Circuits for Analog System Design

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Lecture No. # 08

Temperature Indicator Design Using Op-amp

Today, we will discuss some other designs used related to the operational amplifier. So, as an example today, I will take how to design a temperature indicator.

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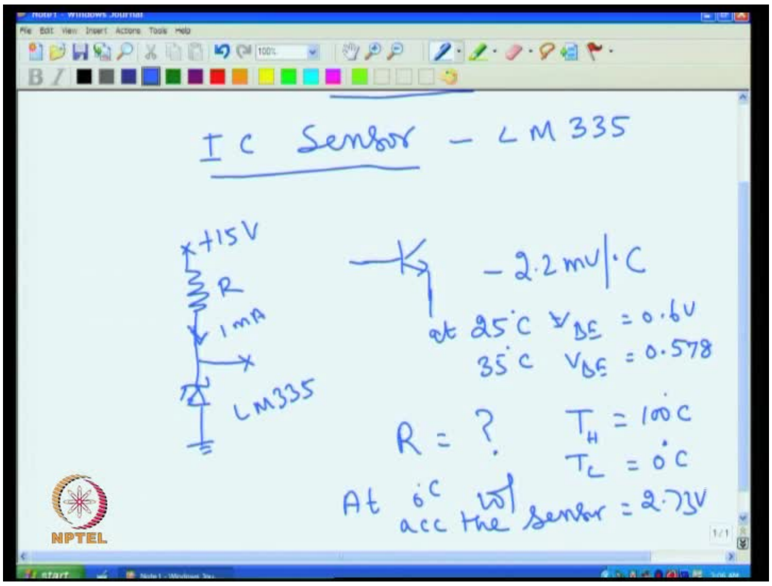

So, we will take temperature indicator design. Now, for this we have to first select a temperature sensor. So, you have, various sensors are there, I will see about them little later. Today, we take for example, I C sensors, so we have I C sensors are available in the market, using that how to design temperature indicator, for example, - I C sensor ever classical sensor is L M 335 is available. This is temperature sensor and it is used essential in the industry. This is an older version of this, the new version of this also L M 35 is there. Let us see, how to use this L M 335 and then operational amplifier, and other components so that, we can design a temperature indicator.

Now, this L M 335 is basically, a transistor based temperature sensor, because we know, if you take transistor then, if we look at the base emitter voltage for example, we know that, we know between base and emitter, when it is forward bias we have around 0.6 volt. This forward bias voltage changes with temperature, we know the temperature coefficient of that is minus minus 2.2 mill volt per degree C actually, that means, when for every 1 degree temperature raise, you will have voltage drop of 2.2 milli volt per degree C. In the sense, if at 25 degree C for example, if 25 degree C, if the V B E is V B E at 25 degree C, V B E is equal to 0.6 volt.

Then at say at 35 degree C, 10 degree above the V B E for example, we will come down 10 into 2.2, 22 milli volt, that actually means that is you will have 0.5, 22 milli volt comes 77, 78, 0.578 volt, if comes that is a 22 milli volt at decreased for a 10 degree temperature raise. So, using this transistor, base emitter voltage change is a basic element, that the developed is I C sensor L M 335. And the L M 335 today available for as to use in this form like for example, if you look at L M 335, the symbol is given is like as a zener diode. So, actually, there is a third terminal associated with this, let us not worry about that at this point of time.

So, this symbol is like this, now to use it as a temperature sensor. Now, what I will do is I had to pass a current through this, that current should be minimum of 1 milli ampere. So, how will I pass the current? So, I connect one resistance then connect for example, 2 plus 15 volt supply. When I select this resistance R (this resistance R) such that the current, that is flowing through this 1 milli ampere. So, we had to make sure that, the 1 milli ampere current, all the time it flows through that, then only the sensor works properly. At the same time, we also should not send more than 10 milli ampere current through this. You can pass the 5 milli ampere current, then there will be heating up in this and that will give a temperature measurement error.

So, to avoid that we try to operate that at the least possible current that is 1 milli ampere. So, let us have 1 milli ampere current minimum of flowing, more than 1 milli ampere after 10 milli ampere, there is no problem, it works alright except that the small temperature error. So, what is the value of R I have to select? That is the first question that we have to looking in to. Now, this sensor can be used actually, up to 125 degree C, now even if I take this for our application. Let us assume, we want up to 100 degree C, so temperature range is actually up to 100 degree C. Assume, for our design, we have to display temperature of 100 degree C.

Now, if it is 100 degree C then at 100 degree C, what is the voltage at this point? Then assume that, our other temperature range is you know T L is 100 and the lowest value is assumed, we want up to 0 degree C. That means, I should look at this point, what is the voltage I will get 0 degree C? What is the voltage I will get 100 degree C?

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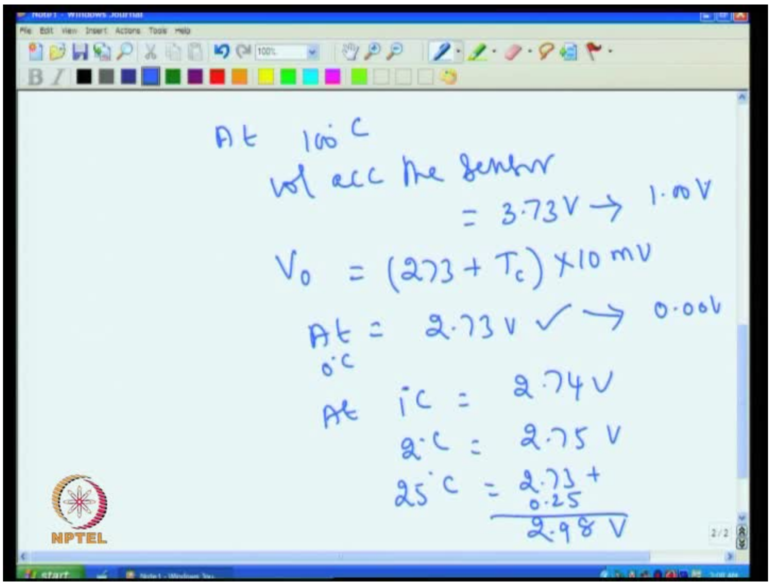

Now, if we look at the data sheet of this L M 335 says that, it gives a voltage across this zener. That is you know, voltage across this (you know, voltage across this) is 10 milli volt per degree k. That is, for example, at 0 degree C at 0 degree C voltage across the sensor will be (sensor will be) 2.73 volt. Then at 100 degree C voltage across the sensor, sensor will be 3.73 volt, because 0 degree corresponded to 273 k. So, basically, the V output of sensor is actually, 273 plus temperature in C into 10 milli volt. That is what the temperature gives, that is why at 100 degree C we will get 3.73 volt, at 0 degree C it gives you 2.73 volt, at 0 degree C. At for example, 1 degree C then you will get 2.74 volt and 2 degree C, you will get 2.75 volt like that. For every 1 degree 10 milli volt increasing in voltage, we will see across the sensor.

