues is offset voltage drift

So if I look at the data sheet most of them give more importance to offset voltage drift than offset voltage for example, if it is if you look at the 741 741 data sheet says offset voltage drift as offset voltage drift as the offset voltage drift as plus or minus 15 microvolt per degree c that is v offset drift they call it is a v offset drift. So the v offset drift of 741 is s plus or minus 15 microvolt it means the change in voltage here at this point is 15 microvolt per degree c that means if I take 100 degree temperature change for ambient temperature then the voltage change here supposed to be 15 microvolt 15 microvolt into 100 that comes one point 5 millivolt. That means this voltage will the worst case it can be 1.5 millivolt for 100 degree that means, if I have a say a 10 gain then output will be 15 millivolt.

Now the offset voltage drift is obviously a big problem because for given op amp for example, 741 if I take even if I take 100 pieces each piece will have different amount for example, one one 741 from the same manufacturer can give you zero offset voltage drift another 741 can give you plus 15 microvolt another 741 can give you minus 15 microvolt that is why they called this is plus or minus 15 microvolt per degree c. So the exact value for a given op amp is not known this is the biggest drawback in this that is why we are struggling to compensate this offset voltage drift. There is no easy mechanism to solve this problem now that means while designing we have to make sure the offset voltage produces very little error at the output that is opposed that we have to take in the as the operational amplifier circuit design, so we have to select the required op amps such that the offset voltage drift contributes very little at the output.

Now for example, in this case we had taken 15 microvolt so if I want to amplify the in this case the offset voltage drift 15 microvolt per degree c. So if I have a signal for example, if I want to amplify a thermocouple voltage signal then for example, I put this circuit and connect the thermocouple I connect for example, an operational amplifier here then I connect I give some gain I have given gain then I put the input voltage now you get v zero here now the gain I put R F R 1. Now this is thermocouple voltage I want to amplify thermocouple gives me 40 microvolt per degree c that is thermocouple this is not a volt this is a voltage source. Assume that I want amplify say thermocouple voltage which is 40 microvolt which is nothing but, 1 degree temperature or do not worry about temperature. Assume this 40 microvolt to be amplifying then by a factor of 10 then I supposed to get here 400 microvolt after amplification v zero will become 400 microvolt but, then assume that this is at minus 20 degree this op amp is at minus 20 degree c now, if this goes to plus 80 degree c which is which happens for the industrial grade equipments now if we take this 80 degree then total temperature change you know if we see this is 100 degree.

Now for when that means when 100 degree temperature change occurs in this op amp and if this remains 40 microvolt which is the voltage we want to amplify when 100 degree temperature change occurs. We have to anticipate there is a offset voltage here that offset voltage comes in series with this we have to take it like that this offset voltage that can be now 1.5 millivolt because if it is a 741 for 741 this becomes 1.5 millivolt. Because the drift as I said is 15 microvolt per degree c so for 100 degree c that tends out to be 1.5 millivolt that means automatically this 1.5 millivolt can appear depending upon that piece you know one piece can be plus 1.5 millivolt another piece can be minus 1.5 millivolt another piece can be even zero but, none will be more than 1.5 millivolt. So in that case worst case now my output will be that will be this 400 microvolt see that this is assumed this is at this for 80 degree this would be 1 microvolt plus or minus this 1.5 amplified by 10 times that is actually 15 millivolt.

Now if you look at the output at 80 degree c it will be 15 millivolt plus this 400 microvolt. Now you see that this is error this is not the you know this 15 millivolt is a error and this is the signal that means the signal makes no meaning at this point of time that error is so large and you will you will see that you know the this amplifier is of no use because the error is much more than the signal. And you know you will think 400 microvolt is corresponding to 1 degree c because you know that 40 microvolt is 1 degree c so I have amplified 10 times I expecting here 400 microvolt because 400 microvolt is 1 degree c now if we get for example, 15 millivolt that 15 millivolt corresponds to if you calculate in terms of temperature 15 millivolt corresponds to 15 into 1000 microvolt divided by 400 that that is this is I am converting 15 millivolt into microvolt point divided by 1000 then 15 millivolt is corresponding how much temperature because 400 microvolt is 1 degree so I divide by 400 that comes 150 by 4.

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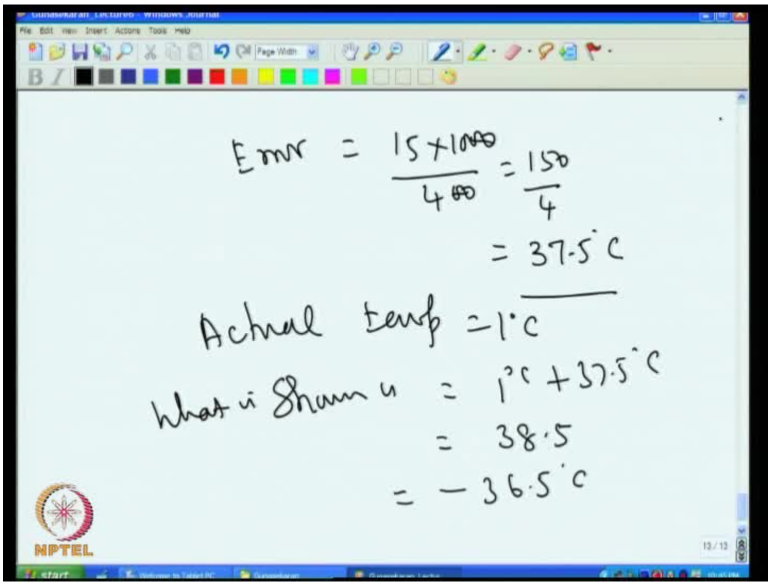


So if you see this so the error will be 15 into 100 divided by 400 that comes 150 divided by 4 that is 37.5 degree c error that means the actual temperature is 1 degree temperature is 1 degree c. But, what is shown is what is shown is 1 degree c plus or minus 37.5 degree that means it may show in one case 38.5 degree in another case it may show minus 36.5 degree c because if 1 op amp I can have plus offset voltage another may give minus if it is a plus it comes 1 plus 37 if it is a minus 1 minus 37.5 that comes to 36.5. So different op amps will give you different temperature from 38.5 to 30 minus 36.5 it is a huge error so offset voltage drift is a significant problem in low level d c voltage amplification so one has to worry about this offset voltage drift drift as well.

