Mathematical Aspects of Biomedical Electronic System Design

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Week – 12

Probability Distribution and Biomedical Systems Design

Lecture – 39

Temperature Sensor Interfacing Analysis

Hello all, welcome to the module. So, in this module I will show you the interfacing of external real world signals to a PC. In order to show, what I will do I will consider a data acquisition device which is DAQ or NI DAQ, USB DAQ, I will connect that NI DAQ to the PC using a USB cable, then as we discussed in the last class, I will take LM35 which is a temperature sensor I will show you the datasheet of a temperature sensor so, that you will understand what parameters that we have to look when we are selecting a sensor. Then, I will discuss about the internal circuitry of a data acquisition device once again.

So, I will show you the interfacing connections between the sensor and the NI USB DAQ, then I will make a small program in the LabVIEW environment, where to acquire the data and the parameters that we have to select for acquisition of data. What I mean by parameters in a sense, what, how many number of channels that you want to use, and what rate at which you want to acquire? Is it a single mode of acquisition or multiple sample acquisition? And using an express VI I will show the recording, I will show the acquisition of the signal.

Since acquisition will be in terms of voltage, we have to convert that voltage into a temperature too. So, in order to do that, again we require to understand about the sensitivity factor which we get this information from the datasheet and from that, using the scaling factor or the sensitivity factor, we will multiply the acquired voltage with the sensitivity factor to display the temperature. So, this complete procedure, how to do this, how to interface to which channels we have to interface everything we will discuss in today's class.

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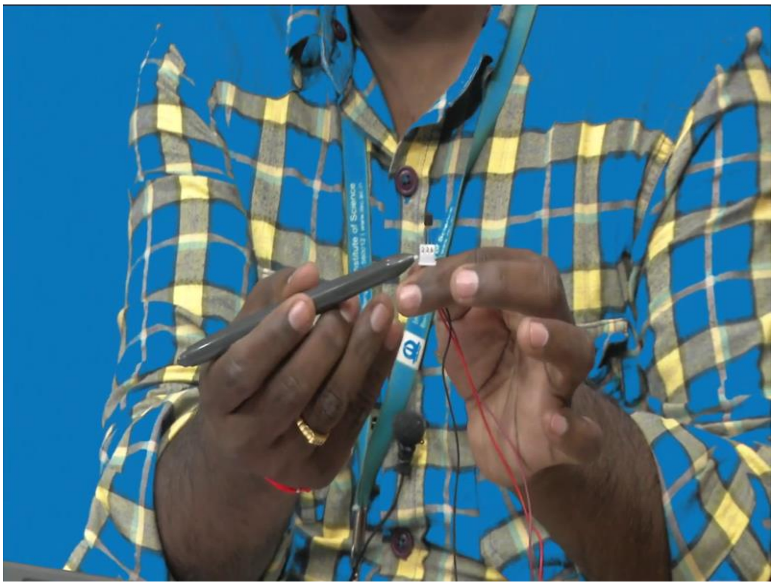

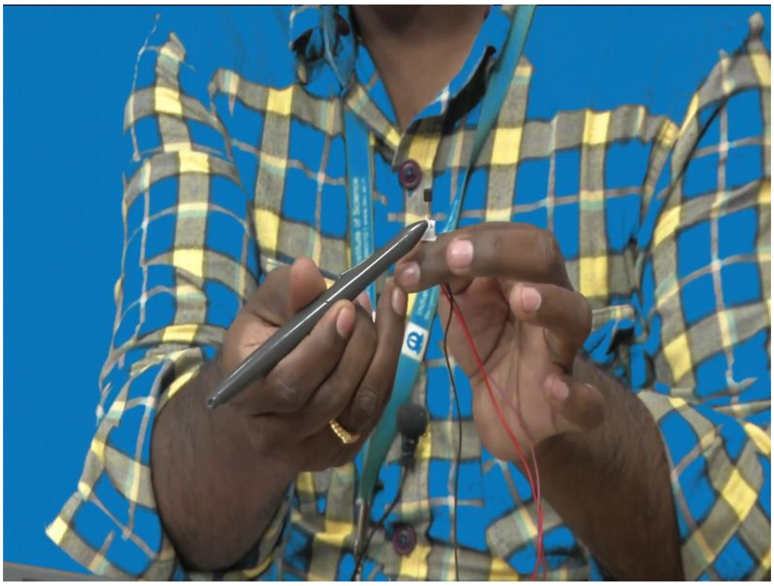

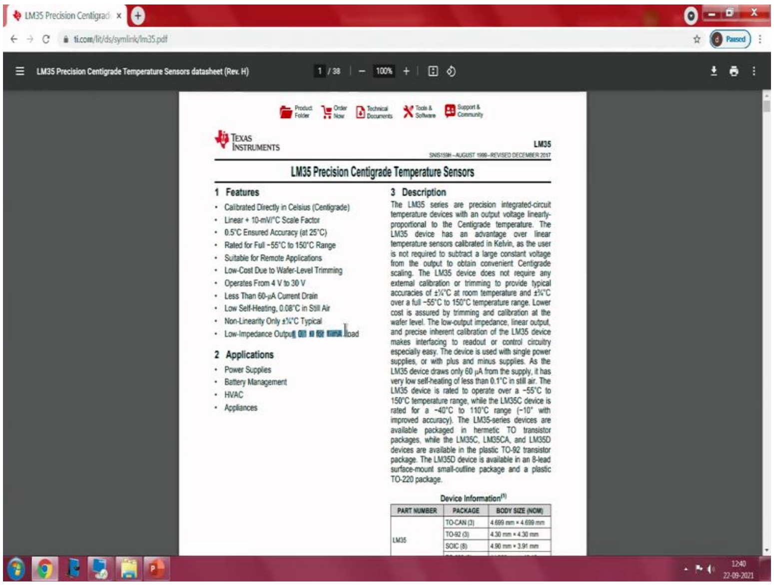

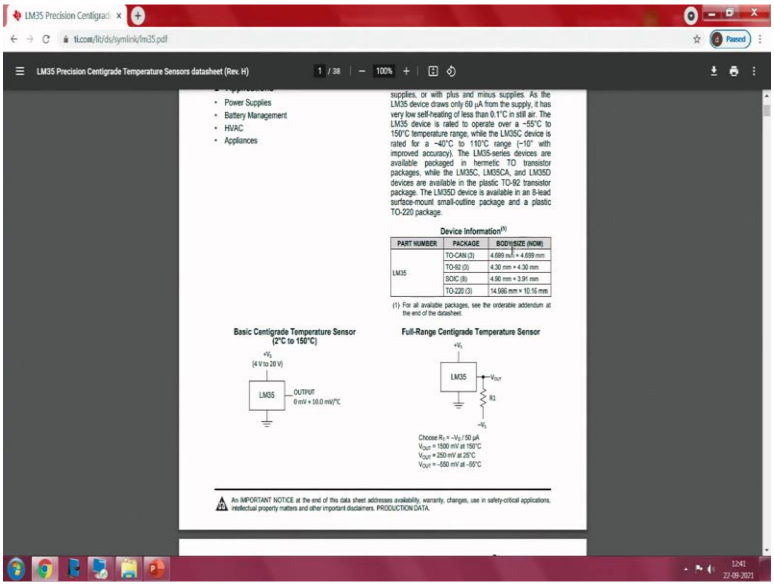

So, as we discussed in the last class, about using a temperature sensor. So, if you see this, this is the temperature sensor, which is LM35. So, the connections to the temperature sensor using our RMC cable I have connected to the terminals of an RMC cable here. So, the pin numbers which is VCC which is output and which is ground can be understood from the datasheet.

So, temperature sensor is LM35, let me open the datasheet from the datasheet we can see that it is a linear and the scale factor which is nothing but sensitivity. So, sensitivity is which gives the relationship between input and output or in other terms we can say rate of change of output divided by rate of change of input.

So, the output is in millivolts whereas the input is a temperature, this is a temperature sensor. So, input is a temperature so that is the reason you will see 10 millivolts per degree centigrade and the accuracy of the sensor is 0.5 degree at 25 degrees centigrade and the full range is -55 to 150. So, above which or below which this particular temperature, the property whatever they mentioned may not satisfy the scaling factor or the sensitivity factor may not satisfy and it may not be linear too.

So, this is the operable range above which of course it can withstand for a little higher temperature, but it may not meet all the properties they have mentioned and the operating voltage if you see it requires a 4 to 30 volts. So, any voltage between greater than 4 volts and lesser than 30 volts as an input since this is an active sensor, we always have to give an input voltage to operate it and this is a semiconductor base. So, it is required to provide some operating voltage that operating voltage range is 4 to 30.

Then low self-heating which is also another important parameter in case when we are providing higher current. So, this causes the internal system to heat or internal IC device to heat and because of which again the temperature the accuracy of the measurement will change. So, and the nonlinearities ± one-fourth of the degree, which is typical and output impedance when you see it is pretty low, so which is 0.1 ohm for 1 milliamps load.

So, these are the applications where you can see for what it can be used and some other information about the temperature sensor, all the information is available and of course, depends upon where it has to be mounted because another important thing is a packaging of the device is important where it has to be mounted what application that you are using everything matters.

So, depends on that application there are different packages available. So, T-92 and their body size the dimensions of it are everything shown here. So, they have also given the way to connect it. So, as I told you, since it is an active sensor, it is required to provide input voltage and based upon that based upon the temperature it gives an output. So, since it is a 3 terminal device, so the connections in order to do everything it has been provided.