So, if I want to measure the temperature, then I should keep the sensor wherever, I want to measure. And then I will get a voltage like this, I will say at room temperature for example, 25 degree C I will get 2.73 plus 0.25 volts, that will give me 2.98 volt. So, we will get, but only problem is you know, if I want use as a temperature indicator then it is good, if I get at 0 degree C 0 volt and 100 degree C 1 volt, that would be good, because I can connect the meter directly and then the display will show me the actual temperature, need not worry about the 2.73 volt.

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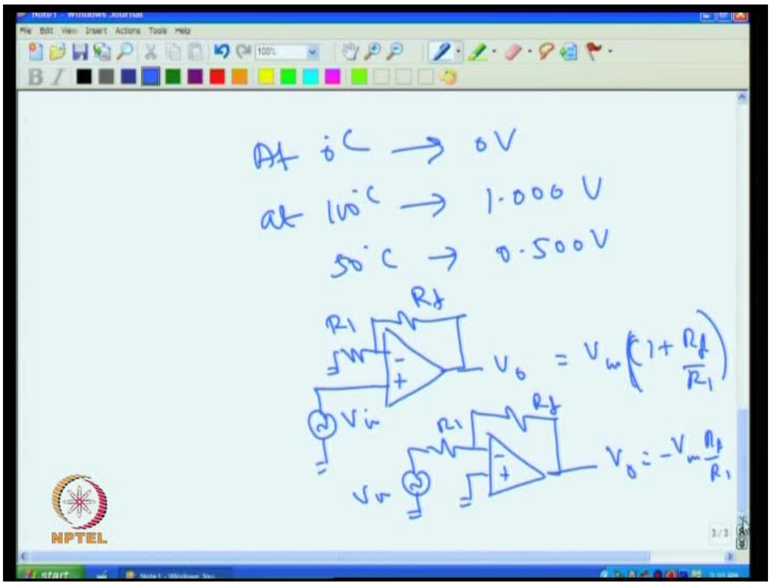

So, the actually, see at 0 degree C it is giving 2.73 volt, but this I have convert into 0 volt at three points at 100 degree C gives me 3.73 volt, that I have convert into 1 volt. So, essentially, if I look at the thing what I required is from the from the instrument, that is the sensor, I will connect to the my circuit, my circuit should give at 0 degree C 0 volt, at 100 degree C is should give me 1 volt. So, at any other temperature for example, 50 degree C obviously, it will give me 0.5 volt. So, one can connect the display and then directly see the temperature, that is our aim. So, how to achieve this? So, what I do this, I leave operational amplifier and then I can do this job in a simpler way.

So, I take the operational amplifier, I know the operational amplifier, we can use it as a non inverting amplifier. In that case, I will give a voltage here and then I give the resistance here, this you have already studied in your earlier class. So, you know that this is R f and R 1 then V input is this and that V output is here, then V output is given by V input into 1 plus R f by R 1, this you may be familiar from earlier circuit. So, I will not get into the regulation of this one can easily do this work, we have already done this under graduated course.

Now, R if I, if we are using non inverting amplifier, then I can show that, you know the circuit looks like this. That is I can put the same thing, I give a input here around this and then give the input at this point, then connect the feedback resistance, then you have R f and R 1, and V n. Then you will get V 0 is minus V n into R f by R 1. So, this also you have studied, now we also know operational amplifier can be used as a summing amplifier or it subtract the voltages. So, in this application, first what we will do is? We will use non inverting amplifier and then try to get this one.

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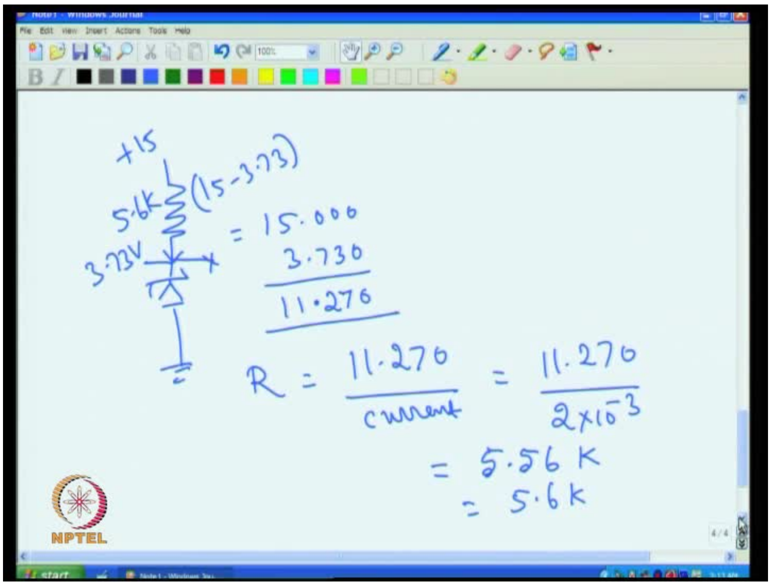

So, what I will do is? I will take the sensor first. So, I have to bias the sensor, so I put the plus 15 volt, then I want make sure 1 milli ampere current going through this, I know the 100 degree C this point will be 3.73 volt at 0 degree C, it is 2.73. So, at the worst case the 100 degree C, I will have 3.73 and then that makes voltage across this resistor will be 15 minus 3.73 volt. That is the worst case voltage, that will see across this resistance and that works out to be, if you calculate that, you will get 3.73 volt. So, we will get 11.27 that is the 11.27 volt, you get across this resistance, I want make sure 1 milli ampere current minimum. In this example, let me take 2 milli ampere, because it can work from 1 milli ampere to 10 milli ampere, I will come back to this why taken 2 milli ampere.

So, if I want to pass 2 milli ampere current through this, then the voltage across the the voltage across the this resistance is now, the worst case will be 11.2 volt. So, 11.2 volt, if you want 2 milli ampere current through that, then the resistance value R will be that 11.27 volt divided by this current. That actually, turns out to be 11.2 volt divided by 2 milli ampere current I take that, if you convert into the resistance, then it will comes 5.5

then you will have 5.6 K resistance you will get, do this division you will get 5.6 K. Now, if I look at the nearest value, that I can put a 5.6 K resistance.

