Automation in Manufacturing
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Week - 05
Signal conditioning and Microprocessor Technology
Lecture – 01
Signal Conditioning: amplification, filtering

Hello everyone, I welcome you all to the week 5 of the course automation in manufacturing. Well, in previous weeks, we have seen the fundamentals of automation in manufacturing, we have seen how to design a system, how to manufacturer system. Now, in this week we will be studying the various concepts associated with the microprocessor technology and signal conditioning. In the previous week we have seen the elements of measurement system.

Sensors are the basic element of a measurement system. Sensors are giving us the input signals, but whether the input signals are usable, can we use them for our intended application i.e. the micro processing.

For that purpose we need to carry out certain operations and then we have to take decision based on that information. The terms, technology and various aspects associated with signal conditioning and micro processing technology will be learnt in this week. Let us start the lecture 1, i.e. signal conditioning, amplification, and filtering.

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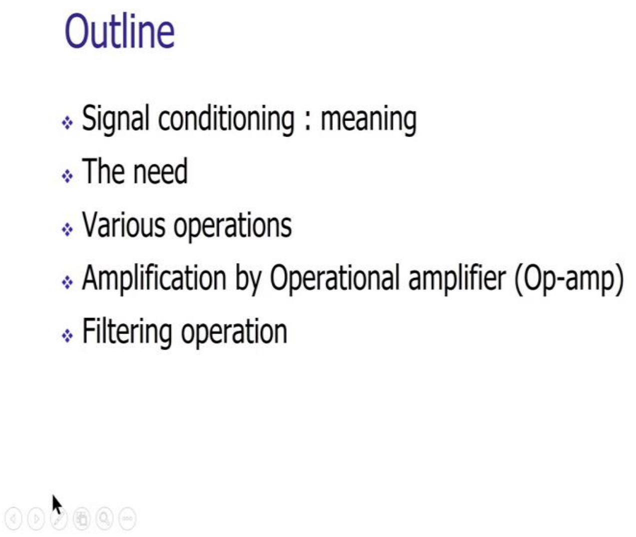

At the start of the lecture we will be studying the meaning of signal conditioning. The raw signals which are coming from the sensors may be non-linear, their level may be low, may have noise and this signals cannot be used for our operation.

For that purpose we need to carry out certain operations; that we will be studying at the start of the lecture. The importance or the need of signal conditioning will be studied. Various operations under the umbrella of signal conditioning will be learnt, then we will start the first and important operation of signal conditioning i.e. signal amplification. Operational amplifiers are widely used to carry out this operation, that will be learnt in detail.

We will be studying only one configuration of operational amplifier. After studying the operational amplifier, we will see why the filtering is to be carried out. What are the various operations required for the filtering.

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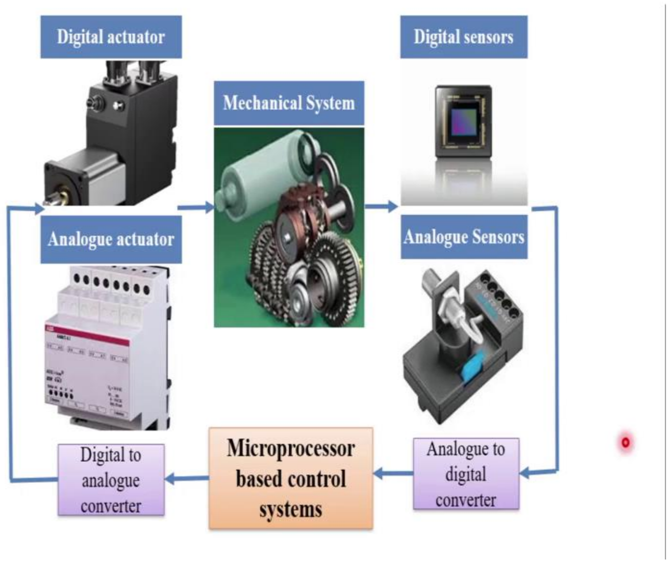

Well, let us begin the lecture 1. In our previous class we have seen various building blocks of microprocessor based mechatronics system. The basic element is the mechanical system itself, the measurement system which is measuring the field variables and which is taking the status of the mechanical system and that status will be sent to the microprocessor.

Microprocessor analyze the status of the mechanical system; and as per the program written in the system, it will take action whether to actuate the system or to change its parameters. Accordingly, the signals will be sent to the actuators and then the system will be in operation or will be in control. Well, in previous lecture we have seen various types of sensors.

The second constituting element of measurement system is signal conditioning devices. In this lecture we will be studying about the signal conditioning devices.

