Circuits for Analog System Design

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Lecture No. # 27

4-20 MA Based Temperature Transmitter

In today's class, we will discuss, how to use resistance measurement effectively in case of temperature control and temperature measurement. So, for this example, we pick up platinum Resistance Thermometer and so, how this Resistance changes measured indicate the temperature. We will see in two domains, one is in voltage output producing circuit, in another case current producing circuit, that is 4-20 milliampere current source is a temperature measurement, another one is voltages temperature measurement.

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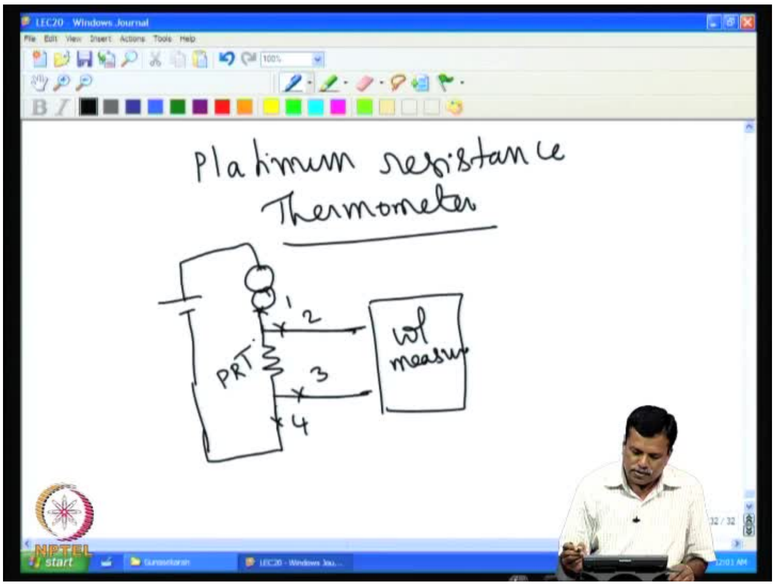

So, we will take PRT's temperature sensor so, we use Platinum Resistance Thermometer, Resistance Thermometer, we use as a temperature sensor. So, essentially what we going do is, we will take PRT and then, we are apply a constant current source. (( )) We have a constant current source and a constant current source apply to the PRT and then, we will make a four wire method so, this will be made as the voltage measurement. So, essentially, we have four leads that is one current lead, second is the voltage lead, third is the voltage lead and then fourth is the current lead. So, four wire technique we use to measure the temperature and this is the PRT Platinum Resistance Thermometer.

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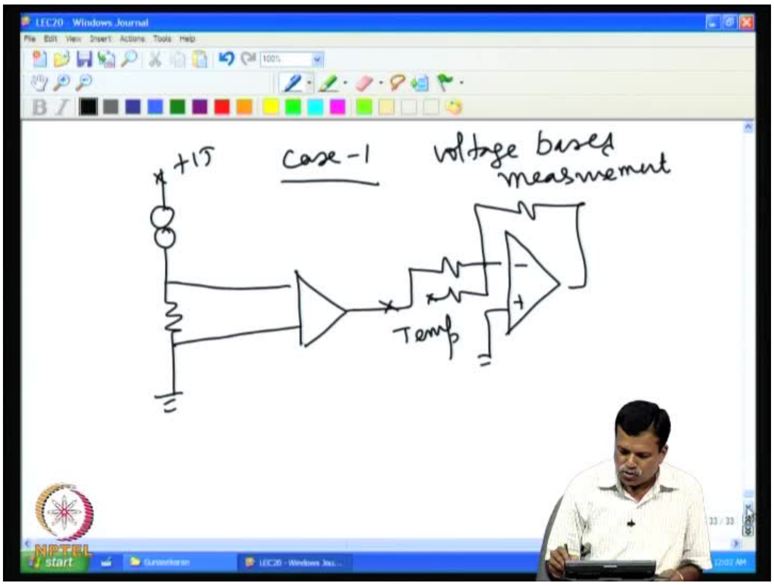

So, as I said to use two methods that is, one is, what we see in one case, I use PRT and then, use simple voltage amplifier. For example, you have the plus 15 volt and then you have the PRT and then, this PRT will be connected in a four wire method to instrumentation amplifier. The output instrumentation amplifier gives you the temperature of course, this is to be the voltage to be subtracted in case, if you want make a temperature measurement. So, the base voltage has to be subtracted so, that has to be done that is a one case. So, case one voltage based measurement and then in case two, we go for 4-20 milliampere current based measurement.

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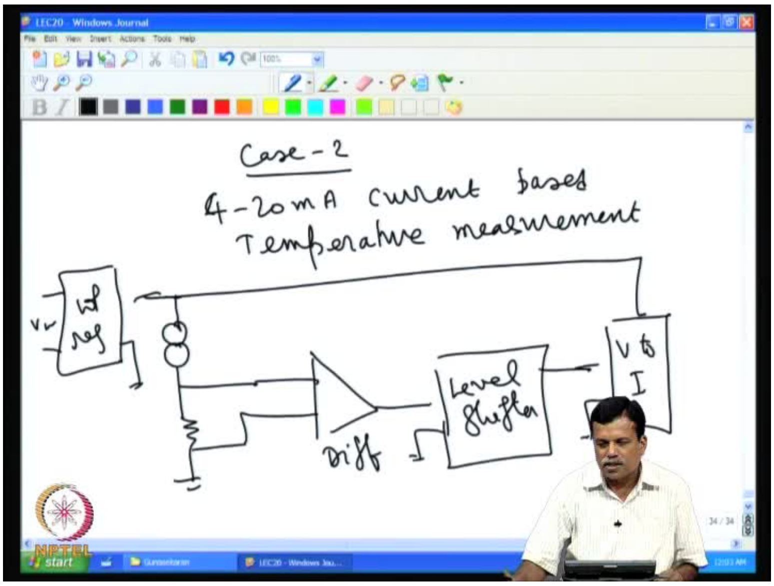

So, case two, the current based measurement 4-20 milliampere, current based temperature measurement. (No Audio From: 03:29 to 03:41) For this, what will be use? You will have the current source, then similar arrangement, then we have a differential amplifier, then we have the level shifter, then we have the level shifter output is given to the current converter so, V to I converter. And then the whole thing is integrated to the input 4-20 ampere with the voltage regulator, you will have a voltage regulator, that is given here, that will by act as a input. So, we see 1 by 1, how the these two systems source, first we pick up 4-20 milliampere current based temperature measurement.

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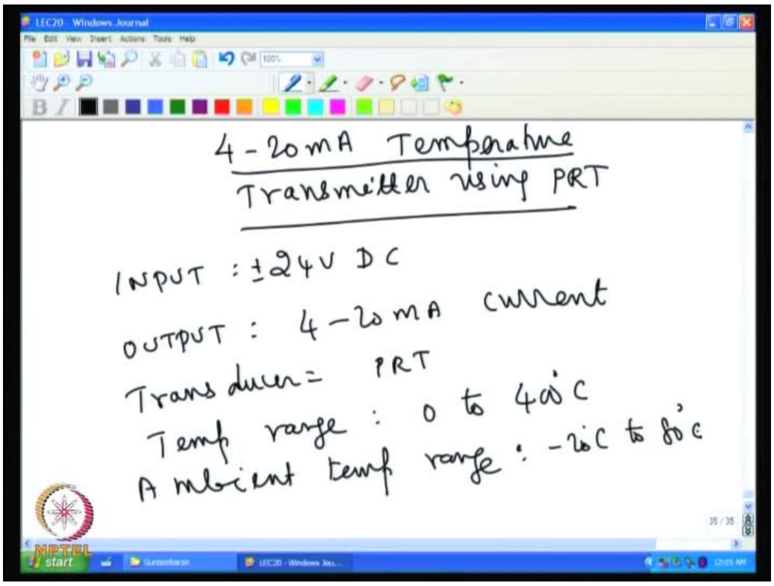

(No Audio from: 04:40 to 04:47) So, we will see (No Audio from: 04:49 to 04:56) 4-20 milliampere temperature transmitter (No Audio From: 5:00 to 5:10) using PRT. So, in this actually, the input is 24 volt DC to a system, 24 volt DC the output is 4-20 milliampere current. Of course, the transducer is PRT and we keep temperature range as 0 to 400 degree C and then, ambient temperature range, that is the instrument working range, that we take minus 20 degree to 80 degree C industrial grade equipment. And then, what the accuracy that we are aiming is 1 percent, accuracy is plus or minus 1 percent, that is what we are actually aiming at.

So, what will do is, we will take 24 volt DC as the input supply and then, we use Platinum Resistance Thermometer as a temperature sensor. And then, the Platinum Resistance Thermometer Resistance changes 0.4 percent every 1 degree temperature, that it is the positive temperature coefficient, temperature Resistance increases by 0.4 percent, every 1 degree increase in temperature. So, what we do is, we will pass the constant current through the PRT so that change in voltage will be reflected as a change in; change in Resistance will reflected as a change in voltage.