So, if I put 5.6 K resistance, then I know approximately 2 milli ampere current is maintained through this sensor, so I will put here 5.6 K. Now, if I see the voltage at this point voltage at this point that will give me temperature actually. So, at 100 C get 3.73 K and then at 25 degree C get 2.98 volt across this. So, R voltage at this point with respect to ground so, I will say the simply voltage at this point.

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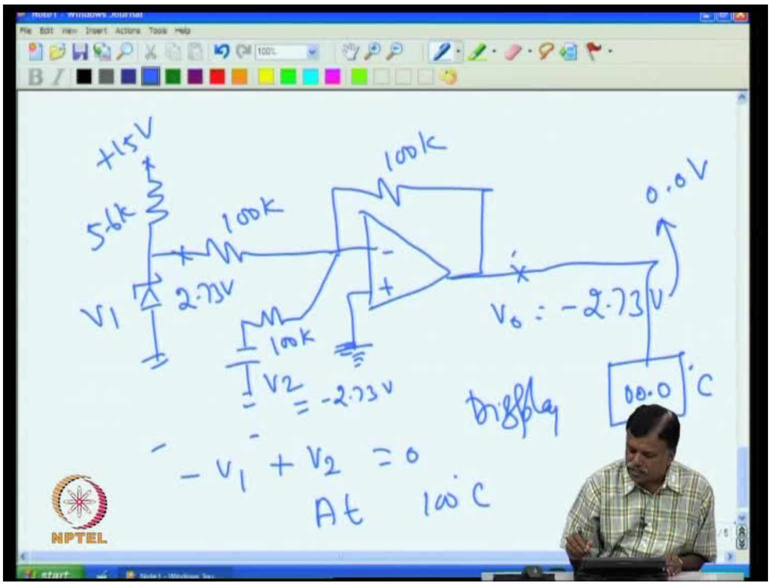

Only thing is at 0 degree C it is giving 2.73 volt that, I have to make it 0 degree C using in the operational amplifier. So, that, I can do it in the following way, so what I can do is now I put the sensor, connect this and I put this 5.6 K connect this to plus 15 volt, then I take the operational amplifier this plus grounded, you got minus, so i can do this. This is simple inverting amplifier assume, I have put equal resistance here say 100 K and 100 K I have put the equal resistance. So, essentially, at 0 degree C at this point I will get 2.73 volt, then at this point that V 0 that will give me minus 2.73 volt, assuming there are no other errors in the operational amplifier, this is simply a inverter amplifier.

So basically, the plus head becomes minus, you may wonder that why did I select the 100 K, because I would have selected a 10 K, that I would have selected 1 K. Remember that, if I this current whatever, that is going through this, it is 2 milli ampere. Now, if I put a resistance here and I know that this is 0. So, this point is also at 0, is essential of the operational amplifier working that, we have discussed earlier. So, this input and this point are essentially same, so if this is 0, I really this is also 0. So, the current that is flowing through this resistance is 2.73 volt divided by this resistance. So, this current basically comes from here and then part is going here, and part is going here.

So, this current should be small, if this current should be large, then the current flowing through this will come down. And it happened below 1 milli ampere then temperature indication will go wrong. That is why I have selected it here at 100 K of course; we can go very high value, if I go for high value here, high value here. So, will have error associated with a operational amplifier, that we will see little later that is because of the bias current, you may get larger that is we that is, we do not want put more than 100 cross, larger value also gives more problem. But smaller value, if I put that gives problem, because most of the current will go through this and less current will go here.

So, need either want to select low value, because at this point if I take 2.73 divided by 100 K, it comes roughly about 27 micro ampere current and 2 milli ampere come here, and 27 micro ampere going is no issue at all, is still at enough current to say that current is a 1 milli ampere. So, 100 K is perfectly alright here, but then our original aim was that you know V 0 should be 0 volt, when the temperature is 0 degree. Suppose, if you keep this one in ice, then ice this will be give 2.73, but I want here 0 volt. So that, I can connect meter here, you know display here and the display will show me the actual temperature that is our aim. So, I will put display and the display will show me, you know say like this, keep like this, if it shows and happy.

So, for that you know, it give the 0 volt that means, if I want to I have to remove minus 2.73, how to remove? So, I can do one thing, I can subtract you know, I can add is this operational ampere can be used as a summing amplifier as well. So, I can give a voltage here for example, I can give minus voltage here, this voltage can be minus 2.73 volt. Now, if I give a minus 2.73, if we put a 100 K, then you will find that this V 0. Now, actually, 10 to 0 volt this is because now you have two sources, one is this you have got V 1 and another is V 2. So, how to find the net out voltage, we have one at a time so, first we take V 1, then fit as V 1 with V 2 grounded. So, I will take assume that this is grounded so, I remove this guy then put this to the ground.

Now, what is the output voltage that I will get here? For example what is the voltage I will get here, I find out the voltage due to V 1, what is the effect V 0, then I ground V 1 and give V 2 find out the what is the effect? I add both, that will give me the net voltage at the output. So, all already those are similar, this may be so much, you can say that you know the two voltages here. This is V 2 and other one is V 1 the net output is V 1 and the gain is 1. So, V 1 is any way inverted, so output will be minus V 1 and V 2 again, gain is 1 and that is again inverted. So, we will have plus V 2, so V 1 V 2 are equal, then output will tend to 0.

So, to make output is 0 all that, I need to do is make V 2 that is equal to minus 2.73 volt. So, give here minus 2.73 volt then this will become 0 at 0 degree C then, if temperature goes up, this will go to temperature goes up this will go to 3.73 at this point, say 100 degree C then it goes to 3.73 this remains 2.73. That means, if we see the output due to V 1 that will be at this point at 100 degree C by C, at 100 degree C, then what is the condition that we get.

