Circuits for Analog System Design

Prof. Gunashekaran M K

Centre for Electronics Design and Technology

Indian Institute of Science, Bangalore

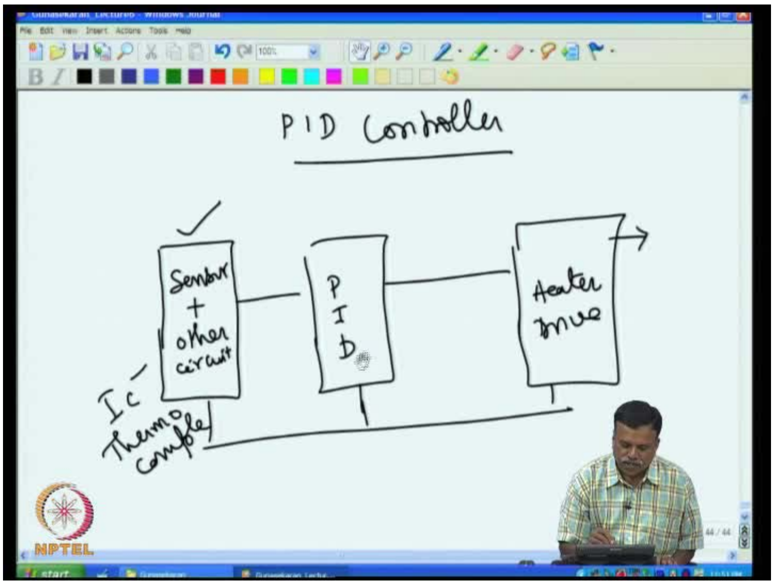
Module No. # 04

Lecture No. # 15

PID Temperature Controllers with Error Budgeting

Today, we will discuss further about PID temperature controller, because in the last class, we had explained what is PID controller, how to design P stage, I stage and differential stage? Then, I also said, how to set these time constants.

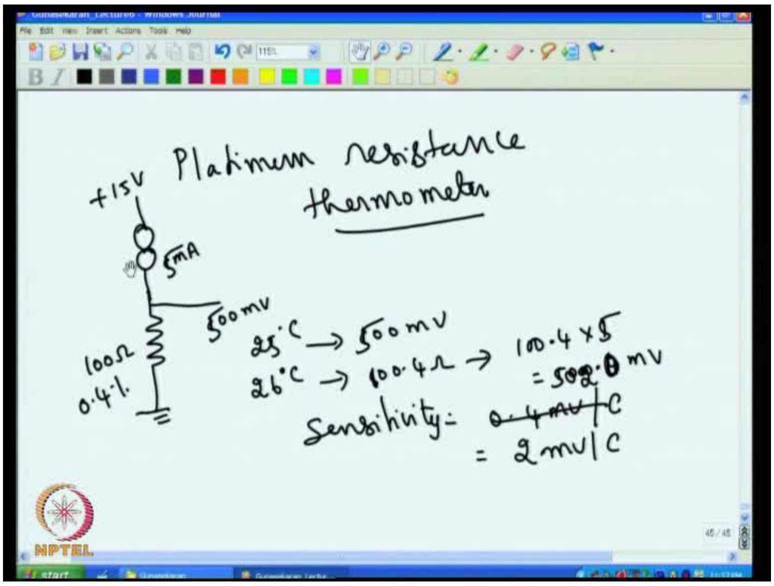
(Refer Slide Time: 00:44)



Now, we relook at this PID temperature controller and then, we look into the other issues now. Actually, if you look at the PID controller in general, for example, you have 3 stages: one is input stage design; there is sensor plus other associated circuit, sensor plus other circuits like temperature compensation, ampere temperature compensation and so on, these are one area. Then from here, we have to go to the PID stage. Then, we have third area that is a heater drive, these are the 3 distinct areas there, which have to be looked into that separately.

As per as this sensor is concern, we had seen 2 different sensors actually: one with I c sensor and another with the thermocouple. The two examples we are seen, how to design the distance circuit. PID control we had shown, how to design P separately, I separately and differentiator separately. Heater drive we are not seen extensively. So, heater drive also we have to see what are the different possibilities are there and then, also we had said that how to set the proportional gain and integral time constants, differential time constants and so on. What are the actual electronic time constants and then the physical time constant, how they differ? That also we have to see in detail.

(Refer Slide Time: 02:44)



Now first, let us take this sensor design circuit. For example, we had look into different types of sensors like for example, we can take now other important sensor that is our platinum resistance thermometer. Suppose, if I use PRT as a sensor then, how to design their stage, because in analog circuit design, handling the sensor is a very important thing and then how to compute the error budgeting for that is a very important thing. We are not discussing the error budgeting and so on for quite long; we are moved into the PID temperature controller. Our main aim is not the PID temperature controller; our main aim is how to design analog circuit that is the issue in this course.

On the way we will look into PID temperature controller but, our focus is not the control. Now, our focus not the control but, actually the sensor design and the circuit design. Let us look into the input stage that is now, we will take platinum resistance thermometer and see, how to design sensor circuit, how to make a PID using platinum resistance thermometer.

Now, platinum resistance thermometer for example, if we take look at the commercial available sensors you have 100 ohm thermo resistance element, platinum resistance element is available as a sensor. Now, if you look at these with temperature this resistance goes up by 0.4 percent actually. That means for every 1 degree resistance, temperature will increase the resistance by 0.4 ohm, because it is the 100 ohm is the basic element at 25 degree c. So, every 1 degree will increase the resistance by 0.4 ohm.

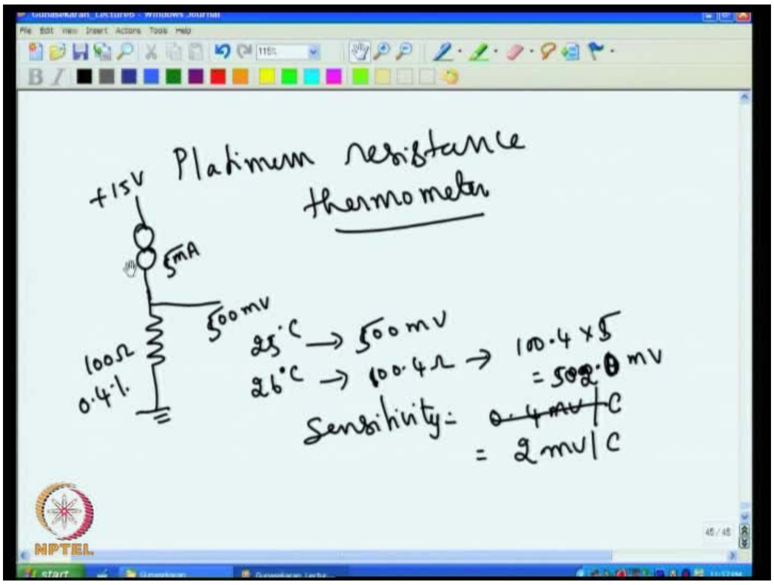
Suppose, if I want to use this and make a temperature controller, how to go about doing this? Now, simplest way of doing this would be passing a constant current source to this; that is we have a constant current source obtain from plus 15 volt say for example, if I have a 1 milli ampere current, it gives you constant current always. Assume, it is 1 milli ampere then, when it is 100 ohms here 25 degree it is 100 ohm, so you will get 100 ohm into 1 milli ampere that will be 100 milli volts. When you will get at 25 degree c 100 milli volt, when temperature goes to 26 degree c, we will get the resistance become 100.4 ohms and then the voltage become that 100.4 into 1 milli amps that will be 100.4 milli volt that means, the sensitivity becomes 0.4 milli volt per degree c.

