Sensors and Actuators
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Lecture – 30
Signal Conditioning Circuit for Temperature Sensors

This is a very interesting lab class because we will be teaching you extremely important Signal Conditioning unit, where you will be looking at lot of you know interfacing modules including your amplifier, including your ADC, including your controller right and we will be teaching you temperature sensors and how can you know how can you design the circuit for this kind of temperature sensor and we will demonstrate there is in the laboratory that we have in my department.

So, focus on this particular lab class. If you have any questions feel free to ask and we have designed particularly this lab class so that you can understand that you can not only use temperature sensors, but you can also use several other kinds of sensors if you understand the signal conditioning units. This will be like an interfacing unit or module between your sensor and your display. till then you take care I will see in the next lab class. Any questions feel free to ask me in through the NPTEL forum. Bye.

Welcome to the module. Today we are going to see the design of a signal conditioning circuit for the temperature sensor. In order to design any signal conditioning circuit first, we should understand the requirements of our system. after that, we should understand the complete system requirement. After that, we should understand the characteristics of the input system as well as the characteristics of the output system.

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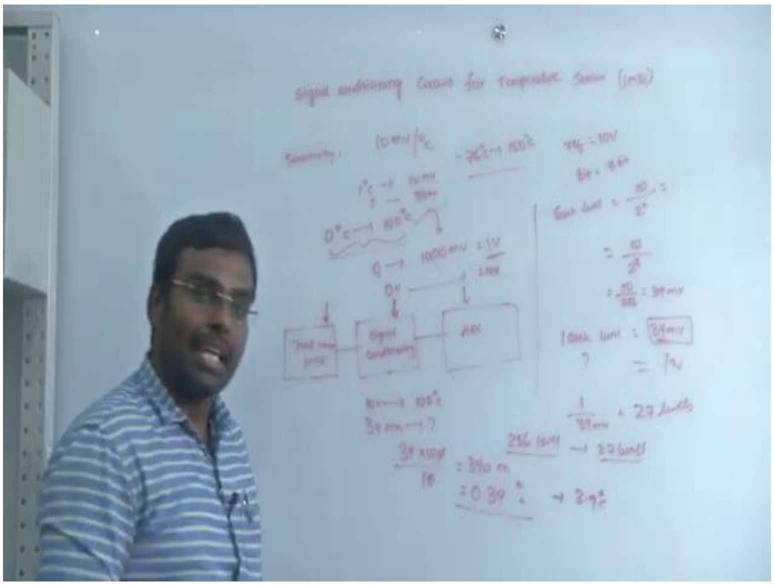

So, in this case, since our intention was to go with LM35, first let us know the datasheet of LM35. When we look into the datasheet of LM35 it provides the information called sensitivity. the sensitivity of the temperature sensor is 10 millivolt per ^{0}C. What does it mean? For every 1^0 rise of temperature, it gives an output voltage of 10 millivolts.

So, what it means? It means it is basically a semiconductor-based temperature sensor where based upon the change in the physical parameter, in this case, is the temperature will be converted into the electrical output voltage and that electrical output voltage is millivolts in this range. the main intention you know the use of a signal conditioning circuit is in order to meet the requirements of the temperature sensor to the next stage which is our ADC circuit.

So, that means, if we look into the if I represent the complete system using a block diagram way. if I say this is my temperature sensor which is LM35 and if I want to interface to ADC which means another system we will use some kind of you know signal conditioning circuit or interfacing circuit in order to meet the requirements of ADC from the temperature sensor. Why do we require it? The reason is that when we look into when if we directly interface the temperature sensor to the ADC circuit the accuracy of the complete system will come down.

What do you mean by this accuracy in this case? Excuse me. When we see ADC if I represent say the reference of ADC is 10 volts. and if the bit resolution of ADC is the 8-bit resolution we know that this complete 10 volts will be divided into 256 number of levels. How? That means each level height can be represented with reference voltage ÷ 2^n. since n is 8, 2^8 which is 10 /256 which is 39 millivolt.

So, which means that each level height is 39 millivolt and total it will have 256 in the number of levels. if I say the complete system has to be operated within a temperature of 0^0 to 100^0 where this is the reason of interest even though the temperature sensor can go up to -75^0 centigrade to +150^0 centigrade, but our reason of interest is between 0^0 centigrade to 100^0 centigrade.

So, which means that the temperature sensor without any signal conditioning circuit can provide an output voltage from 0 millivolts to 100x1000 millivolts which means 1 volt. In order to utilize a complete 100^0 this 1 volt will be corresponding to how many numbers of levels if we calculate. Each level is 39 millivolts. 1 volt will correspond to how many number of levels out of 256 number?

So, that means, 1 / 39 milli. Which means it will use a total of approximately 27 levels. Out of 256 levels if we directly interface sensor to ADC it can only utilize 27 levels the remaining it is not utilizing. rather than using that if I can able to utilize the complete output voltage from the temperature sensor to all the levels of ADC, then the resolution of the ADC is the accuracy of the complete system will be higher.