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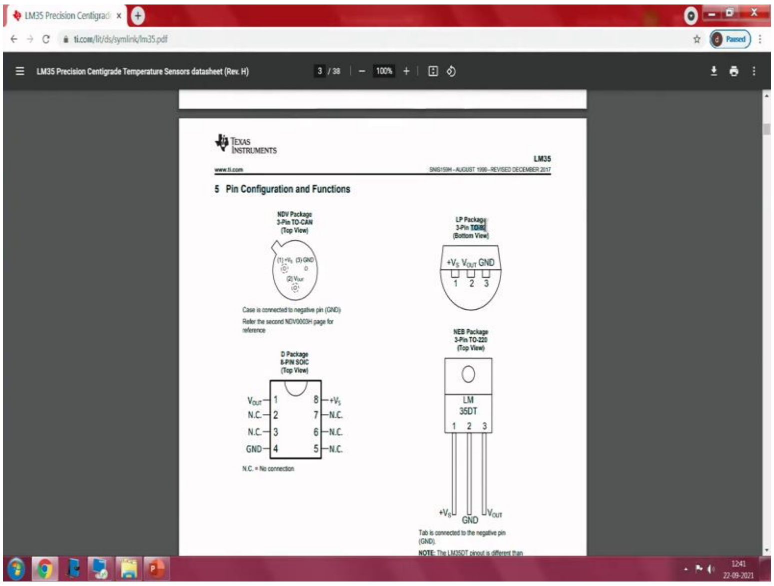

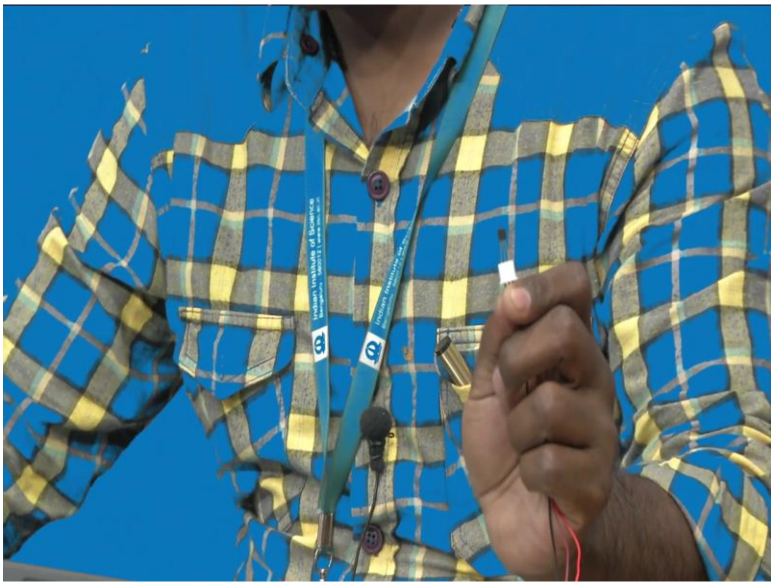

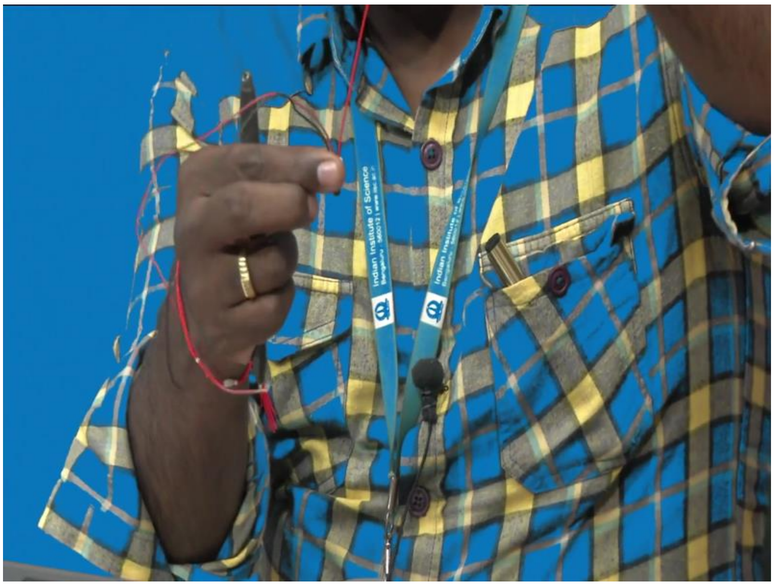

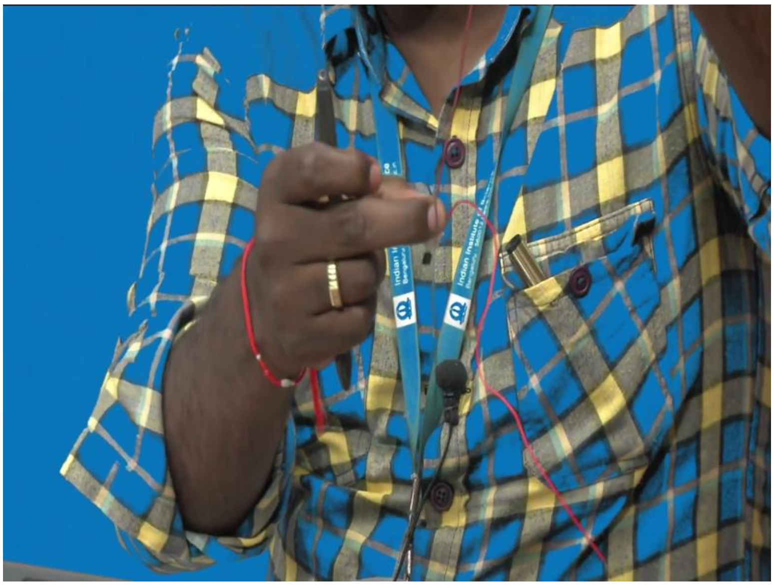

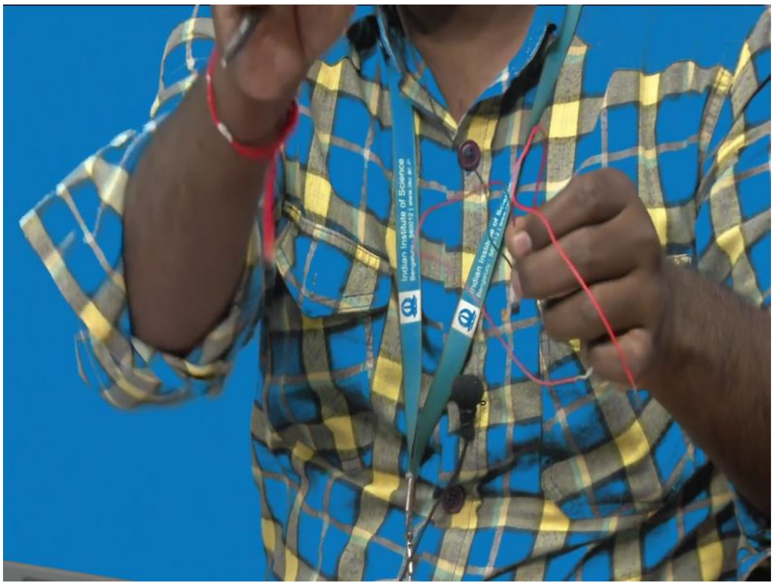

So, these are the different packaging things. So right now, whatever I showed you was T092 and there are other packages, TO-CAN, SYAC then we also have LM35 DT, this is another package TO 20 package. So, right now, whatever I showed the package, which is in my hand, T092. Now, if you see from the flat and keeping it down the left side is V_S, the left side is V_S V_{OUT} is the centre pin and the ground pin is the right side.

So, here we can see that this red wire connects to this red wire of RMC cable connects to positive so positive voltage which can be applied from 4 to 20 volt, then the centre which is a brown cable is a V_{OUT} whatever the voltage we can measure is with respect to the ground and the ground terminal is a black wire. So, we have connected in such a way that connecting these wires to any device, to a power source and an oscilloscope or a data acquisition device will directly connect to the LM35 temperature sensor, this is what we have seen from the datasheet.

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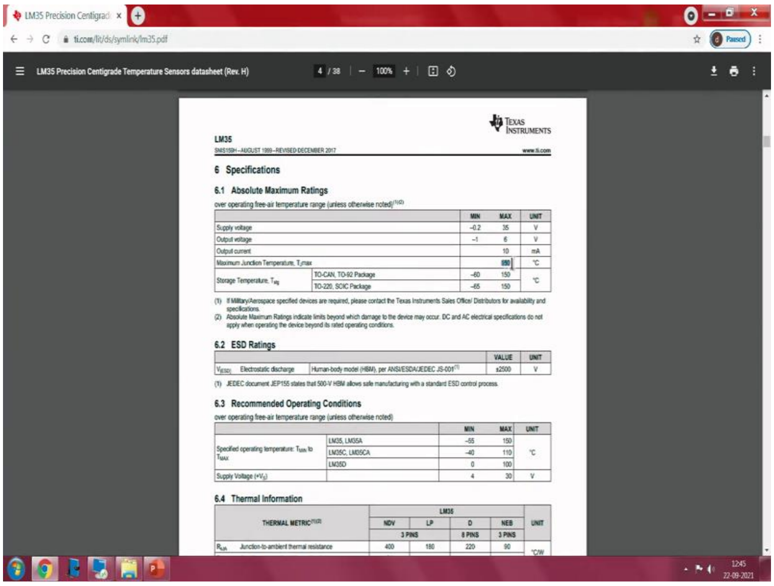

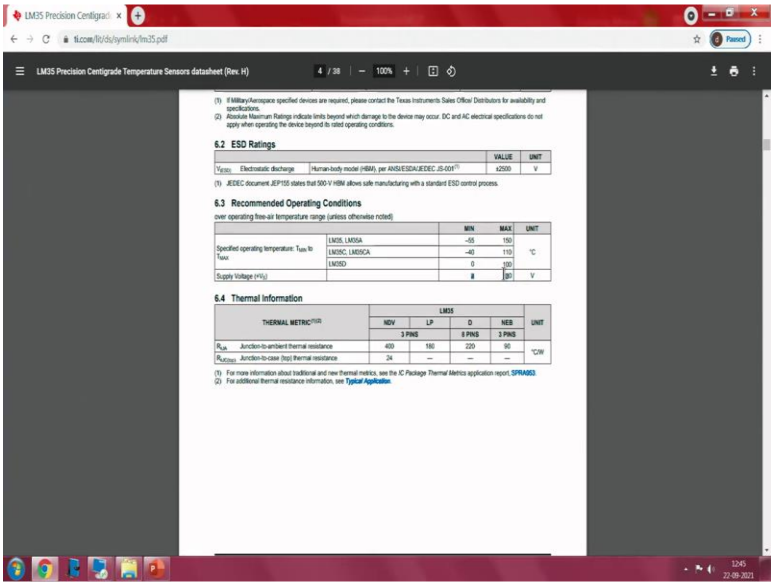

And another important thing what we have to notice is about its sensitivity as we have already seen previously, how much the sensitivity is. It was 10 millivolts per degree centigrade and another important thing is output current when you see the output current the maximum output current it can produce, or it can provide is 10 milliamps.

