Automation in Manufacturing
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Week – 05
Conditioning and Microprocessor Technology
Lecture - 02
Pulse modulation Protection devices and Wheatstone bridge

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Hello everyone, I welcome you all to the lecture 2 of week 5. In this week we are studying various signal conditioning operations and the microprocessor technology. In this lecture we are continuing our discussion on various signal processing operation. We will be studying Pulse modulation, Protection devices and Wheatstone bridge.

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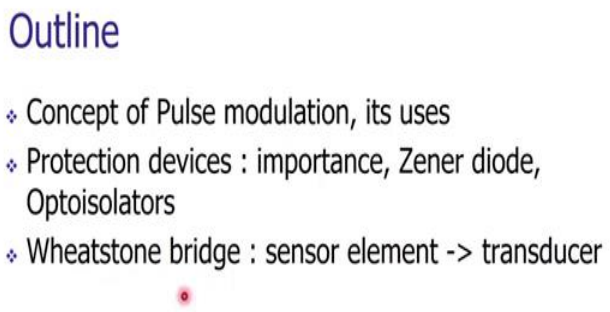

The outline of this lecture is as follows: at the start of the lecture we will see the concept of pulse modulation, its uses, its importance in the signal processing. Then we will see various protection devices that are required to employ. We need to protect the instrumentation or the devices from very high level of the signals or from the wrong polarity.

We will learn the constructional details and principle of operation of two protection devices; that is zener diode and optoisolators. The third important element in the signal processing is the Wheatstone bridge.

Wheatstone bridge are used to convert a sensor element into the transducer. One application of the Wheatstone bridge have already been discussed in our previous lectures, that is in sensors.

We have seen how Wheatstone bridge are helping us to convert strain gauge into a strain gauge element, sensor into a transducer. Well, in this lecture we will be studying little more details about the Wheatstone bridge.

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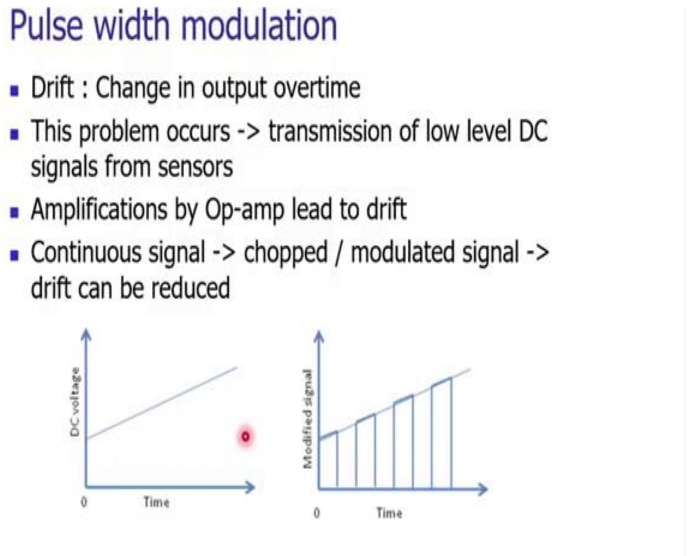

Let us continue our discussion on the various signal processing operations. In the previous lecture, we have seen the amplification by using operational amplifiers and we have seen various filtering operations that need to be carried out during the signal conditioning.

Now, third important signal processing operation is pulse width modulation. During collection of the output from the sensors, there is a problem which is often occurring and that is the drift. Drift as we have seen in our previous lecture, it is a change in output overtime. If we are expecting a continuous output at a same level that will not occur due to variety of inherent problems in the system itself.

The problems may be due to the device or due to the environmental factors. Thus, the drift is defined as or the concept is change in output overtime. We are expecting a horizontal or a constant output from the transducer, but we do not get that. This drift is creating problem in the microprocessor operations. In general, the drift is occurring when we are transmitting low level DC signals from the sensor.

Now, to understand the problem of drift, let us consider a sensor. And that sensor element is producing a very small voltage value in microvolts. To amplify that signal, we are using an operational amplifier.

Let us say, the inverting configuration that we have seen in our previous lecture is used to amplify the signal which is coming from the sensor. It is expected that we will be getting a constant output from the operational amplifier over a period of time.

But, we are getting a drift, we are getting an increase in the output signal over the period of time which is not desired and not expected. In the slide we can see the output at DC voltage which we were expecting in a horizontal line or at a constant level, but over the period of time we are getting increase in the DC voltage. We have instructed the microprocessor that DC voltage at the end of certain duration would be a certain constant value.

But the operational amplifier is producing something else. Then in this situation, the microprocessor will take the wrong decision and that may harm the entire process. To solve this problem, we are chopping off the continuous signal into modulated signal. So that the drift can be reduced. If I chop off this continuous signal into modulated signal, this slope will be reduced for that particular chopped signal and the drift will be reduced.

Here we can see the modified signal. I am converting a continuous DC signal into modulated pulsed signal. This modulated pulse signal will lead to the change in drift. If we program the microprocessor based on the drift itself. If we are giving any tolerance value to the drift say the drift should not be plus or minus this percentage then the microprocessor will understand that and it will take the decision appropriately.

