Mechanical Measurements and Metrology
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Module - 4
Lecture - 49
General Issues in Mechanical Measurement

So this will be lecture for 49, in our ongoing series on Mechanical Measurements. We are actually going to have two lectures which form module 5 and the last module. So the two lectures will look at some general issues that are important in measurements which have been considered in some small detail as we went along the course of lectures.

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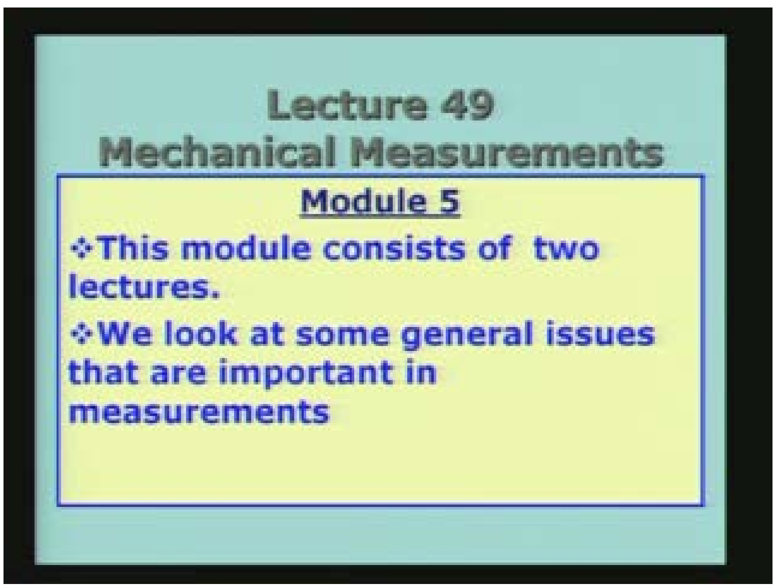

But I would high light some of these things which are important in any measurement practice. So let us look at the things we are going to discuss. The issues which we are going to look at are data acquisition, data manipulation and data presentation. Of course, we have been referring to some of these as we have discussed different ways of measuring different quantities. But here we will try to generalize to some extent, and discuss the important things which we should know.

Then I will also look at case studies pertaining to the design of experimental setup. It is not like design of experiments as we have seen earlier which is to determine how many experiments we have to do for a particular study. But here, we are talking about the experimental setup itself, and we will take may be one or two examples as it becomes possible. For the case studies we will talk about the layout, selection of instruments and also to some extent the aspect of design of experiments.

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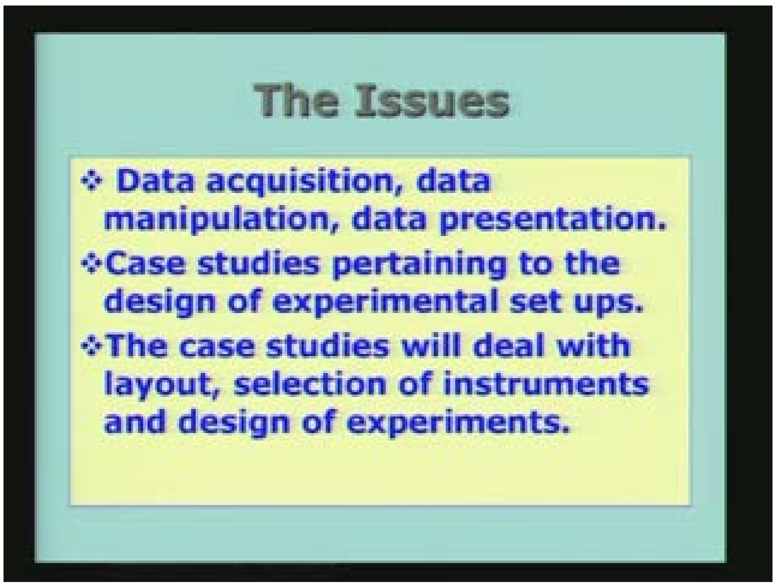

So I will go back to one of the earlier slides which I showed, at the very beginning of the lecture series and that was the sketch showing the general measurement scheme. The general measurement scheme consists of, as you can see here, the detector and transducer, this is the heart of the measuring scheme, and the signal from the detector is conditioned before it is communicated to the computer or to the display unit or to the controller as the case may be.

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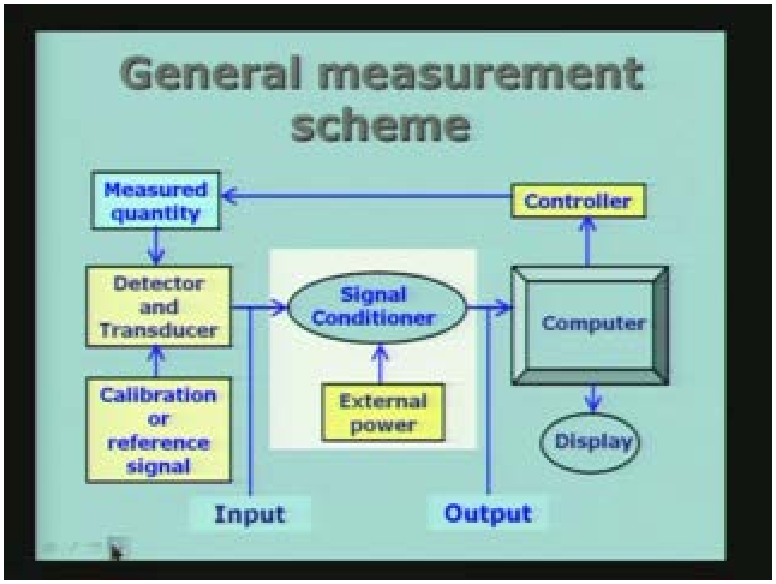

But you will see that, between the detector and the user, if you consider this as the user or where the information is going to be looked at in detail, there is something called the signal conditioner as shown with the white back ground here. So we will be discussing some of the important features of this particular thing the signal conditioner. So we have an input coming from the detector and the transducer which is in form of an electrical signal, and I have an output, which is in a form suitable or being communicated to the computer.

Between the input and the output, we have what is called the signal conditioning circuitry. What it does is, it changes the input level to the desired level at the output by either increasing the value or decreasing the value that is by amplifying or reducing the amplitude or the signal magnitude, or it may also manipulate in many other ways. For example, by taking the logarithm, or integrating the input, or differentiating the input and so on, and so forth.

These are possible conditionings which can be done. Many times the detector signal is very low, and it needs to be amplified to a suitable level so that it can be communicated to the computer, or the display or the user in general. So we will look at the signal conditioning, and see what are the things involved. The signal conditioner should transform the input to a level desired at the output, here, by using some external power. It should not draw any power from the detector; the detector itself should not be loaded. That means that no current or no excessive power should be taken from the detector. So the idea is to condition the signal, using external power which will actually supply the power required for this transformation, from one level to another level. So let us look at the type of things one would like to do in signal conditioning.

I have just labeled a few of them. One is of course, amplification, where the magnitude of the voltage or the current or whatever signal we are getting is too small, we would like to make it bigger by amplification. It may also be amplified after some manipulation, like multiplying by a factor or by taking the logarithm, and things like that as to what we mentioned earlier so some manipulation may be also done For example, we may subtract some particular factor out and then amplify it and so on.

Invariably we have in the modern practice, a conversion of analog signal to digital signal, because most computers and most display unit's nowadays will use digital form of signal. So analog to digital conversion is an important part of this signal conditioning. In the digital form, it can be communicated to a computer, and the computer can also put it into data storage which can be retrieved for later use or later analysis using appropriate software.

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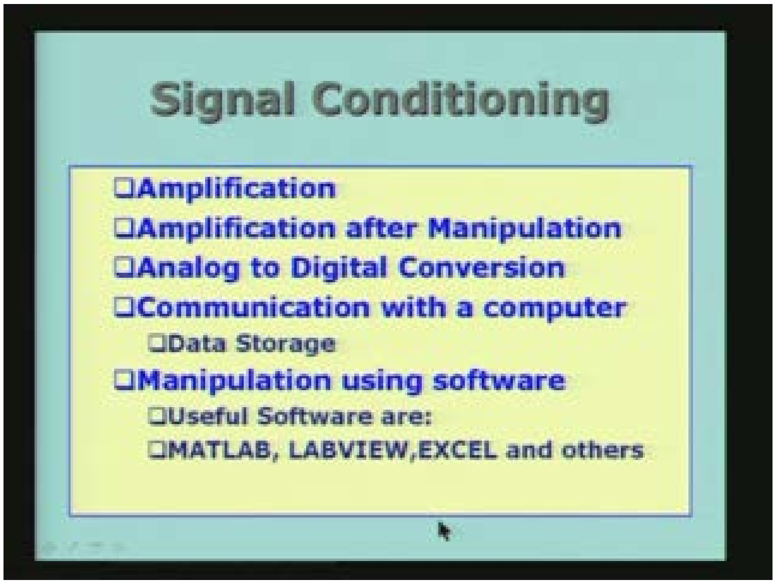

So I have mentioned here manipulation using software, there are some useful software available now, one is MATLAB and the other one is LABVIEW, and LABVIEW is specifically useful for signal analysis and then excel for example, which can be used for plotting and things like that. So all these are software which is useful in processing the data after it has been gathered or after it has been communicated to the computer or may be it is stored in data storage where we can use some of these things. In fact LABVIEW can be used as a virtual instrument that is what it means laboratory virtual instrument is what it stands for. So we will be using some of this software for doing the job.

The software can be used only if the signal is available in the digital form. So this analog to digital conversion is an important aspect of this signal conditioning. Let us look at the some of the simple things which we should know in using these instruments in the laboratory. The first one I am going to discuss in some detail is the amplifier which is very useful in increasing or improving the signal size. If the signal is very weak or very small in magnitude, I would like to make it much bigger so that it can be communicated to an external device.

