**Op-Amp Practical Applications: Design, Simulation and Implementation**
**Prof. Hardik Jeetendra Pandya**
**Department of Electronic Systems Engineering**
**Indian Institute of Science, Bangalore**

**Lecture - 27**
**Experiment on Temeperature Controlled Circuit using Op-Amp as ON-OFF Controller and Proportional Controller**

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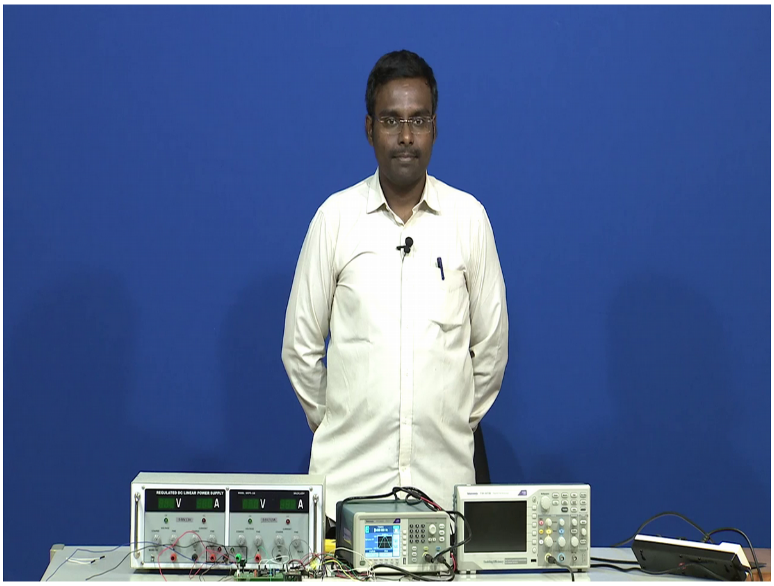

Welcome to the module. So, in last module we have seen different blocks of closed loop control system. So, we have discussed about error detector and what is a functionality of an error detector and we also seen how to implement an error detector using operational amplifier, and we also discussed about signal conditioning unit and the sensor that we are using on the plant.

Now, in today’s class we will extend our other modules that are you know you know used in our closed loop control system.

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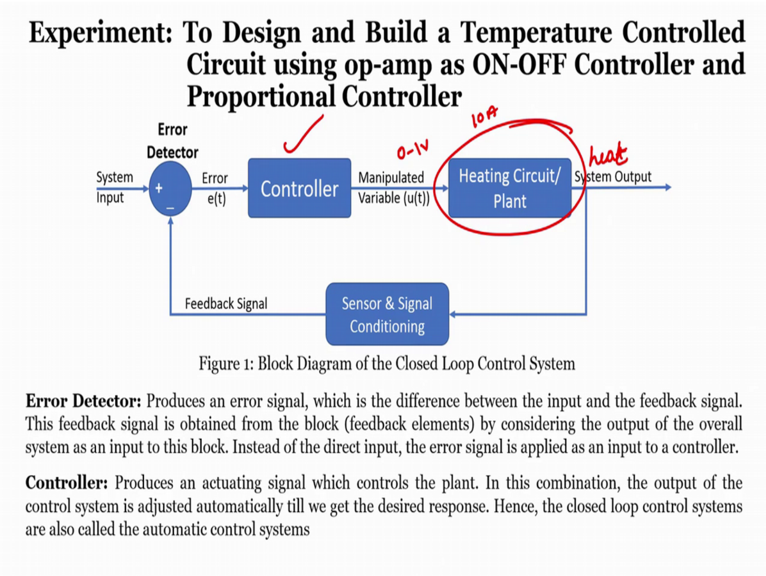


So, what we will do; you know is that we will discuss about heating circuit, heating circuit on the plant. And we will discuss about different type of controllers that we are planning to or we are going to show demonstration on you know using an operational amplifier, their working. So, specially we will be discussing about on-off controller, proportional controller and if time permits we will look into the proportional and integral controller.

Now, in order to understand in order to understand about the functionality of this controller and in order to understand about the implementation of these controllers using operational amplifier, one thing is important that how exactly this work, what is a role of these type of controllers in the system.

So, as we have already seen in the theoretical session their importance, their working. We will also briefly discuss about how exactly these functions and we will see the implementation of this control as using an operational amplifier, right. Before going back to the controller what we do is that we will discuss on how exactly we are using a plant circuit.

See the plant circuit need not be the same circuit that what we are using in this demonstration or in this experiment. It can be of you know any other plant 2. So, since our intension was to show demonstration, we have buildup our own plant circuit using a transistor and we are generating a temperature on the transistor. How exactly the temperature is being generated on the transistor that we will discuss and after understanding about the input parameter or input voltage or input value that is required for the heating circuit to heat. Or since we are saying this particular plant is heating circuit, what is the requirement in order to heat the plant and what is a range that we have to give as an input signal as an input to the heating system as a result it heat the system.

So, in order to understand that first we have to understand how exactly the circuit looks like.

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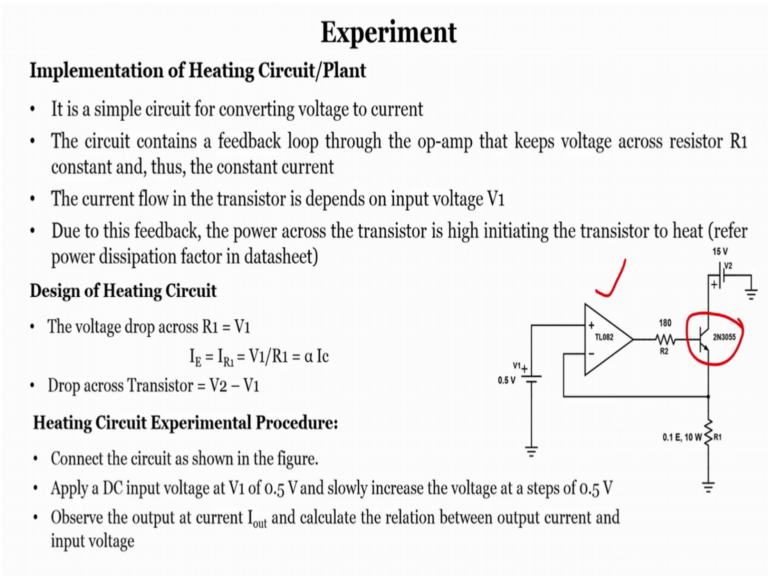


Now, when we look into our plant circuit. So this is the plant circuit that we are using in this module. So, basically what we are using is, we are using on operational amplifier. This is a major and important thing one has to be understand where we will be; understanding about the role of an op-amp when interface when connected in a negative feedback fashion to our transistor here and we are using a transistor.

So, this transistor will generate a heat that is because of the op-amp how exactly. So, when we recall what we have discussed in our previous module similar to that where we are using voltage controlled current source. This is also similar to that voltage control current circuit itself.

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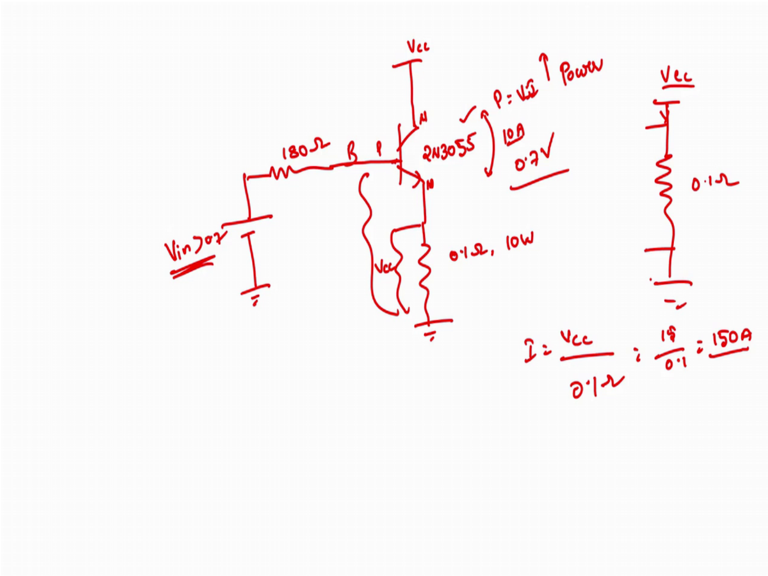


So, just to understand just to realize, if you recall we are taking a transistor circuit and here we have a resistance, and we are saying the resistance values 0.1 ohm and watt is this is very much important. The watt is very much important.