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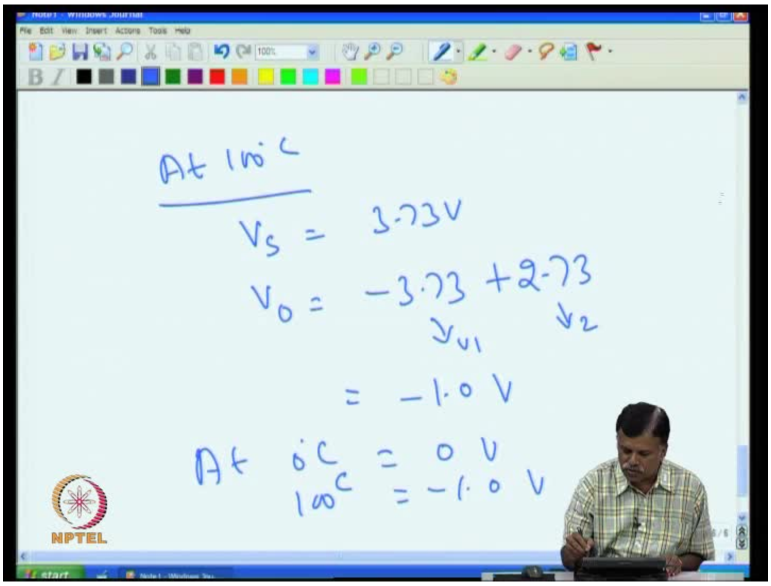

At 100 degree C then sensor V sensor V would be 3.73 volt. So, V output will be V minus 3.73 then plus 2.73 due to the V 2. So, this is due to V 1, this is due to V 2 and the net output voltage minus 1 volt. So, 100 degree C, so minus 1 volt, right now we need not worry about this minus sign, but it solves the purpose at 0 at the degree C. Now, it will give me at 0 degree C, it will give me 0 volt at 100 degree c, it will give me minus 1 volt. So, if I connect the meter then it will show correctly, but then there is one issue, now if I go back to the L M circuit, if I go back here we have achieved this you know achieved 0 volt by connecting minus 2.73 volt at this point, but then this voltage was stable, if this changes then output temperature also, output voltage also changes that give a zener reading.

So, we have to connect a voltage source, which is officially is stable and it is 2.73 volt, if the stable voltage, so we had to connect a zener diode only. So, if I have a zener diode of 2.73 volt, then the issues very simple, then I can connect zener and then the work is done. Unfortunately, reality you do not get zener of minus 2.73 volt, you have for example, very good zeners available, voltage of 1.2 volt, at 2.5 volt zeners available, 5 volt zeners available. Now, I am not talking of the regular junction zeners, I am a taking of lower drift zeners with temperature, even though we are not putting this zener inside the oven where, we are measuring the temperature.

But with the ambient temperature this voltage should not change. So, we are to have a stable zener, stable zener you can get it in the band gap zeners are very stable for example, we have a zener the band gap zener, say the classical one is L M 336 for example, that gives you 30 p p m solubility against temperature. So, we have to use only 2.5 volt this available in 2.5 and 5 volt varieties. So, that will give very stable voltage against temperature, with the temperature, the voltage of the zener changes only 30 parts per million. So, they are that will see, even that is some times of the objectionable, but in this example we will take assume use L M 336 zener to generate V 2. Only issue will be it is not 2.5 volt, what the zener would have is only 2.5 volt.

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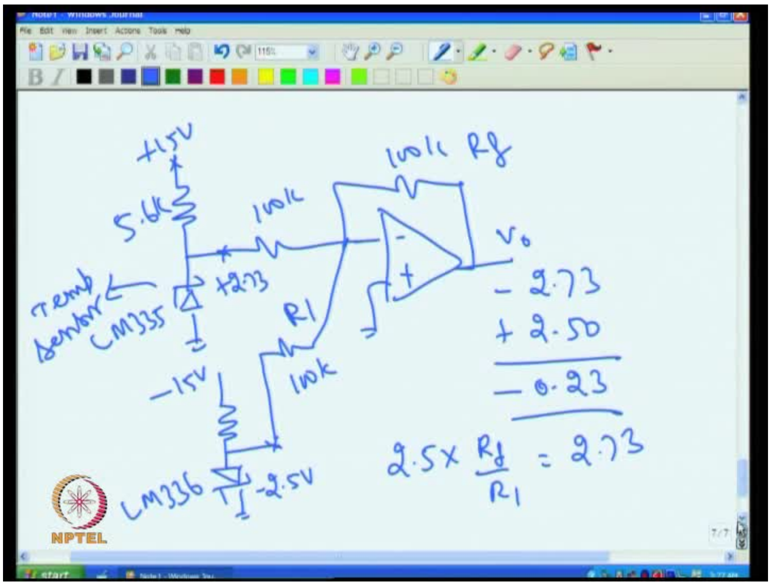

So, what happens, if I connect the zener no other go I have to use only that 2.5 volt zener. So, if I take 2.5 volt zener, then with that how I will design the circuit. So, what can I would be I can take the our temperature sensor, they are 5.6 K here and this is L M 335 that is sensor, then take the output then I connect to the operational amplifier, then put on the 100 K here and then 100 K here, and that is the output. Now, I put one more zener diode, that zener are also to be bias that has be minus, because that depends on how we connected it. For example, I put minus 15 here then, if I put look at this it gives 2.5 volt say L M 336.

The symbol looks like both zener, but this is temperature sensor this is not zener, this is a temperature sensor. Unfortunately, in industry the follow the same symbol and the manufacture, also give you the zener symbol only for the temperature sensor. So, we have to accept it and use it, so nevertheless this is a temperature sensor, this is a zener, this voltage you know at this point changes with temperature, whereas here the voltage at this point will not change, much it will be very very small that is want, we want stable voltage at this point, we want a variable voltage with respect temperature at this point.

So, if I take L M 336 this will give me at this point 2.5 volt, so I can do one thing I can connect this 100 K and connect to this. Then at 0 degree C, this is 0 degree C then I will get plus 2.73 volt and at the time it is minus 2.5 volt, then I will get output the difference between these two, that will be minus 2.73 and this gives you plus 2.5. So, the net result will be minus 0.23 volt that is sense of getting 0, I am getting 0.23 volt at 0 degree C, that is because we could not get that 2.73 volt zener is not available in the market, that is why this problem are happened. Now, there is one way of solving this issue now, if I want my aim is want make output 0, when this is when the when the sensor is kept at 0 degree C.

Now, one thing I can do since, it is only 2.73 volt I need not keep 100 K for example, this 2.5 volt should produce this minus 2.5 volt should produced here, plus 2.73 volt to cancel out this 2.73 volt given by this. So, what I can do is, I keep this 2.5 volt change this resistance such that, you know this and this, put together gives gain little more than 1. So that, this 2.5 itself able to give 2.73 the output. So, if I look at this route then I had reduced this resistance from 100 K, so how much get reduce. So, what is required is that, I have voltage of this 2.5 into this R f, I take this, this I take R 1 into R f by R 1 should give me to 2.73.

