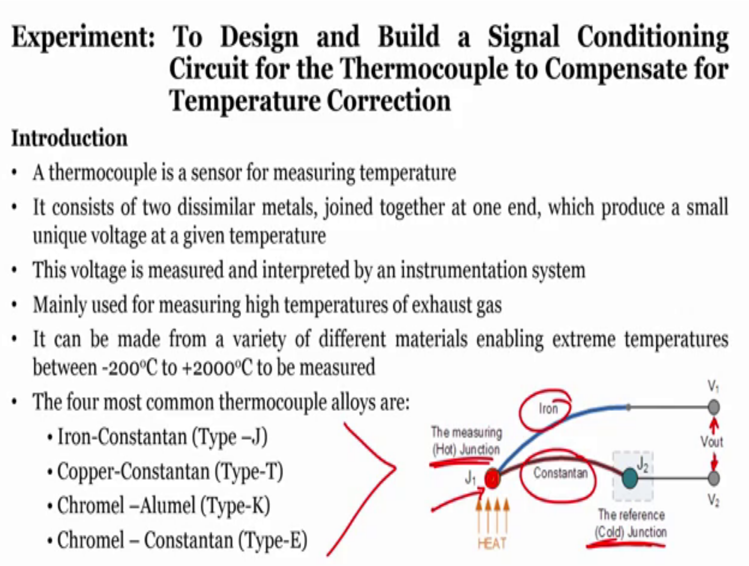
Op-Amp Practical Applications: Design, Simulation and Implementation
Prof. Hardik Jeetendra Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 30
Experiment: Design and Implementation of Signal Conditioning unit for Thermocouple Cold Junction Compensation

Hi. Welcome to this module. In this module what we will learn: we will learn how to design and build a signal conditioning circuit for thermocouple to compensate for temperature correction. Now thermocouple is a temperature sensor or it is used to measure the temperature. Same thing there are RTDs there are temperature sensors which are also used.

But thermocouple is most widely used because of its ease of operation is a low cost, it can be used from minus 200 degree centigrade to 2000 degree centigrade. It is exclusively used in automobiles and home applications. So, let us see how you can do the temperature correction, or how we can design a signal conditioning circuit that can be used for compensating the temperature correction in case of thermocouple.

(Refer Slide Time: 01:08)



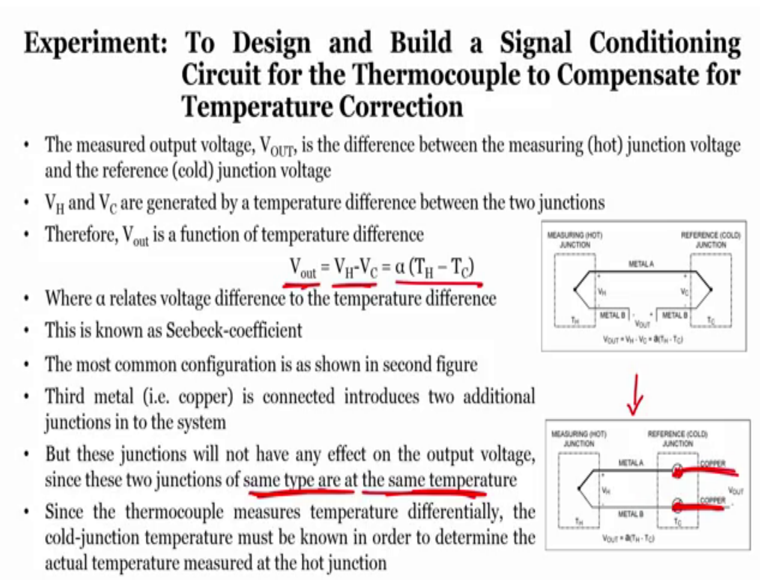
So, if you see the slide like I said a thermocouple is a sensor for measuring the temperature. It consists of two dissimilar metals joined together at one end which produces a small unique voltage at a given temperature. So, we can see here which is junction J 1 right and you can see there is two different metal right iron and constantan. So, they are joined together fused together to form a bid and this bid is the measuring hot junction. This is where it measures the heat ok.

And there is a cold reference junction which is right over here and then there is a voltage difference. So, it creates a different signal voltage we will see that now. So, it consists of two dissimilar metals joined together at one end which produces a small unique voltage at a given temperature. This voltage is measure and interpreted by instrumentation system.

So, here the voltage is generated at this particular end and is further connected to the instrumentation amplifier mainly used for measuring high temperature of a exhaust gas. It may also made from variety of different materials enabling extreme temperatures like I said from minus 200 to 2000 degree centigrade.

The four most common type of thermocouple alloys are first is type J which is iron constantan which is a exclusively used. Then you can also use Chromel Alumel this is type K. There is a another called copper constantan which is type T and we have chromel end constantan which is type E. So, four basic types of common thermocouple alloys are shown here right. And based on what kind of alloy you are using you can name the thermocouple with J with the alphabet J T K E ok. So, you need to remember this.

(Refer Slide Time: 02:54)



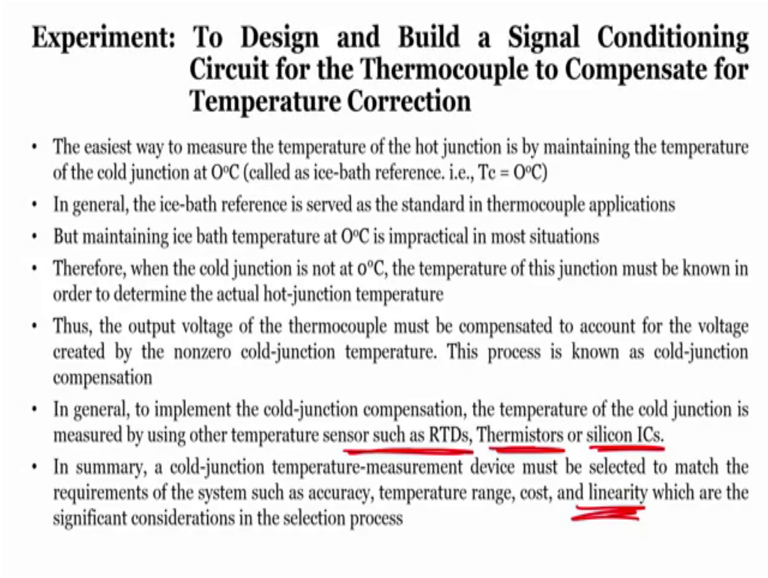
Now, to measure the output voltage V out this is the difference between measuring hot junction right hot junction which is right over here, cold junction right over here. So, I can measure V out which is the difference between hot junction and cold junction V H and V C are generated; V H which is voltage here, V C which is voltage here, and are generated by a temperature difference between two junctions. Therefore, V out is a function of temperature difference because V out equals to V H minus V C or alpha times T H minus T C, right; so temperature at the hot junction minus temperature at the cool junction; so where alpha relates a voltage difference the to the temperature difference.

Now this is what is called is also called Seebeck effect right. We have said earlier in physics what is Seebeck effect right. So, Seebeck effect the most common configuration is shown in the figure 2 which is right over here right. And the third metal is copper is connected introduces two additional junction to the system you can see here we are adding a copper we are adding a copper here right. So, there are two more junctions which are created right over here, but this junction will not have any effect on the output voltage. Since, two junctions are same type and are at the same temperature right.

So, adding two junction with the help of copper wire will not really change the output voltage. Next is since the thermocouple measures the temperature differentially differentiality the cold junction temperature must be known in order to determine the actual temperature measure at the hot junction. Now, if we want to understand what is the um temperature differentiality of the thermocouple or actually the thermocouple measures the temperature differentiality. So, the cold junction temperature must be known in order to actually measure the hot temperature that is very important

So, if you see the slide what we are talking about is that the cold junction temperature must be known in order to determine the actual temperature measure at hot junction. So, if you do not know the cold junction temperature it is very difficult to measure the hot junction temperature.

(Refer Slide Time: 05:12)



Now, the easiest way to measure the temperature of the hot junction is by maintaining the temperature of the cold junction at 0 degree centigrade. And it is also called ice bath, and temperature is 0 degree centigrade. So, the easiest way to make the cold junction or measure temperature of a cold junction is you just put this cold junction in a ice bath. Now we know the temperature of a ice is nothing but 0 degree centigrade. So, this is a easiest way to measure the hot junction temperature is by maintaining the cold junction temperature at 0 degree.

