Mathematical Aspects of Biomedical Electronic System Design

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Week – 11

Random Variables and Signal Conditioning Circuits

Lecture – 36

Signal Conditioning circuits units and design

Hello, welcome to the module. In the last module we discussed about a simplest way of converting resistance to voltage. The reason why we have converted the resistance to voltage as the next stage can accept only the voltage, any form of a signal has to be converted into the voltage. So, that it can so that the next stage can easy to process it. Then we have considered different sensors. So, since, we have seen about the discussion about a sensor where the output of a sensor can be of any form, it can be voltage, resistance current or impedance change resistance change or a capacitance change.

So, we discuss the ways of converting a resistance to voltage but what we have seen, using a resistance as simple as resistance to voltage conversion circuit will provide an offset. Though it converts the resistance to voltage, it provides an initial offset when we are designing it and we have also seen how to eliminate and offset. What is the use of different subsystems? What is the role of signal conditioning circuit? What different properties that each subsystem should have so that no loss of the signal from the sensor to the acquisition side and we have also designed the circuit to eliminate the offset to amplify it and different ways of designing that using different operational amplifier configurations.

So, in this we will see another way of converting a resistance to voltage by using a Wheatstone bridge circuit. So, the advantages of Wheatstone bridge circuit is instead of using a one pair of resistive divided network, it uses a two pairs of resistive divided networks, but the output voltage will be difference between these two. So, that we will see how can be used how resistance bridge circuit has to be designed in order to convert this resistance to voltage what is the advantage of using Wheatstone bridge when compared to resistance divided network we will see in today's session.

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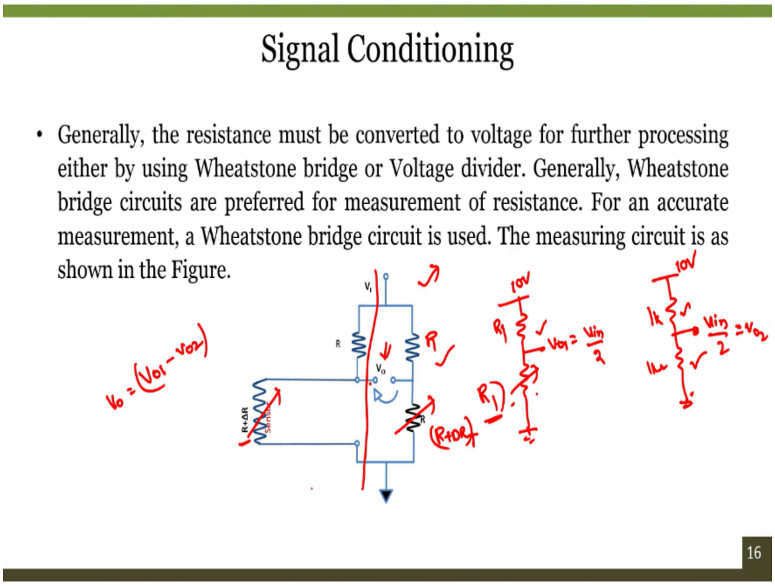

So, Wheatstone bridge circuit uses four different resistors which can be helps to identify the unknown resistance available. So, when you look into the Wheatstone bridge circuit, as here you can see it can it contains if you look into the left side as well as the right side, left side contains one resistive divided network whereas the right side also contains another resistor divided network. The output voltage is nothing but the difference between the first resistive divided network configuration to the second resistive divided configuration. What I mean in the sense, imagine say the previous circuit whatever we have which is a 10 volts which is R_1 which is 1K if I imagine or this is also R_1. R_1 base resistance, the output we know the output whatever we measure is with respect to the ground.

So, this will be is if R_1 if both the resistance are same, then it is $\frac{V_{in}}{2}$ which is 5 volts. These are resistive divided but whereas resistors which uses two pairs of a resistive divided network so but whereas in this case is the unknown resistance which we have to find out whereas in this case, both the resistance are fixed. So, this is also 10 volts the same voltage that we are using. Here it will be always $\frac{V_{in}}{2}$, but here the output voltage depends upon R_1, the sensor but whereas in this case, since both resistance are fixed, so it is $\frac{V_{in}}{2}$. Now this output voltage whatever we measure is also with respect to the ground.

When we take the difference between the first output, the output from the first pair of resistive divided network to the second resistive divided network, then that is nothing but your Wheatstone bridge circuit. So, the V_0 is nothing but if I say this is V_{01} and this is V_{02}, V_{01} - V_{02} but what is the advantage of going with Wheatstone bridge circuit? One is since we are measuring the difference between the two terminals and the selection of resistance will make will provide an output voltage to not to have any offset. It starts from so if what I mean in the sense, if you consider all the four resistance, equivalent or all the other three resistance is same as the base resistance of the sensor under no loading condition, the output world is will be always starts from 0.

So, the effect due to that we have seen in the resistive divided network in the previous case where it always gives an offset of $\frac{V_{in}}{2}$ or half of your input voltage by using another pair of resistive divided network and differencing the output voltages will compensate for the offset created by the resistive divided circuit alone. So, this is the advantage of going with resistive Wheatstone bridge circuit.

And another advantages so, when we have two different sensors, one with R + ΔR, other one with R - ΔR configuration or with the same R + ΔR suppose say this is also another sensor which is R + ΔR but, but it is only for measuring the temperature, but the change that we get so, this is $(R + \Delta R)_T$ but whereas, this is R + ΔR which is based on the changes with respect to the physical measurement but whereas, this is for the temperature compensation.