So, how it is important when we are interfacing the previous stage to the next stage if the input impedance of the next stage the next subsystem is of very high so that it consumes a lesser current from the previous stage. What if the input impedance is smaller? Say if the input impedance is; see the output we are getting is 1 millivolt or 10 millivolt and the input impedance is of 100 ohms.

So, now if you calculate it , 10 millivolts divided by 100 ohms. So, if you calculate the current it requires for the next stage, it should not exceed more than 10 milliamps, if it exceeds again it drives it takes the energy from the you know the previous stage which is a sensor in this case, so that the sensor goes to a loading effect sensor cannot drive. So, this is another important thing which we have to see.

And later on the output voltage, the maximum output voltage that you get out of it is -1 to 6. It will not give more than that. Then, T_{Jmax} is 150 degree it can withstand up to a junction temperature of 150 degree. So, as we have already seen about the supply voltage which is 4 to 30 volts.

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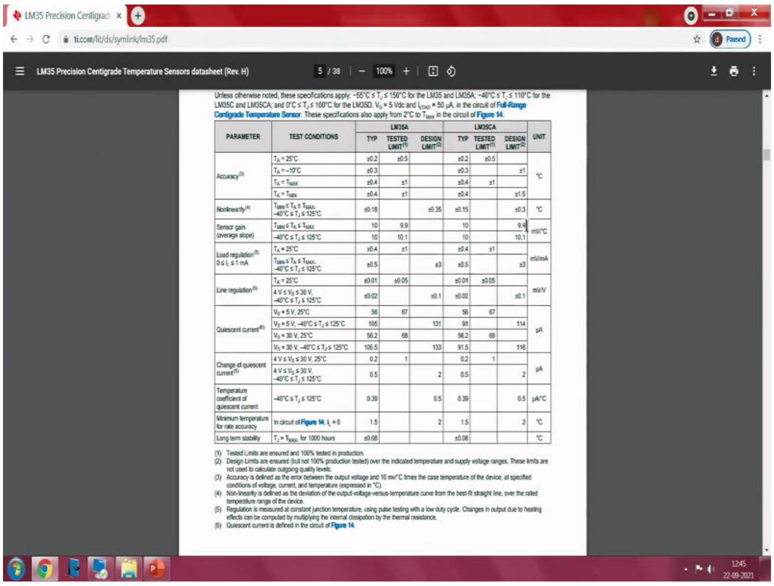

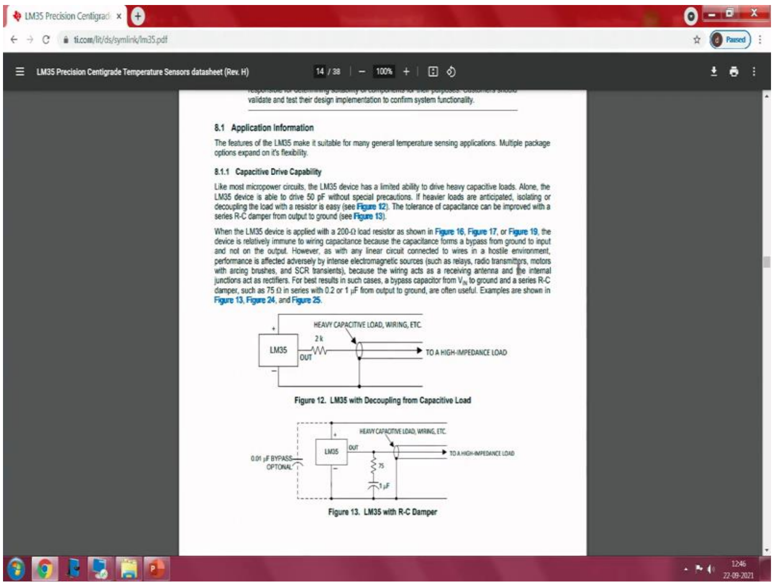

So, accuracy things which we have seen, the non-linearity things, then the sensor gain, average slope. So, this is an average slope again. So, with small error, it will be 9.9 to 10.1. So, that is why most of the cases we will consider it as 10 millivolt per degree centigrade, every 1 degree change in the temperature it changes the output voltage by 10 millivolts approximately.

Now, there will be few characteristics or further information about the sensor can be found out from this datasheet. And there will be an application note where you can further refer about the connections of it for better accuracy and in order to eliminate the noise that creates because of the ground loops or common more noise or differential noises.

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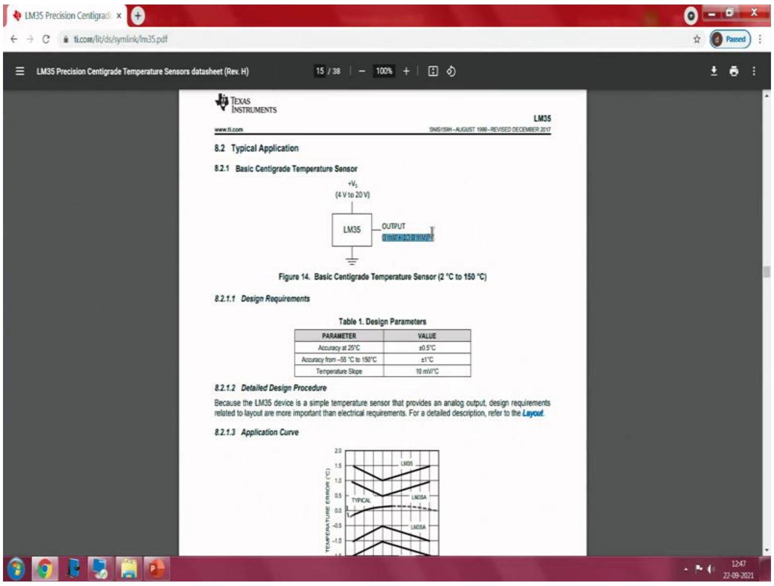

Here if you see it is basically a centigrade temperature sensor which means that it can only measure degrees centigrade. In case if you want to show it as a foreign heat you have to use a signal conditioning circuit if you are utilizing the same sensor or there are other kinds of sensor like LM335 or another kind of sensor where LM75 where it can measure the temperature in degree Fahrenheit.

So, output voltage will be dependent on Fahrenheit or else you have to use a scaling factor which converts the degree centigrade to Fahrenheit to display in terms of Fahrenheit of course, since we are interfacing it to a microcontroller or a data acquisition device where we are using hardware acquisition but converting into a software and displaying it in a software. So, in the software we can apply a scaling factor to represent the degrees centigrade to Fahrenheit.

Now, if you see that the output voltage is 0 millivolt plus 10 millivolt per degree centigrade, which indicates that at 0 degrees centigrade output will be 0 millivolts which means, the inherent property of the temperature sensor is, it will not give any offset in the output voltage. So, if the temperature is 0 degree, the output we get is 0 millivolt. So, it starts from 0, no offset at all.

So, considering all these factors, now we will see how to interface to a data acquisition. So, in order to do the interface, I am using here we can see NI USB 6008 since I will be using LabVIEW software. So, this NI USB device has a compatibility which has drivers that can directly interface to LabVIEW. So, this is NI USB 6008, since it is a data acquisition device, it has on board instrumentation amplifier as well as an ADC. Further information about that we can see in the datasheet.

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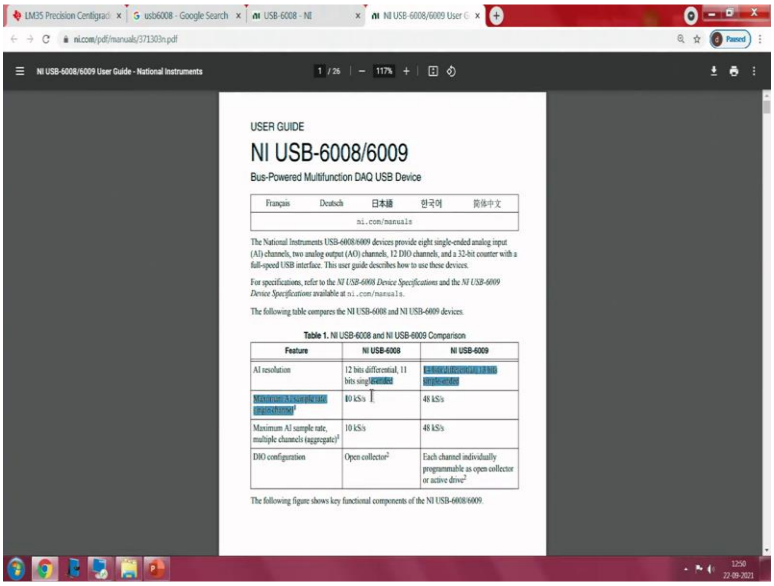

USER GUIDE

NI USB-6008/6009

Bus-Powered Multifunction DAQ USB Device

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The National Instruments USB-6008/6009 devices provide eight single-ended analog input (AI) channels, two analog output (AO) channels, 12 DIO channels, and a 32-bit counter with a full-speed USB interface. This user guide describes how to use these devices.