So, what I mean to say that in this case if we observe the minimum temperature that it can measure is only 39 millivolts. What is the corresponding volt, what is the corresponding physical parameter for 39 millivolts? If we root to the calculation why do we have to do? When we look into the temperature sensor you will understand the physical parameter which means, in this case, is of temperature only by looking or by observing the output voltage that temperature sensor is giving in this case.

So, that means, if the sensitivity is 10 millivolts per ^{0}C 39 millivolts will be corresponding to. 39/10 which means the resolution of the system is 3.9^0 which are approximately 4^0, but whereas, if I can utilize complete levels then each level height will be. if I want to utilize complete levels of ADC so that this complete 1 volt will be divided into 256 levels will be 256 level then the accuracy, as well as the resolution of the complete system, will be higher, but how do we do that?

And, not only that when we are designing this particular signal conditioning circuit another advantage of going with signal conditioning circuit is that the any mismatch between the temperature sensor and ADC will be completely minimised by using a signal conditioning circuit. The interfacing circuit should always have to have a property of you know providing proper matching between the output sides to the input side of the next circuit. because of that reason we generally go we design signal conditioning circuits using operational amplifiers.

Now, in this case, the whole idea is that 100^0 has to be represented with, that means, now in this case if we observe 0 volts is represented with 0 volts; 100^0 is representing with 1 volt. But, whereas, if to utilize the complete levels of ADC, if I represent 100^0 with 10 volts whereas, 0^0 with 0 volts my problem would be solved. that now in the previous case only 27 levels were utilizing whereas, if we have 10 volts as an output for a 100^0 all the levels will be utilized.

So, that means, what is the resolution of temperature sensor right now of the complete system right now? One thing is that if we calculate if we do the recalculation of the utilization of the resolution of a complete system. 10 volts are represented with the 100^0 centigrade and now I am getting 39 millivolts; which means that 39 x 100/10 which are 390 millivolts. If the temperature sensor has a resolution of 0.39^0 centigrade 0.39^0 centigrade, then the complete system can give the change in the input temperature for every 0.39^0 centigrade which is less than 0.5^0 centigrade.

But whereas, if we are not using the signal conditioning circuit if we are not using this particular signal conditioning circuit then the resolution of the system is 3.9^0 centigrade. one thing it is clearly understood that using a signal conditioning circuit can achieve the best accuracy as well as the resolution of the conditional circuit. You may ask it will it be not useful if you go with the higher bit ADC? Yes, it can also be achieved even higher with ADC. But, the problem with higher bit ADC is that cost.

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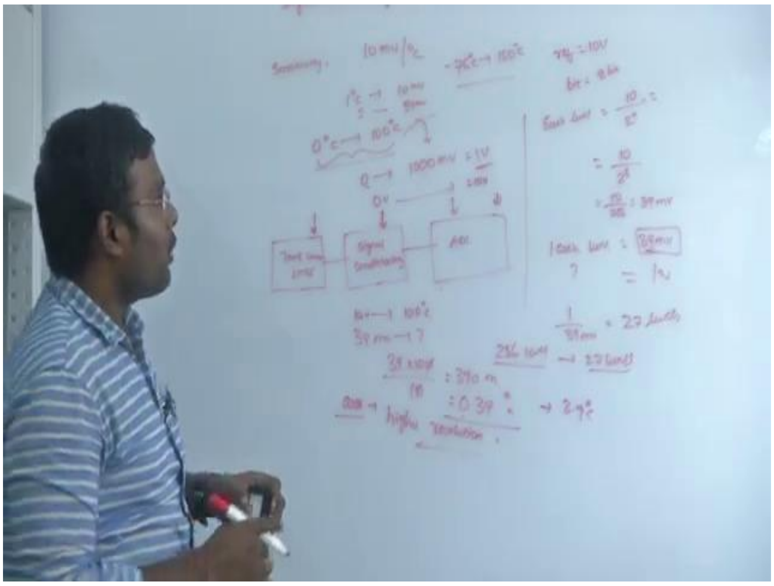

So, one way with a low cost by using a simple operational amplifier between the output and the input side of an ADC can utilize or can achieve higher resolution now. it is clear why we are going with the signal conditioner. Now, the next thing we will see how can we implement such a system to get 100^0 with 10 volts. in order to understand that let us see well let us calculate the gain factor.

So, now, let us see how can we implement such kind of signal conditioning circuit using operation and amplifier. Before implementing it let us calculate what is the logic behind in order to convert that 100^0 centigrade or the output from the 100^0 centigrade to you know to the input of ADC.