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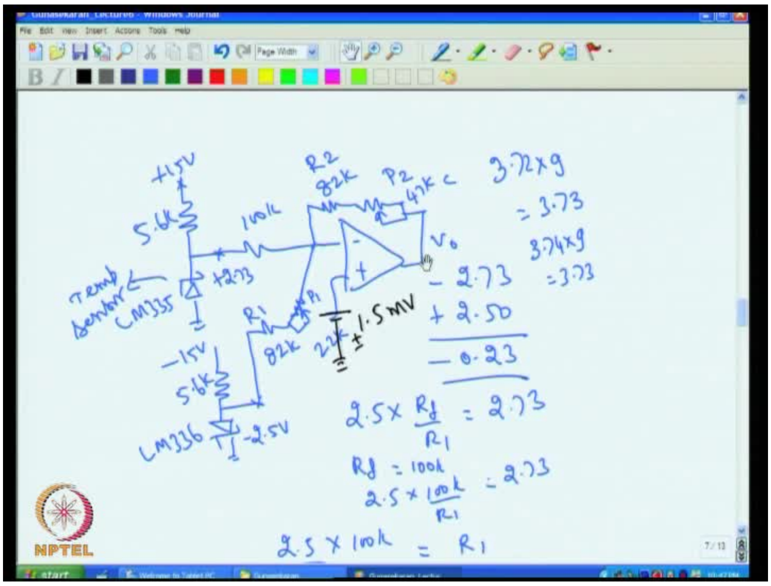

So if I go back to our circuit that is our temperature indicator that we were discussing that errors involved we had seen error due to this zener drift that was 7.5 millivolt drift and that corresponding to almost 7.5 millivolt change here that is 0.75 degree drift comes because of this. Now this op amp also will have offset voltage and the offset voltage will be drifting the offset voltage drifting is the major problem even offset voltage is not a problem that can be adjusted while calibrating this v 1 and v 2 adjustment it can be taken care it automatically taken care so offset voltage is not a problem in circuit but, offset voltage drift is a problem. Now in this case if offset voltage drifts then what will be the error that we will get now if the offset voltage drifts here to put the corresponding offset voltage and see. So I can put offset voltage here for example, if I had put here 1.5 millivolt here because I am using 741 and that has a 15 microvolt drift. So it is plus or minus 1.5 millivolt for 100 degree temperature change if I put 1.5 millivolt what will be the voltage that I will be getting.

Now to find that I have to ground this and this and see how much times it is amplified at the output now the this is about 100 k you know this resistance is coming around 100 k and then you have here 100 k. If you take this also nearly 100 k then if I ground this and this then these 2 are coming this resistance and this resistance coming in parallel because I am grounding this and grounding this and find out what will effect of this. That means 100 k parallel 100 k 100 k gives me around 47 k the 47 k gives me gain of you know 1 plus R F by R 1 that is around 3 so you will have output voltage change of 4.5 millivolt I will show the calculation separately here in the next page so let us see how will you now let us see the…

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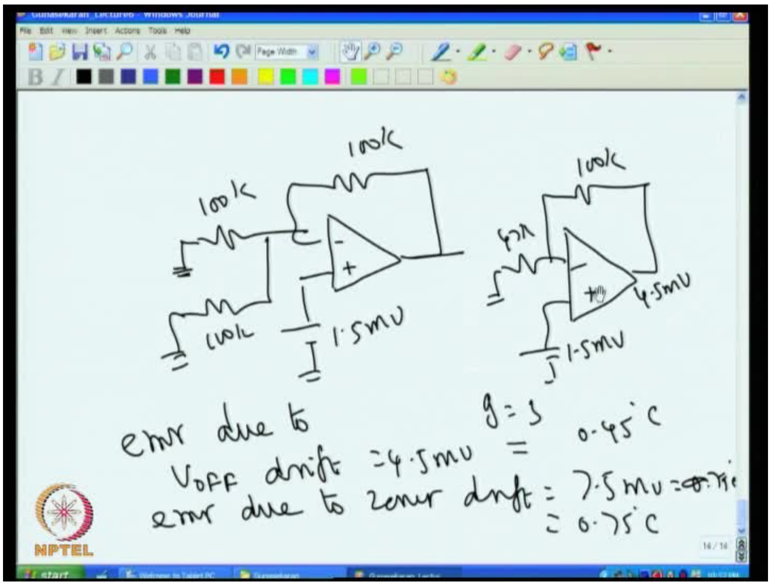


Now if you see the effect of offset voltage drift so I can show like this here this operation amplifier minus plus and then we have this is around 100 k here and then this is 1.5 millivolt here this is to come due to the offset voltage drift and then you have one connected to this end another connected to this end. This is nearly 100 k this is nearly 100 k in actuality this is connected to our temperature sensor you know this is connected to temperature sensor that I grounded this was connected to the zener that 2.5 millivolt the to find the effect due to this I grounded this and this. Now I find what is the effect at the output now this will give me obviously you know the equivalence circuit of that if I draw that comes like this if I put this and I have 47 k and then 100 k that gives me gain of 3. So if 1.5 millivolt will give me 4.5 millivolt here that means offset voltage can give me 4.5 millivolt error at the output. Now that is a error that means error due to offset voltage drift v offset drift is equal to 4.5 millivolt we have seen error earlier error due to zener drift that was at the output equal to 7.5 millivolt

So we have this if you take this this is corresponding to 0.45 degree c error at the output this correspond to 0.75 degree error because 10 this is equal to 0.75 degree error that means you see now already you know we got error due to offset itself 0.45 degree and error due to zener is 0.75 degree at the output of the temperature indicator which works out to be about 1.2 degree error total. Due to these 2 errors alone that offset voltage drift and zener drift. Because the drift is coming because the operational amplifier whichever whichever we are using that actually is sitting in the ambient temperature and the ambient temperature is changing because we should not assume the operational amplifier is always at room temperature because room temperature is different at different place. As I said if you are using in industry this unit what happens if it kept in the open air for example, if it is a process control industry all the equipments are put in the open air where sunlight falls directly on it at the noon you will see that temperature of the unit goes up to 80 degree. So if you are making for industry grade industry grade equipment then we have to take temperature change as minus 20 degree to 80 degree that is total change of 100 degree c and one have to calculate the offset voltage drift for 100 degree c that is how we landed up at 1.5 millivolt.