Now, if I take this R f is 100 K, then this comes to 2.5 into 100 K divided by R 1 will get me 2.73 volt. Now, if I see this one, then what is the R 1 comes, you will have 2.5 into 100 K divided by 2.73 that is the value of R 1. So, you will find that the R 1 will be little less than 100 K, where this is little less than 1. So, that means, you will have this 100 K little less than 100 K, may be 82 K, we have to calculate and see. So, once we put this value of R 1 here, not 100 K then i will, i will get i will get at 0 degree C, this is 2.73 and then this is 2.73 and this will be 0, at the time this is fixed at minus 2.5 volt. So, I have to put this value of this value of R 1 here.

So, this, if you workout it may come to you do not know find, even that value readily available. So, normally what is done is we will put this this will be around 82 K. So, what I will do is, I will put one one more additional resistance here. And here for example, put it 82 K and very small resistance here is variable resistance, and then that actually should cover, the this range for example, this make them something like 91 K, 92 K. So, if it is 82 K then this has to be adjustable to 10 K may be, I can put 22 K pot here, so I can adjust this to get 0. So, normally, what is done is you keep this one at ice and this gives you 2.73 adjust, this to get 0 degree here, so that 0 degree C, it gives you 0 volt. So, that is how you know, the zero adjustment is done.

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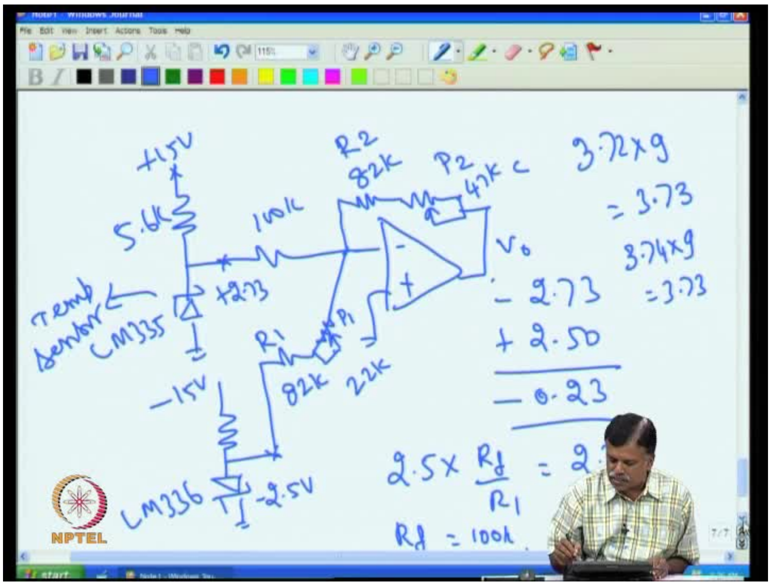

So, you can adjust this potentiometer meter so, I will call this as P 1 and of course, this resistance is R 1 here. So, we have this resistance we call R 1 82 K and this is P 1. So, I adjusting P 1, we can calibrate this instrument, that is keep this one at ice and adjust P 1 to get 0 volt at this point, that represent 0 degree C. Now, the problem is not yet fully solved, because we know that, you know the sensor also has error. Some you know, at 0 degree C will not give exactly 2.73; it may give you little less or more. And see data sheet, if you are not adjusting, you know given third terminal, if you are not using and adjusting this have an error.

So, at 0 degree C, if it is not giving 2.73 it gives 2.74 or 2.72, it is not a serious problem. I can adjust these and get it 0, that is a reason I have put in fact potentiometer. So, even so that, to that means, we can calibrate out even whatever error is there under zener. So, that is why the potentiometer is required here to do it. Similarly, the other problems comes that, one temperature goes to 100 C then suppose, this goes 100 degree C, then you may not get 3.73 exactly, it can have a error. Suppose, it goes only 3.72 then 100 degree C, I will not get 1 volt, I will get only 0.99 volt. Because you the difference 10 milli volt will be lost here, this is having gain 1. So, whatever, changes equipment is going take place as it is with only the inversal, the polarity inversion.

So, the problem comes at if I, if this is not this is not exactly 3.73, then there is nothing to adjust. So, we it is essentially, that one put it in ice, even though this is not going 3.73, I have to make this go to 1 volt. So, then only our instrument will be correct, so what I do is if this is going less or more, then I should able to adjust some of the sensors, may go on more than 3.7, it may go to 3.74 at 100 degree C. So, I should able to adjust, when the when the voltages is less or more. So, that I can do by adding gain resistance, you know by varying the gain here, because if the, if it is not 3.73 only 3.72 all that, I need to do is I had to go more than 100 K, because if both are 100 K gain is 1, because little more than 100 K. Then the gain will be little more than 1, then 2.73 will be amplified by little more than 1.

So, if it goes with 3.72 then, if I have a gain little more than 1, that means what I need is 3.72 into the gain whatever, I have that give me should give me 3.73. So, the gain will be obliviously little more than 1. So similarly, the voltage goes more for example, it is goes to 3.74 at 100 degree C, then I add 3.74 into gain should give me 3.73 at the output. So, the gain must variable more than 1 as well as, if necessary we have to bring down that less than 1. So, that I can achieve by changing this feedback path, so what I do is, I will add the resistance here, then I add the one more potentiometer at here. So, this I keep it as a potentiometer like this and this is, a this is a fixed resistor I call this is a P 2 and this resistance is R 2. So, at any given time the combination of P 2 plus R 2 should give me the gain.

So, if it is 100 K one, then 100 K with 1 gain then R 2 plus P 2 should be 100 K, if you want more than 1 gain that case P 2 plus R 2 should be more than 100 K, if less than 100 K then P 2 plus R 2 should give me less than 100 K, if less than 1 gain, then this combination should give me less than 100 K. So, normally, what is done is I will keep this one somewhat you know, because we are that variation normally, within 1 or 2 degree only, you will get a sensor. So, I can keep this 182 K and then I put to here for example, 22 K that will give me maximum of 104, if I want I can also increase the value, you know so that, it is easily adjustable ok what I do is, I will put the whereas now, I take P 2 little higher so that, adjustable is better. So, I can put example P 2 is 47 K and then this is put 47 K and then this is fixed 82 K.

So, I can adjust now 129 K at one side, when the potentiometer maximum the X point symmetry goes down, I will have 82 K. Now, what I do is I will add put this at 100 degree C and adjust P 2 to get 1 volt. Then I keep this at 0 degree C ice, then adjust this P 1 to get 0 degree C. So, like that I should repeat, repeatedly do three four times that is first I kept it at ice adjust P 1 to get 0, then keep it at 100 degree C, then adjust P 2 to get 1 volt. So, that means, that iteratively do three four times, because when we are adjusting P 2 in fact this gain also get altered. So, it is essential that you have go back and readjust at 0 degree C P 1. So, we are adjusting P 1 and P 2, few times to get the correct value.

