Design for Internet of Things
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Lecture - 26
Introduction to Sensors and Actuators

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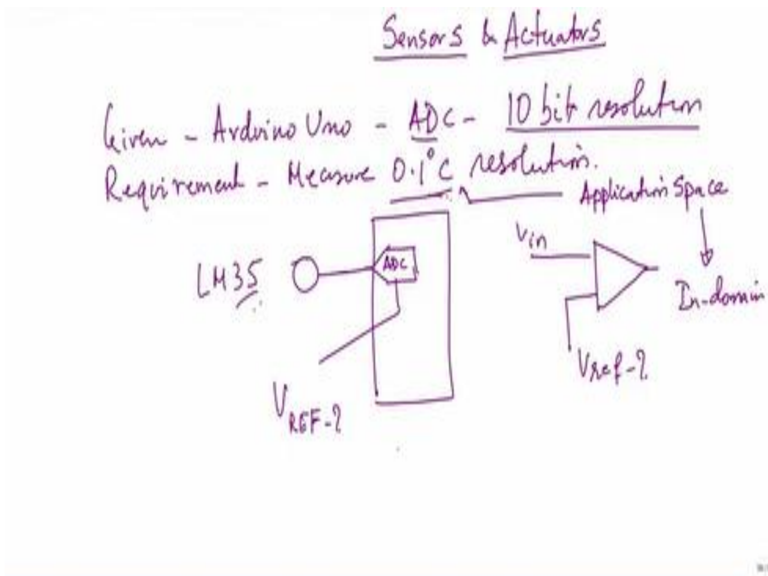

Welcome to this module on sensors and actuators. So, let me write down here, sensors and actuators. Let us follow the tradition of starting a module with a nice demo, or a nice question. Now this module is about asking you a question. But I am going to help you to solve that problem as well. Here is what I have given you, here is an Arduino Uno board which has an integrated ADC and it gives you 10 bit resolution, it is already there it is given to you.

What I want you to do is, I want you to interface LM 35, which is a temperature sensor to this ADC port, and the resolution of measurement should be 0.1 degrees. This is the question how do you measure the resolution of 0.1 degrees? In other words, what I am asking you is what should be your V ref such that you will be able to measure 0.1 degree resolution. See, you should not talk about voltages anymore, you should talk about the application here, he is giving you the application – I want to measure point one degrees, he does not care what is your input voltage.

Now, as electrical engineers, you must be able to map from the application space, from the application space to the in domain space? What I mean by in domain? The electrical domain that is your domain of interest. So, that is what you should check. So, how will you do that? Best is look for the data sheet of this LM 35.

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So, let us open up LM 35 data sheet and see what actually happens. Look at what all he has given here, if you buy this LM 35 precision centigrade temperature sensors. You will get linear 10 millivolt per degrees Celsius, you will get 10 millivolt per degree Celsius. That means for every one degree there will be a 10 millivolt change and 0.5 degree Celsius ensured accuracy and so on.

Now, the question is what should be your V ref such that you will be able to measure 0.1 degree resolution? That is a question of interest. So, what should be your V ref, that is all that we are asking. So, try to solve this problem and we will take it up if you do not understand this problem in clear detail and read this datasheet and let us see how we can address this issue. So, once again I want you to feel comfortable looking up data sheets, understanding the specifications of these data sheets.

And what you should look for in the data sheet depends on the application of interest. You can see here we are looking at these 10 millivolts per degree Celsius, which is of great interest to us. And with this it will tell you a little more if you read the description of this, this LM 35 you will be able to definitely, be able to decide what should be your V ref. So, that is the point. So, let us move on and do a few more things about sensors in this module.

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And what I have now is I will take you directly to show you something about a small demonstration.

