Micro and Smart Systems
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Lecture – 03
Microsensors

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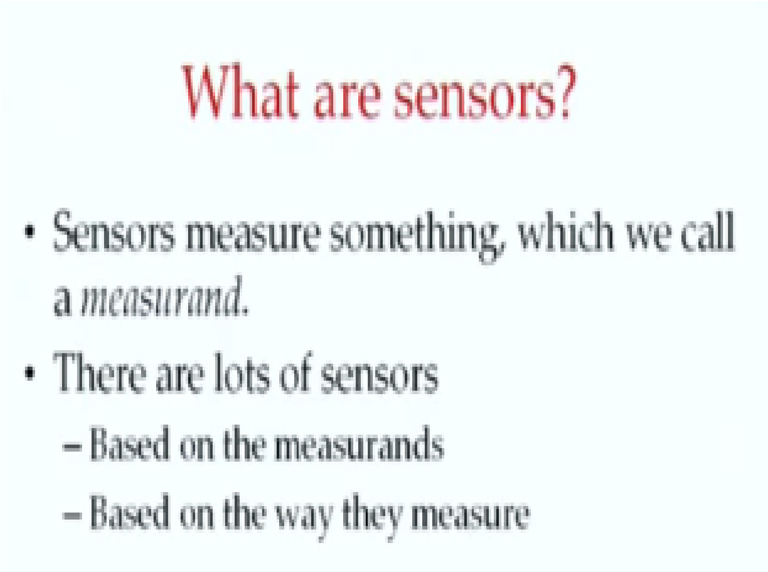

Hello, we are going to talk about micro sensors today. This is the third lecture as part of the micro and smart systems course that you have here. Micro sensors have the term itself implies, they are small sensors, small here is of the micron dimensions and they are sensors, so let us begin with what sensors are. So, what are sensors? Sensors measure something which we call a measurand that is the quantity or a thing that we want to sense.

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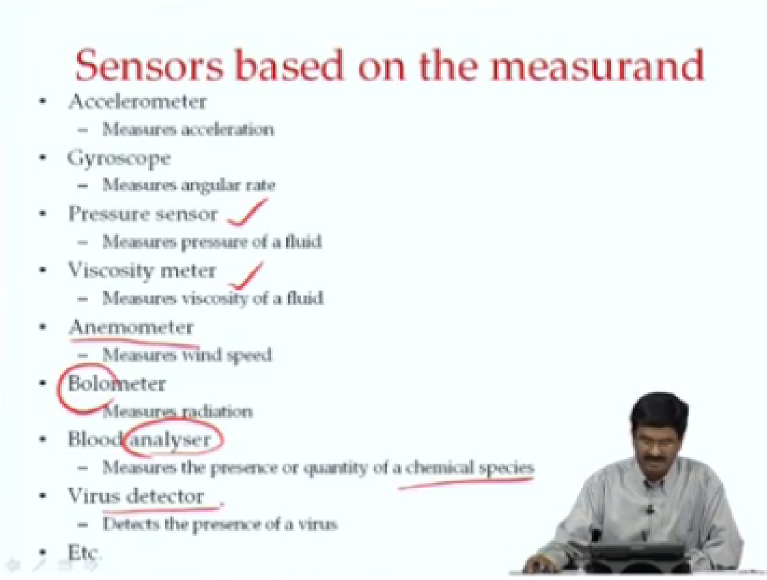

There are lots of sensors, their based on different types of measurands, you can classify them as different types of sensors and also by the same measurand that is the same quantity that you want to measure, we can also classify them based on the way they measure that thing. So, let us look at a few examples of the sensors. So, here we have an accelerometer is a sensor that measures acceleration.

Acceleration, as you all know is the derivative of the velocity; that is the rate of change of velocity. So, if you want to measure the acceleration of a bus that you are travelling in. I need an acceleration sensor, I need an accelerometer. Similarly, let us I want to measure the angular rate of an aircraft, then I would need a gyroscope. A gyroscope is an angular rate sensor and here we also have shown, let me choose a pen here, we also have a pressure sensor.

Pressure sensor measures the pressure of a fluid, it can be a gas or a liquid and we want to know the pressure of that, which is usually, needed a lot in industries and also here we have shown a viscosity meter. Viscosity is a property of a liquid or a gas; is a property of a fluid in general. If you want to measure that, then we need a viscosity meter, viscosity meter is also a sensor.

We also have shown here; what is called an anemometer? Whenever, you see the word meter in something that means that is the sensors, it is going to sense something. Here the anemometer is a word for something that measures the speed of a wind or a gas. We also have another term called bolometer here. Bolometer is a sensor that measures radiation. I have put here something called a blood analyser that is also a sensor.

But it is going to sense the presence of a particular chemical species or a virus that would be; it can be called an analyser but it is actually going to measure the quantity or the presence of a chemical species. Similarly, we can have just a detector, a virus detector, so if you want to go and find out if you have particular virus in your body or not, you need a sensor that is also can be called just a detector.