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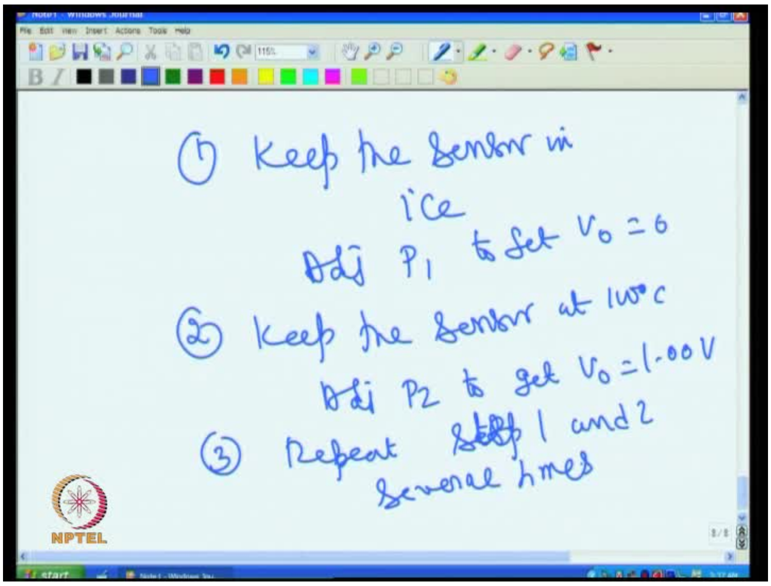

So, essentially, what we do is, we will first the step, calibration step would be keep the sensor in ice in ice adjust P 1 to get V 0 is equal to 0. And keep the sensor at 100 degree C adjust P 2 to get output as 1 volt, then repeat repeat step one step one and to several times. That is how it is calibrated, once it is done, then we can use this for temperature measurement, once that you know, it is calibrated then if you put it at 50 degree C, then you will get 0.5 volt, keep it at room temperature then you will get 0.25 volt. This is how operational amplifier is used here for temperature measurement. I had taken this example to illustrate, how can use the operational amplifier for summing application.

Here actually, we are summing 2 volts this V 1 and V 2 are summed of course, we are reverse summing and then you are getting the voltage here. And the individual gains also can be varied by varying this, because this voltage is this is producing output corresponding to the ratio between this and this. This voltage is producing output corresponding to the ratio between this and this. So, not necessary that, both at all three have to be equal. So, to illustrate this example only, I had taken this L M 335 and had shown you how to make a temperature indicator, and how to calibrate, how to make a real world equipment, you know what is the situation that existing.

You know for example, the sensor may not be exactly giving you 10 milli volt per degree C or it may not be 0 degree c, exactly may not be giving 2.73 volt, all that consideration with all that reseek limitations you can get the required output. This is essential in (in) electronic circuit design of course, we are not done one more work that is, what is the value of this, you know this resistance. You know, we are not fixed the value for this resistance; this is not very difficult this is similar to what we are done here. This is also zener only, this is zener so, if this is 2.5 volt and this is 15.

So, you have a 12.5 volt across this. And here also it needs 1 milli ampere current through this and some small current is flowing through this. Even if I neglect that, if I want to keep the same 2 milli ampere current like, what we are done here, 2 milli ampere current through this, because this also works well from 1 milli ampere to 3 milli ampere. So, if I want 2 milli ampere current to flow through this, then 12 volt is you know 12.5 is across this. So, 12.5 divided by 2 milli ampere gives me 6.2 K, that I can use very well 5.6 K resistance here, which will be little more than 2 milli ampere, because this access up to 10 milli ampere. So, no issue I can put 5.6 K, so that will give a 2 milli ampere and then very small current few micro ampere current flow through this, because this is, this point is zero.

So, this is 2.5 so, 2.5 82 K is only very small current, that will still maintain 1 milli ampere current through this. So, no issue I can put 5.6 K, that completes the complete circuit design for temperature indicator. Of course, the output is minus for example, even it is 100 degree C this is going plus 3.73 that will come as minus 1 volt here, if I want output to be plus, then I have to do one thing I have to reverse, these zeners that is all. Then the same thing works all right for example, I can do that by reversing this minus is not a issue.

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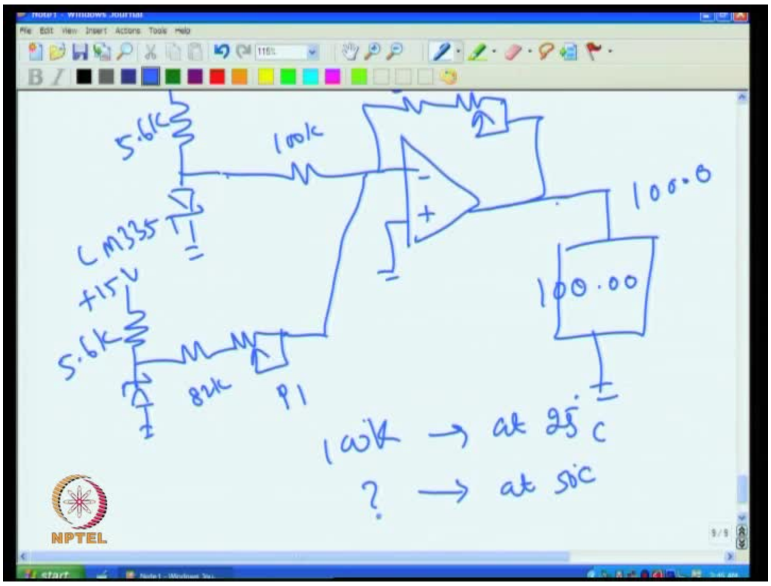

One can retain the same circuit nevertheless one can do this it is, it would not take much time. So, we can put the minus supply here and then we put the sensor reverse it. So, that gives you L M 335 sensor. Now, you will get here minus voltage, that will become plus when I connect this then for the reference zener 2.5 volt I will put plus, when this is minus, this must be plus then only it will take care of that. So, I can have this 100 K and that is P 2 and you have 82 K, and this P 1 and this is 82 K and this is at 5.6 K and then this is also around 5.6 k.

So, that makes output go positive when the temperature goes, because when the temperature goes up this voltage will go up. So, that minus going up will make the plus to go up at this point. So, V 0 becomes plus now so, this also can be done to give positive voltage. Now, all that need to be done, we connect the meter here and that will show 0 degree C 0, 100 degree C it will show 100 and that can be achieved. For example, I can connect volt meter of 1 volt full scale, then 1 volt comes definitely will show this all that needs I put 1 dot and that it comes as a display.