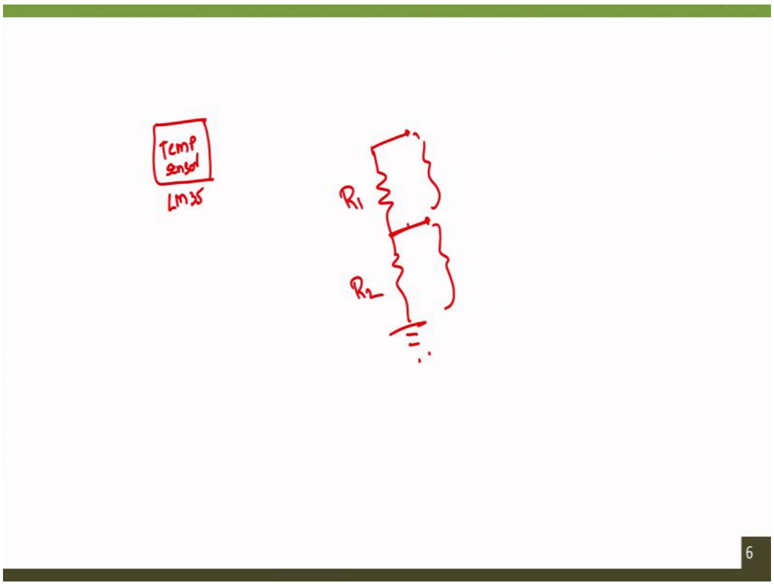
For specifications, refer to the *NI USB-6008 Device Specifications* and the *NI USB-6009 Device Specifications* available at ni.com/manuals.

The following table compares the NI USB-6008 and NI USB-6009 devices.

Table 1. NI USB-6008 and NI USB-6009 Comparison

Feature	NI USB-6008	NI USB-6009
AI resolution	12 bits differential, 11 bits single-ended	14 bits differential, 13 bits single-ended
Maximum AI sample rate, single channel[1]	10 kS/s	48 kS/s
Maximum AI sample rate, multiple channels (aggregate)[1]	10 kS/s	48 kS/s
DIO configuration	Open collector[2]	Each channel individually programmable as open collector or active drive[2]

The following figure shows key functional components of the NI USB-6008/6009.



So, here it shows that it has a 12 bit ADC. So, yesterday's class we discussed about 8 bit ADC if we are using NI myDAQ it has an 8 bit ADC probably or if in case if you are using any data acquisition device with 8 bit ADC whatever we discussed yesterday will work out, of course, the generalized concept of interfacing at the same time the selection of ADC is pretty much same provided the formulas or the resolution of the ADC slightly changes.

So, accordingly based upon the reference that you selected, the number of levels that ADC will have depends upon here then the resolution of your ADC since in this case it is a 12 bit resolution. So, total number of levels the reference voltage will be divided will be 2^{n-1} where n being the number of bits, so it is 2^{12-1}.

And another thing is sampling rate the maximum sampling rate per channel which is 10 kilo samples per second. So, it cannot measure more than 10k samples 10,000 samples. So, as per the Nyquist criteria, as you are already aware that, what Nyquist criteria says? It says in order to replicate the input signal the minimum samples required to replicate the input signal is twice that of the frequency of your input signal.

So, which means that in this case, that is the minimum number of samples required to understand the input signal, but to replicate multiple features in general cases we use 5 to 10 times imagine like 5 to 10 times considering the factor as 10 times. So, which means that 10 kilo samples divided by 10 it can measure up to 1 kilo hertz of frequency if we can use a lower sampling rate say 5 it can go up to 5 kilo hertz as input signal 2. And another important thing what we have to see is that whether this particular USB measures a differential or a single ended, what I mean by differential.

So, in the previous case, we have seen two different things one is say if I have a resistive divider network where we are measuring with respect to the common ground. So, whatever the output voltage we measure here will be with respect to the common ground. So, this is called common reference single ended, single ended because other terminal is directly ground. Whereas, if you want to measure if the requirement is to measure the difference between these two terminals, this particular resistor say R1 where the other terminal none of the single terminal is connected to the ground.

In such a case we require to use a differential output because the voltage at this point which is with reference to the ground is different when compared to the voltage at this point with respect to the ground. So, the difference between these two terminals. That is the reason when we are discussing about a Wheaton’s bridge circuit, we mentioned it as the output voltage is a difference between two resistive divided network configurations, it is a differential output.

In case of a Wheaton's bridge circuit, it is mandatory to use a differential input whereas in case of a resistive divider where the output is referenced to a common ground then a single input is enough to acquire the data. So, even in the datasheet it is mentioned it is a 12 bit differential and 11 bits single ended. Then maximum input, analog input AI meaning analog input rate when we are using multiple channels is also 10 kilo samples per second in case if you require more sampling rate, there is another USB device called 6009.

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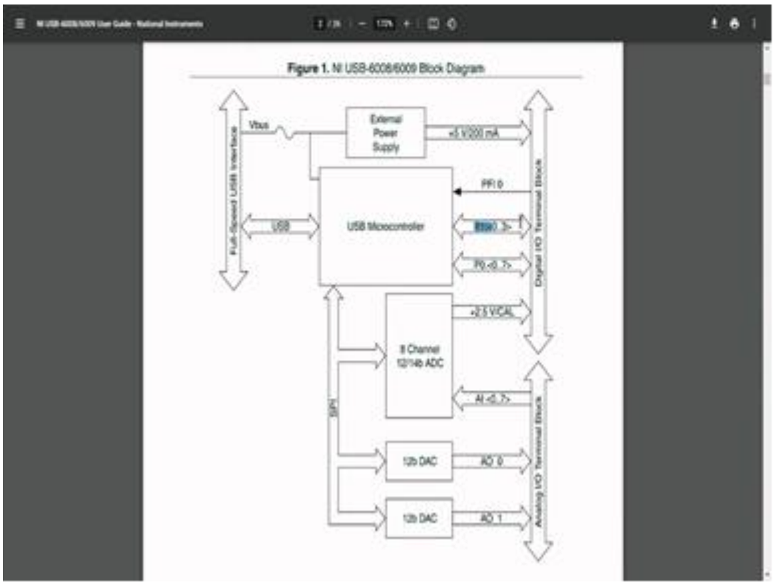

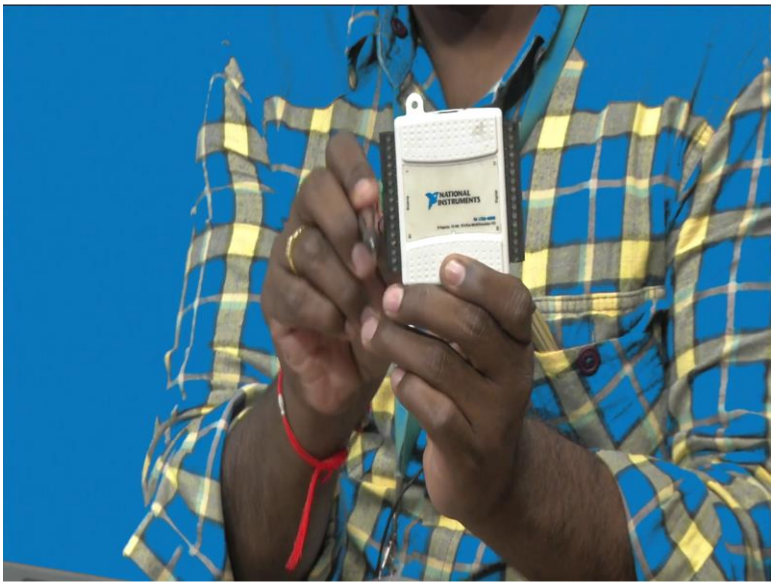

Now, the internal circuitry, the block diagram looks in this way. So, on the side have you observed we have 1 rail on the right side 1 rail on the left side. So, the left here if you see here it is written with a digital, this guy is a digital terminal whereas this rail is an analog terminal, and we have a USB interface here where we can connect the device USB DAQ device to the PC using USB cable.

As we have seen here it uses a full speed USB interface to transfer the data from the microcontroller which is already available inside to the PC and it can provide a power supply. In case for example, for active devices like the sensor that we have considered where it requires 4 to 20 volts or 4 to 30 volts we do not need to have an external power source to power it. Using the external power supply where it takes the power from the full speed USB interface it can provide 5 volts output voltage and which can support up to 200 milliamps of current.

Whereas the interface between the USB to the microcontroller no it is already internally connected. This is a USB microcontroller, the communication between the analog blocks to the USB is using the SPI in between we have 8 channel ADC 12 bit ADC, so, it can support up to 8 channel. As it is a data acquisition device it should be capable to produce an analog output signals too so in order to do a conversion of digital signals to analog.

So, since a microcontroller can only support digital data, so it has a 12 bit DAC internally available. That digital data will be again converted to analog by using this DAC. So, even that information can be collected or acquired or given from the analog input terminal block. There are dedicated analog input terminals as well as analog output terminals available on the analog rail.