Here, it is connected to supply V cc. So, as you know this is an NPN transistor NPN and this is 2N3055. Why consider 2N3055? Because 2N3055 is a power transistor. Since in this application you have to generate heat, one important parameter is power, right. When you look into the data sheet, you will understand the amount of power it is dissipated like the amount of heat it is dissipated entirely depends upon power dissipation factor which you can get the value in our datasheet and that means, higher the power, higher withstand capability of your transistor.

Since, it has to generate and heat it has to withstand for somewhere around more than 5 amps of current 3 to 5 amps of current. It depends upon what is input voltage that you are applying to the system in this case. So, no matter what the power is an important factor. So, if our transistor has to be withstand for such a higher current. So that is the reason we have chosen 2N3055 which is a power transistor and forget about how exactly you know it heats first. We will understand the working of this particular circuit.

Now, if you clearly see the difference between the previous circuit and this circuit, we do not have this particular portion we have taken only this portion. We will also take R2 resistor which is of 180 ohms. So, this resistor is just simply 180 ohm. Resistor is simply a current limiting resistor. So, here we are applying some voltage.

Now, what happens in this case if I say this is V in? If I say this is Vin, what happens it looks similar to that of your transistor operating in a switch mode. Isn't it? So, since the voltage across base and emitter is greater than 0, so basically it should be greater than 0.7 that you can look into the data sheet what is your V, sorry be voltage drop. So, if applying more than that particular voltage, your transistor will be operated in on condition in a saturation mode, right.

So, since it is operated in a saturation mode, it is nothing but a simple switch, right. So, I can rewrite the circuit in this fashion since I am applying voltage greater than 0.7. Isn't it? This will be V cc this is 0.1 ohm. So, what happens when I observe the voltage drop? The voltage drop across this resistor is nothing but your V cc and the current flow if I see. So, I is equal to V by R V cc divided by since I am using 0.1 ohm. So, if I say 15 ohms is my current and 0.1 ohm, it will be 150 amps of current. Actually speaking it has to pass 150 amps of current, but does your transistor withstand such a current? No, if you look into the data sheet 2N3055 can withstand only a current of maximum 10 amps.

Now,, how exactly it is heating? The reason why it is heating because one important factor is power so that is nothing but what is a voltage drop across? Voltage drop across your transistor and what your current flow is. Now, when you calculate the voltage drop since it is in a saturation mode. And we have already known that when the transistor is in a switch mode, the voltage drop across your collector and emitter is nothing but your 0.7 volts. That also you can refer in the data sheet approximately somewhere around 0.7 volt.

So, in this case only because of your current, that means 150 into 0.7 because of your current this may heat, but when you understand when you see the voltage drop across this point, this is simply V cc right, but how do I how do I control the current. So, in this case you do not have any option even though whatever the voltage that are applying above 0.7, it does not matter. The transistor will be always in the switch on condition. So, what voltage drop across is V cc will be always the voltage drop across is resistor will be always V cc. So, you cannot control the temperature or you cannot control the flow of current or voltage drop across this particular circuit.

So, we require, so since our intension was to control the plant should have an ability to change, you know the input to change the output parameter based upon the input parameters. So, in this case output is temperature and input is some either current or voltage. So, if you can do such kind of a mechanism to system right, even we can make use of the same system to control to control as per our requirement. So, how do we do that?

So, in this case it is not possible. So, that is a reason we are using another operation amplifier which is tl 082. We can go with any other op-amp.

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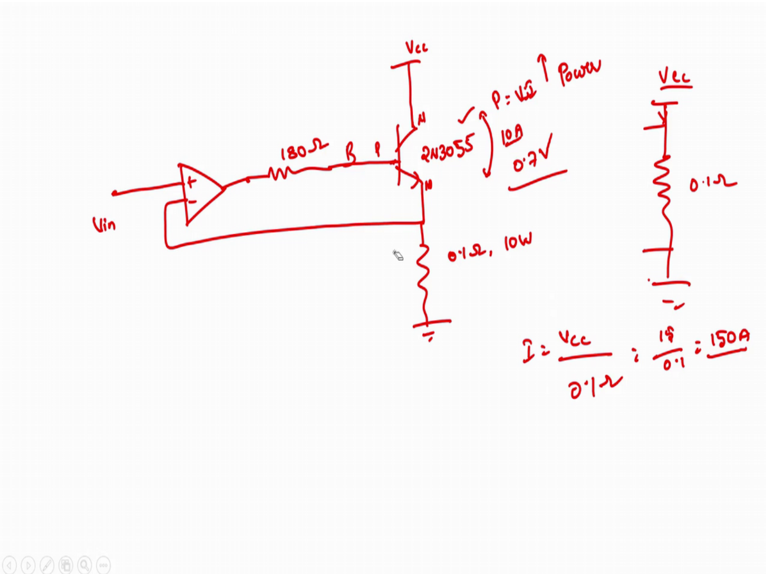


So, what we are doing is rather than connecting this voltage, we are connecting here. Now, the complete working will change. How?

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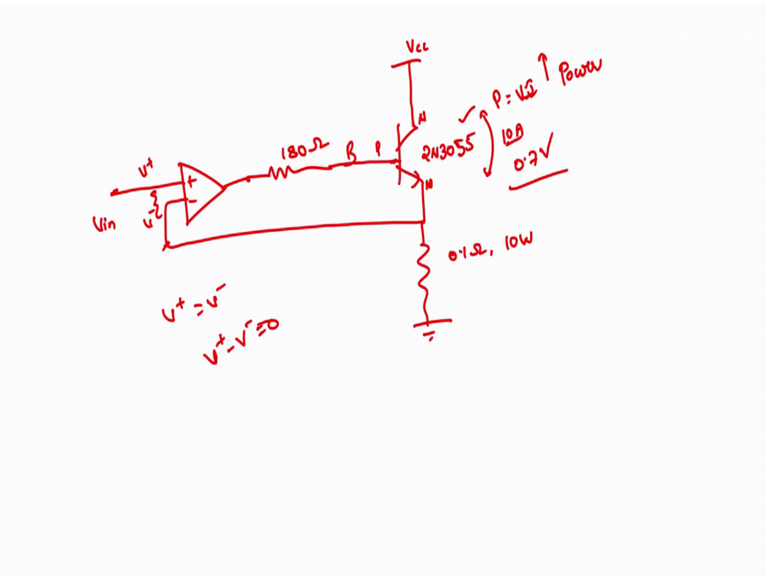


If you recall, if you remember about operational amplifier basics, one thing is clear that say two golden rules if you remember. One is virtual ground concept. What does it mean? What are the input voltage that you applied? The positive that the same input voltage will be even at your negative. That means, the voltage drop, the voltage drop across the positive terminal and the negative terminal will always be same. So, if I say this is V plus and this is YV minus V plus is always equal to V minus or V plus minus V minus is equal to 0. So, this is the golden rule. Another important thing is very high input impedance, no control input impedance system that we already know.

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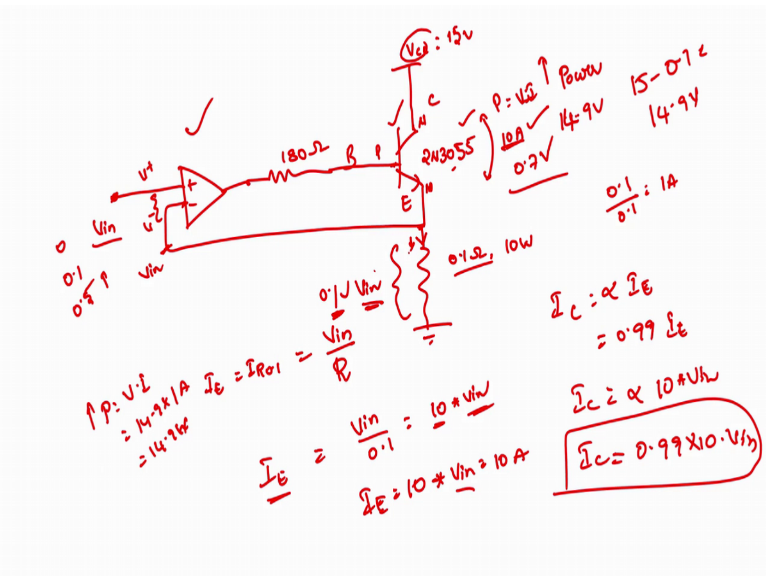

So, now in this case what will happen in a previous case when there is no when there is no this particular circuit, we have seen that the current flow here entirely depends upon what is a resistance that we are connected here and what is a voltage source and the voltage drop across is V cc, but in this case it will not be the same. The reason is we have connected the negative terminal of an op-amp to the resisted point here which is nothing but the emitter, right. This is base, this is collector and this is emitter, emitter point.