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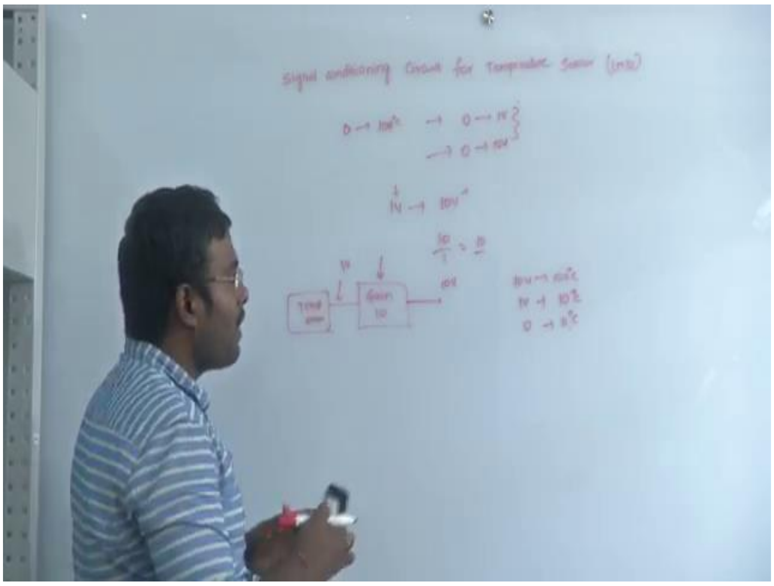

So, which means that in our case 0^0 to 100^0 is the reason for the interest or the operating range that we are looking for developing a system. we are getting output from generally we get an output of 0 millivolt to 1 volt, but whereas, if we can implement from 0 to 10 volts then the resolution of the system will be higher.

The minimum change that it can record is of 3 0.39^0 centigrade. However, provided our temperature sensor could change our provide an output signal for a change of 0.39^0 centigrade. Now, so that means, 1 volt I should convert into 10 volts. the output is 10 if the input is 1 and this is completely linear even this is completely linear.

So, whenever there is a change it will also output also has changed at the same factor, but what is that factor which has to be provided to the system or the interfacing circuit such that any change in the input should change by that. that means, if I want to do that we can say output by input which is nothing but gain 10.

So, that means, if I have a temperature sensor which in this case is of LM35 and if I provide a gain amplifier with a gain of 10 give it as in input of ADC my problem is solved. That it utilizes all the levels of ADC or even if you do not have an ADC we can easily visualize the effect of having a gain of 10 into the system. how can we utilize it? In a previous case if we do not have it. we are by looking into the output say if I get 1 volt which means that we can understand the temperature sensor of 10 volts.

But, in this case how it will be represented? It will be represented in 10 volts which means that if I say 10 volts I am getting the output of 100^0 means the physical parameter or physical interest is 100^0; the temperature is 100^0 in this case. If we are measuring 1 volt which means that we are getting 10^0 centigrade right whereas if the input is output is 0 which means that the output is also 0 or the input is also 0^0.

So, understanding this is very easy with the higher gain; higher gain lower the higher the signal to noise ratio everything will you know will be easy. Now, how can we implement it? there are different ways of doing it either we can go with an inverting amplifier or non-inverting amplifier configuration, but we will see one by one implementation of gain of 10 with inverting amplifier as well as a non-inverting amplifier to.

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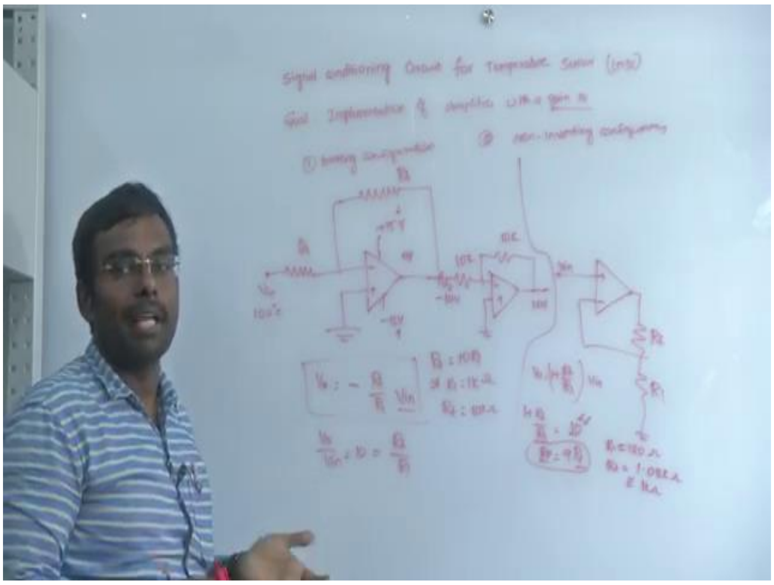

So, the goal of this is the implementation of the amplifier with a gain 10. If we recall the working of. This can be done in two ways – one by using inverting configuration and the other one is non-inverting configuration using operational amplifiers. In case of inverting configuration we will use an inverting amplifier if you recall the connections of the inverting amplifier will be always provided to +15 one side and -15 another side these are the operating voltages of op-amp.

So, that the saturation voltage of the output of the operational amplifier entirely depends upon what is a +Vcc and -Vcc and it will also contain as you remember if we recall it will always have a three terminals: one terminal is for the input which is the negative terminal which is nothing, but non-inverting sorry inverting terminal, the other terminal is positive which is the non-inverting terminal other one is an output.

In case of inverting amplifier configuration since it is an amplifier, we should always have to have negative feedback and the positive terminal should be connected with the ground and we will also have another resistor that is connected. If this is input if this is output V_0 I am representing and if I say this as Rf and this is R1 the gain the output voltage of the inverting amplifier is -(Rf / R1) x Vin.