So an amplifier is basically an instrument to which, I input the input signal, this is the signal V_{in} and it will amplify the signal to a value V_{out} and the gain is shown here G equal to V_{out} by V_{in}, it is simply determined by the values of resistors R_f and R_1, this is the feedback resistor, and this is input resistor R_1 and the amplifier itself is some kind of black box for us which draws power from an external supply. We have a positive and a negative supply usually it may be plus 15 minus 15V or plus 12 or minus 12 or sometimes it may be 5 and 0 or 5 and minus 5 and so on. So these are possible values.

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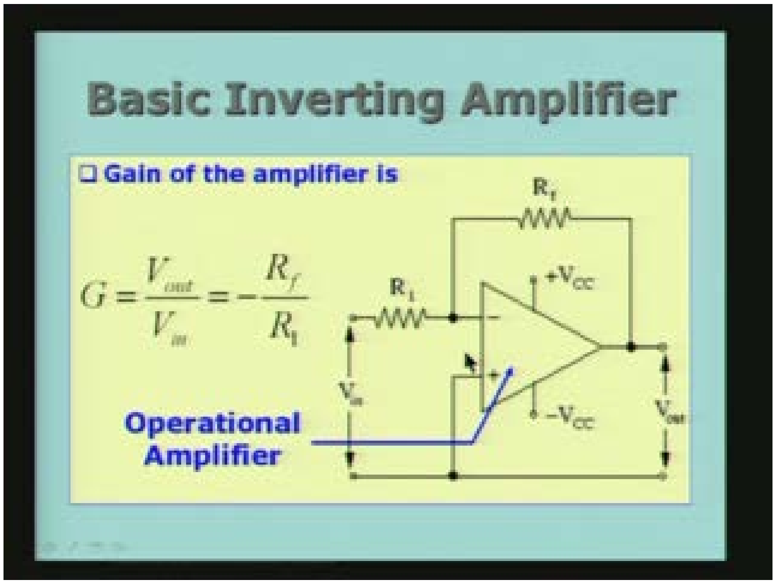

Therefore what the operational amplifier does is to give a magnitude give a gain which is purely determined by the resistance which we choose in this fashion here. We are talking about an amplifier and we just want to look at the basic features of an operational amplifier.

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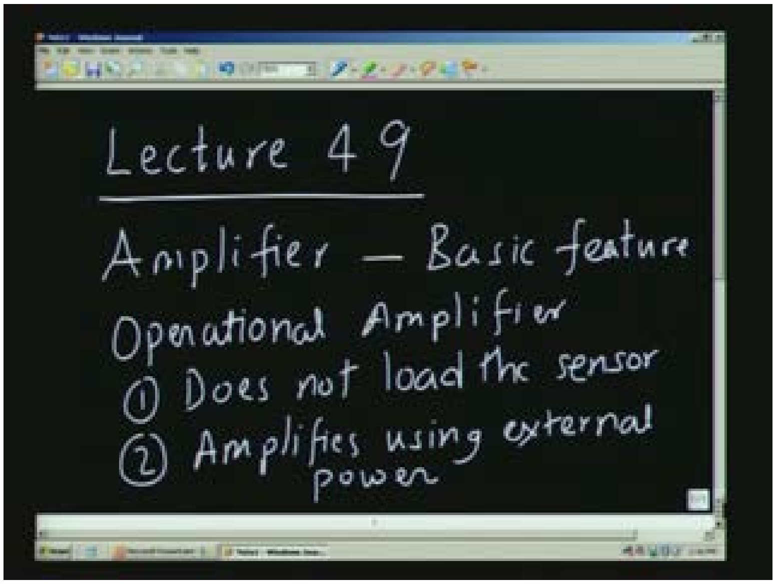

So, the operational amplifier is the heart of the signal conditioning system, and what the operational amplifier does is one does not load the sensor. So it draws no power from the sensor, or very little power from the sensor, amplifies the signal using external power. And in fact, I can represent the amplifier in a very schematic way as follows.

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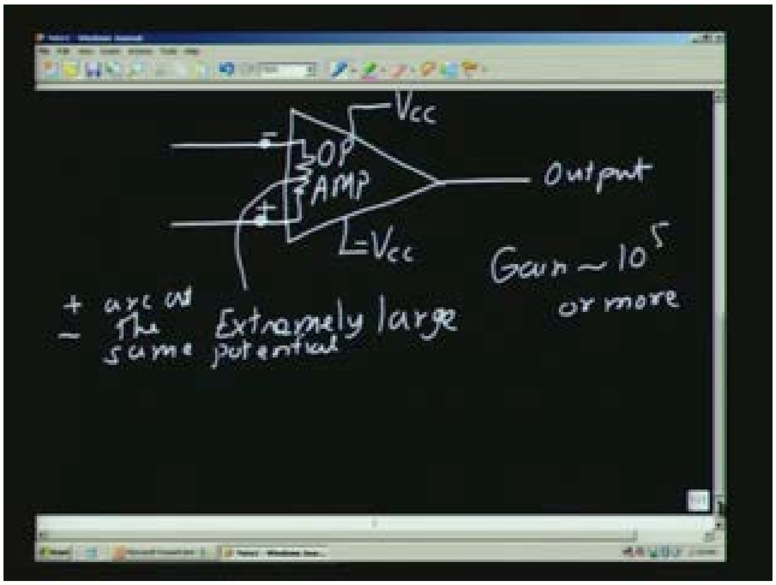

Usually, it is given by this triangle shaped symbol, this is the amplifier we will call it the operational amplifier op amp for short, and I have actually two inputs; one is called the inverting input, and the other one is called non inverting input. There will be a positive power input and the negative input and there is the output terminal. So we have two input terminals, and if you look at these two input terminals it is suppose I show it in terms of a resistance between these two terminals this is extremely high, extremely large.

So we say that the operational amplifier has almost infinite input impedance, number one, and number two the operational amplifier also has a very large gain. That is, if you do not connect anything to the terminals, the gain may be something like 10 to the power 5 or more, and the consequence of not having a very high input impedance is that if I show a terminal here and another terminal here as the inverting and non inverting terminals essentially they are at ground potential, the plus and minus are at ground potential or at the same potential, because there is no current or there is a very small current.

Extremely large value for the input impedance means that the current through this is negligibly small, therefore we can say that these two are essentially at the same potential. Hence based on this we can do a simple analysis. This is the differential amplifier.

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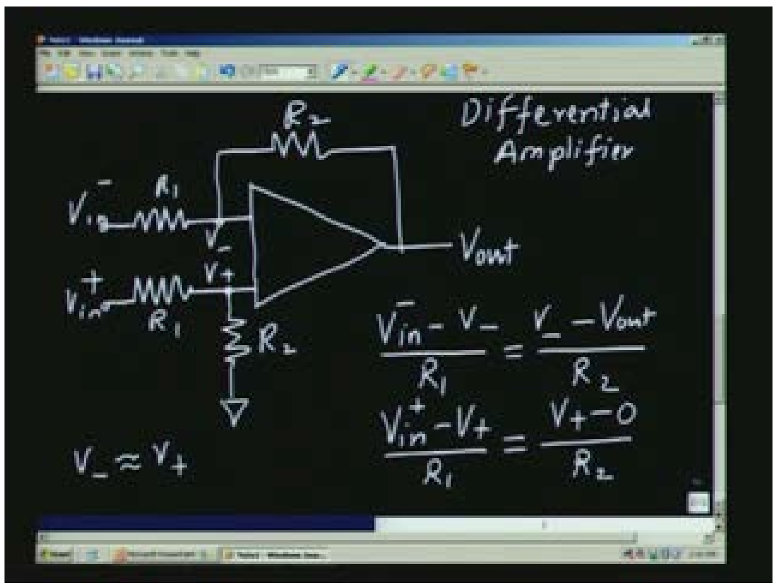

Most students in electrical engineering will learn this in their regular classes but mechanical engineers are not usually exposed to some of these. Therefore it is necessary to discuss some of these in this particular set of lectures. We have a resistor, another resistor here, so we will make these two equal to R_1 and this is the input negative, and this is the input positive. So I am connecting the positive input resistance and negative resistance therefore these are two potentials this positive and negative are with respect to the ground. So the ground is here, and there is a resistance R_2 and here you have one more resistance R_2 and this is your output.

Suppose the potential here is going to be V_- and the potential is going to be V_+ and we know that V_- equal to V_+ both of them are equal. This is the assumption, because, there is no current between the two terminals. Now you can see that if I do an analysis of the circuit the current through this resistor is nothing but V_1 V_{in} minus V minus that is the potential difference divided by R_1 so it is V_1 (V_{in}^- minus V_-) by R_1 this is the current through this. And because there is no current through this as far as this node is concerned whatever current enters here it has to leave and the current should be the same. So this should be equal to (V_- minus V_{out}) by R_2. This is one equation derived from this. Now you can do the same thing here because there is no current through this and whatever current comes here must go to the ground and therefore you can write the other expression as (V_{in}^+ minus V_+) by R_1 equal to (V_+ minus 0) by R_2 where 0 is the ground.