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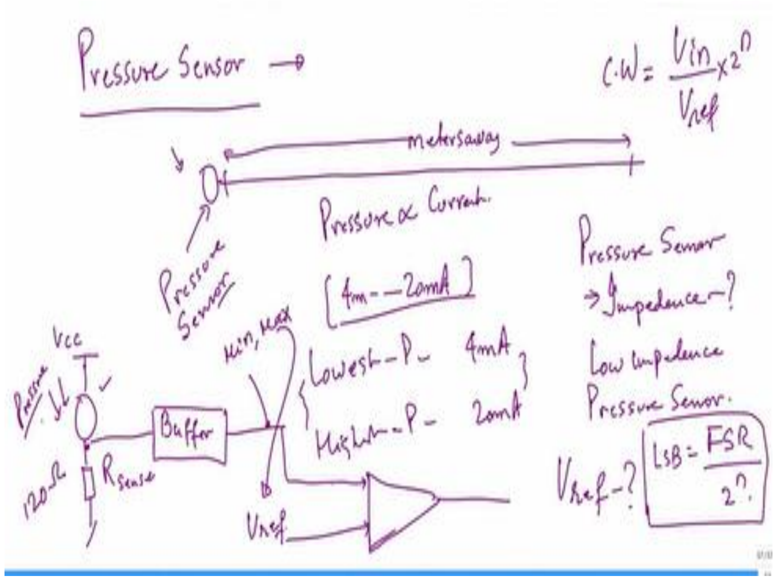

This demonstration is about working with a pressure sensor. Now this pressure sensor, you know this is a very practical application which we have in mind. Several situations require pressure sensors you take from airplane to very small places like even homes.

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You want to keep the pressure under some value or industrial activities or industrial sheds in that say a factory floor. So, you want to maintain under certain pressure. So, you can think that pressure sensor is an ultimate sensor required for many 1000s and 1000s of applications. So, it is good to know temperature, pressure, & humidity, these in fact, pressure does not - if you are looking at atmospheric pressure for a given place, it never changes.

So, pressure from an atmospheric pressure perspective may not be very attractive. But if there are pressure changes in a controlled environment, it becomes very, very critical. In health care pressure is important. You may have to measure the pressure very accurately.

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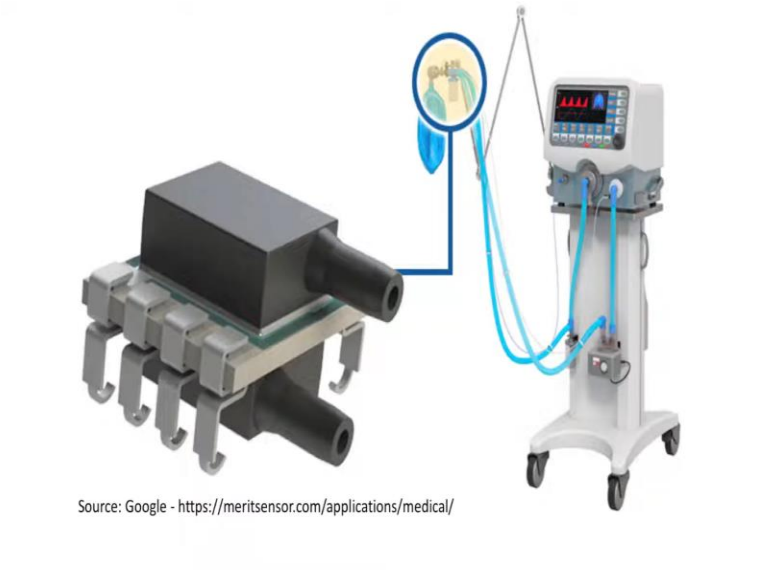

For example, you are building a ventilator, you are to feed the oxygen and air - mix and you have to feed it at a particular pressure to humans. So, those issues will start coming up. So, even in health care, maintaining pressure inside an airplane cabin, which is flying at cruising altitude, factories, where certain controlled environments are there, many many applications require pressure sensors. Now, let us understand one pressure sensor how to interface it and how to make, put it into action and do a few small demonstrations of that.

If you buy the good ones that top end pressure sensors they typically, since they come for industrial applications and they are typically you know sensed at one point but measured at several meters away. This is the pressure transducer/ pressure sensor. If you make it voltage based, if you make it voltage based, that is if pressure is made proportional to the output voltage. Then your accuracy of measurement of pressure can be a problem, because there can be a drop of voltage across this long long cable several meters away.

So, this is not normally a practice in the industrial environment. Normally pressure is made proportional to current. Because you want to exploit Kirchhoff's laws and their current in a loop is the same. If you make a current flow in a loop, then you have a nice advantage that the pressure if it is made proportional to the current. Then current in a loop will correspond to the right pressure.