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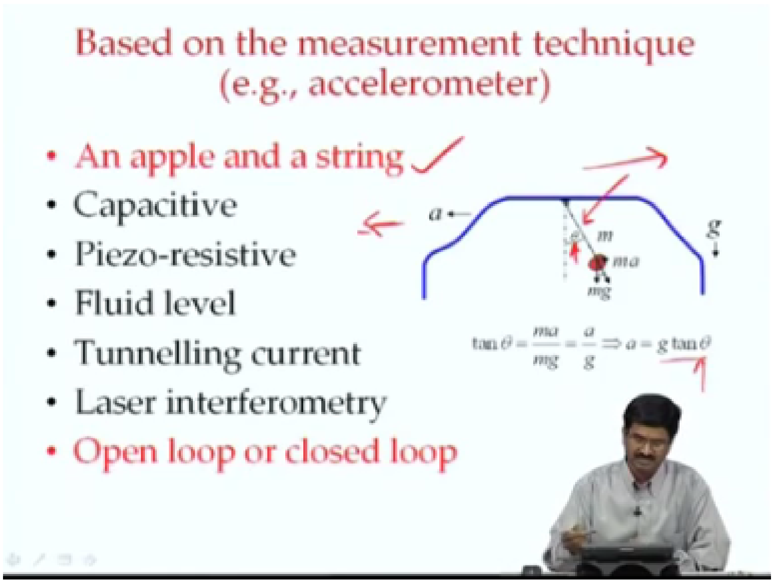

So, you have lots of different type of sensors that are there and all of these today can be miniaturized, meaning that it can be; they can be made as small as one can imagine in a sense of the size, you can make something or the micron size and that becomes a micro sensors. So, based on the measurement technique, let us take an accelerometer which is the most successful micro machined sensor.

In an accelerometer there are some elements which help you to measure the acceleration. Let us look at a few ways of measuring acceleration. First one is simply an apple and a string; we are taking an apple because apple has lot of connection with the gravity which is acceleration. Let us say you are sitting in a car and you want to measure the acceleration of the car, then all we need to do is; if we have a weight not just an apple just about any weight and a piece of string as shown here, a piece of string.

You take that piece of string and attach this apple to it, there what will happen, when the car is moving, I shown here in this direction because of the inertia force the string with apple will move backwards, in this direction and that is what is shown here. If you were to measure this angle which is shown here the theta, then you can calibrated for acceleration, how is that possible?

Because when the string instead of being straight if it is slightly rotated as it shown here, we can do the force balance, because there will be a tension in the string that is shown here, part of that has to compensate this mg weight of the apple and the other part has to compensate this acceleration or inertia force m times a, m is the mass of the apple and a is the acceleration.

Now, if you look at the force balance here that is if you split this mg and ma in the 2 directions that we have shown, the tan theta here has to be ma / mg for static equilibrium, m is cancelled in the numerator and denominator, so we get a/g, so if you want to know acceleration, I have to use this formula g times tan theta; tangent of theta times g will gives the acceleration.

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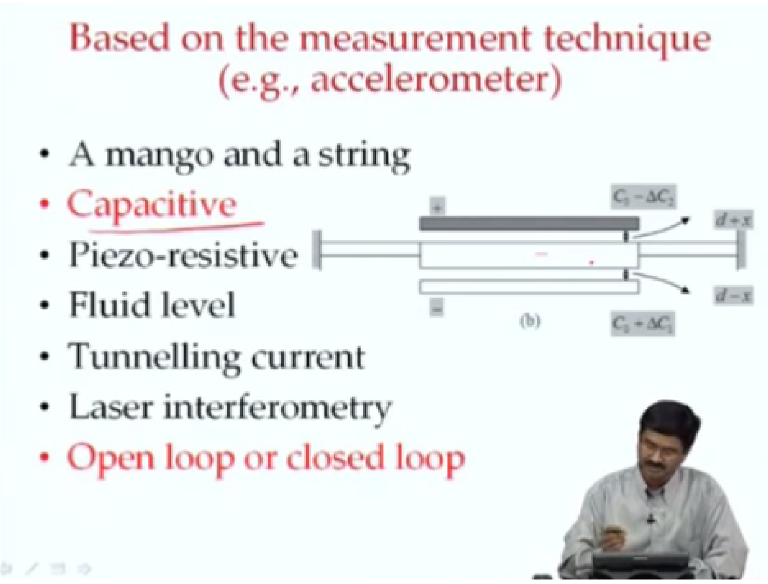

G is acceleration to the gravity, that acceleration that acting on the apple in the downward direction. Now, if we can measure this theta, you have measured the acceleration that is the simplest way to measure acceleration. Let us look at other ways of measuring acceleration. Here, we are using a capacitor accelerometer. The figure here shows a plate which is this thing here and there are 2 plates above and below.

These plate on the top and plate on the bottom are fixed, whereas the plate in the middle can move in response to the acceleration that is present on this device. As this movable plate moves, if you can measure the capacitance between the movable plate and the fixed plate at the bottom and the top, you can calibrate again for acceleration, just as in the case of an apple tied to a string where measuring theta and said this is acceleration.

Similarly, here based on the capacitance changed in the top and bottom plates we can say how much is acceleration acting on this device. Note that, if you have an accelerometer and if you want to measure the acceleration of something, you have to mound this accelerometer over that something. In the case of a car, you have to attach the accelerometer to some portion of the car, whenever the car experience acceleration, the same thing gets transferred to the accelerometer.

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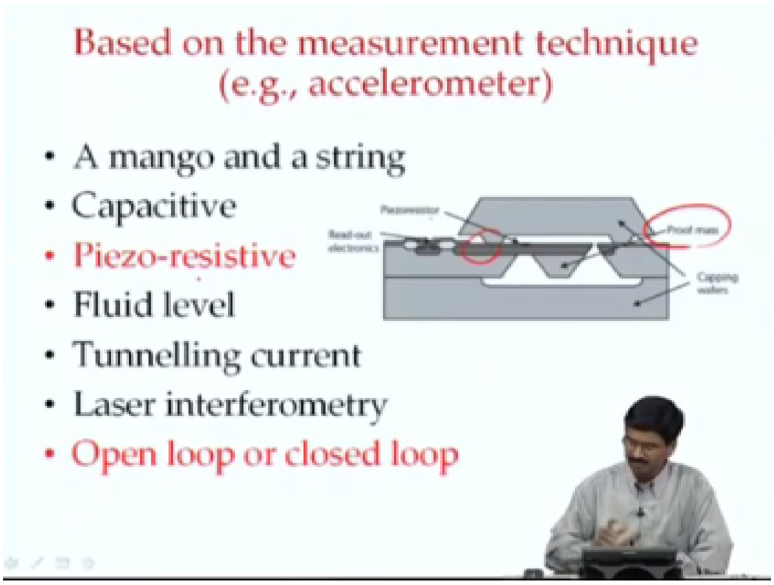

Let us look at another type of accelerometer, this is what is shown in red here piezo resistive accelerometer, so here we have a mass which has to explain acceleration, the mass is the equivalent of the apple that you saw in the simplest case. Instead of the string here, we have a beam and that beam is fixed at one end and there is big mass here, which is called a proof mass.