In general the ice bath reference is served as a standard in thermocouple application, but maintaining ice bath temperature at 0 degree is a impractical in most situations. And therefore, when the cold junction is not at 0 degree the temperature of this junction must be known in order to determine the actual hot junction. If you do not know this one if you cannot maintain at 0 degree then what is the temperature of the cold junction it is very important to know.

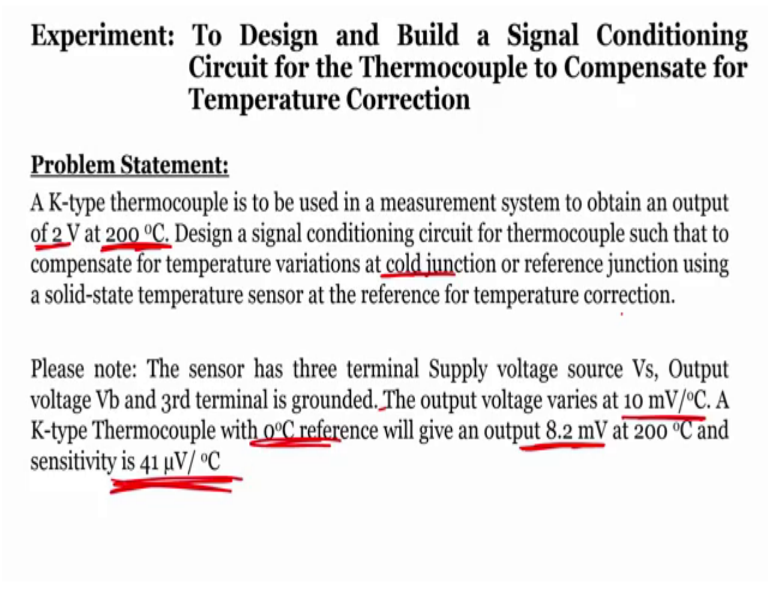
So, thus the output voltage of thermocouple must be compensated to account for the voltage created by nonzero cold junction temperatures right. And this is known as cold junction compensation that is what we are looking at the how to do a cold junction compensation ok. So, the idea here is if you do not have a ice bath and you cannot maintain the temperature of a cold junction at 0 degree centigrade. But you if you do not know the cold junction temperature then you cannot measure hot junction temperature.

So, you should know the cold junction temperature for understanding cold junction temperature you have to use a ice bath. But if you do not have a ice bath and it is a impractical to keep it a 0 degree centigrade then what is the voltage created. Because of the nonzero junction temperature in the cold junction we need to know and to compensate that nonzero value be we have to do a cold junction compensation.

So, in general to implement cold junction compensation, the temperature of a cold junction is measured by using other temperature sensors such as RTDs thermistors or silicon ICs. In summary cold junction temperature measurement device must be selected to match the requirements of the system right.

So, what are the requirements of the system that it should be accurate? It should have temperature range, it should be less costly, and linearity which are the significant considerations in selection process. It should be linearly changing with respect to temperatures. So, these are they all the important parameters when we select a temperature measurement device for cold junction.

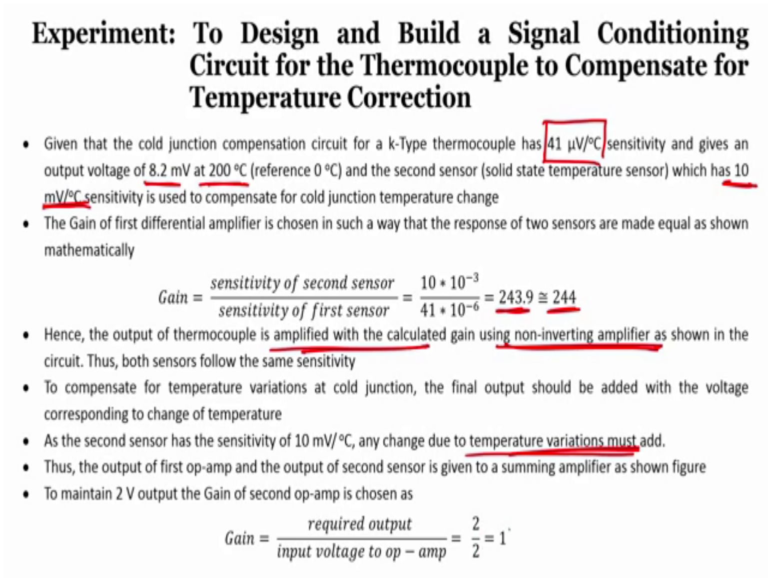
(Refer Slide Time: 07:38)



So, now if for a given problem how we can solve this let us see. For K type thermocouple is to be used in a measurement system to obtain a output of 2 volts at 200 degree centigrade this is a question. Design a signal conditioning circuit for thermocouple such that to compensate for temperature variations at cold junctions or reference junction using a solid state temperature at the reference for temperature correction.

Now what is that please note a sensor has 3 terminal supply voltage Vs, output voltage Vb and third terminal is grounded. The output voltage varies at 10 millivolt per degree centigrade. A K type thermo coupled with reference 0 degree centigrade will be given as a output given a output of 8.2 millivolt at 200 degree centigrade, sensitivity is 41 microvolt per degree centigrade. These are the things given to us.

(Refer Slide Time: 08:34)

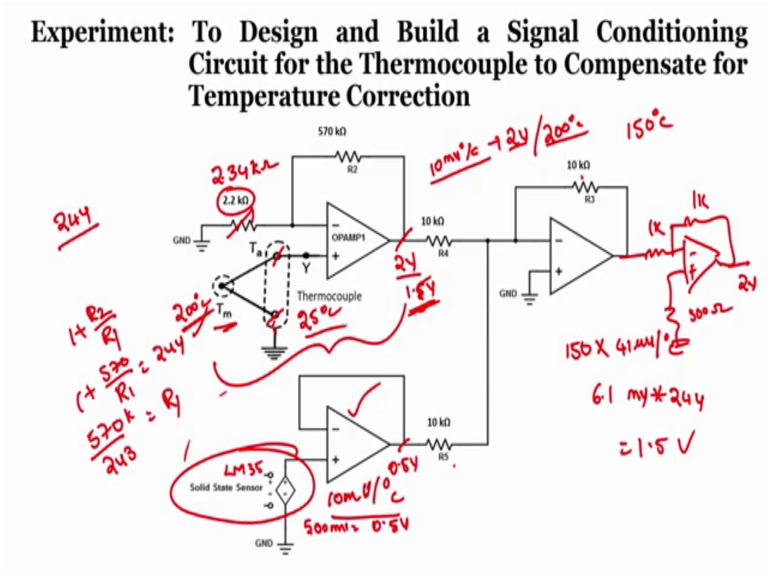


Now let us see how we can design a signal conditioning circuit for thermocouple such as to compensate temperature variation at the cold junction ok. So, given that cold junction compensation for K type thermocouple is 41 microvolt’s per degree centigrade which is already given right and gives an output voltage of 8.2 millivolts, at 200 degree centigrade also given. And second sensor which is solid state temperature sensor which has a 10 millivolt per degree centigrade, which is a also given right is used to compensate for cold junction temperature change.

So, gain of the first differential amplifier is chosen in such a way that the response of two sensors are made equal. And so mathematically if you want to make equal then gain is nothing, but sensitivity of second sensor divided by sensitivity of the first sensor.

What is sensitivity of second sensor? Sensitivity of second sensor is 10 millivolt per degree centigrade, so 10 into 10 raise to minus 3 divided by what is a sensitivity of the first sensor? Sensitivity of the first sensor is 41 microvolt per degree centigrade. So, you can write down 41 into 10 raised to minus 6. So, when you divide this when you solve this you have a equation value of 243.9 or approximately 244.

(Refer Slide Time: 09:38)



Hence, the output of thermocouple is amplified with the calculated gain using non inverting amplifier right. As shown in the circuit thus both sensor will follow the same sensitivity this is the circuit right, but the output of the thermocouple is amplified. So, that both sensor follows the same sensitivity right. This is what? Now to compensate temperature variations at the cold junction the final output should be added with the voltage corresponding to the temperature right, because the final output should be added to the voltage corresponding to the temperature.