Because Resistance of the PRT changes with temperature, we are passing a constant current so, net result is, the voltage across the PRT will change with temperature, that voltage will be convert into 4-20 milliampere current to indicate the temperature. And the temperature measuring range is 0 to 400 degree C and the instrument the suppose, the work minus 20 to plus 80 degree, we aim for 1 degree accuracy. Let us see, how to go about designing the circuit. So, the input is 24 volt DC so, the input only in the input only we will be connecting the measuring instrument also.

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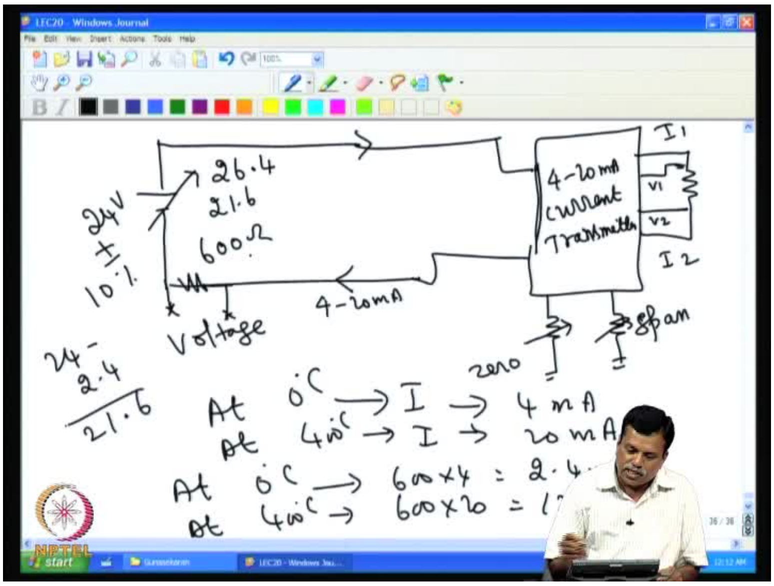

So, essentially the 24 volt DC is a input supply looks connected like this to the system. So, you have a 24 volt DC supply and it is connected through a long wire and then, you have our electronic circuit coming here. And this circuit to this circuit, the PRT is connected, it is the four wire method so, we will have four points you knows voltage to current point, voltage points and two current points. So, this is I 1 and I 2 and the two voltage points are V 1 and V 2 so, four terminal connection is made and this is actually the current transmitter 4-20 milliampere current transmitter.

(No Audio from: 08:52 to 09:01) Because this has the adjustable; adjusting potentiometer so, one for zero and another for span zero and span, that is, these two potentiometer requires to make sure that you know, the current flowing through this, current flowing through this is going like this and then while making measurement their connect here up to 600 ohm Resistance and voltage across this is measured. So, this voltage, gives you the temperature information. For example, when the temperature is 0 degree C, we adjust this zero part to get 4 milliampere. So, at 0 degree C, current is 4 milliampere, at 400 degree C, the current will be 20 milliampere.

So, this current 0; 4 milliampere to 20 milliampere varying so, 4 milliampere at 0 degree C of the PRT, 20 milliampere at 400 degree C of the PRT. So, corresponding to that, we will have voltage at 4 milliampere, we will have 600 ohm into 4 milliampere, we will have 2.4 volt. So, as a essentially means, at 0 degree C, we will have 600 into 4 milliampere 2.4 volt, at 400 degree C, we will have 600 into 20 milliampere, that will be 12 volt. So, voltage across this will indicate the temperature status of this one, where this is attached to the oven or any other object whose temperature to be measured.

So, essentially, this temperature is indicated as the voltage across this. These lines can be few kilo meter, that is what happen in the industry, that you know, the process can the industry, this will be actually in the field. And this will be in the control room the distance invariably goes few kilo meters and you see that, the temperature is correctly reproduced, the voltage here, correctly gives you the temperature indication of this; the object is attached to this.

So, this is actually a popular 4-20 milliampere system and the zero and spans are used to adjust, such that at 0 degree temperature of this, you get 2.4 volt here, that is the current will be 4 milliampere, that is adjusted using this and then, keep this at 400 degree C and then adjust the span to get exactly 20 milliampere through this. So, at 400 degree C, you will get here 20 milliampere, if not adjust this.

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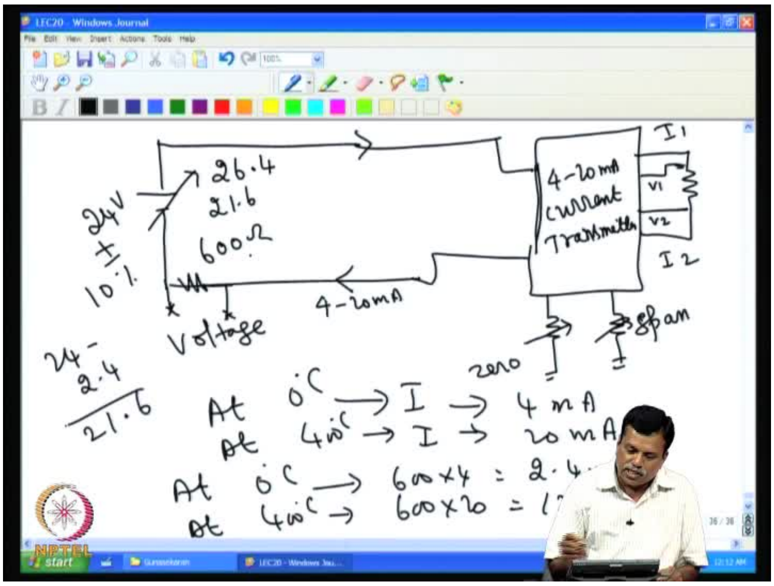

So, zero and span are repeatedly adjusted, such that, at 0 degree C, you get 4 milliampere current through this at 400 degree C, we get 20 milliampere current this. So, this is the two potentiometer that is required for adjustment zero and span adjustment so, this is the system that, we have to design now. So, we start our story from the supply so, if we take the supply here, this supply voltage normally given as 24 volt supply, but this has invariably varies plus or minus 10 percent. That means, it may go to 26.4 at the higher side and minus side 2.4 volt down, that is 24 minus 2.4, that comes 21.6.

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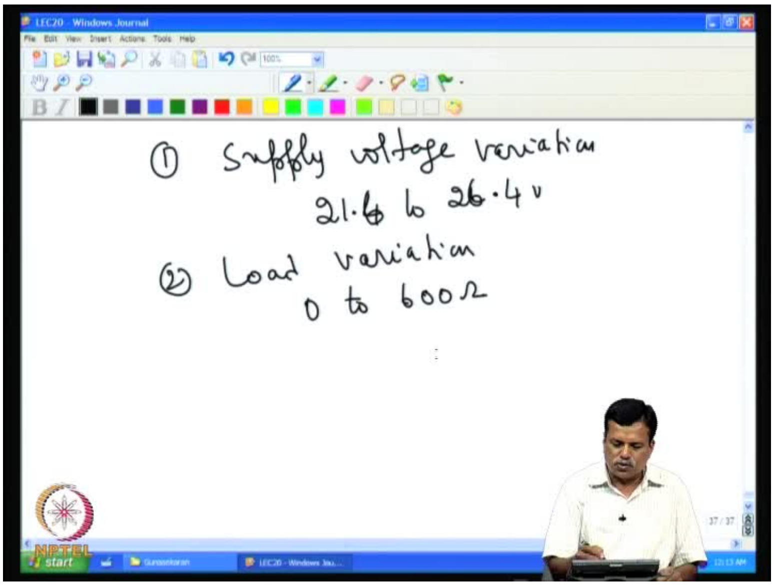

And similarly, the Resistance also, they may not keep all that time constant, the Resistance also the vary from 100 to 600 ohms. So, the variable C R R in this design, 1 supply voltage variation, (No Audio From: 13:38 to 13:47) that is from 21.6 to 26.4 volt and then load variation, load can vary from 0 to 600 ohms not more than 600 ohms.