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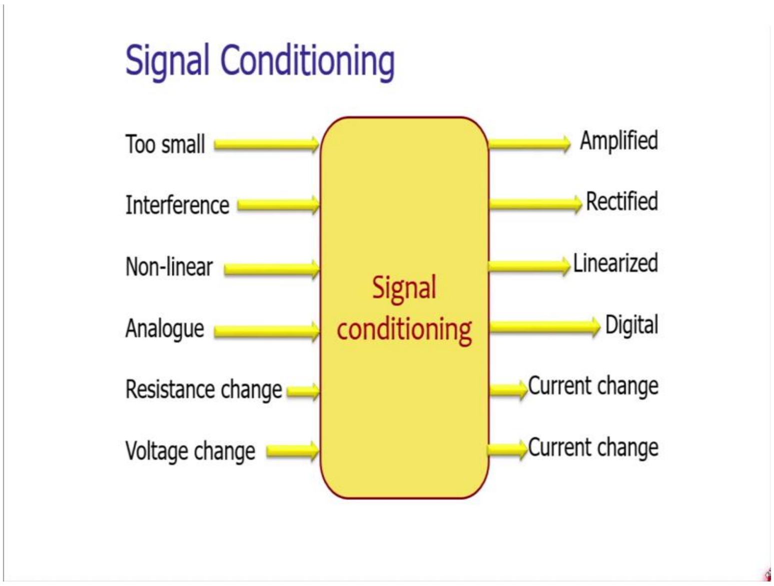

The main objective to condition the signal is to make the input data from the signals into an appropriate and useful form, which can be processed by the microprocessor easily. If we look at the signals which are coming from the sensors, some of the signals may be of too small magnitude.

Let us consider the example of a thermocouple. The thermocouple output may be in millivolt or microvolt which may not be sufficient to process in the microprocessor. Or if we take example of biosensors which are working on electrochemical analysis, the chemical analysis is generating the electrical signal, but the magnitude of the electrical signal may be in microvolt, that is not sufficient for the microprocessor. For that purpose, we have to amplify the signals.

The next aspect in signal conditioning may be the interference. At ground or in real life conditions, there may be unwanted signals or there may be unwanted factors, which are affecting the signal coming out from the sensor. This undesired factors may be the radio waves or sound waves or electromagnetic waves, which are there in the environment. These are interfering; these are influencing the raw data which is coming from the sensors. At the effect of these parameters is not in in a control level format.

For that purpose, we have to rectify the interference generated by the signals. The third aspect is non-linearity; the signals which are coming from the sensors are expected to be linear, but they are non-linear. We have to rectify; we have to linearize them. The sensors are giving us the input in analogue format. We have to convert that analogue form into the digital form, which can be well understood by the microprocessor.

For that purpose, we have to have the signal conditioning that we call analogue to digital converters. Then we have seen some of the sensors are giving the passive signals. The resistance change, inductance change, or capacitors change, we have to convert them into the active signal that is the voltage change or the current change. To process the data which is coming from the sensor and convert them into usable format is called as the signal conditioning.

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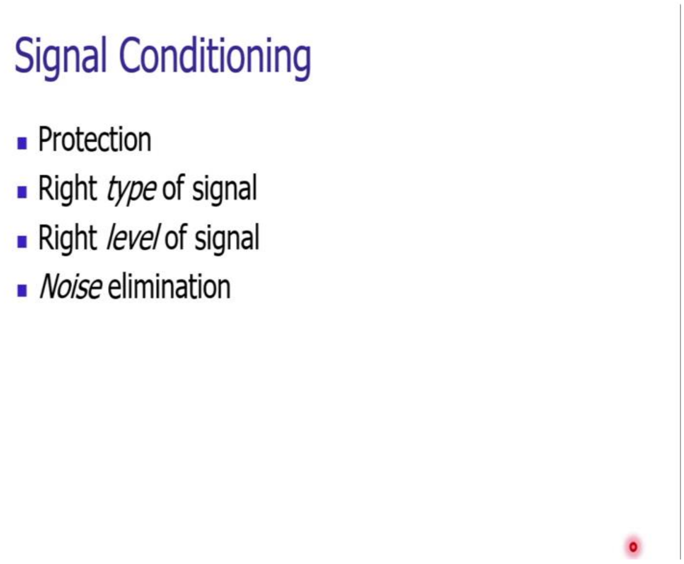

Thus, we can say that the signal conditioning has four basic functions;

first is the protection function: the signal conditioning device should protect the microprocessor from undesired level of the signal.

We have to have the right type of signal with right level of magnitude without the noise or the interference. Protection from harmful level of signal, harmful types of signals and elimination of the interference or the noise.

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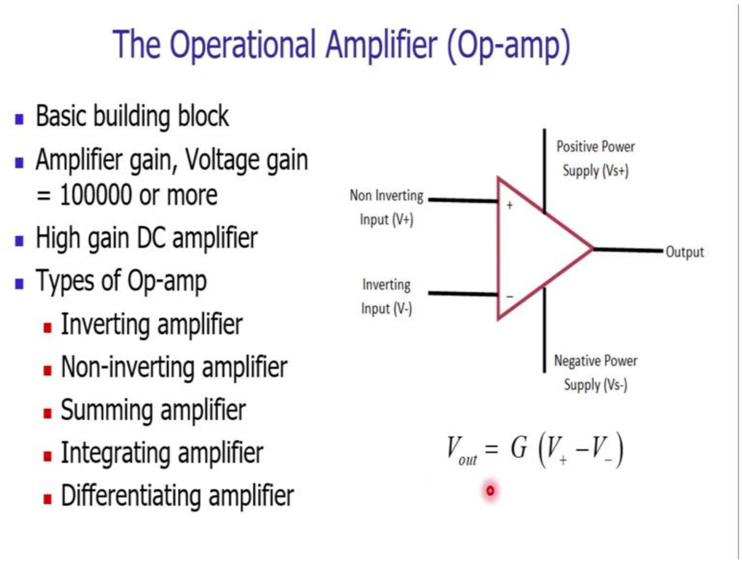