So, this output voltage this output voltage both are both should be added to the circuit. As a second sensor has the sensitivity of 10 millivolt per degree centigrade any change due to temperature variation must be added to the equation.

Thus, the output of first op amp and output of the second sensor is given to a summing amplifier as shown in figure. We can see very clearly by the output of the first amplifier and a output of the second amplifier second output of first op amp 1 and output of op amp 2 is given to a summing amplifier which is right over here right.

And to maintain 2 volts output the gain of second op-amp is chosen to be required output by input of the input voltage to op amp, so 2 by 2 which is equal to 1 right. So, here our gain is nothing, but 2 by 2 equals to. So, now in our experimental class we will see how we can use this whole thing whole circuit to compensate the temperature correction in case of when the cold junction is not at 0 degree centigrade.

So, again if we quickly repeat it what we have seen is how we can design a signal conditioning circuit for thermocouple to compensate for temperature corrections. Like I said if we were started with the understanding of what is a thermocouple? What kind of a alloys are used for thermocouple? What is a hot junction? What is the cold junction where the output voltage is generated?

Now, what is a problem the problem is that the cold junction should be at 0 degree centigrade? Now before that we have showed that the output voltage is nothing, but V H minus V C equals to alpha times TH minus TC where alpha is nothing, but the voltage difference due to the temperature difference.

We also generally if you add the couple line to the metal A and metal B what will happen? There is no different it will not effect because both are at same temperature and both are of same type. So, the copper wire adding to the thermocouple is not going to affect our system. Then we have also seen that we have to keep the cold junction at 0 degree centigrade which can be done by using ice bath.

But, we can it is very difficult to keep ice bath at 0 degree centigrade and of impractical in actual situation or most of the situations. So, we have to use another sensor to measure the cold junction temperature. So, that finally, we can measure the hot junction temperature correct. And the sensor that we can select should have a better accuracy, the better temperature range, it should be less costly and it should be linear.

Then we have seen that, if we want to design signal conditioning circuit for a given problem statement. Then how can we design such a circuit and when we solve this you can have a circuit which is right shown here. And we will do this kind of experiments to an extent using simulator rather than showing you actually because we need to otherwise get the ice bath.

So, it is kind of difficult, but anyway so this will be the end of this particular module. And in the next module we will see some of the applications. So, actually a applications of op-amp we can say or we can say that the how the analog to digital control systems, or how to analog to digital converter and digital to analog converter will work all right.

So, for these particular module this is a last slide and please learn about this whole module understand what are the what are the stages to design such a signal conditioning circuit. And if you have any questions you will free to ask me through the forum and I will try to answer your questions. Like I said this is just an example just to help you out; how can you use the operation amplifier in favor to deign your signal conditioning circuits. You can take many more examples and try to implement such circuits alright.

Now, mighty discuss about the circuit design and perform a simulation. Then they will discuss about how the circuit operates we have seen in theory in detail. But we just to have a quick recall of how circuit operates. They will show you about that circuit operation and compare it with the simulation to design the circuit using multi SEM. Again you will ask our friend Sitaram.

So, now we will see the experiment on to design and built in signal conditioning circuit for thermocouple to compensate for temperature correction. So that means, we have to develop a signal conditioning circuit for the thermocouple. So, why do we require this signal conditioning circuit to compensate for temperature correction? So that means, we should understand how exactly thermocouple works.

Now, what will be the problem associated with the thermocouple then after that we have to think about how to correct that particular we have to introduce a correction factor in order to compensate for that for a temperature. So that means, if you recall what professor has already discussed about thermocouple a thermocouple is a temperature sensor which can use to measure temperature.

Of course, there are other different temperature sensors which we have also seen in this module one is a LN 35 which is also a temperature sensor. Other temperature sensors like thermistors, RTDs are also available. But why a thermocouple is important because it can measure up to a more than 1000 degree centigrade. It depends upon what type of thermocouple a combination that you use.

What type of alloys that you use? Like iron constantan, or copper constantan the range the temperature measuring range will be entirely depends upon you know what type of alloy that you use. And the temperature ranges will be even higher you can measure up to 1500 degrees 2000 degree centigrade temperatures too which cannot be possible with other temperature you know sensors.

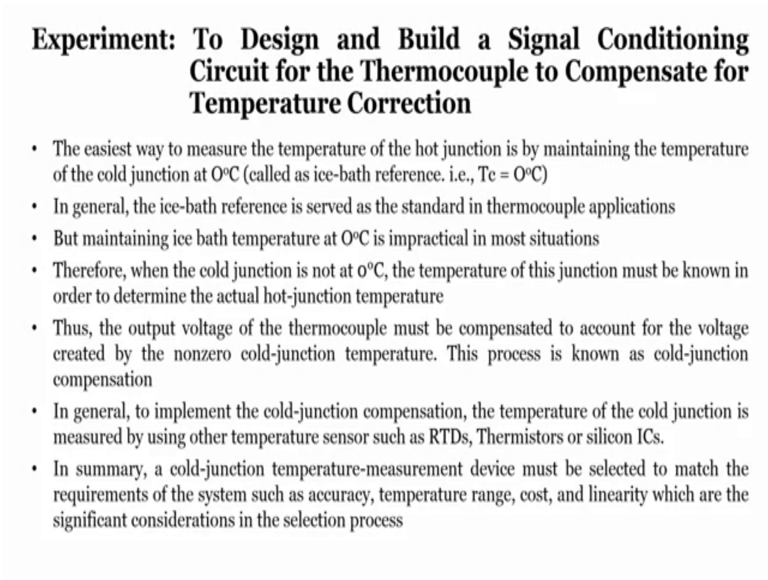
But if it is a case if we understand how thermocouple works? It is easy for us to develop an signal conditioning circuit. So, to make you understand about how a thermocouple works if we consider this is a one. So, if we consider this is one material, this is another metal.

If you combined at two different junctions say let us check a green is one particular material other one blue is another material. If I you know create a one node here, and another node here. So that means, I am joining these two thermocouples two different metals. So, this forms one junction, this forms another junction right, this is one junction, this is another junction.

So, when you place this particular junction in one particular temperature and this junction in other particular temperature depends upon the difference between these two junctions. The difference the temperature difference between these two junctions generates an EMF in your wire in this metal right. So, that is what your Seebeck affect do. So, thermocouple generally uses a Seebeck effect.

So, if you look into the slide; so one particular combination one particular junction kept at heat; so another junction if it is placing another reference temperature or a known temperature it generates an EMF voltage; that EMF voltage generally depends upon the difference between this junction temperature and this junction temperature right.

(Refer Slide Time: 17:44)



So, but what is your reference temperature is you know is not at the known temperature. So, when you understand in order to measure in order to measure the temperature one way is by looking into the output voltage of a sensor right. So, for example, like say if the sensitivity of this particular thermocouple K type thermocouple is 41 you know microvolt per degree centigrade. That means if I look into the output voltage of 41 microvolt I can understand that the temperature is at the difference in the temperature is 1 degree centigrade.

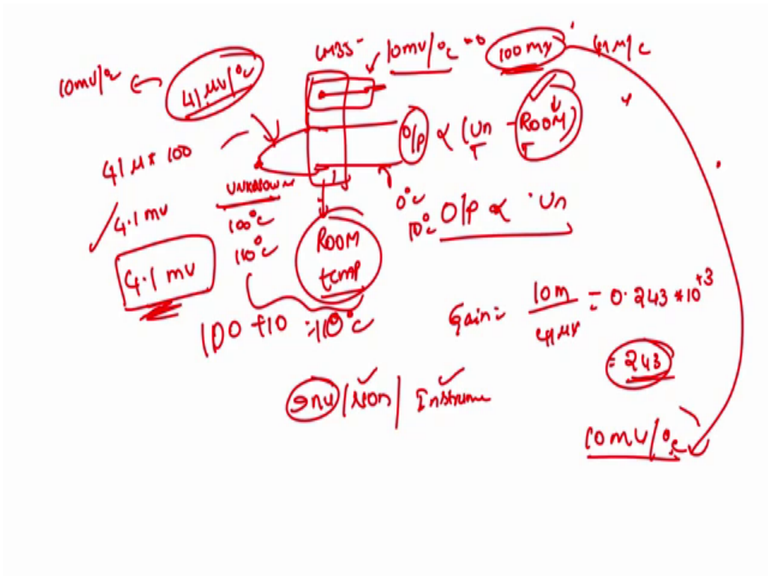
Now, if I say the cold junction temperature is at 0 degree which is a known to me right. And so that means, the other junction temperature will be always at 1 degree centigrade. What if your cold junction temperature is at is not at 0 degree, because it is very hard to always maintain the temperature right, cold junction temperature at 0 degree that is one thing. Or you can also keep it as a reference temperature or room temperature as a reference temperature. But even if you observe the room temperature will always vary depends upon the climatic conditions it cannot be always at a constant at 27 degrees or neither at 25 degrees it was always vary.

