Circuits for Analog System Design

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Lecture No. # 09

On/off Temperature controller design

In the previous class, we have discussed about the temperature indicator, how to design a temperature indicator using i c sensor. So, there we had used L M 335 as temperature sensor and then, using that we had discussed with the discussed about how to design the temperature indicator.

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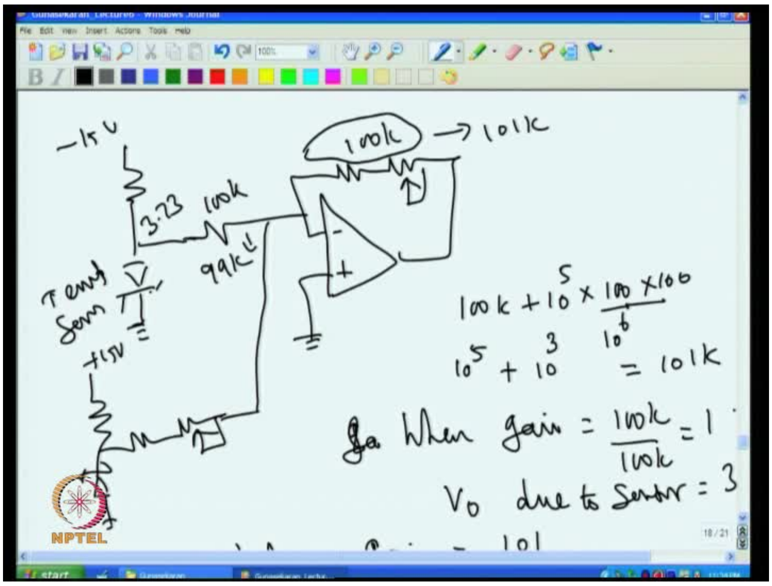

So, if you go back to the old circuit so that is how the old circuit looks like. So, the old circuit, what we had discussed in the previous class is this. So, here we are used this L M we are used this L M 335 is a temperature sensor and then, this gives you 2.73 volt at zero degree C. So, to subtract that, we had used L M 336 zener 2.5 volt zener and then, we selected these resistance and design temperature indicator. And then, we also discussed about what are the errors involved in this. For example, we have discussed about what happens, when the resistance drips, when the resistance drifts will get a temperature error, then offset voltage drifts then, you will get the temperature error.

Similarly, the zener voltage drips, then also you will get a temperature error.

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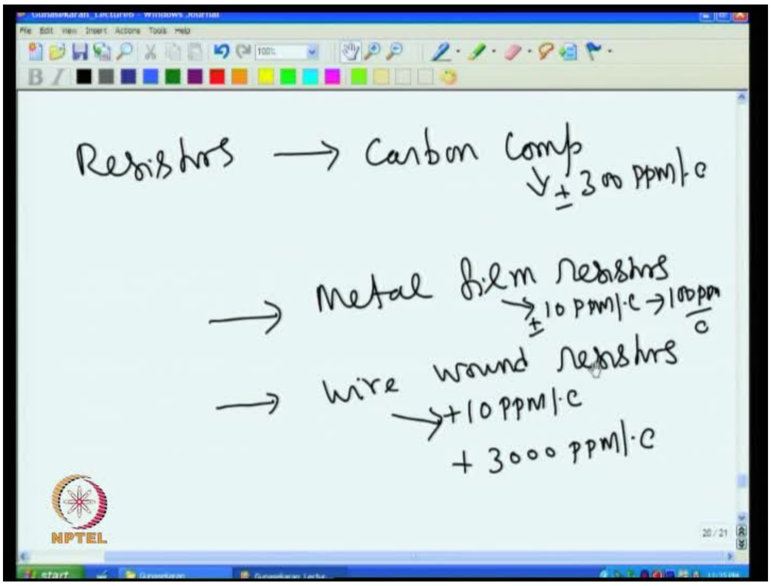

So, in this connection we also discussed, what are the different types of resistors that is available. For example, if you are using a resistor the reason it is the drift, but, then we have you know, if we see carefully, that we have three different types of resistors that is one is carbon composition resistors, second one is metal film resistors, third one is a wire wound resistors. Carbon composition resistor use 300 P P M per degree C drift, metal film resistor gives you 10 P P M that is 10 parts per million resistance drift per degree C and wire wound resistor gives you from plus 300 P P M to plus 3000 P P M.

So, we have discussed about these resistors and if you want very good drift then we have to go for metal film resistors. Of course, we have to pay higher price for that, wire wound resistors they have only positive temperature coefficient, there is metal film resisters and carbon composition resisters. You do not know, even the polarity polarity of the drift, because some from the some may have positive drift, some will have negative drift, some may have 300 P P M, some may have plus 200, some may have minus 50 P P M. Anyway from minus 300 to plus 300 P P M it will be there. So, that term is not wire wound resistors but, they are bulky normally, we use only these two unless you need high power or very load drift. Then mangan in resistance is good, which gives you 10 P P M per degree C drift.

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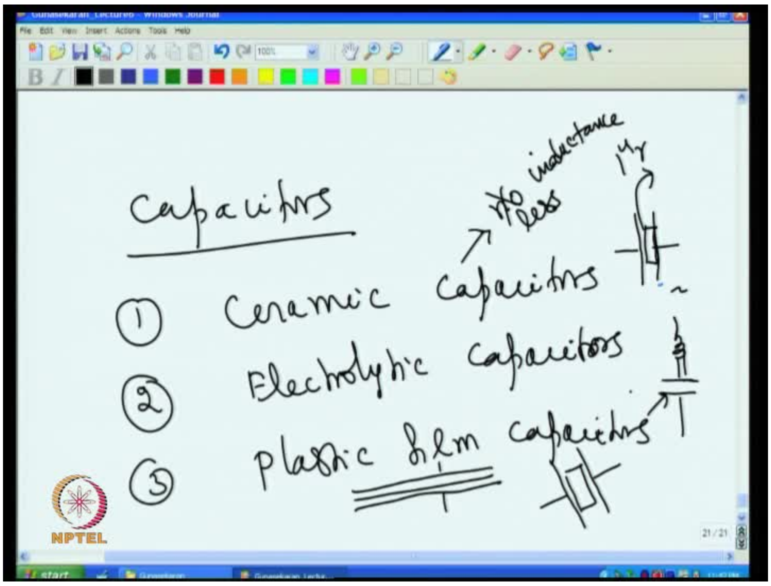

So, this is what we are seen in the previous class and also we had seen, what are the different types of capacitors, because resistors and capacitor play important role in electronic circuit. So, once you have a good understanding about them, how to use this resistors and capacitors effectively in a government circuit. Without that probably your design capacity will come down by almost 50 percent. Because normally, we think that resistors and capacitors are not very important, but, it is wrong; actually, you should know more about the resistors and capacitor.

Then then you know about i c, because they play a significant role. So, if we see capacitors we have three different types of capacitors. One is ceramic capacitors, then other one is electrolytic capacitors, third one is a plastic film capacitors. Now, if you look at the characteristics of these capacitors. Ceramic capacitors actually, the value change quite a lot with temperature. For example, the temperature coefficient can be plus or minus 3000 P P M whereas, if we take a plastic film capacitors, there temperature coefficient is very low you get 30 P P M 25 P P M like that.

Now, if you take electrolytic capacitors, we also have a large drift with temperature, but, the it is available in large value. For example, if I want one farad capacitor I can get in electrolytic, but, there is not possible with this or with this ceramic capacitor. So, ceramic capacitors are actually, ceramic is a is a dielectric, because of that what happens, you know normally, what is done is you take you know the ceramic dielectric and then, put two plates across this and then get a capacitor. And this dielectric constant of this ceramic is normally, very high, that mu r is very high it can go up to one lakh. Because of that in smaller size you will get large value capacitor, large value means one micro farad up to 10 micro farad value. But net result is you know you get the capacitor without the inductance.

So, this ceramic capacitor is the one, which gives you the capacitor values with no inductance at almost no inductance or very less inductance. So, wherever, we need capacitance with less inductance with less inductance one go one can go for ceramic capacitor. That is why ceramic capacitor used as a decoupling capacitors or surge suppressant purpose we can use this, but, they are not good for frequency determining work, for example, I should not use in oscillator circuit, ceramic capacitor. Because it oscillate frequency as to be a stable with temperature, what will happen, capacity value will change the frequency of the oscillation also be change

So, we do not use wherever, you know very critical about the drift very critical about the drift then, we do not use this ceramic capacitor. But you know for decoupling work we can always use ceramic capacitors. Electrolytic capacitors also have large inductance and also drift large with temperature but, they are available large value and they are unipolar. So, wherever, you know filtering purpose power supply filtering and power storage and so on use electrolytic capacitors. Then, plastic film capacitors plastic is used as dielectric that you have; for example, that you have a plastic like a metallized polyester, polycarbonate, polypropylene, there are plastics their electric constant is around seven.