So, there is something called AO 0 and AO 01. AO represent analog output channels 0, AO 01 represents analog output channel 1, whereas AI represents analog input 0 to 7. So which means a total of 8 channels can be utilized. Along with this we also have seen the digital terminal on the other side in which we can use it as a PF1 0, then PI 0 to 3 and P0 0 to 7 different channels 0 to 7 one byte 0 to 4 another half bite total of 16 on one side.

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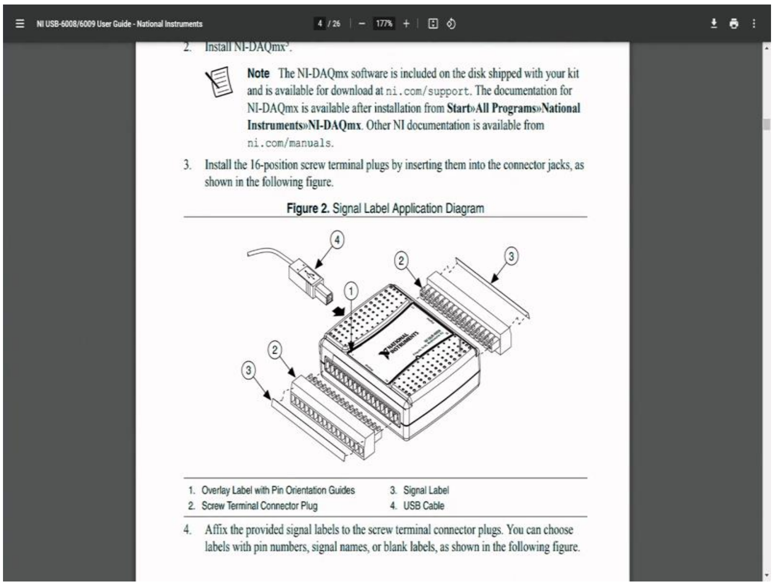
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2. Install NI-DAQmx[3].

Note The NI-DAQmx software is included on the disk shipped with your kit and is available for download at ni.com/support. The documentation for NI-DAQmx is available after installation from **Start»All Programs»National Instruments»NI-DAQmx**. Other NI documentation is available from ni.com/manuals.

3. Install the 16-position screw terminal plugs by inserting them into the connector jacks, as shown in the following figure.

Figure 2. Signal Label Application Diagram

1. Overlay Label with Pin Orientation Guides
2. Screw Terminal Connector Plug
3. Signal Label
4. USB Cable

4. Affix the provided signal labels to the screw terminal connector plugs. You can choose labels with pin numbers, signal names, or blank labels, as shown in the following figure.

So, the connections to this as we have already seen the digital representation of NI USB DAC so here we have USB connection on one side, in this side 16 to, 1 to 16 pins is for analog input where we have a screw terminal connector plug and 17 to 32 pins from 17 to 32 we have another screw terminal plug which is for digital communication.

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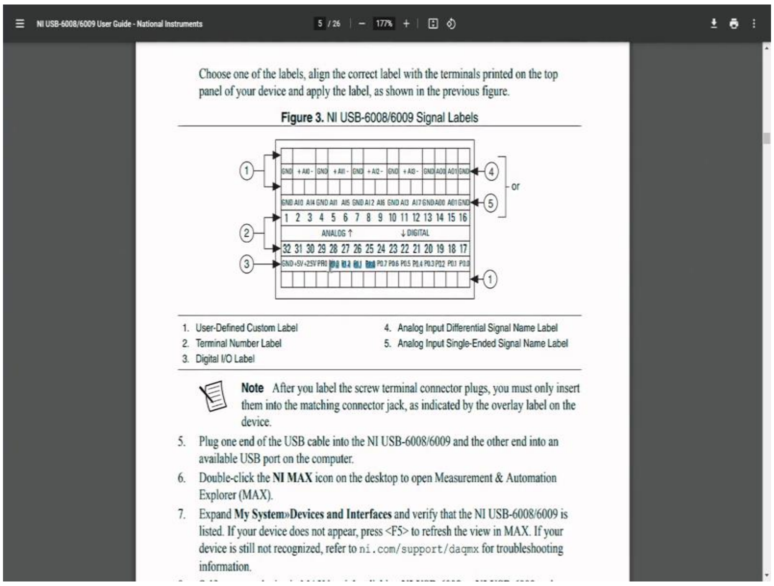

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Choose one of the labels, align the correct label with the terminals printed on the top panel of your device and apply the label, as shown in the previous figure.

Figure 3. NI USB-6008/6009 Signal Labels

1. User-Defined Custom Label
2. Terminal Number Label
3. Digital I/O Label
4. Analog Input Differential Signal Name Label
5. Analog Input Single-Ended Signal Name Label

Note After you label the screw terminal connector plugs, you must only insert them into the matching connector jack, as indicated by the overlay label on the device.

5. Plug one end of the USB cable into the NI USB-6008/6009 and the other end into an available USB port on the computer.
6. Double-click the **NI MAX** icon on the desktop to open Measurement & Automation Explorer (MAX).
7. Expand **My System»Devices and Interfaces** and verify that the NI USB-6008/6009 is listed. If your device does not appear, press <F5> to refresh the view in MAX. If your device is still not recognized, refer to `ni.com/support/daqmx` for troubleshooting information.

So, the complete pinouts of the screw terminal plugs can be seen here. So, one side the top side is completely for the analog and which means that here if you see this particular rail information is seen on the top side here whereas the other rail, the digital rail information can be seen on the bottom side.

Here if you see the pin number 1 is a ground and 2 and 3 is analog input. As I told you, this particular device can support 8 single ended channel information. It can convert the input voltage using a 12 bit ADC. If we are using a single ended information as a resistive divider output voltage as we have discussed previously, we can utilize all the 8 channels.

But if we require to use a differential information then it supports up to 4 channels. So, plus minus indicates the positive terminal and the negative terminal in case of a differential data. In case if you are using single ended the other negative terminal can be directly connected to the ground.

So, in order to avoid the noise, to avoid the ground loops it has been provided with multiple grounds after each differential channel. So, that directly the terminal pin can be connected to the ground. So, here we can see and since it also supports for analog output so, we can utilize AO 0 which is at 14th pin and 15th pin, analog output channel 0 and channel 1 and preceded by a ground terminal 2.

In case of utilizing it as a single ended reference data here we can see the second pin will be acted as analog input 0 whereas a third pin, individual pin can be considered as analog input 4. Whereas analog input 1 is 5 and analog input pin number 6 is analog input 5. So, similarly, a total of a single ended 8 number of channels can be utilized whereas a differential input 4 channels can be used. Then similarly, for the digital we also have different channels starting from channels 0 to 7 total of 8 bits 1 byte 8 bits and P10 to P13, so, total 4. So, for a counter case we can use PFI.

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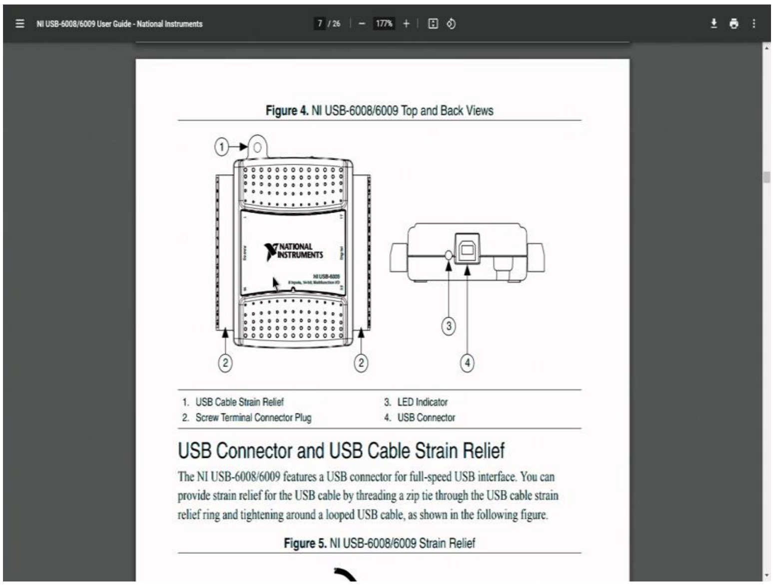
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Figure 4. NI USB-6008/6009 Top and Back Views

1. USB Cable Strain Relief
2. Screw Terminal Connector Plug
3. LED Indicator
4. USB Connector

USB Connector and USB Cable Strain Relief

The NI USB-6008/6009 features a USB connector for full-speed USB interface. You can provide strain relief for the USB cable by threading a zip tie through the USB cable strain relief ring and tightening around a looped USB cable, as shown in the following figure.

Figure 5. NI USB-6008/6009 Strain Relief

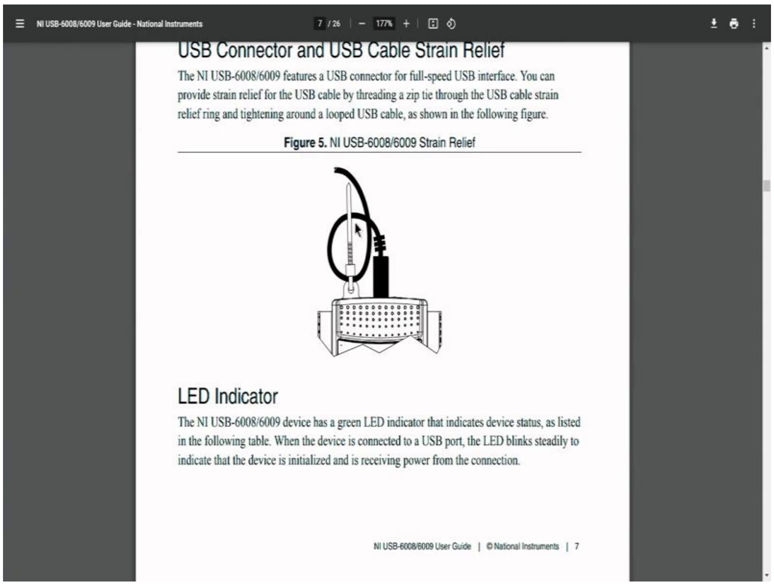
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Figure 5. NI USB-6008/6009 Strain Relief

LED Indicator

The NI USB-6008/6009 device has a green LED indicator that indicates device status, as listed in the following table. When the device is connected to a USB port, the LED blinks steadily to indicate that the device is initialized and is receiving power from the connection.