So that means, that when you see the output voltages of a thermocouple it is completely relative, it that it is not a absolute it is a relative it entirely depends upon your cold junction temperature. What if your cold junction temperature changes? Obviously, your output voltage will also changes as a result it is very hard to understand whether the change in the output voltage is a either due to the change in your plant, or due to the change in the cold junction.

So, because of that reason generally they use one per another temperature sensor right such as an RTDs, or thermistors or other silicon type of ICs in the cold junction. So, by using those particular sensors we will generate an output voltage and that output voltage is corresponding to the change in the temperature in this in this cold junction.

As a result whenever there is a change in the cold junction this particular output voltage from the temperature sensor. If you use as an input too adding added to the output voltages of thermocouple we can compensate for the temperature variation in the cold junction. So, but what happens that the temperature sensor which is placed in the cold junction the sensitivity of that temperature sensor may not be always same as a sensitivity of your thermocouple right.

(Refer Slide Time: 20:21)



For example, like say for example, I will take so consider this is my thermocouple, this is unknown temperature which we need to find right. These two forms another junction these two I am placing it on room temperature right, one junction is at a unknown temperature, one is at room temperature. So, if I measure the output voltage this output voltage will always be proportional to difference between unknown temperature and room temperature.

Now, if I know the room temperature value I can; obviously, understand the output voltage. So that means, output voltage, now it is only depends upon unknown temperature, because I know the room temperature right. But if I consider the room temperature as 25 degree centigrade depends upon the climatic condition the room temperature will always fluctuate from 25 to 30 degrees or in another countries it may also go from 0 degrees to I mean it will always vary from you know 20 to somewhere around 40 degree centigrade to right.

As a result it is very hard to understand the room temperature until unless you have another temperature sensor. So, generally what they do is that? They will place they will place one more temperature sensor at the cold at the reference temperature, or near the at this particular junction reference temperature junction. So, by measuring the output voltage from this temperature sensor right we can incorporate that particular temperature value at this point. So, as a result we can easily find out output voltage.

Otherwise, it is very hard to understand by observing simply observing the output voltage we cannot understand whether the change is due to the unknown temperature or because of the change in the room temperature right. But what happens? Whatever the temperature sensor that we use the sensitivity factor may not be the same as a sensitivity factor.

In this case for example, like say if I take LM 35 as a temperature sensor. The LM 35 temperature sensor sensitivity is 10 millivolt per sensitivity of LM 35 is 10 millivolt per degree centigrade. Whereas, thermocouple sensitivity is 41 K type, thermocouple 41 microvolt per degree centigrade. For example like say if this is at 100 degree centigrade. If this is at 0 degree centigrade right if it is at 0 degree centigrade. So, I should get an output voltage as 41 micro into 100 degree right.

So, this is 4.1 millivolt, but this one should give it as 0. For example, if it is at 10 degree centigrade, so and if it is at 110 degree centigrade right. So, the difference is again it will be always at 4.1 millivolt. So, first case is 100 degree, second case is this is at 110 degree centigrade. But the output voltage still shows the reference temperature is 0 degree 10 degree. So, still the output from the thermocouple always shows 4.1 millivolt because the difference is again 100 degree.

So, it is very hard to understand by looking into the simply by looking into the output voltage 4.1 we will assume that the unknown temperature is at 100 degree. But actually speaking the unknown temperature is at 110 degree the plant temperature is at 110 degree that is because of we do not have we do not have any tracking system at our reference temperature. Suppose if I use LM 35 right so by looking into the output voltage. So, for 10 degree it shows 100 milli right; we can understand yes it is at 10 degree

So, I say so 10 degree this is nothing but 100 degree this is 100 degree. So, as a result we can understand 10 plus 100, 100 plus 10, so which is 110 degree. But these are all these are manual way of understanding, but if I want to correct it using an electronic system right. I should always go with go with some temperature sensor which gives an output voltage right.

So, if I say this is 10 millivolt per degree centigrade which gives 100 millivolt, 100 millivolt for 10 degree, but I cannot directly add this 100 milli to 4.1 millivolt. The reason is that the sensitivity factor of this and sensitivity factor of this is different. So, as a result if I add it goes to some other value.

So, one way to do that is either we have to change the temperature sensor sensitivity factor to 41 microvolt per degree centigrade or LM or the thermocouple sensitivity factor from 41 microvolt per degree centigrade to 10 millivolt per degree centigrade either this should be attenuated from 10 millivolts to 41 microvolt per degree or the thermocouple output should be amplified from 41 microvolt to 10 millivolt degree centigrade. So, which one is easy by amplifying 41 microvolt to 10 millivolt is good one. The reason is that attenuating under 2 micro volts from milli to micro volts the signal to noise ratio percentage will be really poor, but whereas, amplifying the signal to noise ratio will be higher.

As a result rather than attenuating it if I amplify the output of thermocouple to 10 millivolt per degree centigrade it will be easy. So, so if I want to amplify from 41 micro volts to 10 millivolt we have to use a sensitivity factor or amplification factor. So, what amplification factor we have to go with this? In order to understand what gain of an amplifier that I have to use right the output should be 10 milli, but the input is 41 micro.

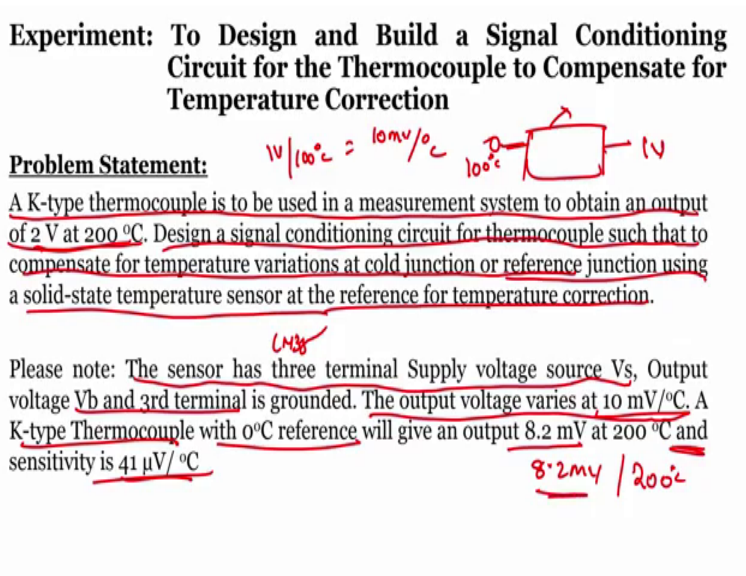
So; that means, if I take a calci. So, 10 divided by 41 which is 0.243; 0.243 into 10 power minus plus 3, because milli 10 power minus 3 10 power minus 6 when it takes to when I take it to upside it will become 10 power minus 3 plus 6 10 power plus three. So; that means, 243 milli sorry kilo sorry 243.

So, a gain of 243 has to be applied to the output of a thermocouple to get a sensitivity factor of 10 millivolt per degree centigrade right. So, how do we achieve this 243 gain right either we can go with an inverting, or non-inverting or instrumentation amplifier right.

So, either we can go with a non-inverting an instrumentation amplifier other than go with an inverting amplifier the reason is that the inverting amplifier may have some loading effect. Because, the output will be directly connected to the input of you know a resistor if the input impedance of this complete inverting amplifier depends upon the R 1 resistor.

If you chose a smaller resistance value and the voltages output voltage of this one is really really smaller. As a result there are chance of having a loading into system. So, as a result rather than going with the inverting we can go with a non-inverting or an instrumentation amplifier.