And they are used as dielectric material but, the problem is a dielectric constant is only seven, not like you know ceramic capacitor electric constant very high up to one lakh like that you will get. So, because of that to get high value, normally, what is done is there you take a long foil you know the take a long foil and then the deposit, you know take plastic in between and the two foils are put and the two plates are put on capacitors made. They make a long foil and then fold it, to get a capacitor, because of that plastic film capacitors give you very low temperature coefficient, but, they will all come with the equivalent inductance. For example, we had say the plastic film capacitor that always associated with the inductor.

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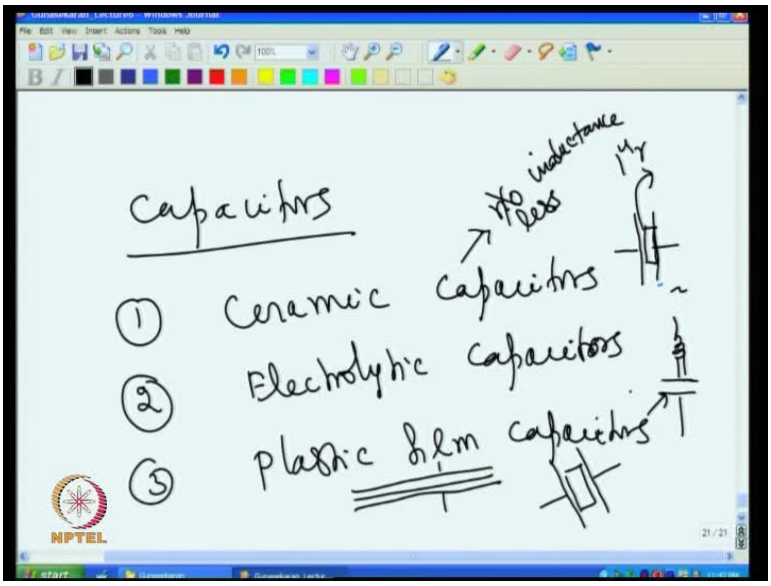

So, they are used only, where you know you need accurate value of capacitor require and should not drift to temperature use this, but, when they always associated with the inductance. So, they cannot be used for decoupling on network and so on. So, this we see little later more about this properties yes we want in this course more about this capacitors and this resistors we can discuss. Now, let us take next another important design, that is temperature controller. It will assume me, what make a temperature controller and then how to go about designing that. Because we have discussed earlier about temperature indicator design, now we design temperature controller actually. So, let us see how to design a temperature controller.

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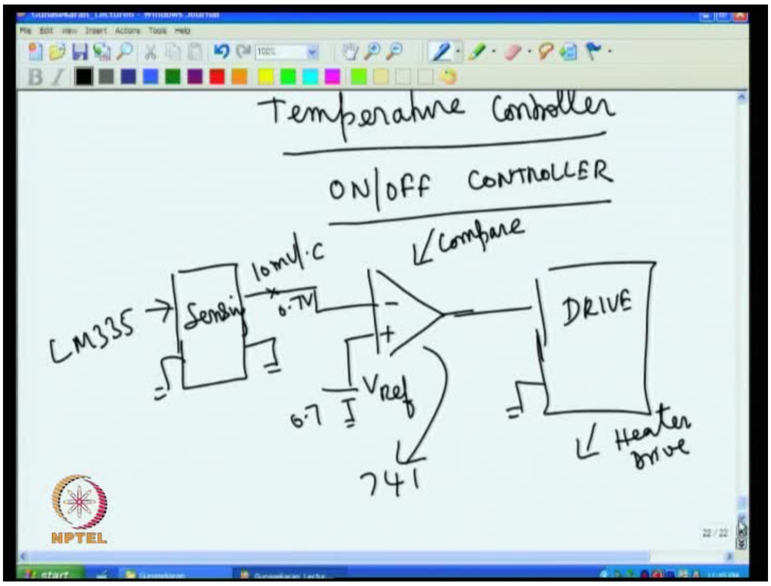

So, in this lecture describe a design, what is call on off controller? I will talk about these different types of controllers little later. So, let us take now here on off controller, just to the name had come mainly, because we going to switch on or off, and then that is our controller going to work. So, we will talk more about you know on off controller p i d controller and so on little later. So, let us see how to design a temperature controller. Now, I for this took we need a temperature indicator first, because if you want control something, all that we need is we have to sense the temperature and then compared it to the reference and then control the heater.

So, we have a three parts in any control system that basically, we have one block for temperature sensing, for example: sensing, this case is temperature. So, I have to sense the temperature then after sensing, the sensor gives me the this is the input temperature input and this gives you the electrical output. So, in this case, we are sensing the temperature and corresponding to the temperature, we will get we will get a output voltage. Now, this is so, we need a sensing part first, then the sensed voltage must be compared with the reference. So, we will have a comparator and then where in we will have a reference is given.

So, if I want to sense the say, if you want to stabilize at 70 degree, then I give for example, corresponding to 70 degree voltage. For example, assume that I am getting here 10 millivolt per degree C. That means, if it is a 70 degree I will get 0.7 volt 0.7 volt then, I give reference also 0.7 volt. So, the temperature sensing first part, then the second part is comparator, you have to compare the compare with the reference whatever, temperature you want stabilize that that corresponding to that voltage to be compared with the sensor voltage. Then you have to have a heater drive or motor driver whatever it is so, you need a drive.

So, any ways control system needs these three part, that is you know drive, then comparator and then sensing. Now, in this case, let us take L M 335 as a temperature sensor and then, we take 1 op amp for example, our friend 741 we take as a comparator and then here, we want control temperature so, the drive will be heater drive. So we will have a heater that has to be driven. So, this is what we going to design in this lecture.

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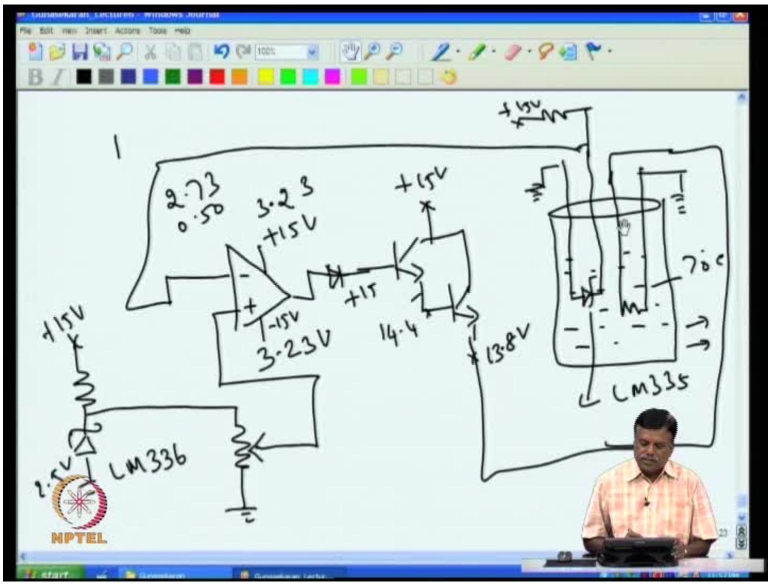

So, let us see next, what we do with this. Now, what I do is first I should sense the temperature. So, for example, in this case assume I want to maintain the temperature of bath and you have a water in this, assume I want maintain temperature of this water at say 70 degree C. So, what I do is, I will put the sensor here, which is L L M 335. So, we have a sensor that is dipped into this. It measures the temperature of you know you put L M 335 here this is the temperature sensor, which we have discussed earlier. So I take this, then I had to bias this, because I note say 1 million current through this. So I give plus 15 volt to this, then voltage at this point gives me temperature of this water. For example, if it is 25 degree C, I know that I will get a 2.73 plus 0.25, because it gives you at zero degree C 2.73 volt, at 25 degree c, it gives me 0.25 volt. So you will get 2.98 volt you will get at room temperature.