Since both the sensor materials of the same type, this introducing another sensor into the second pair of resistive divider network topology can compensate for that temperature losses, temperature effects first stage of temperature effects can be completely compensated easily. This is another advantage of it.

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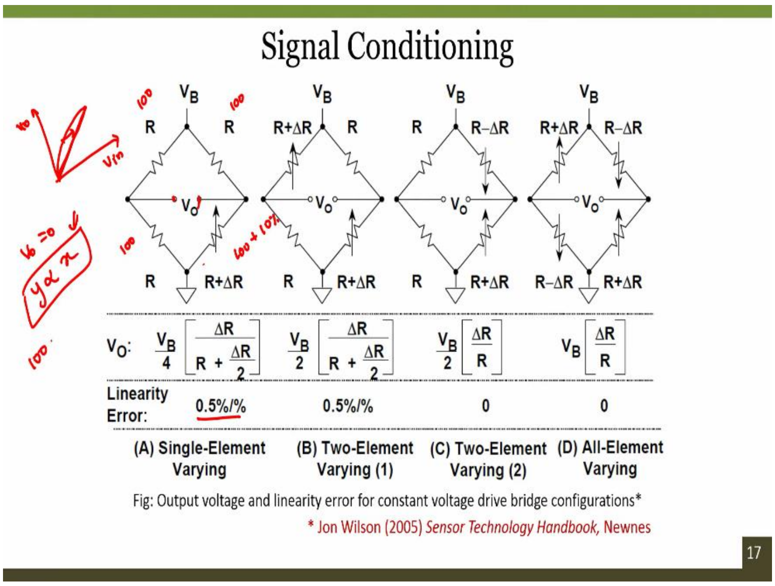

But the problem is utilizing a single varying element. Here if you can see, using a single element, varying element in a Wheatstone bridge configuration introduces a non-linearity error. What I mean by non-linearity error? So, imagine if I have output voltage. If I see the characteristics between V_0 and V_{in} as this linear but because of only single varying element bridge in the Wheatstone bridge circuit, it leads to some kind of a nonlinearity.

This non-linearity error when you consider, it will be always point 0.5 %/%. What I mean? I can simply show you one simple example imagine say I take R as 100 ohms, 100 ohms, 100 ohms and 100 ohms. So, whereas, this is a sensor. So, 100 is a base resistance of the sensor. So, in order to compensate or in order to make to avoid the offset, all the resistance have been designed in such a way that the value of the base resistance is selected.

So, now, under no loading condition where R = 100 ohms, the $V_0 = \frac{V_B}{2}$. Here also $\frac{V_B}{2}$. So, which has become 0. So, when do you say there is no non-linearity? So, in order to say the system does not have a non-linearity, two different conditions are satisfied. One is superposition, other one is a scale. So, any one of the problem does not satisfy, any one of these two theories does not satisfy then the system is said to be non-linear. So, first consider a scaling factor.

What it is? If y = kx, if the k is a constant throughout the operation of a y or x, then the system is said to be completely it satisfy the scaling factor. So, the value of k should be always constant. What I mean imagine if k = 0.5, for input of 1, y should be 0.5. Input of 1, y should be 1 but if I say for input of y, the scaling factor is 0.5 if input of 1 if the scaling factor of 0.5 and if input of 2, if the scaling factor is not 0.5 and if it is changing, it is varying with respect to the input, then it is not satisfying the principle of scaling which means that it is not a non-linear that can simply understood because the case should be constant.

So, that means y should be always proportional to x. Now, by observing this if this particular theory does not satisfy, we can simply say the system is a non-linear. So, now consider it. So, now, what happens when we when all under no loading condition and all the resistance are same, we V_0 is zero good. Then say for any change of resistance because this is only the sensor. For any 10% change of resistance, if I observe the output variation is some y%, if that y% is constant throughout the operation, I can say this is linear. Now, say for 100 ohms × 10%. So, 10% will be 10 ohms.

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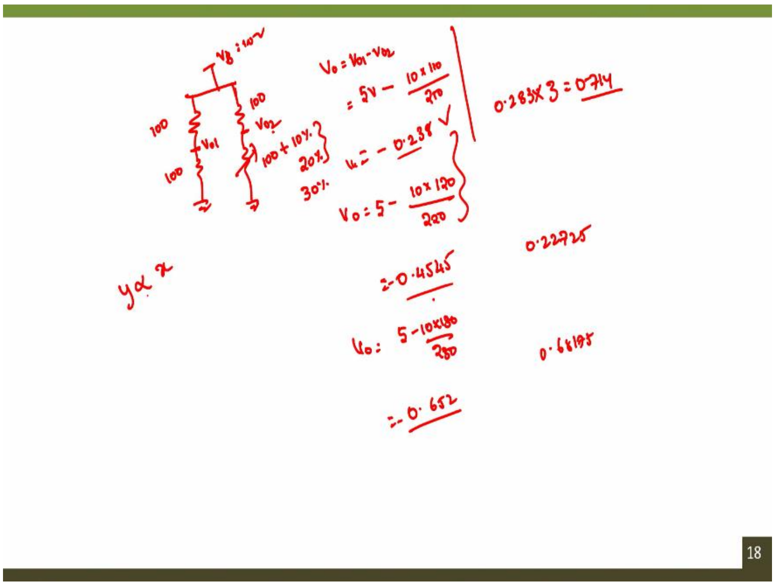