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So, other features of the devices can be seen here.

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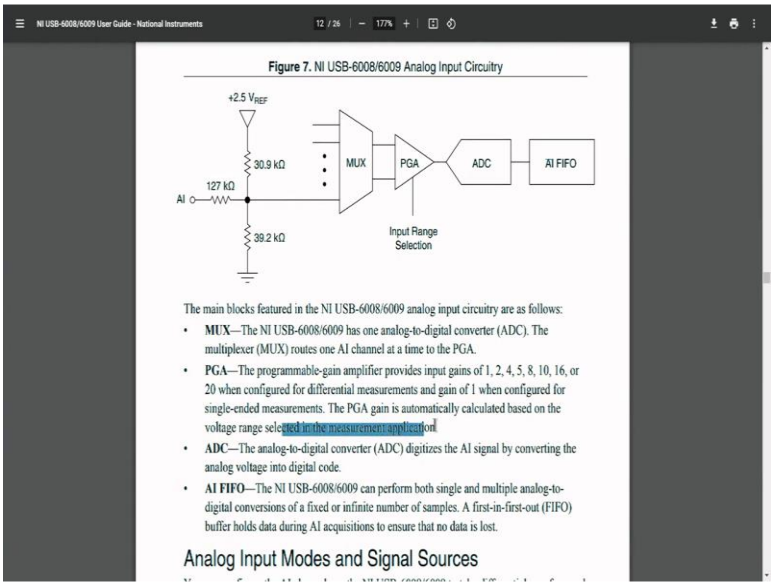

Here it has been also provided with the internal block diagram. Since it uses a single ADC and it can support up to 8 channels, single ended 8 channels and differential of 4 channels. How a single ADC is being interfaced with multiple channels in order to have an interface? They use a MUX. MUX is a multiplexer. So, here the analog input terminal is connected to this MUX.

So, depends upon what channel you select the MUX will be automatically get activated to the channel and the output of the MUX is connected to PGA. So, PGA indicates programmable gain amplifier, it is a differential PGA differential programmable gain amplifier where we can select different gains, either we can use an external gain amplifier to set the gain as we discussed in yesterday's class or we can use a software based gain setting where based upon the gain that we require, the software will select a proper resistor to connect as a feedback to this.

So, even that gain can be utilized using a PGA and the output of the PGA is connected to an ADC. So, in this case, the ADC of 12 bit ADC analog to digital converter that is communicated to the microcontroller. So, AI meaning analog input first in first out device. So, here we can see the programmable gain amplifier provide input gains of 1, 2, 4, 5, 8, 10, 16 or 20. So, we have a limited and we can only use the limited gains.

In case if we require a gain of 3 this cannot be utilized we have to externally use gain. So, when configured for differential measurements and gain of 1 when configured for single ended measurements. So, it can be used for both differential and single ended. The PGA gain is automatically calculated based on the voltage and select in the measurement range.

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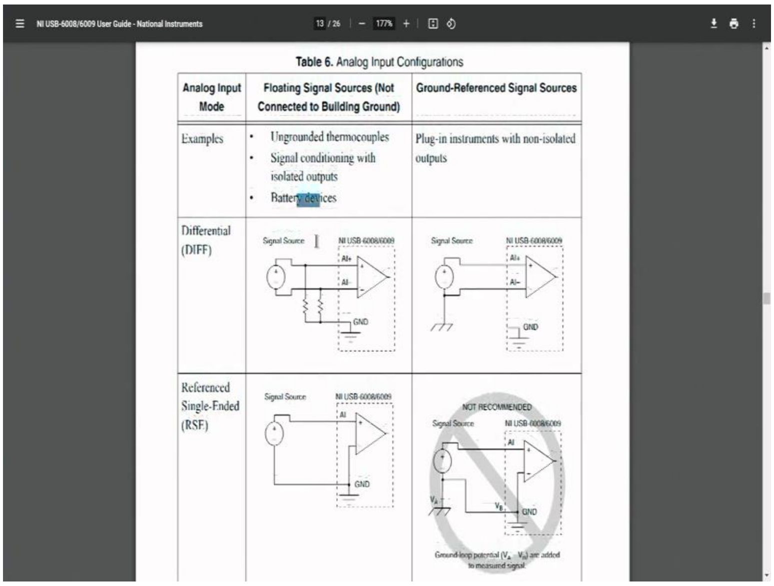

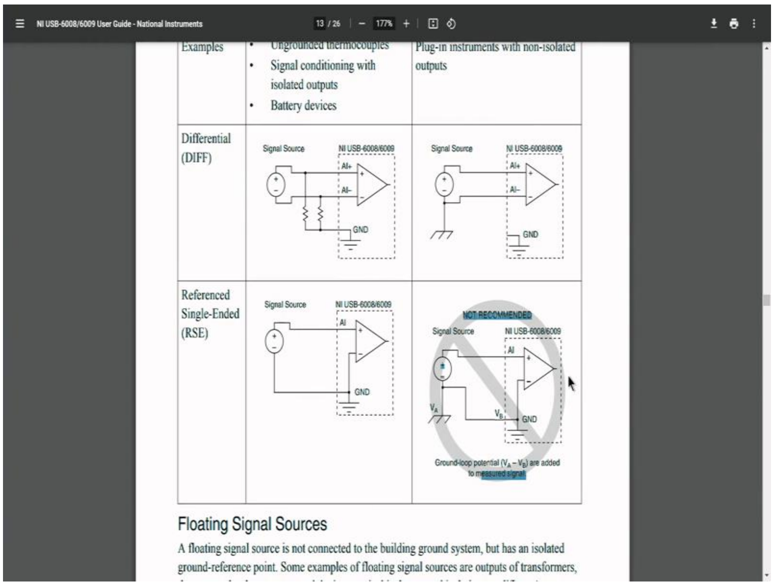

Similarly, one thing you should understand about analog input configuration where otherwise it leads to a noise or errors. Now, in case if we want to measure a differential so imagine say we have voltage source, where each channel can be referenced the same ground we can use a differential amplifier inside or instrumentational amplifier inside where one terminal can be directly connected to the positive terminal, other terminal can be directly connected to the negative terminal.

So, whatever the voltage of each terminal is directly reference to the ground. So, whatever we measure difference between these particular terminals to this particular terminal. So, this is a differential. But whereas, we are utilizing that common grounds of the USB device. Suppose say ground reference signal sources where it has non-isolated outputs.

So, where the signal source is connected to one common ground where this common ground will never be connected to the USB ground. This is another approach of using it. Then, I was mentioning about a reference to a common ground where if the negative terminal is directly connected to the ground configuration, which means that whatever we measure is with respect to this common ground.

In such cases we can only utilize 4 channels of analog inputs whereas in such cases we can utilize 8 channels which is not recommended in utilizing USB DAQ configuration which leads to ground loops is by connecting in this configuration utilizing the grounds of the source as well as the ground connecting to the ground of the USB device can have a grounding loops across this and it leads to an inaccurate output value which will also contain some noise into that.

So, that noise will compromise on the accuracy of the complete measurement. So, in this section what we do we will use this particular reference to the common ground we will directly connect out the grounds of LM35 to the ground of USB device so, that we can consider it as an RAC difference single ended.

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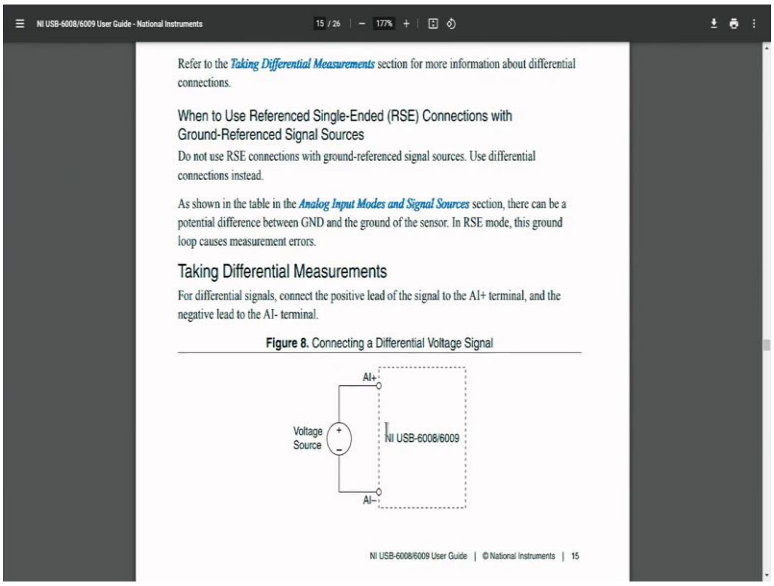
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Refer to the *Taking Differential Measurements* section for more information about differential connections.

When to Use Referenced Single-Ended (RSE) Connections with Ground-Referenced Signal Sources

Do not use RSE connections with ground-referenced signal sources. Use differential connections instead.

As shown in the table in the *Analog Input Modes and Signal Sources* section, there can be a potential difference between GND and the ground of the sensor. In RSE mode, this ground loop causes measurement errors.