So, since in our case we require to have a gain of 10; that means, V_0 / Vin should be 10 which means Rf / R1 should be 10. If R1 is 1K and I consider Rf as 10-kilo ohms, my problem solved I will get a gain of 10. But, the problem or in this case what is the problem is that since it is an inverting configuration op-amp configuration the output voltage and will always be out of phase with V in.

So, if we provide a positive input voltage you will get an output as negative if that is then we can go with, but in our case if the next states have a reference of 0 to 10 volts where it cannot accept the negative signal then I have to change the phase from 0 negative to the positive. in order to do that what we do is that we will take another operational amplifier with a gain of 1, but in even in this case we have to go with the same inverting operational amplifier. 1, in this case, I will take 10K, 10K or 1K, 1K.

So, now, if both Rf and R1 are the same resistance will get Rf / R1 as 1. V_0 we will be followed by Vin. as a result even though if for 100^0 centigrade if this is giving -10 volts, here we will get the output as 10 volts. that we now we could able to achieve 10 volts for 100^0, but this is by using an inverting operational amplifier configuration. we will be using two operational amplifiers.

So, whereas, in case of a non-inverting amplifier configuration if you recall the working of the non-inverting amplifier Rf, R1, say this is Vin. V_0 is equal to (1 + Rf / R1) x Vin. now, in this case, if I calculate if I want to know what is the values of Rf and R1 we should substitute our required gain. we will get Rf is equal to 9 times of R1. if we can consider a resistance of Rf and R1 in this fashion we can understand we can get a gain of 10, but the only problem is that finding out the exact resistance of R1 and Rf in order to get a required gain is little challenging, but you can use of you know potentiometers even to get the same distance.

But, in this case, If I say R1 has 120 ohms so that Rf will be 9 times of 120 the value will be 1.08 K = 120 x 9. 1.08 k, but finding 1.08 K it is a difference closely associated resistance is 1 kilo. if I use 1-kilo ohm and 120 we will get a gain at close to 10. but in case of a non-inverting amplifier with a single operational amplifier, we could achieve the same gain as 10. just remember the input should be connected to the V in you know non-inverting terminal in case of inverting configuration using R1 resistance whereas, in case of the non-inverting amplifier will be directly interfacing to the positive terminal of the operational amplifier.

Now, we will see the implementation of both inverting amplifier as this is non-inverting amplifier for a gain of 10 using our TI board, then we will understand the working of each system then I will interface LM35 temperatures sensor to this and by looking into the output voltage you can understand what is the system temperature at present ok. Let us see about working using the board.

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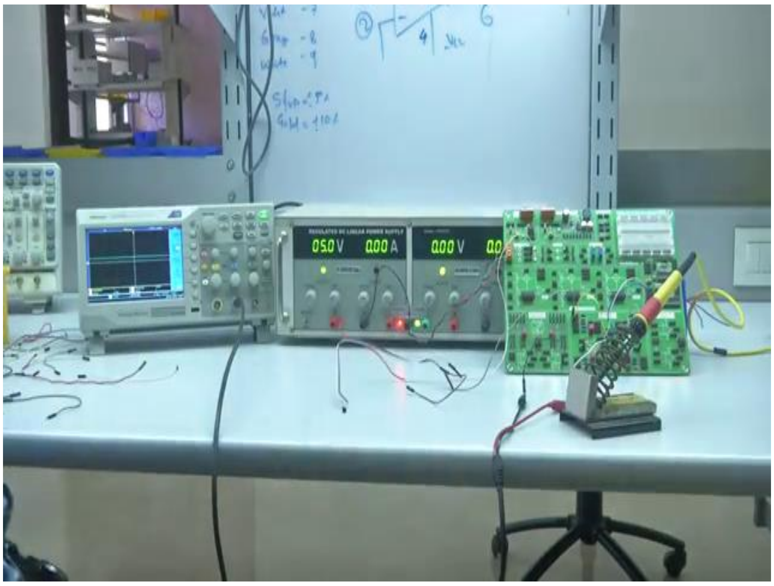

Now, we will see the connections of what we have discussed you know in previously using the implementation of the inverting amplifier as well as a non-inverting amplifier for a gain of 10 using our TI board. if you look into our TI board it is analogue system lab kit pro so; it contains a different sub system. here on the bottom side if you observe there are three different variants of the operational amplifier. the first variant that they call it as op-amp type and inverting where it along with the operational amplifier which is, in this case, is a dual operational amplifier, it has different resistances as well as a capacitance.

So, any configuration that we want to implement can be easily implemented using this using any type of subsystems at this point. there is another thing op-amp type 2 full it also contains a different resistance as well as a different capacitance when we are going with the say, for example, filter configuration we can use either op-amp 1 and op-amp 2. But, the challenging part here would be. it is fixed with you know the different fixed number of resistances.

However, in case if you want to use extra resistances are the resistance which resistances and capacitances are not available on the board by using the breadboard and by using the jumper connections we can simply connect from the breadboard to the operational amplifier say. Along with these two, another type of op-amp subsystem which is op-amp type 3 basic, where it has only the connections of input-output you know connections without any resistances and capacitances.