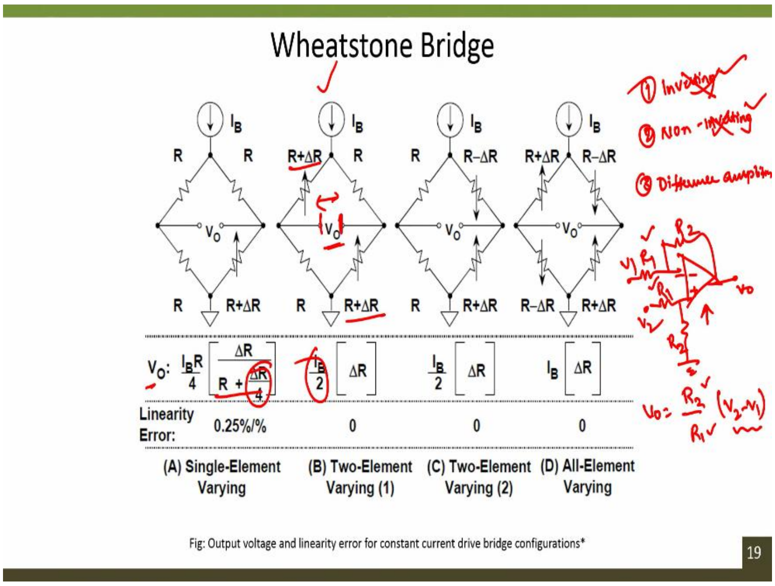

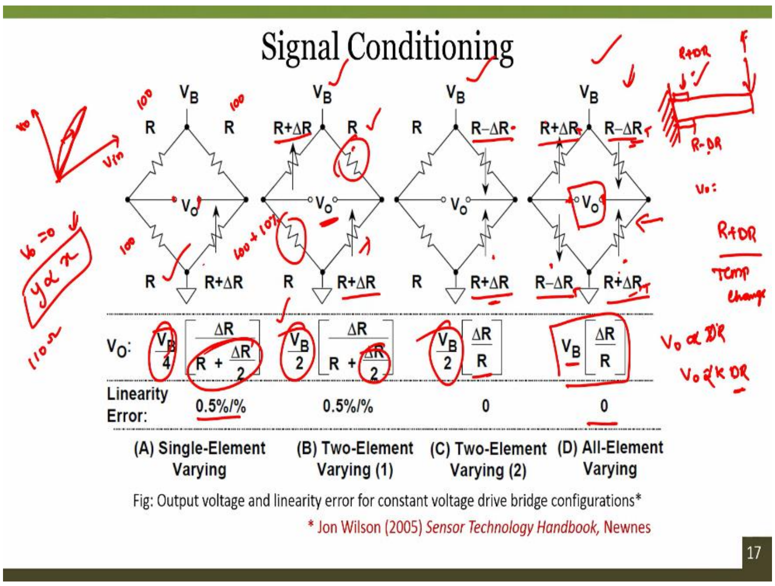

These are sensor 100 ohms, 100 ohms, 100, 100. So, both are connected with V_B which is 10 volts. Now, this is V_{01}, I am considering and this is V_{02}. So, $V_0 = V_{01} - V_{02}$. We are observing the scale. Now say if this is increased by 10%. What would be V_0? Now, V_{01} is equal to since the resistance are same, it is 5 volts. $\frac{V_B}{2}$ minus whereas, $V_{02} = \frac{10\times110}{100+110} = 210$. Solving for this we get -0.238.

So, this negative because since we are measuring between V_{01} and V_{02} it is a negative. If you measure between V_{02} and V_{01}, then this will be positive. So, now we got point 0.238. Imagine now, if we if the change is of 20%, if the output change is also doubled, then I can say linear. Now, if I consider this value case 2. Now, the change is 20%. $V_0 = \frac{(5-10)\times120}{220} = -0.4545$.

Now see, when I am dividing $\frac{0.4545}{2}$ half because the changes also half. Here in this case doubled from 20 to 10% it is change is of half. Now, if you see the change is not exactly half. Now, consider say if the change is 30%. So, that means, $V_0 = \frac{(5-10)\times130}{230} = -0.652$.

So, calculating 0.238 × 3 times, the value 0.283 × 3, we get 0.714 but increasing by 30% which is 3 times higher than the original one, I should get 0.74. But now, I am not getting 0.74. It is only 0.652. Even doubling is also the same. So, which means that so when you see for change of 10% as an input the change is not the scaling factor is not the constant for the output.

So, which means that y is not proportional to x anymore. So, there is a slight deviation. That deviation is because of the $\frac{\Delta R}{4}$ which is acting in the denominator, R + $\frac{\Delta R}{4}$. This R + $\frac{\Delta R}{4}$ causes the output to have non-linear. So, that is why a single element varying bridges not only it has an advantage of removing compensating for the offset voltage, but it introduces a non-linearity error into the system. At the same time, it cannot even compensate for the temperature effects or temperature changes. But how to solve this? One way is using two element or four element wearing bridges.