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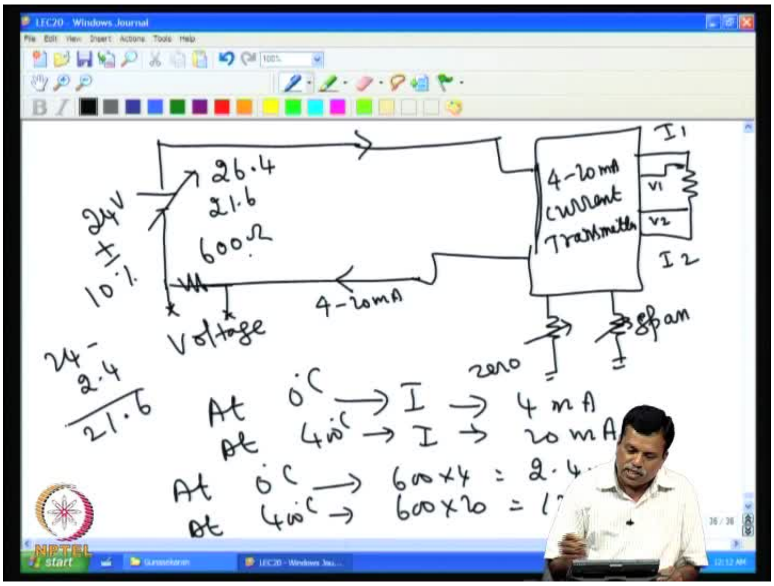

So, while designing, we at consider these two factors as well, because the voltage of the battery may not be constant and different people use different load. Some people use only few ohms, some people may use full 600 ohms so, one have to consider this, because varying the load makes. Suppose, the current is 20 milliampere, then if 600 ohms is put then you will have 12 volt drop here and if the input is 24 volt, then you will have only 12 volt appear here, because 24 and here 20 volt gone only 12 volt will appear as the supply to the instrument. Whereas if another person uses 100 ohms, then for same 20 milliampere, you will have only 2 volt drop and in that case you will get 22 volt across this.

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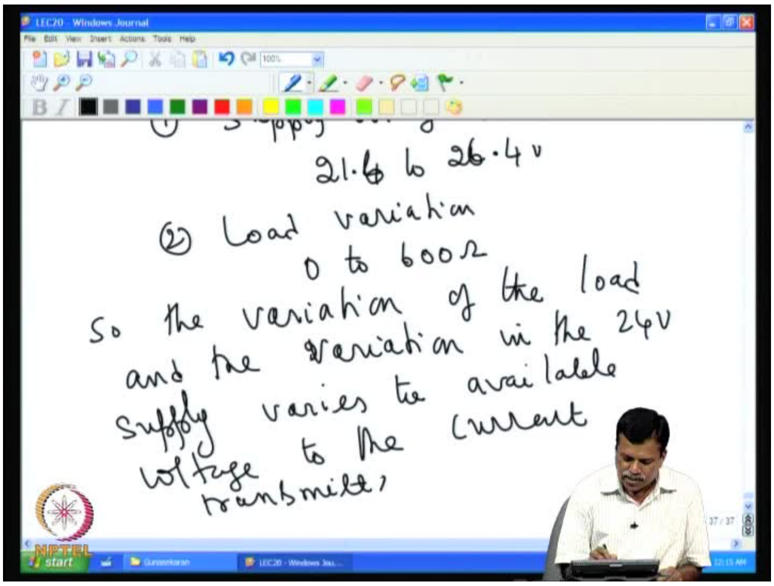

So, variation of the supply and variation of the load, changes the available voltage to the current transmitter so that is an important consideration while designing the circuit. So, the variation of the load and the variation the 24 volt supply varies the available voltage to the current transmitter. So, one has to consider this factor, while designing this.

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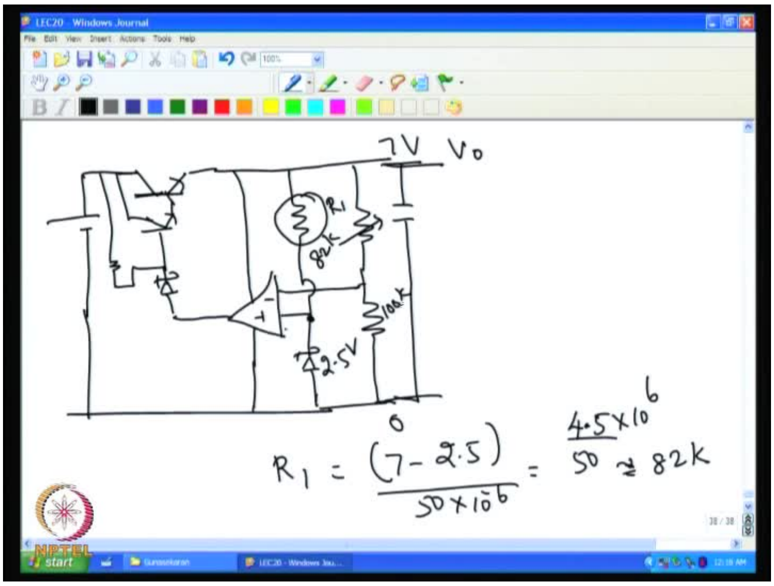

So, if essentially, the supply voltage varies to the current transmitter should we tackle this, we are done earlier voltage regulator circuit for this. So, the same thing can be adapted in this, so, one can re look at this one. So, we are design the earlier circuit for this two for 20 milliampere current transmitter, the same circuit we use now here. I do not spend much time on this, I will just show you, how this regulator is made. So, you take this voltage, then you will have a regulator here and then, we are used error amplifier for this purpose so, operation amplifier was used is an error amplifier. And then, you also used one Zener to startup the current so, we have put this, then we have put very high Resistance to bias to give a base current to the transistor.

Then the output of that, actually used a voltage divider and then I connected this, then I connect at this to minus and the plus input we are given the reference voltage. Bias in the reference voltage was done using this and supply for this up amp is drawn from here. And then, we also put a small capacitor, you know one we have so that this voltage is regulated so, let take 0 may be since the voltage at this point, that is the available voltage can go down as slow as 10 volt. Because this 24 volt sum of them will be lost on the load Resistance and this voltage also can go out 22. So, essentially you will get only around 10 volt reliably so, we will make it this circuit work up to 7 volt also we get the regulated voltage.

So, we can adjust the voltage to get 7 volt. For example, we can have 2.5 volt Zener here and then we can adjust this values can be selected this and this can be adjusted to get 7 volt and this can be selected for required bias current. For example, if you need 2.5 volt 50 micro ampere current, in that case, the this Resistance can be selected, such that the output is 7 volt. So, V 0 is 7 volt so, this is R 1 so, R 1 will be 7 minus 2.5, because this is sitting at 7 volt, this sitting at 2.5. So, the volt here across 7 by 2.5 and the minimum current required for the Zener is a 50 micro amps.

So, that is the Resistance that we are to take that comes for example, 4.5 volt divided by 50 micro amps, that comes close to an say 82 k Resistance will do for this purpose. So, we will have 82 k Resistance so that, the current drawn by basis limited to slightly more than 50 milliamps. And then, we can take this 100 k, then this R 2 can be selected such their output is 5 volt.

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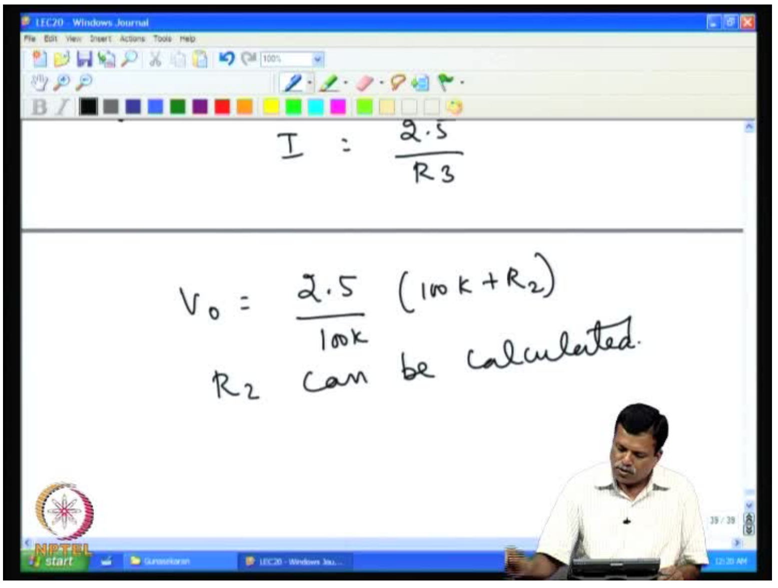

So, we can calculate the value of R 2 so, voltage across say R 3, R 3 is 2.5 volt. So, the current actually comes 2.5 by R 3 and same current flows through R 2, you know the same current is flowing through R 2 so, current through this is now gone by 2.5 by R 3 and same current flows through this. So, the voltage across this I into R 2 plus this voltage. So, essentially means output voltage will be V 0 is given by 2.5 by 100 k into 100 k plus R 2.