Taking Differential Measurements

For differential signals, connect the positive lead of the signal to the AI+ terminal, and the negative lead to the AI- terminal.

Figure 8. Connecting a Differential Voltage Signal

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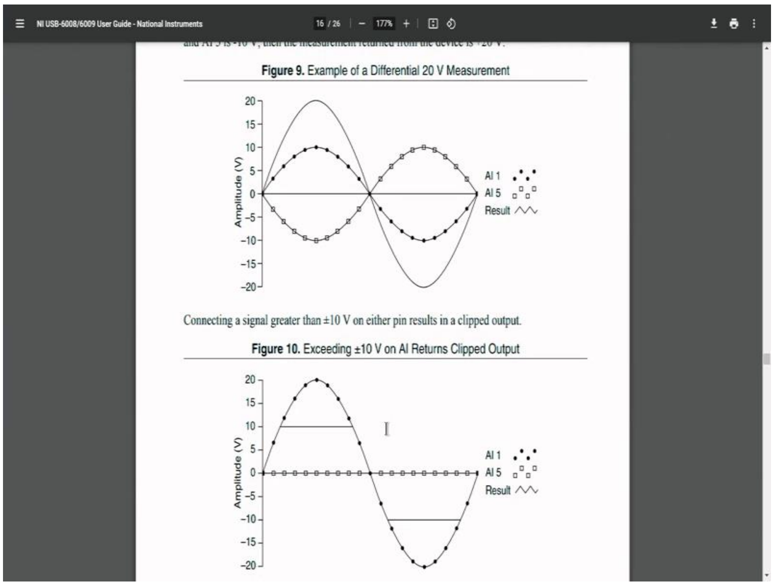

Furthermore information about you know the connections and how to take the differential measurements what different types of sampling rate to be considered otherwise what happens, what if the input voltage is greater than 10 volts? So, how the signal will be represented. Complete information can be further looked into that for your own reference.

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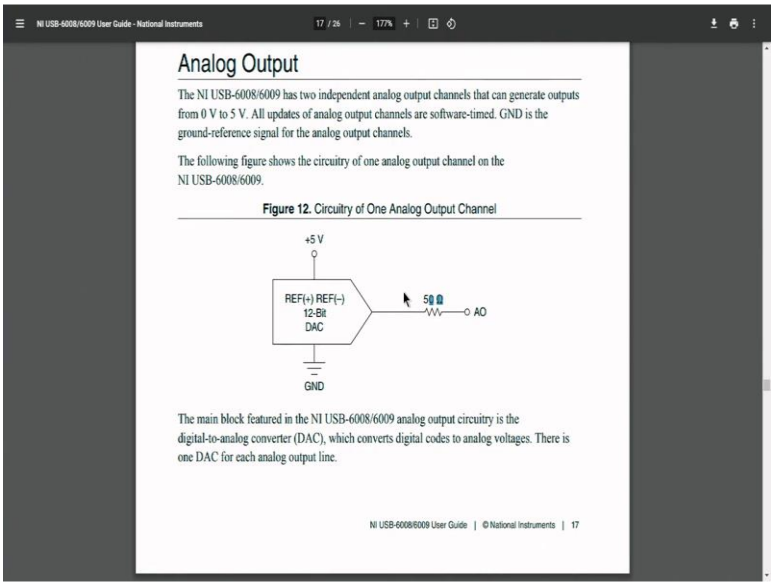

Then similarly, for analog output. So, since, we have already seen that USB 6008 has internal 12 bit DAC which converts your digital data that receives from microcontroller to analog output. So, using this DAC it is connected to the analog output channel with a 50 ohms load, 50 ohm load is nothing but your output impedance of your device that decides how much energy or how much current this DAC can support.

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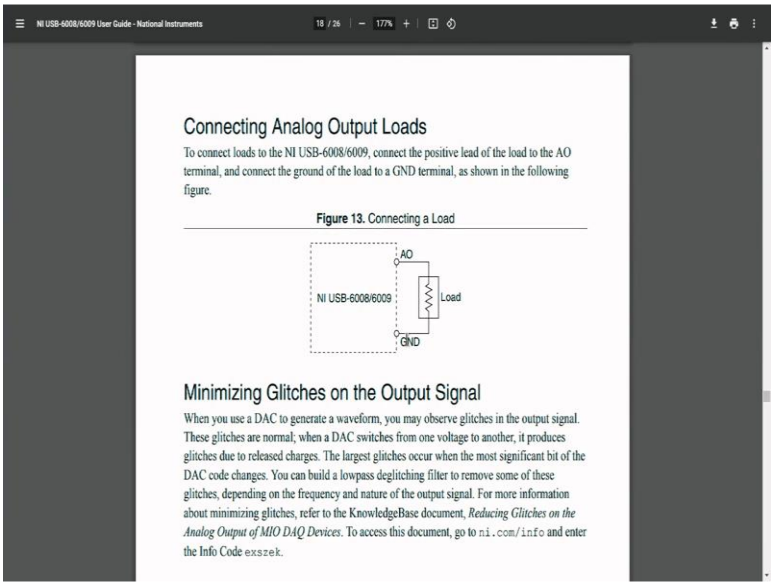

So, the way to connect it is also shown here if this is one analog output, if this is a load, if it is with the load resistance or input impedance of the load is within the limits of output current that USB device can support we can directly interface output to the ground, most probably we can use up to 30 milliamps of current like an LED can be driven, but in case if we want to drive the motors where it requires higher than 100 of milliamps of current, then this configuration may not be utilized. We may have to design a driver circuit using a triggering circuit.

So, we can utilize the digital outputs of microcontroller and we can trigger on and off. Whereas the power required for the load can be utilized from the main source.

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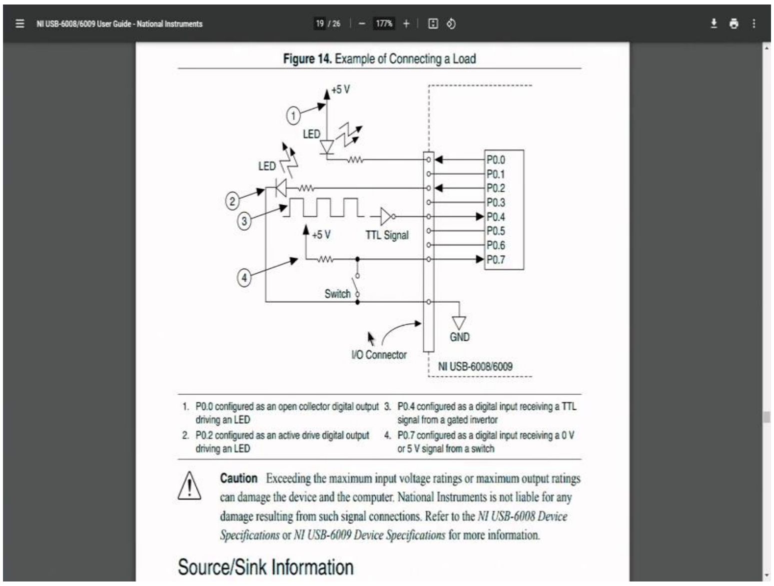

The digital configurations, interfacing of a digital configuration where it can be used as boost in both input and output can be used here. So, complete information about how to interface can be seen.

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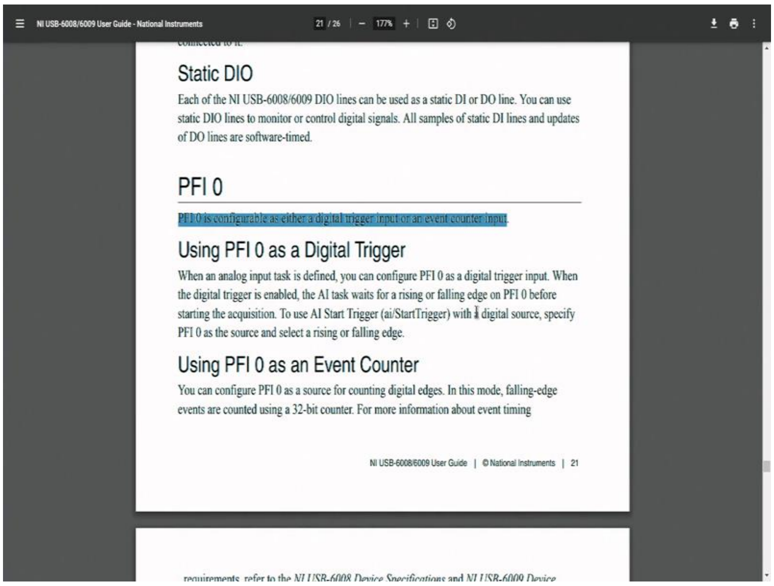

So, PFI 0 is configurable, that particular pin can be configured as either a digital trigger input or an even counter input. So, this terminal can be used as a triggering input or a counter input too. So, in case if you want to measure the number of pulses that has been achieved or at this particular triggering input need to activate some other circuit. So, this can be used as a proper terminal or as an even counter. So, this is about the information about our USB DAC.