So, you have another topology here, two element varying bridges too. So, these two elements varying bridges where if you have the same type of resistance change when you consider the same type of resistance change and adding in this way, why we should not add here? Why it should be always added in this configuration? Because when we add here, if both are changing at the same rate, the output voltage that we observe will remain same. It will not change even though the sensor is changing with respect to the load. When we are having the same resistance change, the effect will never be same.

So that is the reason for a temperature compensation, if the sensor we are using is only for the temperature compensation adding a resistor at this point always advantage provided that sensor should not change with respect to the input load, input parameter or input measuring. It should only compensate with the temperature effect.

Imagine say if you want to amplify, if you want to eliminate the offset and if you want to amplify this amplify the output voltage. See here if you see it is attenuating $\frac{V_B}{4}$, even in this case of course it is amplifying by twice that of the previous circuit by utilizing two different same type of a sensor which can measure the same physical measurement, not for the temperature compensation for the physical measuring, same physical measurement.

It cannot avoid the non-linearity error, but it can amplify your signal when compared to the single element varying bridges. But another topology what we have is if we have one as a positive resistance change another one as a negative resistance change. So, which means R + ΔR, R - ΔR the base resistance will remain same, but one is a PTC other one is an NTC.

So, for a same x load, if the change is of y but whereas, in the first case if it is adding with respect to the base resistance whereas in the second sensor, it is subtracting from the base resistance then it is said to be R + ΔR and R - ΔR nothing but one is PTC other one is an NTC. If such kind of sensors are available introducing into the one pair of a resistive divided network, not only solves for not only avoid a complete non-linearity error it compensate for the resistance temperature effects, it also increases the amplifies your output when compared to the single element varying bridges.

But having one with a PTC and another one with NTC is very difficult which cannot be happen in all the cases. Another thing is four element varying bridges, where in case of four element varying bridges, see the selection and the placement of sensor should be as follows. Any change of the position again leads to no change in the output voltage even though the change even though if input measurement is being changed.

So, if this is R + ΔR, this should be R - ΔR. If this is R - ΔR, this should be R + ΔR and this is R - ΔR. Placing in this configuration avoids a complete non-linearity error is 0 and the output voltage is V_B. So, no attenuation involved into this. So, in this case, V_0 is directly proportional to ΔR. So, $\frac{V_B}{R}$ is the factor which is a K proportionality constant K.

So, when you use a load cell where they uses a strain gauges, two strain gauges we will fix on the top and two strain gauges we will fix on the bottom on a cantilever and when a cantilever so imagine say, if this is a cantilever structure and if you want to see the application of all element varying bridges, if I use two different sensors on the top and two different sensors on the bottom and applying a force on this, these two sensors will experience R + ΔR and whereas, these two sensors which is which are attached on the bottom side of the cantilever will experience R - ΔR. So, one R + ΔR placing it here.

Another R - ΔR placing it here similarly R + ΔR and R - ΔR, the V_0 we will get as ΔR from the output voltage is directly proportional to ΔR. Remember that this non-linearity error is not because of the sensor, it is purely because of the signal conditioning circuit that we have designed. So, that is the reason the proper signal condition designing of a signal conditioning circuit is also important to solve, to provide a linear output, accurate output with very good information about the input.

One is non-linearity error is solved, at the same time since we are utilizing all four resistance, all four varying resistance are varying any affected due to the temperature will also be compensated because if the change in the resistance is due to the temperature where ΔR now is because of ΔR_T, R_T, R_T, R_T now all the element, if this is a strain gauge, all the resistance will have change with respect to a positive change with respect to resistance. So, that means all resistors will behave as R + ΔR for case of a temperature change.

So, when all resistance R ΔR, the V_0 will be $\frac{V_B}{2}$. Here also $\frac{V_B}{2}$. So, $V_0 = V_B$, $V_0 = 0$. So, it compensate for the temperature effects, at the same time if any physical measurement change when the force is applied, the output voltage will be linear. This is how the four element varying bridges utilizing reasons which configuration works. Of course, getting in all the cases you cannot achieve the same type of you cannot get us all four combinations, all two combinations of resistance.

If it gets, we can introduce it but what if we do not get it all combinations of resistors here, one with a PTC other one with NTC. Then we have to optimize your design in a similar fashion. So, instead of using a voltage, we can go with a simple current. When we go with a constant current as an input into the voltage, here we can see V_0 is proportional to ΔR and with a proportionality constant of $\frac{I_B}{2}$ even when you have R + ΔR and R + ΔR as your sensor system.

This is another way of designing, another modality of designing a signal conditioning circuit with the same element varying bridges instead of using voltage as an input using as a constant current producing constant current again it is a problem, we have to look into that. Now, how do we measure this output voltage? Of course, we have measured of course, we know how to utilize, but if you want to give it as an input to the ADC where ADC does not have a differential output, a differential input ADC cannot measure a differential input.

So, remember that the output voltage that we get from a resistive divided network is with reference to the ground whereas, the output from the Wheatstone bridge circuit is a differential output. So, which means that you should always measure one voltage with respect to the ground with respect to the another voltage, with respect to the ground. The difference between these two voltages is nothing but V_0. It is not with respect to the ground.

So, in such cases we cannot use either an inverting amplifier configuration or a non-inverting amplifier configuration because the inverting amplifier or non-inverting amplifier configurations can only be amplified or attenuated with for a single input voltage or with reference to the ground but whereas in this case a differential. So, for that we will be the general procedure is using a difference amplifier, differential amplifier or a difference amplifier. But again, when you look into the difference amplifier, this is V_1, this is V_2 this is output R, R, R, R. If I say this is R_1, R_1, R_2, R_2. So, $V_0 = \frac{R_2}{R_1}(V_2 - V_1)$.