That proof mass experiences a force whenever this acceleration, the mass is m and acceleration is a, it will experience acceleration m times a, in the direction of the acceleration. Because of that force, inertial force, m times a; the beam will bend, beam will be deformed and that deformation can be measured just as we measured theta in the case of apple tied to a string, here we have to measure instead of theta something else and that is the strain at a fixed end of the beam.

In order to measure strain, we use a strain gauge. In the case of micro machined sensors, the strain gauge is actually implanted or deposited here and that we call a piezo resistor, you put a material whose property is that whenever there is a strain, its resistance will change that is why it is called a piezo resistor. So, when acceleration acts the mass will deform, the mass will move, the beam will deform and the strain will change and that is why the resistance appears resistible change.

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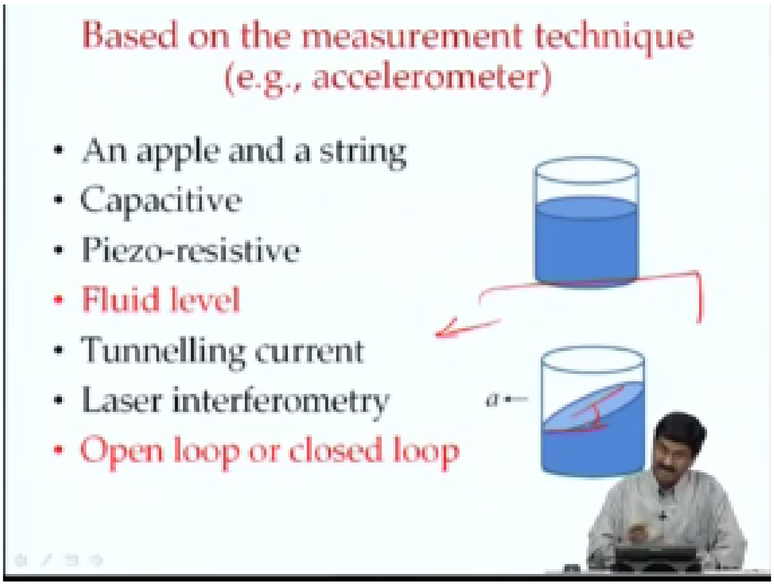

If you measure that, you can again calibrate for acceleration. So, now we have seen 1, 2, 3, types of sensing acceleration, there can be many more, so let us look at one more thing. Again a very simple one, if I have a glass with some water, whenever the acceleration, let us say there is a table here and when this table moves this glass has to move with it but then the fluid does not want to because it has inertia so, level will change as it shown here.

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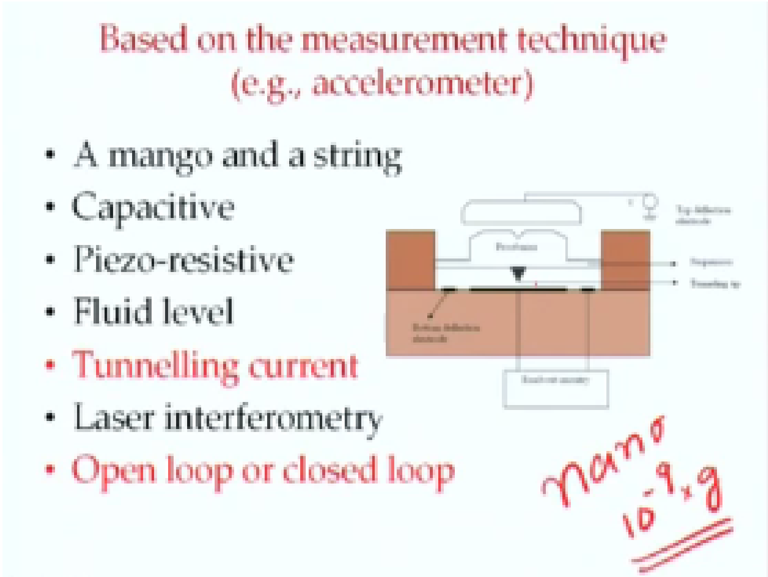

If we can measure this angle again, you can calibrate it for acceleration. So, again another simple way to do it and there are micro machined accelerometers that use this kind of principle as well. Let us look at a more sophisticated way of measuring acceleration to the tune of nano g; nano as you know is 10 power – 9, so 10 power -9 times the acceleration to the gravity, a very small acceleration that also can be measured with a micro machined accelerometer.

If we use the concept of tunnelling current, so here we have the proof mass and there is a short tip and between that tip and the electrode at the bottom, there is a very small gap. The gap is so small that electrons actually tunnelled through that establishing a tunnelling current. That tunnelling current changes whenever this tip moves toward that electrode reduce in the gap.