So, this is grounded and then I bias it this. So, it will give me 2.98 volt at this point. So, assume that I want to maintain this at 70 degree, if you want to maintain 70 degree then I at have a heater. So, I will put heater inside, so we got a heater here. So, I should it temperature is low for example, I want 70 degree, now in the morning, if I switch on the temperature is the temperature of the water is 25 degree C. So, I want to take 70 degree means, I have to apply a voltage to this heater. So, that this dissipates heat and then the temperature of this goes up once we reach 70 degree then I switch off the heater. Then again, because of the radiation here, then temperature will come down, once it comes to 69 I will again switch on this, so again, reaches 70 switch off.

So, by monitoring this temperature and correctly switching on off this heater I can maintain this. Now, this is to be done electronically so, what I decide; connect this to the ground, then I take this heater heater then, I want switch on the heater means I have to do it through a transistor. So, are assume this high power circuit so, I put a dolington pair, then assume this is plus 15 volt so, I connect the heater to this. So, if this plus 15 volt and assume that I for example, I give here 10 volt give base, if I give 10 volt, then I know that at the base I will get 9.4 volt and here I will get 8.8 volt. Now, the we see this, the voltage actually goes here and this 8.8 volt apply to heater.

Now, the temperature will this will be heating up and the temperature will be raising. So, here we apply 10 volt, if I can apply up to 15 volt I cannot go more than 15 here, because our supply itself only 15. And this is a dolington 10 pair; this is used to boost the current. Because the heater current say for example, if it is say 5 ampere, then we know that the base current of this will be beta times less and then this base current will be ever beta current lesser than this. So, what happens, if it is 5 ampere, if the beta this is 50, then this current will be 100 milli ampere, if this beta is 100, then this base current will be one milli ampere. So, near one milli ampere current will be flowing whereas, here 5 ampere current will be flowing.

So, to boost the beta only we have done this dolington pair arrangement. So, that advantage is now I need very small base current. Suppose small base current that is multiplied by the beta time high current come. So, my controlling device, which going to be operation for here; need not give high current that is why, this arrangement is made to drive the heater.

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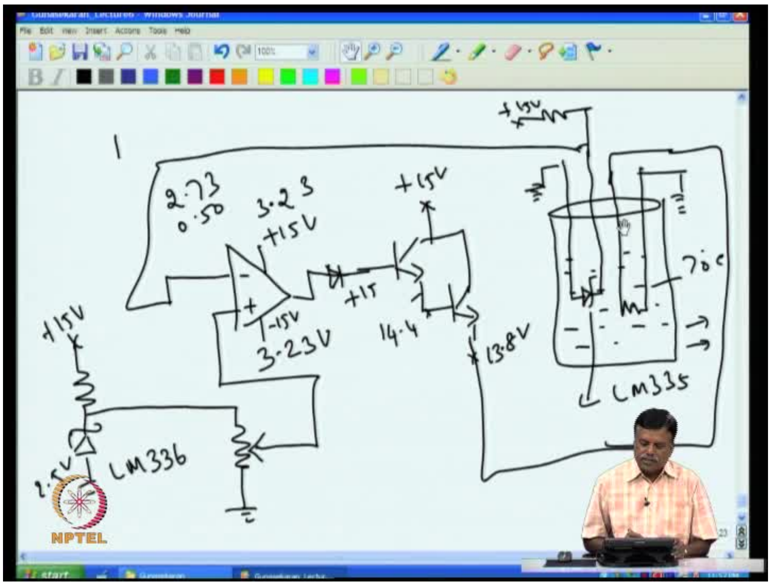

Now, let us continue our discussion now, I remove this 10 volt now I give this one from my control circuit. So, what I do is, I had say I know the temperature here I know the temperature here so I have to give for example, the simplest controller could be this I can plus minus upon that I can give it to this fine. Then the temperature give to here and then the plus I have to give a reference. So, reference can be from a zener for example, I can have a zener diode say for example, 2.5 volt zener is there, L M 336, because used familiar with some of that device available in the market. This is the very important thing as a designer one should know, what are the components available, how much its cost.

So, that one can have a correct choice of components, because the prices is an important factor. We should not end up insulating a device which is costly, which cannot be used in the practical world eventually. So, one should aware of few commons at least so, that design strain may be very less. Now, if I want at 70 degree I know that this will give me 2.73 plus 0.5 that gives me 3.23 volt. So, at 70 degree it will give me 3.23 volt at room temperature it will give me 2.98. So, that means, when the temperature is lower than 70 degree is should heat up. So, what I do is I will put one point's ammeter here and connect this to here I keep this one at 3.23 volt. I adjust I adjust the potential meter such that I get 3.23 volt to this input to the plus input.

Now, that basic temperature controller is now complete. If you see how this works? See, we have sense the temperature here for example, in the morning, when you come and switch on and water would be at room temperature. So, room temperature corresponding say roughly 25 degree C, if it is 25 degree C then, obliviously this will give me 2.98 volt will be there at this point. We have set this one at 3.23 volt that means the plus is higher, minus is lower. And this op amp is supplied with plus 15, minus 15 supply plus 15 volt and minus 15 volt supply is given to this op amp.

Now, if you see this is sitting at 3.23 and the morning this is sitting at 2.98 that is corresponding to 25 degree C. That means this is higher, so output automatically goes to plus 15, once it goes to plus 15 this comes to 14.4 this comes to 13.8 that means, this goes to plus 15 and this comes to 14.4 and then this comes to 13.8. That means, now heater is getting 13.8 volt and started heating up as it heats up the water temperature goes up and then this temperature also goes up and then this voltage also goes up. So, slowly that based at at this point will be voltage at this point so slowly voltage at this point will be raising.

The voltage at this point raising, then basically what happens, if you see the difference between these two is keep decreasing. But we know in any op amp the difference between this two multiplied by the open loop gain is the output whether, it is close loop are open loop this is always true. So, the difference between plus and minus multiplied by open loop gain is what is appearing at the output of the op amp. Now, this is 3.23 and if this is less than 3.23 even, if 1 millivolt less so, even 3.22 say just 10 mille volt away then 10 mille volt into open loop gain, which is very high, which is around fifty thousand the automatically output become plus 15. Because it cannot go more than plus 15 so it is stuck with plus 15 and it is heating up.

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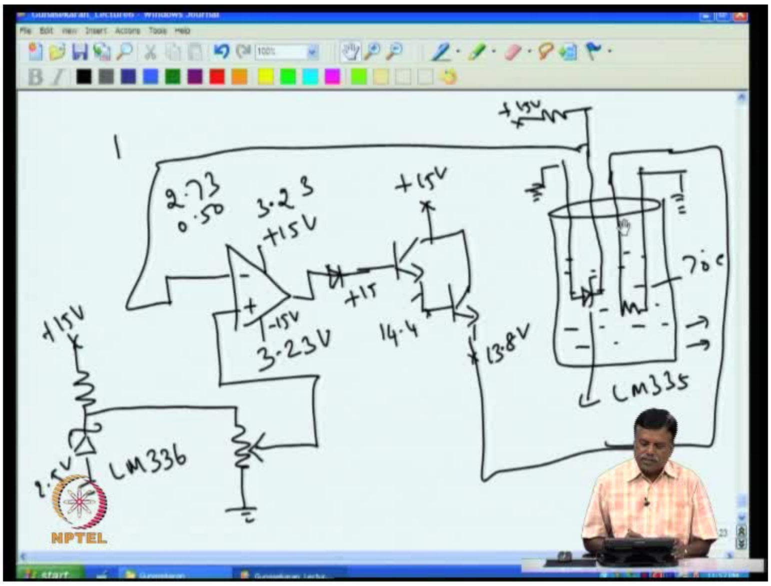

But moment it comes to 3.23, where the temperature is rising and the moment comes to 3.23 then, the difference become zero and then output become zero or even, if you go slightly more than 3.23, then output shift to minus 15 once minus 15 comes we should not apply minus 15 to this one. So, to block the minus 15 I put one diode. So, minus 15 comes no voltage comes, plus is their, the plus voltage goes the diode conducts and except that 0.6 loss, which we are not worried. Then the voltage concern, when in it then goes little more than the this is 3.23, when it is go little more than 3.23 output come minus and no voltage comes here and then no voltage comes here and the heater goes off. Once heater goes off, then because of radiation from the the beaker then what happen, the temperature start coming down.

And once the temperature comes down then this voltage also be start coming down, and if this course say below 3.23 again, this will go plus 15 and then 14.4 and then you will see 13.2 here and the heater heats up again, and again temperature go up. Once temperature again, goes their own goes 3.23 more than 3.23 again, 10 minus and go off. So, like that it will you keep going on off on off and then maintain this around 70 degree C, not exactly 70 degree, it will be maintaining little more than 70 and then it will come down little below 70 like that. It will be doing and then frequently it will be switching on and off and then maintaining this temperature.