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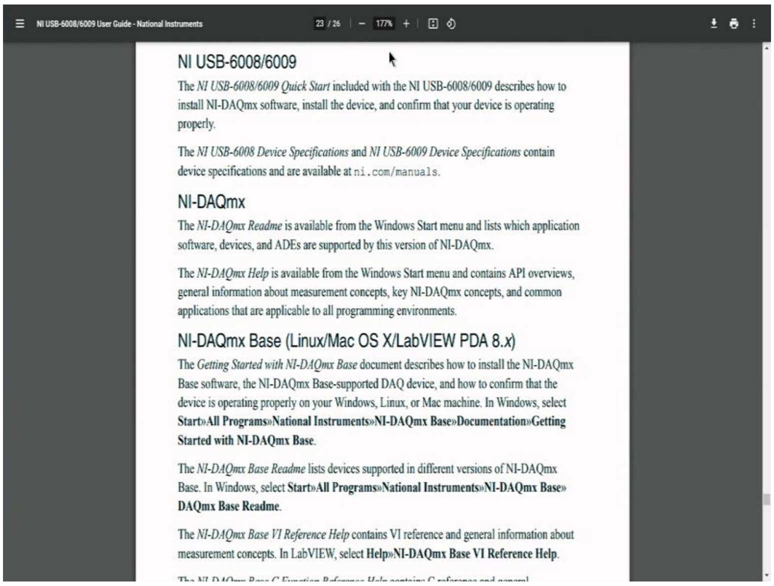

Now, we will see how do we create a program in a LabVIEW environment in order to acquire the data using USB and the configuration connections between input and output.

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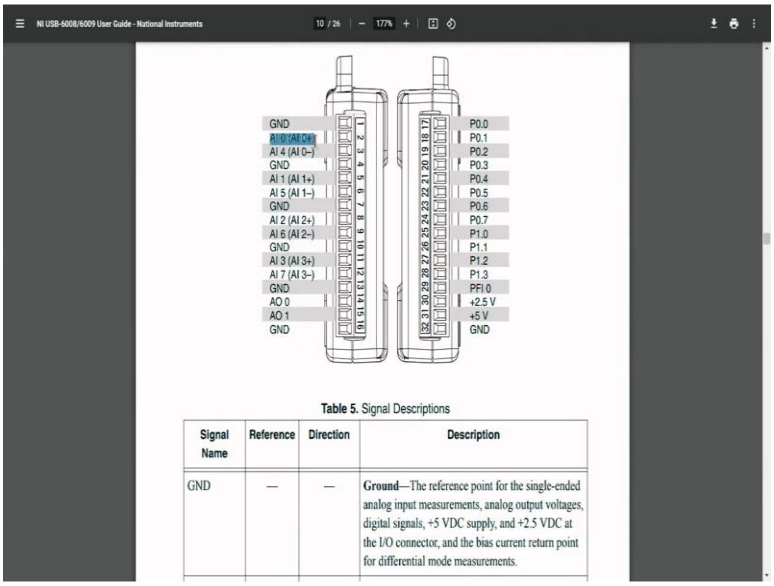

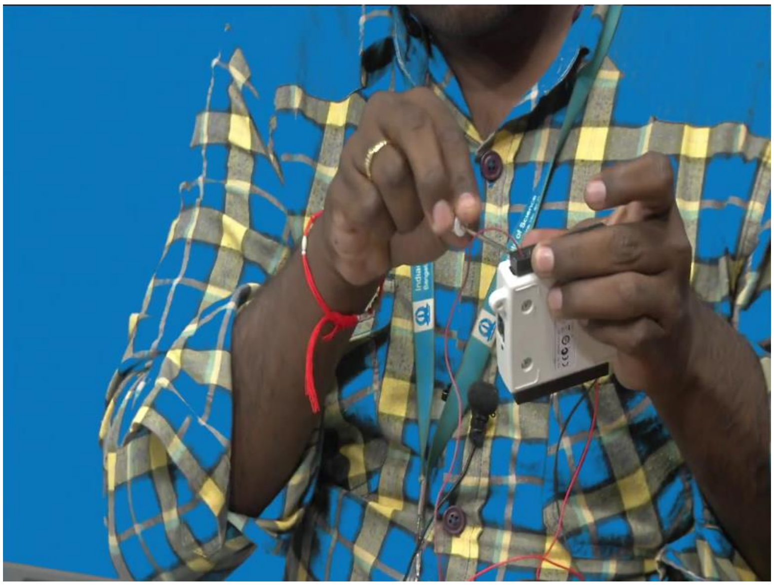

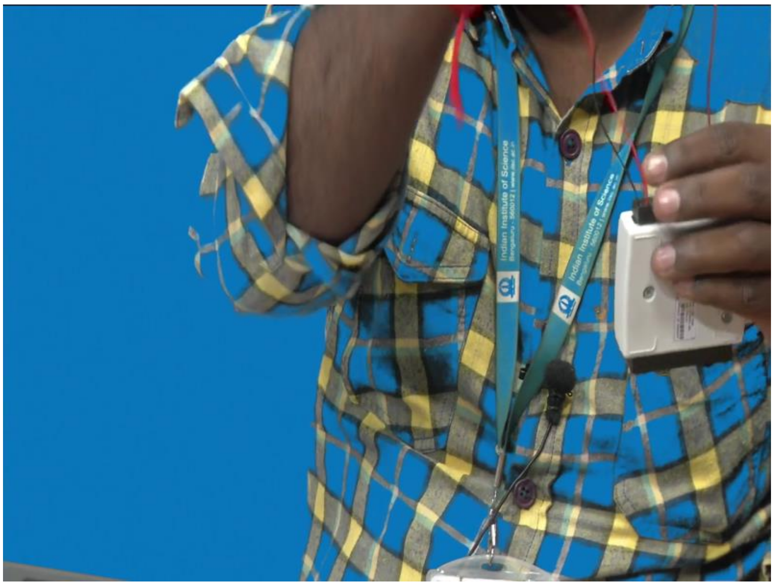
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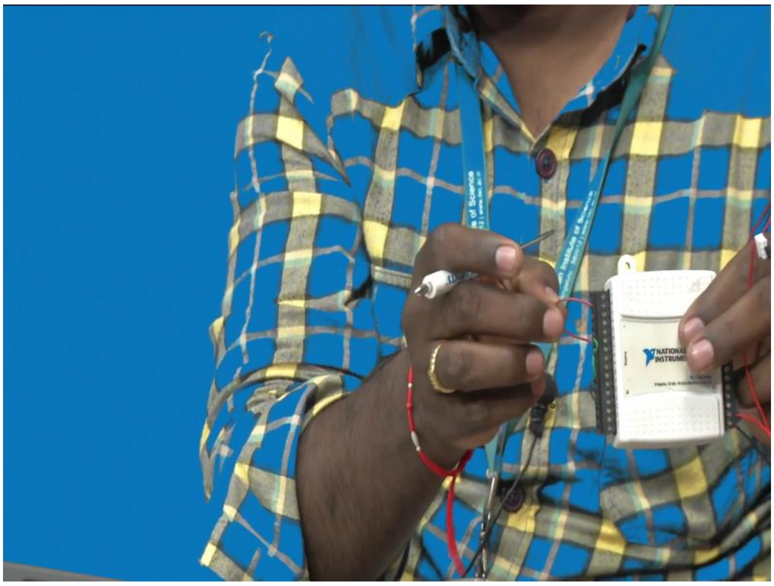

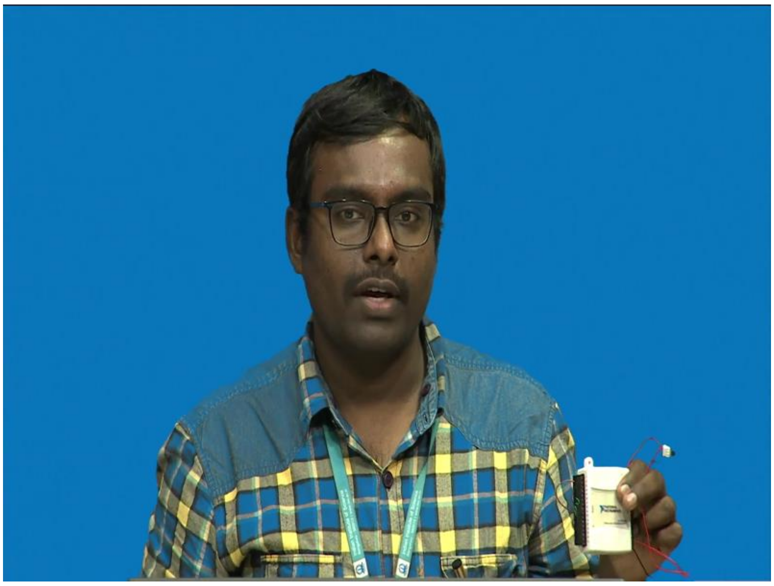

Here we can see I will use analog input 0 and output will be connected to analog input 0 since the power required to power the LM35 to power the temperature sensor, can be utilized from the DAQ. What I will do I will show the connections and I will show you the way that I have connected to it, 31 pin can be used as 5 volts, that red wire will be connected to the 31. Then all grounds are internally shorted.

So, any of the ground we can connect it so I will be connecting it to the 32 pin. The ground is the black wire, the black wire I am connecting it to the 32nd pin. So, once I power this device using an ESB cable, it produces an output of 5 volts. The 5 volts is enough for LM35 to operate.

Now the second pin which is an output which gives an output in in the range of 10 millivolts per degree centigrade will be connected to the second terminal. The second terminal here is AI0+ or AI0. So, if you are using as single reference as we discussed previously, since the grounds are common in this case, what I will do is I will use a single reference then AI0, I will only connect to AI 0 that is the second pin.

So, here we can see the red wire is connected to 31, whereas the black wire which is a ground wire is connected to the 32nd pin number and this is the brown wire which is output wire, which is connected to the second pin.

So, since I will be configuring the device in a single ended reference mode, I do not have to connect the third pin to the ground. In case if we are using a differential output configuration then the third terminal should be connected to the fourth terminal to use it as a differential. Since it is single ended the grounds are common. So, whatever the connections we made is good enough. So, these are the configurations. So, we will see how we make a program in the LabVIEW software and how to acquire the data in the next class.