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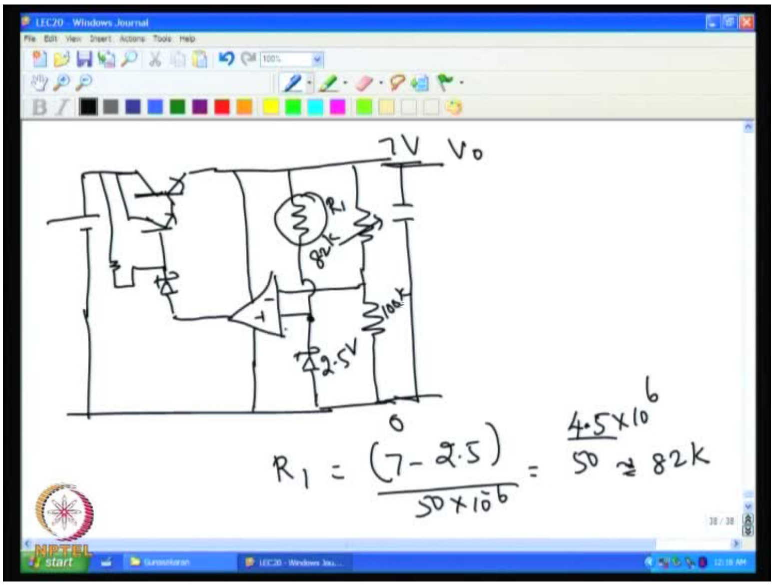

So, R 2 can be calculated. So, by fixing the required R 2 one can get 7 volt that is required at the output. So, the you will get the regulated voltage, as we explain earlier. And this Zener is used this, because the circuit have to start initially, the initially the voltage here is 0. So, if 0 voltage is there, the op amps not going to work. To make the circuit work, bias to be using this. So, we have put for example, here high Resistance as a 470 k. So, whatever current that is coming here, it has to goes through this and then small voltage that whatever voltage few volts, it need not be Zener breakdown voltage more than 1.2 volt present here.

Then the voltage comes out here and that makes this voltage that much go high and that also increase this, like that slowly the voltage builds up and stabilize the 7 volts. So, this Zener is not for breakdown; not operating the breakdown. It is only to provide a initial voltage such that, the circuit starts. So, and you need a darlington, such that, the base current is negligible so that, we able put high Resistance here. We put high Resistance only we will have less current variation through this when the supply voltage changes. So, this is the first part of this design, the voltage regulator, which we are done earlier also in the in the 4-20 milliampere current source.

Now, from this source the regulator source basis, I will take and then I built up the constant current source plus the other circuits to goes with Platinum Resistance Thermometer temperature sensor.

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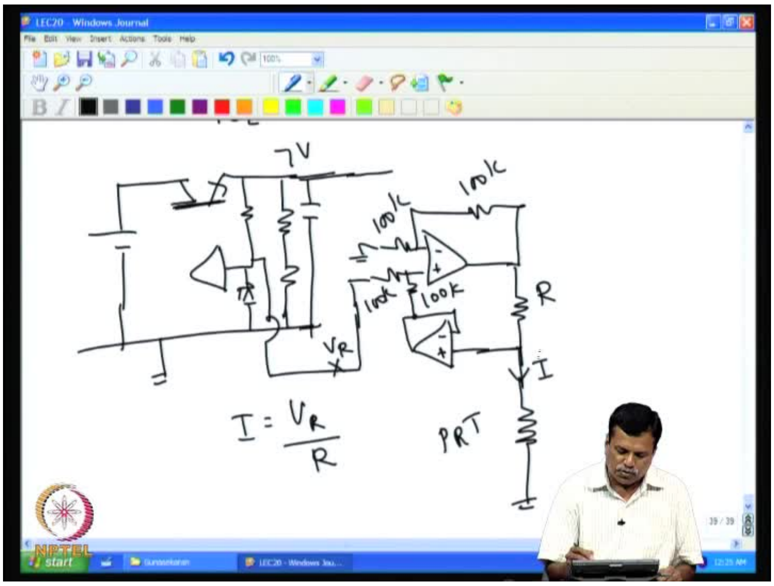

So, you will have now voltage source, then we had this regulator here. I will skip the other part of the circuit and keep only output here and then the regulator output is coming here. So, the other part, I skip it here and you have a regulator output voltage say 7 volt or 8 volt whatever is required, you can achieve this, then this supposed to be given to a Platinum Resistance Thermometer. So, what we do is, we at make a constant current source, one possible constant current source is this take in have. We need only a small current so, we need not have a transistor to drive this so, one possible current source would be we can have a input voltage, we can have a possible current source.

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And this supposed to be given a V reference and we have V reference this is ground at. And then regulator, we had only V reference 2.5 volt. The same 2.5 volt can be utilize, if the current drawn is small. If the more current required, one can adjust, re adjust this Resistance, because if you need more current through this, and then this current to be increase. In that case we have to reduce the Resistance to supply the required amount of current to this. But normally, this Resistance can be kept high, so that, this current is negligible.

So, one have a current source like this. So, this current source output suppose, we connect it to PRT, this is the Platinum Resistance Thermometer, that should be connected to here. So, the current in this is, I is given by, if this is V reference and this is R and we have this four Resistance equal. Particularly I value Resistance we have 100 k for example, 100 k and then 100 k, all four must be equal. So, this kind of constant current source, we are discussed earlier in connection some other circuit. So, the current that is flowing through this is constant and that current is given by V R by R.

So, here we are to select the current I, because the current I, that is flowing here should not be too much, because we do not have more current the total current available is only 4 milliampere. So, this current can be kept 0.5 milliampere at the worst, it be can maximum 1 milliampere not more than that. That higher current also creates problem because higher current also will heat up the device and we will have more issues with that later.

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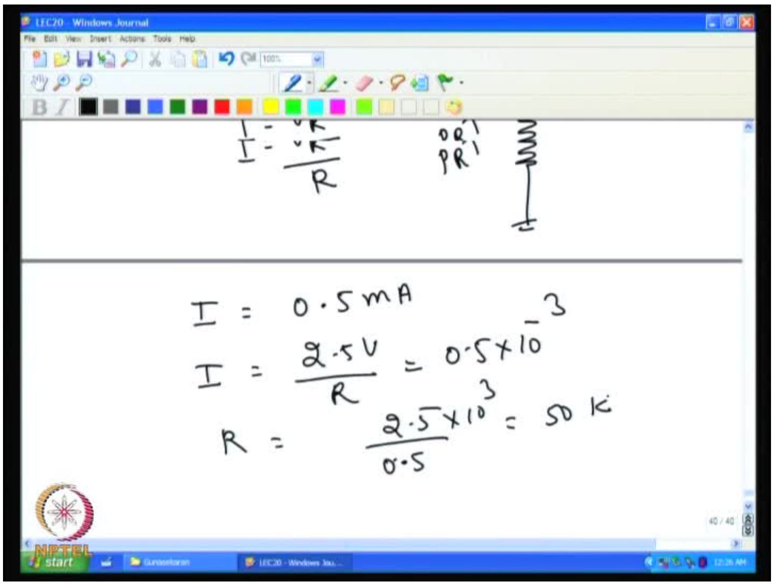

So, we keep the current I as 0.5 milliampere. So, I actually what is allowed is 0.5 milliampere so, I actually is given by 2.5 volt divided by this Resistance R, which is 0.5 into 10 power minus 3. So, the value of R can be computed 2.5 divided by 0.5 into 10 power 3, that comes 50 k. So, you need a 50 k Resistance so, 50 k here 0.5 into 10 power minus 3, becomes 10 power 3 so, you have 5 k, this will be 5 k.

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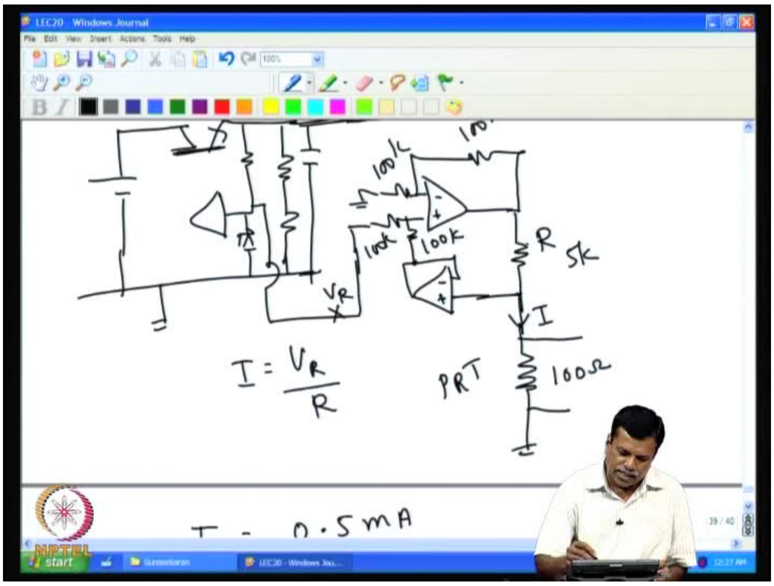

So, we need to have R s 5 k here so, 5 k Resistance in make sure that, the current flowing through this is only 0.5 milliampere. So, normally Platinum Resistance Thermometer of 100 ohms is, what is the used? Platinum Resistance Thermometers of 100 ohms Platinum Resistance Thermometers used, that actually makes 100 ohm into 0.5 milliampere at the lowest, you will have 0.5 volt across this. This 0.5 volt is good enough for most of the single supply op amp circuits, because higher the voltage, then you will have more issues in reducing the voltage later, when we are convert this voltage into current.