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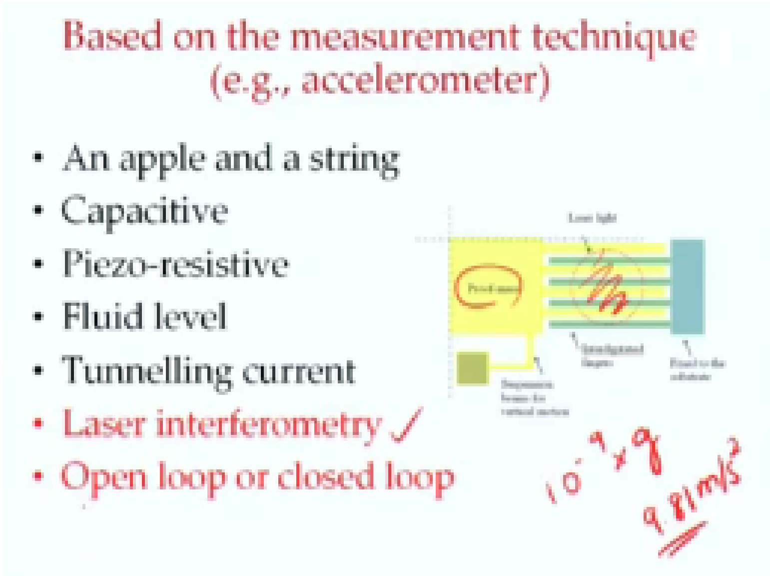

This is the very sensitive accelerometer, even if you apply a Nano g acceleration on the proof mass. The tip will move enough to create a sizeable change in the tunnelling current and hence we can detect. Let us look at one more which is again a very sensitive accelerometer, which uses laser interferometry. Here, the yellow colour is the proof mass that is the mass which is going to experience acceleration.

And hence it experiences inertial force m times acceleration, in the direction of the acceleration and here we have a set of green comb fingers, there are yellow fingers attached to the proof mass and the green ones attached to a fixed support. Now, if you shine a laser, let us say this circle here, this entire thing is a laser spot, so it is the very small one, so laser spot is also very small, you will see some interference between the 2, the movable fingers and the fixed fingers.

Now, whenever the proof mass changes the little bit, the fringe pattern will change by count in the number of fringes, you can calibrate for acceleration. So these also a very sensitive accelerometer, which can again measure nano g that is 10power -9 times g which is as we all know 9.81 meter per second square that means that you can measure 10 power -8 meter per second square because g if you approximated to 10.

All of these, if you noticed we have put this open or close loop, what that means is that; we can just measure; let us go back to the capacitive accelerometer, where we had a movable plate and a top plate and a bottom plate. It I want to; let us say use it in close loop, open loop is what we just discussed, whenever there is acceleration, the movable plate moves and the top and bottom plate are fixed and we can see the change in capacitance.

Instead of doing it that way, we can also apply a force on this movable plate, so that it remains stationary even when there is acceleration. If we do that, we call it close loop and a force required to keep it stationary in the presence of acceleration can be used for calibrating the accelerometer. So, if you have go back to our simplest example, let us say you are in the car and car is accelerating and the apple tied to a string is moving this way.

But if you use your hand to bring it back to where it was, then that force that you need to apply to keep it here will tell you the acceleration. So, that will be the closed loop and close loop operation has certain advantage over open loop operations which will learn later when we discuss this accelerometer in detail. So, there are different kinds of accelerometers and they all have different features.

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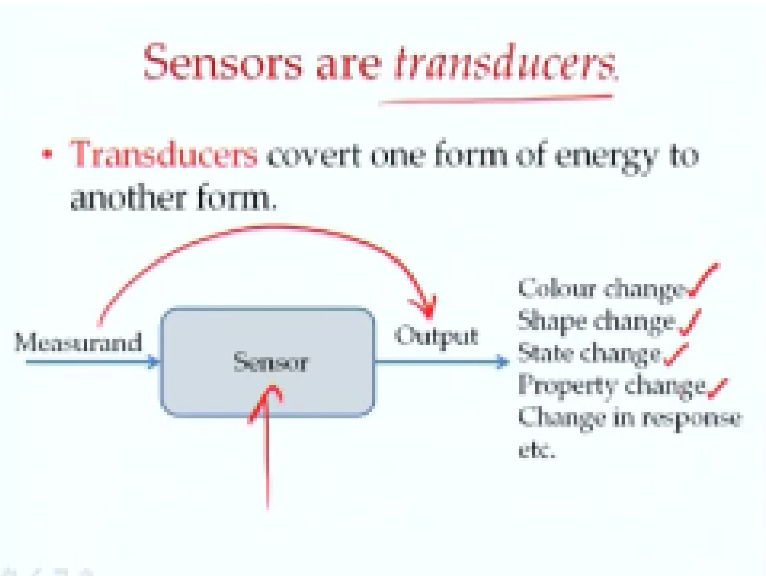

Now, let us note one more important thing about sensors in general. Sensors are transducers, it is in term transducer, it is an element that converts one form of energy to another form. Here if sensor if I take there will be a measurand that can be any domain meaning mechanical electrical, magnetic, optical, biochemical any of those domains the measurand is there, the quantity wants to measure. The output will usually be different so, this sensor converts this measurand to certain output.

So, it actually converts energy that is in one form to an energy in a different form, so that we can sense it. So, sensor is a transducer. This change from measurand to output can be many different ways, there can be simply be a colour change, litmus paper, for example is a sensor, it tells you if a liquid is acidic or basic, what you see there? When we dip a litmus paper into a liquid, that changes colour.

So, based on that we can tell, what is the ph value of that particular liquid? Similarly, a shape change can also indicate a sensor. If you have, I say a plant which is very sensitive to the moisture content in the soil whenever the soil is dry, the plant will wither. So, the shape of the plant instead of being straight, it withers and that is also a sensor and it can also be state changing.

If you have; let us say coconut oil, if it is a cold morning when you look at a coconut oil, it would have frozen, if it is a hot day, it will be a liquid. The state of the matter can also indicate something about the environment that is it is the sensor or a property can change. We already had seen that piezo resistor, resistance changes whenever there is a strain, so you can have property changes also in the case of the sensors.