Well, let us study the first signal conditioning device i.e. operational amplifier. Operational amplifier is considered as a basic building block of many signal conditioning devices.

As the name suggests, it amplifies the input signal. Op-amp is nothing but a system which has certain input and certain output. Input to the Op-amp system is voltage and the output is also the voltage, but the difference is that the input is at very low level, while the output is at a multiple times. It is at very high level.

It is desired that the output of the Op-amp should be of very high order say 100000. That increase in the amplitude of the input voltage, it is called as the gain. How much gain the amplifier is providing in the amplification? A high gain DC amplifier is called as the Op-amp. A typical arrangement of the Op-amp can be represented by using the triangle which is shown in the slide. We are representing the Op-amp with a triangle. It has two input terminals.

The negative terminal is called as inverting input and the positive terminal is the non inverting input. The operational amplifier has the output terminal and the magnitude of the output terminal is dependent upon value and nature of the input terminals. In addition to these three terminals, it has also two more terminals, these are the positive power supply and the negative power supply.

Now, we can say the voltage at the output is directly proportional to the voltage at input and the constant of proportionality is the gain G. And as mentioned, high gain is around 100000, the gain is very high.

The gain we can define as the ratio of voltage output to the input voltage. But how to get this high gain? There are various types of configurations available. These are inverting amplifier, non inverting configuration of amplification, summing nature of amplifier.

And then integration used in amplification, some amplifiers they are based upon the differentiation that we call the differentiating amplifier. In this course we will be studying the inverting amplifier, the rest of the amplifiers you can refer the standard textbooks.

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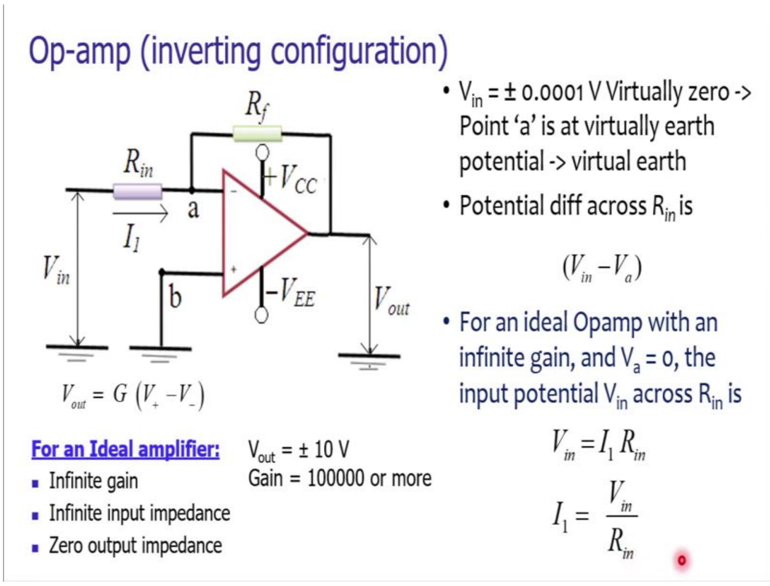

Let us study how the inverting configuration of operational amplifier works. The schematic of a typical inverting configuration of an amplifier is shown in the slide. In this configuration, we are taking the operational amplifier. As we have seen that it has two input terminals and there is one output terminal.

The inverting terminal at the input is taking the input through resistance R_{in}, while the non-inverting terminal is connected to the ground. The output we are drawing at the V_{out}, the circuit also takes feedback from the output through reference resistor R_f. Here you can see the feedback is being taken from the output at the input through a resistance R_f.

As per the definition of the gain, the gain is defined as the ratio of voltage output to the voltage input.

Now, if we try to study the inverting configuration, then we have to first consider the Op amp as an ideal amplifier. In general, the ideal amplifier has infinite gain, it has enormous gain. When we will have the infinite gain? To have the infinite gain, there should be infinite input impedance and zero output in impedance. There will be more or infinite resistance of current flow at the input and there is zero resistance of current flow at the output.

To understand this, let us consider one example. Let us consider we want to have a gain of 100000 or more. The output terminal is about ±10 V. With this gain and with this voltage output, the input voltage will be coming very low. Before that let us understand what is the meaning of impedance. The input impedance can be defined as the ratio of input voltage to the input current and the output impedance can be defined as the ratio of output voltage to the output current.