So, what happens since this is V in as per the property of your op-amp, this also tries to maintain as V in. As a result it forces the voltage drop across the resisted to be of V in, right. So, that means this is completely in a forced condition. The previous case is it is not a force. It is free. Remaining we do not have any influence of input parameter on the voltage drop across the resistor, but in this case because of the operation amplifier, it forces the drop across the resistor to be same as what is a input voltage that we are applying here.

So, as a result when we calculate the current flow through this particular resistor, which is nothing but your IE are which is nothing but the current flow through point one of resistor. It is nothing but voltage drop across your resistor divided by resistance, right. So, what is voltage drop V in? So, V in divided by 0.1 which is nothing but 10 times of your V in.

Now, what range of V in that we have to use that is also very much important. Now, if we understand, so if we understand the collector current in this case when we see the collector current, sorry the emitter current in this case entirely depends upon the input voltage and with a gain of 10.

So, as if you recall the 2N3055, when you look into the 2N3055 data sheet, one thing we can clear it what is a maximum current it can it can operate. So, when you will see that it is somewhere around 10 amps. So since it can operate only at 10 amps of current more than that it will damage. So, the IE maximum value should be always 10. So, in order to achieve that the maximum range of V in should be always 1,so that we will get the IE current as 10 amps.

Now, if I want to understand the relation between if want to understand relation between V in V in and IE, so since we know IE in this case which depend upon V in, you can also convert into IC. As we know that IE is alpha times of IE IC where sorry IC is alpha times of IE where alpha is nothing but somewhere around 0.99 into IE, right. So, IC value will be alpha times of 10 into V in. So, if I know V in 0.99 into 10 into V in is the relation between IC and V in, but our intension was not about the relation between V in and IC, you should understand how it is responsible to generate heat on the transistor, right. So, as we have seen the responsible parameter in order to generate heat is power.

Now, in this case what happens because of when you apply input as 0 volt, V in will be 0. So, no current will flow through that. So, the transistor will be always points and volts. So, since no current, no voltage, now what if apply 0.1 as V in. Since this is 0.1, this will also be 0.1. If we understand the input voltage, let say V cc is 15 volts and the voltage drop here is 0.1 what about the rest of the voltage drop? If I do not have the operational amplifier, we can see that the drop across transistor is of 0.1 volts and out of 15 remaining will be completely across your resistor which is 14.3, but in this case if we see in this case if we see the voltage drop across the resistor is point 1 volts. So, that means 15 minus 0.1 is nothing but 14.9 volts.

So, what is happening to 14.9 volts as we know energy in either we created or destroyed. So, because of that out of 15, we got only 0.1 volt here. So, remaining 14.9 volts will be the drop across the transistor and because of this 0.1 volt what will be the current flow? So, when we calculate it is nothing but V by R 0.1 divided by 0.1 which is 1 amp. When we calculate the power dissipation fact power across the across the transistor, it is nothing but V into I. So, voltage drop is 14.9 into I is 1 amp.

So, that means some around 14.9 watts is being generated is utilized by your 2N3055. When you are look into the data sheet, it gives you the power dissipation factor which gives you the relation between the watt is and the temperature generation, right. So, based upon that V in we can get a relation between the power and the degree.

Now, if I increase the voltage to 0.5, so one thing is clear that if the power is higher power is higher, as a result of the temperature generated on top of transistor will also be higher. Now, in this case the power is higher, sorry in this case when increase the voltage, one thing is clear that we may understand since I am increasing the voltage, the current flow will always decrease, right..

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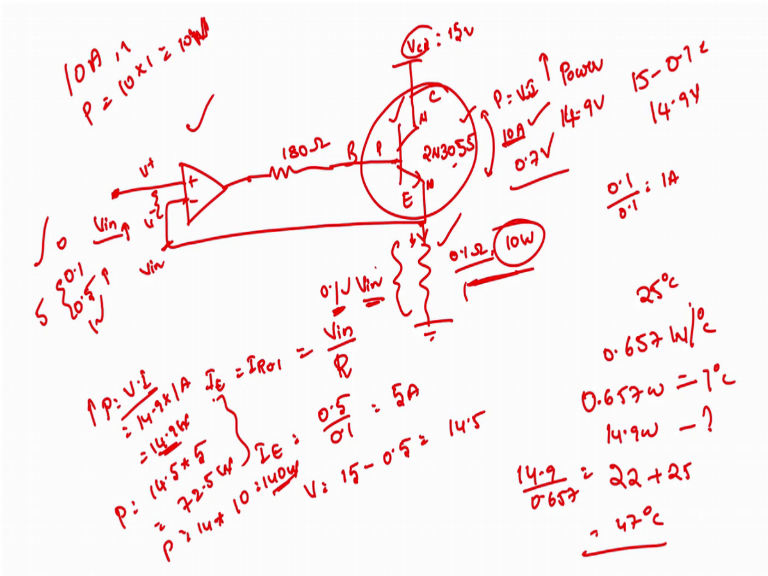


So, consider when we calculate IE is equal to 0.5 divided by 0.1 which is 5 amp, sorry the current will be always higher, but the voltage drop will be decreased, but when you see the ratio the amount of current flow is completely higher when compared to the voltage drop across your transistor and as a result the power will be even higher. So, that is why increasing the voltage increases the current flow. Even though the voltage drop across a transistor is decreasing, the multiplication factor of your current and voltage will be always higher the power will be always higher.

So, when we calculate the power at this point, so when we see the voltage drop across collector and emitter, it is 15 minus 0.5 which is 14.5. So, when we see the power 15, sorry 14.5 into 5 amps, so it is somewhere around 72.5 watts approximately, right 145. So, which means that when you see increase of 5 times, it is increasing drastically almost equal to the 5 times even though the voltage drop across is increasing. Imagine if it is of 1 volt, so here the voltage drop will be 14 and the current will be 10 140 watts.

So, this one thing it is clear that as we keep on increasing the voltage, the current flow through the system is increasing even though the voltage drop across the transistor is lower compared to when it is in a low voltage low voltage input value, but the fraction of the multiplication, fraction of voltage with and current which is nothing but the power is really higher, and because of that this 2N3055 will start heating. So, in order to understand how much voltage, how much degree centigrade it will heat you have to understand about the power a dissipation factor which you can get from data sheet.

So, when we look into the power dissipation factor, we will open just will see we will see how can we look into the power dissipation factor. Let me open the data sheet.

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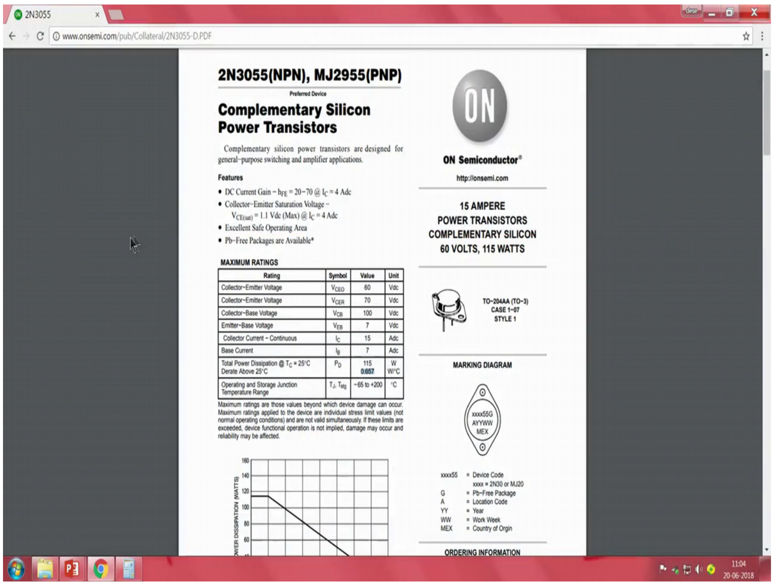


So, when we see here it is clear that watt per degree centigrade it is 0.657. So, it is 0.657; 0.657 watt per degree centigrade, right. That means, 0.657 watts is responsible for 1 degree.

Now, we have a wattage of 14.9 watts. So, how many degrees it will be? It will be 14.9 divided by 0.657. When we do, we can understand the value. So, let me calculate 14.9 divided by 0.657. So, approximately 22 degree and when we see it is starting from 24, see this value somewhere around 25 degree.

Now, 22 plus 25, it will be somewhere around 47 degrees integral, right. So, because of 0.1 and is you know that the temperature it is an energy it changes with respect to the time. So, if we keep on applying the same voltage for a particular duration, if the temperature will always H, but the factor it which changes you will be always smaller when compared to the fraction at which changes when the input voltage is higher right, but it starts heating right if you are apply higher current. So, the higher watt is as a result higher current flow through that higher current flow higher watt is higher power dissipation, higher power dissipation and higher temperature with a lesser time, right and when we also see looking to the data sheet of 2N3055, the maximum operating temperature of 2N3055 is 200 degree centigrade.