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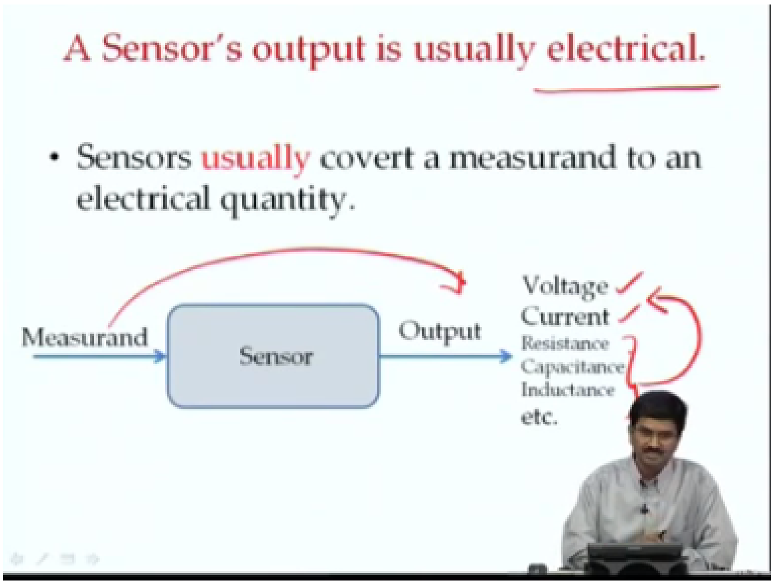

And change in response, the sensor element will behave differently in case of application of a measurand that also can be sensitized an output. Usually, the sensors especially the micro sensors, the output is electrical that means that a sensor at the micro scale will convert a measurand to an output which is in the electrical domain, it can be a voltage or a current or it can be resistance, capacitance or inductance.

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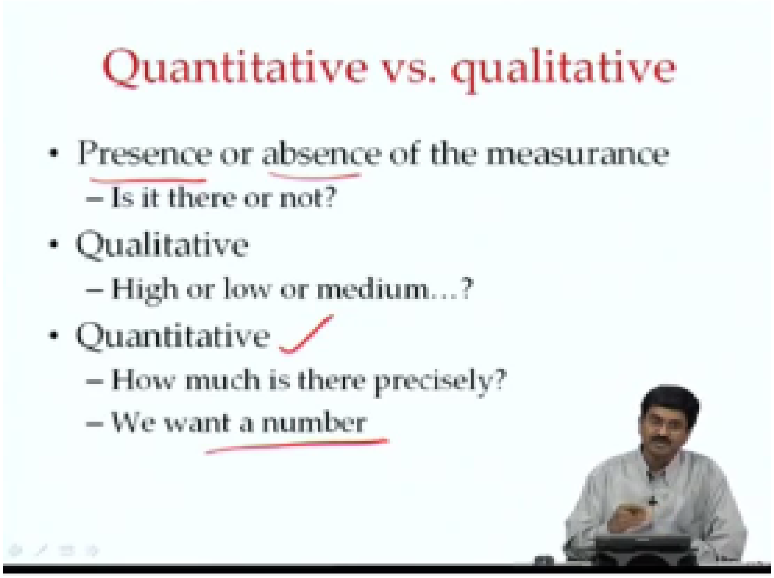

All of these again when we use electrical or electronic circuitry will be measuring voltage or current. So, most of the micro sensors will take any measurand and put it back into the electrical domain in the form of a voltage and current which we measure then we will see how much the measurand is. A sensor can tell you something about that quantity being measured that is the measurand either qualitatively or quantitatively.

First, it can just say whether something is present or absent, so presence or absence indicating those itself can be a sensor job. For example is there some carbon monoxide in this room then I can put a sensor and then say it is there or not. It just tells you whether it is there or not. We can go one step further and just say little bit more qualitative that is the content of carbon monoxide in this room, is it very high or very low or medium range that can be a qualitative one.

Or we might just want to know precisely how much carbon monoxide in this room, then we will need quantitative information, we want a number, right. Sensor can be just on off sensor that is it will tell you whether something is there or not or it will tell you qualitatively whether there is a lot of it or little of it or it can tell you a precise number. Any of these are applicable depending on what you want?

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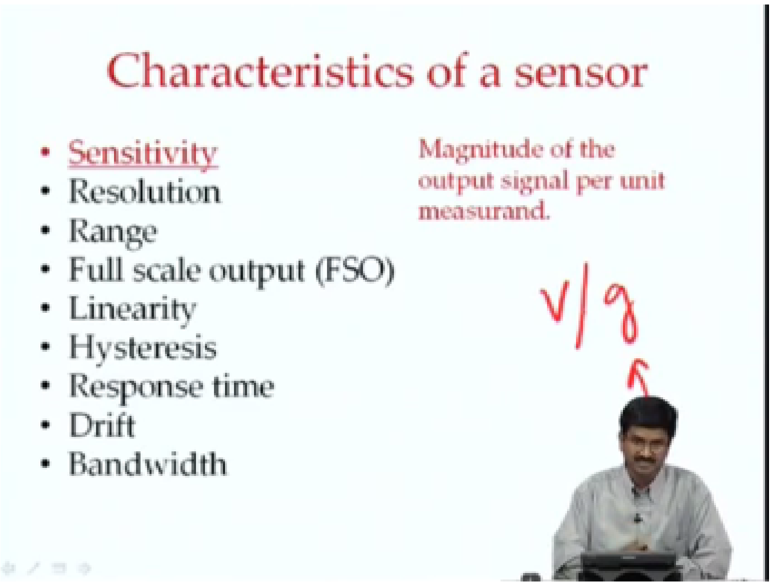

When we go quantitative, we have to define certain terms related to sensors in general. Here, we have listed 9 terms; let us look at each of them one by one. Sensitivity; sensitivity is the magnitude or the output signal per unit measurand that is if I have accelerometer, for one unit of acceleration, how much output am I getting? If my output is going to be voltage, so I will say so many volts per g; g here refers to a unit of acceleration, which we take it as 9.81 meter per second square.