On similarly, if you have a higher current keeping higher current also is the issue, because higher current will make this device to heat up. Because we are measuring the temperature and the current itself should not heat the Platinum Resistance Thermometer, this is call self-heating to limit, the self-heating also we are to reduce this current. I will explain already the working of the circuit in connection with some other design, but essentially you know this is acting as a voltage follower. So that, this voltage is, whatever voltage is here, is put up at this point and whatever voltage is there, it comes here. So, we know that voltage at this point must be equal to this point.

So, if the more current flows through this, voltage at this point decreases, that makes this voltage decreases, that makes the output to decrease. And similarly, when the current is less, then equivalent telling this voltage is going up and this makes this to go up and it will push this output voltage high. Like that, the current is self-regulated and you will have a constant current source constant current source with this arrangement.

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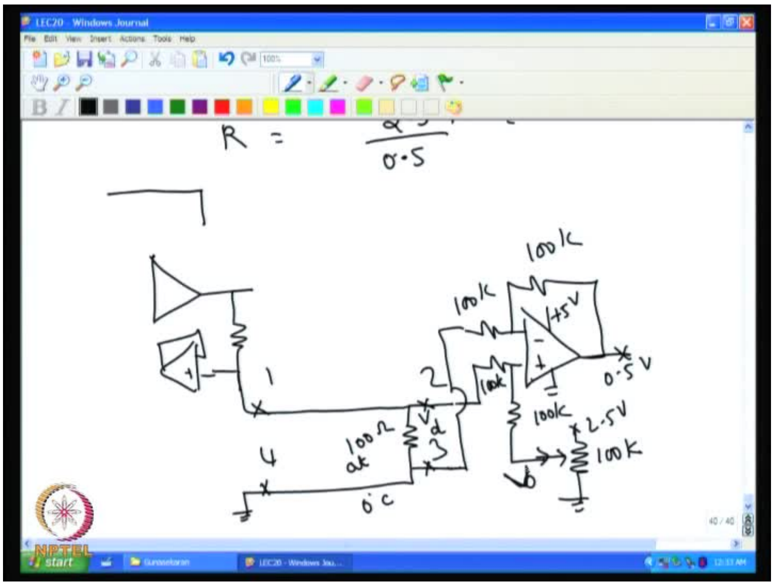

Now, this voltage that is, there across this resistor should be converted into current. So, we said, we will use the four wire method. So, what we are done is, now, I will pick up from this current source onwards so, you will have this so for the current source, that is nothing but this op amp circuit. So, this op amp circuit gives you the current and this is the regulated part. So, here is the, if you draw this PRT, more Resistance so, what is normally, this very long wire going in and that is the Resistance coming back. And then we have to take up the voltage between these two points only for measurement, the show four points 1 2 3 4.

And this voltage should be convert, this voltage converting differential voltage. So, normally, what is done is, to convert, we will use a differential amplifier. So, this is at higher potential this is at lower potential. So, one can do this or even, one can do in or we can have a differential amplifier first, someone can have this and then this is ground at, then the difference between these two points will appear across this. So, the difference between these two for example, if it is 100 ohms, say at 0 degree C, then you will have 0.5 volt difference across this.

And if this Resistances are equal, then you will be getting 0.5 volt the minimum voltage, but one small issue in this is that, we put the single supply op amp. Normally this is op amp, is operated single supply, because we are making 4-20 milliampere current transmitter. So, this op amp is invariably operated in single supply. So, you have a ground here and then plus 5, if this point is at 0.5, this will be 2.5 volt and this also will be 2.5; no 0.25 volt, If this is 0.5 volt, then this is 0.25, this also 0.25. Most of the single supply op amps accept 0.25 volt, like LM 324 accepts 0.5 volt. So, one can use this arrangement there is no problem so, you will get the 0.5 volt at the output.

Output also most of the single supply op amp, like LM 324 gives you up to 0.5 volt linear output. So, no issue with that only worry would be this 0.5 volt may be too small for the next stage, that is, we have to convert this into a current. So, to solve that problem, what we can is, we can this of grounding it, we can float it at some fixed reference voltage, that can be done by modifying this. So, what can be done this, this 100 k, I can give it to a potentiometer, which is 2.5 volt here, this can be obtain from reference voltage, which was used in the earlier case. So, you will get for example, this can be high range 100 k potentiometer.

So, one can keep this one at whatever point we want. For example, if the difference is 0.5 volt here for example, the difference is 0.5, because this is 0, this will be 0.5 and if this is kept at 0, then you will get 0.5 volt.

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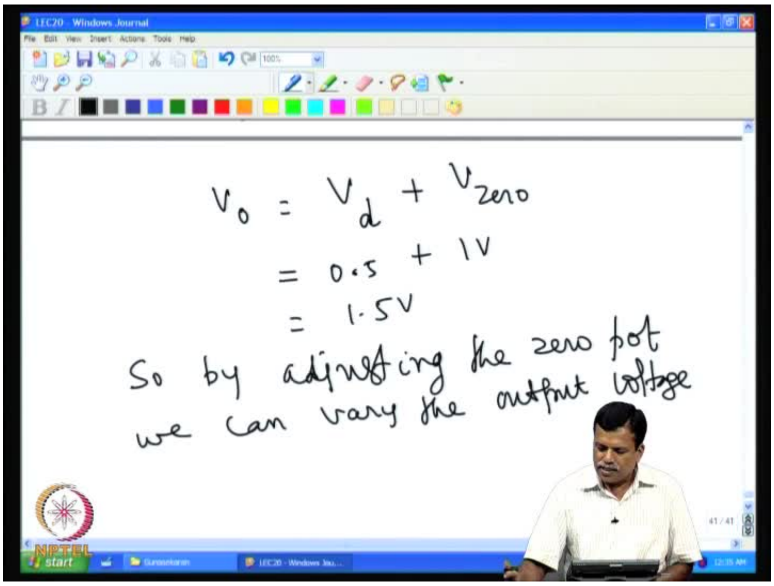

So, output if I keep it 1 volt, then output also will be added to 1 volt. So, the output voltage, I will mark it now, V difference I put it here, this is V difference and this is V 0, this can be uses 0 adjustment. So, if I take V 0, then the output at op amp is given by V 0, is given by V difference plus V 0. So, whatever if it is in this case, it is V d is 0.5 volt, the voltage across the Platinum Resistance Thermometer is 0.5 volt, this is 0.5 volt. We are kept this 1 volt, then output will be 1.5 volt. So, one can adjust this, to get whatever voltage we want, nevertheless if the temperature changes, the Resistance of this changes, because of that the voltage across this will change. For example, what 400 degree C, the Resistance would have burn up by;

I complete this first, that is, you have the output will for example, if it is 1 volt plus V 0 is 1 volt, then the V 0 will be the output will be 1.5 volt. So, by adjusting zero pot, we can vary the output voltage (No Audio from: 35:39 to 24:52) this is required in later our design, that we have to vary this voltage depending upon the requirement. So, this 0 adjustment is required.

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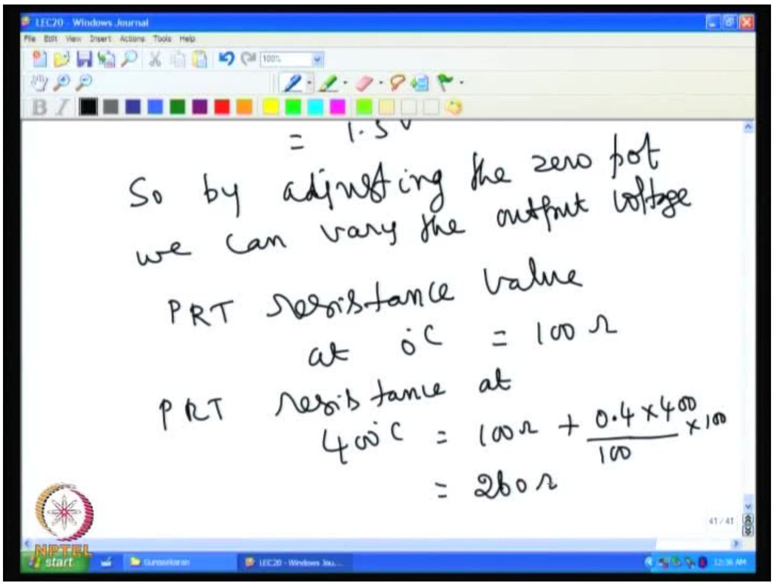

So, only thing is now, we have to estimate, what is the expected output voltage here at when the temperature of this goes to 400 degree C. So, for this, we are to find out, what is the Resistance change? So, PRT Resistance value at 0 degree C is 100 ohms so, PRT Resistance at 400 degree C, that actually 100 ohms plus 0.4 percent it changes, 0.4 ohms by 100 into 400, 0.4 percent it changes, 0.4 percent into 100 ohms. So, that actually gives 0.4 ohm into 100 that will actually become 260 ohms. So, at 400 degree C, the PRT

Resistance will come 260 ohms, then the voltage across that will become correspondingly more.