So, if it is more than 200 degree centigrade, there are chances of damaging the circuit. So, in order to not to damage, what we can do is that even in normal day today life application which we see 2N3055 at power transistor, they will be always kept under you know heat sinks. The purpose of heat sink is if the heat is higher, it will dissipate across, it will convict to the air. As a result the average temperature will be smaller. So, it can operate for higher range. So, that is whole idea. That is why you will always keep on the heat sinks. So, when we look into circuit here, this is all 2N3055.

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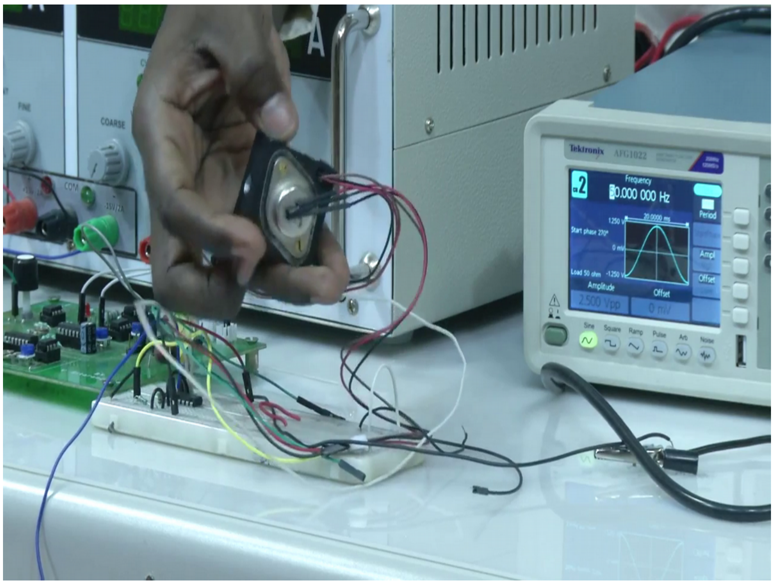

So, this is our 2N3055 and on top of heat we have sticked in 35 which is a temperature sensor which we have already discussed in the previous session, right and this is a heat sink, the black color one whatever you say heat sink. So, if it is heating automatically dissipate to air, it will convection, it happen convection will take place and these are the connections and this is being connected to the board. This is the board, right.

So, we will come back to the board later on. Now, we will see other part. So, what we have seen we understood about how exactly and what range of input voltage is being applied to the input plant, such that it will not damage of plant. So, that means we require the input voltage maximum of 1 volt, not more than that right.

So, since when we look into the system, the manipulated variable value will be 1 volt. So, this 1 volt is not generic for all the plants. This is particular to this plant. If you change the plant, if you know what range it can operate and what current like what is a maximum current with can with stand, so based upon that you can tune these parameters, you can you can vary the output voltage. How can we do? It is by look by changing the parameters of a controller.

So, in order to understand that we look into the controller 2; so now we will see the same working in a multi sin. So, I will create a new circuit.

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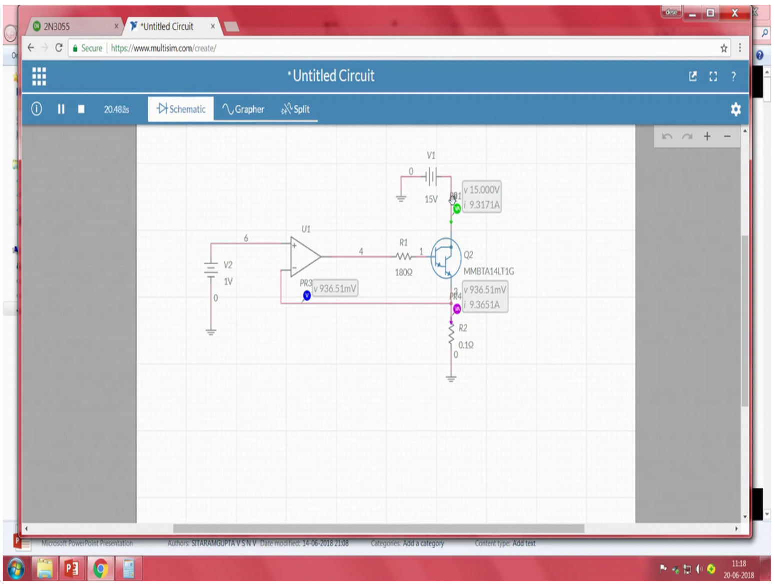


Since, it is not first term here using multi sin I do not want to explain anything. So, we will take op-amp and we need a transistor. So, I will go with NPN transistor, ok. So, this is 100 amp.

So, I will take one more resistor and I will take one more resistor here. Let me rotate connecting and this is to be connected through the ground. We are as I need a power supply. I will go to the power supply DC voltage connect it here. So, since we are discussing about 15 volts, let me change to 15 and this is 180 ohms. What is this value? This is 0.1.

So, the watt is that we have taken 1s higher which is of 10 values now. Let me take this power transistor which is some connecting it here, make it two, connecting it here and then, this should be connected to a voltage source ground. So, the maximum voltage is 1 volt. Now, when we switch on, we can see the voltage drop. One thing is clear that at this particular terminal, so the voltage is 999.99 millivolt almost equal to 1. That means, both are at same voltage. So, since this is connected the same point, I do not know why it is not showing. This should be also at the same value. Let me close and take a voltage. Let me run, ok. See we can see 999.99, that means the voltage drop across is resistor is also 999.99.

Now, what will be the current? So, since for simulation purpose I have used 10 1 divided by 10.11, right of 0.1 approximately 100 million. So, if I see the current flow here, the IC and as we know that IC and IE always close and alpha times is a relation and alpha is also 0.99, it is also close to 0.1 amps right.

Now, what I told you is, so this is 15 volts what we apply and this is 1 volt. What about the rest of the voltage? So, the voltage drop, so I would we character when you apply KCL KVL, this is 15, this is 1. So, the voltage drop across will be 14, right. As a result the complete voltage drop will be at this point Now, if I keep on change if I decrease the input value, even the voltage drop across will always decrease, the current flow will always increase, right because it is divided by when you see sorry the current will be always decreasing, right 19.

Now, what if I change the resistance value? So, we will go back to the 0.1 ohm resistance. Let me see start from 0.1 volt, right 0.1. What I will do is that I will take voltage and current and I will keep it here. So, we can see both the voltage and current now. So, this is showing. So, 0.1 volt is input we applied; so 99.99 to almost equal to 0.1 volt. So, the current is 1000 milli amps meaning 1 amp of current, right 0.1 by 0.11 amp. I am increasing point, I will say 0.2 right. See 2 amps of current 0.55 amps of current see the voltage drop. So, this is also somewhere around 0.54, 99.98 is almost equal to 0.5 volts. 15 volt is input applied 15 minus 0.5 is 14.5 is a voltage drop across collector and emitter of the transistor.

So, this current and the voltage drop across is responsible to generate heat. Since it is a simulation, we cannot see the heat. We can only understand about what is a current flow, what is the voltage drop. So, based upon the data sheet, based upon the parameter, the relation between the temperature and the watt is we have to calculate what will be the power, what will be the temperature on top of the transistor.

Now, I will change it to 1, right. When I change it to 1, the value is 936 milli approximately equal to let say 0.9 volts 0.93. So, it is close to 1 volt. This is 1 volt; this is

15. So, because of that we can see 10 amps. Approximately of 10 amps of current is flowing through that, right.

So, this way we can understand how exactly how much to be applied, so that you know with plant will always with will be in a safe zone. So, in this case one thing is clear that the operating range input, voltage range is of 0 to 1 because the input to the system is only voltage. So, this is also called as voltage control current source because voltage is changing based upon the input voltage. The current flow the current flow in the collector is completely changed in. That is why reason it is also called voltage control current source.

Now, what is an importance of having a 10 watt? When we recall what we have seen when we recall our simulation, we have mentioned 10 watt. Why? The reason is the reason is the current flow maximum we are using it 10 amps right, the voltage drop is 1 your transistor should not you know damage your, sorry your resistor should not damage. So, in order to not to damage, it should, the capacity of your resistor should able to you know withstand for such a higher power. So, if you want to calculate the power dissipation, the power it can withstand which is nothing but 10 into 1 which is 10 watt. So, that is the reason we are using 10 watt is resistor point 1 ohm, 10 watt is a resistor. If it is possible, try to go with even 20 watt, so that the withstanding capability you cannot even see any kind of heat on the resistor at all. So, that is the reason we are using 0.1 ohm 10 watt resistor. So, depending upon the operating current and depending upon what is a voltage drop, we have to choose your resistor.