So, like the basic design can be completely implemented, but any resistance or any passive elements that you have to use have to be connected to connected using this. if we carefully look it this is the IC which is the TL 072 which is the dual op-amp. since it is very difficult to understand you know the configurations directly the negative terminal has been connected with 4 buck connectors, positive terminal, and the non-inverting terminal also being provided with 4 positive 4 buck connectors.

And, also has a separate pins for the ground and 10 volts power supply if we want to provide you know single power supply only to the board this particular sub system at this point we can do or there is also option where by using a main power by providing +10±10 and the ground we can either access the power choosing this port or it can direct you know internally it has been already rooted for you know connections from this to powering all the operational amplifier as well as other circuits available in the board. in order to tab the output voltage is again they have provided with a 4 buck connectors.

So, now what we do is that we will use this particular configuration either this or this and we will implement both inverting amplifier configuration, non-inverting amplifier configuration we will see whether the design circuit is giving a gain of 10, how do we test it? We will be applying a non-input voltage, we will measure the output voltage and the difference and output by input give the gain of the complete system. By looking into what we will see whether we have achieved the targeted gain as well as the practical gain or not. What I mean the practical gain and the targeted gain are the same or not.

So, if you carefully look into that along with this other type of operational amplifier this type of subsystem also has another type of subsystems like analogue multipliers, it also has diodes where if I want to use a particular diodes we have an option where you can directly connect and you can tap by using this buck connector. It also provided with trimmers in case if in if it is required along with that it also has a DC-DC converter provision for placing the transistors LDO regulators too.

And, they have also given with the dated digital to analogue conversion. instead of using the breadboard and connecting all the ICs on the breadboard and use wires to do that by using simple jumpers whatever the design that you required to do we can use using this board with a minimal effect ok.

So, now, let us see the implementation of the connections of implementing both inverting amplifier configuration and non-inverting. let me go with a non-inverting amplifier configuration. Say, in order to provide a gain of 10 if we recall the circuit that we have used we require a feedback resistance of 10 times the input resistance. I will take input resistance of 1 kilo, so that our feedback resistance I go with 10 kilos. let me take a few jumpers in order to do the connections.

So, if you observe here what we required the input has to be provided from 1K. if we carefully see to the inverting terminal 1 mb is connected to OPA-2A in. OPA-2A indicates this is the second subsystem on the operational type, A indicates since it is a dual op-amp it has you know divided with A and B; channel A indicates the first operational amplifier, B indicates other operational amplifiers excuse me.

So, to the negative terminal along with that it has provided with fixed resistances the resistance they have given was 1K, 2.2K, 10K, 4.7K and 1K whereas, another end of the resistance if you noticed it is you know connected to the buck connectors. Similarly, the output side if I see it has provided by the buck connector. what I will do is that since the input has to be connected to the R1 resistance I will take a jumper and input resistance should be 1K.

So, the input I will be providing at this terminal; that means, to the input one end of the resistance it is provided with it will be provided with an input whereas, another end is directly connected to the negative terminal whereas, whereas, we require a feedback resistance of 10K. in this case, the third resister is a feedback resistor where the feedback resistor should be connected between the negative terminal and the output.

So, since one and of the resistor is connected to the negative terminal. simply by using another jumper connecting at the other side of the resistance to the output shows the connection for feedback. that means, now I have given connections for both inputs as well as an output feedback resistance, but the positive terminal which is the non-inverting terminal should be connected to the ground. what I will do is that I will take the positive terminal if you noticed it is also having a ground you know buck connectors. if we simply connected between the ground and ion place which means, that the positive terminal is connected to the ground.

So, now, I make the connections of the first operational amplifier, let us see the working of it. in order to do in order to understand the test the working and the gain of this operational amplifier we have to provide a power supply. The power supply will be connected to this. since here it is grounded which means that this and this grounds are same internally shorted whereas, the positive internal +10 and -10 whatever you noticed here if we connect power to this automatically the power to the all the operational amplifiers will be you know will be provided using internal wiring.

So, let me connect the raw power to the main power sorry let me connect the output from the linear power supply DC source to this particular to these connectors. And, we will provide an input known signal at this point and will observe what is an output we are getting, then we can we will calculate output by input in order to understand the gain let us see the connections.

So, what we have made, the power supply the DC power linear supply that we have has a dedicated power source for +15 -15 and ground. we have connected the +15 to the main power one side which is the positive terminal; even though the board chooses +10 -10 we have connected to the 15 because the operational amplifiers can withstand up to + or -18 volts. that is why since we have a dedicated power supply for 18, we have directly connected it and for a negative, the green wire has been connected to the other side and the ground which is the common terminal, in this case, is connected.

So, since we have to provide a known input to the system we are taking one the first channel in that regulated DC power supply. the positive terminal at this point is connected to this you know 1K input 1K resistor to the input side of 1K resistor along with this in order to visualize and in order to see the input and output responses it is connected to the first channel of CRO. Similarly, to visualize the output voltage to the second channel of CRO DSO, in this case, we have connected the output terminal to this. The grounds are common which is commonly connected.