In fact this what we do, in real life for the example, if the controller is not there, if without that if I have to do then, what you do is you will put a thermometer here. And then, if the temperature is slow will switch on the heater. Once I reach set temperature I will switch off that same thing is done by the electronic controller here, by switching on of on off. So, this is a famous temperature controller, in fact most of them today it is used it is very easy to construct, but, only problem is that if you want 70 degree it will be going up and down. If you would not switch on it will go about 70 and then slowly it will come down then come to 69.

So, depending on the system, the there will be overshoot on the shoot. If the system is fast overshoot on the shoot will be small otherwise, overshoot on the shoot will be more. Other than that it is a good and famous controller, age old controller and works beautifully there is no problem, but, except that you have a small temperature fluctuation. And also, if you see in this mode that this will be frequently going on off on off and many people even use instead of this various other possible device, which I will explain you little later. So, if you see this one, there will be it will have a on off on off feature going very frequently. We can reduce this number of times going on off on off by introducing a hysteresis. That we can do like this, what I can do is that I will show you in the next circuit.

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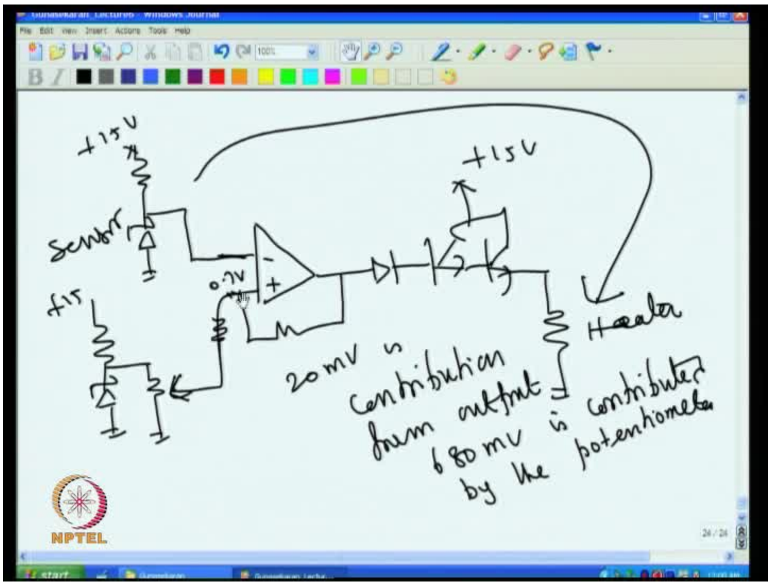

Now, I will draw little simpler circuit to this, so all that need is that I have this controller minus so, to this I have a reference temperature, which is to be set that I have done it here. Then minus, so this is a temperature information from the this is sensor so, this is given to this and then the output to block the minus we have done this. Then we have driven this and then the heater. Of course, this and this are actually, mechanically coupled this and this mechanically coupled. Now, our worry was that you know frequently it is going on off on off so, we want to avoid that now I can do that by adding a small hysteresis for example, when it is on, it should not go off so, I can take this I can add one resistance to this.

Now, whatever voltage is here only it is coming here, we can add one more resistance here this this will add a hysteresis called hysteresis. And then this will avoid frequent switching on off on off. So, what is really happening is that when the when the initially when the temperature is high that you will have this voltage is plus 15, and part of the voltage is coming here. So, if I am setting at 0.7 here say, if this is a 0.7 assume that 0.7 volt that is what we have set here by adjusting this. So if I if I make it 0.7 here, this 0.7 partly had come from here as well as from here assume this contribution is a small that you know, assume that this contribution is a small.

So, you have a contribution from here and you have a contribution from here, assume the contribution from here at this point is only to 20 millivolt 20 milli volt is contribution from from output. Remaining, 680 millivolt 680 millivolt is contributed by the potentiometer. And so, how to compute that? So, we have taken here, because of this the contribution is that this point this 0.6 that is 680 millivolt from here, because of the output some voltage at this voltage. And the you know this this this voltage and this voltage both are added here and that is what you got 0.7 out of 0.7, 20 millivolt had come from here.

Now, what happens is when initially when the room temperature is low, that is when the oven temperature is low then this will be high and you got 0.7 here. But moment the when it is heating then after some time find that this voltage is going up, once it comes more than 0.7, then this will take to minus minus 15 volt. Now, once minus 15 volt comes this contribution becomes minus that means this fellow will drop to 600 this is 680 millivolt is coming from here and 20 millivolt is comings from here. Now, this will 680 minus 20 become 660 millivolt at this point. So, when it is plus it was 0.7 then it is minus 15 it becomes 660 that is 660 millivolt.

Now, what happens, since it is set at 660 only when this point goes 660 millivolt the output will change again to positive. That means, what is happening is once actually, if I take this once it is minus 15 that is if this is minus 15 volt, then this voltage is 660 millivolt. When it is plus 15 millivolt when it is plus 15 volt this is 700 700 millivolt, when it is zero it will be 680 millivolt. That means, once it takes minus 15 this voltage reduce 6 6 that means again, it will turn on only when this only when the temperature here goes below 660. Because now, when it is minus 15 this is shifting that 660 millivolt and the heater is off minus 15 heater is off so it is cooling down.

Once it goes cools down four degree, that is 660 millivolt then, the output again will go high once it goes high. This follow shift to 700 then then again, the it will go off only when this will reaches to 70 degree. That means, you will see it switches on at 66 degree and switches off at 70 degree. So, you got four degree gap so, you will have not get frequent going on off on off. So, the now a given of four degree Celsius, by adding 20 millivolt at this point due to this we got four degree Celsius.

So, we can set whatever, you say this we want for example, if I select the region such that only 10 millivolt is added here then I will get two degree is 10 millivolt corresponds to 10 millivolt at this point corresponds to one degree C error. So, 20 millivolt change here will correspond two degree error so, you will have this is of 20 millivolt here and temperature swing of two degree here. So, it will switch on and off only once in two degree change that will reduce the frequent switching on off on off. So, this is called addition of a hysteresis. So, one can add a hysteresis by is seventeen this resistance and this resistance.

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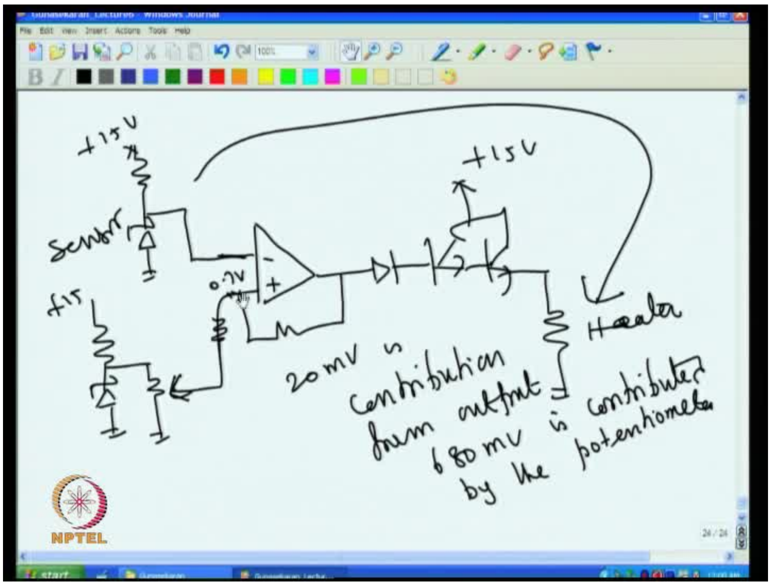

Now, we have to talk about this more, we will come to that little later we can reduce this drift by suitably selecting this. I will show you the calculation right now do not get very too much about this calculation, all that matrix is when it is plus 15 the voltage is added that will minus fifteen this voltage is decreased. So, once the voltage decreases this has to go to much lower temperature to make it come on again. So, by this way on off on off control can be made by adding hysteresis, which will avoid frequent switch on and off. And this frequent switch on and off is if this used transistor, because we need to avoid frequent switch on and off if you are not using transistor.