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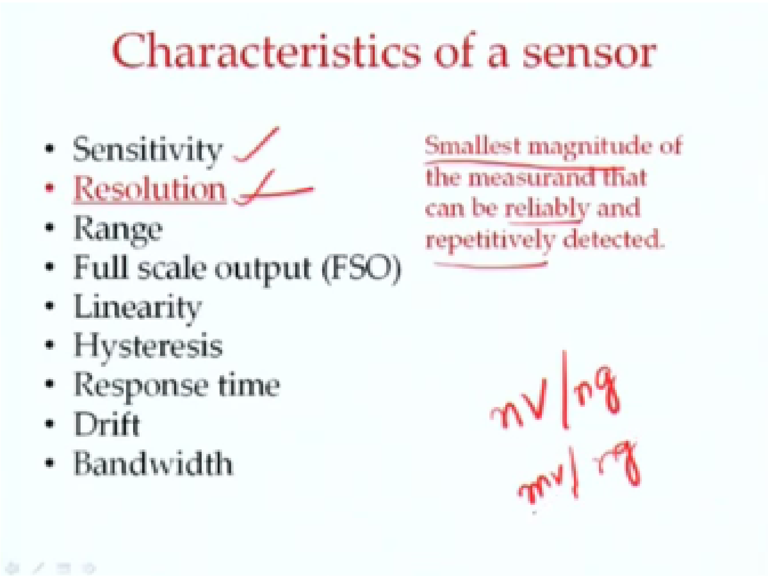

So, we will say if I have so much acceleration applied on it how many volts output do I get? That is the sensitivity. There is a related term which is resolution. Resolution is a smallest of the measurand that can be reliably and repetitively detected. The words reliably and repetitively are very important because we do not want a sensor to give you different volts output at different times or the same acceleration.

We need to have reliably all the time under different conditions, it should give you the same thing and for resolution we are calling it smallest magnitude, meaning that smaller than that a sensor cannot tell you right, that resolution is very important. We have to understand the difference between sensitivity and resolution, the related terms something that is highly sensitive will also have the refined resolution.

Refined resolution means that the smallest magnitude will be very low. But then something that has high sensitivity that does not necessarily mean that it will also have high resolution that is because they will be noise in any sensor. Noise comes from various sources, there is a noise in the sensor element itself, there could be noise in the electronic circuitry, there could be noise in the packaging that will be enclosed in the sensor.

In all those cases, we will have to worry about the resolution. Because you may get, let us say nano volts per; let us say nano g or you may get 1 millivolt per nano g which case you can detected but if your sensor has very high noise which is larger than let us say 10 millivolts nano g cannot be detected then that it is not the resolution and resolution or noise also depends on the frequency that we will discuss a little bit later with the context of an example.

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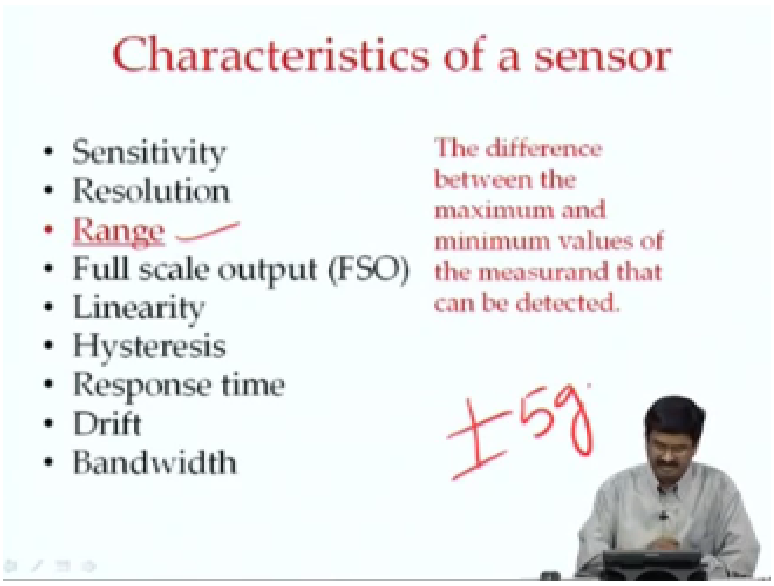

Let us look at another term which is called the range that is the difference between the maximum and minimum values or the measurand that can be detected in the case of acceleration we can say, we can detect an acceleration of + or – 5 g that is; I can detect acceleration anywhere from – 5g to +5g that is the range. There is also another term that is often used which is full scale output.

It is the difference between the maximum and minimum values of the output signal. Let us contrast with the previous definition which we said range is a difference between the maximum minimum values at the measurand whereas the FSO, full scale output is the minimum and maximum value difference of the output signal. This is also important because you want to know what kind of output you can expect for a certain sensor.