(Refer Slide Time: 28:17)



Now, let me take up a small problem to make us understand about how to design a signal conditioning circuit. So, the problem states that a K type thermocouple is to be used in a measurement system to obtain an output of 2 volts per 2 degree. That means, that if the plant temperature is 200 degree the final system output voltage should be at 2 volts.

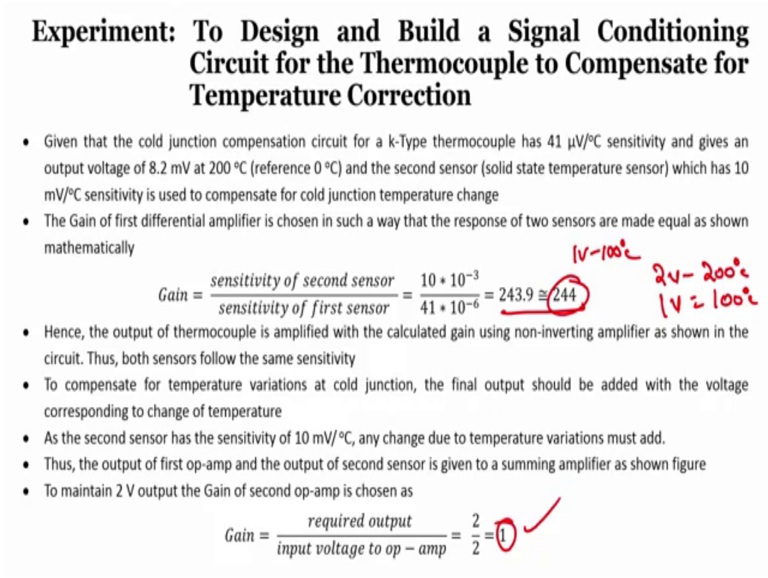
So, the when you see the sensitivity factor it is nothing, but 1 volt per 100 degree centigrade, or I can say 0 10 millivolt per degree right that should be the final system final system sensitivity right. So, that by looking into the output also we can understand what is the temperature acting on the plant on the sensor. So, we should design a signal conditioning circuit for thermocouple such that to compensate for the temperature variation at the cold junction, or reference meaning. Even if your cold junction or reference temperature is varying it should not have any effect on your output voltage.

So that means, if the plant temperature is at a 100 degree centigrade, but the room temperature is keep on varying it should always show it should always show 1 volt no matter what your room temperature is at it should always show output is 1 volt right. So, in order to do that what they are saying is? You can either go with an solid state temperature sensor at the reference for temperature correction. So, the solid state temperature sensor whatever they are choosing at the reference is a 3 terminal input. So, because we are using LM 35 which is a 3 terminal and the sensitivity factor is 10 millivolt per degree centigrade.

Whereas a K type thermocouple with a reference of 0 degree centigrade will give an output of 8.2 millivolt per 200 degree centigrade. So, when we calculate the sensitivity factor it comes as 41 microvolt per degree centigrade. So, one thing is clear. But finally, we should get output as 2 volt per 200 degree centigrade how do we do that? So, as we have discussed here if I use a gain of 243 to and you know what is this? A thermocouple we can get an output as 10 millivolt per degree centigrade.

But still the correction factor has not yet done. In order to you know in order to not to have any influence of your reference temperature the output of this LM 35, or the reference sensor has to be added with the output of thermocouple. The conditioned thermo coupled output right.

(Refer Slide Time: 31:00)



So, what we are doing is? So, we have calculated the gain as 243.9 which is 244. Now what about the final output circuit we require? Then finally, 2 volts has to be shown for 200 degree centigrade so; that means, 1 volt for 100 degree centigrade.

Right now if I multiply with the gain of 244 and even still consider that we are compensating for the circuit. I will discuss how do we compensate it. If you see that we will get a gain we will get an output as 1 volt per 100 degree. So; that means, the final output the final gain should be 2 by 2 which is nothing but 1. We do not need any gain apart from this, but how do we compensate. So, for that what we are doing is we have to add the output of the thermocouple to the output of LM 35. As a result any change in the reference temperature will be automatically added. If it is at 0, the output will be added with 0. So, as a result it gives the unknown temperature.

If this is varying; obviously, since the both sensitivity factors of LM 35 as well as thermocouple are same. So, it will be the output voltage will be added according to the reference temperature value as a result it will show you the correct value. So, the final circuit looks like this. So, how to understand this? So, this is basically apart. So, when you observe that this is a non inverting amplifier this is our solid state temperature sensor which is 10 millivolt per degree centigrade. So, consider thermocouple a T m is at 200 degree centigrade right.

So, if it is 200 degree centigrade what is the problem says that? If it is 200 the if you apply the sensitivity factor of 41 microvolt per degree centigrade it gives an output of 8.2 right say, so this will be 8.2. In this case the reference temperature is at 0 degree centigrade consider right. So, we are using a gain we should use a gain as 244, 243.9 right. So, since it is an non inverting amplifier configuration right non-inverting amplifier configuration sorry 8.2 millivolt, this is 8.2 millivolt. I require to have both sensitivity is to be of same. So, it should be 10 millivolt per degree centigrade right.

So, if I multiply the gain of 244 for 200 degree centigrade I will get an output as 2 volt for 200 degree. So observe; what is the gain of the system 1 plus R 2 by R 1. So, 1 plus 570 by R 1 should be 244; that means, 570 by 243 570 k by 243 should be the R 1 resistor. So, when we calculate the resistance value right 570 divided by 243 we got it as a 2.34 kilovolts, right we got 2.43.

So, if I use a 2.34 kilo ohms resistance value I will get an output voltage as 8.2 into 240 244 right. So, when I calculate that 8.2 milli into 244 I got I will get it as 200 milli which is nothing, but 2 volt right. But what if this reference temperature is not at 0? For example, like say the reference temperature is at 50 degree right If this is at 50 degree do we get an output as 8.2 milli. No, even though the unknown temperature or the measuring temperature is at 200 degree, but the difference in the temperature is a 150 degree. The output voltage will be 150 into 41 microvolt per degree right.

So, along this circuit along this particular circuit it cannot compensate. So if I if I do the calculation 150 into 41 right so it will be 6.1 millivolt right. So, for reference temperature of 50 we will get an output as 6.1 millivolt. Now if I see if I calculate the output voltage it will not be at 2 volts. So, 6.1 into 244; 244 I will get it as 6.156 into 244. So, it is nothing, but 1.5 volt, the new value is 1.5.

So, when we understand what is the unknown temperature by looking into the output voltage we will understand it. So, if when I look into the 1.5 volts what do we understand. If I say the sensitivity factor is 10 millivolt per degree centigrade we will understand that the voltage is at 150 degree centigrade, unknown temperature voltage is 150. But actually speaking the unknown temperature voltage is 200; that means, with the simple first op-amp we cannot compensate.

How do we compensate? So, I will be choosing another temperature sensor LM 35, where the sensitivity factor is also 10 millivolt per degree centigrade. So, when I place this on the reference junction on the same plate on the same reference junction. So, this gives me how much 50. Since it is 50, 500 millivolt; that means, it gives an output as 0.5 volt.

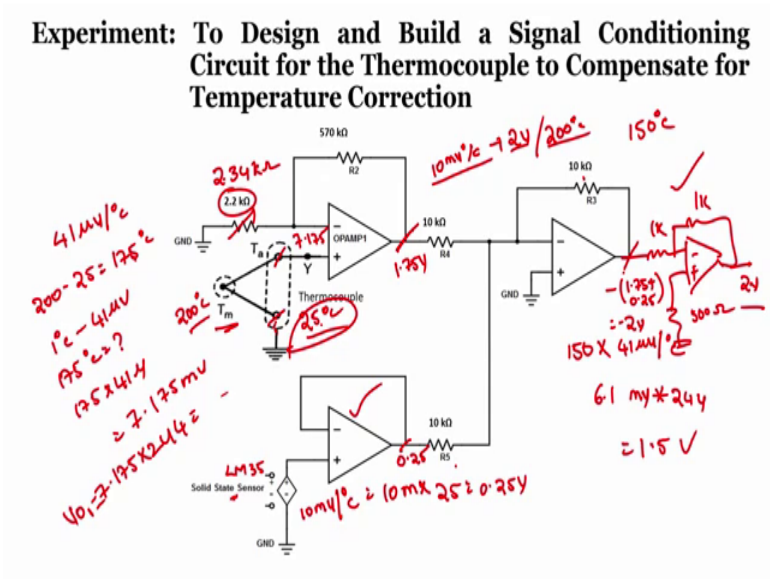
So, this is an isolation amplifier this also gives an output as 0.5 volts right. So, now, what is this? This is an adder circuit is not it 10 k; 10 k, so the gain is 1. So, 1.5 plus 0.5, I will get an output as minus 2 because of inverting configuration we will get an output as minus 2. So, when you see the complete system output it shows you a 2 volts forget about the phase look into the magnitude of this, we will get a 2 volts. When you look into the 2 volts we can understand that 2 volts is nothing, but 200 so that means, here unknown temperature is at 200 degree centigrade.