As mentioned, when we want to have a voltage output of around ±10 V with a gain of 100000, the input voltage will come around ±0.0001 V; which is virtually 0, which is very small value. Therefore, we can say that the point 'a' which is at the inverting terminal is at virtually earth potential. It is having virtually earth potential, it is a virtually earth point. Thus, the potential difference across R_{in}.

Now, if we try to find out the potential difference across the resistor R_{in} ,then that would be the difference between the voltage at the input terminal the voltage at point a, i.e. (V_{in} - V_a). As the input voltage is coming very low, that is why we can say that the point 'a' is at virtually earth potential, point 'a' is virtual earth point.

Now, as we have considered the inverting configuration of Op-amp as an ideal Op-amp and when we are saying that $V_a = 0$, then the input potential V_{in} across the resistor R_{in} can be written as

$$V_{in} = I_1 R_{in}$$

where, I_1 is the current which is flowing through the resistor R_{in} into the resistor value of the input resistor. So, rearranging the above equation we get

$$I_1 = \frac{V_{in}}{R_{in}}$$

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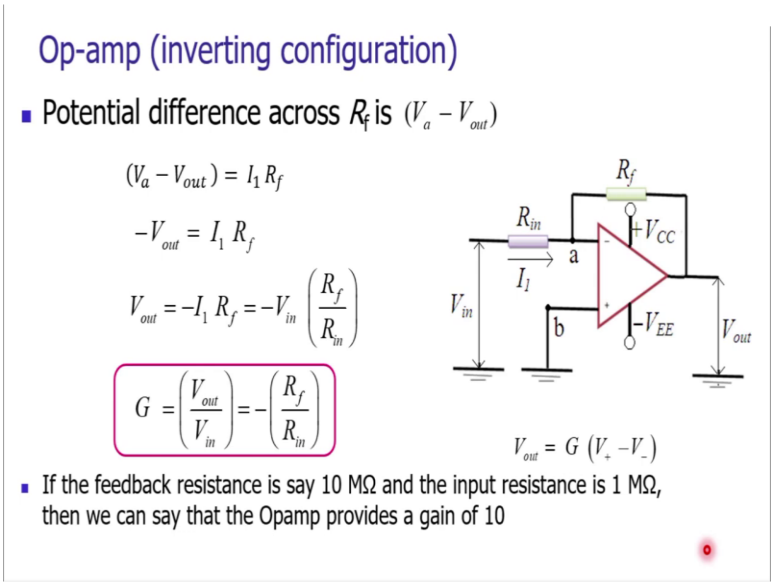

Now, refer the inverting configuration once again. Operational amplifier has very high impedance at the input, that we have seen in the definition of an ideal amplifier. Since, this high impedance can be considered as infinite in case of the ideal Op-amp and since, the impedance at the input is very high, we can say that there is no current is flowing through the point 'a'.

There we therefore, we can say that the current which is flowing through a resistance R_{in} must be the same as in the resistance of the reference resistor R_f. The potential difference across the reference resistor

$$R_f = V_a - V_{out}$$

Therefore,

$$V_a - V_{out} = I_1 R_f$$

Note that I_1 is the same value of the current which is flowing through R_{in}; however, we know that the value of voltage at point 'a' is approximately 0.

Therefore, we can write

$$-V_{out} = I_1 R_f$$

This equation can be rewritten as

$$V_{out} = -I_1 R_f = -V_{in}\left(\frac{R_f}{R_{in}}\right)$$

Thus, the ratio of V_{out} to V_{in} can be written as

$$G = \left(\frac{V_{out}}{V_{in}}\right) = -\left(\frac{R_f}{R_{in}}\right)$$

We know that, the ratio of voltage output to voltage input is nothing but the gain of the operational amplifier. The gain of the operational amplifier in this case is dependent upon the relative values of the resistor values of reference resistor and the resistor value of the input resistor. By modulating these two resistors we can achieve the required gain.

Let us consider simple example, if the feedback resistance is about 10 MΩ, the feedback resistor value is 10 MΩ and the input resistance is 1 MΩ, then we can say that the Op-amp is providing us a gain of 10. G is equal to 10 divided by 1 that is 10. Now, the question comes what is the significance of this negative sign? So, the negative sign indicates that the output is inverted.

What is being said is that, the output is inverted meaning, which means that it is 180 degrees out of phase with respect to the input voltage. That is why the negative sign comes over here.

This is very simple configuration of Op amp. As mentioned, by changing the resistor values we can easily get the required gain and we can utilize the operational amplifier for your intended purpose.

There are many other advanced configurations are available in operational amplifier; however, the detailed study of these amplifiers is out of scope of this course.