And notice that I am going to make V_- equal to V_+ in these two equations and then we can simply manipulate and get the following expression. We can see that V_{out} will be simply given by (R_2 by R_1) [V_{in}^+ minus V_{in}^-]

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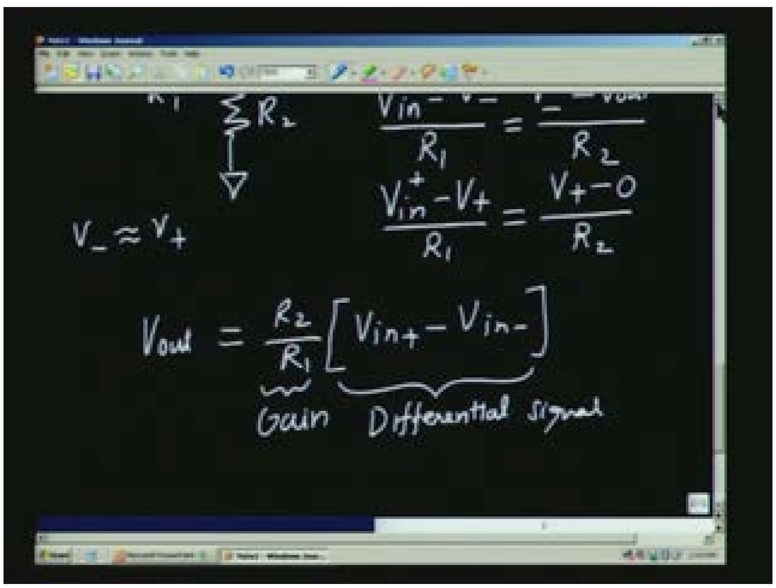

So this is the differential signal, and this is the gain of the amplifier given by the resistance ratio, R_2 by R_1. This is a simple analysis which shows that we can use this as a differential amplifier, because it is the difference between the voltages that is applied. As you saw in the figure here there is a difference in voltage which is going to be amplified, and the output voltage is simply given by the difference in the voltage here multiplied by the gain which is given by R_2 by R_1 which is simply the ratio of the resistance.

The gain could be quite high; easily we can have 10 to 100 gains without any problem. And if you want a large gain, suppose the input signal is only

microvolt range, and you want to make it millivolt or even higher then we require a gain of 1000 or more in which case instead of a single amplifier we can use one more amplifier so that the amplification can be done in stages.
Number two, if you look at this carefully, sometimes what we do is we simply have what is called voltage follower which is a unity gain amplifier. The advantage of that is, if you have a unity gain amplifier the input impedance is very high, that means that it does not take any current from the sensor, but the output can give you sufficient current for driving some external circuit.

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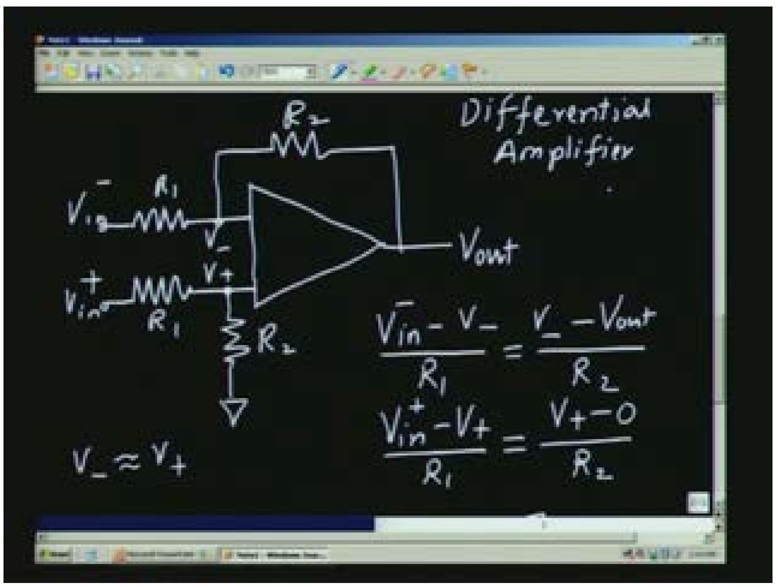

So sometimes we can simply have a unity gain amplifier which will give you a capability for supplying larger current but not without loading the input or the sensor itself. These are some of things which one can do.

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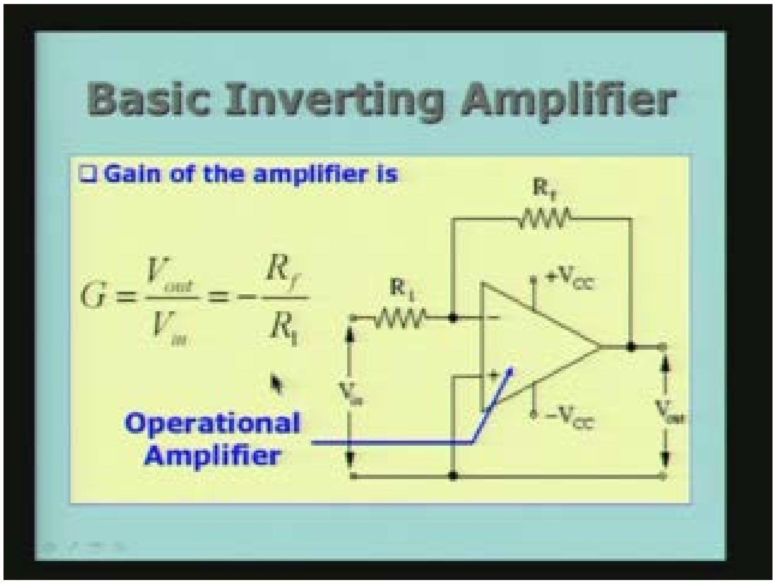

Now here this is the basic inverting amplifier. What I showed was the differential amplifier.

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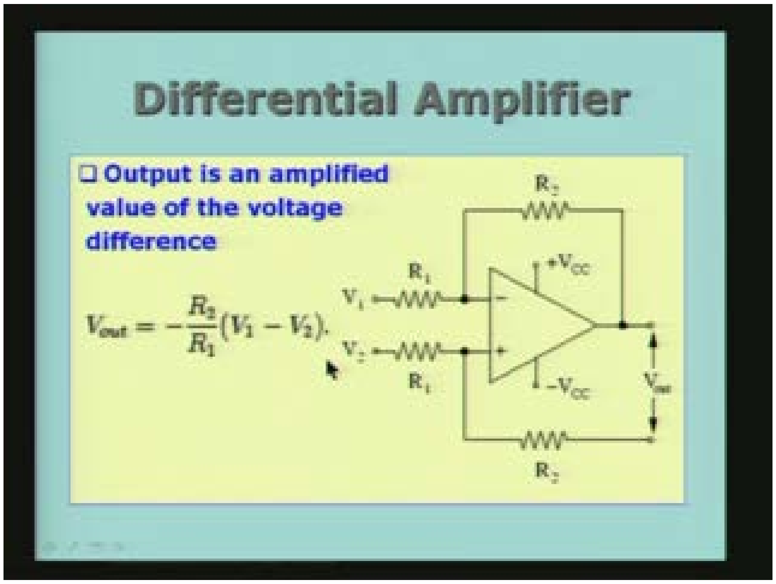

So you can see that if V_1 and V_2 are the potentials here and here so this gives you minus R_2 by R_1 (V_1 minus V_2) which is the same form which we obtained. So the output becomes an amplified value of the voltage difference. Now there are many other issues also. Here are some variations of this. So you can also have a summing amplifier. For example, if I have several voltages to be added together and amplified to a larger value I can connect like this V_1, V_2, V_3. If you remember we did that in the case of set of thermocouples where we wanted to average the thermocouple reading, a similar arrangement was shown there.

So we have V_1, V_2, V_3 etc connected to the inverting pin of the amplifier and there is a feedback resistance R_f and then V_{cc}, and minus V_{cc}, are the positive and negative power supplies so you can see that the output is now given by minus R_f[(V_1 by R_1) plus (V_2 by R_2) plus (V_3 by R_3)].

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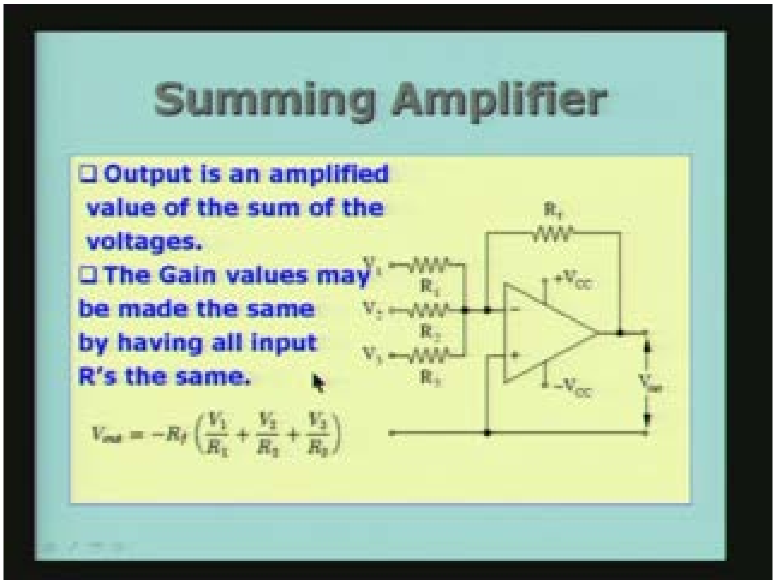

So if I make R_1 equal to R_2 equal to R_3 all these are going to be summed and amplified by the same factor. You can also sum by either with the same amplification, or different amplifications that you can have for different signals. By choosing R_1, R_2, and R_3, suitably, you can manipulate the signal. The variation which is shown here, is an integrating circuit. Suppose, I want to integrate the input voltage with respect to time all I have to do is to connect the RC like what is shown here, this is the capacitor and this is the resistance, choose these values properly so that you get a V_{out} equal to minus

1 by RC, and RC is the product of this, and this and the integrated value is going to be the output.