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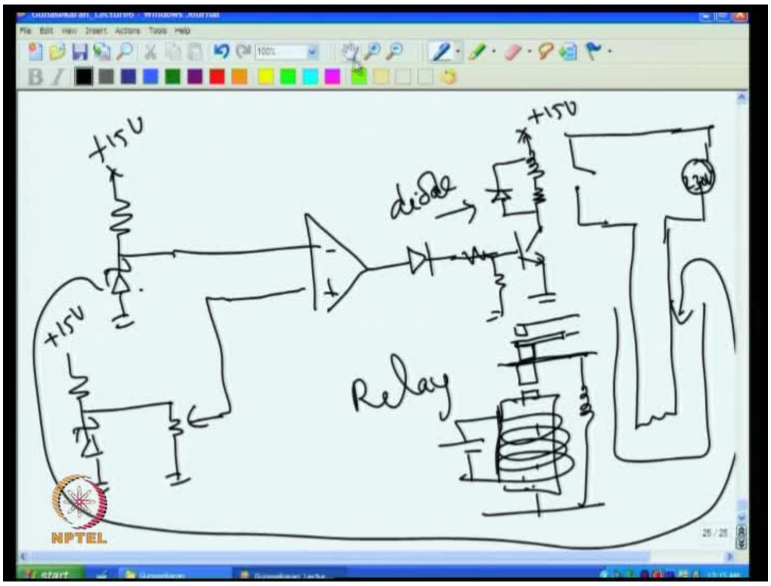

Then what is the option that we have if we are not using the transistor, switch on and off the heater. Now, that that I show in the next circuit that, what I do is I need not use only transistor to make it on off on off. I can use it for many other options I have for example, I can do this, so I redraw the circuit again for example, this is a sensor. I give plus 15 volt to bias this, then I will have reference voltage from zener. So, they have here plus 15 and then I have a set value I can get it through put centimeter and I have a comparator here. So, I compare this minus and plus right now we need not worry about hysteresis ok.

Than I put one diode, then instead of giving a dolington pair and then switching on and off the heater directly I can do this, for example, I can give to a transistor. Then I put a relay, this for the plus 15 volt and I put one diode, then I show you, what I explained you what is relay, then this relay can be connected to the supply and then the heater. This is the heater, which is connected to the oven and then for example, if I want show that in the this thing I can show it like this, I can have a heater here, then the heater wire can go here and comeback.

This voltage now in a way, take this voltage (No audio from: 32:38 to 32:48). So, whatever, voltage are given that is applied here when this is on, when this is off whatever, voltage given here you know when the when the contact is open, this voltage will not appear here. Then the contact is close this voltage is will appear on the heater. So, this is actually this is the connect of the relay and this diode so, we this relay this kind of arrangement we use very frequently we know the reason for this is called relay. Now, the what is a relay? Relay is actually, a you know, if you take this one I have I take a barbin and wind a few turns of wire, then I pass a current through this.

Once I pass a current that magnetic field will set up and then you will have a magnetic field produced, this and what can we done it you know. I can use this magnetic field to pull some iron piece and that can may to make a conduct here. Suppose, if there is no voltage here then no current and then for example, I can have a metallic strip and then I can attach it to this. So, whenever, the whenever you know this is the core of this so, whenever current is flowing then this get magnetized and this fellow will pull this and when no current is flowing and this will not magnetized and it will not pull.

So, what they do is they will attach a spring to this, and fix it to this. So, whenever, when when current is flowing through this the magnetic field is setup and will it attract this.

And then no current is flowing that will release this. So, like this we can make a mechanical movement and then to this can attach you know to this you can attach with insulation various other contact that you need like this. Like for example, if this is there it will may contact otherwise is will not may contact you can do this kind of arrangement can be made.

So, whenever, current is flowing there will be a magnetic field and that will be pulling this and that will make this to close, when no current is flowing then this spring will pull it back and this this contact though open up. So, we are just at a free mechanical contact, which opens and closes depending upon the current flowing in this coil. So, that is the that is the coil that we had shown here. So, this is the coil of the relay so whenever, current is flowing through that, eventually it closes and when no current is flowing, then this opens up.

So, other way around, if I apply a voltage here, then the transistor will conduct and current will flow through this that will make the contact to close and then the current will flow and the heater will be getting the power and this is will be started heating. If I remove the voltage this to zero, the no current will flow through this and then relay conduct open and then no current will flow through this that heater is off. So, we can make the heater voltage should go on off, you seen the relay also instead of transistor. Now, the relay as some advantage, the advantage is that you know, I can apply even 300 volt or it can a C or d c, anything or it can to 5 ampere 10 ampere or 230 volt or 440 volt. Whatever, you want we can apply that freedom you get, if you are using a relay.

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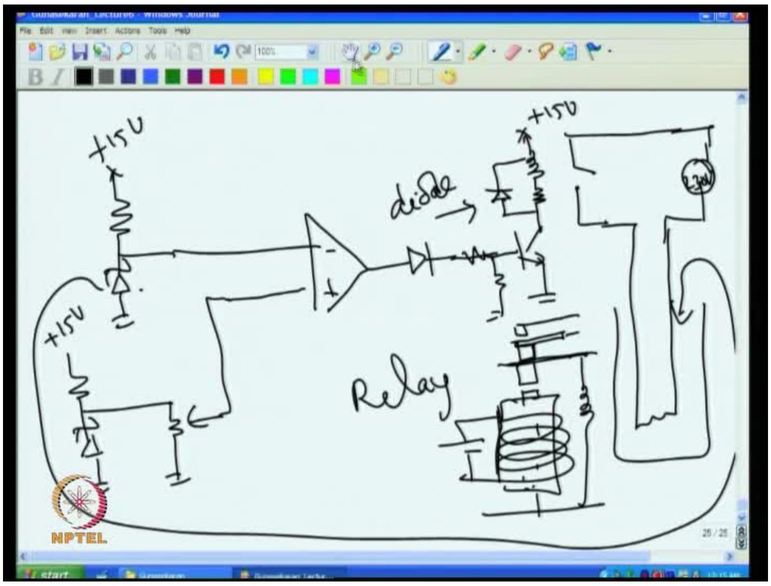

So, for high power or it is a c current this is go to need not struggle with transformer one need not struggle with transistor. The transistor can I has a voltage rating you know L M, if I use for example, two one three zero five five as a transistor. Then it cannot it is it can only 70 volt above 70 volt it the transistor fails so, that kind of limitations not there, if I use a relay. So, in that cases, for high power over for example, if it is a 1000 volt over then, what I can do is I can put here instead of this I can put a a c of 230 volt we can connect. And the when it is on 5 ampere current will be flowing and the heater will be on and then, when I put of this zero the no current will be flowing and this will be open and the heater will go off.

So, this will be easier to handle a c are very high power like this if using a relay. For the relay conduct disadvantage, that you know gives very slow it cannot switched on and off very frequently switch on only, it switch on only the magnetic field setup. And mechanically it has to pull and then, when you off then the spring at pull back the normal on off time itself will be around 50 millisecond. So, normally, we do not time switch on more than ten times a second and also when we switch on every time on and off, if you do you will see a spark coming here and the conduct here actually goes off every time in on off on off and also it produce a it radiates a noise outside outside to the space.

So, relay are the drawback, that after you know several thousand operation you will find the conduct the conduct here is not good. So, the relay is specify, what is the number of on off that you can carry out for relay. For example, there are relay's which concern one lakh operations the relay's which concern only one lakh operations after say, if it is specified as one million operations, after ten lakh times then the conduct goes off and when (when) the current flows to these it will may not make proper contact and current may not be going fully. So, this problem will be there in the relay also this produces a lot of radiated electrometric noise whenever, the contact open and break.

So, that problem also there nevertheless, this is capable of carrying high current a c as well as d c so, this is still used extensively in the industry. For example, this zener be one heater, this can be even a motor where in I if I missing a position control if I missing a position control then I had switch on the motor. When it reaches, if it is below the desired position and when it reaches the actual position I will switch off. So, I had to do this using really it can easily done so, and driving the motor which as soon complications. Of course, the speed what you get through the relay operation is less and it is limited and also accept the noise that is why the relay is used.

So, this is a temperature controller using a relay. For example, if it is a oven temperature to be controlled, then all that I do is that I will put the sensor that is this inside this that is all physically I put it here. So, that the temperature of this is sensed and then accordingly is also suppose, the temperature is high then output goes in this point output goes minus, once minus goes they do not conduct and then this current flowing through that will be stop and this opens up. And you may wonder, what is this I done here you know put one diode here? So, do not put this diode, then what happens is invariably fine, that you know this transistor goes bad whenever, I switch off then the transistor goes bad that save that only we added at this diode here across this coil.