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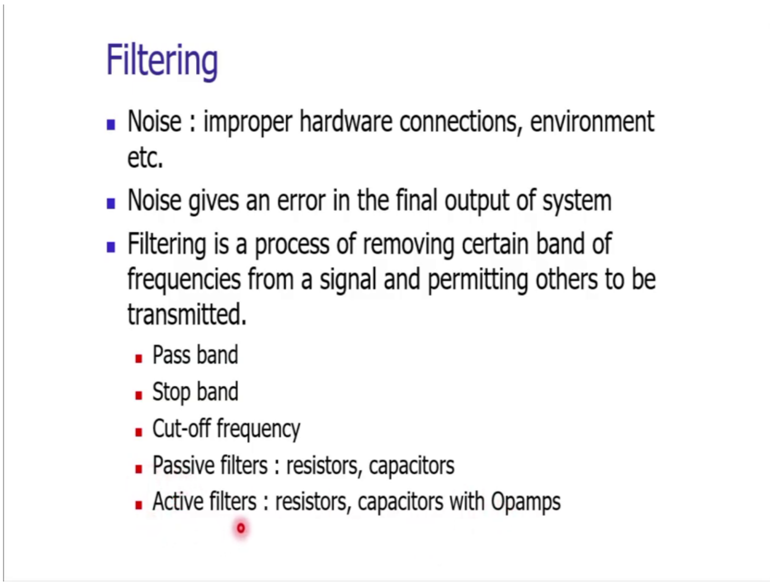

We may go through the standard text related to the basic electronics which are available. Filtering is an important operation being used in signal conditioning. There is noise present at shop floor, there is interference which may occur due to a variety of undesired signals, undesired radio waves, electromagnetic waves.

Moreover, the noise may occur due to improper hardware connections and environmental related factors such as temperature, humidity, dirt, vibrations. The noise certainly is affecting the final output of the system.

The noise will manipulate and we may have an erroneous and wrong output result. Therefore, it is very much essential for us to remove certain band of frequencies from a signal. And we may require to permit a specific band of signals that to be process for our intended purpose.

Thus, the process of removing a certain band of frequencies from the signals that we are getting and permitting others to be transmitted is called as the filtering operation. There are various terms associated with the filtering operation. The first term is pass band. The definition of the pass band is as: it is the range of frequencies passed by a filter.

The range of frequencies that will be passed through, that will be passed by it is called as the pass band. Second one is stop band: the range of the frequencies that will not be allowed to pass through the device is called as the stop band. Third one is cutoff frequency: the frequency between the stopping point and the passing point is called as the cutoff frequency. Well, we can develop filters by using the resistors and capacitors.

When we use the resistors and capacitors only to develop the filters, such filters are called as the passive filter, because there is no gain in the input voltage. Simply we are cutting of the undesired band of frequency that to be passed to the microprocessor.

But certain filters, they increase the magnitude of the input value, they increase the level of the input value and for that purpose we have to use operational amplifier. They are amplifying in the signals and simultaneously, they are allowing a selected range of signals that to be pass through. Such type of filters are called as the active filters.

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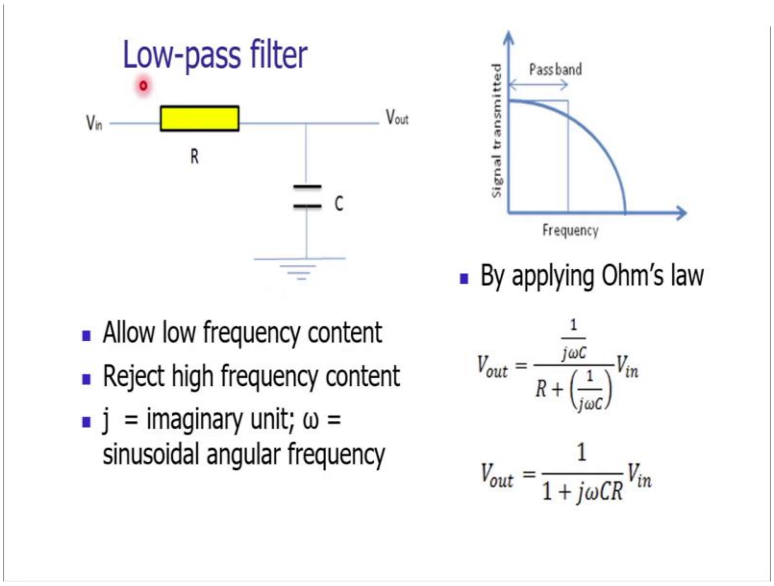

Now, let us study the first type of filter i.e. the low pass filter. As the name suggests, low pass means the filter will allow the low level of frequencies. in the slide we can see a graph. Along the x axis there is a frequency, along y axis there is signal that is to be transmitted. For lower value of frequency whatever the signals will be there, that signals are only to be passed. For that purpose, whatever the filter is needed that is called as the low pass filter.

Here the low is with respect to the frequency of the signals. To have such a facility, we are using resistor, and capacitor connected in series. The input voltage is applied at the resistor and capacitor in series; however, the output is taken out from the capacitor only.

This type of filters allow only low frequency content and they will reject the high frequency content, how? That will seen in the following lecture.

If we apply the ohm's law to a series RC circuit, then we can we can write the voltage at the output as:

$$V_{out} = \frac{\frac{1}{j\omega C}}{R + \left(\frac{1}{j\omega C}\right)} V_{in}$$

Here, the *j* is the imaginary unit, ω is sinusoidal angular frequency of the signals that we are getting, C is the capacitance, R is the resistance of the resistor.