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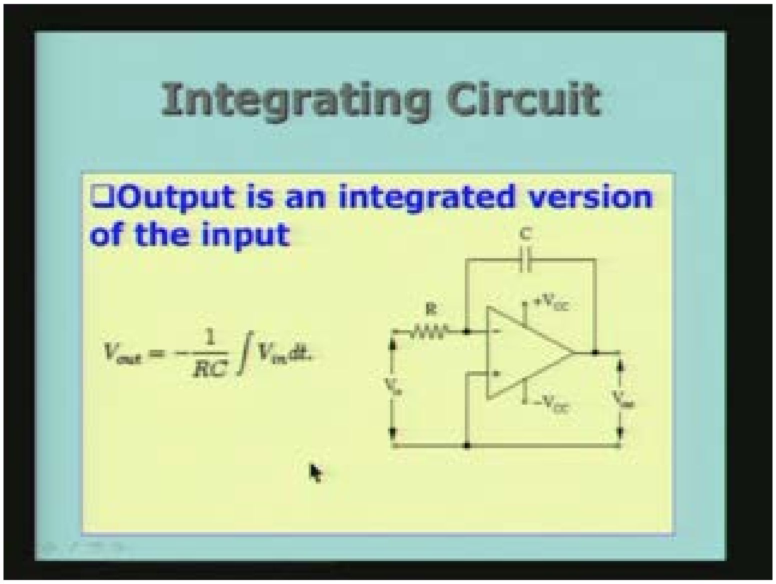

And similarly a differentiating circuit is also possible. If I just invert the C and R, the capacitance, instead of the resistance, and the resistance, instead of the capacitance you will get an expression like this, V_{out} equal to minus RC (dV_{in} by dt) that is the derivative of the input signal.

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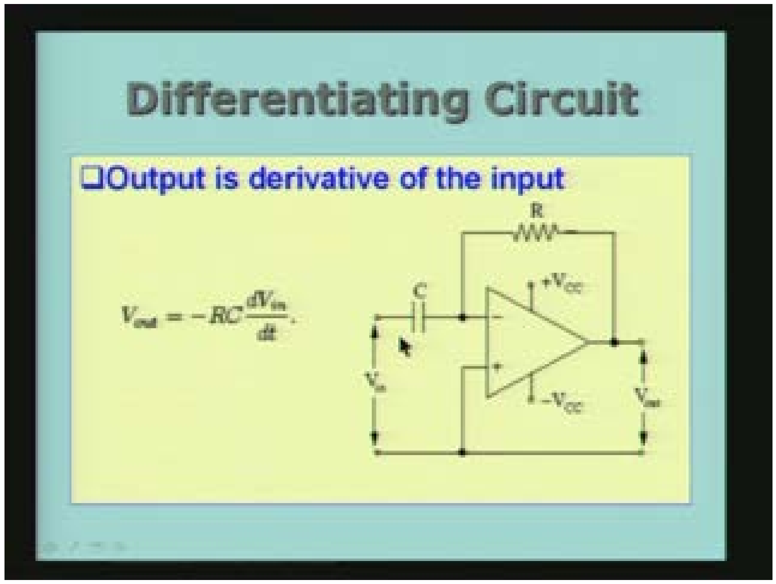

The other point is, in any measurement where you are going to look at signals coming from the sensor, we also have a little bit of noise that accompanies the signal. In fact, we have already seen in our discussion earlier that all measurements are prone to errors, and we discussed some of these errors. These errors could be in the form of a noise which is present along with the signal. And if the noise is very large compared to the signal it may be sometimes not possible to find out what the signal or what the noise is. Therefore many times, we have to suppress noise or eliminate this noise.

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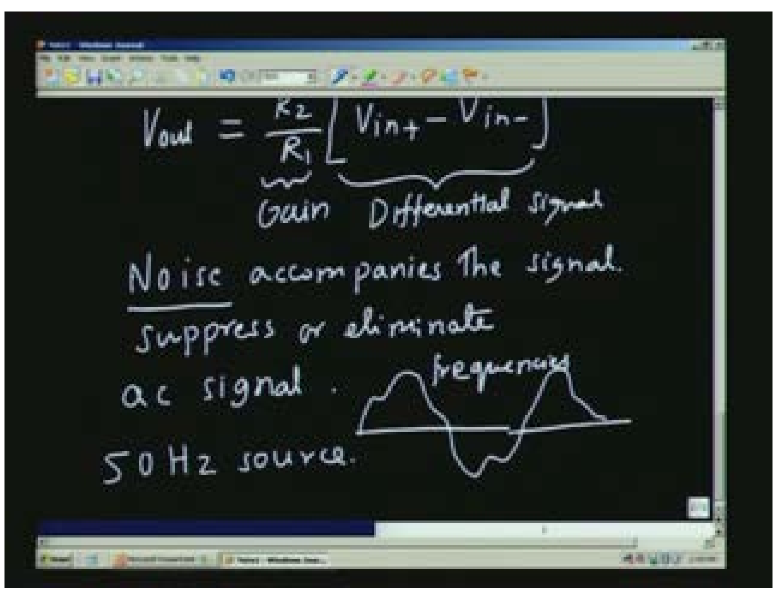

Suppose, we have an amplifier which is amplifying an ac signal, you know that ac signal consists of some kind of a periodic signal like this, and it will contain different frequencies, and you also know that we usually use a 50 Hz source. Our electricity system supply is at 50 Hz. And many times what happens is, the instrument or the amplifier is close to the electrical line in which case it will catch little bit of this 50 cycle noise. So it is 50 cycle noise 50 Hz. Noise can become a problem, for example in radios, in televisions for example, this noise will be appearing as a hum.

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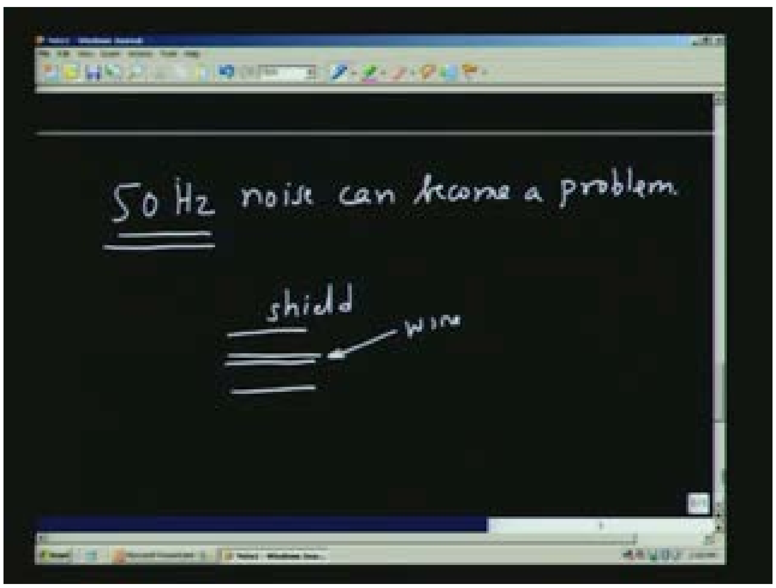

In audio amplifiers, 50 Hz becomes a hum. You get that background noise which is annoying to the person who is listening to the music or speech or whatever. So, one way is to not allow this 50 Hz noise to corrupt your signal by following proper wiring practice.

We use, for example, coaxial cables where the cable is in the form of a wire surrounded by a shield so that the outside noise does not get transmitted to the wire, because the shield will not allow the 50 Hz, or, whatever the noise to corrupt the signal, so that is one way of doing that. Of course, with all this you cannot really eliminate the noise, but can only minimize it. So the only way of doing that would be to use a proper filter. Filter is something, which is going to remove the unwanted stuff. Therefore, this removes the unwanted noise. So in this case, I am taking about 50 Hz noise.

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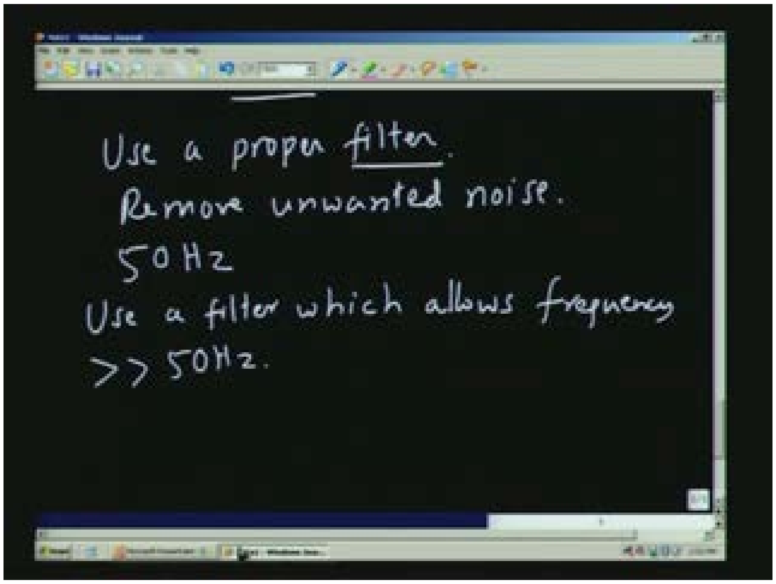

If I have an ac amplifier, and if I am looking at signals which are at sufficiently high frequency compared to 50 Hz then, I can use a filter which will remove the low frequency part of it and only pass the high frequency, so we have what is called a high pass filter. So, we can use a filter, which allows frequency much larger than 50 Hz. That means that the signal is also a part of the signal conditioning. As you can see, we are trying to remove the unwanted oscillations which are taking place at 50 Hz by doing this. This can be done by what is called a filter, which allows only high frequency signal to pass through, and the low frequency is removed.