So, V_0 can measure the difference between V_2 and V_1 and if R_2 and R_1 are same, then the gain is one. So, output voltage is purely difference between V_2 and V_1 but because of this, R_1 input resistance, the input impedance of the system entirely depends upon R_1 and in this case, since the output from the previous stage is not directly connected to the input terminals have an operational amplifier, the loading the chances of having a loading in this case is higher because of the input resistance while selection of input resistance is also very much important.

Of course, there are other ways of doing it which can avoid the effects due to input resistance that is instrumentation amplifier, 3 upon base instrumentation amplifier where even though it uses a differential amplifier inside 3 upon base instrumentation amplifier because of the topology or the configuration of 3 operational amplifier, it the input impedance is of very-very higher. At the same time the CMRR which is a common mode rejection ratio, the ability of the system that can measure the common signals, the same signals is also high.

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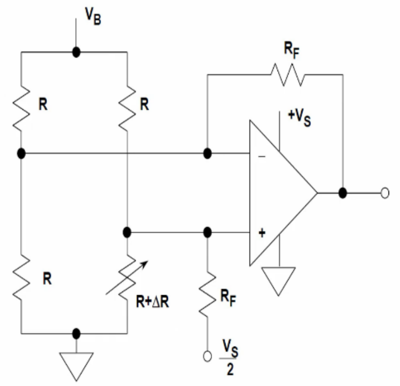
Amplifying and Linearizing Bridges



So, this is a difference amplifier. So, as we discuss, in order to meet the properties of the next subsystem, the difference amplifier input impedance of the next stage should be always higher so that no current will be drawn from the preceding stage. So, in order to have a very high input impedance by utilizing an operational amplifiers, if we connect the output from the preceding stage directly to the input terminals of an operational amplifier, it will have a very high input impedance so that no current will be taken from the previous stage which means that from the sensor side.

Otherwise, the current drawn from the previous stage entirely depends upon the input impedance that you have selected or that we have designed. So, that is one disadvantage of going with a difference amplifier because as we discussed, the difference amplifier will have an input resistance both on the negative terminal side as well as on positive terminal, in between the output from the previous stage to the direct input to the inverting or non-inverting terminal, it always contains an input resistance because of that resistance the complete input impedance is decreased.

Because of that, input resistance values and moreover, a difference amplifier will always have a very poor CMRR which is nothing but a common mode rejection ratio, the ability of the system to measure the common signals. So, one way to avoid that problem is by using an instrumentation amplifier.

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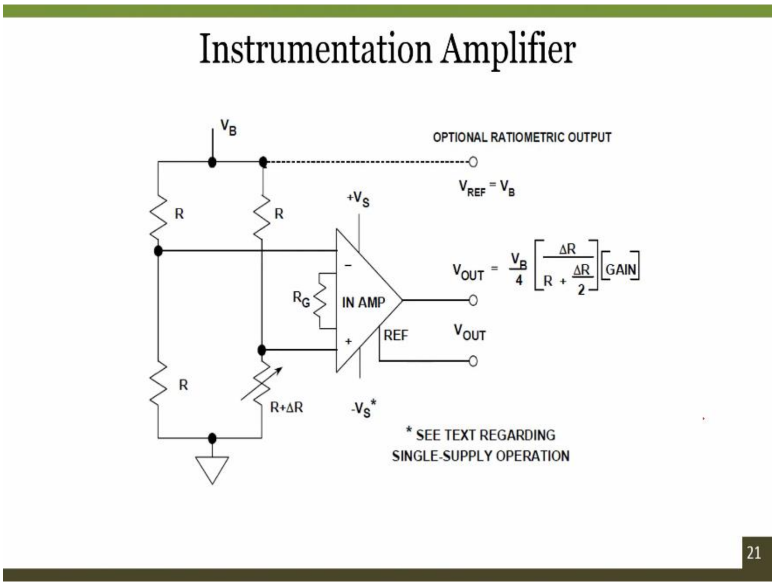

So, though this is this approach, though this approach helps us to measure the difference between these two terminals, it cannot compensate on the non-linearity that we have discussed previously which is $\frac{\Delta R}{R}$. In order to avoid this non-linearity either we have to go with a two element varying bridges as we have seen, or we have to use some other topology to eliminate the non-linearity.

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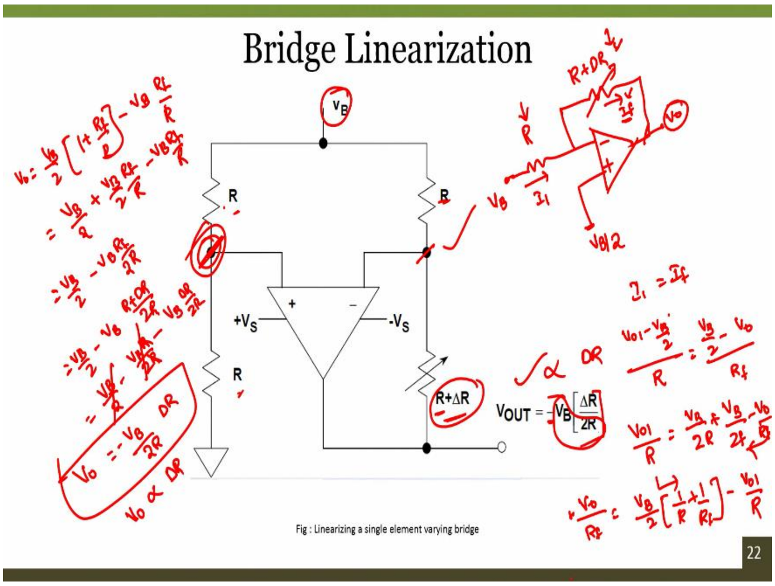