If I use the system then sensitivity is equal to 0.4 milli volt per degree c remains for every 1 degree change in temperature we will get 0.4 milli volt change at this point. This is actually quite enough because, if we see our earlier thermocouple it was only 40 micro volt per degree c sensitivity whereas, this is 0.4 milli volt per degree c we are getting.

Our other sensor that is namely I c sensor was giving us 10 milli volt per degree c which was very high; of course, we can increase this by increasing this current but, once you increase this current the self-heating becomes more and that creates problem. Of course, we can go for example, 5 milli ampere current sources if I make then, this will be 500 milli volts that is at 25 degree it will be 500 milli volts. At 26 degree it will become 100.4 into 5 milli amps that will become 502.0 milli volts, because if I multiply this then, the sensitivity actually not becomes 0.4, it becomes 2 milli volts per degree c.

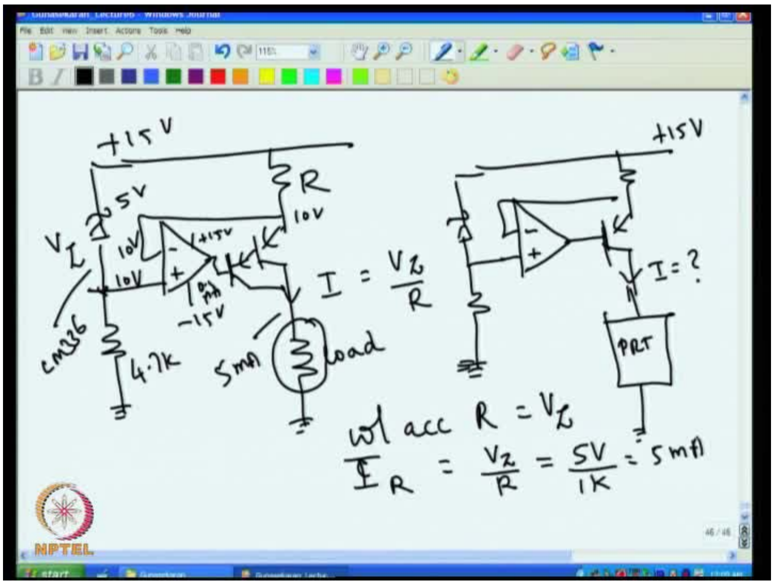
By increasing the current we can get more sensitivity, it is compromise between the self-heating, because if I put more current then the more self-heating takes place, then the accuracy lost but, if I give less current then sensitivity reduces. You can increase the sensitivity by increase in the current but, at the cost of self-heating which gives a temperature error. In this case that is taken for example, 5 milli ampere current and then produce 2 milli volt per degree c sensitivity.

(Refer Slide Time: 02:44)



The question is now, how to design these constant current sources? Because constant current source is an important element in analog circuit design and the constant source will be extensively used, so one should know how to design a constant current source. Let us see, how to make this constant current source.

(Refer Slide Time: 08:14)



Now, what I do is that we have different types of current sources, I just give you the two different types at this point, so I can make for example, this is one constant current source which is popularly used. So, I have plus 15 volt and then this is load, because apply as plus 15 minus 15, where all this is a simple constant current source, through this load. If you see this current through this load is always constant in the sense that whatever maybe the resistance value of this current flowing through, this will be constant. This current actually is given by - if I take this is a V Z and if this is R, is actually V Z by R. So that is the current that is always flowing irrespective of this load resistance.

Current is constant even if I changed this region that is why we call this is a constant current source. In our case, what we going to do is, we going to connect our thermometer that is our platinum resistance thermometer in these place of load, so essentially it looks like this, if I look at the over temperature sensor that it looks like this (Refer Slide Time: 09:49).

Here, the temperature sensor is put, PRT is put here, this is acting as a load now, and then why the current through this is constant; I is constant, why it is constant? Now, to understand this we look at the circuit here. Now, for example, this is V Z suppose, if I put 5 volt zener that means voltage across this is 5 volt. We already discussed about this for example, I can use a zener diode like, LM 336. LM336 available in 2.5 volt as well as 5 volt configuration, I take 5 volt LM 336. If the current is 1 milli ampere through this, then if the current is 1 milli ampere through this, then we know there will be a 5 volt across this (Refer Slide Time: 10:17).

How to maintain 1 milli ampere through this? Because the 15 volt supply now between this and this resistance, if the voltage is 5 volt across this, the remaining 10 volt will be across this, because total voltage is 15, so the current through this and current through this are same. That means, if I want 1 milli ampere through this, I also maintain 1 milli ampere but, the zener specified as 1 milli ampere minimum current, the maximum current can go up to 10 milli ampere (Refer Slide Time: 10:58).

Let us work out take as 2 milli ampere current; I maintain 2 milli ampere, so I maintain here also 2 milli ampere. If it is 10 volt across this 2 milli ampere if I need I had to put 5 k, so I put the nearest value of 4.7 k here, which will make sure little more than 2 milli ampere current that is flowing through this. So that will make sure the voltage across this is 5 volt.

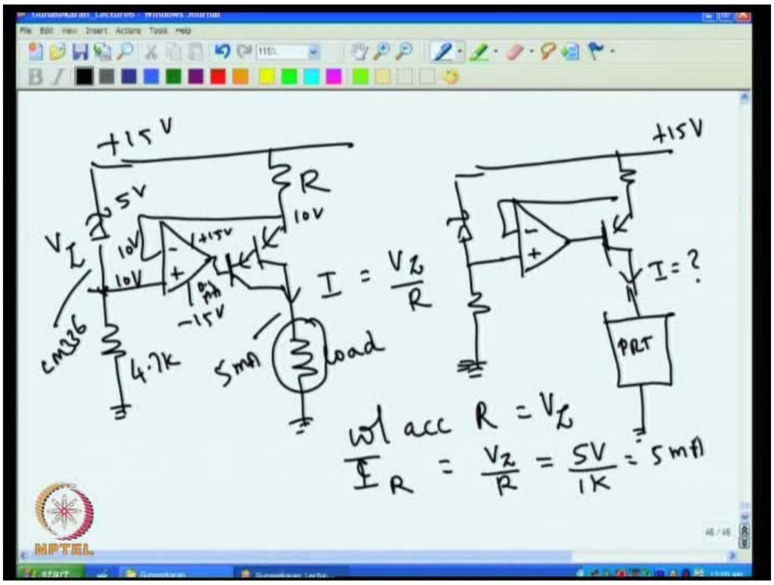
The voltage across this is 5 volt then if this is a 15 then automatically this comes to 10 volt, so plus is 10 volt. If it is a plus is 10 volt then what will be the voltage at this point (Refer Slide Time: 12:11)? We know that voltage at this point will be equal to this in a closed loop system in the op amp because this and this must follow each other. So, I will explain more about this.

Now, we will see if I assume this is also 10 volt then, if this is switching at 10 volt all the time, because this is switching all the time 10, so this will be switching all the time 10 then automatically voltage across this becomes 5 volt. That means, if I take this is 10 and this is 10 then, voltage across the zener is equal to voltage across this resistance R (Refer Slide Time: 12:38).