So, if you go with higher resistance value and if you go with 2N3055 with high other than 2N3055 if you have any other transistor with can withstand even higher current, the same plant can be used for higher current application and very fast temperature output applications too right.

So, one thing is clear that the working of op-amp, working of heating circuit and making use of a transistor and op-amp, how we are going to generate a heat and it is clear the input voltage is 0 to 1, such that the current, the maximum current it will be will be at which is 10 amps and because of that it generates heat and that heat is being sensed by a sensor, right.

Now, what we need is an automatic control. We do not need a manual controller meaning in a manual controller a human or some person has to observe what is a what is the heat of the system and based upon that he has to take a call whether to switch on or whether to switch off or whether to change the input voltage, such that it will be maintained and as long as human is involved into the system, it will be always there will be always an error. So, now to avoid it one way is going with automatic controller how can we design it.

If you understand if you understand we have discussed about on-off controller, right. So, if you see on-off controller, the name itself sense you that it will always switch on, switch off, switch on, switch off and more over in a day today life applications if you see the same type of controlling can be seen in refrigerator circuits.

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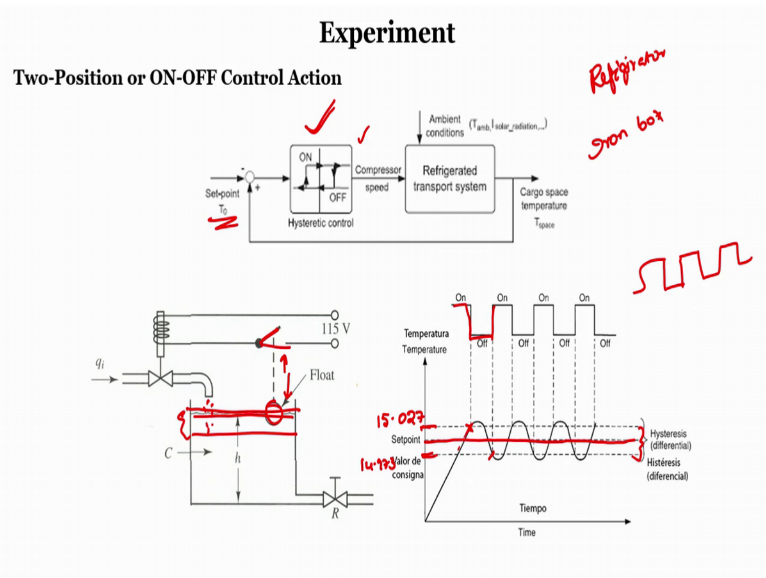


So, if you observe when the temperature is decreased, the refrigerator it will stuck. When the temperature is I mean when the temperature increased based upon the set point. So, in order to maintain to the set point, it will switch on to the refrigerator.

So, once the temperature is below another threshold value, it will switch off. You can even here see you can even here when you are very close to refrigerator, we can see tuck sound kind of thing. It is nothing but the relay switching on and off of your power supply, right and even iron box.

So, when you say automatic iron boxes that has it by metallic strip which access activator. So, when the temperature is, so if you understand about by metallic repeats is made up of two dissimilar metals joined together, so that because of different properties of two different materials, the expansion coefficient will be completely different form different materials. Because of that expansion, it will be causing it two bend to one direction and as a result the switch will be on or off.

So, such kind of you know actuating system can also be used which access on-off controller in such case of applications so to switch on or switch off your system. So, if you want to understand very indeed about circuit, we can see that. So, a mechanical system if you can see that if I have a tank and if this value is connected to the float right, so as long as in you know this particular tank is filling right, till it reaches to particular level right, the float the float will be causing it to move upwards. So, it causes the circuit to break.

As a result no power since it is switch off, there is no power. So, no input to the tank. Now, when that when the level is decreased below this value, so the float will come down. So, gain the circuit will be all. So, it will try to maintain within this particular range. So, in order to even much more understanding about the system, we can see that if I say this is my set point. So, consider this is 50 degree right, in case of on-off controller, you will always upto set 3 thresholds, right.

So, let say this is 55 and this is 45. If your input voltage is keep on increasing and increasing more than your 55 degree centigrade right, so a controller, so this is your higher threshold point, this is your lower threshold point. If the input voltage is greater than higher threshold point, as a result the controller output will be off. Now, again it will switch on only when the input voltage is lower than the lower threshold value. So, it will always fluctuate between these two thresholds. Moreover, when we see the output across the controller, it will be always on for some time depends upon the system parameters off again on off, right.

So, such kind of operation we can see on-off kind of thing in our circuit.

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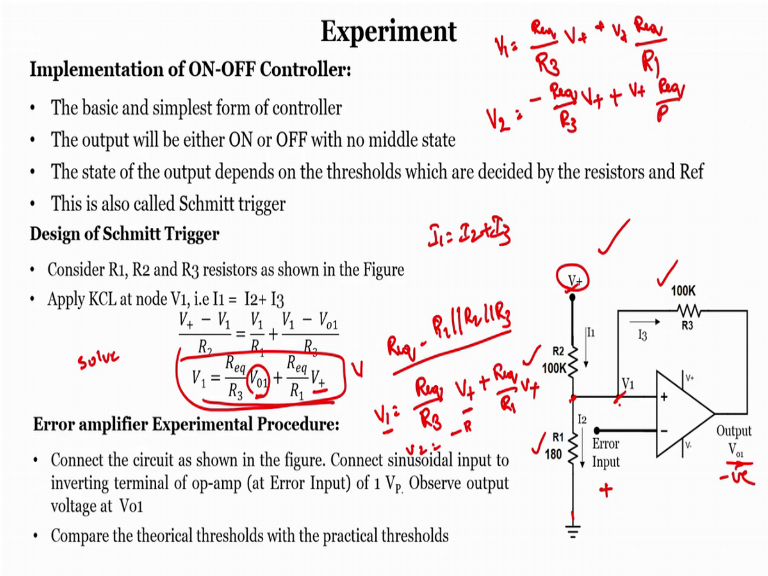


So, how do we design? So, the idea is that how do we design an on-off controller using an operation amplifier, right? So, this is an inverting type inverting type of on-off controller or also called as Schmitt trigger. If we recall we have already discussed about on-off controllers or Schmitt trigger in our previous session. So, it is also similar to that, right.

So, since it is inverting time when the input is positive, we will get a negative right. We will get a negative output that is clear. Now, how do we set off threshold? So, when we recall, we have to set two thresholds. One is here higher threshold point and other one is a lower threshold point. How do we set that will be completely done by choosing this resisters.

So, in order to understand ok, in order to understand how exactly towards, so just simply apply KCL right. We can see that when you apply KCL, one is equal to I2 plus I3, right and if I say this is V1 right, so what is I1? So, we can say V plus minus V1 by I2 which is nothing, but V1 by R1 and I3 is nothing but V1 minus V naught term. In this case, I am saying it has V1 as V naught divided by R3. So, when we calculate if the things, so we can re-write V1 has T equivalent by R3 into Vol plus R equivalent by R1 into V plus, where R equivalent is nothing but R1 parallel to R2 parallel to R3. We can write, we can solve it when we solve this just solve the previous equation.

So, take all V one's to one direction and remainings to the other direction. So, we will get and we are saying R equivalent is nothing but R1 parallel to R2 parallel to R3. When we do that, we will get V1 as R equivalent by R3 into Vo1 and R equivalent by R1 V plus. That means, it is clear that it depends completely upon our V plus and it also depend completely upon Vo1.

Now, how does Vo1 works? So, we know that one if the input voltage if this particular voltage is higher than this value, this will be minus V cc, right. So, if the V caller Schmitt trigger, right; if the input voltage is greater than higher threshold value, it goes to minus V cc and if the input voltages in this case since it is negative, then input voltage is lower than the lower threshold, it goes to plus V cc right. It is a reverse of fear nor inverting time. So, sometimes we will get plus V cc and sometimes we will get minus V cc.

So, if I rewrite this we can rewrite it as R equivalent by R3 into sometimes it is V plus plus R equivalent by R1 into V plus and sometimes it will be this is one threshold. Other threshold will be minus R equivalent by R3 into V plus plus R equivalent by R1 into V plus because this V plus is fixed. So, V plus is nothing but the plus V cc and minus V cc in this case, right. So, Vo1 is nothing but sometimes it will be plus V cc which is nothing but V plus in this case we are saying and sometimes it will be minus V cc.