Now, the in this case, we have just taken a design example and then we had done using the summing property of the operational amplifier of course. There are worry, there are several issues, they have still we may ask how accurate is this sensor you know, we are caliber, once you calibrate you know the instrument will give this, will give you 0 degree C 0 volt, 100 degree C 100 volt. But then, when temperature room, temperature changes not the temperature of this, we assume this temperature is fix it is not changing, but room temperature assume it is changing then all these components, which are in the room the all will change. If they change like for example, operational amplifier temperature changes, then it is property changes that produce a different output voltage.

Similarly, the resistance value may change, with temperature and this resistance may change, and this resistance may change with temperature, this also will change with temperature, this also will change. All this thing make it, this is not accurate, because this may give accurately, 3.73 volt at 100 degree C. But this job may not give all that time 100 degree C equal to 1 volt at room temperature, it may give 1 volt, at high temperature this may not give 1 volt it may go higher or lower depending upon the components, that how these components are drifting? And how the operational amplifier, parameters are drifting? And that is the error budgeting.

Because error budgeting is very important in analog circuit, I just by designing the circuit is not much use, because if this components drift quite a lot. And then, if at 100 degree Celsius the (( )) is going 100, if it goes 100 and 20, then you have a 20 degree error and that will ruin the entire design. So, one should aware what is that in store for us, when we are using this or when (( )) matter, when use any analog circuit, how the way, how the components values will change? And how the operational amplifier behaves? And how that thing will affect, the output voltage? This is to be considered and should be looked into that from the beginning.

Now, if I look at the resisters here, now do the change with temperature for example, I have a 100 K, I take for example, 100 K that resistance value is 100 K sorry 100 K at 25 degree C, then I look at 100 degree C or for example, room temperature, we take initially for example, only room temperature the room temperature goes at say 50 degree c. Then the question is what will be the value of this resistance that is? The, if it is the 100 K at 5 degree C, at 50 degree C what is the value of that 100 K resistance? It will be higher or it will be lower.

And, if it is higher or lower how much it going to change? And we know that for example, in this case, if the for example, this 82 K, use this 82 K, if the you know the temperature goes up, if this goes to 85 K then we know at 2.7 at the room temperature at 100 degree C of this, you will not get 1 volt, you are going to get more than 1 volt. And that will be read as error. So, it is very important to know, how this value of resistance changes temperature, how this changes, how this changes, how this changes and how this changes. And considering all that only, I can reliably use this circuit, so one must know the error budgeting.

Similarly, for example, we are using the zener diode here, it suppose give me a 2.5 volt all the time. For then I know that this is not going to 2.5, because considering this voltage is 2.5 only, we adjust at P 1 and then P 2 to get the correct calibrated output, but what happens? The temperature changes, the voltage even by the zener also changes, because you should not assume that is 2.5 means, all the time it is 2.5 zener supposed, to give that 2.5 all the time, but then it also has an error. For example, if I take this our classical sensor L M 336 the manufacturer says, the zener drifts with temperature by 30 p p m, if you look at the data sheet of L M 336 then L M 336 says, temperature drift is equal to 30 p p m per degree C.

That is the voltage, at this voltage, at this point voltage available, voltage at this point what is that will be changing by 30 p p m per degree C. There are telling whether, it increase or decrease, if we look at the data sheet carefully, that will plus or minus 30 degree, 30 p p m that means some sensors that the the voltage may increase with temperature, the same L M 336 some other piece, it may decrease with temperature. So, you do not know, which the sensor the L M 336 with that particular piece, what we have used whether, it has positive temperature or negative temperature coefficient, positive temperature it will increase with temperature, the negative temperature coefficient, it means will decrease with the temperature.

Now, that is not known and also you have to see a one more this spike, the temperature drift is start telling plus or minus 30 p p m per C is says plus or minus 30 p p m per degree C max maximum. Because is not telling, we know this temperature that with that temperature, with the temperature the voltage at this point will exactly increase or decrease by 30 p p m. In one sensor there may not be any drift at all, you know in one sensor it can be plus 20 p p m, in another piece it can be minus 20 p p m, in third piece it can be plus 5 p p m, fourth piece may not have drift at all.

So, we have to find only the worst case drift with that, what is the error that you going to get? Now, consider only this L M 336 and with that only, if this alone a drifting what is the expected temperature error at the output. Let us calculate this today, now so this is given as plus or minus 30 p p m per degree c.

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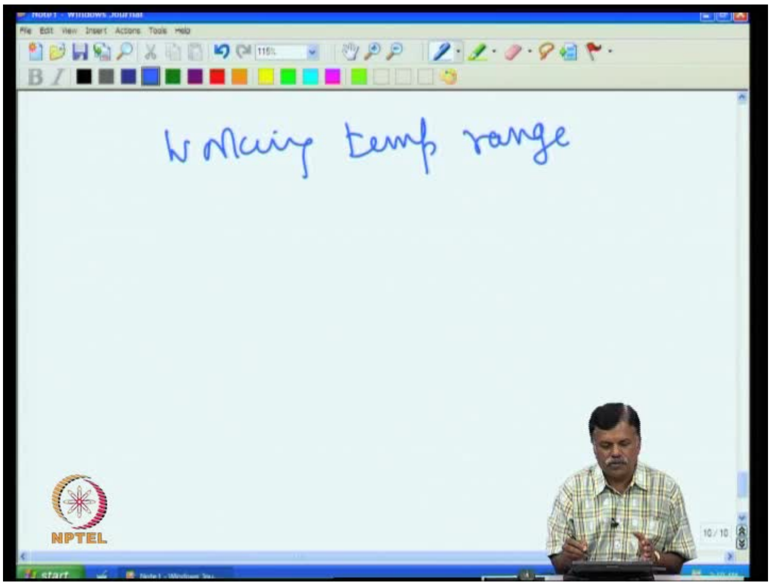

Now, we have to find for what is the working temperature range? So, we are desired on what is the working temperature rang. In the sense, this temperature indicator will be kept in the room are wherever, it is going to use. And then you will have the sensor, that is that is this and this sensor of course, will be kept over not wherever, the temperature to be measured, there it will be kept. But all these comments will be kept inside the instruments and instrument will be kept very close to probably, the sensor where it is measuring the temperature, but not at the same point.