So that comes automatically even, if this voltage goes up then this also will go up and this also will follow that and automatically voltage across this will be equal to this. Essentially, voltage across R becomes this and if I assume that whatever current is flowing there actual everything is going through this and assuming the base current is negligible and assuming this current negligible then, the current flowing through R is actually the current flowing through this load.

That means the current flowing through this R same as current flowing through the load. Since, voltage across this is constant which is equal to zener diode, so current through this is constant automatically current through this also constant. We can say voltage across R is equal to V Z. So, current I through the resistance R is equal to V Z by R, because voltage across this is known, so R is known, so current through this is this (Refer Slide Time: 13:00). So that is why the current through this is constant and that is given by this amount V Z by R.

(Refer Slide Time: 08:14)



That is how the current is constant so even if I vary this current will remain constant but, actually how is the circuit is working? You know, using this mathematics if we look at how the circuit is working, we can approach this in a different way. Assume that you know, if this is 10 and if this is not 10 suppose, if this is more than 10 say 11 volt; suppose, if it goes more than 10 say 11 then this point will come down, because this is 10 and inverting input is 11.

Automatically this output will go to minus 15 and if this is sitting at plus 11 the enormous base emitter voltage difference comes then automatically it conducts heavily. If it conducts heavily more voltage drop will occur and this voltage will come down. That means one should goes more than 10 say it goes 11 then the conduction increases and that push down this voltage (Refer Slide Time: 15:03). Other way around suppose, if the voltage is not 10 and if this voltage is say 9 then, if this is 9 and if this is 10 then, output will go to plus 15. If this is the basis plus 15 and if this is sitting at 9 with that is what we are assume then this is reverse bias no current will flow, if no current is flowing then, no voltage drop across this.

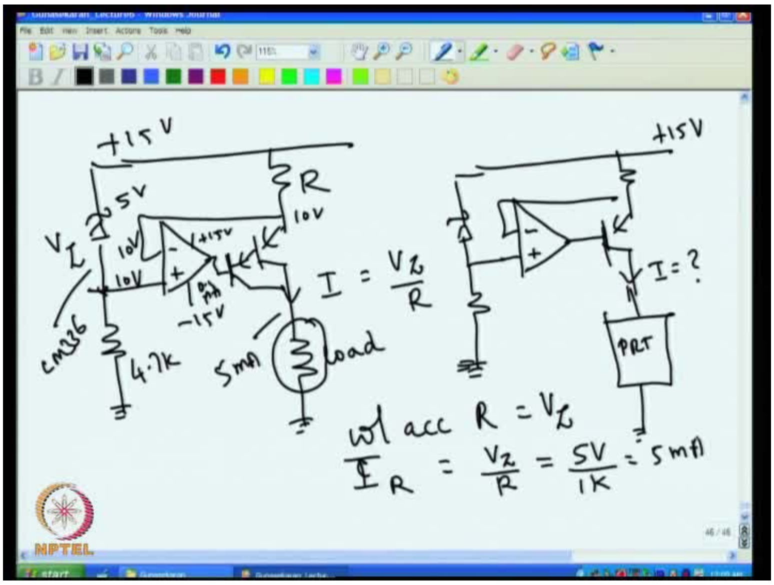
If this is 15 then automatically if there is no current then, no voltage drop and this also become 15. That means if I assume this is lower, then automatically current reduces and make this go high. Other way around this if it is 10 this has to only a 10 if it goes more then, automatically it pulls down and if it comes less, automatically the current reduces and this point goes up. Eventually, what happens that this voltage is 10 and this also comes to 10 that is how it regulates and keeps the current constant of course, our assumption is valid only if this current is negligible and the base current is negligible; anyway, the base bias current of the op amp is small that is a negligible. So, if you want make this current, the base current small, we can use the Darlington for example, I can always put Darlington here and redraw the circuit, so I can put Darlington here (Refer Slide Time: 16:28).

Obviously now, whatever current that is coming here only beta times that is 1 by 100th of this current only coming here and that current also most of them running here. Only 1 by 100th of that only flowing through this for example, if I want 5 milli ampere current through this if I take this what is required is 5 milli ampere then obviously, this current is 5 then this will be 5 by 100 if the HFE is 100, 5 by 100 will be 50 micro ampere. This base current 50 micro ampere divided by 100 that will be 0.5 micro amperes only will be flowing from here. So, this current will be 0.5 micro amperes. Obviously, this current is negligible so if it is 5 milli ampere comes, all the 5 milli ampere goes through this so only 0.5 micro ampere is going through that that can be neglected. So, by this way the current is maintained constant.

Of course, current will change only if this resistance drifts for example, if the resistance changes with temperature then the current will change, then at the zener voltage changes with the temperature current will change, the offset voltage of this op amp changes then the current will change otherwise, the current will remain constant. Of course, these errors we have to look into that if the transistor base emitter voltage changes the current will not change, because the base emitter voltage is in the closed loop.

For example, all that matters is if this is at 10 and this will be less by 0.6 that means this point will be 9.4 and automatically this will be another 0.6 less that point will be 8.8 but, when temperature goes up instead of 0.6 it became 0.5, this is 10 this becomes 9.5, this becomes 9 that is all (Refer Slide Time: 18:05).

(Refer Slide Time: 08:14)

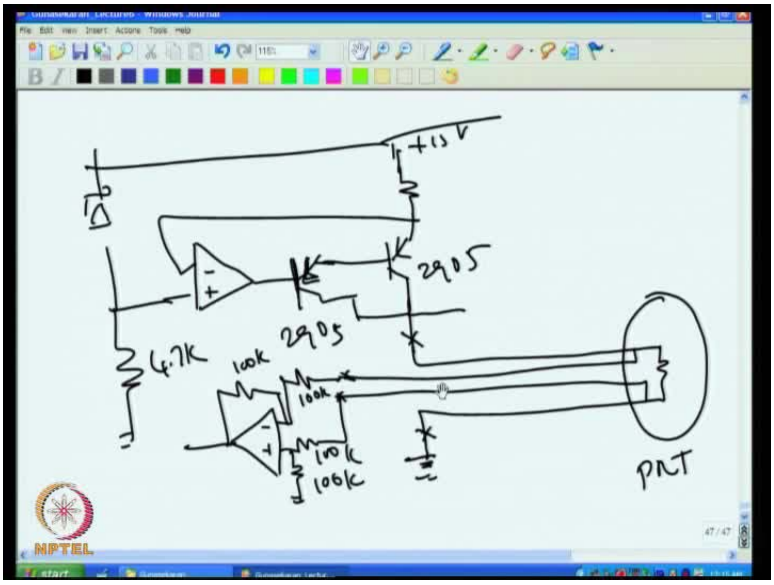


The base voltage output of the op amp have to change when temperature changes, whether output have to change say by 0.1 volt, the required difference change is a 0.1 divided by the open loop gain. The open loop gain is very high, so if the base emitter voltage changes with temperature then output voltage have to change by 0.1 volt or 0.2 volt then required change here, look at this is remaining 10 and the required change will be only few micro volts, because the gain is very large.

At any given time the difference between the two inputs multiply by the open loop gain is the output. If the output change has to be if it is 0.1 volt then, change required will be in few micro volt, then change will be here few micro volt, the current change because of that will be negligible. Of course, there will be a current the change that is negligible that is all because it is reduced by the open loop gain times of the op amp.