So, are there any ways to use a single element varying sensor utilizing a circuit so that the output should be directly proportional to the resistance? Of course, a modified version of a Wheatstone bridge circuit, it looks like a Wheatstone bridge circuit, in reality it is not. It is similar to an inverting amplifier configuration, but it has an offset which is connected at this terminal.

So, utilizing this configuration, the output voltage we can achieve as a directly proportional to ΔR, that proportionality constant here is $\frac{V_B}{2R}$. V_B is nothing but the input voltage that we have connected to the complete system and whereas, R is nothing but the base resistance. So, how does it work? As we have already seen about the working of an inverting amplifier configuration.

So, if you see this. I am retrying in a different way so that it is easy for us to understand the circuit R and this is R + ΔR. R + ΔR represents the sensor, here we have an offset. That offset is created by this. So, since R and R are having same resistance value, then this particular voltage is nothing but $\frac{V_B}{2}$.

So, we are applying a fixed voltage at the non-inverting terminal which is $\frac{V_B}{2}$. What we have seen in the previous discussion? This $\frac{V_B}{2}$ will subtracted will be added to the output voltage. How? So, we know that

$$V_0 = -\frac{R\ +\ \Delta R}{R}V_{01} + \left(1 + \frac{R + \Delta R}{R}\right)\frac{V_B}{2}$$

So, this is the equation, this is the output that we get. Solving for everything, we get V_{OUT} is nothing but V_{OUT} is directly proportional to ΔR. So, how this particular configuration is making an output to be linear? So, how in the sense since the sensor is connected in the negative feedback topology, as we are already aware, this I_1 will be always equal to I_f.

So, this particular potential will be varied, depends upon the varied in order to maintain the same current to flow between same current to flow in the resistance R as well as R + ΔR. So, which means that the current flowing through R + ΔR will be a constant throughout the operation. So, what is going to happen? Any change in the sensor resistance since the I is already constant, it changes the output voltage because of which we get output voltage proportional.

You can further solve about this. So, $I_1 = I_f$, this is a basic rule which we already know.

$$\frac{V_{01} - \frac{V_B}{2}}{R} = \frac{\frac{V_B}{2} - V_0}{R + \Delta R}.$$

So, just for easy understanding I am saying R + ΔR as R_f. So, now we can see,

$$\frac{V_{01}}{R} = \frac{V_B}{2R} + \frac{V_B}{2f} - V_0.$$

Taking V_0 in this direction, $\frac{V_{01}}{R}$ in this direction so, this is $\frac{V_0}{R_f}$. So, we get

$$\frac{V_0}{R_f} = \frac{V_B}{2}\left[\frac{1}{R} + \frac{1}{R_f}\right] - \frac{V_{01}}{R_f}.$$

Solving for that, so,

$$V_0 = \frac{V_B}{2}\left[1 + \frac{R_f}{R}\right] - V_{01}\frac{R_f}{R}.$$

So, this is what we have seen previously. The simplest way to understand this circuit is you can use a superposition principle too. So, in the superposition principle, since you have a 2 voltage, making one voltage to connect it to the ground other making only one voltage available.

So, if this looks like a non-inverting amplifier configuration, if it is a non-inverting amplifier configuration, $V_0 = \frac{V_B}{2}\left[1 + \frac{R_f}{R}\right]$. So, this is what we have seen $\frac{V_B}{2}\left[1 + \frac{R_f}{R}\right]$. So, in another case $\frac{V_B}{2}$ will be ground and then it looks like a non-inverting amplifier configuration. So, during the inverting amplifier configuration, it is $-V_{01}\frac{R_f}{R}$. So, $\frac{R_f}{R}$, this is what we have seen in the previous equation.

Now solving for this so, imagine say if R_f so, what is V_{01}? This is not V_{01}. So, this is V_B. Now, taking V_B as common,

$$= \frac{V_B}{2} + \frac{V_B}{2}\frac{R_f}{R} - V_B\frac{R_f}{R}$$

which is equal to

$$= \frac{V_B}{2} + V_B\frac{R_f}{R}\left[\frac{1}{2} - 1\right]$$

$$= \frac{V_B}{2} - V_B\frac{R_f}{2R}.$$

So, what is R_f? We know R_f is nothing but R + ΔR. So,

$$= \frac{V_B}{2} - V_B \frac{\mathrm{R} + \Delta\mathrm{R}}{2R}$$

$$= \frac{V_B}{2} - V_B \frac{\mathrm{R}}{2R} - V_B \frac{\Delta\mathrm{R}}{2R}$$

$$V_0 = -\frac{V_B}{2R} \Delta\mathrm{R}.$$

So, that means V_B is directly proportional to ΔR but we always get a phase shift to minus of course, we can use another inverting amplifier configuration in order to remove the phase shift which can also help us to amplify the signal as well as to remove the phase shift that it is that we are getting from the previous stage. But in this configuration, by using a simple a single element resistance, we can convert the resistance to volt, a linear output voltage. This is another way of designing a signal conditioning circuit.