If I want to reduce this error then I have to go for another op amp for example, if of 741 if I take 714 then offset voltage drift is only 0.5 microvolt per degree c then 0.5 microvolt per 100 degree will give me 0.5 into 100 will give me about 50 50 microvolt change and that will be very small corresponding to 1.5 volt here. And correspondingly the output also will be only 50 millivolt into 10 will in this case 50 millivolt into 3 will give me only 1 150 50 microvolt into 3 will give you 150 microvolt then automatically error comes down. So if you want to reduce the offset voltage drift then we have to go for another op amp which is having a low offset voltage drift that is why we have for different purpose different op amps some of them you know for d c applications we have to go for low drift op amp. If the error what we are getting is considerable if the error is not significant one can use this the same low cost op amp because if you’re looking for op amp of low drift the cost enormously goes up because you know for example, 741 which is available for around 4 rupees automatically jumps to 50 rupees if I look for 714 which is a low drift op amp. If I want still lower drift you have to pay much more money. So one has to see how much is the error and accordingly we have to settle at the correct op amp which out without blowing up the cost of the equipment so this is the very important consideration.

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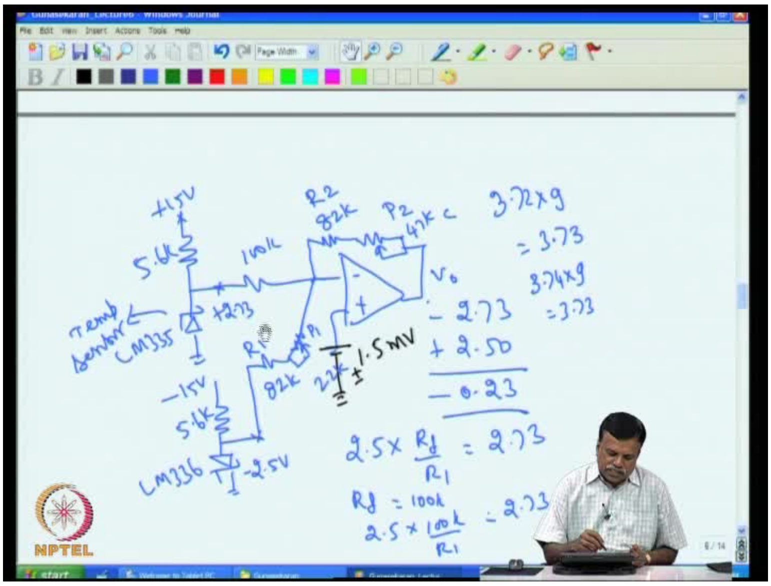


So we had seen two errors and if you go back our old circuit you know our temperature indicator circuit this circuit. Now we have 2 errors that is a this error is due to offset voltage drift then we had seen the temperature of this when temperature of this changes and the voltage of the zener also changes little bit that was 7.5 millivolt. So totally this produces at the output of here 0.75 degree error and this offset voltage produces 0.45 degree error at the output. Now we have to see what are the other errors because not these the not that these are the only 2 errors. There are another significant error is the resistances actually. The resistance values change with temperature and they change in very peculiar manner so we see the resistance drift how the resistance drift is occurring in a detailed manner.

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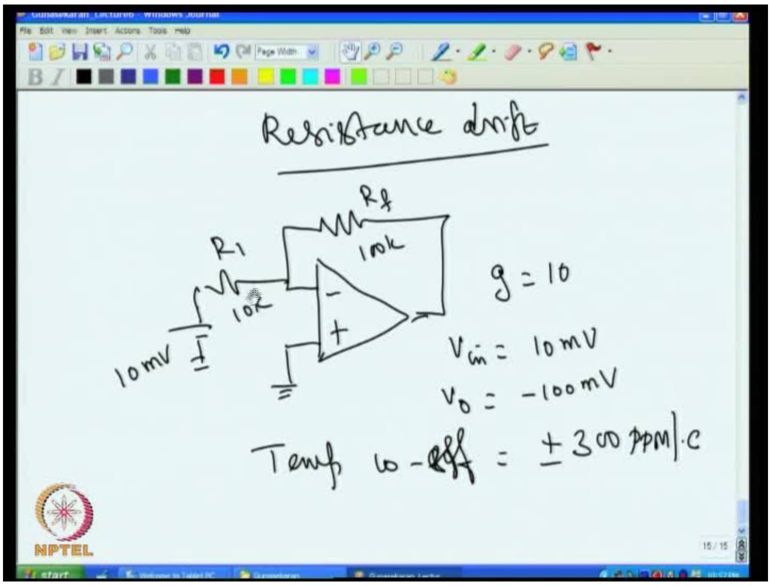


So we will see look into the resistance drift now if you look at the circuit for example, I take a 2 resistance I put here then I connect this then I give the input here and connect this to ground. This is a just a inverting amplifier and then we have a gain here R F and then R 1 so assume that I have put here 100 k and then 10 k then the gain is actually 10. Now if I give here for example, 10 millivolt then my v output v in is 10 millivolt and then v output comes minus 100 millivolt because it is amplified 10 times and inverted so I got minus 100 millivolt. The problem comes whether this 100 millivolt what we are getting here is it constant or is it varying assume that this 10 millivolt input is constant is not changing and assume the op amp temperature also not changing that means no parameters the op amp is changing. Even if you assume this say it as long as this 10 millivolt constant we expect these output supposed it at minus 100 millivolt but, this will not happen in the real life because when ambient temperature changes resistance value of this is changing and the resistance value of this is changing. What is the gain that we have now is actually 10 that is because this is 100 k this is 10 k the ratio is 10. So we got a gain of 10.

But then when temperature goes up then this resistance also will change this also will change. And if you look at the temperature co-efficient of these resistors they will say the temperature co-efficient of the resistance look at data sheets they will give you temperature co-efficient for example, if a normal carbon resistance sheet take they will say it is plus or minus 300 P P M per degree c. That means the resistance value can change by 300 P P M every one degree change and note the problem is it is plus or minus 300 P P M not just 300 P P M that is the one which actually complicates what is happening is if I buy 100 resistors from the same manufacturer 1 resistance can go up another resistance can come down it can be same 100 k here 100 k. Even in even then one can go up one can plus when temperature increase this may increase this may decrease. However in the other case 1 may not at all change with temperature other may change minus 100 or 1 may change plus 100 P P M another may change minus 75 P P M. Because it can be anywhere from minus 300 P P M to plus 300 P P M. Where normally we think that you know for example, if I take a wire that will have always a positive temperature co-efficient but, when you make it a wire wound resistor you will not get temperature co-efficient as plus alone because the characteristics of the entire resistor property changes when you make it as a pellet or you make it as a wire wound resistor you make it as metal film resistor then the property of the resistor is totally different from the pure metal property. So one should not think that resistance will always increase only or if I take all 100 case all 100 case will increase that is not true. So even if you come buy from the same manufacturer same batch each resistor will behave differently as far as temperature with temperature change is considered one can increase one can decrease or one can change no change at all but, none will change more than 300 P P M that is the bottom line.