If the temperature changes the transistor base emitter voltage changes, it will not give any error in the current but, offset voltage change will give error, zener drift will give a error and the resistance change will give a current error. So, this is the way you can design a constant current source to energize our PRT, which is used as a sensor. Of course, if I want for example, in this case our example we want 5 milli ampere current then our zener is 5 volt, so that will be 5 volt. To get 5 milli ampere I have 1 k resistance which will give me 5 milli ampere constant current source.

(Refer Slide Time: 20:20)



In actual case, the PRT is actually connected like this, so what we do is we will have this constant current source. Now, I can draw both of them as Darlington pairs - I put it as a our load like this now, then connect this, this goes to plus 15 and then here actually will have our zener connected and this we have already decided at 4.7 k for example, we can use transistor like 2905 is a good choice, which has 100 volt collector emitter breakdown voltage V C of 100 volt breakdown, so which we are using 15 volt. So, this kind of transistor is perfectly alright and this is our PRT (Refer Slide Time: 21:21).

Now, the PRT normally has to be put inside an oven or somewhere where you know the temperature should be maintain, because we want measure the temperature of the oven and maintain that at constant. PRT may have a long wire, so in practical terms this looks like this, the PRT connection looks like this. So, we have a long wire which go there and come back. This is the length of the wire that is used to carry this one but, normally you know you will put a copper wire here and copper wire here (Refer Slide Time: 21:57).

When room temperature changes this will be kept inside the oven, this is PRT. This is kept inside the oven, so that temperature it measures but, then this connecting leads which are actually this one and this one (Refer Slide Time: 22:17), if it is longer then they also add a resistance. If I try to measure the voltage here and here, between this point and this point then I measuring the platinum resistance thermometer, resistance plus the wire resistance, the copper wire resistance. The problem with this copper wire is the copper wire also changes with the temperature may be this is in room temperature (Refer Slide Time: 22:07).

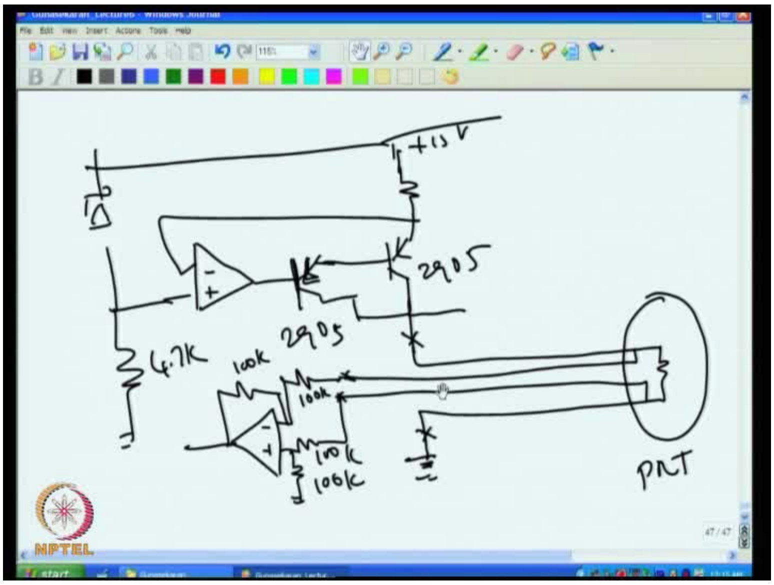
Now, the problem is but, room temperature also if the wire resistance appreciable then you will have this resistance will also change with temperature and then, you will get a wrong reading here, because we want to measure only a change here not the change in the resistance, because the wire resistance also will change when it is appreciable. If you want to make measurements then what we do is we will make the two more wires we take from here, one wire from here, one wire from here; one wire from here and we will take the voltage across this. You measure with I impedance amplifier this voltage, so that this because there is no current through these leads which have carrying the voltage.

Actually this is the 4 terminal method because you have 1 wire, 2 wire, 3 wire, 4 wire these two wires are carrying the current (Refer Slide Time: 23:41); this wire and this are carrying the current, whereas these two wires are carrying the voltage. Of course, we have to measure it with high impedance, so that high impedance amplifier there is no current flowing through this to make the measurement accurate. This is normally done this 4 method is used normally, when you looking for a high measurement.

If you want this, then I can amplify this voltage using an amplifier. Now, for example, I can use different amplifiers, this I can put for example, one simplest thing is I can use a difference amplifier. So that whether the difference between these two voltage amplifier of course, I can keep this resistance higher (Refer Slide Time: 24:42), I can put 100 k 100 k, so that I have only gain 1 because now it is difference amplifier of unity gain.

The difference between these two is now appearing as it is here. Since, this is 100 k the current flowing through these leads are very small, because of there is the negligible voltage drop on this and this wire. Exact voltage between this point and this point is now reproduce here, the difference between whatever the voltage difference here that is reproduced as it is here without involving these connecting lead wire resistances, so that makes our measurement accurate (Refer Slide Time: 24:55).

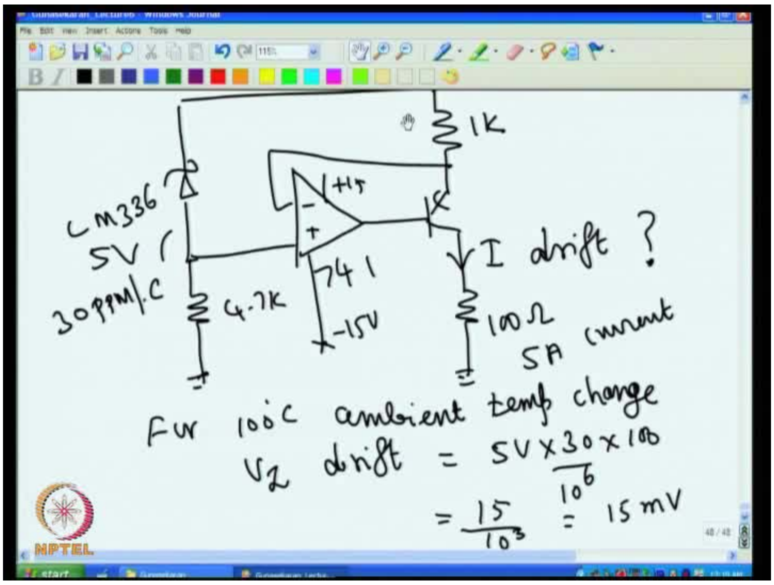
(Refer Slide Time: 20:20)



Now, this can be used further for controlling because this if we want to use it for control then, I have to find the error voltage. I take this and subtract with respect to reference temperature then I can get a difference and then I can do the same thing, which I have done the earlier that is in the case of thermocouple we are done. The same thing can be done I will not repeat this but, I am just concentrating on this sensor design.

Now, having done the sensor design let us look into how to make error budget for this, because we have not done this for quite long. Of course, there are various options we can have an instrumentation amplifier here, rather than a difference amplifier which will give a better result, we will talk about that more. Let us see the total errors involved in this.