We are instructing the microprocessor that if the constant value is expected say x and the drift is allowed of about 5 % only. But here in this case the drift is more than 5 %, that is around 20 to 30 %. In that case, the microprocessor will not process the signal which is given to the microprocessor.

Well, in this case, although the value of the signal is increasing, but at modulation at modulated signal the drift is in acceptable range. In this case the drift is not in acceptable range. The drift is unavoidable problem. It will be there in the sensors and the transducers, but by chopping off the signal we can tackle this problem.

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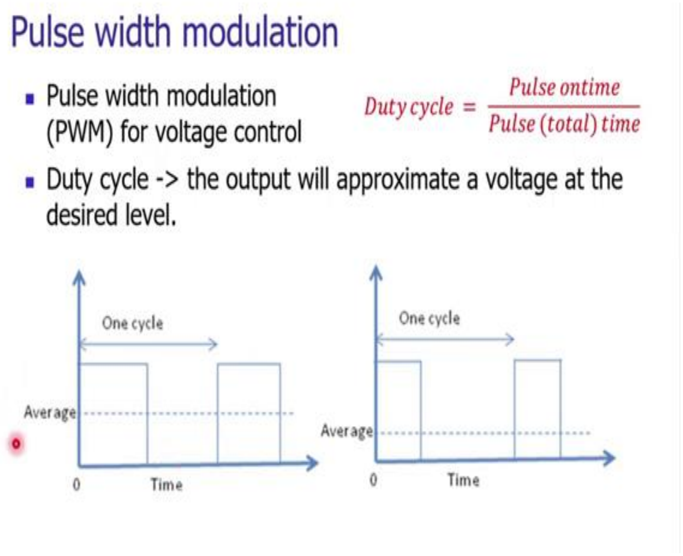

The concept of pulse width modulation is also useful in the voltage control. Voltage control of variety of the DC motors which are used in robotics and automated guided vehicles. How we can control the voltage by using the pulse width modulation?

Now, let us take an example in which we are applying a continuous voltage to the actuator at a certain level, but it is not essential, it may not be required to have the continuous mode of the actuation. In this case, if we chop off, if we convert the continuous mode of application into the modulated mode or the pulse mode, we can easily reduce the average voltage application. On x axis we are having the time, on y axis we are having the voltage.

If we would have applied the continuous voltage, then the continuous voltage maybe x volts, but that is not required, so in that case what we have done? We changed the continuous mode into the pulse mode, we are applying a pulse width on time say for 10 seconds and there is an off time for the pulse is 10 seconds. So total pulse time is 20 seconds, but the actuation we are carrying out only for 10 seconds. For the next 10 seconds, there is no application of the voltage.

In one cycle we are applying the voltage only for 50 % of the total time. This reduces the average volume of the voltage over the period of the pulse cycle time. This x would be reduced to x/2 i.e. 0.5 of the x.

Now in the next case what we have done? We have increased the off time, as we are increasing the off time then naturally the on time is reducing. For the same pulse on time or for the same total pulse time, now the pulse on time has been reduced. As the pulse on time has been reduced, the average voltage is further reduced it has gone down.

If I consider the on time is the 5 seconds and the total time is the 20 seconds. So, 5 divided by 20 that is the 25 %. This particular parameter or a factor is called as the duty cycle.

Duty cycle is defined as:

$$Dutycycle = \frac{Pulse\,on\,time}{Pulse(total)\,time}$$

The pulse time is the addition of pulse on time plus pulse off time. In this way, by controlling the duty cycle we can easily control the application of voltage inside in the automated systems. We just define the on time and the off time and we can easily have the required application of voltage for the desired purpose.

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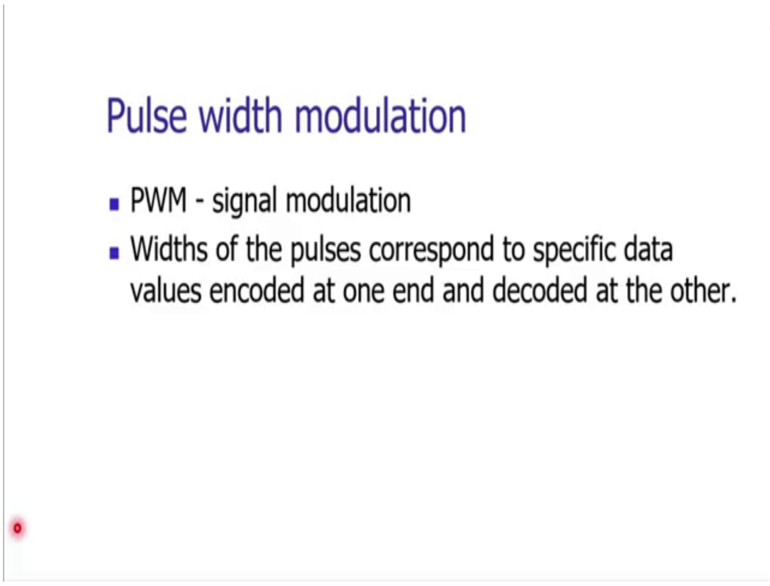

Well, the pulse width modulation has an interesting application in signal modulation. This signal modulation is pertaining to the communication signals. My friends we have seen that the signals are modulated, they are chopped. They have been defined by the time of application that is on time and off time. As we can modulate the width of the pulse and we define a meaning to the width of the pulse, that would be very helpful to the microprocessor to take the certain decision.