So if I take for example, normal carbon composition resistance they will say it is 300 P P M that means assuming this is increasing by 300 P P M this is decreasing by 300 P P M that is the worst case that can happen. Then we see what is the error, that we get because of the resistance change.

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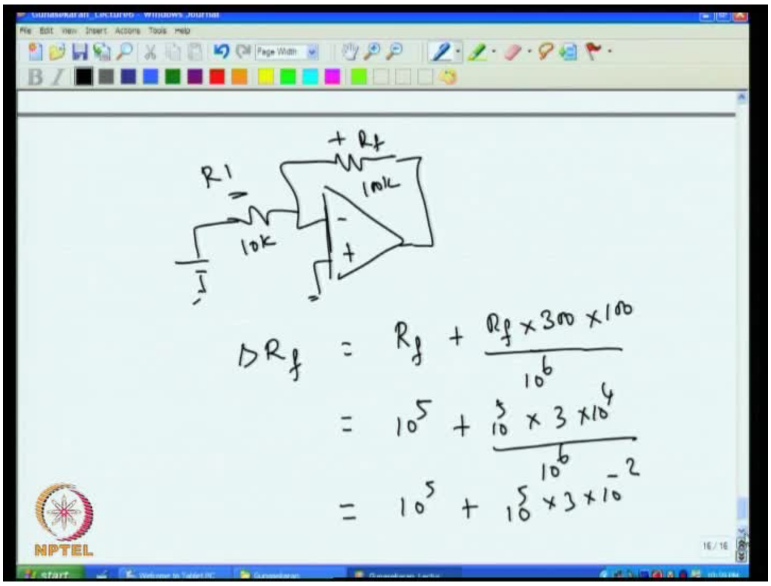


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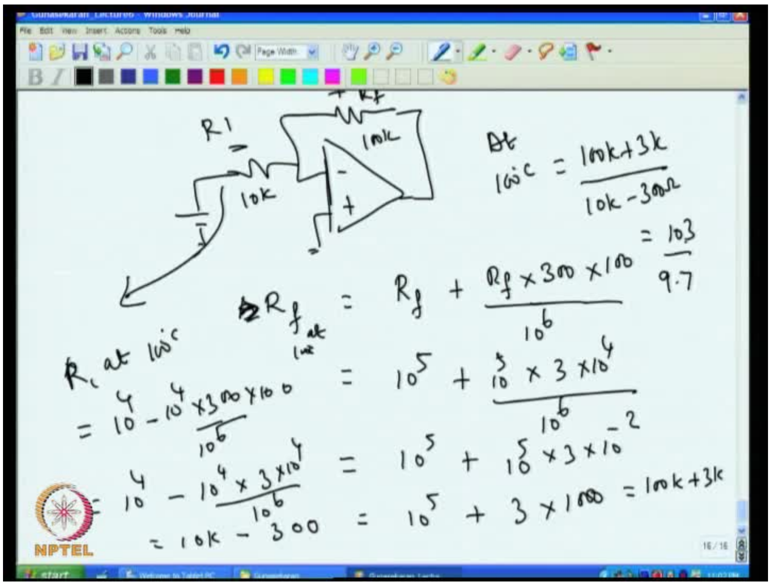


Now we can calculate and see for example if I put 300 P P M I put the circuit, so if I take this so I assume this is plus temperature co-efficient and this is minus temperature co-efficient now if this is 100 k this is 10 k. We find out what is the change in resistance so delta R F this is R F this is R 1 will be R F that is 100 k. So we take that is R F plus R F into temperature co-efficient which is 300 P P M 300 divided by 10 power 6 that is the 300 parts in in 10 power 6 into temperature difference which is 100. So if I take R F as 100 k that is 10 power 5 then this becomes 10 power 5 into 3 into 10 power 4 and I combine these two and get 10 power 4 divided by 10 power 6 that comes out to be 100 k plus 10 power of 5 into 3 into 10 power minus 2 that tends out to be 10 power 5 plus 3 into 10 power 3 that is 1000. That actually becomes 100 k plus 3 k that means the resistance value of this had gone up by 3 k this 100 k become 103 k at plus it is assuming that minus 20 degree it was 100 k then at plus 80 degree this at become 103 k. Same way this 10 k 10 k. We assume this actually minus if I calculate for this 10 k then you will get the same equation if I put delta this is actually actual R F at 100 degree c same thing I put R 1 at 100 degree c. That will work out be 10 power 4 plus 10 power 4 into 3 300 P P M. So, 310 power 6 into 100 degree c. So, that if you simplify you will get 10 power 4 plus 10 power 4 into 3 3 into 10 power 4 divided by 10 power 6. That works out to be 10 k remains there and then that actually 10 power minus 2 comes there that if you go with this then that become 10 power 2 that becomes 300 ohms.

So this actually actually we want take this as a minus temperature negative temperature coefficient so eventually this actually becomes minus actually if it is decreasing then I should take it as minus. So I remove this I am taking this is decreasing temperature so I am putting minus sign so this is minus sign. So eventually it now turns out at 100 degree c R F at become 100 k plus 3 k and R I at become 10 k minus 300 ohms. Now the gain is 103 divided by 10.3 not 103 divided by 10.3 which is not it now if you see this gain this is 9.7 this is this is 9.7 k. So now the gain is not 10 now the new gain.

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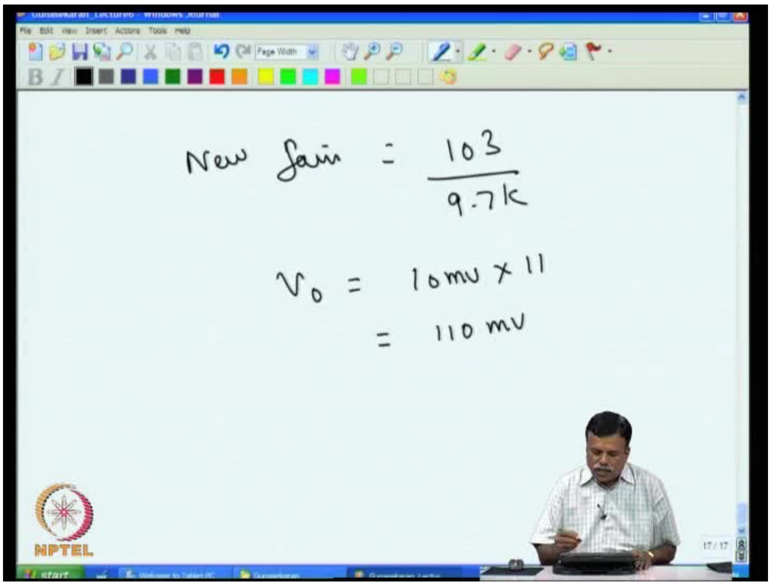