(Refer Slide Time: 26:35)



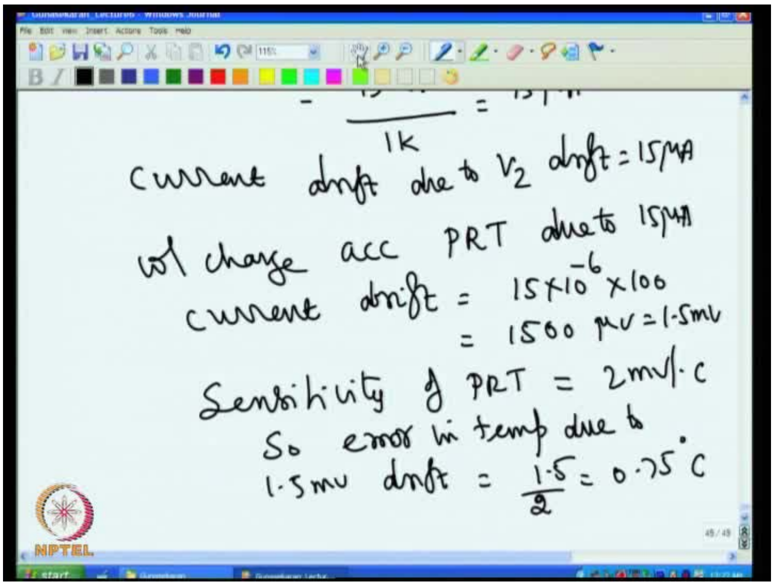
Now, if you look at this our zener, we will redraw the circuit for error budget purpose. If I redraw the circuit and then tried to find the error budgeting. I will concentrate now only on the – there is a simple circuit I take constant current source and then simple load I take. Find out what is the current error here current drift, I drift is submerged that is our main aim.

So, I take this plus 15 and then that is 4.7 k, this is LM 336 zener 5 volt, this is R which is actually 1 k resistance (Refer Slide Time: 27:12). Assume that are used say 741 here, general purpose op amp which comes to our mind immediately so, let us assume LM 741. Let us see, if I want to use 100 ohm platinum resistance thermometer of 5 milli ampere current, what is the drift that we can except in I this current and then, because of that what is the excepted temperature error, we try to find out in this case.

First take zener drift this a minus 15 is given here, so let us take the zener drift. If this is zener is having 30 PPM per degree c drift. For 100 degree temperature changes because if I am designing for industrial grade then 100 degree temperature changes to be considered. For 100 degree c ambient temperature change, V Z drift that is change in zener voltage with temperature V Z drift will be 5 volt into 30 PPM, 30 divided by 10 power 6 into 100 degree. So that is the expected drift in voltage in zener that will be equal to 15 divided by 10 to the power 3, because you have 5 into 3 15 and 10 to the power 3 goes 10 to the power 3 here that is 15 milli volt change.

If it is a 30 PPM zener then you can except 15 milli volt change in the zener voltage; if the 15 milli volt changed here that will demand automatically 15 milli volt change here that means 15 milli volt change have to occur across these resistance that what will be the current change, so current drift due to V Z drift.

(Refer Slide Time: 30:01)

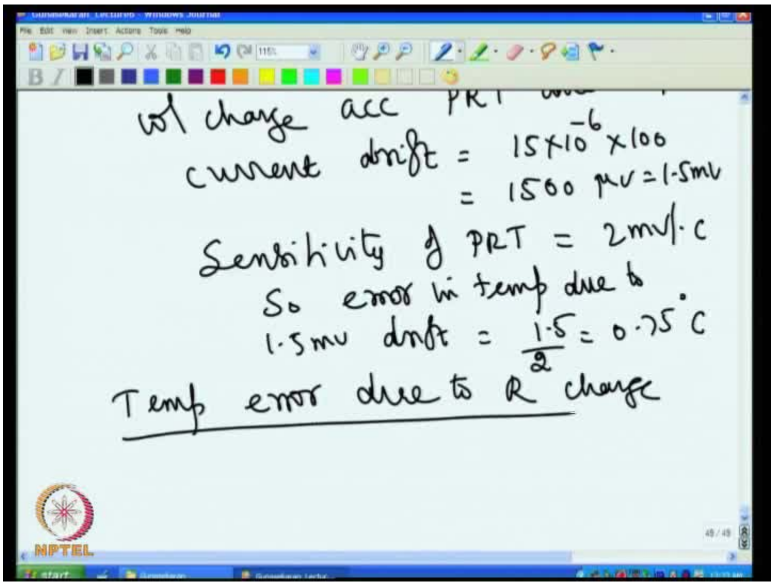


So that will be equal to current drift due to V Z drift would be that 15 milli volt is the actual change in the zener voltage divided by 1 k that will be 15 micro ampere. There will be a 15 micro ampere current drift due to the change in zener drift. So, current drift due to V Z drift that is equal to 15 micro amperes. What will be the temperature error that will give? 15 micro ampere current changes through the 100 ohm priority then that voltage across the priority will change, because the current through the priority change in 15 micro amperes so voltage changes.

Voltage change across PRT due to 15 micro ampere current drift that will be 15 micro amperes into 100 ohms that comes to be 1500 micro volts that is 1.5 milli volts. Voltage across the platinum resistance thermometer will change by 1.5 milli volt but, we know 2 milli volt is considered as a 1 degree c, if 2 milli volt changes across the platinum resistance thermometer temperature error is 1 degree. Sensitivity is actually 2 milli volt per degree c; sensitivity of PRT in this case is equal to 2 milli volt per degree c.

So, 1.5 milli volt will give error, we had find the error due to error in temperature due to 1.5 milli volt drift that will be 1.5 by 2 degree, 2 that will be equal to 0.75 degree c error that means, because of the zener drift you will have a temperature of 0.75 degree in temperature measurement actually. So, this is one of the error is significant or not depends upon the actual application but, you have this much of error is excepted then, we see other errors.

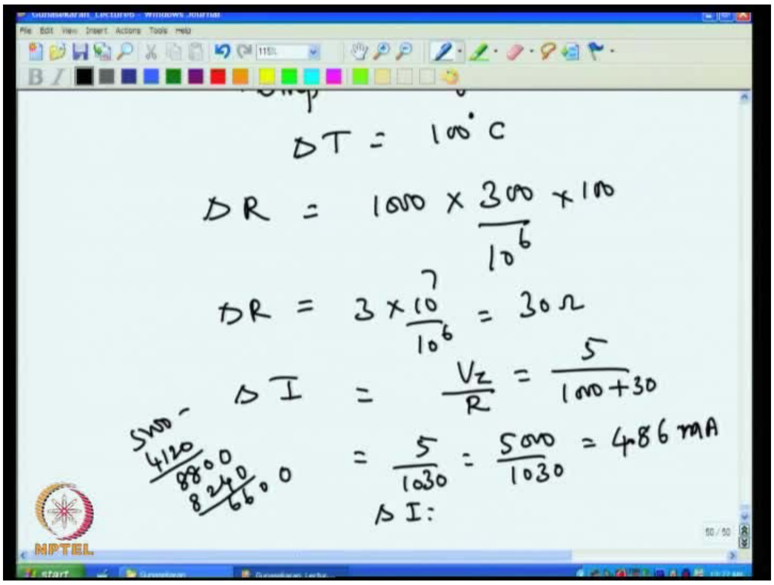
(Refer Slide Time: 33:03)



The other error will be resistance drift. We have this resistance for example, we take this resistance; this resistance we call this is R, this is R drift will have error of course, this resistance, this resistance drift has no implication this has no problem, because this resistance changes only zener current changes but, we know that zener and zener current changes, voltage across the zener hardly changes, so that is no issue with that, so need not worry about this resistance (Refer Slide Time: 33:03).