Another approach of signal conditioning circuit by using a single element varying bridge to get a linear output. I hope this is clear. Now we will see another practical application where in the next class, we will use the similar application interface it to a data acquisition device and we will display the temperature of the sensor on the screen using data acquisition module and LabVIEW.

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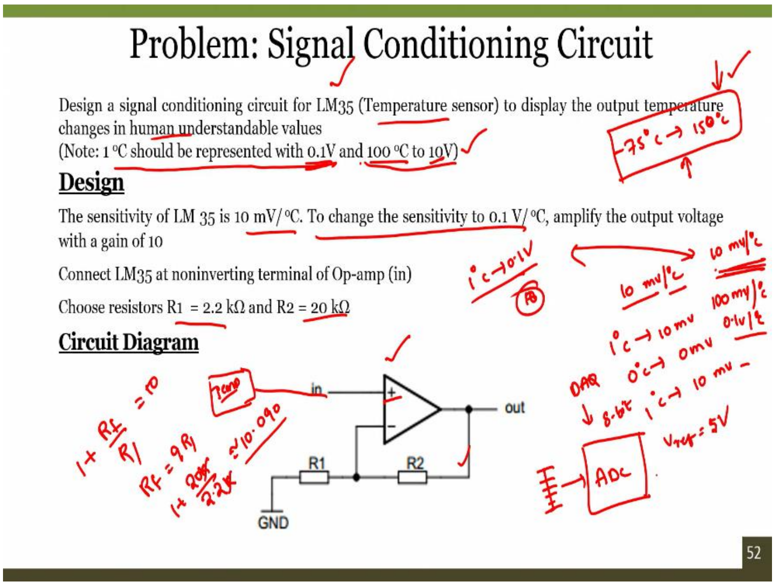

So, in order to do that, I will consider a simple example. So, this is a problem of a signal conditioning circuit that I am considering showing it to you tomorrow. So since, we are directly interfacing to the system, we should understand what exactly the problem is. So, the idea is that we want to display the temperature of a system or temperature of a boiler or temperature of room temperature. So, in order to do that, since temperature and data acquisition device accept only voltage as an input, the temperature has to be converted into a voltage.

So, in order to do the conversion, we use a transducer, input transducer which is nothing but a sensor. So, in this case, since there are different varieties of sensors which uses a different physical phenomenon to convert the temperature to output. So, in this particular example, I am considering LM35. LM35 is a semiconductor based temperature sensor where it gives an output in terms of voltages. So, when you look into the datasheet of LM35, here we can understand the datasheet shows that the sensitivity of LM35, the temperature sensor which is easily available in the market is 10 millivolt per degree centigrade.

What does it mean? Every change in one degree centigrade, it changes the output voltage by 10 millivolt. So, that means one degree centigrade will be changed by 10 millivolt. If that does not have any offset, so this will be my starting. So that means 0 degree will be shown as 0 millivolt whereas one degree centigrade will be shown as 10 millivolt. Any change in a degree will correspondingly the output voltage will also change. Now, what is the operating range? The range at which it can be operated is -75 degree centigrade to 150 degree centigrade.

Since the idea of using this temperature sensor is to measure the room temperature and the linearity is also very good. So, considering all these factors this particular temperature sensor we have selected. Now, how do we design and what is the need of a signal conditioning circuit here?

Since we are planning to interface to ADC, where in one of the data acquisition devices DAQ has an ADC inbuilt ADC, which is 8-bit ADC let us say directly connecting the output of sensor to ADC it will not meet all the levels of ADC. So, that means, though we can achieve a better accuracy as well as the resolution of the temperature because of limited uses because of improper signal conditioning circuit, we are unable to display with a very good resolution.

So, the problem says here is design a signal conditioning circuit for a LM35 to display the output temperature changes in human understandable values. What it means, it should represent in terms of degrees centigrade whereas, the temperature sensor can only show in terms of millivolts. So, one degree centigrade should be represented with 0.1 volt, 10 degrees centigrade should be represented with 10 volts. This is the condition, the sensitivity of LM35 is given as 10 millivolt per degree centigrade and to change the sensitivity to 0.1 volt per degree centigrade amplify the output.

So, what it shows here? Now, when you look into the scaling factor, the scaling factor is 10 millivolt per degree centigrade is what given by the sensor. But what the problem says, we require to represent in case if we are not using a data acquisition device and if you want to display using a voltmeter measuring unit, voltmeter where the voltage is corresponding to the temperature. So, that means 10 volts when you measure it should it is an indicator that this is 100 degrees centigrade with 0.1 volt is being measured which is an indication of one degree centigrade. How do we design a signal conditioning in such a case?

So, which means that when you look into that one degree should be represented with the 0.1 volt. So, which means that now one degree is represented with 10 millivolt. So, in order to match the scaling factor of what we require and what is already existing, we require to multiply gain of 10. So, if I multiply a gain of 10 to the output of a temperature sensor, so which means that 100 milli volt will be represented with for one degree change which is nothing but 0.1volt per degree centigrade which is matching with respect to what we require.