We have a high pass filter here. You have an R, and another R, here, and two C's. You know that when you have an ac signal passing through, the impedance is the one which is going to modify the output input relation for a filter like this. So in the case of a high pass filter, the high frequency will pass through, and low frequency will be bypassed through this, and will go to the ground. That means what is going to come out is only the high frequency signal, and low frequency will be filtered out. In this case, what I have done is, I have taken an RC notch filter it is also the twin T, the twin T is, because, there is one T here, comprising of two resistances and capacitance, and there is another T here, corresponding to this with two capacitances and resistance.

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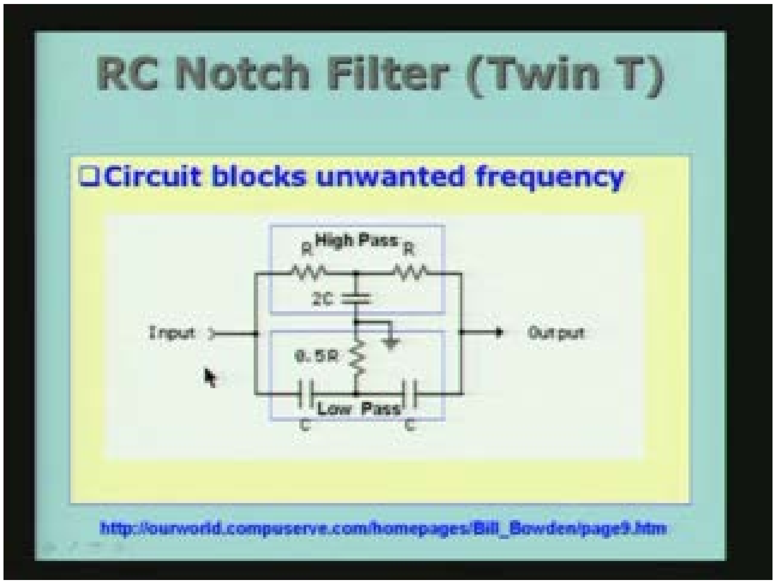

This is grounded here, and the input and output are connected here. The characteristics of this particular notch filter or RC notch filter is actually shown here. This is the filter the low pass, and the high pass, and then you have a summing amplifier.

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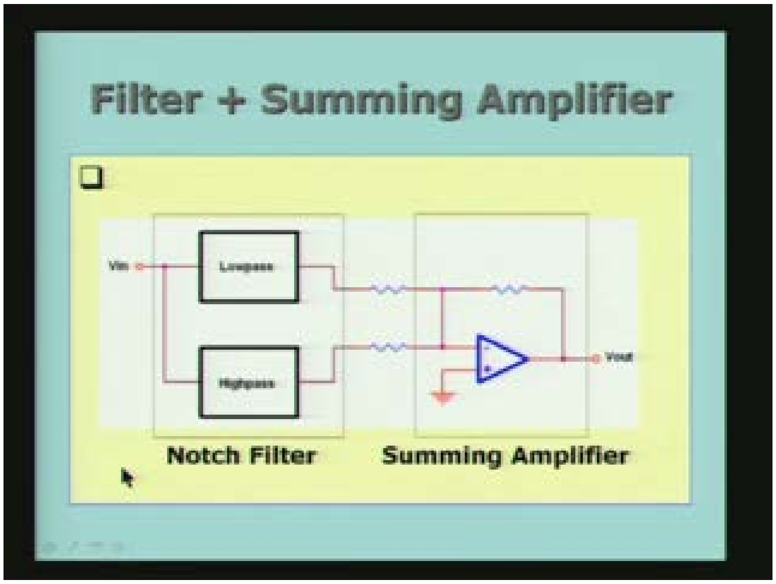

This summing amplifier is like what we showed a little while ago. And what you see is that the notch filter frequency response is like this. In this case of course, it is made for some other frequency and not for 50 Hz.

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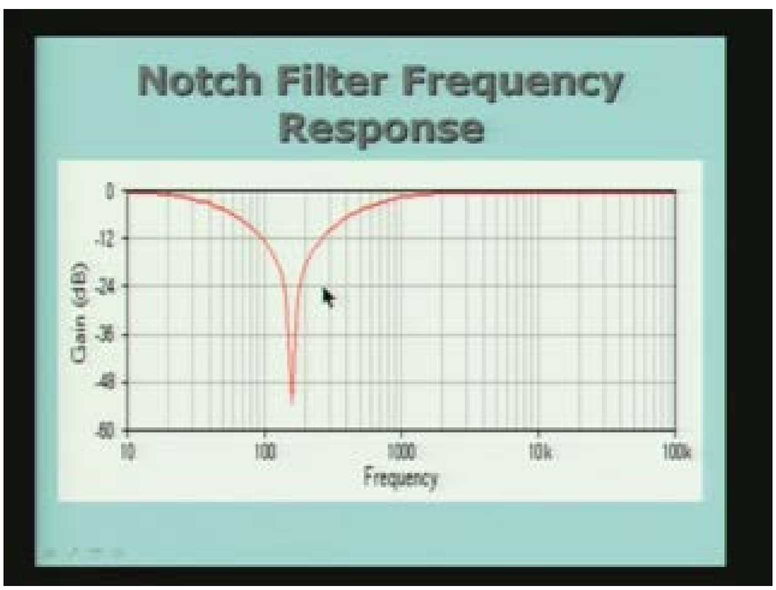

What you see here is that it allows the frequencies up to this and then at this particular frequency it blocks out completely. This is gain in db this is the logarithmic scale so it is attenuated to a large extent, therefore, this particular frequency will be totally absent. If the noise is particularly localized at this frequency you can have a notch filter designed with this as the frequency at which this notch is going to occur so that you remove that particular unwanted signal of that particular frequency, and it will pass the other signal without any attenuation.

So, signal conditioning means removing unwanted noise or removing unwanted frequency component passing only what is required, and may be amplifying it to the desired extent and so on. These are some of the issues. Many times, the instruments especially used in industrial practice also use what is called a 4 to 20 mA current loop. You have a sensor, it may be a temperature sensor, pressure sensor or any other sensor which we are interested in. The output of this sensor may be in the form voltage or may be in the form of current or whatever it is.

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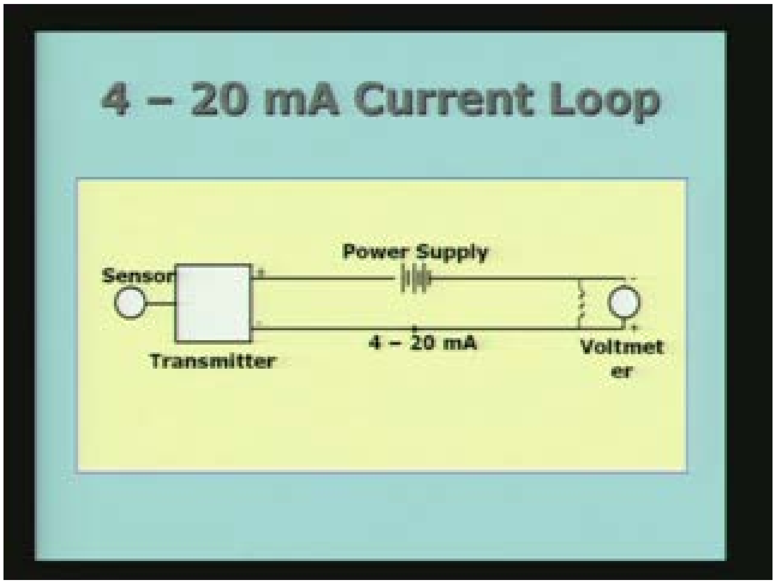

So you have a transmitter, and what the transmitter does is, it takes the sensor output and modifies it to a current proportional to the sensor output. If the sensor is a pressure measuring device, the pressure signal is converted to a current, and in this case if it is 4 to 20 mA that means that the maximum value of the current corresponding to 20 mA will correspond to the maximum of the pressure signal for which that pressure sensor is designed.

And the minimum will correspond to 4 mA and it is not 0 because when the sensor does not have any output it will still give you 4 mA so that we know that the circuit is working essentially. So why do we convert the signal from the voltage or whatever form it is to a current signal? Secondly, how do we use such an instrument? These are the two things we will look at. If you see the way the measurement is done, I have the sensor here, and the transmitter very close to the sensor.

Usually, these two are almost like in the same box, or same enclosure, and the voltmeter or the computer whatever I am going to use may be at a certain distance from the place, where I am measuring the sensed signal. For example, in a laboratory the instrument itself may be mounted on some equipment which may be tens of meters away from the voltage measuring device or the cabin in which we have kept all the measuring instruments. So the distance between here, and here, may be quite large. So if the signal is transmitted over a long wire like this, there will be a potential drop, and therefore it is not possible to transmit voltage signal over such long distances, it is simply not possible.

However, if you have a current signal, the current is not going to reduce or increase, but it is going to remain the same. The current is going to flow through this loop, and that is why it is called the current loop. It starts from here, and the transmitter gives a current proportional to the sensor output, and then it goes through this, and there is a load which is located quite far away, so the load is here and across the load I am going to measure the potential difference. That means, I am converting the signal which might have been originally a potential difference. I am converting it to a potential difference here, at the user end bu,t I am using a current to transmit this information. So the 4 to 20 mA current loop is a standard feature in many of the instruments. And what does it require? It requires an external power supply a dc power supply, usually about 24V or it may be even 12V.

The size of the power supply or the voltage which the power supply should supply depends on the losses, because the current is following through this wire. The loss in potential is due to the transmission through the wires, and also across this load resistor. Across this resistor, I am going to measure the voltage. For example, I may want 5V or 10V across this and this resistor has some particular value chosen such that it gives you 5V so this 5V plus whatever voltage drop takes place in all the other wires that the power supply must be able to supply.