We consider, what is the excepted current change due to this resistance change? Now, for example, we can have different options for this resistance. Now, assume that you know if I had put this resistance, this for illustrate, what happens if I use normal carbon combination is 300 PPM.

(Refer Slide Time: 34:08)



We had find out now temperature error due to R change, we had to calculate this. For this we take resistance value we know is 1 k so, 1000 ohms temperature coefficient of this temperature coefficient. For example, we take 300 PPM resistance per degree c that we know it is plus or minus 300 PPM. If I take R as a 1000 ohms when temperature coefficient as plus or minus 300 PPM, then our delta T is usually take 100 degree c that is expected ambient temperature changes 100 degree c because this is required for individual grade equipment.

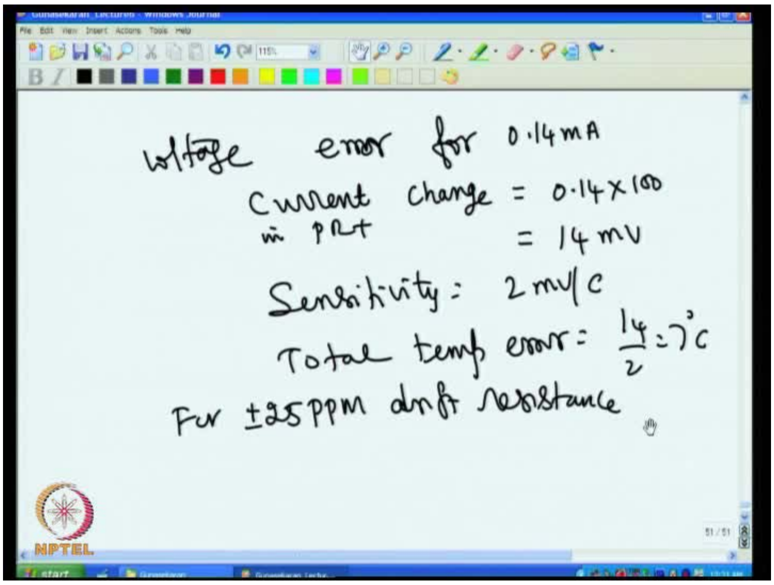
Then delta that is change in resistance when we calculated like this, so you have original 1000 ohms into 300 PPM 300 divided by 10 to the power 6 into temperature 100 degree c. So that comes 357 so 3 into 10 power 7 divided by 10 power 6 that is 30 ohm change; the resistance value will change by 30 ohms. If the resistance change is 30 ohms that is delta R is 30 ohms then what is the current change? Because we know the delta I that is current change actually is equal to V Z by R; V Z by R is the current through that so originally we had 5 volt and then we have 1 k. Now, it becomes 1 k plus 30. Originally it was 5 milli ampere 5 k divided by 1000.

Now, actually the resistance value assuming that value increased, you know the resistance it can increase or decrease it does not matter and we take it here increase and we find out how much current decrease? Other way, around if I take minus current would have been increases, so does not matters but, we do not know for given resistance whether increasing or decreasing that is why we are put this temperature coefficient as plus or minus 30 PPM.

We had to find out now, what is the error? Now, the error would be 5 by 1030 actually that if you take it will be milli amps, so 5 volt divided by that is the milli amps that will actually comes 4 that actually works out 4120, so 5000 minus 4120 that actually comes 880 ohms that actually make 0. So that will go 8 times, so 8240 you will get that actually gives you 660.

Again, you make this that will go 6 times, so it become 4.86 milli ampere, so 5 milli ampere current and actually becomes 4.86 milli ampere at high temperature or other way around I can also say, if I take this as minus then it can become 0.14 milli ampere higher that is 5.14 milli ampere it can be, does not matter we can take in both ways, because we do not know which unit whether it is increasing or decreasing. Some unit it will be increasing, the current will be decreasing by some amount, some unit would be decreasing by this amount, some unit may not be changing at all and because the drift is specified like that the resistance drifts that way.

(Refer Slide Time: 38:27)

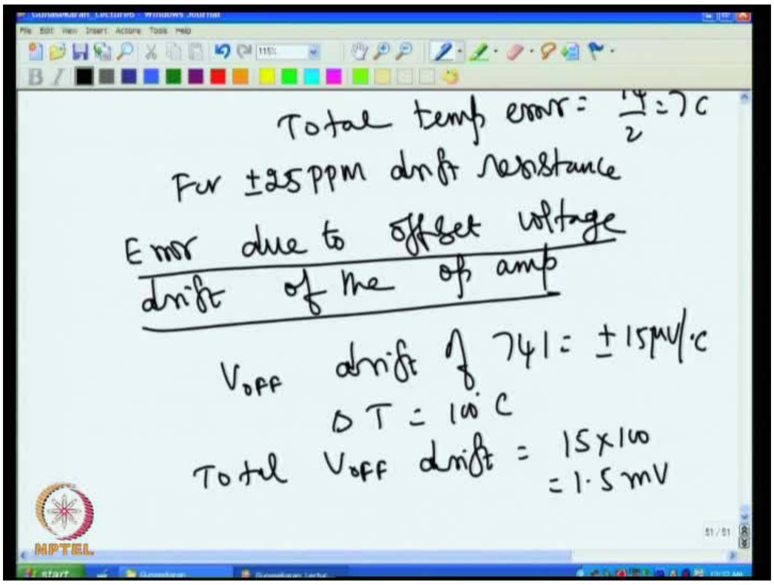


If it is a current delta I then it becomes I will take delta I. Delta I actually becomes 0.14 milli ampere is quite a lot of change. Now, what is the temperature error it will give? Then, if the current is this much changing, then temperature error can be calculated. Temperature error for 0.14 milli ampere current change that is equal to 0.14 into PRT resistance that is 100 ohms. So that voltage will be 14 milli volt change, this temperature error or voltage error I can write it as a voltage error here. So, voltage error for final current change current change in PRT, so that will be equal to this that is 14 milli volt but, we note sensitivity is equal to 2 milli volt per degree c. That is equal to 2 milli volt per degree c, because 2 milli volt change as we take it as 1 degree c, so 14 milli volt gives a total temperature error and 14 divided by 2 that is 7 degree c.

If the resistance our temperature measurement will go wrong by 7 degree c, so resistance drift is very large, contributes, gives a large amount of error. Of course, we can reduce this by going for a load drift resistance. For example, instead of 300 PPM if I go for lower resistance with lower drift then the temperature will come. For example, if I take for 25 PPM resistance then the error will come down because of 25 PPM, 100 PPM or 300 PPM or actually by a factor of 12 difference is there, so error also will come down by 12 times. That means the error will come to roughly 0.5 degree if I use 25 PPM resistance.