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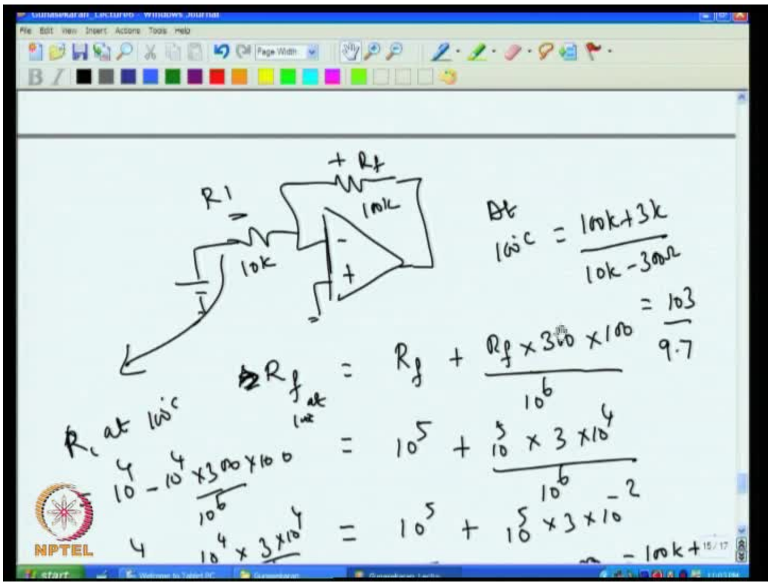

To calculate the new gain is 100 k become 103 k and 10 k become 9.7 k that is the new gain which is much more than 10. So the actual calculation can be done and then you get v output will be now 10 millivolt into this new gain which will be closed around 11 and then you will get 110 millivolt. So originally is supposed to 100 millivolt now we are getting 110 millivolt this is the significant error because the resistance had error change so much and if want reduce the resistance drift one way is that you go for resistance which is having lower drift for example, if I look at metal film resistors you will get instead of 300 P P M various for example, we had shown the drift calculation here we are taken drift as 300 P P M that so we are put 300 you have metal film resistor 10 P P M is there so 300 becomes 10 or you also have 50 P P M we also have 100 P P M. So you have the resistors of various values available right from from 10 P P M to 300 P P M and of course, cost goes up if we are looking for low drift resistors then automatically the cost goes up. So automatically when you look for low drift then automatically cost goes up.

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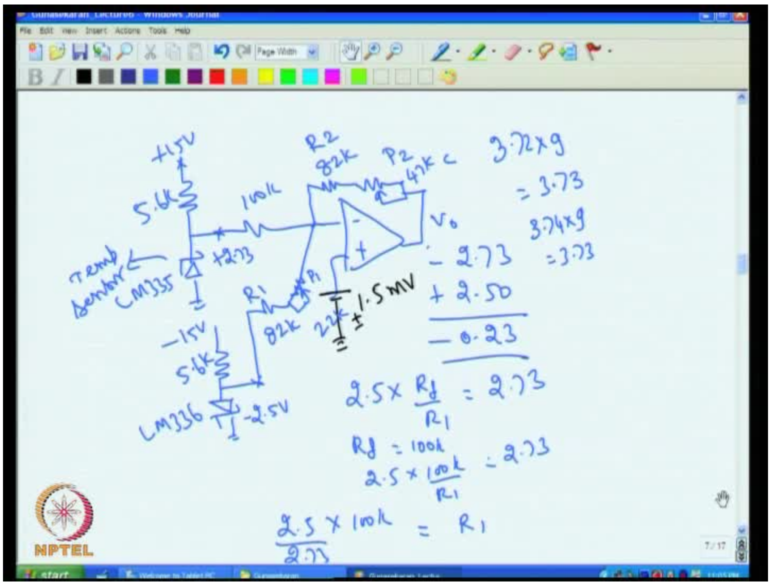


So one have to make a compromise you know whether you need low drift resistors or not that depends upon the application. So this is your third error which you had seen because in our temperature indicator example, we already shown 2 errors 1 was due to zener drift which was 7.5 millivolt per 100 degree c other one is due to offset voltage drift that was 4.5 millivolt at the output and other one is this gain error that we at calculate we are not calculate we are take approximately 1 op amp and then we are taken 10 k and 100 k because of the resistance changes how much is coming. Now the same thing we have to go and calculate the error for our example circuit that is temperature indicator circuit what is the expect at error. So we go back to our yah we go back to this we take this circuit and find out if this is resistor and this resistor and this resistor changes what is the expected error that you will get. Because we cannot assume that this resistors are not changing in fact resistor is a important part played in electronic circuit where in any circuit if you see most of the parts will be actually resistors and invariably they are ignored but, then even if we ignore they will change against temperature and you will get an error.

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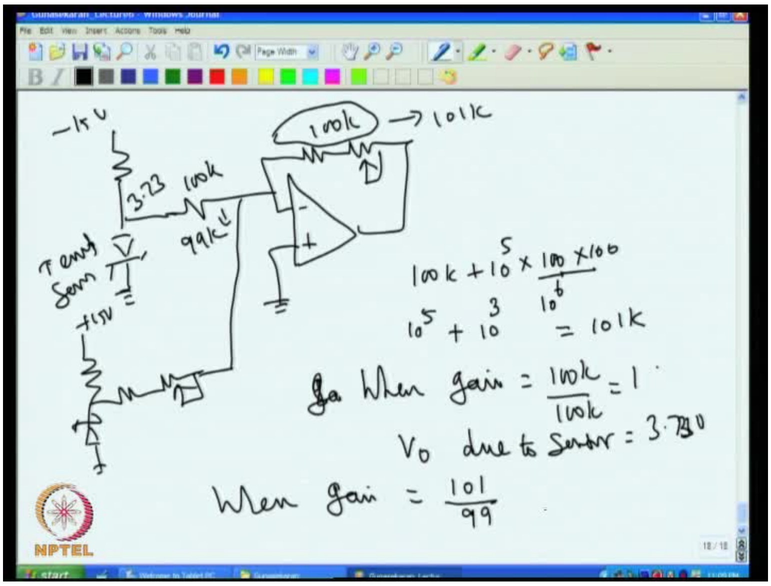


So once if you very careful in dealing with the resistors for example, if we had seen if I used 300 P P M resistor here and here and here and forget about the function when I told you in last the very small the contribution can be for the simplicity. We can neglect at this point of time the actual case we are to worry about than drift also in variably many time potentiometer drift is more because you do not get very low drift potentiometers you will get up to 100 P P M only. Whereas, resistors you get up to 10 P P M now for example, we take assuming that this also 100 P P M they also got 100 P P M there means total drift is 100 P P M this is 100 P P M now plus 100 P P M 300 P P M this is minus 100 P P M if I take what is the expected error at the output assuming this is not at all drifting that can give a worst case error. So now we take this circuit and then we work out what is the expected error due to resistance drift in our temperature indicator circuit.