So, these are the two thresholds. So, when I rewrite the thresholds, it will be V1 is equal to R equivalent divided by R3 into V plus plus V plus into R equivalent by R1 and other value other threshold is nothing but minus R equivalent by R3 into V plus or we can say V minus 2, V minus is nothing but minus V plus plus V plus into R equivalent by R1.

So, how do we calculate R equivalent? When we see you know that R1 and R2 R3 values are 180 R3..

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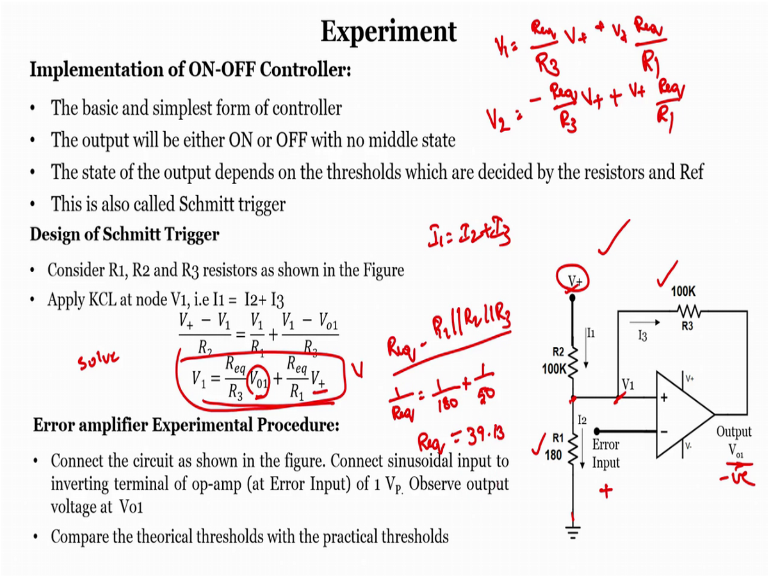


So, when we calculate R equivalent value, so one by I can say one by R equivalent is equal to 1 by 180 plus 1 by 100 plus 1 by 100. So, first what I will do that I will calculate for these two; R1 R2. It will be 50K when resistors are same. If those two are in parallel, it will V R by 2. So, it is 50K.

Now, 1 by 50 plus 1 by 180; so let me solve it are 1 divided by 180 plus 1 divided by 50. So, it is 0.255. So, one divided by the answer. So, we will select 1 by X. So, that is nothing but 39.73. So, R equivalent is 13.39, ok. One more thing is this is 50K this is ohm. So, whatever the calculation you made is wrong..

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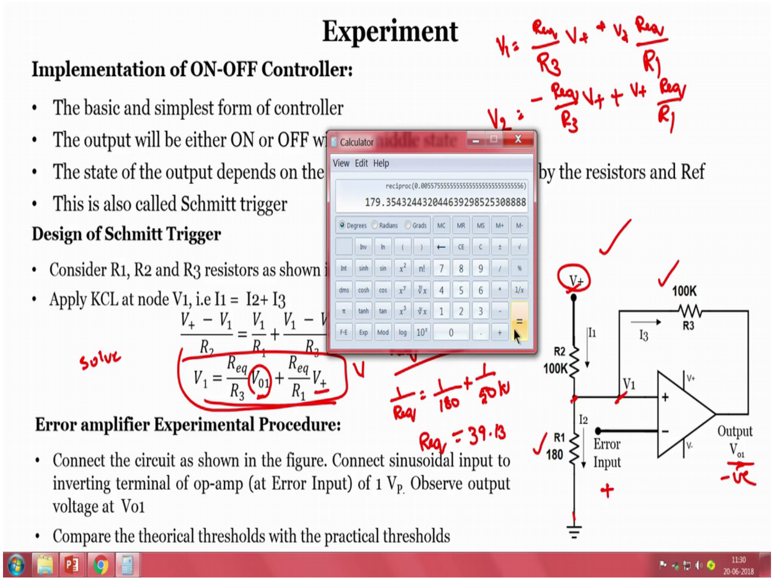


So, let me do one second. 1 by 100 1 2 3 plus 1 divided by 100, 123, so 1 by x. So, this is 50K. So, it is 1 by 50K. Now, we need 1 divided by 180 plus 1 divided by 50K 123. So, it is 0.0055. So, answer inverse will be R equivalent 179.35 approximately equal to 185 ohms. So, R equivalent is 180 ohms. Now, we need to find out V1 and V2 thresholds. Let me erase it. So, we understood R equivalent value is 180 ohms.

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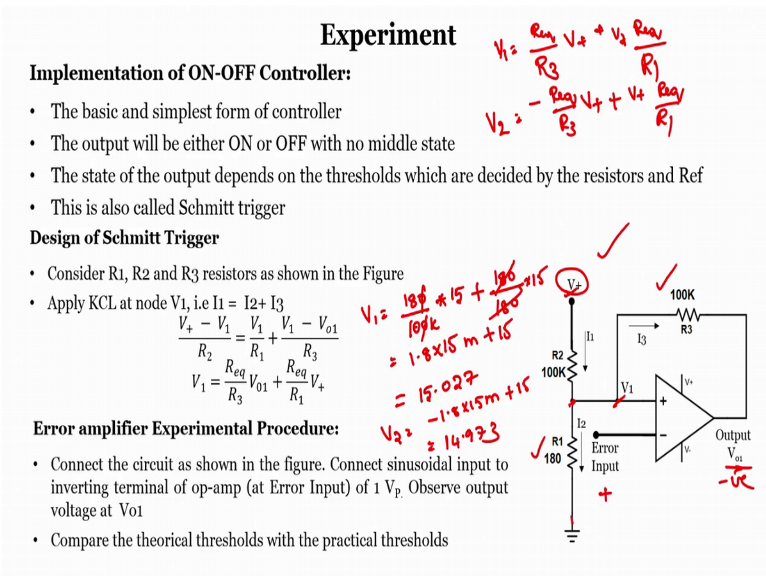


So, 1 threshold V1 180 divided by 100K into 15. Let us take another plane plus 180 divided by R1. R1 is 180 into 15. So, 180 180 cancel; so 180 by 100K 18 by 100. So, 1.8

into 15 milli plus 15 where I see the value 1.8 into 15 into 0.001 it is milli plus 15. So, one threshold is 15.027. What about the other one V 2? So, minus 1.8 into 15 milli plus 15; so this will be 15 minus 1.8 into 0.0015 15 milli which is 14.973.

So, these are two threshold in this case. So, when we recall one threshold is 15.027 and the other threshold is 14.973. So, since reason is inverting type of schmitt trigger when the input voltage, that means if the input value is greater than 15.027, the output will be on right and when the input is slower than 14.973, the output will be of reverse to this value.

So, how do we understand in terms of degree centigrade? So, if we want to understand we have to understand; what is the sensitive factor that we have used as an input as set point to the system, so that we understand we can do that, but this is not the final output. So, in order to understand we should understand; what is the signal conditioning circuit that we are using it here, right.

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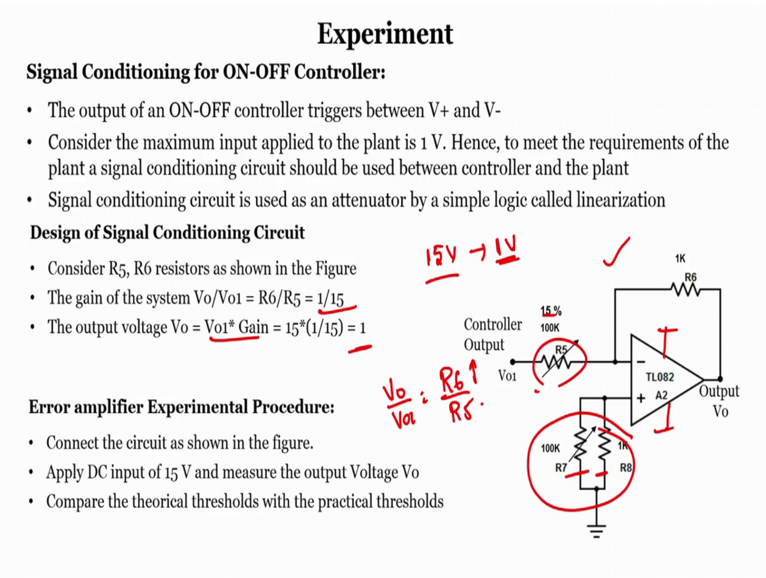


So, now if we see if we see the output of a control V is somewhere around 15 volts, but if 15 volts is good for or op-amp or for the plant to withstand no because when you apply 15 volts as an input to the plant, if we recall, if we apply 15 volts here. So, here will the voltage drop will be 15 volts to the current flow will be 150 amps. That is not we required that is also any know generation of 150 amp is really difficult to power. So, we cannot generate such a higher current. So, that is a reason since our operating range of the plant is somewhere around 1 volt, so we have to convert 15 volts to 1 volt if your output of the plant is 15 plus 15 or minus 15.