So the strength of the power supply is determined by the potential difference required here at the user end, and also the losses in the wires, because the current is going to pass through all the wires and the sensor itself may require power which is also drawn from this power supply. Actually the sensor does require the power supply because either the sensor voltage or the current is sensed and then it has to be amplified or signal conditioned. The transmitter is actually a signal conditioner. What it does is to convert the sensor output into a 4 to 20 mA signal which is what we are going to transmit over a large distance.

We have discussed two or three different ways of doing the signal conditioning. One was actually using amplification, and the second one we looked at is the current loop. But whatever may be the method we are going to employ, finally we need to connect it to the external world which is usually done by using the following kind of arrangement.
We have the sensor shown as a circle here, and from there, the signal is available, and the signal is now amplified, and filtered, if necessary. Then, I still have an analog signal here, because the sensor gives an analog signal. Now I have to convert it to a digital form, so I require what is called analog to digital converter, ADC and then this should be given to the output device.

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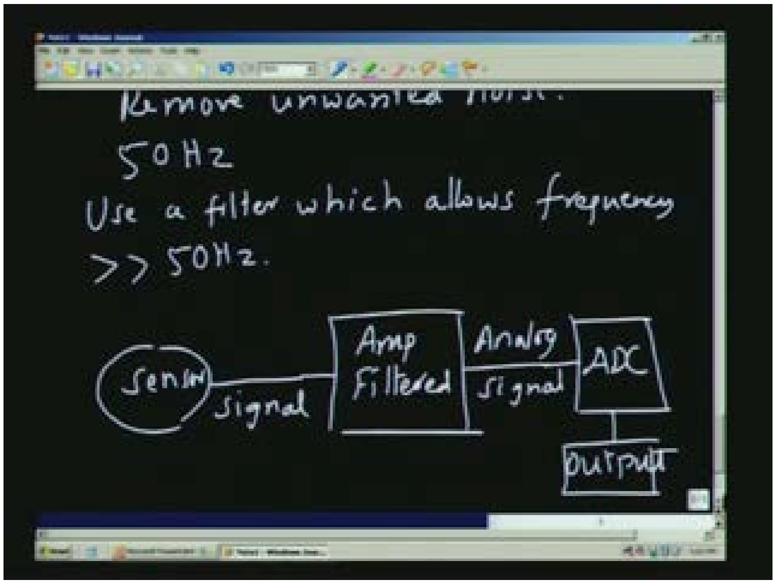

The output device may be a computer or may be digital voltmeter or whatever may be the type of instrument? So the input or the signal is analog and the output is digital, and this is communicated to an external device.

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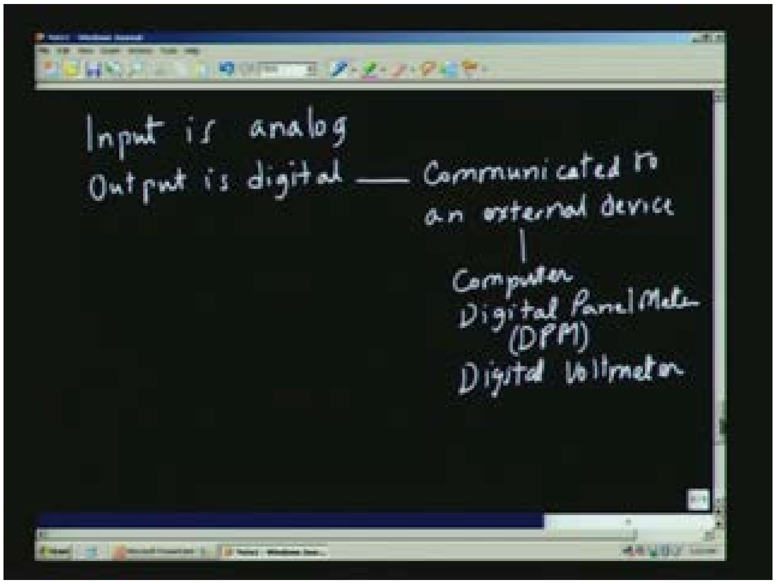

For example, it may be a computer or a digital panel meter of the DPM, or generally, we can call it as a digital voltmeter. Of course, in the case of the current loop we can also measure the current directly using an ammeter and that is one option which is always available. The output is digital, means I have to convert it from the analog form to digital form ,and that can be done by using a suitable analog to digital converter. The analog to digital conversion process is going to be important for choice of the instrument and so on. Let us look at what analog to digital converter means. You have an input range, for example the signal may go from 0 to 1V or 0 to 10V or 0 to 3V for example, and these are all possible input ranges. Now I am going to convert this to digital form, using a suitable ADC using a certain number of bits.

You know that the digital signal is always in the form of binary signal so it is a binary output. For example, I can take a simple A to D with a small number of bits, just to understand what is going to happen. For example, suppose, I take a 4-bit ADC the input is coming here in the form of analog, and here is your A to D converter and you get four of these output.

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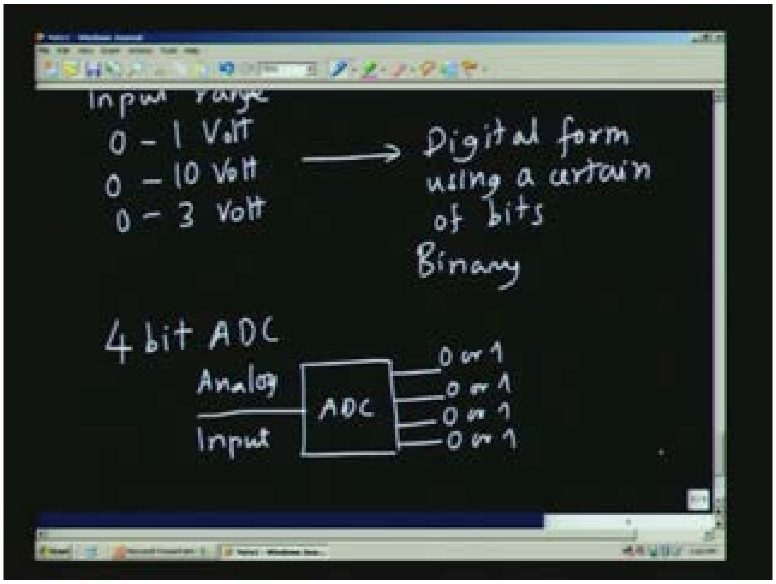

So, each one of these can be either 0 or 1. Of course, these can come in serial fashion or parallels as I have shown here. Now what we mean is that the each input is converted to an integer output. For example, if I have 4-bits the lowest bit is 2 to the power 0, 2 to the power 1, 2 to the power 2, 2 to the power 3 this is the 4-bit we are talking about. For example, I can have a number like this, all zeros of course, the value is 0, I can have one here the value is 1, I can have 2.

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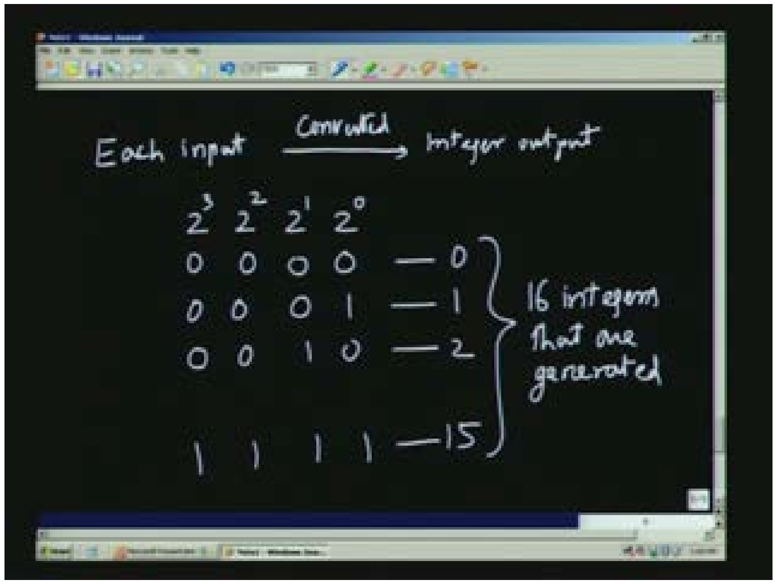

So, if I do this you see that the biggest number I can think of is 1 1 1 1 which corresponds to 15, so 0 1 2 3 up to 15 so there are 16 integers that are generated. That means if the input 1V corresponds to the last number here 1 1 1 1, all high, and 0 corresponds to, 0 0 0 0, the 1 2 3 corresponds to the fractions. So it is like dividing the range by the number of such integers, which I can represent.

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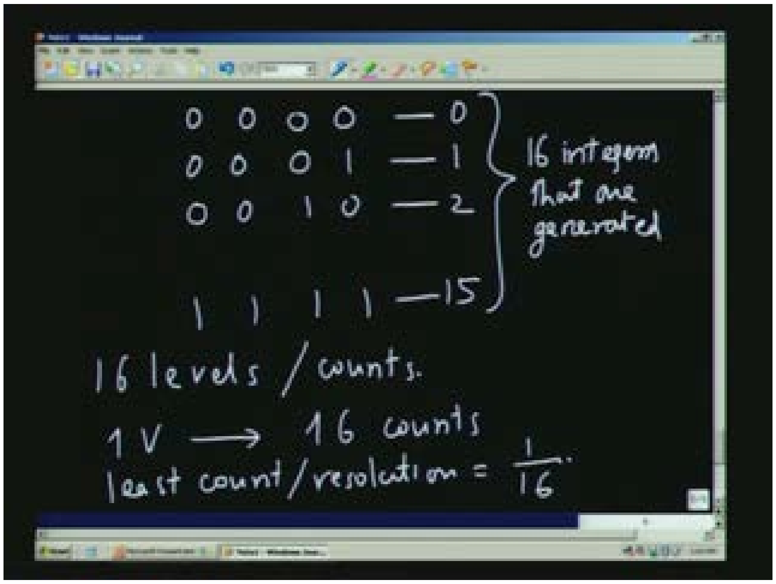

So in the case of a 4-bit conversion, I only have sixteen levels so sixteen levels are there, they are also called counts there is a possibility of sixteen counts. So you can see that if I have 1V that corresponds to these sixteen counts, the least count or it is also called the resolution is 1 by 16. That means, that the step by which I can measure the voltage, is in terms of 1 by 16V, and count number 1 will correspond to 1 by 16V. So what it means is that the digitalization process introduces an error, because it will not be able to show a continuous variation but it will be able to show a step wise variation.