Consider we are instructing the microprocessor that this amount of width equals to this instruction. If the amount of width is say x, then you take this decision, if the amount of width is more than the threshold value or the less than threshold value the microprocessor can take the appropriate decision. The width can be programmed in the microprocessor application. The program can be developed to encode the width of the pulse, to utilize the definition of the width of the pulse.

By encoding the width of the pulse, the microprocessor would be taking the decision appropriately. Now consider the case where the transducer is sending the pulses of signals at a very rapid way of fast rate. Then which signals are to be processed and which are not to be processed, that can be programmed at the initial level itself, we can filter out. To carry out the filtering operation, the width can be examined at the entry level itself.

If the width of the signal is in the desired range, that pulses can be used for the processing application. Thus, the width based encoding and decoding will be very much useful in processing the communication signals. This is a very interesting application of pulse width modulation.

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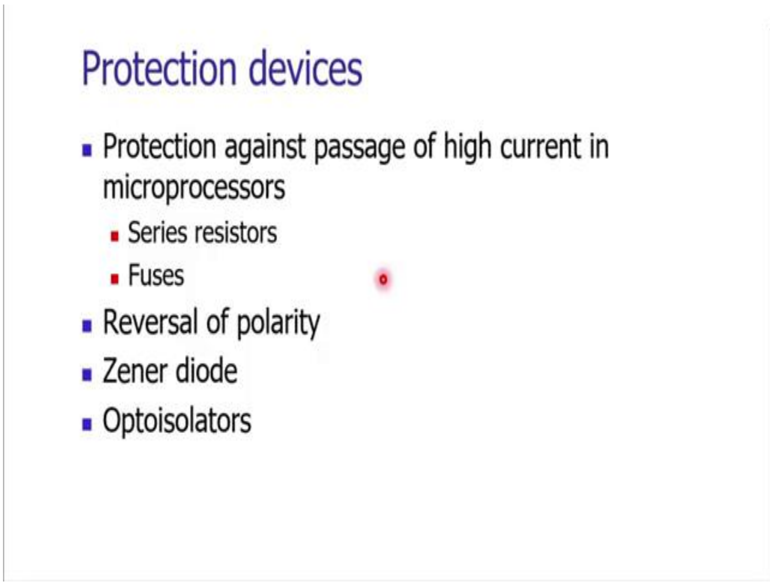

The next set of signal processing devices are the protection devices. These devices are very useful, very important as per as the microprocessor base systems are concerned.

Why it is important? Because, these devices are safeguarding. They are protecting the brain of the system i.e. the microprocessor from the damage due to high current, high voltage and reversal in the polarities. The microprocessor is very delicate element of automated system. It requires the precision levels of the input signal. If the signals are of very high magnitude, then that will certainly damage the system itself.

The first parameter which may damage the microprocessor is the high current. To protect the device from the high current levels we can simply use a series of resistors. If we connect various resistors in series and put inside the system, then the high current values can be reduced and we can safeguard our system.

The second thing is very simple which often we use in our day to day devices, day to day home appliances; that is the fuse. Even whatever the electrical connections are there to your laptops, computers or electronic devices, we are using the fuse based protection devices.

As we know the level of current is increased, that fuse will come into picture and it will disconnect the given power supply to the appliance, to the device itself. Basically we are disconnecting the power supply, we are not allowing the high current to reach the appliance.

There are certain cases in which the high voltages are also creating problem and by mistake there may be chances of having the reversal in the polarity. To take care of this problems a typical p-n junction based diode that is the zener diode is very much useful. We will be learning how it works and how it is useful. There is another useful device that we call the optoisolators, that is also used in protection of the microprocessors based system.

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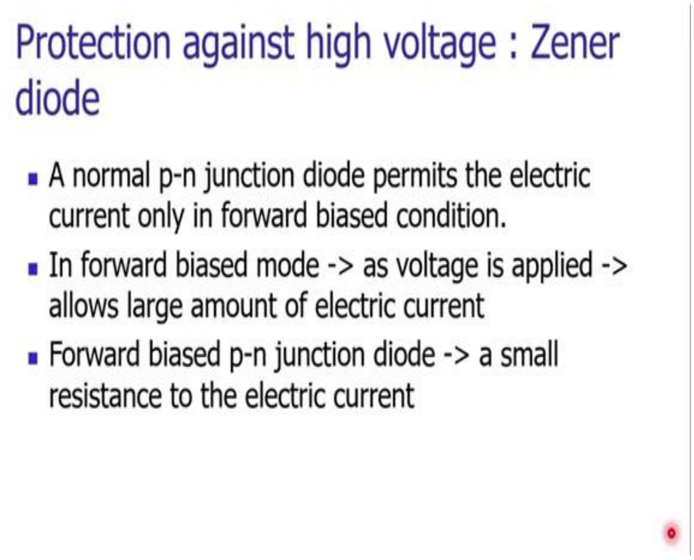

Let us see how the zener diode works. Well, we need to protect the microprocessors even against the high voltages. For that purpose, we are using a diode that we call the zener diode. A normal p-n junction diode permits the electric current to flow only in forward biased condition. This we know very well. In forward biased, basically as we apply certain voltage the forward biased mode allows large amount of current to flow through the circuitry.