Now, how do we design a signal conditioning circuit to have a gain of 10. Now, one thing what we have to understand what kind of output the temperature sensor is given it is directly voltage. Since it is an output voltage, we do not have to think about conversion of resistance to voltage, we can directly use it.

Then second thing what we have to think about loading effects, since we are interfacing to another stage there should not have a loading effect. If there is a loading effect, the previous stage which is nothing but a temperature sensor should have enough energy to operate it. So, since temperature sensors cannot provide enough energy which means that current is also a part of energy. So, since it cannot provide enough power or enough energy, we have to have a limited current drawn from the previous stage.

So, in order to do that, in order to create a gain of 10, one way is either we can use a simple inverting amplifier configuration. But since input inverting amplifier configuration has an input impedance in this case, we are selecting to go with a non-inverting amplifier configuration where the output from the previous stage can be directly connected to the input of a non-inverting amplifier configuration, a non-inverting terminal so that the input impedance is very, very high. So, no current will be taken from the previous stage.

So, from the temperature sensor. Now, how do we design with a gain of 10? Since we know the gain of non-inverting amplifier configuration is $\frac{R_f}{R_1}$, so and it is required to have a 10. If I design $R_f = 9R_1$, then the problem is solved. If I consider R_1 as 1 kilo R_f to be of nine kilo but matching, identifying a matching resistor is very hard. So, in this case to have a gain with availability of the resistance in the market, we have considered R_1 as 2.2k, R_2 as 20k. So, which will become 1 + 20k divided by 2.2k which is close to 10.

So, the value is 10.090. So, which is close to 10. So, this can be used to convert 10 millivolt per degree centigrade to 0.1 volt a simply signal conditioning circuit. So, tomorrow in the next session, we will use the same temperature sensor.

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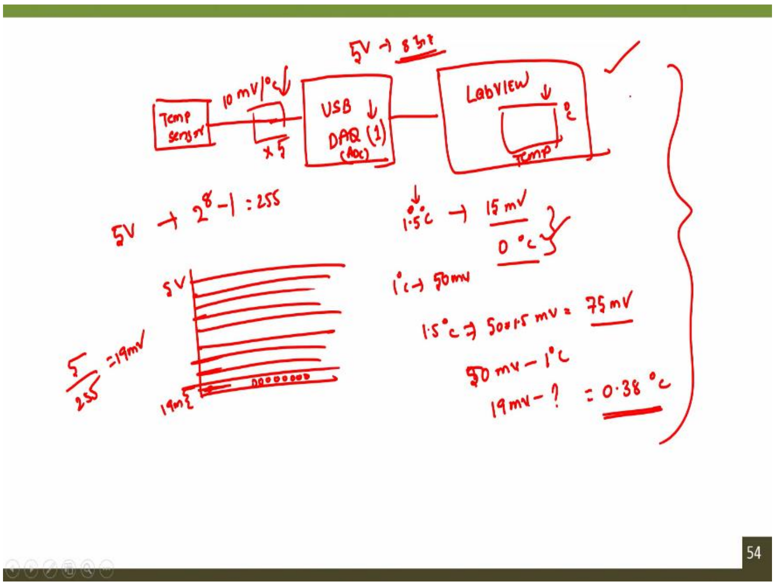

Since, the output is very small and ADC in this case, the reference voltage of an ADC is of 5 volts let me take empty slide I will take temperature sensor output where the output is 10 millivolt per degree centigrade this I will be directly interfacing to USB DAC with a gain of one which has an onboard ADC and we use a LabVIEW software to display the temperature values. When the gain is one, we will see what is the resolution that we are going to get. So, since USB DAC operates it with 5 volts, temperature value 5 volts and it has 8-bit ADC onboard.

So, 5 volts will be divided into 2 power 8 number minus 1 which is 255 volts. So, that means when I say this is 5 volts, these 5 volts will be divided into 255 levels. Each level height will 5 divided by 255 which is 19 millivolt. That means anything lesser than 19 millivolt will be always considered as 0. So, now if we imagine if the change in the temperature is 1.5 degree centigrade that means the actual output voltage will be only 15 millivolt. So, it is only 15 millivolt but it falls under this particular level which is starting level.

So, 0,0,0,0,0,0,0,0 so 19 millivolt will be always considered as 0 degree centigrade. Even though the actual temperature is 1.5 degree but the sensor the display unit can only measure 0 degree. That is not because of improper selection of an ADC, I can say even by utilizing 8-bit ADC by slightly changing the gain by introducing a signal conditioning circuit between a temperature sensor and ADC with the gain, the output or the temperature can be displayed with a very high resolution.

Imagine, say in the same situation if I have a gain of say 5, so that means now it will be one degree centigrade will be represented with 15 millivolt. Now 1.5 degree is nothing but 50 into

1.5 millivolt, 75 millivolt. Now, this 75 will fall under which category? So, which means that if 15 millivolt is represented with one degree centigrade then 19 millivolt will be 0.38 degree centigrade. So, the temperature can be measured with a resolution of 0.38 degree by introducing a gain amplifier, by introducing a signal conditioning circuit.

So, but utilising the same 8-bit ADC. So, since theoretically we can show this but practically as a temperature varying such a small temperatures are different, I will show you considering the same room temperature with a gain of one how the output voltage, how the temperature is being displayed in the LabVIEW and the configuration the interfacing thing will be discussed in the tomorrow session. Thank you.