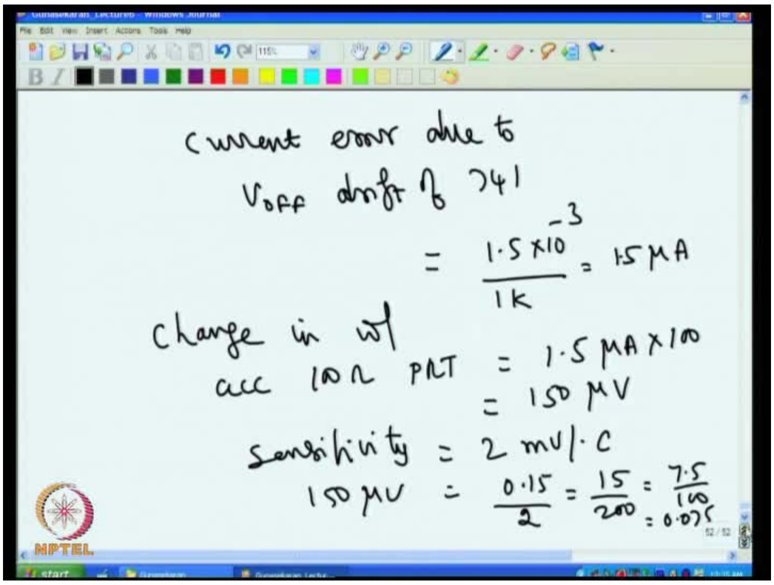
Why I had shown this calculation is how important is the temperature drift of the resistance, so one have to realize very often, we ignore this fact but, if you ignore this then you will end up in having very large drift in the parameters. In this case, the temperature measurement is the actual issue, so error in the temperature measurement in the case will go very high that is 7 degree error will come if I use ordinary 300 PPM carbon resistance. If I go (( )) the resistance of 25 PPM automatically the drift will come down significantly, one can calculate and see this, I leave this exercise to you I will not repeat this.

(Refer Slide Time: 42:25)



Now, there is one more error that we calculate. We have calculated the offset voltage the drift error. We will see what will be the error due to the offset voltage drift of the operation amplifier. Error due to offset voltage now, in this case, we are taken 741 as the operation amplifier, so V offset drift of 741 is given as plus or minus 15 micro volt per degree c. Delta T we take it as 100 degree c, so total offset voltage drift, the total offset drift will be 15 into 100 that will be 1.5 milli volt change, so the offset voltage will drift by 1.5 milli volt if I use 741.

(Refer Slide Time: 43:25)



Now, we have to find out what will be the current error? Current error due to V off drift of 741 is equal to - because 1.5 milli volt drift in the offset voltage will be equal to 1.5 milli volt drift in the resistance R, because if we take the circuit here (Refer Slide Time: 44:15). The circuit is here that is if we take 1.1 milli volt drift in the offset means I have to add here plus or minus 1.5 milli volts that means, this also had a drift by 1.5 milli volt that means, voltage across this will change by 1.5 milli volt.

So, 1.5 milli volt divided by 1 k that will be the current change, so that will be 1.5 micro ampere current changes. If I write this, so current change due to the offset voltage drift - current error that will be equal to 1.5 milli volt divided by 1 k that is equal to 1.5 micro ampere current. So, 1.5 micro ampere current will change through the platinum resistance thermometer.

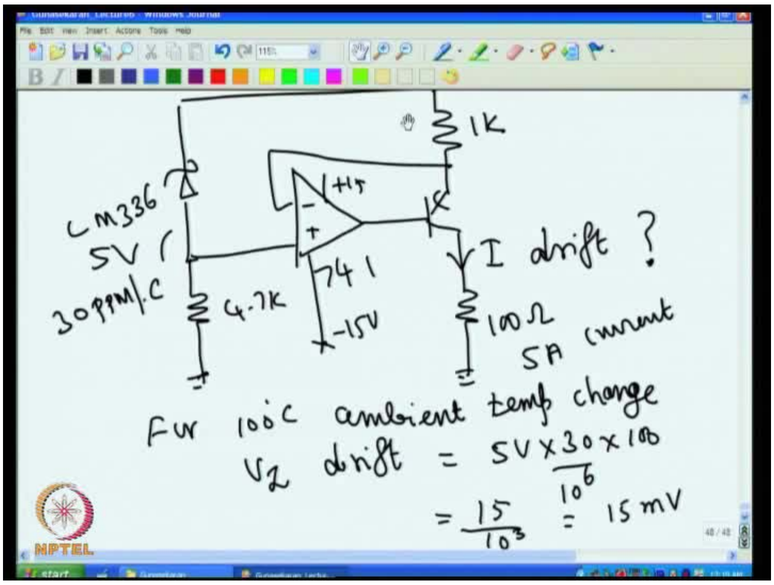
Change in voltage across 100 ohm PRT will be equal to 1.5 micro amperes into resistance value 100 ohms that will be 150 micro volts. So, 150 micro volts is the expected change in voltage across the PRT due to the offset voltage drift but, then sensitivity is 2 micro volts here; sensitivity at this point is again sensitivity equal to 2 milli volt per degree c. So, 150 micro volt will corresponds to - if I convert into milli volt that is 0.15 divided by 2 degree that is 15 by 200 that is the temperature error that will actually corresponds to 7.5 by 100, that 0.07 degree error is negligible actually. Temperature error is equal to temperature error due to offset voltage drift; op amp is 0.075 degree which is very small.

So, one need not go for high cost low drift op amp, 741 itself is good because that error what will come is less. The reason is that we are used 5 volt zener reference, so when we compared to 5 volt, 1.5 milli volt drift in offset is very small. Plus 5 volt is our reference and if we compare 5 volt and 1.5 milli volts that is the ratio is very larger that is why we got a very low drift drop set voltage drift. So, one can use a 741 itself for this temperature measurement.

This I had shown you how to make this temperature sensor for the controller using platinum resistance thermometer. Of course, we now see other issues because there so many sensors available LVDT and so on, which will discuss one by one little later because my aim is here, how to design temperature controller including sensor design and then the heater drives design. Because our aim in this course is to make a good circuit designer, is it able to design any analog circuit for a given application? This will help you in electronics quite a lot, because if we not able to draw a circuit, then you will not become an electronic engineer however, good in other aspects in electronics. Learning the circuit design is essential part of electronic engineer's life that is why I am more concentrating on the sensor circuit design.

Now, you may wonder that we had shown here in this example, how to design temperature sensor using platinum resistance thermo meter. Earlier, I had shown you, how to design using thermocouple and then also I had shown you, how to design the temperature indicator using I c sensor. Of course, this sensor design using this platinum resistance thermometer, we are using constant current source and power flow methods.

(Refer Slide Time: 26:35)

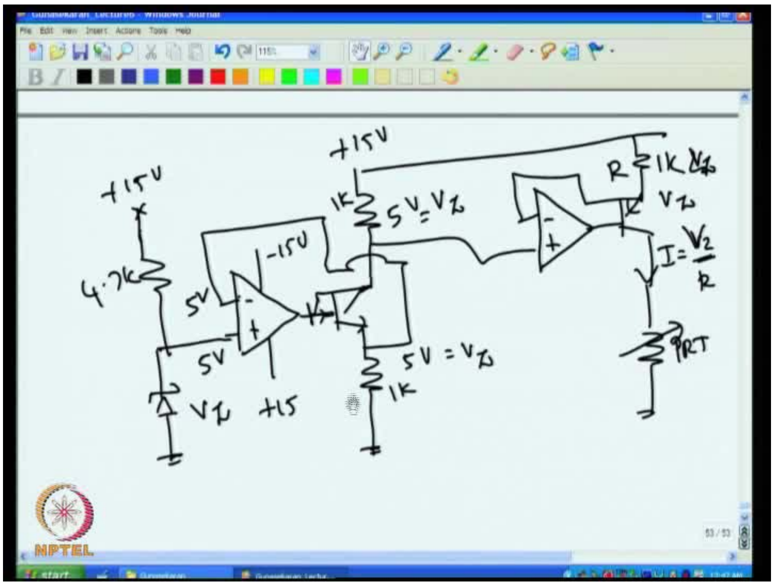


We can also have different constant current sources because this is one constant current source where in, we are used zener diode in a different passion. That is now we have used the zener diode refer to supply voltage, because zener diode is kept with supply and the op amp. The zener diode in this case, disadvantage is the zener diode is not refer to ground, because normally in a instrument you may have a zener diode already available which is used for some other purpose. The same thing can be used for this purpose because in the whole circuit most costliest the zener diode, because if we want to load the temperature drift in current reduce a load drift zener. We had taken LM 33 which is

30 PPM zener, we have for example, LM 339 which is 1 PPM temperature coefficient zener but, then if we go for that it costs more, so normally zener cost quite a lot.