Thus, we can say that the forward biased p-n junction diode has a very small amount of resistance to the flow of electric current.

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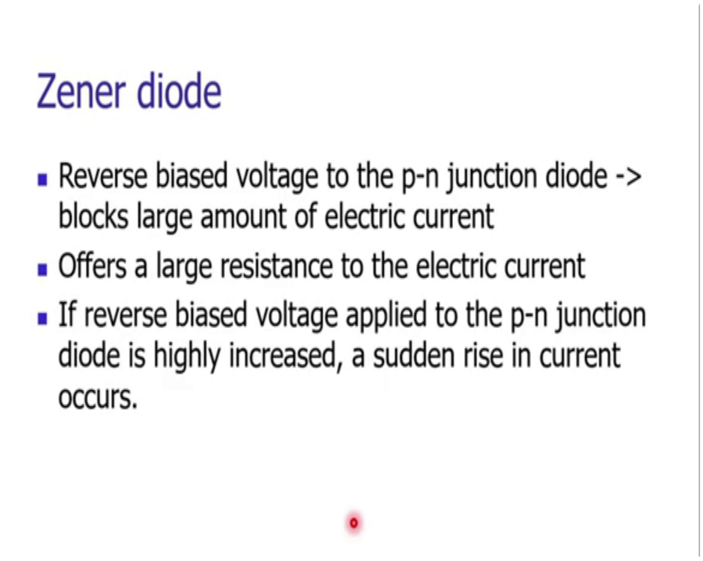

But when we apply a reverse biased voltage to this p-n junction diode, it blocks large amount of electric current to flow. Thus we can say that, it is exhibiting large resistance to the flow of electric current when the reverse biased voltage is applied. If we increase the reverse biased voltage at the p-n junction diode at a very high level, there will be increase in the current suddenly.

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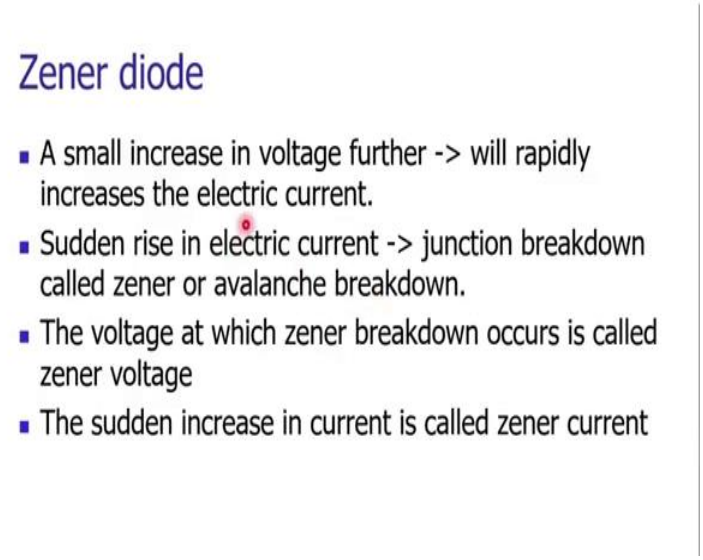

A small increase in the voltage further, already we have applied a voltage and due to that there is sudden increase in the current. But if we increase the voltage further in the reverse bias mode, that will rapidly increase the current further. This sudden rise in electric current further will break down the junction and that is called as the zener breakdown or the avalanche breakdown.

What we are understanding here? In a forward biased mode, there is a low resistance to flow of electron, low resistance to flow of electricity or electric current, but when we apply reverse biased voltage, it exhibits the resistance of flow of electricity.

But if we increase the reverse biased voltage there may be sudden increase in the current, and if we further apply the voltage in the reverse bias mode then the junction will breakdown, and that breakdown of the junction is called as the zener breakdown or avalanche breakdown.

The voltage at which the zener breakdown occurs is called the zener voltage. And the sudden increase in the current is called the zener current. This property of the zener diode can be utilized to safeguard our microprocessor based devices when there is a spike in the voltage, when we are applying very high level of voltage suddenly.