So, how do we do that? So, in order to do that we are using a signal conditioning unit here; this signal conditioning unit if we recall if we remember how do we how do we set a gain for an inverting or non-inverting amplifier. The gain of a system inverting amplifier if I see the gain of an inverting system if I say V naught by Vo1 in this case entirely depends upon your feedback resistor divided by input resistor which is nothing, but R5.

So, if we want to use as an amplifier, the R6 resistance value should be higher than R5 resistance value. As a result we will get a higher value, but in this case we need to attenuate the reason is the plant can only withstand with the maximum value of 1 volt and since 15 is maximum voltage that we are getting right. So, that means 15 volts as should be converted to 1 volt. How do we do that? In order to do that we have to use an attenuator.

So, in this case the gain of the system should by 1 by 15. So, if I take gain of 1 by 15 and multiplied with input voltage of Vo1, so the V naught will be always 1, right. So, the combination of on-off controller and the signal conditioning circuit i the output of the signal conditioning circuit is the input of the plant. So, that whole combination is our controller in this case. I hope you understand why we have used a signal condition is circuit of the output of on-off controller, right.

So, we have to design in order to match the input parameters of the plant with respect to the controller output. So, we need to have one more block, right. So, that block is signal conditioning block in this case.

Now, what is a use of having these two resistors? When you recall the characteristic of an op-amp, we can see that the input bias currents and the inputs off set currents right who changes the output voltage even though when you apply the, when you do not apply any input voltage, right. So, in order to eliminate the effects due to the bias currents right, so rather than having rather than simply connecting positive terminal to ground if we connector are R compensation resistor of the positive terminal of an op-amp, the effect due to the bias currents can be eliminated. So, what R compresses should be the parallel combination of feedback resistor and the input resistor. That is a reason so one input resistance and other one is feedback resistance.

Now, this is part, so that we can vary. So, if I say 15 percent, so 15 percent of 100 kilo is nothing, but 15 kilo and this is 1 kilo; so 1 kilo by 15 kilo which is nothing, but 1 by 15. So, even if I want to increase or decrease by using this, we can do or you can replace this with simply 15. So, why we have used a part because even in case if the plus V cc and minus V cc is changing, the same circuit should be responsible or the same circuit should be used even to generate the required output volts. That is a region by simply using a part we can even the input voltages are changed. By tuning R5 resistance value, we can achieve the required output voltage.

So, that is a requirement of a signal conditioning circuit. In this case let us see whether our signal conditioning circuit theoretically whatever we have seen are signal conditioning as well as the on-off controller. Whatever we have designed as per our requirement is working perfectly or not? So, before looking into the experimental, we will see the simulation version and we will understand, ok. So sorry; so let me say this. So, the name I am saying it has heating plant, ok. Let me open a new file.

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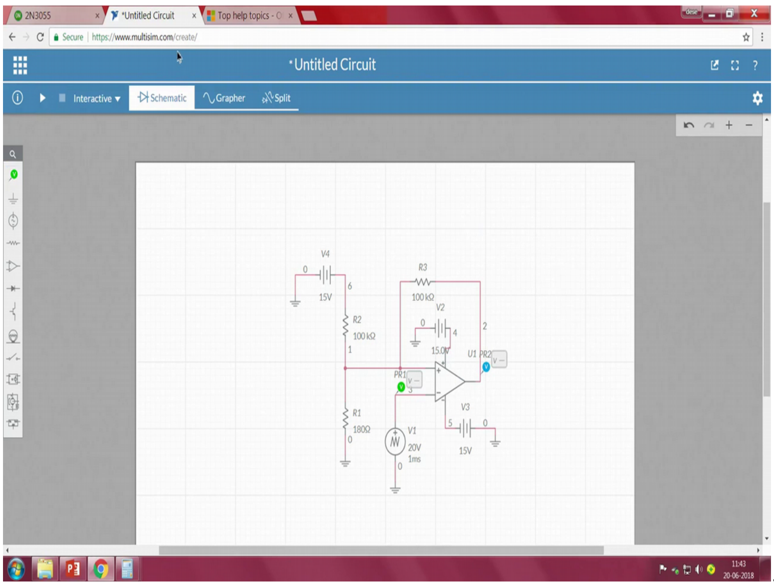


So, I need an op-amp some taking an op-amp positive negative, I need 3 resistors. So, this is R1; so R1 180 ohms 180 ohms and R2 100K 100K. So, right and R3 the resistance value is 100K. So, this is input negative terminal is input in this case. So, you need to connect round, ok. Since you do not have power supply, what I do is, I will take an op-amp with 5 terminal. So, even we can connect plus V cc and minus V cc here and this is my error input. So, that will be passed through a triangular voltage, triangular generator. So, easy for us to understand when it is switching on and switching off sorry. So, the voltage should be let us say 20 is the maximum voltage amplitude.

Because the thresholds are 15 point something and 14 point something right, the lower and higher, so input voltage should be always greater than that, right. So, plus V cc and minus V cc should be corrected. So, what I will use, I will take a DC voltage. So, rotate it. So, plant to use 15. So, what I will use this, I will change it to 50 right.

Now, this should be connected to the ground. I will take a ground, connect it here. I need another voltage source because for negative terminal negative voltage and the value should be of 15 and other terminal should be connected to ground, another voltage source which should be of same V plus oh sorry now this DC voltage let me rotate this should be. So, this is very much important what voltage we are using because when we see the threshold value, so it depends upon what is a supply voltage that we are connecting as well as what is voltage that we are connecting at this point. So, since we have calculated of 15, let me change to 15 and other terminal should be connected to right.

So, now we have to understand this. So, the circuit is ready. Anything we have to do the simulation, before doing simulation let me connect voltage source is sorry voltage proves as output as well as input, ok. Let me change the input to some sine.

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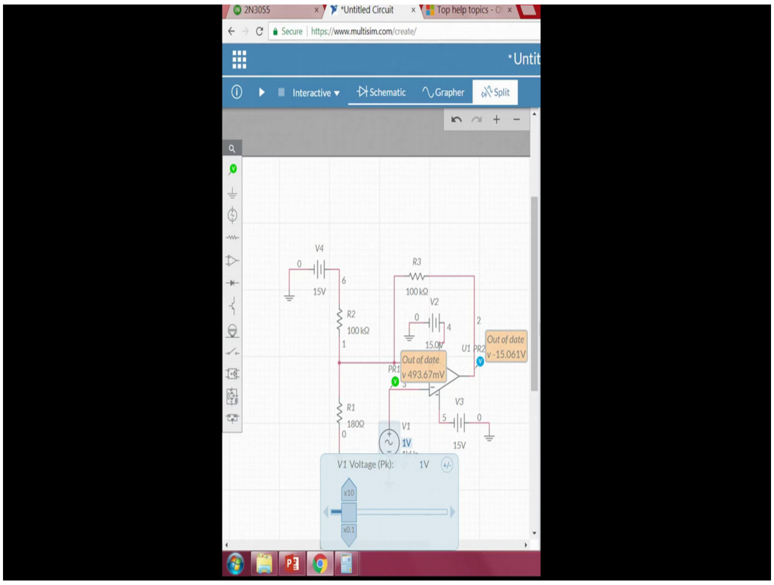

AC voltage, so peak values somewhere around 20.

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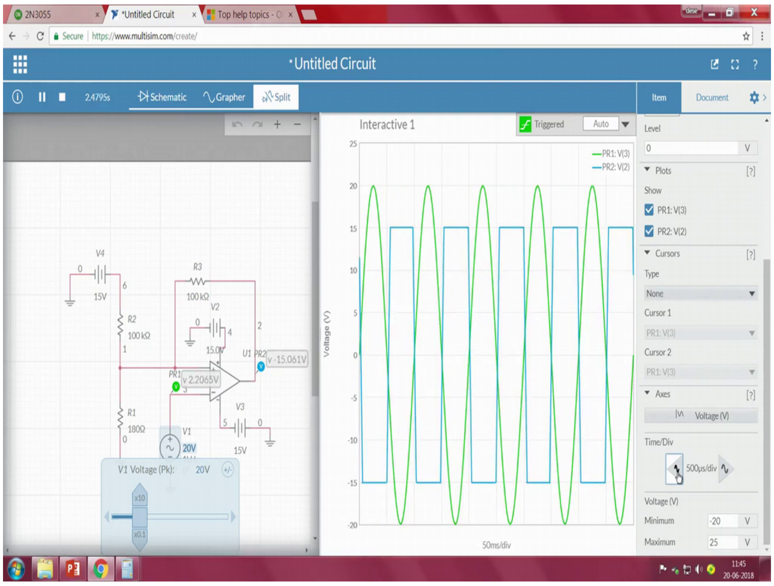

Now, if I assume the system,, so let me go to the grapher. So, how do we understand this? So, let me make it as single, right. So, this is the input. The green corresponds to the input, the blue is output. So, one thing we can see that it always fluctuate, but whether it is fluctuating the same time, so to understand let me take two cursers. So, one is y axis curser. So, one value is somewhere around 15 point something. So, if we calculate, the value is 15 plus 0.027, 15.27, other one is 15 minus 0.027 which is 14.97.