So, this a way by simply adding unknown temperature value right to your output voltage where the both the system should have the same sensitivity factor we will get an value. So, how do we change the phase? So, if you want to change the phase we can use one more non inverting amplifier sorry inverting amplifier configuration here with the gain of 1, 1 k, 1 k or 10 k, 10 k. So, 10 1 k parallel to 1 k this is nothing, but 500 ohms. This is to eliminate the effect due to the bias currents right we get 2 volts as an output.

Now what if? So, one condition we have seen. What if the unknown temperature this is a 200, consider this as a 200. Finally, I should get an output as 2 volts, but the reference temperature is at 25 consider 25 degree. Now will this value will be 8.2 milli now or 6.1 no right.

Since, the reference temperature is changed right we will get an output as. So, when we say this is a compensating; that means, this should always show at 2 volts when we are T m a measuring temperature is 200 degree no matter what your reference temperature is at.

(Refer Slide Time: 39:28)



So, since it is 25 degree centigrade and we know the sensitivity factor as 41 microvolt per degree centigrade for thermocouple. So, now the difference is 200 minus 25 which is 175 degree right, 175 degree. So, 1 degree corresponds to 41 microvolt. So, 175 degree will be how much? So, 175 into 41 micro the value will be when I calculate 175 into 41 micro this is nothing but 7.175, yes 7.175 millivolt right. So, now the new value is 7.175.

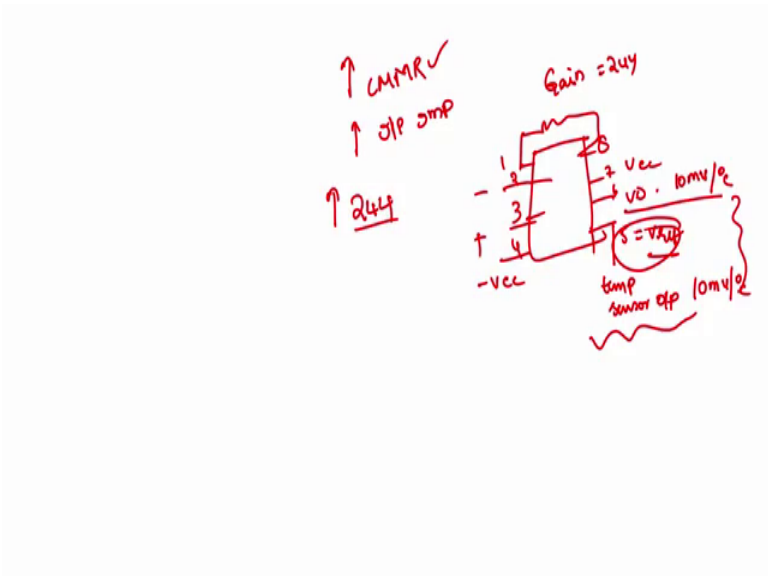
Now, what is the gain of first op-amp 244? When I multiply 7.175 milli with the 244 to get an output voltage of op amp 1 right observe into 244 that is nothing, but 1.75 volts. So, now the new value is 1.75. So, when if I look only the output of a op amp 1 we can understand it is at 175, but actually speaking it is not at 175; it is at 200 degree centigrade, but when I look into the output voltage at this point.

So, since this temperature sensor is also at this reference junction. Since at 25 degree LM 35 gives you an output as 0.25 volts is not it. Because sensitivity factor is 10 millivolt per degree centigrade, so 10 milli into 25 which is which is nothing, but 2.5 volts sorry 0.25 volts right. So, this is nothing but 0.25. So, what is a gain of this op amp 3? The gain of the op amp 3 is simply one and this is an adder circuit. So, we will get an output as minus of 1 into 1.75 plus 0.25 we will get output as minus 2.

So, we have one more op-amp configuration here with changes the phase to 2 volts. So, as a result no matter what so it is showing 2 volts for 200 degree centigrade even though the reference junction temperature is keep on changing. So, by using this particular circuit we can simply compensate for the effect due to we can correct for the effect due to the temperature at reference junction.

Now since, we are using non inverting amplifier configuration we are using so many number of op amps and resistors. What if I go with an instrumentation amplifier? If you understand the instrumentation 3 op-amp base instrumentation amplifier the advantage is it will always have higher CMRR value dB. Since the reference since your output of thermocouple is also in micro volts which is almost close to 0. We should always have to go with an higher CMRR in this case so which will be which will be useful if you go with an instrumentation amplifier too.

(Refer Slide Time: 42:48)

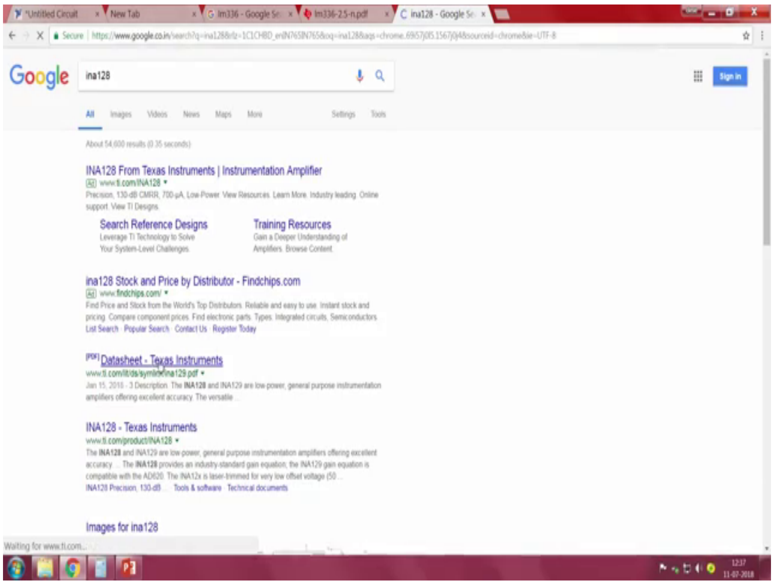


And another thing is that you need to also have an adder circuit right and input impedance should be always higher. Now if you see instrumentation amplifier instrumentation amplifier will always have very high CMRR value sorry input impedance too input impedance right. And we also have to apply a gain of 244 244 to our thermocouple right.

So, in this case by using this op amp 1 we are setting a gain of 244 and even with an instrumentation amplifier we can design we can choose a resistor value such that it gives a gain of 244 right. But what about what about adding of this adding of this the output of a LM 35?

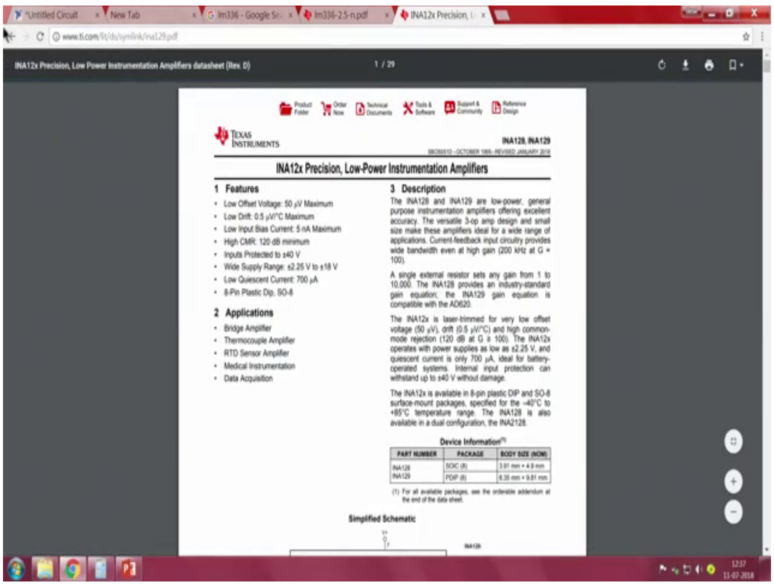
So, rather than using these three right; if you refer your any instrumentational amplifier op amp right 1 and 8 will be always gain. So, we can choose a resistor such that which has a gain of 244 and 213 is nothing, but minus and positive right 4 is minus V cc right 5, 6, 7.