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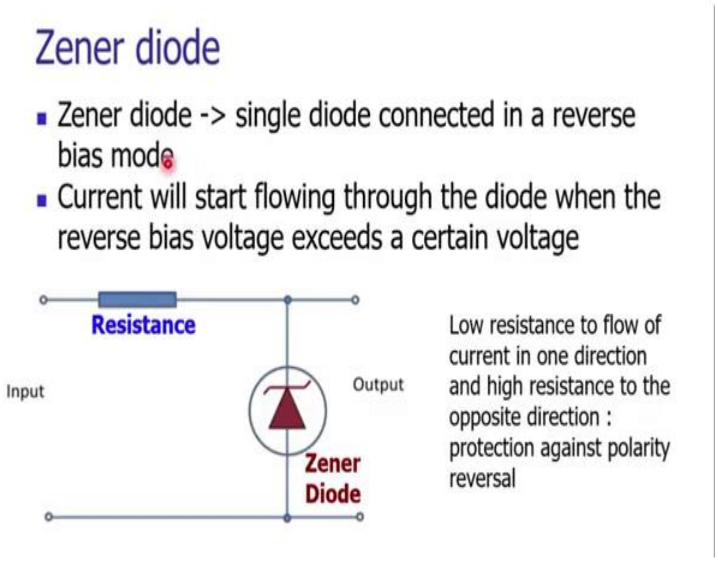

Thus, we can utilize the zener diode in its reverse bias mode. In the slide, we can see a typical arrangement of a zener diode; the input is applied across a series of resistance and zener diode circuitry and the output has been taken across the zener diode itself. As we are connecting the zener diode in the reverse bias mode, it will safeguard the microprocessor which is connected to the input.

If the input is giving very high level of voltage, then the zener diode will breakdown and it will not allow that high voltage to be applied to the microprocessor. It will bypass, it will allow the electricity to flow through the circuitry and in this way we can safeguard the microprocessor. The peculiarity, the current will start flowing through the diode when the reverse bias voltage exceeds the certain voltage.

When the input signals are exceeding the critical voltage or threshold voltage then the current will start flowing through the zener diode and the connections which are there at the output that is the microprocessor will be protected. The peculiarity of the zener diode, that is the low resistance to the flow of current in one direction, and the high resistance to the opposite direction, it is useful for the protection against the polarity reversal as well.

When the current is being applied in one direction, if its direction is changed due to reversal in reversal in the polarity, the zener diode will protect for such application.

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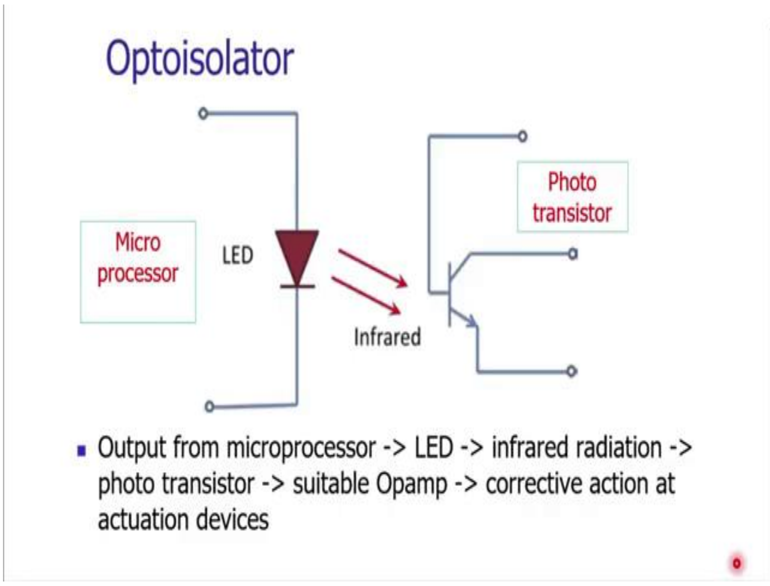

The next protection device is Optoisolator. As the name indicates, it is carrying out the function of isolation. Isolation of what? Isolation of the microprocessor circuitry from the harsh signals. This isolation will protect the microprocessor.

On what principle the isolation will be carried out? That will be carried out based upon the optical energy, based upon the light energy which is coming from a device, that device is the LED device. In this device there is a LED, that LED is connected to the microprocessor. The current flowing through the microprocessor is passing through the LED.As the current is flowing through the LED it is glowing, it is radiating the light energy.

Intensity of the light is directly proportional to the flow of electricity through the microprocessor. The light energy will incident upon a photo transistor. The photons which are coming from the light will be incident on the photo transistor. That photons will be utilized to convert an electrical signal and that electrical signal will be continuously monitored.

Now let us consider the current which is flowing through the microprocessor has suddenly increased. Due to the sudden increase in the flow of electricity through the LED, the LED will start glowing with high intensity. The intensity of glow will be increased; therefore, the infrared radiations will also increase and the corresponding current that is generating in the photo transistor will also increase.

Sudden increase in the current in the photo transistor will lead to generation of an alarm or it will directly switch off the power supply to the microprocessor. It will isolate the microprocessor from the flow of high current which is flowing through its circuitry.

In this way, the flow of high intensity of electric current in the photo transistor is the measure of possible damage or it is an indication of possible damage due to high flow of electric current in microprocessor. Based upon the alarm, the operator will switch off power supply to the circuitry or we may have an automatic system which will take the decision intelligently and will disconnect the power supply to the microprocessor.