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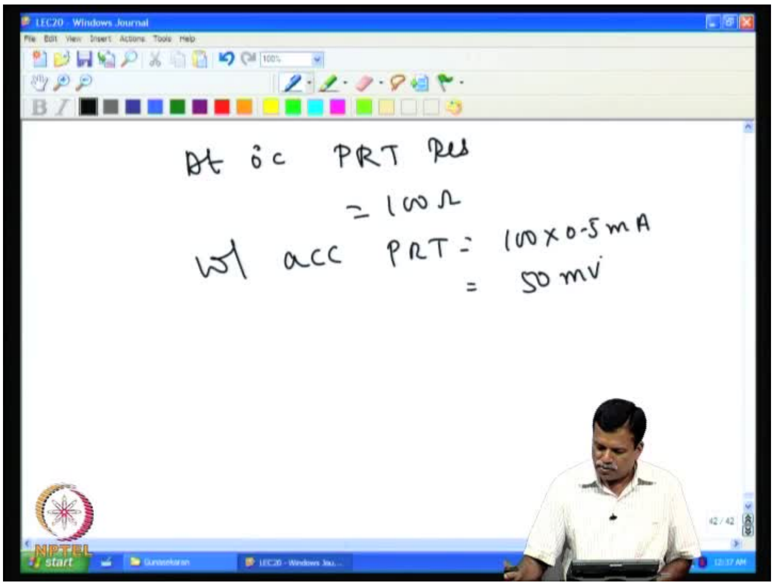

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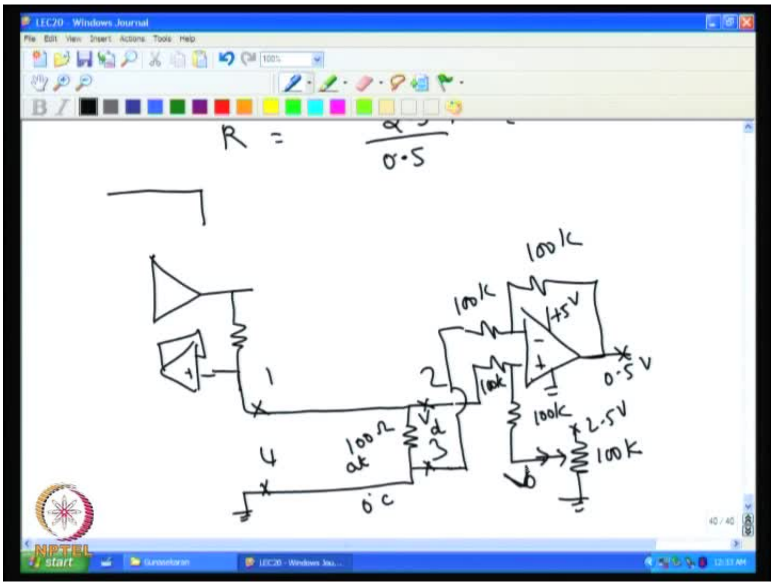

So, at 0 degree C, PRT Resistance is 100 ohms and then the voltage across PRT will be 100 into 0.5 milliamps that will be 50 millivolt. Actually, our assumption of 0.5 volt here, there is a small mistake, it supposed to be 50 millivolt, because if 0.5 milliampere is going through this. 0.5 milliampere into 100 ohms will give you 50 millivolt and then 50 millivolt at this point will make 25 millivolt here. So, in that case, we at use op amp like LM 10 to accept this level of voltage and you will also get here 50 millivolt only. So, this actually to be modified as 50 millivolt, this will be 50 millivolt and this will be 1.05 volt, would be the output voltage.

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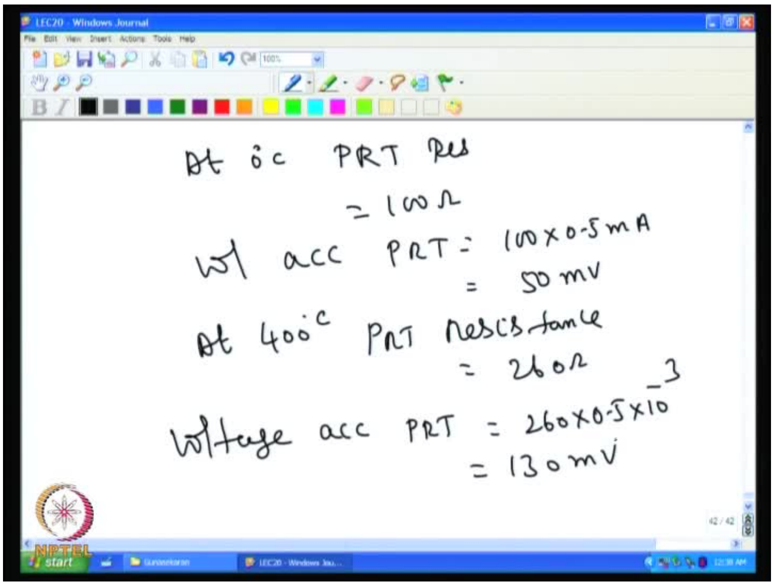

So, we are wrongly taken as 0.5 volt it is actually 50 millivolt is what it is coming, plus this voltage to be added up here. So, if we take this one, then it is at 50 millivolt, then at 400 degree C, PRT Resistance, because PRT Resistance is 260 ohms and the voltage across that PRT will be 260 into 0.5 milliamps that becomes 130 millivolts.

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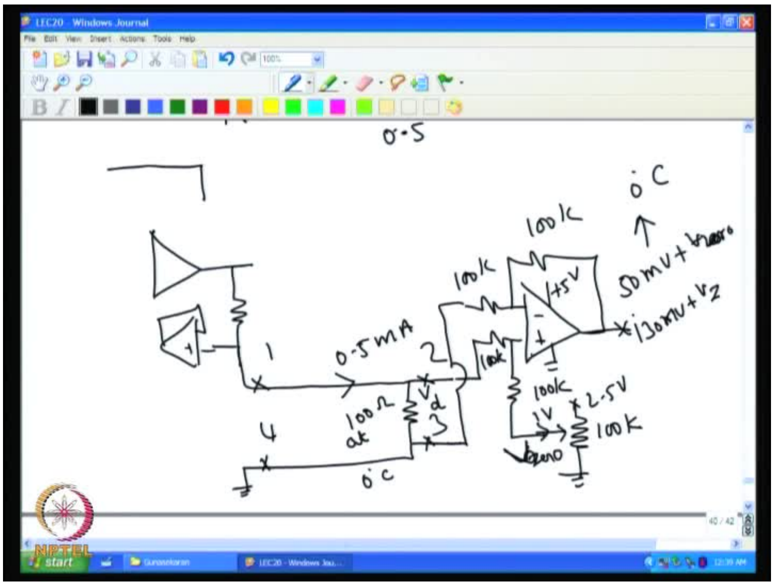

So, the voltage across this goes to 130 millivolt at 400 degree C. So, correspondingly the output voltage, if we look at the output voltage at this point so, we can rewrite this so, output at this 0.50 millivolt plus V zero. V zero at 0 degree C, at 400 degree C, then this becomes 130 millivolt plus V zero.

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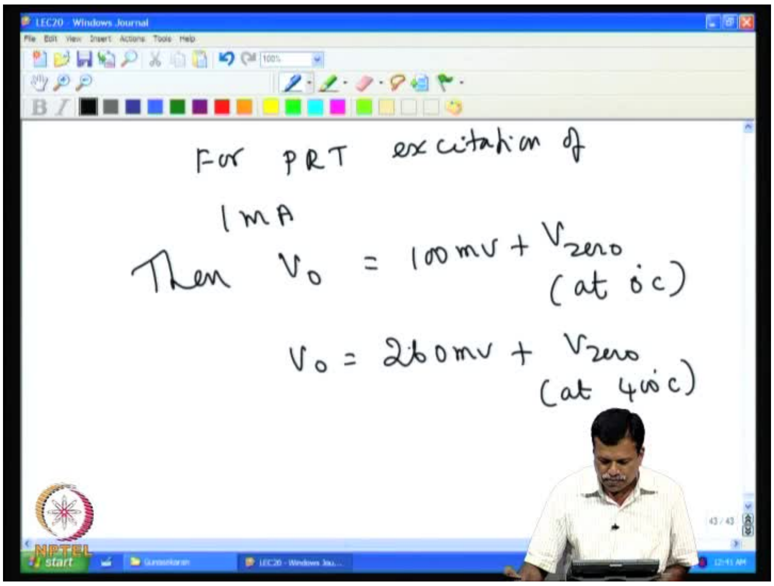

So, that is the net output at this point. So, you will have 80 millivolten variation at this point, one can also design the circuit for 1 milliampere current. In this case for example, if design the circuit for 1 milliampere current for PRT excitation of 1 milliampere, then V zero will be 100 millivolt plus V zero, this is at 0 degree C. Then V zero will be 260 millivolt plus V zero, this is at 400 degree C. So, one can select the current even if required for 1 milliampere as well, because we will able to use slightly low cost op amp in the current. If increase the current, because the op amp need not to go down to such a low working voltage. If you are using and also drift would be less if the excitation current is more and 1 milliampere current is actually possible to use in this design.