So, therefore, making it proportional to current is the key point. But then pressure is an analogue quantity it can be varying continuously. So, much so, even current should be made to vary and how much should it varies the question. Normally they make it 4 milliamperes to 20 milliamperes. In fact, the whole communication between the pressure sensor and the unit itself is called 4 to 20 milliampere communication.

In fact, it is also interchangeably used as a communication protocol. So, 4 to 20 milliampere is a very very old protocol and you can think of the lowest pressure is something like 4 milli amperes and the highest pressure is indeed 20 milli amperes and any other in the middle is actually measurable. That essentially gives you the same analogue quantity out there. But the conditioning electronics for current type of pressure sensors is not straightforward.

You should know some basic electronics that you want to build. So, pressure here is proportional to current. That is all I wanted to say. So, for that what they normally do is they convert any measurement of current is actually done by dropping it across a resistor, usually a shunt resistor. And that shunt resistor is the one that very accurately captures the current flowing through the pressure sensor system. So, that is the right approach.

And if the; impedance of the pressure sensor is very, very high. So, you can have pressure sensor, you must look at the impedance of this. If it is a high impedance system then 4 to 20 milliampere is one part and driving the further electronics can get even more complicated. Therefore, you may want to examine the manufacturer who provides you a low impedance pressure sensor. So, that easily with very simple electronics you should be able to drive the ADC directly.

Let us draw a very simple picture of what this means, what you can do is you can supply power to the pressure sensor and you can put one sense resistor here. And this itself can be connected directly to Vin of the ADC. Now, this is easily doable if the impedance as I mentioned is low. That means, this current based on the pressure. This is the pressure that is applied on the sensor. You use a simple R-sense and build it.

Sometimes pressure transducers also can give you a differential output in which case you will have to use a differential circuit and sometimes you may not want to directly connect to the ADC instead you may want to pass it through a buffer circuit, and the output of the buffer circuit is fed to the ADC. So, I will take the output and then this is as usual Vref this will go to the ADC in. Now, one such circuit which I can show you, which is this buffer circuit is right here.

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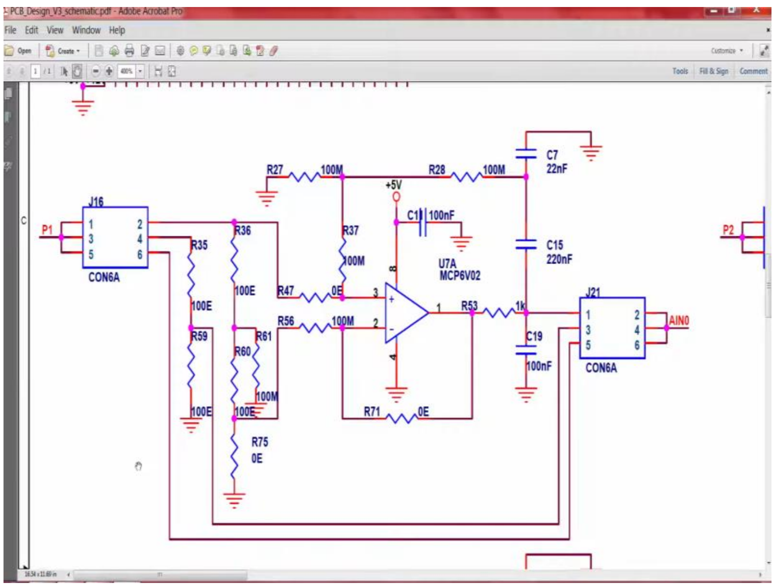

And you can see that the sensor that we have chosen is connected here, to this part here and this part here actually connects to the ADC. What is the circuit in the middle? This circuit in the middle is essentially a amplifier with certain gain and the required electronics built around this chip called MCP6V02. This is a microchips op-amp and you can see that, this is the circuit we built for driving pressure sensor. Now, what is the pressure sensor that we are talking of?

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We are talking of this pressure sensor, is something that we will put into action and see how to measure the pressure as well as based on the pressure can we do some actuation. Because this is a module on sensing and actuation, we should see a nice example of sensing through a pressure sensor and some actuation that happens either through a relay or through a solenoid valve or something we should be able to actuate something and some small code that is running here which is not very important.