Actually, if you closely look at what is happening at the coil, the coil actually actually have a wire and oven on this and the coil as a appreciable resistance so actually, if you see in the actual this thing, if I draw the equals to the relay it is nothing but, a resistance on that coil equals and then we have this diode connected here. So, when you switch on the when you switch on the transistor, when you get plus 15 then current flows here, the base current beta time that current flows here. So, current flows through this and as the current flows through this, then the coil the current magnetic field setup in the coil.

And then eventually the current that is finally, flowing through this limited by the resistance for example, if it is a if it is a 100 ohm resistance, assume this a 100 ohm resistance. Then, the current that receives take this is the 100 ohm's then maximum current that it can go through this will be 15 volt divided by 100 that is 150 milliamps.

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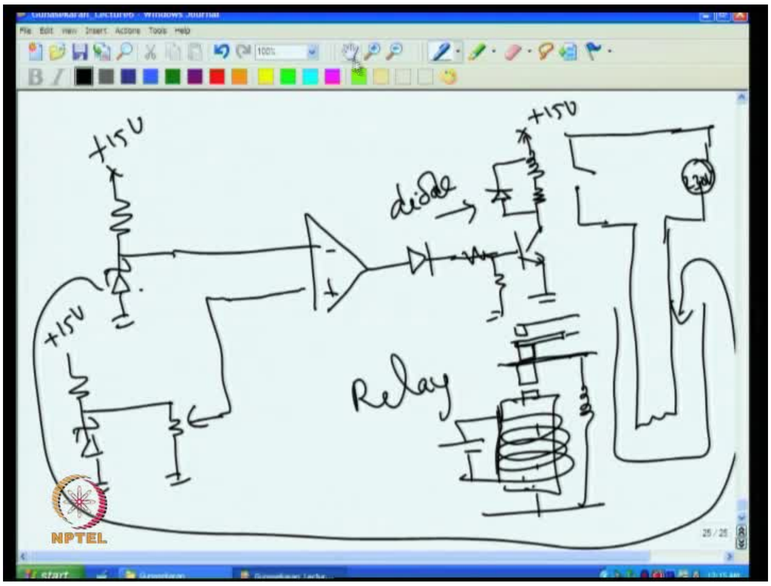

So, what may happen, if the current that can flow may be will be 150 milli ampere current will be because a taken this coil is 100 ohm's. So, once you switch on, the current will slowly raise, how much time raise because the inductor current raises only by this, I is equal to v by L into t probably, it will take few millisecond between upon inductance value to reach the 150 milli ampere. Then current cannot go 150 more than 150 milli ampere because once 150 milli ampere flows, that you get 15 volt all 15 volt across this and there is no more volt to drive the inductor.

So, at 150 milli ampere current will searched it and that time the definitely the coil would have pulled the contacts so, no problem. But then the problem comes I apply the voltage and 150 milli ampere flows and the contact is closed and the heater is on, that is fine. Then the temperature goes up, once the temperature goes more than this set value output takes minus once minus 15 comes, then the base voltage is removed and the transistor involve cannot conduct any more. If the resistance are not conducting then the switch off the transistor, once you switch off the transistor, at that time you know before switching off 150 milli ampere current was flowing through this coil. If if you know at this point if I cut then whatever, current that is coming from here that not able to find the part here.

And, if I do not put this diode, to do not put this diode then what happens, that you are trying to stop the current through the inductor appropriately, because chances switches off. For example, in one micro second time it takes to switch off then, under milli after current is flowing in this stopped in one micro second time.

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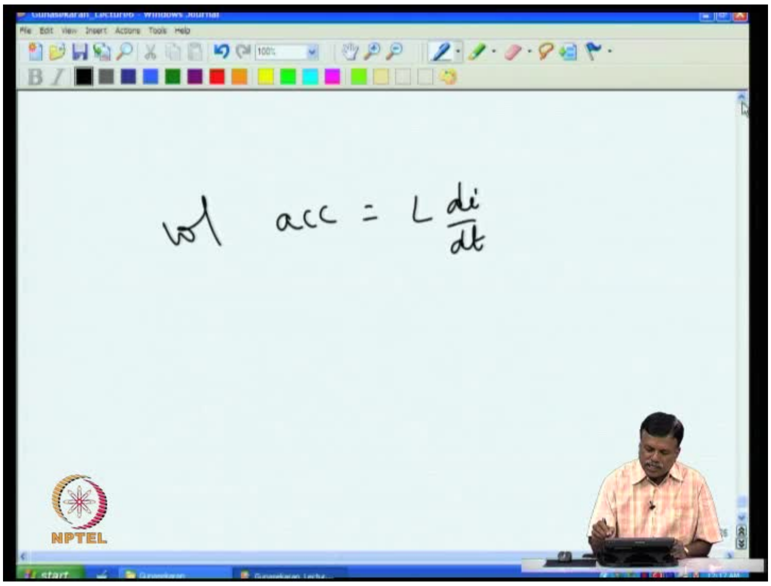

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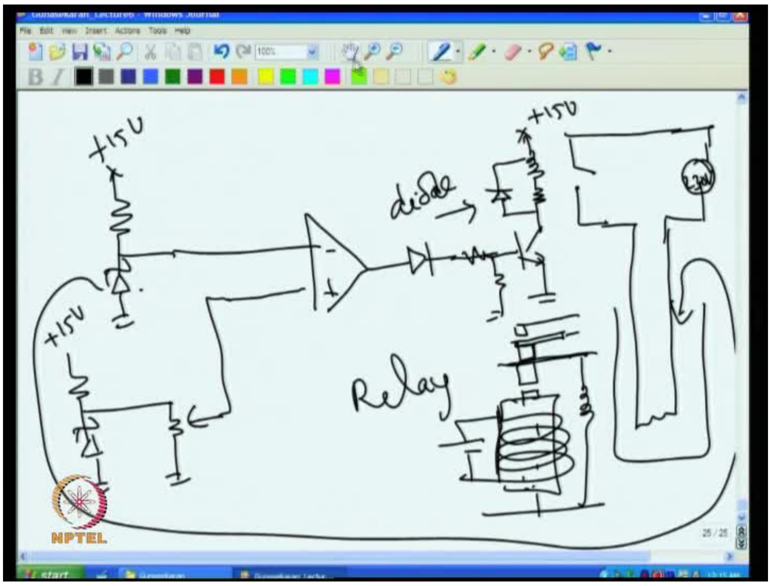

So, the current flowing through the inductor you are trying to stop in one micro second time. So, the voltage developed across the inductor is the l into d i by d t is the voltage developing across the inductor. So, see this little detail, so voltage across the inductor goes to l into d i by d t that is the voltage. That means, if I try to stop if I try to, if I switch off the if I switch off the if I switch off the transistor, then the current stopped in one micro second, that 150 milli ampere current stopped in one micro second, that means and your d i is d i is 150 milli ampere and the time was taken is one micro second.

So, if then, if you take this l d i by d t then, voltage in this on the are the inductor will be very huge, because stopping current through inductor appropriately that is in one micro second 150 milli ampere current is stop. So, if I take for example, l as one henry then, 150 milli ampere is stopped, then d i is 150, time is 1 micro second. Then you will get 150 1000 volt developing across the inductor that is very high. So, what will happen, if you take try to stop the volt at this going to varies very high value then the transistor cannot this on that voltage the transistors goes bad.

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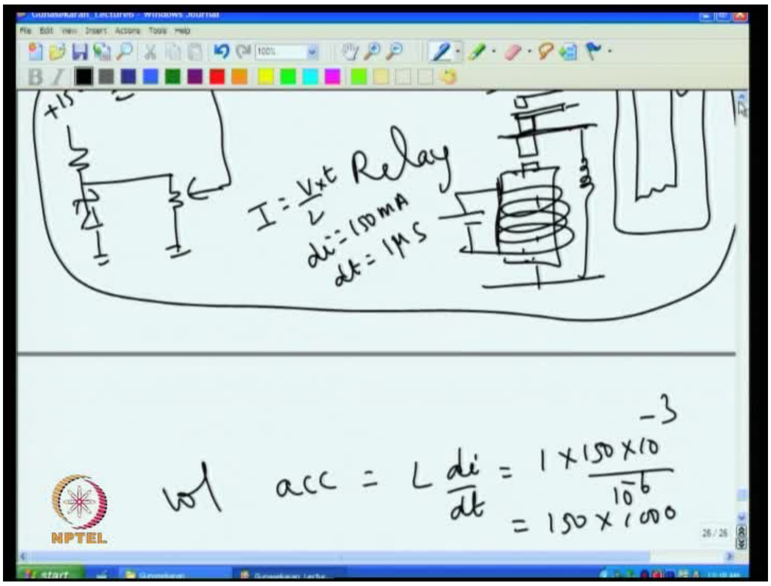