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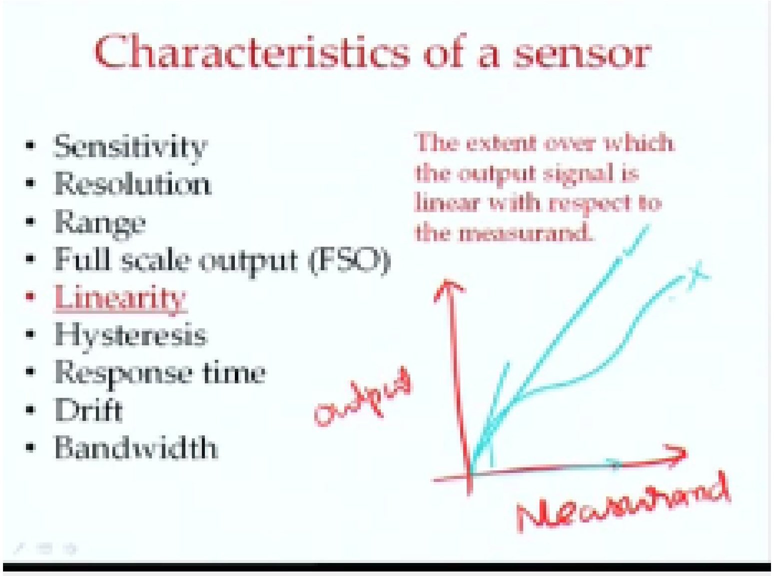

And next one is linearity. Linearity is if I were to have let us say here, I have my measurand and this is my output, okay, if I were to draw the output verses the measurand, I have intentionally drawn it to be nonlinear but in practice a good sensor you wanted to be linear, so here it is linear over a small range and that is what is the linearity. If over a large range of measurand, if I have a linear sensor something like this; this is preferred rather than something that is nonlinear.

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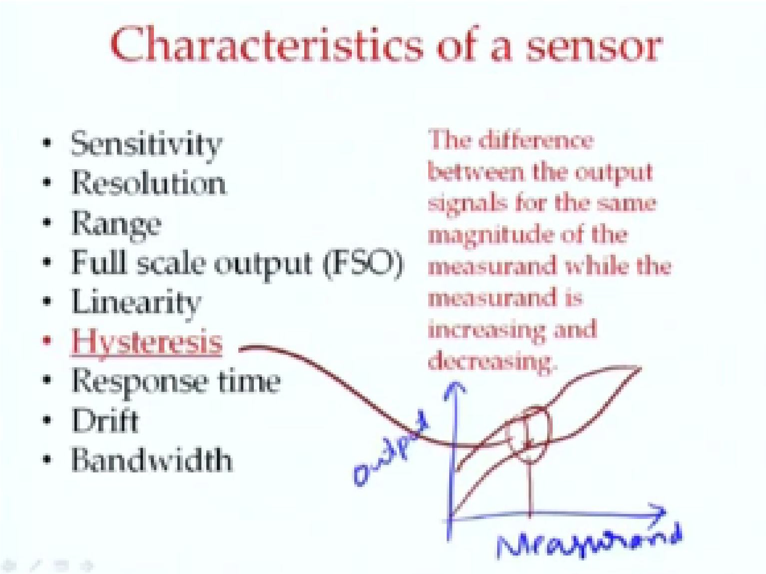

So, linearity is an extent over which the output signal is linear with respect to the measurand and that is linearity. We also have another term called hysteresis. Hysteresis is a difference between the output signals for the same magnitude of the measurand but different times, you may increase the output signal, let us indicate what the hysteresis is. Let us show again the output that can be a voltage or current and we have the measurand.

Let us say that this has certain characteristic; let us say this goes like this, that is based on a modelling you know that is how it works but then when you start measuring that is your measurand that can be acceleration keeps increasing, you might see a certain value as it is shown but when you decrease the measurand it may not exactly follow this curve. If it follows, we say that there is no hysteresis, if we do not it may come something like this from there.

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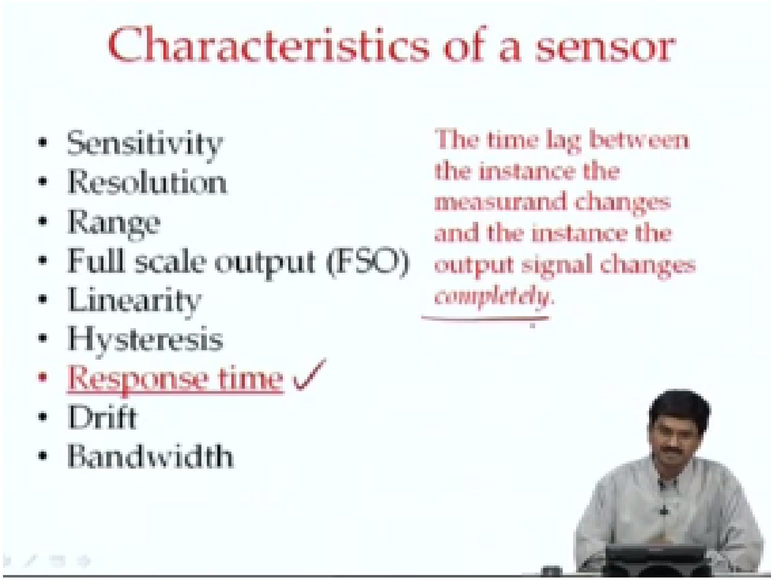

So, at this point we have for the same measurand, 2 different values of output that means that there is certain hysteresis in this sensor. So, a good sensor will have a very little hysteresis that is a very important thing to remember when you have a sensor, when you use a sensor or when you design a sensor. Next thing is the response time. Response time is the time lag between the instance the measurand changes and the instance output signal changes completely.

The word completely is important here, what we mean by response time is; if let us say I have used the accelerometer and I have mounted it on a car and the car suddenly moves, then how long does it take for the accelerometer to respond and tell you that a car has moved and now it does not receive acceleration anymore, it has this much acceleration and it has to reach that value completely.