(Refer Slide Time: 44:28)



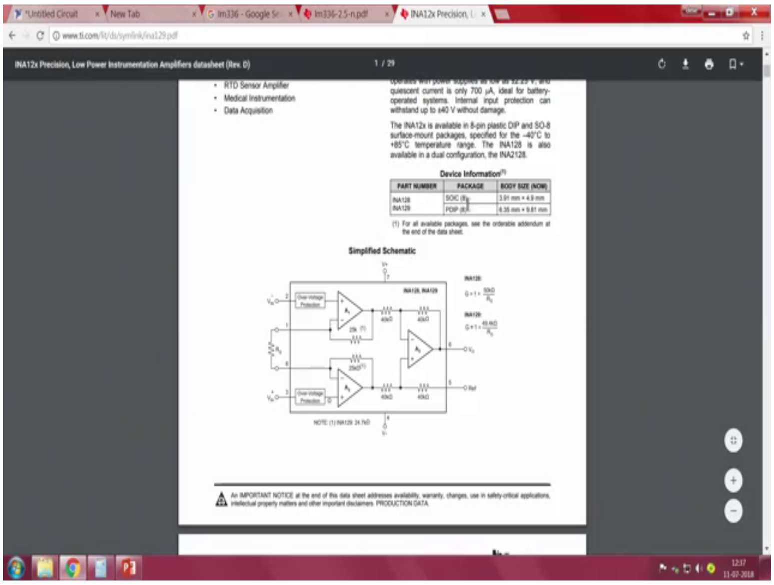
So now, let me open instrumentation amplifier. So, I will take INA128, in this case I will be using INA128 instrumentation amplifier.

(Refer Slide Time: 44:37)



So, this is both for INA 128 and 129.

(Refer Slide Time: 44:42)



If you see at this point right 1 and 8 R G, so the RG by choosing RG as a proper value we can get a gain of 244 in this case sorry this one 244. So, if I connect thermocouple to V in minus and V in plus rather than having connecting a reference to simply reference to ground. If I connect a the reference value from the temperature sensor LM 35 temperature sensor. Whatever the output voltage will be the addition of V naught plus this reference value which gives an output as V naught the correct temperature corrector factor. So, as a result with a single instrumentation amplifier IC we can even design the circuit right. So, this is our 2, 3, 4, 5, 6 and 7.

So, this is our V reference this is our V naught this is our Vcc right rather than connecting V reference to ground what I will do is that. I will connect it to temperature sensor output. Now since your gain of this is also the gain of this op amp instrumentational amplifier is 244. The output voltage will be 10 millivolt per degree centigrade, and temperature sensor gain is also 10 millivolt per degree centigrade. If any reference junction temperature is changing as a result the reference voltage will be changing.

So that means, the V naught the now the V naught will be addition of whatever the voltage we get plus V reference value, so which will be equal to this value. So, with simple instrumentation amplifier even we can construct you know cold junction compensation circuit.

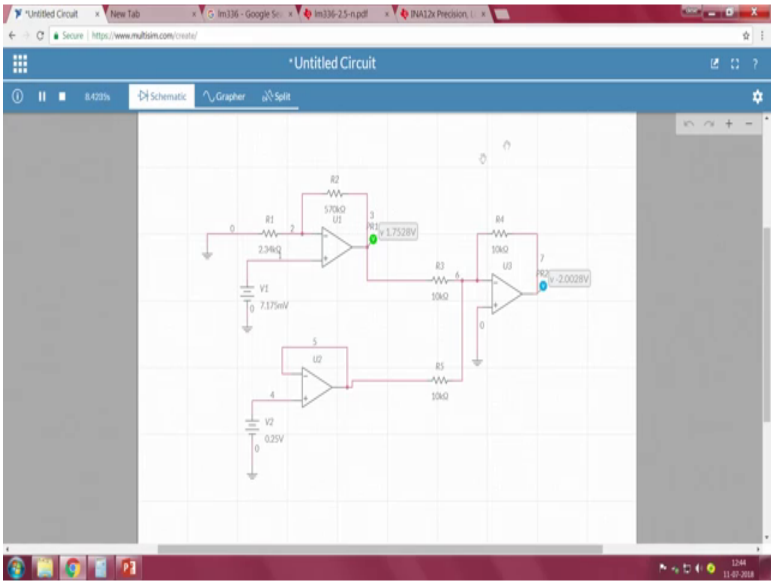
(Refer Slide Time: 46:46)

So, let me show you thermocouple. So, if you see this it has an internally 2 dissimilar wires. Now this is a one junction where the measuring unit will be this is where the unknown temperature can be you know the unknown temperature unit can be connected to. And whereas, this is the reference junction ok.

So, since these are of two different metals you can see 2 outputs here one from one single metal, other one from another metal right. So, these two should be always onto the same junction right. So, that since these two has to be placed on in the reference junction, since these two has to be placed on the reference junction right. So, whenever any temperature sensor another temperature sensor is connected that should be connected close to this wire right.

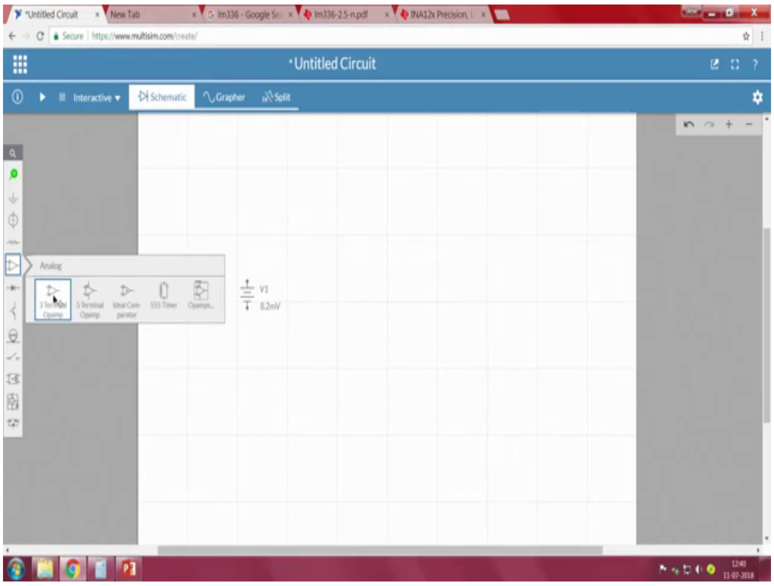
So this is what we have seen in our module. So, in this case I am not going to show any experiment the reason is that it requires you know the heating unit and the we should understand what is a unknown a known temperature in order to compensate for that. So, rather than that I will just explained you using a multisim to make you understand about how do we compensate? How to design a signal conditioning unit in order to you know compensate for any effect due to a change in the cold junction temperature. Let me show you the working of this using a multisim.