Now let me take that circuit redrawn here so that it is is here so I combine the potentiometer and this and other side I had this connected to temperature sensor that is connected to minus 15 this is temperature sensor this is 100 k and then I had this plus 15 and this zener voltage. And then we have this and this so we assume that you know this is not drifting and this is drifting minus and this is drifting plus so this value assume this both value put together is 100 k.

So if I calculate this what is the resistance it will become that actually become 100 P P M if I take then it will be 100 k plus this 100 k is 10 power 5 into 100 P P M 100 by 10 power 6 for 100 degree I put this so that actually becomes 10 power 5 plus 10 power minus this is actually 10 power 9 so that become 10 power 3 here 4 plus 5 9 9 goes with 3 so it becomes 10 power 6 that means that this resistance become 101 k so this will down by 101 k so this actually becomes 99 k this actually becomes 101 k. So gain error will be the so this voltage only amplified here and put out so if I assume that 100 degree c this is sitting at 3.73 because this will be sitting at 3.73 .So we have to find out what is the change that comes when these two 100 k and when this is one naught one and 99 k what is the change that we expect.

So when gain is equal to 1 when gain gain is equal to 100 k by 100 k plus both are 100 k then the gain is actually 1 the contribution or the output contribution v out due to due to sensor that becomes 3.73 because the gain is 1 so that one. When gain is equal to at high temperature, then the gain actually become 101 divided by 99.

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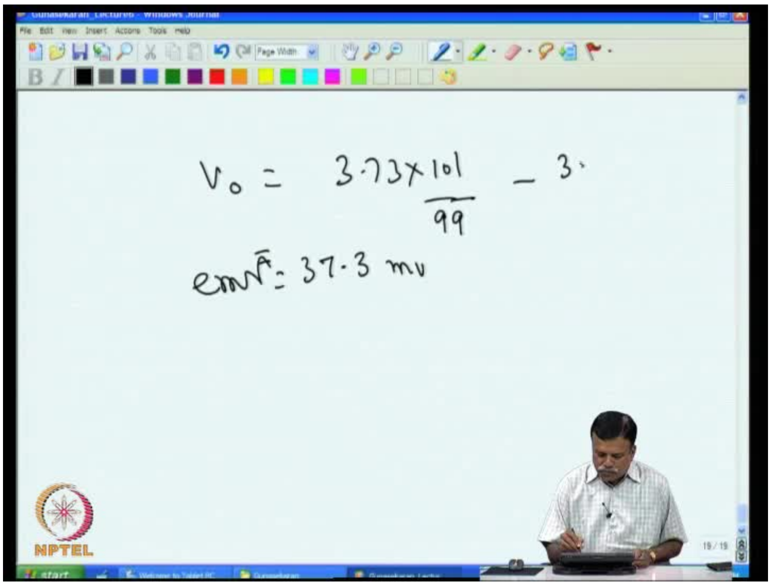

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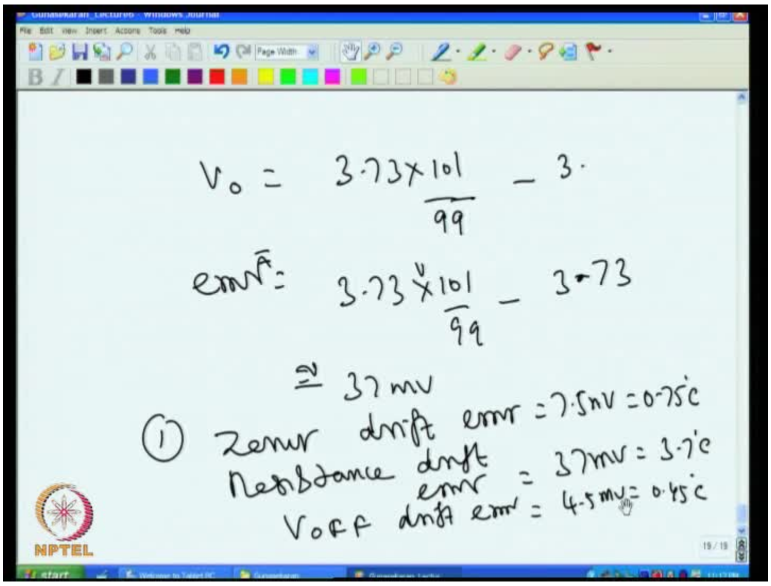

Then v zero becomes Then v zero actually becomes 3.73 into 101 divided by 99 so that actually definitely goes more than 3.73 we can calculate this so you will get you will get roughly about 10 millivolt error is expected it will go to 3.831 percent error that will be nearly 37.3 millivolt error is expected. Because you calculate and see what is the difference because we have to calculate this minus 3.73 if I put that is the error will be error will be 3.73 into 1 naught 1 divided by 99 minus 3.73 which may come around 37 millivolt may be nearly equal to 37 millivolt you calculate exactly I am not doing the calculations here now. This is actually corresponding to 3.7 degree error which is quite large that means resistance drift produces a large error at the output

So if I look at the our circuit now we have calculated 3 errors so far one is zener drift error which was 7.5 millivolt which correspond to 0.75 degree at the output. Then we had resistance drift here that is equal to 37 millivolt that is equal to 3.7 degree error and similarly, we had you had the offset voltage drift of op amp that was 4.5 millivolt and that was coming 0.45 degree error. You see total error goes now already 5 degree that means if the temperature indicator is showing 100 it can very well show more than 100 actually either 5 105 or 95.

Now this is a significant error if I want to reduce then I should go for zener which is having low drift and that costs extra money for example, we have a zener up to 1 P P M this is actually 35 30 P P M which gave me this I can go to 1 P P M then that automatically the error comes down or resistance drift this is for 100 P P M resistor this is 37 millivolt if I go for 10 P P P M then the error will come down but, of course, it costs more money then I can go for much a better op amp so instead of getting 4.5 millivolt error I will get much lower error then this also comes down then of course, again you have to pay a higher cost for that. So of course, now I think you understood why component selection is very important in analog circuit. Because if if you select proper components then error will be less otherwise the circuit may work now but, it will show enormous error when the ambient temperature changes and this is a very important aspect in analog circuit design because the error budget is a forgotten story in analog domain because no one bothers that you know the one at work you know thing the assumption that many of them make is that you connect to op amp and that amplifies and puts it at the output and no need to worry about anything that is totally wrong one had to worry about various errors associated in the circuit. In fact we had seen only 3 errors in this circuit so far there are many more errors in this which we are not discussing at this point of time because I do not want to add in one stroke all the errors we will see in another circuit other errors involved.