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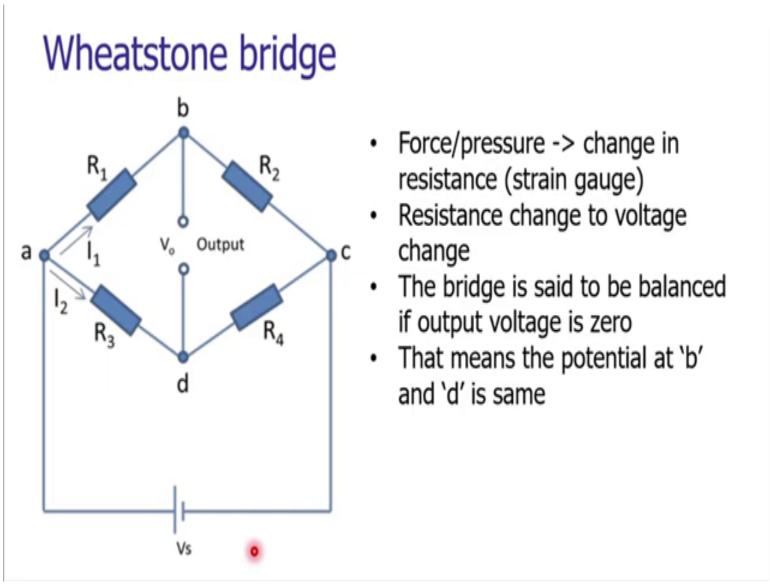

Wheatstone bridge is an important signal conditioning device; it is basically used to convert the sensor into the transducer. If we recollect, we discussed the Wheatstone bridge in the lecture of sensors. We have seen that the strain gauge element is a sensor which is producing a passive signal that is change in resistance.

The change in resistance is not useful to process at the microprocessor level, we have to convert the change in resistance into the change in voltage. For that purpose, a device is needed and Wheatstone bridge is the device which help us to get the required voltage signal. That required generated voltage signal may further amplify by using operational amplifier, and that amplified signal will be sent to the microprocessor for its further utilization.

The force or pressure is converted into the change in resistance, that is in the strain gauge, but we need to convert the resistance change into the voltage change. For that purpose, we got a bridge, this bridge has four resistors R_1, R_2, R_3 and R_4, these all four resistors are arranged and connected in the manner shown in the slide.

A supply voltage V_s is applied across the two junction points a and c. And we are getting the output from the bridge across point b and d. When we are getting the output voltage V_o equal to 0, then we are saying that the bridge is in a balanced condition; means, the potential at point b and potential at point d are same and equal. Then and then only we are getting the voltage across b and d equal to 0. This is the ideal condition.

We are choosing the values of R_1, R_2, R_3 and R_4, in such a way that the output voltage will be zero. Bridge is in balanced condition. But one of these resistor values if we change, then we are getting a noticeable output change across b and d. The change in output is directly proportional to the change in resistor values of one of its resistor. And that change in resistor value may be due to some external factor, it may be due to force, pressure or temperature change.

In this way the passive signal coming from the sensor would be converted into an active signal, that may be useful for the microprocessor application.

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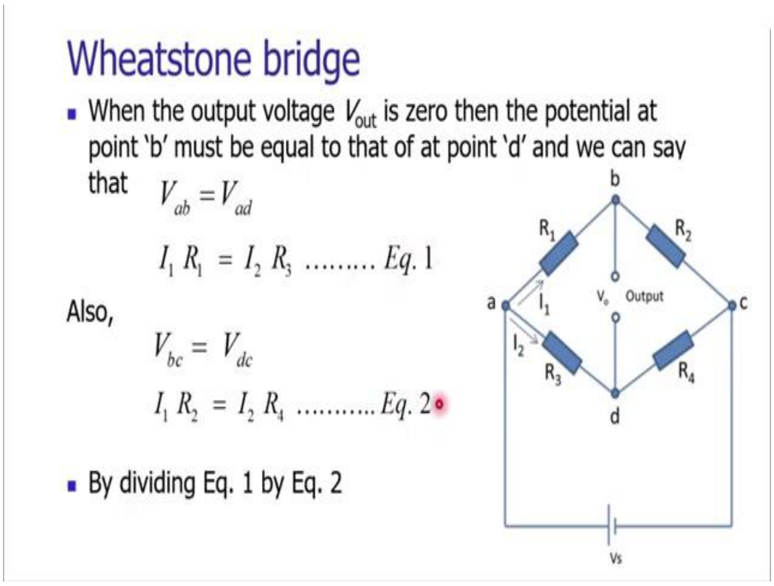


As we have seen, the V_{out}; the voltage at output terminal is zero, then the potential at point b and potential at point d are equal. Then I can write :

$$V_{ab} = V_{ad}$$

If the current which is flowing through the resistor R_1 is I_1 and if the current flowing through the resistor R_3 is I_2 then I can write:

$$I_1 R_1 = I_2 R_3 \text{ ....} Eq.1$$

Also it can be said that, the potential across R_2 and the potential across R_4 will also be same then:

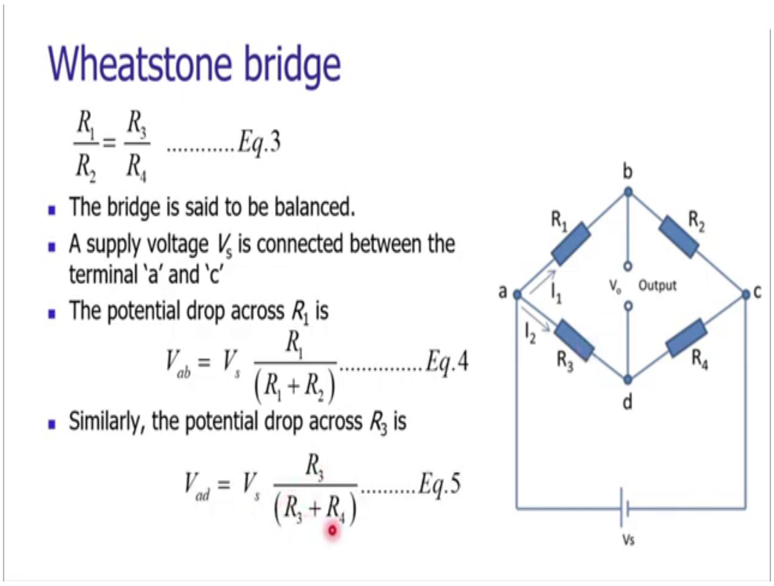
$V_{bc} = V_{dc}$

Converting the voltages into the product of current and resistor values, we get:

$I_1 R_2 = I_2 R_4$ *Eq.2*

Now, dividing the equation 1 by equation 2, we get:

$\frac{R_1}{R_2} = \frac{R_3}{R_4}$ ....*Eq.3*(Refer Slide Time: 35:14)



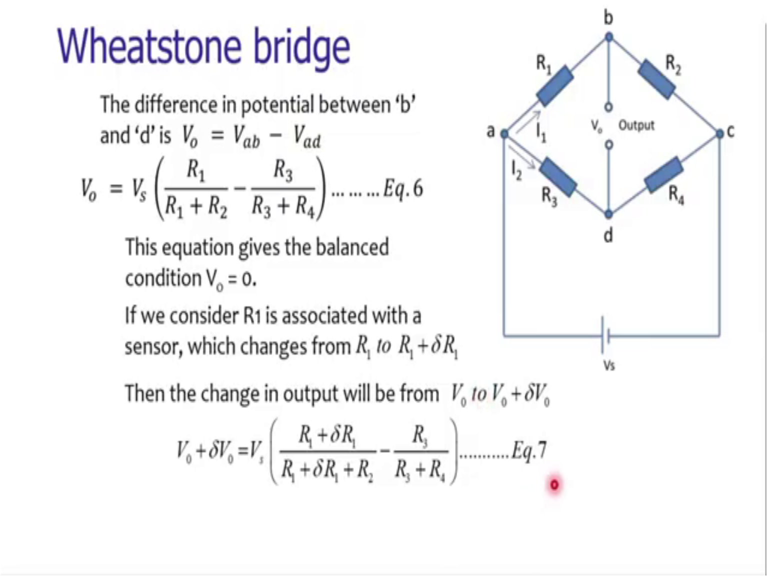
A very simple and useful correlation. If we maintain these ratios, then certainly we are getting the voltage at output terminal is equal to 0. Now, let us find out the potential drop across these resistor values when we are applying certain supply voltage across a and c.

The potential drop across R_1 can be written in terms of the supply voltage V_s as:

$V_{ab} = V_s \frac{R_1}{(R_1 + R_2)}$ *Eq.4*

In a similar way we can write the potential drop across R_3 as:

$V_{ad} = V_s \frac{R_3}{(R_3 + R_4)}$ ....*Eq.5*(Refer Slide Time: 37:01)



Now, let us find out the potential difference between point b and d. The potential difference between point b and d is the output voltage V_o. The output voltage V_o can be written as:

$$V_o = V_{ab} - V_{ad}$$

We got the correlations for the voltage across point ab and ad in the previous slide.

Keeping that correlations of V_{ab} and V_{ad} in this equation, we get:

$$V_o = V_s\left(\frac{R_1}{R_1+R_2} - \frac{R_3}{R_3+R_4}\right) \ldots\ldots\ldots\ldots\ldots\ldots Eq.6$$

This equation gives the balanced condition that voltage is equal to 0, but as mentioned we want to use the Wheatstone bridge to generate the active signal. For that purpose, we may be connecting one of the resistor to the sensor element.

Let us consider the resistor R_1 is associated with a certain sensor, as it is connected with the sensor due to the change in field variable of that sensor, the resistor value of R_1 is getting changed. Consider, there is increase in the resistance value by a small amount that is δR_1.

The resistance of R_1 is getting modified from R_1 to $R_1 + \delta R_1$. As there is a change in resistance of one of the resistors, then naturally there will be change in the output value as well.

I can say the output voltage will be changed from V_o to $V_o + \delta V_o$. I am expecting here, that voltage will also get increased. Now, we know the correlation of V_o, from equation 6.

$$V_o + \delta V_o = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_3}{R_3 + R_4}\right) \text{.................}Eq.7$$

Now, as there is a change in voltage from V_o to $V_o + \delta V_o$ due to change in resistance value of R_1 to $R_1 + \delta R_1$. Let us use that change in resistance at R_1 as $R_1 + \delta R_1$and we got the correlation as shown in eq. 7.