If I am using for some other purpose in the circuit one zener, the same zener can be used here but, then this zener is not with respect to ground, so it is better to have constant current source zener reference is with respect to ground.

(Refer Slide Time: 50:55)



The constant current source design can be looked in a different way. For example, I can have a constant current source with respect to - where the zener is connect with respect to ground. For example, I can design current source now using the zener with respect to ground. I can do it like this (Refer Slide Time: 50:56), I can take this op amp then what I do is I will put, for example, one resistance here and then I put the zener. My aim is that I want the zener with respect to ground, so I put the biasing network for the zener then I give a supply for this plus 15 volt and minus 15 volt then, I give here plus 15 volt the same 4.7 k resistance is I put, so that 1 milli ampere current minimum will maintain.

Now, in this case, 2 milli ampere current will be flowing because this is 5 0 you know, voltage at this point is 0, so this comes 5 and this is 15 so 10 volt across this 4.7 k will be little more than 2 milli ampere, so the same arrangement we can have. Now, what I do? I will take this say, I connect to plus 15 volt and then, I will connect this point, so connecting it there I connect it to this point, because if hitting at 5 and this also at come at 5 that means this is also 5 and that means voltage across this will always 5 that is equal to V Z, so voltage across this is equal 5 voltage is equal to V Z.

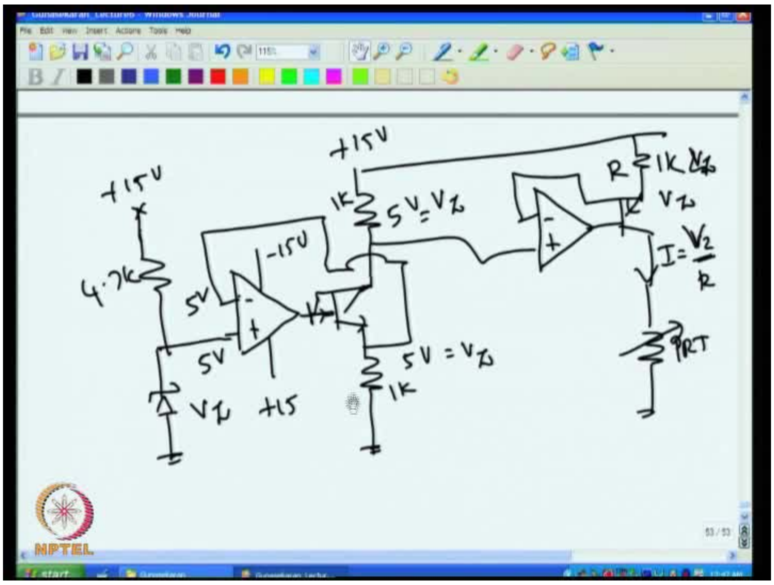
Assume that current that is flowing here is same as this you know, the current flowing through this is flowing through this same. The base current is negligible, if I assume that then the current flowing through this is same as this. If this resistance equal to this resistance then voltage across this will be equal to voltage across this.

If this is 5 volt then automatically voltage across this also will be 5 volt, so all that I do is if I had kept here 1 k then I also keep here 1 k then, voltage across this also will be equal to 5 volt. Of course, this is true only when the base current is negligible, I can make the base current negligible by putting a Darlington here. So that base current (( )) this 5 milli ampere this current becomes where we had shown that this base current becomes 0.5 micro amperes which can be neglected (Refer Slide Time: 52:31).

Now, I got the voltage across this is a zener, which is 5 volt. Now, I can put my regular current source that our earlier current source, because our aim was that we want to make the zener with respect to ground, so that I can use this zener for a different purpose. Now, I put the load here that is PRT is here and then this plus is there, this I connect to this. Now, the current will be constant here. Suppose, if I put here again 1 k now this current will be I and V equal to this is V Z, so voltage across this become V Z 5 volt that is equal to V Z.

Now, we know that the voltage across this equal to V Z, so this voltage is V Z 1 k and the voltage across this becomes V Z. So, current through this become V Z by this R. That is similar to what we are discussed earlier. So, the current is now determined by this V Z, so even if I change the value of this, the current will remain constant. This way we can make the zener voltage with respect to ground of course, there are various other ways of designing, even this can be modified to get, because we had used here PNP transistor, we can also modified this to get a NPN transistor working version but nevertheless, we see what is other errors had come in, if I use this kind of arrangement for example, in this case, this offset voltage drift will give a current drift due to this and that will give a current drift due to this. (Refer Slide Time: 53:52).

(Refer Slide Time: 50:55)



Offset voltage drift we saw produces very little current drift, so offset voltage drift to cause of this additional op amp is not a serious issue. The base emitter voltage change is not an issue at all that is actually controlled by the loop gain, because we know that if this is 5, this is also 5 and this also 5, so the voltage across this is 5 volt (Refer Slide Time: 55:52). The current through this 5 volt by 1 k that is 5 milli amperes, the same 5 milli ampere current is going and that possess 5 milli ampere current through this.

So that the error due to this base emitter voltage drift is not there, this offset voltage drift produces very little error here and very little error here. Of course, the additional errors that occurs is that if the temperature coefficient of this suppose, if the temperature changes then what happen, the resistance value will change and then that will make sure that current through this is changing. The current through these changes, this current also will change (Refer Slide Time: 55:49).

If this resistance having at plus positive temperature coefficient and this is having a negative temperature coefficient then, what will happen is that you will have this current change will occur but nevertheless, if the current changes then voltage across this will change because this current changing and this resistance also changing and you will have a voltage change occur. So, the voltage across this will not be V Z. For example, if this resistance changes, increases by 30 ohms and this resistance decreases by 30 ohm then, what will be the new V Z.

The new V Z will be this current actually will come down by 0.14 milli ampere, this voltage will increase by 0.14 milli ampere, so nevertheless if this is plus and this is minus, we will have twice drift in voltage due to resistance drift. This is disadvantage of this circuit and also added to that this resistance drift also will give error, because we do not know, what is the drift of this, what is the drift of this, what is the drift of this, so compared to the our earlier circuit this adds more error (Refer Slide Time: 57:15).

One has to be very careful when dealing with this because we want to say one zener, which may have low temperature coefficient but, then we end it up in having resistance, which is now producing much larger error than what we had thought of it. One had look in to this aspect also when you are deciding on the circuit and saving the money.

In this class, we had discussed about, how to design a temperature sensor - temperature indicator using platinum resistance thermometer. In the process, we had discussed about, how the constant current source is working and how to compute the various errors involved in the constant current source. The rest of the things we continue in the next class, thank you.