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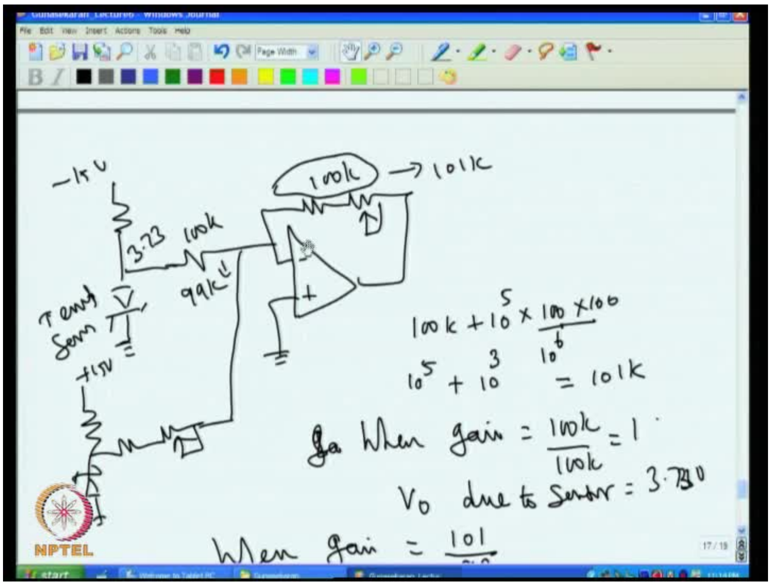

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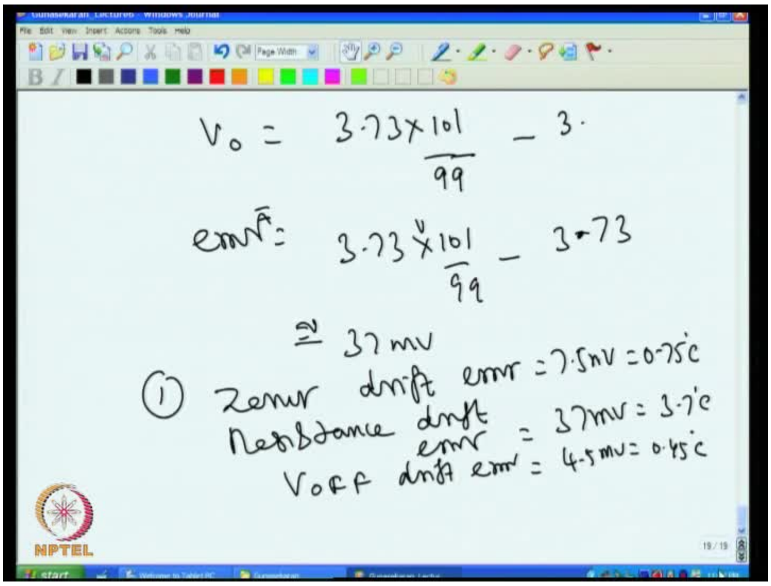


For example in this circuit there are other significant errors for example, if I take the this circuit which in this case for example, we have a bias current to the op amp that current goes through this that bias current also changes with temperature the bias current produce error that we have to calculate that also I am not doing it here because I do not want to burden you at this point itself with all the errors. There are many more errors in the op amp itself so we will see them one after another so in this example we will stop with this 3 errors. Now by now you would have understood that in analog circuit design the component plays a significant role particularly for example, if we take a resistors if we take any for that matter if we take any analog circuit you will find there are plenty of resistors and capacitors and one should not take that you know only the value is important you know the drift of these resistors and drift of these capacitors are not important one should not take that view they are very very important and one should consider them.

So at this point it is appropriate to discuss little bit about what are the types of resistors that is available and what are their characteristics and which one to use where and similarly, what are the different capacitors available and then what are their important characteristics and which one to use where that should be discussed at this point of time before we built up very many circuits using these resistors and capacitors.

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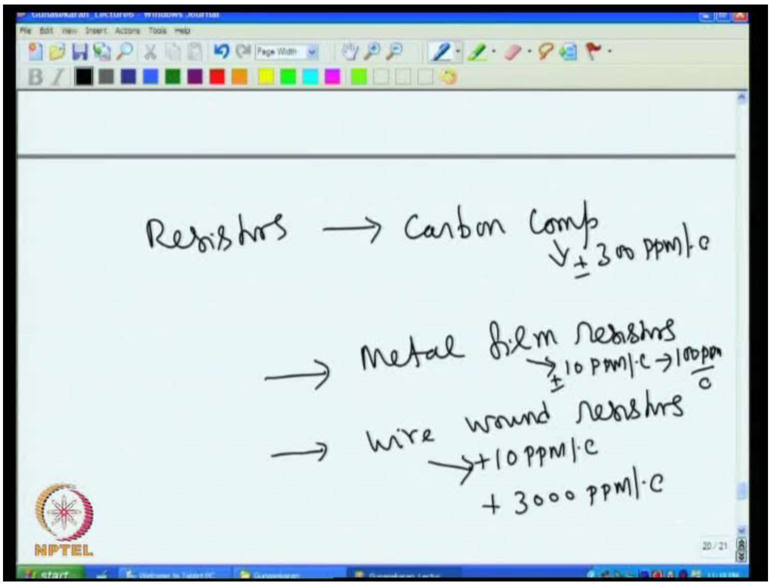

So I will spend another few minutes in explaining what is the what are the different resistors and in what way their characteristic affect the circuit for example, if you take a resistors if you take a resistors you get in the market 3 different mainly 3 different type of resistors that is one is carbon composition, then you have the second type coming as metal film resistors and then third type coming as wire wound resistors. Now if you look at the carbon composition resistors their temperature coefficient is very high you get plus or minus 300 P P M is per degree c that is the temperature coefficient that you get if you look at the metal film resistors you get 10 P P M per degree c to 100 P P M per degree c. That is the thing you get wire wound resistors that you get you know manganin at the lowest side you will get again 10 P P M per degree c these are plus or minus. Manganin means only plus not minus 10 P P M per degree c, the wire wound resistors always temperature will increase with temperature no question of minus actually and other extreme end if you go for copper wire or platinum wire that you will get copper wire then that resistance changes with 3000 P P M per degree c that means the wire wound resistors not all wires have the same temperature coefficient but, nevertheless one good thing about wire wound resistor is all of them will only increase with temperature they will not decrease unlike this metal film resistor and carbon composite resistors they can increase decrease and we do not know how much actual values is it is only maximum value is plus or minus 300 P P M.