So, $V_o + \delta V_o$ is equal to V_s into this term. We are interested to find out the change in output voltage due to change in the resistance value of the R_1 resistor. To find it out subtract equation 6 from equation 7.

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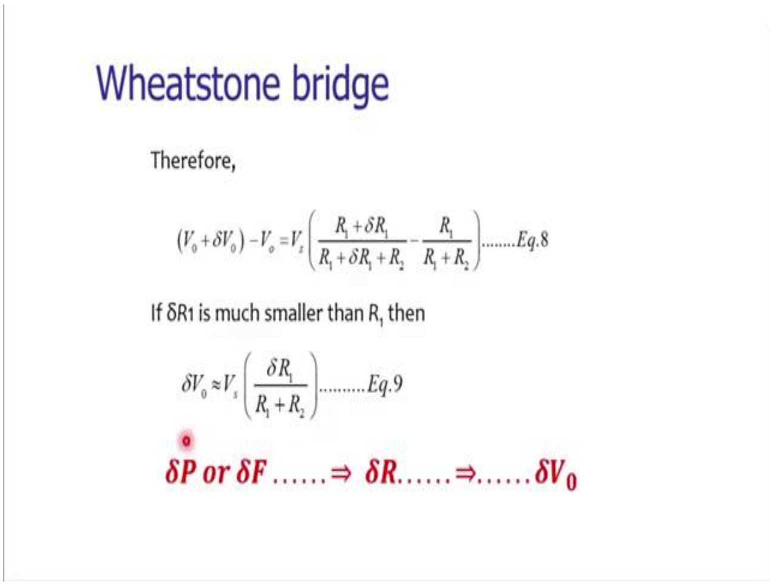

If equation 6 is substracted from equation 7, then I am getting:

$$V_o + \delta V_o - V_o = V_s\left(\frac{R_1 + \delta R_1}{R_1 + \delta R_1 + R_2} - \frac{R_1}{R_1 + R_2}\right) \text{.................}Eq.8$$

In actual sense the delta R 1 values are very small.

Therefore, I am neglecting the presence of δR_1in the denominator. Then the denominator of both these terms would be same and then we can get the correlation of delta V_o in terms of δR_1

$$\delta V_o \approx V_s \left(\frac{\delta R_1}{R_1 + R_2} \right) \text{.................} Eq.9$$

Thus, δV_o is a function of supply voltage and change in resistance value of R_1.

In this way, if there is a change in pressure or a force that is applied on the strain gauge, that will change the resistance value of R_1 resistor and in and due to that we are getting certain change at the output voltage.

$$\delta P \, or \, \delta F .... \Rightarrow \delta R .... \Rightarrow .... \delta V_o$$

That output voltage can be amplified, based on its basic magnitude, original magnitude. And that amplified signal will be sent to the microprocessor and microprocessor will utilize that change in voltage to its further application.

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Well, let us summarize the lecture 2. In this lecture, we have seen the meaning of pulse modulation and its application in designing and development of automated system. We have seen various protection devices, but before that we studied the need to go for the protection devices. We have seen basically two types of protection devices; these were zener diode and Optoisolator.

And then, we have seen the Wheatstone bridge; its configuration and operation of Wheatstone bridge and how it is helping us to convert the sensor into transducer.

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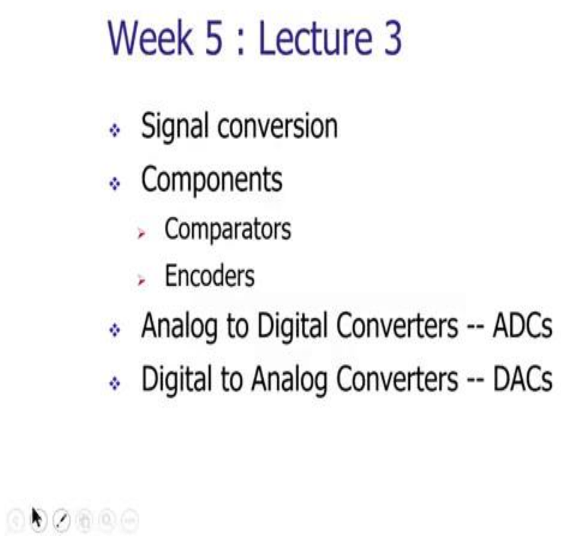

Then what is there in the next lecture? The lecture 3 of week 5, we will take the next aspect of signal conditioning, that is signal conversion. As we have seen our previous lectures as well, some of the sensors are giving us the passive signals. They are giving the output in terms of change in inductance, change in resistance or change in capacitance, which is not useful for the microprocessor.

The microprocessor understands the language of change in voltage or change in current. For that purpose, we need to convert the change in resistance into change in voltage. For that purpose, we are using the Wheatstone bridge kind of electrical circuitry. In many cases of automation, we need to have certain devices which are converting the analog form of signal into the digital form of signal. And certain actuators are understanding the language of analog signal only; for example, a DC motor.

We need to give the input in terms of the voltage. The output from a microprocessor that is in digital format need to be converted into the analog format.

What are the various techniques associated with the signal conversion that we will be seen in the lecture 3 of week 5.