So, we will get the V zero here, at this point depending upon the current that we are selected. Now the next stage is this, this voltage will be convert into 4-20 milliampere current. So, this is to be connected to the next stage, this is the current converted stage.

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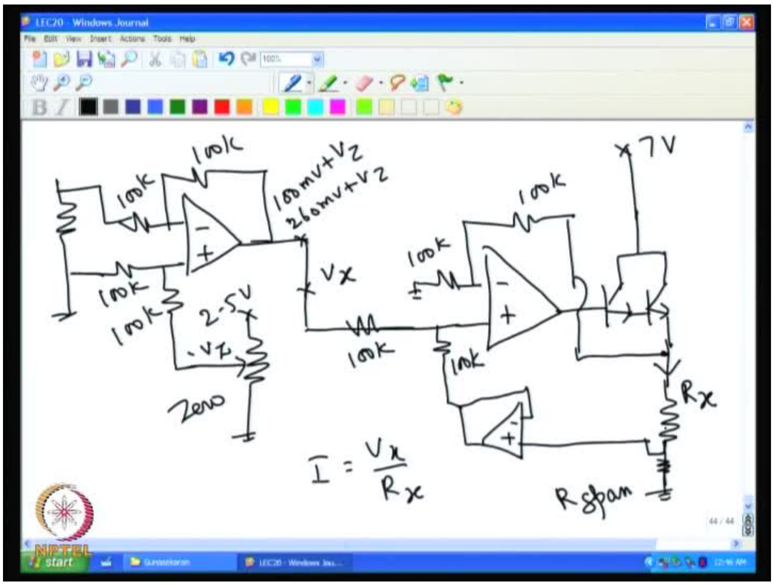

So, I will redraw this circuit now. So, this output of this difference amplifier, this is where, the PRT is there and the PRT terminals are connected here. And this is where the PRT zero pot is connected and this is given to 2.5 volt, this is 0 pot and these resistors are essentially to be same 100 k or 470 k also to reduce the current drawn by the circuit. So, one can have this and this output gives you voltage corresponding to the temperature, that is, we at seen in the case of this in 100 millivolt plus V zero or 260 millivolt plus V z at 400 degree C. So, this is the voltage that you get at 100 degree C, this at 0 degree temperature of this and when this is at 400 degree C, you will have 260 millivolt plus this V z, this V z is this voltage, what we are fix it here.

As I said this is at this is required the V z need to be added, so that, one will easily design the next current converter stage. Now, we will go and design the current converter stage so, for this, what we do is, we will take the operational amplifier and this need to drive the current so, we can have even darlington pair for driving this. Now, it would be easier to go with the similar current source, in this case, because what we can is, we can have fixed Resistance here and then we can have span pot across this connected. So, this is R x fixed Resistance and this is R span and this supposed to go to the 7 volt regulator supply. Then if this voltage increases, we want the current to be a increase so, I can connect this to this point.

Then I have to connect for example, in first case we can connect this, the voltage this point, then we do not want the voltage loss across this. So, I can always have voltage follower connected to this, voltage follower connected to this point and this can be connected to this. Now, this is connected to ground and we have the same arrangement which what we had earlier, the same current source can be now used to get 4-20 milliampere current depending on this voltage. So, we have for example, here we can have all Resistance equal as 100 k.

And we know the for example, for simpler argument we can have for example, I remove this, remove this, I put the things straight away here, then current through this. So, current through this I is actually given by this voltage, say I call V x, V x by R x. Current through this is given by this V x by this Resistance value that the small changes here, this supposed to be connected to this point.

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So, we can have select the R x and this can be any Resistance, there is no problem we can have equal R x or it can be any other value. So, essentially what happens, the current flowing through this, now, determined by this R x and V x. So, the current flowing through this is can be select such that when the lowest voltage that is at 100 millivolt plus V x the current is roughly about 4 milliampere total. So, that is total means, this current plus all the rest of the current put together should not take more than 4 milliampere, may be about milliampere current can be taken. That means, at this voltage level, we need 1 milliampere current and this voltage level, we need around 17 milliampere current. Assuming, 3 milliampere is drawn by other circuit.

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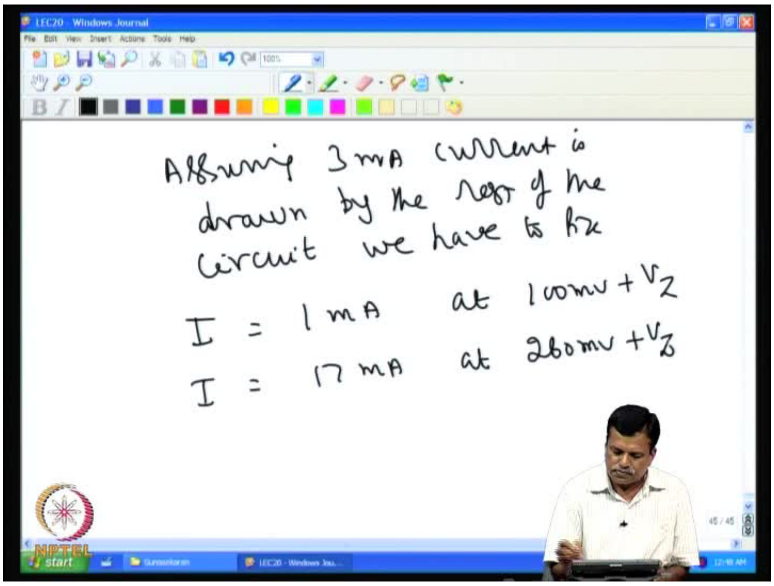

So, we assuming 3 milliampere current is drawn, current is drawn by the rest of the circuit we have to fix. I equal to 1 milliampere at 100 millivolt plus V z and I should be equal to 17 milliampere at 260 millivolt plus V z. Now, this is the non-linear relation so, if you have at arrive at this voltage, then we have to carefully select the biasing arrangement because now the current is given by 100 millivolt divided by R x. So, this current has to vary 1 is to 17 whereas, this voltage is varying only by 1 is to 2 or 3.

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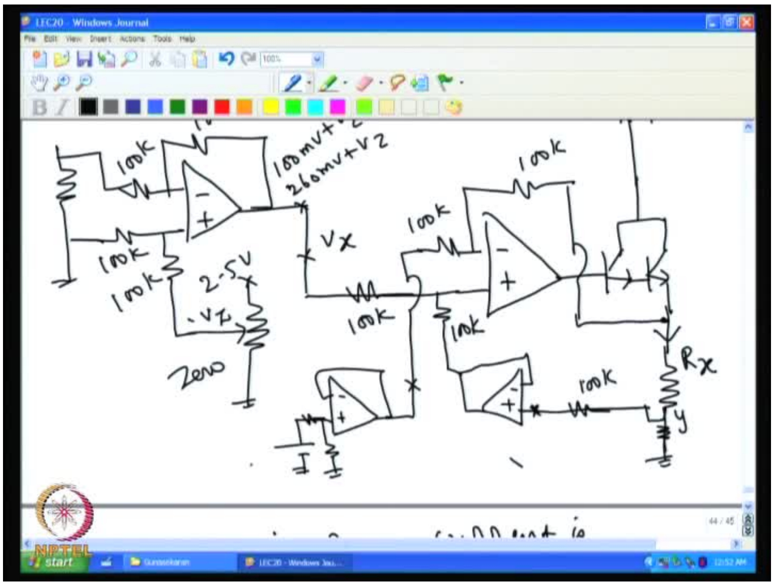

So, by adding V x in fact the change even comes less so, one have to add this dead voltage suitably to solve this issue. So, one can add the dead voltage at this stage actually, one can put the required voltage at this stage, one possibilities that one can have large Resistance drawn here and then we can put this to V reference. So, that voltage at this point, if I taking this is large Resistance and this is a very small Resistance, then one can get voltage at this point contributed by two factors, that is, this is y, if the voltage is y that. For example, if I have equal resistances say 100 k, 100 k, then we are plus this are added together. So, by adding a suitable voltage at this point, one can get the voltage at this point, that actually will be added to this.

Now, one problem this is that we already having a excess voltage, that will call for this minus voltage to be adding at this point, that is not a practical solution so, minus voltage is not available at this point. So, the technic of adding the voltage at this point may not work, because we do not have minus voltage. If minus voltage is there, one could have subtracted the voltage and got the minus and that would have subtracted here. Now, other possibilities keep this voltage as 0, that you know, the zero voltage can be kept here 0 and then you will have 100 to; 100 millivolt to 260 volt only varying, that can be made to vary 4-20 milliampere, that is the another possibility.

Now, to make it 4-20 milliampere, we can do, but one keeping this 100 and 260 millivolt. Varying 4-20 milliampere is not a easy solution, because that ratio's will not match. One have to do lot of (( )) in terms of Resistance variation or other possibilities we can also add the voltage at the plus input. So, one can add the voltage at the plus input, like instead of adding it here, I remove this, I can also add voltage at this point, because plus voltage adding at this point will make this voltage to subtract. So, one can add for example, the plus voltage can be added to this so, and can also keep plus voltage at this point.