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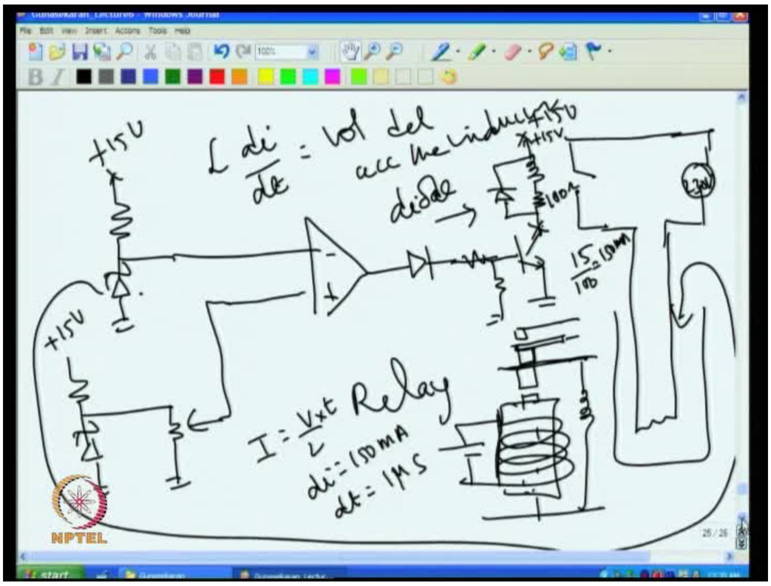

So, it should not the lesson is that you should not stop the current that is flowing through the inductor appropriately. But eventually we any way we have to switch off then only the heater will go off to solve this problem only we added this diode. So, now once you switch off whatever, current that is coming from here, that actually, the voltage is ohms the current stops here voltage trying to rise but, then once the voltage because we know that this stop is switching at plus 15 volt at plus 15 volt, if this is goes switching at plus 15 volt, if this course when this stops the current flowing through this through this start reducing and voltage at this point start raising, because of l d i by d t and then once it was more than 15 this started conducting.

So, this is 15 this can only above go only up to 15.6 that means, the voltage at this point cannot go for 15.6 and then transistor will not go because this is made to work much as 15 volt. So, the whatever, what is happening is current whatever coming here it goes like this like this. And after a few circulations it will dissipated as the heat in this resistance and all the energy stored in inductor dissipated but, voltage at this point never goes more than 15.6. So, the transistor destroyed that is protected. So, you will see this kind of diode protection at many places wherever inductor is there, to dissipate the energy store in inductor this is used however, this transistor would have gone bad so, this is must to use a inductor here.

So, using a relay also we can make on off controller. Now, there are very many base we can do for example, if the heater voltage is we had shown two things how to control the heater. One is through relay that is one case you know, if I show the one may the output so in one case I have done was the comparator output was there. So, I had given through dollingten pair, plus 26 and the second circuit I had shown that I have this and diode then I switched on off, I have put this, I put a relay and then this this plus 15 is second way of doing.

There is another way of doing for example; I can also should like this I can put the heater here or even I can go for I can put this, you can give even 100 volt. Of course, I had selected transistor for 100 volt so, this will be a heater in this case or even I can do it in another way (No audio from: 48:24 to 48:40). I can do in a see this itself I can modify is for very high current I can do this this I can give it to the comparator here. So, I see there are different ways of switching, you know this is actually direct drive this is direct drive. This is through relay at the actual power is going through the conduct here and this is actually, when the voltage is when the voltage goes high and this transistor conduct and full heater voltage operate.

Because here it can go more than 15 volt whereas, in this case, the heater voltage will not go more than 15 volt, because this can go only up to 15 and this will be 14.4 13.8 so roughly around 13 14 volt you can get on the heater not more than that. So, the this is not possible so, compare this and this, here heater voltage can be very high, here this case the heater voltage can be even higher or a c as well as d c this is only d c but, can go higher voltage. Whereas, if I want very high power I can do this, that is I can put this, put the diode to block the negative so I can use the dolington with grounded to one. So, this can be even higher voltage high power.

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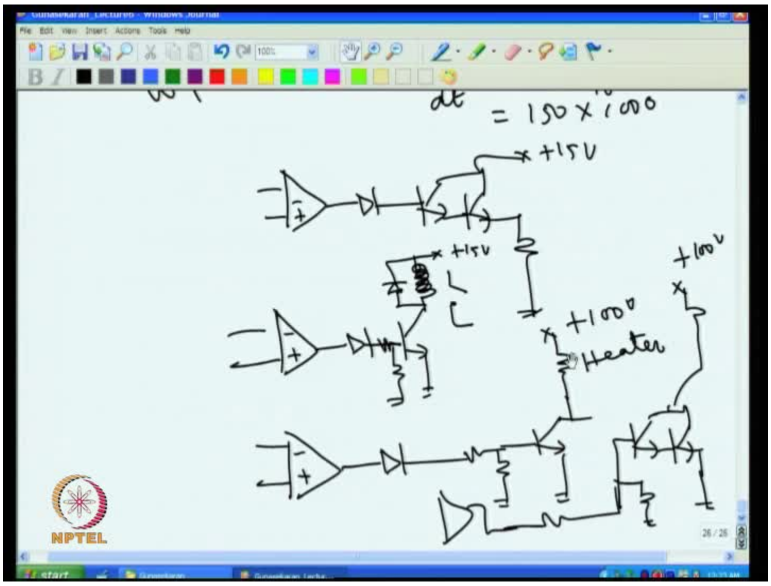

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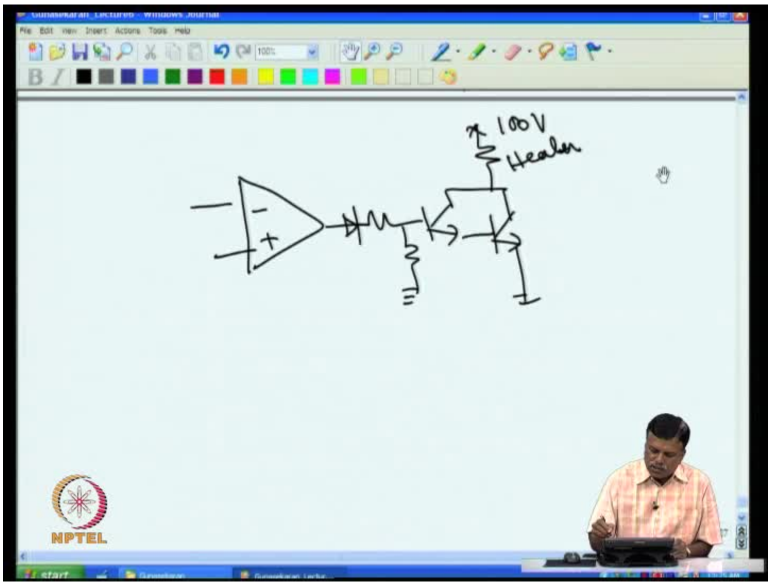

So, I can use this so, the you can do it in very many different ways, depending upon your application and the heater requirement. In this case, this is the heater, it can be even 5 ampere, because we have put a dolington and if it in high power it can go you can have a transistor up to 1000 volt. There is no form it can apply voltage of course,, you cannot use a c voltage in this case, if it is a c voltage it is not difficult you; can rectify into d c and give this. But then one more thing you have to watch here that in all this we reduced this resistance these two resistors to switch on and off the transistors, which I not explain.