Code is not the important thing. It is about sensors and actuators that we have to worry about. So, this is the sensor you can see there are just two leads to the sensor and this is the R-sense resistor. This is the R-sense resistor, this one end will be grounded, this middle point that comes will be connected directly to the ADC. This is the return line this is the VCC line and if you connect, it will give you some pressure.

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Now this pressure sensor has a datasheet. So, let us see what this data sheet says. At least you should know the top level specifications of this data sheet. Now I show you this, this is sensor which is called M3200 analogue output standard part matrix. And several parameters are there out here. First is, they have given you a chart on this site. They manufacture several types of sensors; you may have to look up the marking on your sensor.

And then fill up these gaps based on these charts which are available to you. So, I can tell you after I did all of that, what we ended up is that this is a pressure transducer measuring some pressure of how much 4 bar, maximum of 4 bar. This obviously is quite expensive. So, it gives you all the other related parameters as well. Now, this one what we did was we interfaced it in a very simple way.

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And we did exactly this. We took this pressure sensor that is here, we put in R-sense resistor and this R-sense that we put is 120 ohms. We put an R-sense of 120 ohms and we connected it to a buffer circuit and then fed it to the ADC-in of this system. Now, again your, battle with the same question, what should be the Vref? That is not very difficult if you know your range of pressures that you are likely to measure the minimum and the maximum pressure that you are likely to read.

That will give you some analogue output. You know that full scale is the, that is the maximum output voltage that you will get here, min and max will be known from here only. Now, whichever is going to the maximum try to meet that maximum to the Vref that’s all. Then you will get the full scale reading because remember code word is given by FSR divided by two power n. So, this you should not forget and the code word itself is given by Vin divided by Vref times 2 power n.

This is actually called one LSB, one LSB is FSR by 2 power n and the code word itself is given by Vin by Vref into 2 power n. This is just to give you some fundas and put you back in memory that whatever you have learned in the previous classes, you had applied here and this circuit is not all that complicated either. Now, let us shift to the actuator part. Now what I have in my hand is an actuator.

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This is an actuator, this is a solenoid valve. Let me tell you folks, several applications in the industrial domain, in the industrial world work with 24 volts. It is always 24 volts. By and large you can think about it as 24 volt DC is what they will work with. So, sense the pressure take an action, all of it is done by the industrial systems. That is why we need sensors. And we also need these are sensors (pressure sensor), actuator.

Pressure increases, cut off. Or pressure decreases, switch on and allow the pressure to build. Moment pressure builds, check with this pressure sensor and shut it off. So, this is your actuator, your dumb guy. This is the guy which tells you what the current status, what is the current pressure state. Who takes the decision? The controller takes the decision. And that controller is written in software. That's your IoT node.

This is connected to analogue input, this is connected to a relay; you want to switch the actuator. So, you have to connect it to a relay or you should connect it to some GPIO pin which will allow you to shut down and you know enable it. So, all of this is what you will have to take care. Remember, your IoT node may not give you 24 volts, your IoT node may not give you 24 volts. It will work with 3.3. The solenoid valve only needs a command which is coming from your IoT node.

The valve by itself will operate at 24 volts. So, you connect it to another power supply which is able to give you 24 volts. And then that will take care of the power requirements for the solenoid valve. This is the gist of the hole way by which we will actually want to show you a demonstration. So, let us now move to the demonstration and just let us connect all the bullets that we put together so, that you get a good picture of the whole module related to sensors and actuators.