This equation can be simplified and can be rewritten as:

$$V_{out} = \frac{1}{1 + j\omega CR} V_{in}$$

Now, this is an interesting correlation that we got and this will help us to allow the low frequency signals that to be passed.

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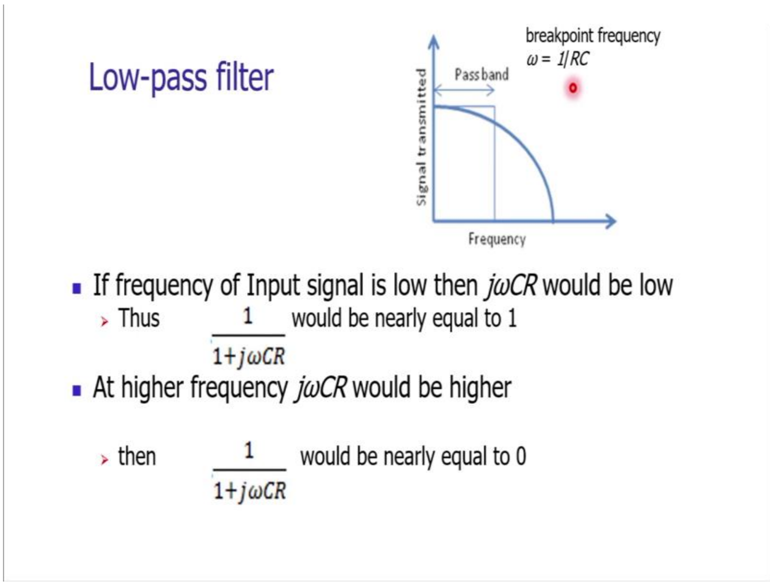

How? If the frequency of input signal is low, that means, the value of ω would be low. It would be definite, but it would be a very low value, j is the imaginary constant, C is a capacitance that is also constant, R resistance that is also constant. For lower value of ω the product of j omega CR would also be low.

If I put this low value of the product of jω in this equation, then I will get the value of this ratio

$$\frac{1}{1+j\omega CR}$$ nearly equal to 1.

Therefore, a certain output at the output terminal will be obtained, but consider the case when the frequencies are very high. In the product jωCR, ωvalue is too high. It is in thousands, if the angular velocity is too high; so, this product will also be too high, then naturally we will get this ratio

$$\frac{1}{1+j\omega CR}$$ nearly equal to 0.

When it is nearly equal to 0, then at the output we are not getting any result, we are not getting any signal. Whatever the input signals are being applied, that will be observed in resistances and capacitance circuitry. In this way the low pass filter is allowing only the low frequency data that to be passed through it.

The breakpoint frequency ω is considered as:

$$\omega = \frac{1}{RC}$$

But consider in certain cases, we want to allow the high frequency content to be filter in and the other frequencies or low frequency content is to be filtered out. We do not want that low frequency content.

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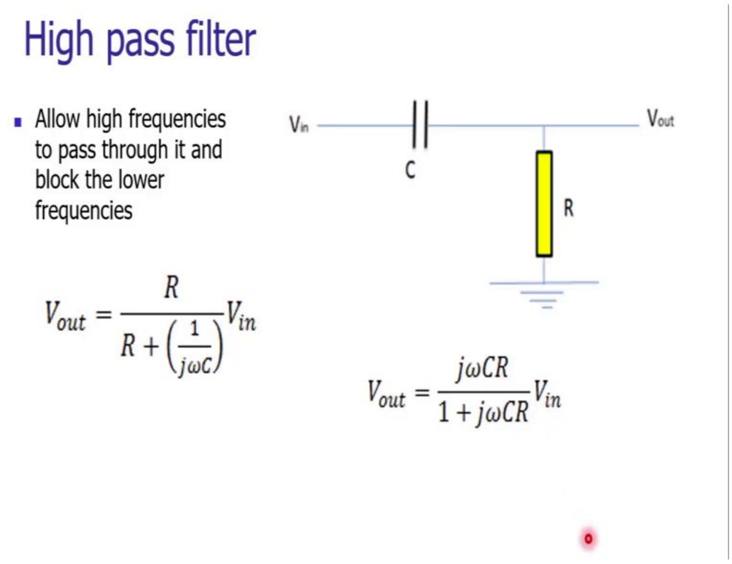

To carry out this task again, we are using resistor and capacitance circuitry, but the positions are changed, the positions are interchanged in comparison with the low pass filter.