We are approximating the linear variation of the signal by a set of steps and each step is of a unit equal to 1 by 16 in this case. But we need not of course, stop with the sixteen steps. In other words, 4-bits are not the necessary the only one's you can think of you can think of larger number of steps. For example, if I have a 10-bit ADC the maximum number or maximum integer that can be represented by this is given by 2 to the power 10 minus 1. This is nothing but 2 to the power of bits minus 1, this is 2 to the power N, where N is the number of bits.

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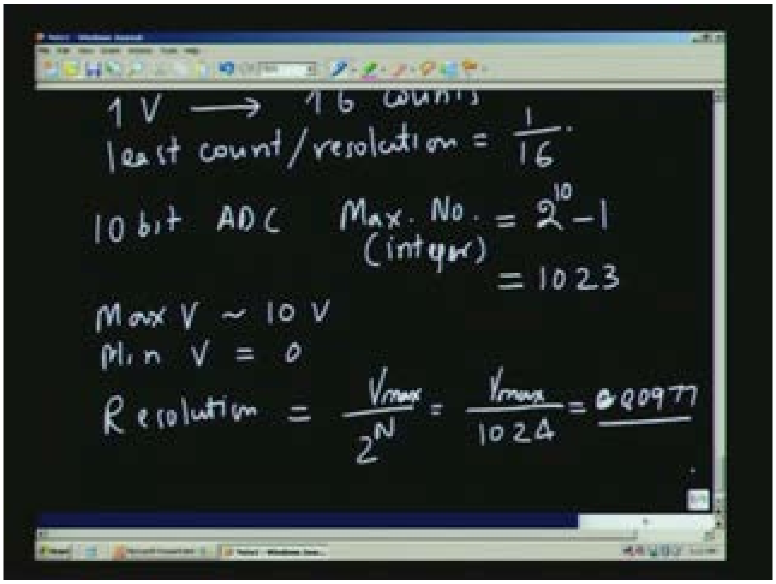

In this case it will come out to be 1023, and if I include the 0, there are 1024 levels starting from the lowest value. So suppose, I have an instrument, where the maximum voltage V is around 10V, and of course, minimum V is 0, so now I am going to measure this 0 to 10V using a 10-bit ADC. That means there are 1024 levels available, so you can see that the resolution is equal to 1 by 2 to the power N really, it is 1 divided by 1024 and that is the value which I am going to have, and that is going to give you 0.00977 and this will be roughly equal to 0 point 01. So that is the fraction. If you multiply by the maximum value this is 0.0077 V_{max}, and that gives you 0.007 into 10 so this will be something like 0.0977.

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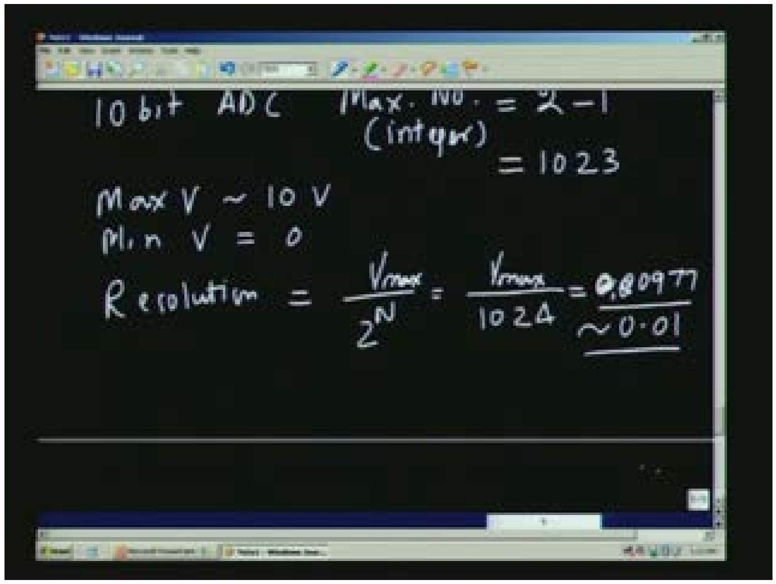

Actually we can make it exactly equal to 0.01, if I choose 10V a slightly higher value which will be just nothing but, if I take 10.24 you will see that it becomes exactly equal to 0.01. That means a 10-bit ADC can measure 10V in steps of 0.01V so that is the idea.

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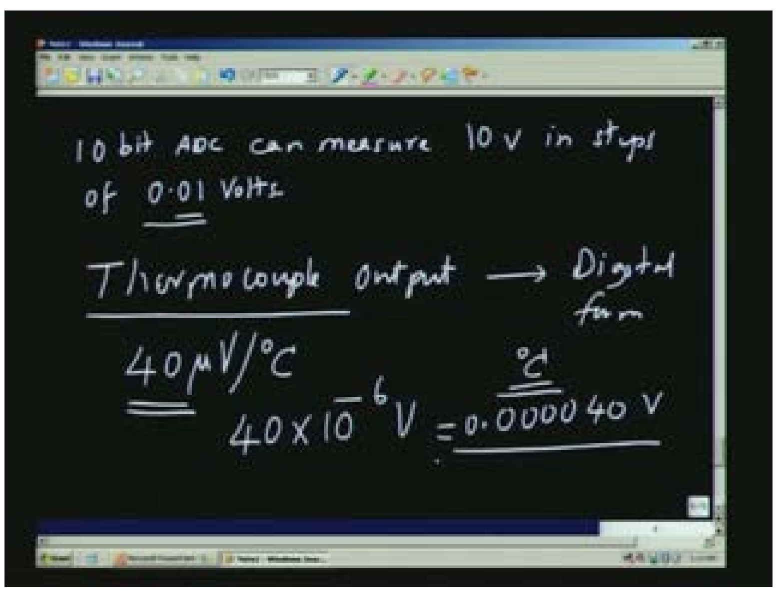

If you are going to convert a thermocouple output to digital form, for example, if you take thermocouple output to digital form, we know already that for a thermocouple, normally it is about, 40 microvolt by degree C. So if I want to resolve 1 degree Celsius, I need to sense 40 microvolt, here we were talking about 0.01V, so 40 microvolt, corresponding to 40 into 10 to the power minus 6V, and that will correspond to, I have to go four 0V this gives 1 degree Celsius resolution. So here, we were talking about 0.01 V and we required 10-bit but here when you require this you require many more bits than what can be got here. That is why, modern instruments which use digital data processing use very large number of bits. Here is an example which is commercially available. That is supplied by the National Instruments.

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This is data acquisition. Data acquisition is one of the most important parts and National Instruments supplies a large number of data acquisition hardware accompanied with software. This is one of them; it is a national instrument USB. USB means it is going to be connected to the computer to the USB port. USB is nothing but Universal Serial Bus.

Nowadays you know, we connect the mouse to USB, then we connect for example a printer to the USB, we also put our pen drive and connect it to the USB etc. Similarly, it is possible to use this data acquisition hardware by directly connecting it to the USB and then use it along with your computer. It is windows compatible and it comes with a driver and other software and all these are contained in a small package.
The size is not as big as what is indicated here but it directly goes into the USB slot. A description of this instrument: It is a DAQ from National

Instruments. It is one of the most recent additions to the National Instruments' family available very recently. It has got four channels, and it has got 24-bit thermocouple input. So you can immediately see that, it is 2^{24}, and you can translate it to a proper resolution value.

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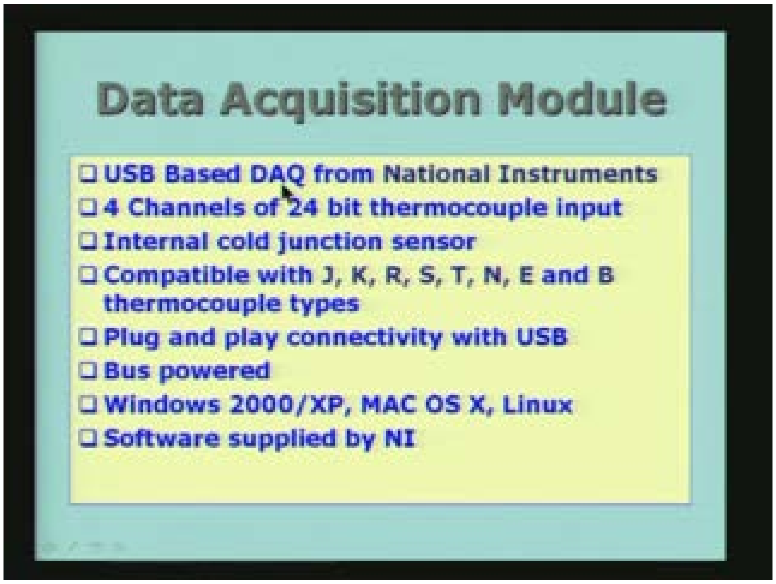

And it also got internal cold junction sensor which will give cold junction composition so you do not require a reference temperature junction to be maintained it is done, by actually sensing the cold junction temperature or the room temperature and correcting for it and it is compatible with all the different thermocouples we have described earlier J, K, R, S, T, N, E and so on. Actually the software will take care of it, all you have to do is to tell the software to specify which thermocouple has been used in your particular measurement, and then automatically it will take care of it.