So one you know in one lot even metal film resistors if you buy 1 resistance can go up another resistance may come down 1 may not drift at all 1 may be drifting 10 P P M another may drifting 8 P P M. Here what this means for example, if I ask metal film resistors ask them to supply 10 P P M temperature coefficient resistors he will give me 10 P P M resistors but does not mean all of them are drifting with 10 P P M. None will drift more than 10 P P M 1 may drift 8 P P M another may drift minus 6 P P M another may drift zero but none will drift more than 10 P P M plus or minus similarly, I can ask metal film resistors of 25 P P M available, 50 P P M available, 100 P P P available.

So we have to specify if we are buying a metal film resistor what is the temperature coefficient that we are looking for it is at 10 or 25 or 50 or 100 P P M that we have to specify. All carbon composite resistors will come only with 300 P P M that you need not specify automatically if it is a carbon composition then you will get only 300 P P M. Even a metal film also we have 2 different types that almost the now a days we have forgotten so need not worry at this point but, wire wound resistors normally what you get all will be about 3000 P P M, manganin is the only wire which gives you very low temperature coefficient of 10 P P M that is very expensive unless you need for a special purpose where low drift is called for you should not go for this. So otherwise if you do not specifically ask they will give you 3000 P P M to 4000 P P M resistance only so wire wound resistance having very high drift

Now in addition to the drift consideration we have to worry one more thing about resistor is you know the resistor value not only changes with temperature. Suppose if I take 1 carbon composition resistors you know which is actually say 10 k which is 10 k and 300 P P M. Now I assume it 10 k at 25 degree c now after 1 year use the same 10 k. If I see at the same room temperature 25 degree c it is not going to be same 10 k with age the resistance value changes and that is very high for carbon composition resistance that is very little for metal film resistors because metal film resistors exhibit very low aging property with age resistance change is very little for metal film resistors they invariably tell in terms of percentage per year how much it will change 0.1 percent that is this changes up to 1 percent.

But wire wound resistors they change mainly due to how oxidation takes place if it is properly sealed then wire wound resistor aging problem is very very little. So for long term use then wire wound this is good but, but they have a large temperature coefficient.

This is actually good because it is very cheap that is all but, then the drift is very high this is good for low drift but, then the cost is high for example, if you take normal quarter watt resistor you will get it for 25 paisa here whereas, this you have to spend about rupee here and this depends upon the wattage of the resistor.

So in addition to tolerance of the resistance and the wattage what is wattage of the resistor there is one more property that we have to realize in analog circuit used that is this temperature coefficient and then the long term drift. So if you want a very low temperature coefficient then you go for metal film resistor and if it is not necessary to be you know low temperature coefficient then it is enough if you go for carbon resistors. Because do not try to put everywhere metal film resistors then your equipment will not be sellable because the cost will enormously go up, so one need to apply their mind and see which resistor to be used which purpose.

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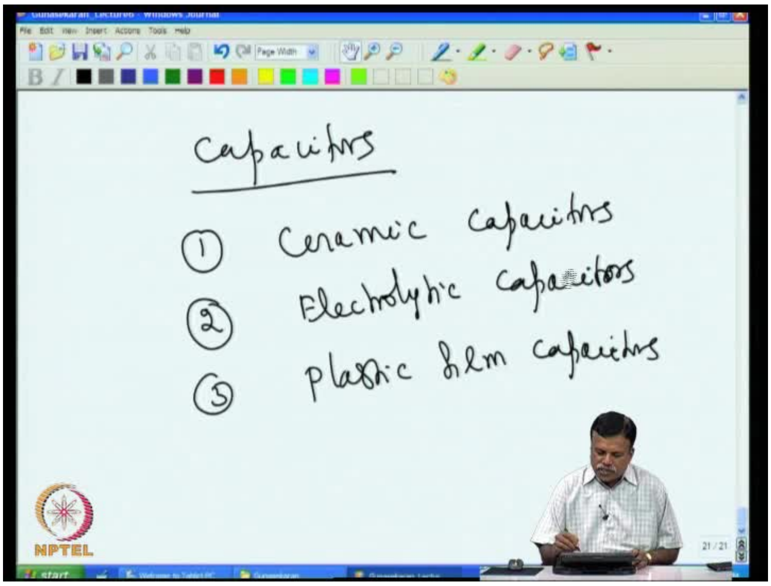


Now similarly, that you know if you look at the capacitors we have 3 different types of capacitors available now, if you look at the capacitors we have one type as ceramic capacitors and the second type as electrolytic capacitors and then third type as plastic film capacitors. Now if you look at these characteristics and their usage you know they are totally different you know like resistors we also be very careful about capacitors' usage and their properties. Because in analog circuit design that is a major issue now ceramic capacitors for example, you have a ceramic resistors are dielectric and these capacitors available a maximum of 10 microfarad value only. Now if you look at electrolytic capacitors, where as you know there are 2 type of electrolytic capacitors one is aluminum electrolytic where aluminum oxide is just a dielectric and then another one is tantalum oxide tantalum oxide is used as a dielectric and they will come as electrolytic but, this is available in large volume you will get it even today few micro few few farads right from ten microfarad to few farads capacitor available large volume. Whereas, ceramic capacitors available only up to 10 microfarad not more than that. Now in plastic film various plastics for example, polycarbonate, polypropylene various plastics are used as the dielectrics.

Now if we see their properties you know the ceramics have very high you know ceramic is used as a dielectric the dielectrics of this this these capacitors have very large drift due to temperature for example, the dielectric constant of this capacitor will change because dielectric constant only determines the capacitor value. So when dielectric constant of this capacitor change then the capacitor value also changes, so ceramic capacitors have large temperature coefficient and electrolytic capacitor also have a large temperature coefficient plastic film capacitors have very low temperature coefficient. So also there are various other properties which we will seek in the next class but, we had to worry about these properties also and we correct this alike them for proper use of these capacitors.

So we had shown in this class the what are the errors that is coming in in the temperature indicators circuit. We had shown three errors that is one is drift due to the zener, other one is offset voltage drift error and third one is resistance drift error these three errors put together how much was the total error that we had shown. And also shown you how to reduce them and also we had discussed about various resistors that is there and their characteristics and we have discussed little about these capacitors we will continue our discussion in the next class.

Thank you