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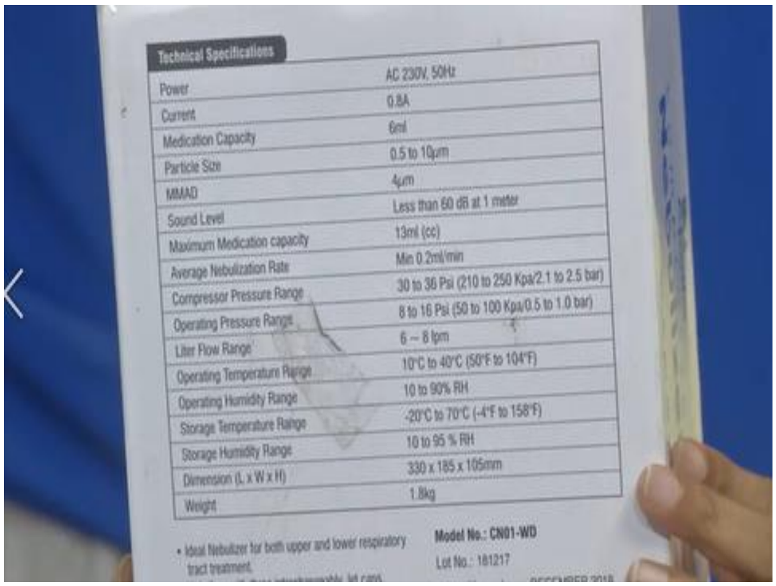

So, let us do a small demonstration, what is of interest is to monitor the pressure built by a simple nebulizer, this is a nebulizer which you can buy for some 2000 rupees or so. And it can generate, if you look at the data sheet here, it can generate operating pressure ranges up to about 0.5 to 1 bar. So, beautifully as written here, you see that operating pressure range, 0.5 to 1 bar beautiful. Compressor can work up to 2.1 to 2.5 bar; but operating pressure ranges 0.5 to 1 bar.

It is the equivalent in kilo Pascal's is also mentioned on the left side do not worry about it, you can easily convert, that is not the focus of this discussion. Now the point is if you set it to some pressure, the pressure transducer should be able to make a measurement and allow the nebulizer to be on till it is within a given threshold, after that it has to cut off. And again, it has to switch on all by itself and so that you are always maintaining a certain pressure. How do you do that? That part is done by this little board that you see here.

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You see this is a small chamber that we built. This is some chamber you can think about this like a cylinder pressure, this cylinder's pressure is what you are interested in. So, you can see that we have connected a pressure sensor to that and who is pumping the pressure into this and other equipment I will show you that as we go along. As we slowly pan our camera, I will show you a few things.

What you see now is this cylinder of interest has an input you can see that there is an input here; this is your input to the pressure to the cylinder. This is your measurement sensor, pressure sensor. And you are interested in the pressure inside this cylinder. Now let us go slowly. If you look at this board, there is one board here and on top there is another board and there is a ribbon cable which is connecting the down board connector that is here.

And that top connector that is sitting here. These two are connected using a ribbon cable and it is a familiar ribbon cable that you know very well folks. If you started dabbling in IoT, you definitely know what this board is and that indeed is a Raspberry Pi. This is a Raspberry Pi computer. There are 4 cores, it has interfaces, It has HDMI, it has Ethernet, it has USB, it has WIFI and so on and so. Feature rich processor board and that is what we are using as a computer.

Down board, that board down here that you see with lot of electronics, resistors, capacitors, relays and so on. This is basically the board which gives you the interface to the analogue inputs, digital inputs as well as actuator output. Relay here is like an actuator. And this actuator, this relay can actually control a solenoid valve. And let me show you that solenoid valve again. You could be connecting a solenoid valve.

You could be connecting a solenoid valve like this, to this output of these relays and then this valve will start getting actuated. Remember I mentioned about the solenoid valve. So, you could connect it to the relay there. And there is fantastic isolation between these 24 volts and the low voltage that is running here, because relay provides you that required isolation. Now, what is the down board here?

The downward here along with this Raspberry Pi together form the Programmable Logic control. Programmable logic controller unit - PLC; which are used widely in industrial applications. So, what we have designed is this, board is a PLC board. Now the where is the PLC program? Well, the PLC program is running on the Raspberry Pi. You use special ways of writing this PLC program, you use, sometimes people used to use ladder logic and sometimes people use other types, there are at least four or five ways by which you can program a PLC.

One of them is ladder logic the other is structured text and so on. So, you can write the code that way. Now, let us pan a little more to the other side. You see folks, this guy is the nebulizer which I showed you, this is the nebulizer. You see two wires coming out here we were able to tap the two wires so that we can switch on and switch off this particular equipment. And how are we measuring the pressure? I mentioned to you about the cylinder.