It is a plug and play connectivity that means it will be automatically recognized by windows, and the driver is already there, it is powered by the bus so you do not have an external power supply to be hooked on to it. In fact it is available in Windows 2000XP and also MAC and LINUX versions. But what you already saw was the Windows version.

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For the other one they have a slightly different thing and the software is also supplied by National Instruments.

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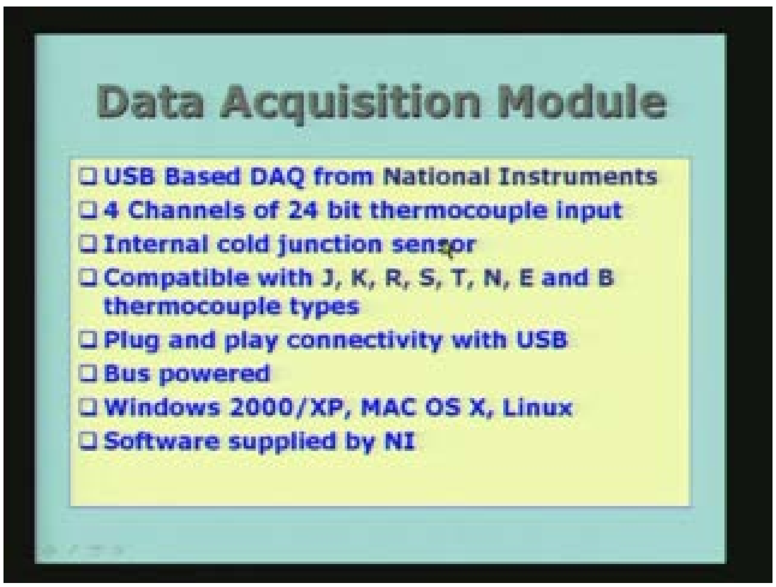

So just to see the resolution we are talking about, resolution of 1 by 2 power 24 is 5.96 into 10 power minus 8 it is something like approximately 0.1microvolt by V.

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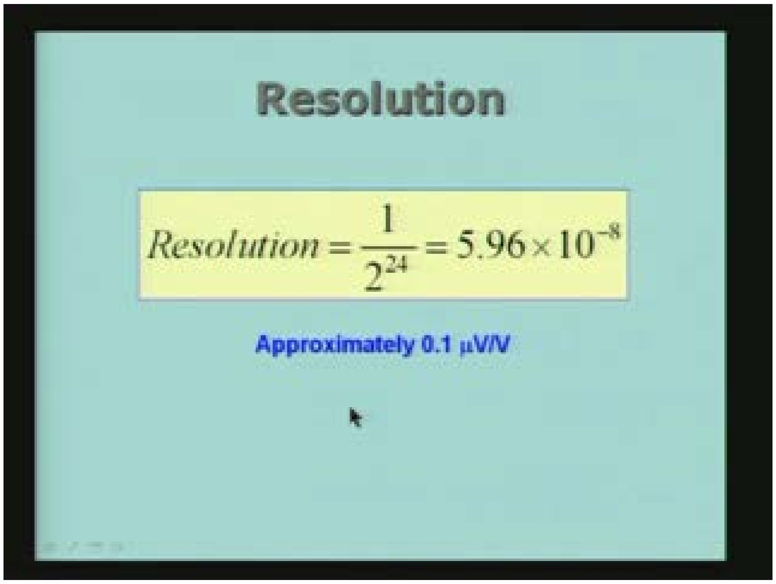

So you see that now we are talking about measuring very small voltage levels. Obviously, the instrument which I just now showed must have its own amplification, it must have its own manipulation, and all the items which we mentioned were already built into this 9211 so you do not have to connect anything specific to that, it is already there. And the software will take care of most of the things. And as I said earlier, the software which comes with National Instruments is the LABVIEW.

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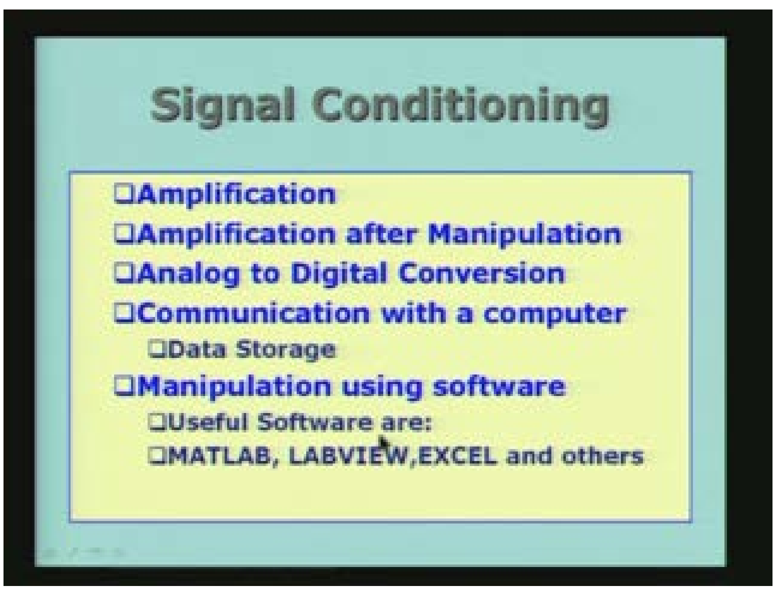

So, if you look at the LABVIEW software, with LABVIEW you can design the appearance of the instrument. That means that the PC monitor will show the front of the instrument. for example, you can have a temperature recording window in which the variation of temperature will be shown by a graphical representation, or you can have a small window in which the actual temperature will be displayed, and things like that. This can be designed by using what is called the LABVIEW software, and it has got various facilities.

The entire thing actually looks like a real instrument that is why it is called virtual instrument. Virtual instrument means it looks like a real one but it is actually virtual, because nothing is physically there it is only the software which is doing it. For example, I can make an oscilloscope and the oscilloscope will show up on your PC monitor, and you can actually use your mouse and then make adjustments. This is because, whatever we see in the monitor behind that there is a program which is running, and the program is controlled by the user input through the windows, buttons and so on. That is as though you are actually operating an instrument, but actually it is done by using a virtual instrument on your console or you see that in your PC monitor.

Just to recapitulate: We have the sensor then signal conditioning, and then you have ADC we have the computer.

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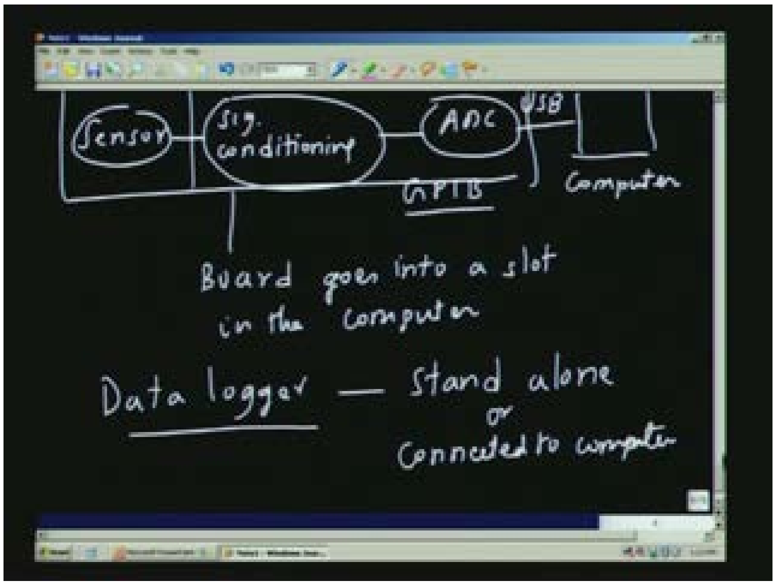

The connection in this case, is through USB. Earlier we used to have what is called, GPIB or General Purpose Instrument Bus, or it could be through a serial port. These are all possible ways of communicating with the computer. This portion, or at least this portion can be in the form of a board, when I say a board it is a Printed Circuit Board, or a PCB. In many versions of the National Instruments supplied hardware this comes in the form of the board which goes into a slot in the computer itself. So the signal conditioning and signal data acquisition board can become actually a part of your computer, it can be put inside or in the new version as we have seen it could be USB connected. That means it connects through one of the USB ports available on the computer. Therefore you do not have to really make any changes within the computer itself. You need not open the back of the computer and put the board inside and so on, that is avoided, because it can be kept outside.

Generally what happens nowadays is, when you have a laboratory or when you want to set up a laboratory instead of buying things separately and assembling it one can simply buy the readymade equipment available and then we can make the measurement very easily. They are also available in the following form which we call as the data loggers.

For example, the Hewlett Packard supplies large number of data loggers of different types. These data loggers are stand alone, or connected to the computer both ways you can do. That means they have some memory of their own so that you can save the data, and you can download it to the computer later on if you want to make any analysis. These data loggers come with several input channels, and may be several output channels also so that you can run or you can use the computer to control some experiments, those are also possible. In this lecture, we have been able to sort of given overview of what is required for running a laboratory or for understanding how to make a choice of instrument and so on. So what we will do is, in the concluding lecture which is going to come as lecture 50 we would take one or two simple cases where we can actually look at how we are going to design the required hardware or choose the desired hardware for performing a particular experiment. Thank you.