So, this comment this zener obviously will be in the room temperature, but then what is the room temperature. You know the room temperature, morning for example, if you look (( )) environment morning, some places you can go as low as 0 degree C. Some other place in the room, it may go out to 45 or 50 degree in the noon particularly in the summer. For example, if I using this to measure a temperature in the process in industry. Now, in the process industry the instruments are kept site in the open field, where sunlight directly falls on that. And also, in some cases when the instrument is a open in cold countries, even ice would be sitting over the instrument.

So, obviously per industry, if it missing a industrial measurement for industrial grade equipment, then I had assume that temperature of this changes from minus 20 degree to plus 80 degree, because even you know noon, if the instrument noted is open field, if you go and touch the instrument, in the instrument at noon that all that instrument is very hot. So, you have to take it as industrial grade working in up to 80 degree. So, assume that this is per industrial equipment, that one worst case it can be minus 20 degree at and the other end. You know at at low temperature go minus 20 degree, at higher temperature, it can go to plus 80 degree that means, up to 100 degree temperature variation of this is possible. I am not taking the temperature measurement, then take now instrument which is used.

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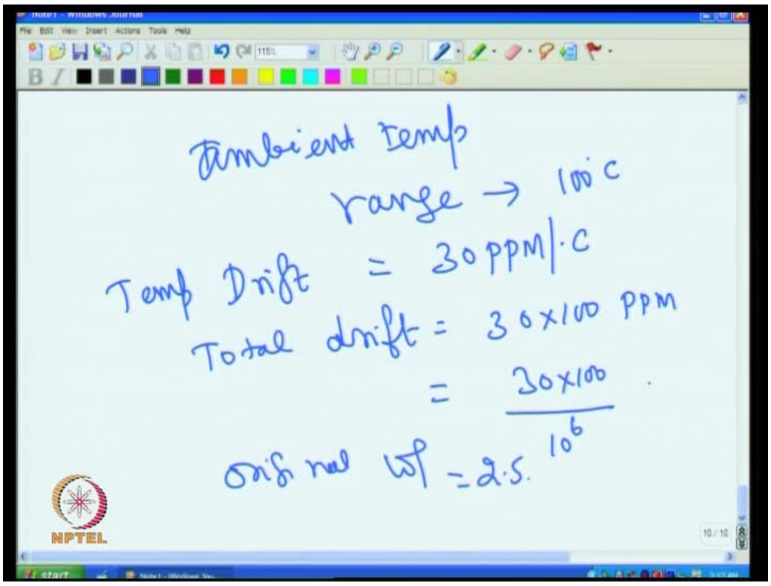

So, we know the this changes by 30 p p m maximum, that means 100 degree, if I take that will be 3000 p p m change in the voltage is possible, for the worst case minus 22 plus 100 degree temperature change. So, then what will be the voltage change here, then what will be voltage change that is expected at the output. So, considering the industrial grade equipment, then temperature changes I take it as 100 degree temperature change, ambient temperature change, this is for the industrial grade equipment. So, the drift of the sensor is temperature drift drift is 30 p p m maximum per degree C. So, total drift will be 30 into 100 p p m that will be equal to 30 into 100. So, p p m means 10 power 6, 1 10 power 6 the that many parts, it can change, but the original voltage is 2.5. So, the original voltage is 2.5 volt.

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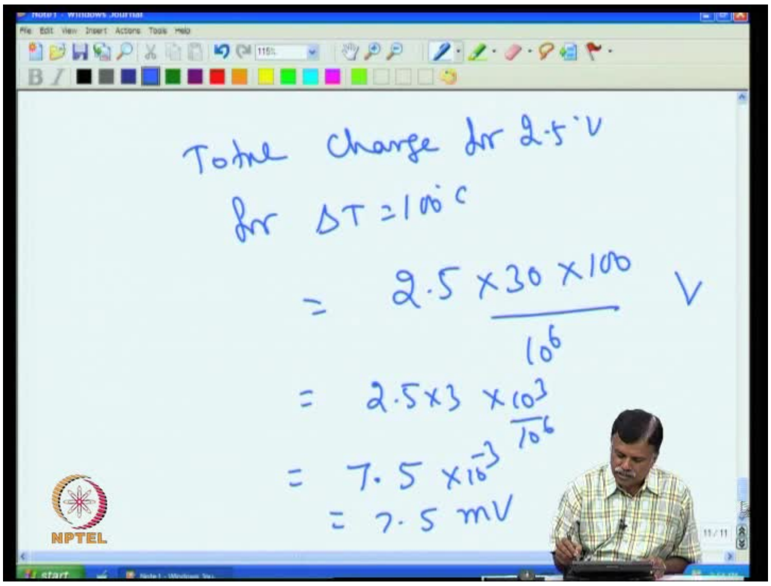

So, 2.5 for 2.5 volt will be the change. So, I will see total change for 2.5 volt for 100 degree, delta T is 100 degree C that is actually, given by this 2.5 into 30 p p m. And the temperature of 100 for p p m output 10 power 6, that is the expected voltage change for 100 degree temperature change. That actually, works out to be 2.5 into 3 into 10 power 3 divided by 10 power 6, that will be 7.5 into 10 power minus 3 that is equal to 7.5 milli volt. That means, the zener temperature will change in this case you know, if I take this the temperature, when room temperature change voltage, voltage at this point will change by 7.5 milli volt. Because that means the 7.5 milli volt, change will produce roughly, because we are seen this and this produce gain.

So, if this changes 7.5 milli volt, this and this more or less equal to 1. So, you will have output 7.5 into 1, that will be 7.5 milli volt change at this point, that will give again at this point 10 milli volt is 1 degree, because 0 degree 0 volt, 1 volt is 100 degree C that means every degree 10 milli volt change occur. Now, here it be changes 7.5 milli volt output also will changes 7.5 milli volt, due to the temperature variation of this. So, output will have an error of 0.75 degree, because 75 degree milli volt corresponds to 0.75 degree error. So, the zener drift alone contributes for 0.75 degree temperature error in this example, here we assume this and this of ratio 1, if the ratio is different that I say 1.1 then I had multiply into 7.5 into 1.1 and put it here, but we are taken it is in fact close to 1 we may have 7.5 degree error. This can be plus or minus for example, if this temperature drift is plus, then it will go reducing if it is minus it will be increasing.

So, we will say that my temperature measurement can be accurate only to 0.75 degree plus or minus 0.75 degree, if I consider the drift due to this zener alone changes, we assuming that no other drift in this case, even this alone changes it can have an uncertainty 0.75 degree in this instrument. So, we have to see all other errors in the next session, because it is essential, when we are designing instrument what is the total error that is expected.