Now, let me switch on. let us understand the working of letting us see by varying the input voltage what is the output that we are getting it. now, in this case, the yellow represents; we have two channels, this yellow represents the input side. whatever the input is being provided to the positive terminal of an operational amplifier sorry to the resistor input of a resistor output indicates an output from the blue indicates output from the operational amplifier. since the power is 0, the input voltage is 0 in this case. the output and input are simply 0.

So, if we observe carefully you know the vertical one box represents 500 millivolts whereas, for the blue one box represents 2 volts. Since a gain of 10 if we provide 100 millivolts as an input to the system we will get approximately 100 x 10, 1 volt. but this is not the right way in the sense we are testing our inverting amplifier configuration we will provide the known input and we will measure the outside.

So, let me provide the input voltage. I am giving the input of a 100 milli. here if you observe the mean value it is approximately 100 millivolts the maximum is 160; whereas, if you observe the output of 1.31 volt ok. let me zoom in a little bit. I will change both is of 200 million 2 volts. easy for us to understand fine. let me change it to 100 milli. now, if we see we are provided a mean of 103 millivolts, we are getting a mean of -1.06 volts which is approximately 10 times.

So, let me go with another voltage which is of the mean of 200 milli and let us see how much you are getting it. here if you observe the mean of input is of 193 millivolts we are getting close to the mean of -2.1. if we observe carefully the output voltage input is positive, but the output we are getting in the negative which indicates that because of you know inverting amplifier configuration we will always have a phase a difference, a difference in the phase magnitude. A magnitude will be 10 times the input, but the phase will always be different that is because of our you know inverting non inverting type of amplifier.

However, if you realize our circuit along with this one stage of the inverting amplifier for configuration again we have to go with another stage of inverting amplifier configuration then we have to observe it, but before that let just have a look. Then, I will go with somewhere around 500 milli. we can see an applied input voltage of 498 milli we are getting -4.91 which is also close to 10; then just go with the 600 supplied input of the mean value of 5.94 milli we are getting a -5.92 volt which is also closed to 10.

So, from that it is clear that as we keep on increasing the voltage just go with 1 volt we should get an output of 10 providers we cannot go more than you know 1.2 or 1.3 volts because if you go more than 1.2 to 1.3 then the output voltage it is since a gain is obtained it will go to 12 to 13 volts. Since the +Vcc and the -Vcc of operational amplifier here provided is a 15 above the saturation voltage whatever it may be the output it cannot be represented.

So, the maximum output voltage is the op-amp can represent can show is only till the saturation that saturation entirely depends upon the power supplies been provided for operational amplifiers. now, if we observe I am giving with a 1 volt let us see what do I get it when I gave input of 1 volt. I have provided input of 1.04 I am getting the output of 10.2. from this, it is clearly seen that it is having a gain which is close to 10. 10 points something, but it is very close to 10, but the magnitudes are same, but there is a phase.

So, in order to correct the phase what we do is that we will use another stage which is also inverting amplifier configuration with a gain of one. Let us see how exactly I am doing the inverting amplifier configuration with a gain of 2. now what will do since we have to realize another you know another says which is by using a non-inverting amplifier configuration with a gain of 1, I will use this particular stage which is OP-2B.

Even in this case we have a dedicated jumper for the negative terminal, positive terminal as well as output also it has been the board has been provided with different resistances, but in this case, since we require a gain of 1, the input resistance should always be equal to the feedback resistance. what I do? I will take another jumper and connect. since we require you know input I am using Rf as well as R1 resistance as 1K the first resistance if I see it is 1 1K.

So, one end of the one end the resistor I am connecting it to the output side of an operational amplifier whereas, another end it is directly connected to the negative terminal. I do not have to do any connections since we require a gain of one the bottom resistor is also a 1K resistor. I will take another jumper I will connect one side of the resistor which is which are you know connected to the jumpers. Is it ok? It has changed.

Since one end is directly connected to the negative terminal another end of the resistor I am connecting it to the output. output, in this case, is this. my connections are done, but I have to observe the output from the output of the second stage. what I have done the CRO probe second channel CRO probe is connected to this. if you recall the output of the first stage anyway have been provided with the to the input of 1K resistor and the feedback resistance which is also anotheR1K is connected to the output, but we have not provided the positive terminal to grow I will take another jumper.

I will connect this particular positive terminal to ground. my connections are done. Again, I have not changed the connections to you know I to the first channel of CRO as well as the second channel of CRO. just have a look at the CRO now. We will observe by wearing the input voltages from 100, 200 till 1 volt, we will observe what is the output voltage. Now, we will also observe along with an out magnitude of the output voltage whether we are getting a positive magnitude or a negative magnitude which is reverse of the input phase that we have connected it.

So, in order to understand that let me if you observe again the blue represents or sky blue represents the output and yellow represents are input. Let me keep both things to the same stage. now, I will apply the input of a 100 milli. here if you apply input applied is of 107 milli, we are getting the output of 1.04 volts but, when you see the phase of both the things, which are positive.