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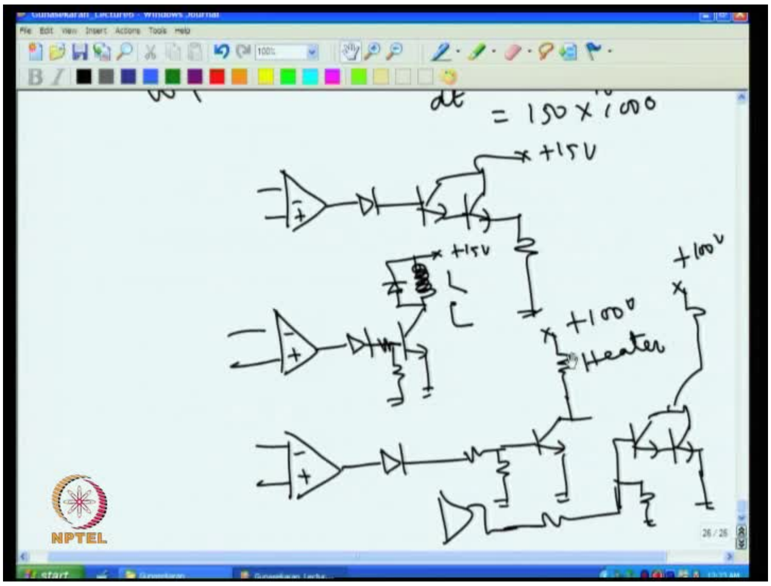

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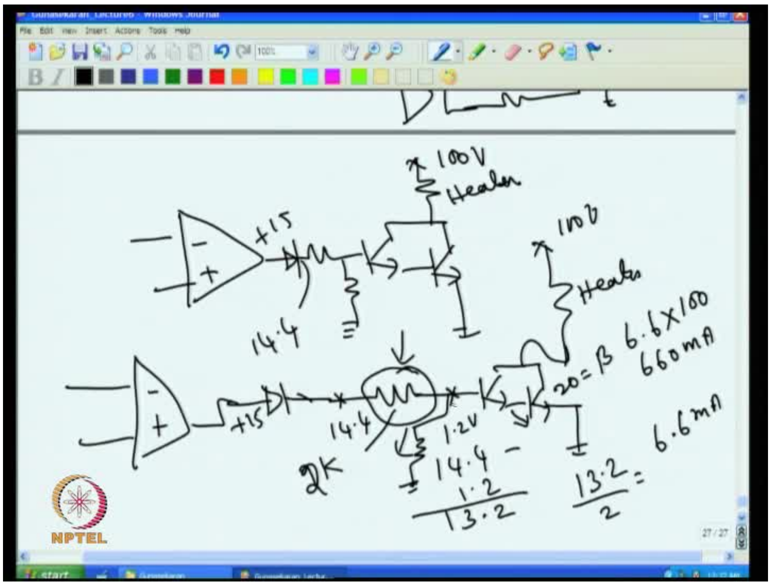

So, if I go back and see, why I used this for example, even here (here) I have reduced this resistors similarly, if you see this, here I reduced this resistors. So, all is pressure reduced, this is to make it on off on off actually to know. For example, why did is use this, because I want to make this transistor to go on so, at that time you know the voltage after here is plus 15, if it is 15, I know 14.4 will come. So, if I want switch on definitely, I should not connect like this you know the output whatever, is coming that you have the diode.

Then I do not put this diode, I do this. For example, I do this and connect the heater here say this is 100 volt, if I do this example this is your comparator. If I do this (this) transistor will go bad, should not do like this, that you are not any resistance here. Here you see, we compare this and this, we are put a series resistance and then also put one resistance to ground. Here you have not done this, if I do like this; actually, this transistor goes bad. Now, you may wonder why it is happening, this because for example, if I if this tends to plus 15, you know that this will go to 14.4 volt, if this goes to 14.4 volt and then this has to go to 13.8 and this is already grounded.

So, this point is ground and it this is heating at 13.8, if we apply 13.8 volt between base and every emitter, this is the base and emitter volt 13.8, then the transistor forward current will be so high and the transistor will get destroyed. Because above 0.6 normally, do not see because any base into voltage 0.7 is a itself so huge. So, you do not see normally more than 0.7 or 0.8, across any transistor the forward condition in a between base and emitter. So, you cannot apply 13. That will definitely destroy this. That is why we have to add, you know we do not use this we do not do this so if you want to try, then put a dolington; no problem, connect this connect this to ground, then you drop the voltage across this resistor that is what you have to do.

So, this resistance is a must we have to have this resistance, without this resistance without this resistance, you should not connect the output directly to that transistor. If you connect, the transistor goes bad. Now, what happens, because of this resistance, if I connect this resistance now this point will come to 14.4, and you know that this cannot be more than 0.6? So, voltage across this only for 0.6, voltage for 0.6 that means this will shift at 1.2 volt maximum not more than that automatically it will come. So, the difference across this, if you see this, voltage across this, is 14.4 minus 1.2 that is actually, 13.2.

So, the extra 13.2 volt will drop across this either on the current that is flowing here voltage across this and then the this volt automatically come to 0.2. Now, for example, if I put here a say say, because this 13.2 volt so, if put is 1 K then, or 2.2 K assume that I put 2 K, then the current through this will be 13.2 volt, 13.2 volt divided by 2 K that will be, 6.6 milli amps. So, you will find if I put here 2 K, you will get 6.6 milli ampere going here and you find this point sitting at 1.2 volt because this switching at zero, this is sitting 1.2, it sitting 14.4 and if you will see that current of 6.6 milli ampere is flowing through this. If I put 1 K, automatically 13.2 milli ampere current will flow. So, depending upon the requirement current requirement I can select this resistance value.

Now, if I select 2 K, then we will find 6.6 milli ampere current is flowing through this. If 6.6 milli ampere flows through this you know this transistor as a h f e. And if it is 100 then, I know that the current here it will be 100 times for the inter current 100 times more than the base current. So, per 6.6 milli ampere current, I know that this current can be as much as 6.6 into 100 milli ampere 100 times. So, that will be 660 milli ampere current will find 660 milli ampere current is flowing here and then that will be multiply again, further by this transistor. This transistor carries a bulk of the huge current, because this will be again at to the beta of this this big transistor, lower beta for example, 3055, if I take the beta is a only 20 smaller transistor have a higher beta that can be even 100.

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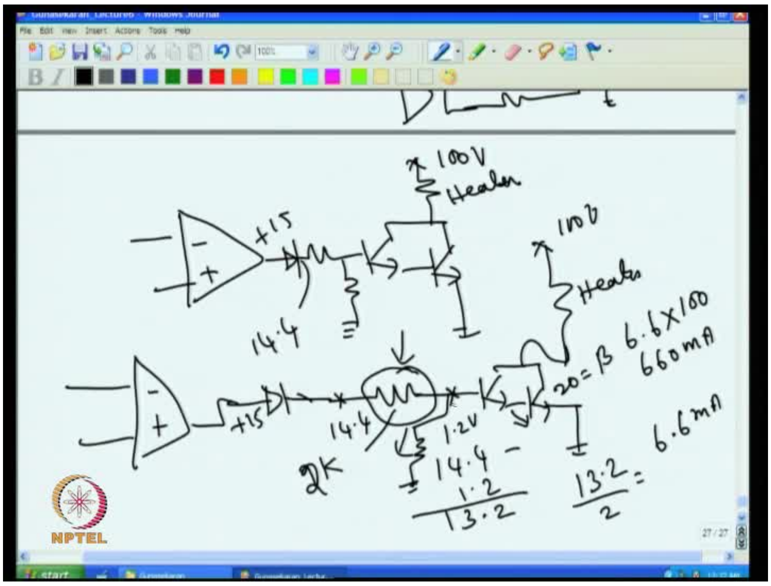

So, this if I take this so if I take this transistor beta as 100 the 20 so I take this as 20 is beta. Then 660 milli ampere multiplied by 20 give me 13 ampere current can go. If 13 ampere current cannot go and limited by the resistance then whatever, current that can flow it will flow. So, up to 13 milli ampere current can go through this, if I use this. So, transistor will not get destroyed, if I put this resistance. So, if I want more current, if I want say 20 ampere current, through this, if I want say 20 ampere current then I should reduce this resistance such that I will get 20 ampere current through this. So, depending upon the current requirement I can select this.

So, the of course,, if if you select lower value then large current can flow, if that much current is not flowing no harm, only thing is effective beta comes down that is all. No issue if you select lower value of course, that lower value than higher current will flow and that must be separate by this op amp. And if that is not able to supply then the voltage will decrease. So, obviously, you should see both no need to drive too much current excessively. So, select this resistor such that suppose, if it is 100 volt and if it is 100 ohm resistance then we need only 1 ampere current through this. If 1 ampere current through this and the beta is 20 then, I know that 50 milli ampere current will require at the base.

So, 50 milli ampere current here will drive 1 ampere current here. Because beta is 20, if 50 milli ampere current here then, if beta is 100 then I will have a 0.5 milli ampere current only I required here. So, to get 0.5 milli ampere and I need 13 volt drop, then I need to have 26 K say 27 K resistance will be enough. So, that is how this resistance value to be selected. Of course, we need one more resistance say in a real case that is one resistance we put here to ground. This is you know when it is going off that is the capacitor here the storage charge is there and that we leaked through this so that depends upon how fast you want this resistance selection of this we will discuss, in the next class.