Here we are using capacitance and resistance in series, but the output is taking out at the resistance, the input is applied at the series of the capacitance and resistance. Say if we apply ohm's law to this circuitry, we can get the correlation as:

$$V_{out} = \frac{R}{R + \left(\frac{1}{j\omega C}\right)} V_{in}$$

If we simplify this equation, then we will get

$$V_{out} = \frac{j\omega CR}{1 + j\omega CR} V_{in}$$

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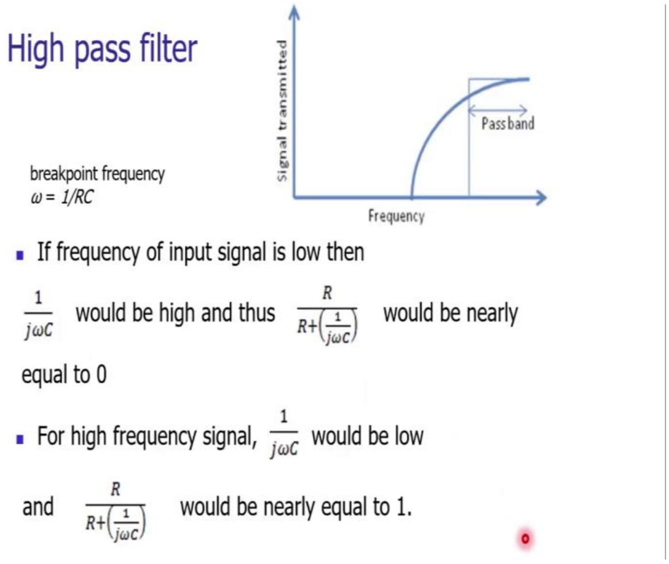

Again, we apply the same concept here to find out what would be the effect of the value of the angular frequency. If the angular frequency is low, if the low frequency content is applied, then what happens?

Since that ω is low, then certainly $\frac{1}{j\omega C}$ would be very high. As this term is very high then naturally, we are getting $\frac{R}{R+\left(\frac{1}{j\omega C}\right)}$ nearly equal to 0 content at the output. That means, for low frequency content we are not getting any output that frequency has been filtered out it is not being transmitted.

If the frequency is of high level, high content, then what happens? The ω would be very high and $\frac{1}{j\omega C}$ would be very low near to 0; as this ratio is near to 0, then $\frac{R}{R+\left(\frac{1}{j\omega C}\right)}$ is nearly equal to 1. In this way if high frequencies are passed through this filters, we are getting significant output at the output terminal. Well, that output can further be enhanced, it’s magnitude can be enhanced by using operational amplifier.

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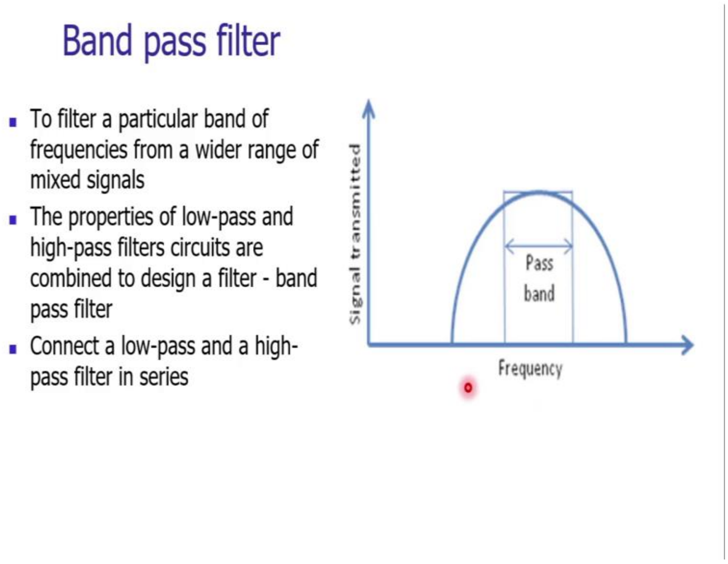

Now, we may have a wider range of mixed signals and in this scenario we have to filter, we have to pass limited frequency, a band of frequency through the circuitry. We want to utilize a band of frequency for our intended purpose, that is a microprocessor based operation. We do not want the low frequency content; we do not want the high frequency content. So such type of filtering it is called as the band pass filtering.

Customize bands are defined and for that band only, we are getting output. How it is possible to design such a filter? We have to use the properties of low pass and high pass circuits and we have to combine them together in series. If we connect the low pass and high pass filters in series, we can easily generate a filter circuitry that will allow defined band of frequency that we passed through the circuitry.

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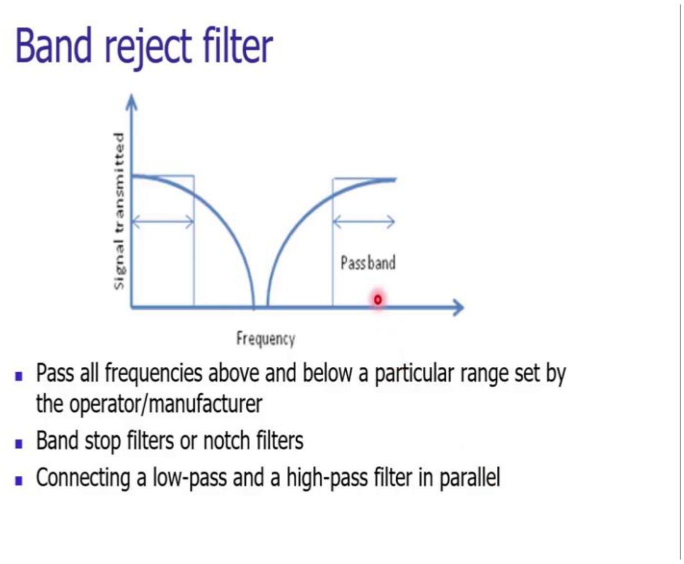