Next, I will go with 500 milli one box corresponding to the 500 milli for yellow. when I see slightly I have to increase the right input applied is of 503 milli, 504 milli output we are getting a 4.96. which is also close to 10 gain of 10, but the same phase. I will go with 1 volt, I am also changing the scale of it. even 5 volts scale. if we observe input applied is of 1.04 1 1.04, the output we are getting 10.3 volt which means the gain is now 10. And, the phase is also the same.

So, with this, we can clearly see that we could able to provide or we could able to design you know the gain of 10 amplifiers right using inverting amplifier.

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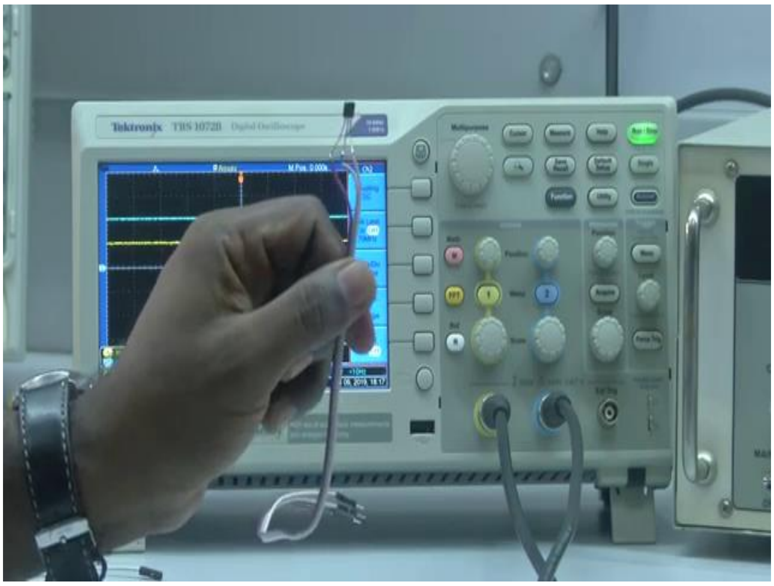

Now, what we do is that here we have an LM35 temperature sensor LM35 temperature sensor we will connect it. the output of this LM35 temperature sensor to the board and we will observe what is the output voltage we are getting from the complete system. Since, in order to understand what is the temperature of any system, we should be looking into the output voltage we can easily do that. How can we do it?

So, since we do not have any heating source we will use a soldering station to which provides which will be kept will be always heated to some particular temperature by we will measure that we will understand by looking into the output voltage of the system at what temperature that heating station is it. in order to do that first, we should understand the terminal configuration of this LM35.

If you observe this when we are facing towards the flat side of LM35 we can see the three terminals. the first terminal is nothing, but a positive terminal which is you know +5 volts we have to apply; the extreme on the right side right some extreme is a ground terminal reference terminal, the output it will be from the central terminal. what I will do? Since maroon brown and white maroon is maroon will apply 5 volts to the maroon, to the brown will connected to the inverting amplifier, input side and to the white, we will be connected to the ground.

So, let us let me connected then we will use a heating station and we will observe whether we are getting any changes in the temperature or we could able to measure the temperature of the heating station. Now, if we see the connections what we have done is replaced the input side of the operational amplifier with an LM35 temperature sensor. if we see the connections of LM35 the input is connected to the 5 volts, the output is connected to the input side of inverting amplifier to the resistance of an inverting first is of inverting amplifier whereas, the ground terminal is connected to the ground and the output again can be measured by using this particular CRO form.

Now, when we look into the output when we look into the oscilloscope here we can see that the mean value represents 2.87 volts. now, if you recall the complete working of the system we know that the gain of the system is 10 and by looking into the output voltage if we understand since it is not connected to any plan right now which means that it is at room temperature. The room temperature is around 28.1^0 centigrade. How can we see it?

The reason is that when we look into the sensitive of the temperature sensor 10 millivolts per ^{0}C 1^0 will be always represented with 10 millivolts. Since we have a gain of 10, 1^0 will be represented with 100 millivolts. But now I got a 2.8 volt which means that it is corresponding to 28.1^0 centigrade. which is also you know compared to the room temperature it is also the same. Now, in order to understand the testing of this one what we do is that we use this soldering station. I will connect the temperature sensor to the soldering station. Let us see whether there is a change in temperature or not.

If we see the temperature started increasing, right now it is at 9.7, 10.3, 10.7 which has been stopped at 10.7 which means the soldering station this particular soldering rod the temperature of the soldering rod is 10.7 volts it is showing which mean that it is at 100.7^0 centigrade. When I remove the temperature sensor it starts cooling. Let it start cooling it started decreasing.

So, right now it is at room temperature. since it is previously heated it takes some time to again now cool it down the little temperature on this. if I touch it cools very fast. here we can see again it is coming down. with this, we can understand that we can use this particular temperature sensor and by looking into the output voltage we can easily understand the output voltage the temperature of the plant.