(Refer Slide Time: 48:16)



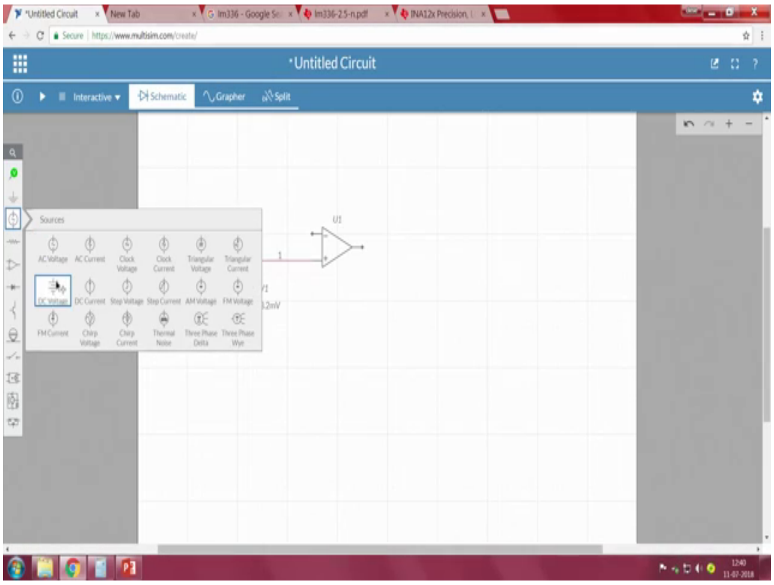
So, since thermocouple is a self generating I will consider as a voltage source considering as a voltage source, but the value should be in a microvolt. So, what I will do is that? Let me set is as 8.2 millivolt, because 8.2 millivolt is an output from thermocouple. If than a T m temperature value one junction temperature is at 200 degree, another junction temperature is at 0 degree right.

(Refer Slide Time: 48:46)



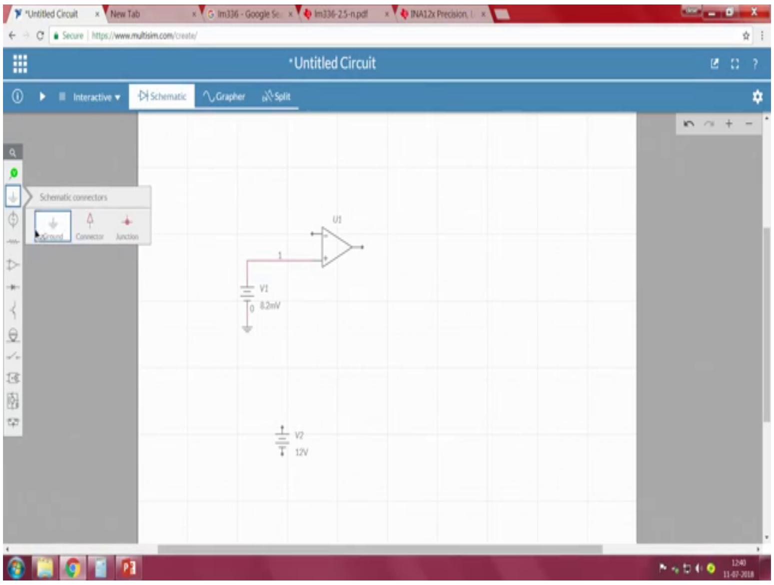
Just for us to understand I am taking a non inverting amplifier configuration. The positive is connecting to the output of thermocouple.

(Refer Slide Time: 48:58)

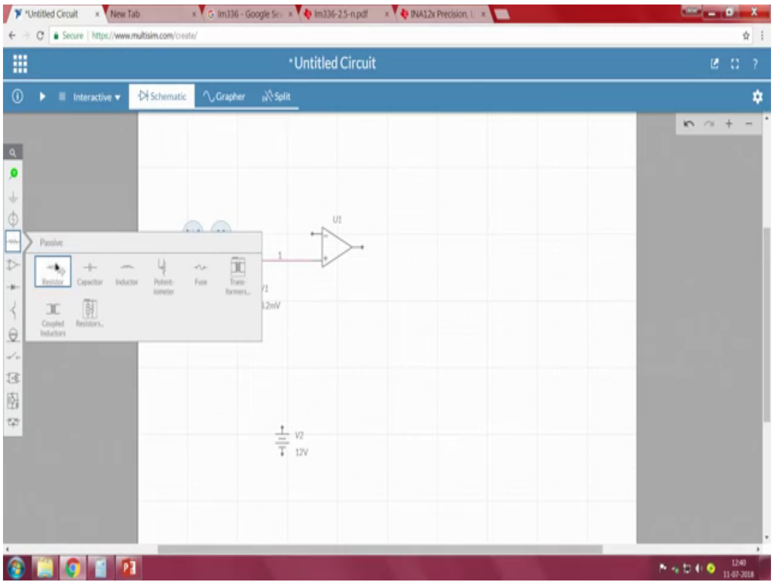


Another terminal should be ground whereas you need 2 resistance.

(Refer Slide Time: 49:07)



(Refer Slide Time: 49:10)



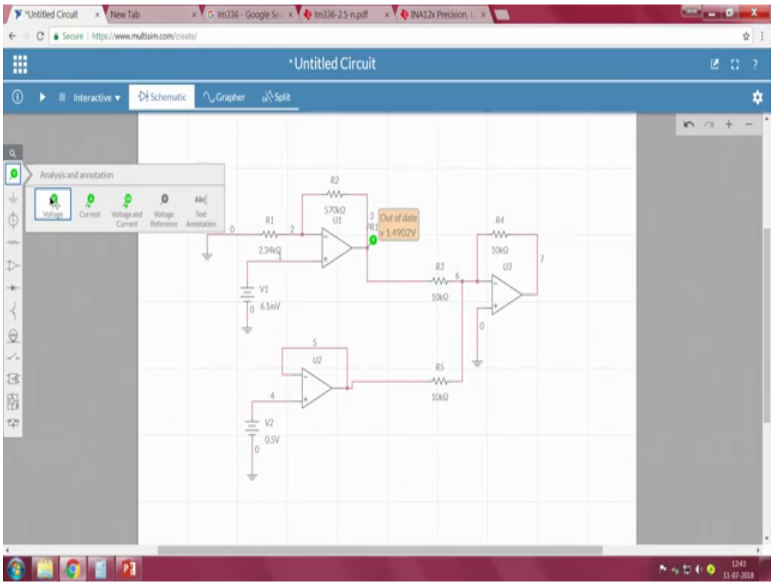
This should be 2.34 or we can take a part 2 2.34 kilo ohms and a one more resistor here. The value of this resistor should be 570 k, 2.34 and 570 k, 570 k. Now if I measure the output voltage simply at this point. Let me run this I have to close this delete this delete. If I run the circuit we can see if the thermocouple is at 200 degree centigrade we will get an output as 2 volts. But what if the reference junction is not at 0 degree?

So, one case we have seen if it is a 6.1 milli, if your reference junction temperature is at one point is at 50 degree centigrade, so we got 1.5 volts right. So, simply with one particular op amp we cannot compensate for the temperature correction at cold junction. So, for that we are using one more temperature sensor. So, I am representing temperature sensor the output with V 2 voltage right. So, if it is at 50 degree centigrade. So, as per you know the temperature sensor sensitivity 10 millivolt per degree centigrade. We will get an output as 0.5

So, this V 2 is a real realization of your temperature sensor and I am taking voltage faller simple voltage faller. So, positive I am connecting temperature sensor output I am connecting it to here and the output I am connecting it here right. Now I will take another op amp which access a difference amplifier this should be tilted and rotate.

So, we have chosen this as 10 k I am also taking it as 10 k. one more 10 k at the feedback, and this should be connected to ground. Actually speaking this should be connected with the 10 kilo 10 kilo 5 kilo ohms resistor in order to remove the effect due to the bias currents. One more 10 k at this point it access an adder connecting it here.

(Refer Slide Time: 51:54)



Now, observe the output voltage at this point now 6.1 millivolts at V 1 corresponds to the output from thermocouple which means that if your reference junction temperature is at 50 degree centigrade. And whereas, thermocouple another junction temperature is at 200 degree centigrade the output voltage that we get will be 6.1. Now, because of the reference junction temperature sensor reference junction is at 50 degree. Since we are placing another temperature sensor which is V 2 so, it shows an output as 0.5.

Now, when I run the circuit still we can see minus 1.9 and which is nothing, but minus 2 volts no matter what since we are using compensation by placing an another temperature sensor and the signal conditioning circuit. Even if your reference junction temperature is at a 50 degree we will get an output as minus 2.

Suppose if it is at 25 degree we know that the value will be 7.175. So, I am changing it to 7.175 millivolt right. When we see that so; that means, this voltage should be 0.25 right still we can see that minus 2 volt. So, no matter what if we change the reference junction temperature right. If we change the reference junction temperature it will always be at you know minus 2 volt. So, it is compensative.