So, one is 15.27; so when a cc 1 curser, so the curser 1 is somewhere around 15.6. So, I have to give it as 15.0, ok. I can keep it as 15.0. Let me keep it at 15.06. So, approximately another curser should be somewhere around 14.97. Let me try where I can get or not yes 14.98 right.

Now, if the input is greater than this point, so it is almost looking same. So, what I will do is that I will change what I will do here rather than saying peak value peak of 20, I will say off set of 10 peak of 10. This is good for us. So, when we look into the grapher,.

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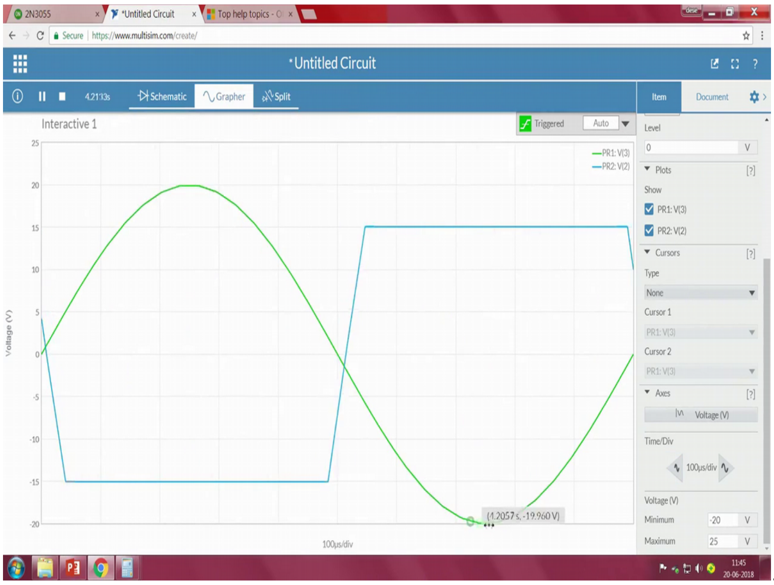


so what I will is assume it. So, the maximum 25 and that the minimum let us take it as 5. So, 14 point curser 14.279 and other one is 15.0273. So, when the input is greater than C1 higher threshold, we can see it is going to switch off again when the input is lower than C2 threshold, right. At this point, somewhere around this point it is started going to the other state.

So, that is clear that as long as input is greater than the higher threshold value or even higher than the lower threshold value, it will be always in that state, right and when the input is lower than the particular value, then it is on. So, that is what even we required, right. So, when do we have to switch on? When the temperature is lower than the lower threshold value, then it has to switch on. So, observe the temperature is lower than, so if I say the green color one is temperature. It is so increasing and at this point since it is on, it is off. So, no power since there is no power, it will start cooling because of the convention or if you have any forcer convention, that is also fine. So, it will start cooling cooling cooling cooling. When it is lower than the lower threshold value, then it starts. That means, it starts pumping current as a result it starts heating. So, due to cycle that due to cycle are the frequency. That means, it switch on or switch off entirely depends upon the rate at which, depends upon your input you know the how it is heating a plant, right.

So, this way we can with stand how exactly the Schmitt trigger can be designed based upon the requirement. Now, when we say the thresholds, the thresholds are closely selected such way that you know it should always on and off at very you know smaller ranges. The reason is that in some of the bio metical applications we require to constantly maintain the temperature of the plant to be you know plus or minus 0.1 degree or 0.05 degree duration in the temperature.

So, such a cases such a close relations are very much important. Moreover one thing we have to understand since the controller is making a system to on off, on off at regular intervals of time, the withstanding capability of your system if a withstand if your system cannot withstand for such fluctuations in you, I know input voltages it may also damage your system since that is very much important. So, we have to say understand whether the if the system operating range as well as the capability of a system when there is input keep on fluctuating as long as that satisfy, there is no problem, but another problem is that when you observe when you observe the diagram, what we have seen right.

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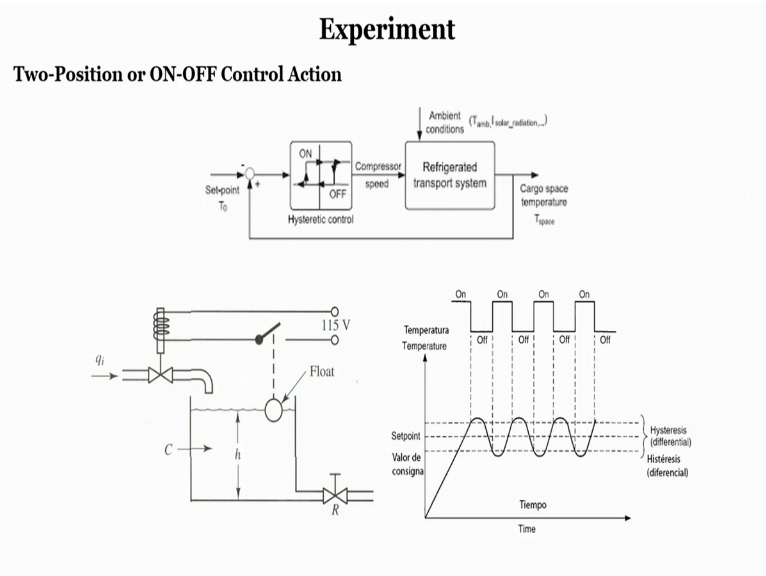


So, these are your two thresholds, your all output always fluctuate between these two ranges, right higher threshold and lower threshold. As long as these two thresholds, this range is ok, we can go with on-off controller. So, it is clear that on-off controller is not controlling it. It is on and off, on and off, so depends upon variation in your input based upon the set point, but sometimes for some particular systems we require to maintain the temperature to be always same, always set as per your input set point let say 50. It should always maintain at 50 and the systems should not switch on and switch off. It should always power should be always in on condition, but the variation input voltage should be always changing. In such a cases if we want to design, so we have to go with other kind of controllers.

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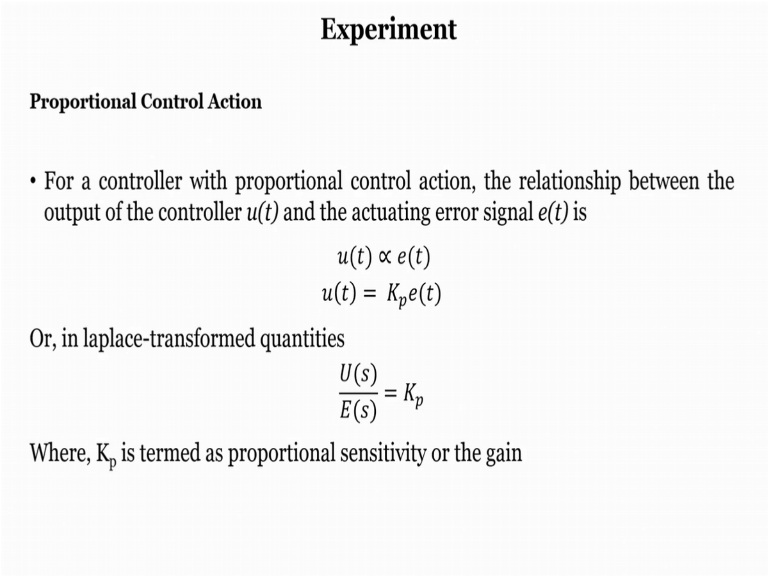


So, those controllers are other P controller and PI controller and PID controller. How complex you make? So, how complex you make entirely depend upon how many number of you know proportionality or how many number of what you call different kinds of controlling mechanism that you are using. If you are using a proportional control is a simple proportional controller, if you want to make it complex, if you want to have a more response, very good response, very less error, then we have to go with a higher complex system. Those are PI and PID controllers.

So, we will see how exactly P controller in works and how exactly the PI controller work in the next module.

Thank you.