Now, we will try to realize the same circuit, the same way, whatever we have done for the inverting amplifier configuration we will also try to implement the same by using a non-inverting amplifier configuration. Now, see how can we implement the non-inverting amplifier configuration at this distance. in case of a non-inverting amplifier configuration, we can only use one operational amplifier where the input should be connected to the positive terminal and the in what the feedback resistance, as well as you, know the input resistance, another end of the input resistance should be connected to the ground.

Since we require we require the gain of 10, we have seen the resistance that we require in order to implement for a gain of 10. what resistance we require? We require one 120 ohm resistance has an input and 1K resistance as a feedback resistance. let me take 120-ohm resistance. since here we are connecting external resistor what I will be doing is that I will use this breadboard, I am connecting this 121-ohm resistance to the breadboard hm.

And, one end of this should be connected to the ground. I will take this terminal I will connect it to the common ground whereas, another end should be connected to the negative terminal of an operational amplifier. I will take another jumper from here connecting it to the negative terminal. the input resistance is connected. Next, what is the feedback resistance? in order to connect a feedback resistance if you remember we require a feedback resistance of 1.08 the closest resister which is available in 1 kilo and that 1 kilo is already there here.

So, if I consider the top 1 kilo if you see that one terminal is already connected to the negative terminal whereas, another end of the resistor I will use it is connected to the back connector. what I will do is that I will use either the other end of the resistor connected to the output terminal which we are feedback resistance is also connected. Now, what? The input should be connected to the positive terminal. what I will do I will take. the positive terminal I will connect it to our DC power supply.

So, if you see one terminal one channel from the power supply connected to the positive terminal so since we have to understand the output voltage what I will do is that the second channel of CRO I am connecting it to the output. whereas, the negative terminal should always be connected to the ground since I have a ground terminal here I am connecting it there; then in order to do the comparison between input and output, and the difference you know that the output by input gives a gain of it.

So, let us to understand what is the input we are provided what I will do it I will use the first channel of CRO will be connected to the positive the input term; input of operational amplifier positive terminal of op-amp whereas, the other the black pin which is a ground pin is connected to the same ground. with this, we finished our connections. Let us see the working of the board.

So, let focus on oscilloscope, we will try to increase the input voltage with a steps of you know with a 100 milli, 200 milli, 500 milli and 1 volt at the same way whatever we have seen them previously in inverting amplifier configuration and we will observe what how the output is also be changing. the output by input gives the gain and we will calculate the gain. let me increase the input voltage. If you observe I have a given an input of approximately 300 milli, 296 millivolts, but I am getting an output of 2.8.

When I do the calculation 2.8 / 295 milli. the gain is of 9.49, 9.5. The difference is because we do not have an actual resistance of 1.08 K there will be a slight deviation from the gain, however, but on you know on the bigger picture if we observe the gain is almost equal to 10. Then I will change it to 500 milli. if you observe I have applied input of 485, 491, 493, 500. applied at around approximately 500 millivolts I am getting 4.67 volts. let us go with 1 volt it should generally get 10 volts, but we will get close to 10 which is somewhere around 9.5. when you apply the input of one volt we are getting the output of 9.36 volt.

So, with this we can understand that there will be always you know the selection of resistance with a non-inverting amplifier configuration is little tricky; like tricky in the sense availability of the resistance close to the required game. However, since the input is directly connecting to the positive terminal the input impedance of the complete system is equal to the input impedance of an operational amplifier which is very high. But, however, if you see that it is following as per our required way or the gain is always is almost close to 10.

Now, what we do is that we will remove the connections of you know input side, we will interface it to the LM35 temperature sensor, we will perform the same experiment as what we have seen previously. Now, if we see the connections that I have done is I replace the input from the power supply to the input to non-inverting terminal replace with an output of the temperature sensor, now has been connected to the input of non-inverting terminal. Since LM35 required some power input voltage than 5 volts have been provided from the first channel of power supply.

So, in order to understand the actual temperature right now, the output from the complete stage, been connected to the second channel of CRO. if you recall what was the temperature, room temperature that we measure it was around close to 28^0. Now, if we see that the mean value it is showing it as 2.6 volts. previously it was 2.8, now it is 2.6. The difference is because of the gain the difference in the gain, but however, there is you know the error of 2^0. But, let us observed by connecting you know the working of this LM35 or by connecting it by you know just connecting it to or probing touching it to the soldering station whether we get the same temperature or not.

So, just I connected it. You can see it right? You see it. It started heating, closely it has come to 10.9, 11.2, 11.4 right, 11.8. now, the heating station is heated to a little high temperature the maximum voltage it is showing it of 12 volts which means that it is right now at if we consider the gain of 10, it is at 120^0 centigrade. now I have removed the connection it will start slowly coming down because the converter cooling comes to room temperature.

So, with this we can see the working of a temperature sensor, as well as we can also understand how can we interphase a temperature sensor to the signal conditioning circuit which will meet the requirements of our ADC or any other states that we are connecting and at the same time the implementation of you know amplifier which is an inverting amplifier as well as a non-inverting amplifier configuration for a gain of 10. with this, I hope it is clear the working of a temperature sensor as well as a signal conditioning circuit and it is important when we are interfacing into our any kind of ADCs.

Thank you.