So, one can do this by putting one more operation amplifier here. We can have V reference here and the output of this can be connected to this, connecting this output. So, you will get this, this required voltage can also be varied by varying this resistors. So, any voltage you want this is because here 2.5 Zener is there. So, whatever voltage you need, that can be taped by varying these two Resistance. So, by adding a additional voltage at this point, we can take care of this extra 100 millivolt or this V z, whatever is there, that can be tackled, because most of the op amps may not go down to 100 millivolt. So, this also essential to add this V z at this point, so that the minimum voltage requirement is taken care.

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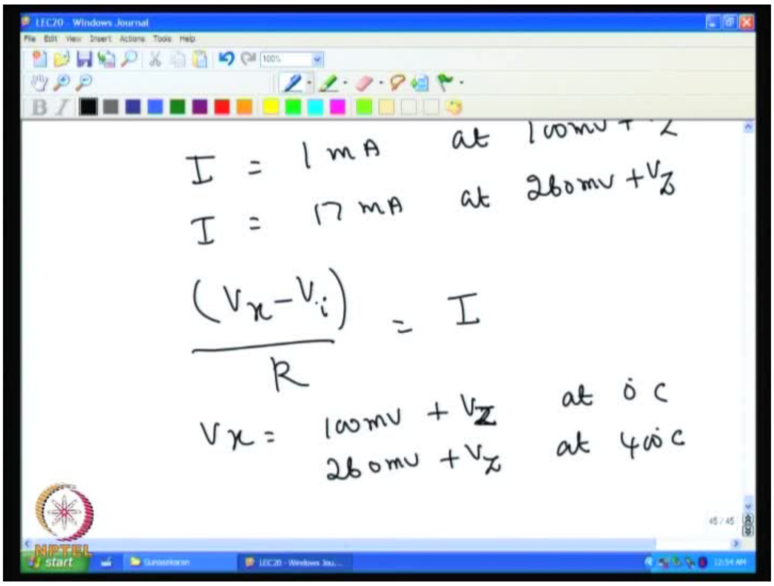

So, this arrangement works alright, only thing is we have to adjust this say voltage V i to be correctly calculated such that you get the required voltage. Now, the current is given by V x minus V i divided by R is coming as I actually. So, one can select the V i such that, you will get the required quantity, because V x if you take, that varies from 100 to 260 millivolt. So, if I take this, V x variation is given by 100 millivolt plus V z, at 0 degree C and that is equal to 260 millivolt plus V z at 400 degree C.

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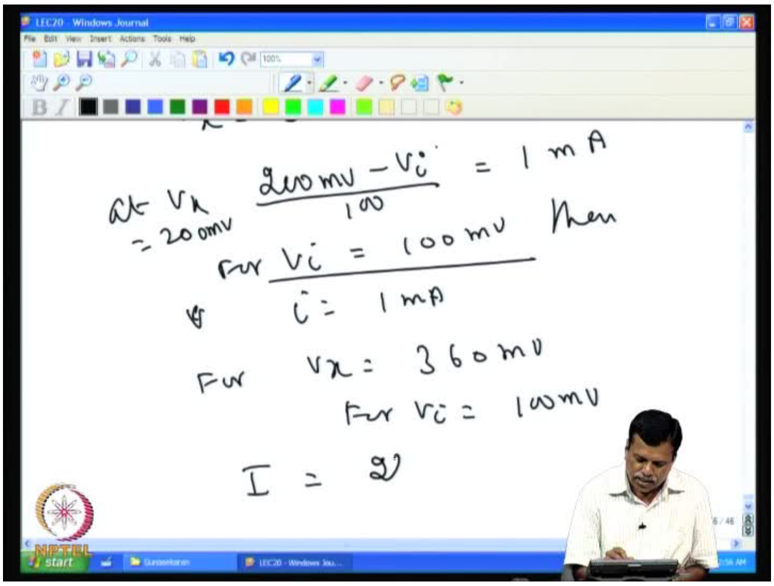

So, one can select V i such that, this V z plus 100 millivolt is can be taken care, such that, I can now write it. For example, we want 100 millivolt plus 100 millivolt, assume V z is 100 millivolt, then I will get, we take V z as 100 millivolt, then we get 200 millivolt. V x equal to 200 millivolt at 0 degree C and then V x equal to 360 millivolt at 400 degree C. For example, if I want total current as 1 milliampere, then what I can do is, V i can take such a way, that for assuming R x 100 ohms. So, 200 millivolt, they substitute in the case and you will get 200 millivolt minus V i divided by 100 should come as, 1 milliamps and then that will come as V i. For example, V i will be equal to 100 millivolt, that will give you 1 milliampere current.

Then at 260 millivolt for example, V x is 360 millivolt at V x equal to 200 millivolt. We will get V i is equal to 100 millivolt, for V i is equal to 100 millivolt, then I will be equal to 1 milliampere. For V x equal to 360 millivolt, for V i is equal to 100 millivolt, then I will become 260 divided by 100 that will be 2.6 milliamps.

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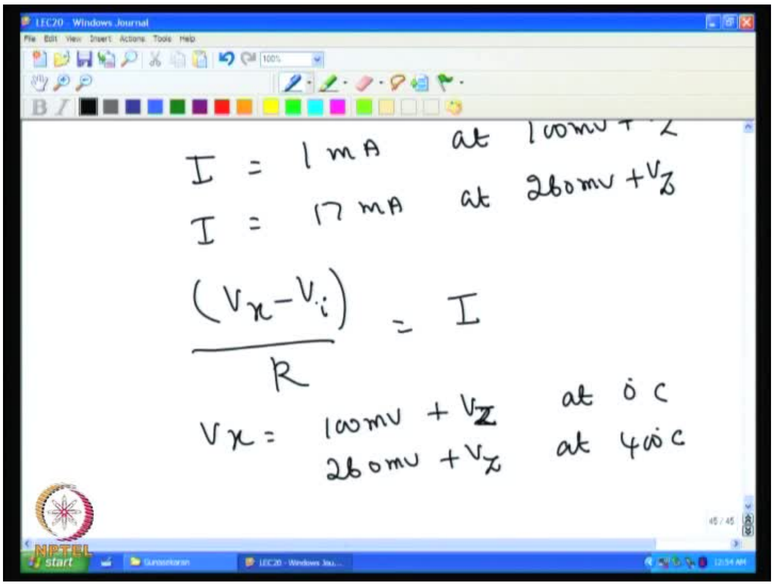

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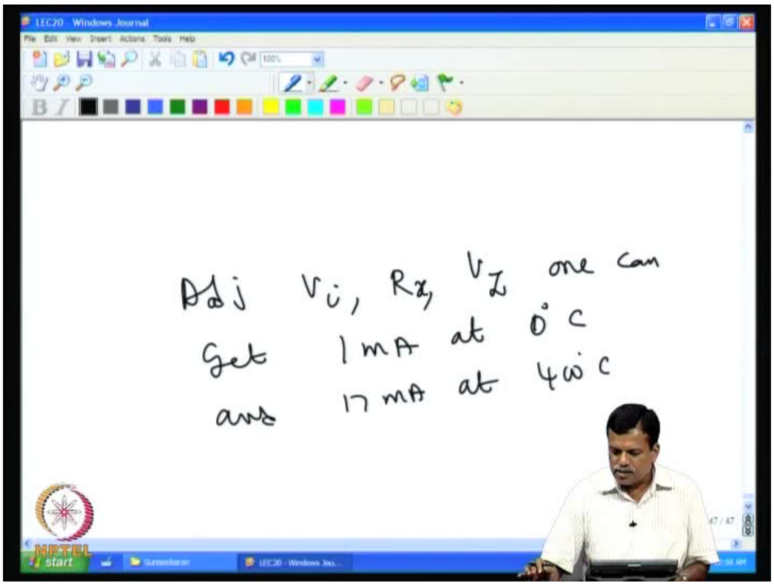

So, this ratio can be at made such that, this is coming as 1 milliampere and this comes as 70 milliampere. One can do this by alternatively adjusting V i and R, because we have the option of adjusting V i, V x and R. All three parameter this can be adjusted such that, at one end I comes as 1 milliampere and the other end it comes as 17 milliampere so, this exercise leave it you can perform this. So, one can adjust this by adjusting V i and R and then as well as V zero, actually, a V zero plus can adjusting V zero and then adjusting the voltage, that is V I and then adjusting this R x actually, this R x, it is not R so, it is R x.

So, one can adjust this three quantities such that, you can get one end 1 milliampere and other end 17 milliampere. One can get 1 milliampere at 0 degree C and 17 milliampere at 400 degree C. So, that will make the entire circuit work as it 4-20 milliampere current transmitter. We can add together the entire circuit and make it as a single circuit in the next class. So that, we can understand as a complete circuit how this 4-20 milliampere design works. Thank you.