You remember the cylinder we were using for measuring the pressure. So, the pressure output from here fills up this cylinder and this cylinder will measure and then it will give an actuation command back to the system here. So, now let us start and see how this whole thing works. That will give you a fair idea on the overall concept of sensing and actuation. So, let us see welcome to open PLC.

And now you will see that this is the dashboard of the open PLC, by the way everything is an open source. We will run the open PLC, so we will run the PLC now. What you see on the extreme right top column is the voltage, the value and there you see the voltage which is 0.9 volts and this, 0.9 volts actually corresponds to 0 bar. Now what will happen is we have set it to 0.2 bar it is very small rise in pressure.

And that corresponds to a voltage of 1.2 volts. So, let us see what actually happens at 1.2 volts. You will see that it will on, it will off, it will on, and off. So, it fluctuates between 0 bar and 0.2 bar and tries to maintain anywhere between 0 and 0.2 bar. It will not exceed, it will ensure, the PLC will ensure that under no circumstance, the pressure exceeds 0.2 bar. So, and that therefore you will hear a lot of relay chatter. As and when the pressure increases, it switches off and so on and so forth.

So, let us see that demo now, you can see. So, now clearly on-off is happening. And one more screen that would be of interest would be to look up this relay. This is the relay of interest, which is getting actuated. You will actually see the relays turning on, there you are. That is the relay which is actually controlling the nebulizer. Actually, the nebuliser's power is being gated through this relay, on off, on off and so on.

Folks, remember, whatever you do, do not forget to read the data sheet that is next to you. Use the data sheet every time you plan your experiment.

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Remember, I asked you a question about the setting of the V, ADC's Vref. I am not going to give you all the answers, but I will solve the trivial problem. So, that you will be able to connect everything again. I asked you to look up the data sheet corresponding to LM 35.

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You can see, you get 10 millivolts for every 1 degree. What you are interested in is 0.1, that was the problem statement we had made. So, if it has to be 0.1 degree resolution, then you need one millivolt at the output.

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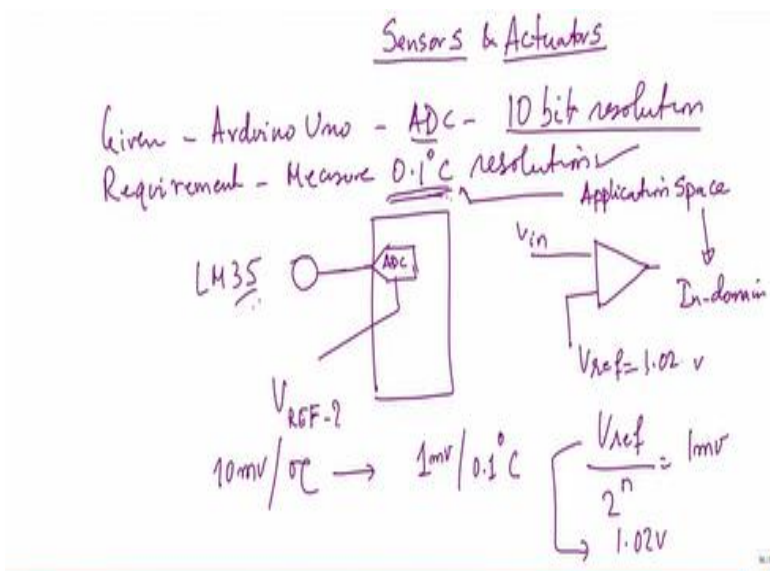

That is what the question is you need to measure 0.1 degrees Celsius resolution. So, you know that it is 10 milli volt per degrees Celsius. Therefore, you need 1 millivolt for 0.1 degrees Celsius. That is pretty straightforward. Now, you know that if it is, 1 millivolt for every 0.1 degrees Celsius, put back the famous expression of Vref by 2 power n; is now equal to 1 millivolt. From here, you now calculate, you know n, you know the voltage that you are looking for, from here you calculate Vref, you will see that the Vref is 1.02 volts.

Now, you feed 1.02 volts then you will get 0.1 degree Celsius resolution. This is how you work with data sheets, folks, you still have to figure out with respect to the other picture, what should be the Vref there. Please work out and be confident about opening data sheets related to ADCs and so on. Thank you very much.