Then in certain cases we have to reject certain band of frequency from the processing operation. We have to allow the frequency other than this band. The lower band frequency content is allowed, the high frequency content is allowed, but the content in between the end of the low frequency band and start of the high frequency band, that content, that intermediate content it is to be filtered out, it is to be rejected.

For this purpose, we have to connect the low pass and high pass filters in in parallel configuration. This band reject filters are also called as band stop filter or notch filter. Well, my friends we have studied various signal conditioning operations in this lecture.

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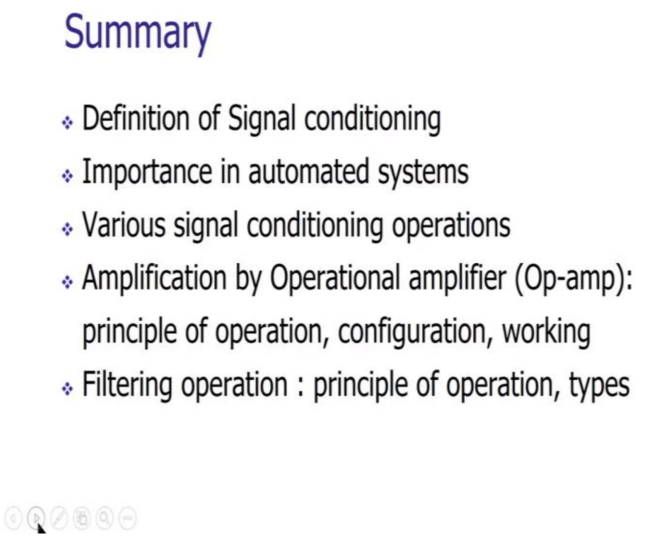

Let us summarize the contents that we have seen in this lecture. We learnt the definition of signal conditioning at the start of the lecture. We have seen the importance of signal conditioning in development of automated systems. After that we have studied various signal conditioning operations which are required to be carried out on signals to make them useful for the designing operation, for decision making operation.

Then we have seen the operational amplifier, the principle of operation of operational amplifier, its configuration, and the working. At last we have seen the filtering operation, the principle of working of filtration, and various types of filtration operations which are in general used in a; in the automation industry.

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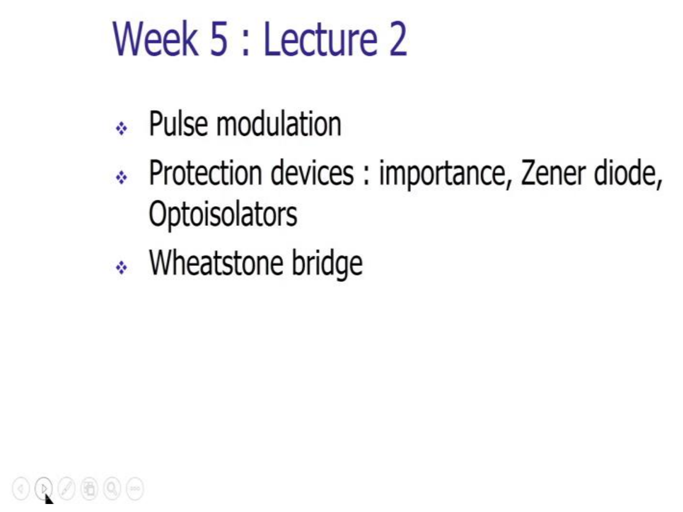

In lecture 2 of week 5, we will be continuing our discussion on signal conditioning processes. In this lecture we will study the pulse modulation. Pulse modulation is required to solve the problem of drift. When we are getting low level DC signals in a continuous format, there may be formation of drift. To minimize or to remove the drift error we have to modulate or we have to chop the signals.

What are the various techniques associated with that, that we will see. The signals which are coming from sensors or the signals which are coming from various electrical or the energy resources, that signals may be having very high energy level. They may not be safe; the signals may not be safe to process there. Their levels may be high; say the current level may be high or the voltage level may be high or they may have the wrong polarity.

To protect our devices, to protect the valuable instrumentation against these kind of risk, we have to utilize or we have to employ certain devices; these are called as the protection devices. Zener diode and optoisolator will be studied. The third aspect is a Wheatstone bridge. One important application of Wheatstone bridge already we have seen in our previous lectures that is in in the strain gauge. As we know the strain gauges are giving us the signal in the change in resistance.

We have to convert the change in resistance into the usable format i.e. a change in voltage or the voltage signal. To convert a sensor into a transducer, we need an electrical circuitry and that is nothing but the Wheatstone bridge.