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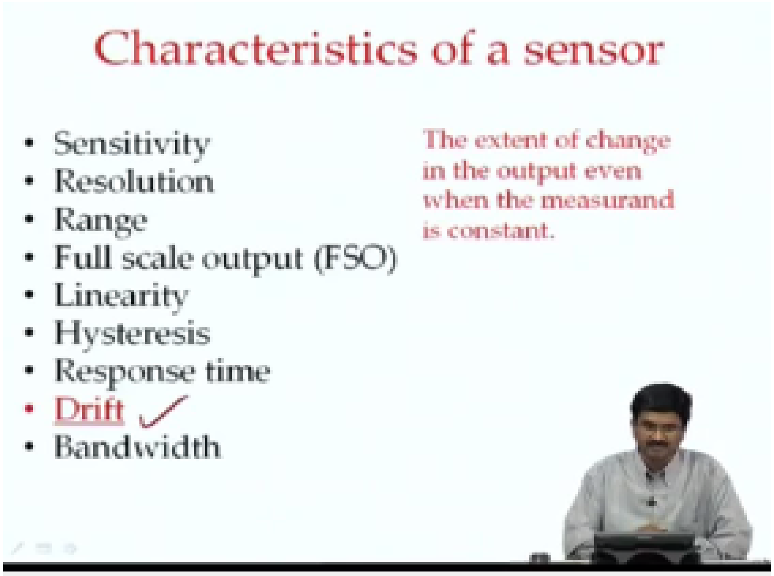

Usually, one can say 90% of the time is okay that is the response time and ideally would like to have response time as low as possible that means almost instantaneously the sensor should be able to tell us what the measurand is. There is one more term which is called drift. Drift is the extent of change in the output even when the measurand is constant, let us say going in the car and you are going at a constant acceleration but your sensor does not show constant output.

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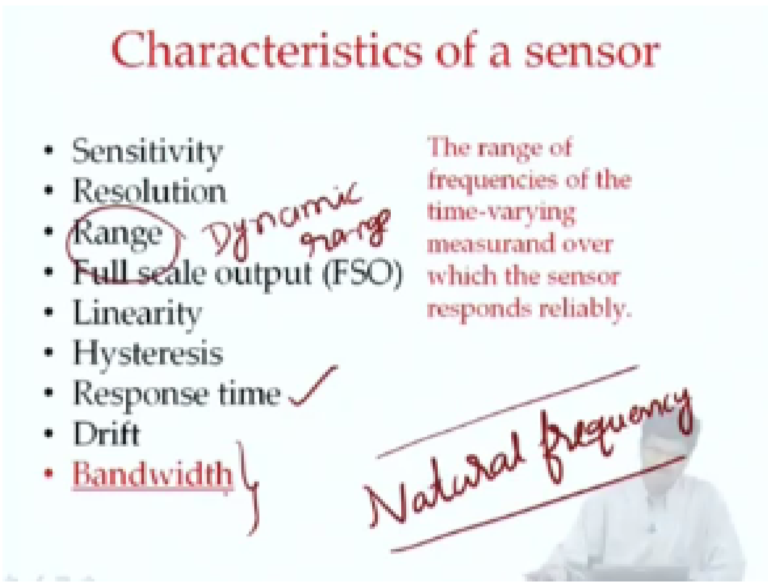

It shows you a little bit of a variation and after a period of time it can drifts to a different value and that is the term that we need to pay attention to when you think of a sensor. The last one is band width. Band width is applicable for measurands that may vary with time which is true for many of the sensors. So, if you are mounting an accelerometer let us say an aircraft then aircraft may go at different speeds that change with time.

And because of the acceleration will change or a range of frequencies. The range of frequencies over which the sensor can reliably and repetitively tell you that this is the acceleration then we will say that is the band width. If you change the acceleration, let us say very quickly then the sensor may not be able to respond, we talked about response time already.

Then over those high frequencies, it may just not be able to tell you that acceleration has change, the measurand has change. So, the band width is an important characteristic, in fact that is why sometimes that range is also referred to as dynamic range. Dynamic range is when there is dynamics in the system you would want to know under those conditions how much can you measure?

That is from what lowest value to the highest value that will be called dynamic range and band width range and the response time are all related and this actually depends especially the band width and the response time depend on what we call natural frequency of the sensor element; natural frequency or normal frequency, resonance frequency that we use the term and that means a lot for the terms band width and response time.

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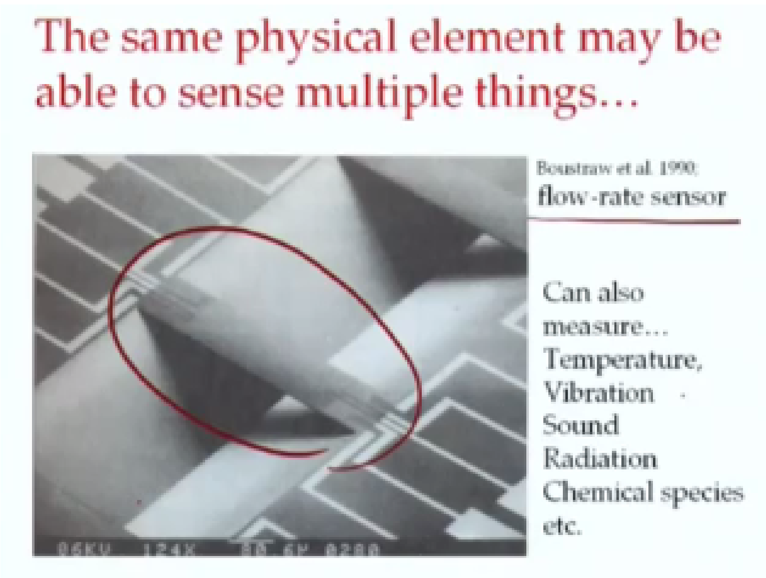

So, we talked about a number of characteristics of a sensor, let us look at another fact which is the same physical element may be able to sense a number of things. So, here that element is this beam which is over a V shaped channel that you see here and this particular beam, the weight was designed by researches who built this is meant to be a flow rate sensor but it can also measure temperature, vibration, sound, radiation, chemical species etc.

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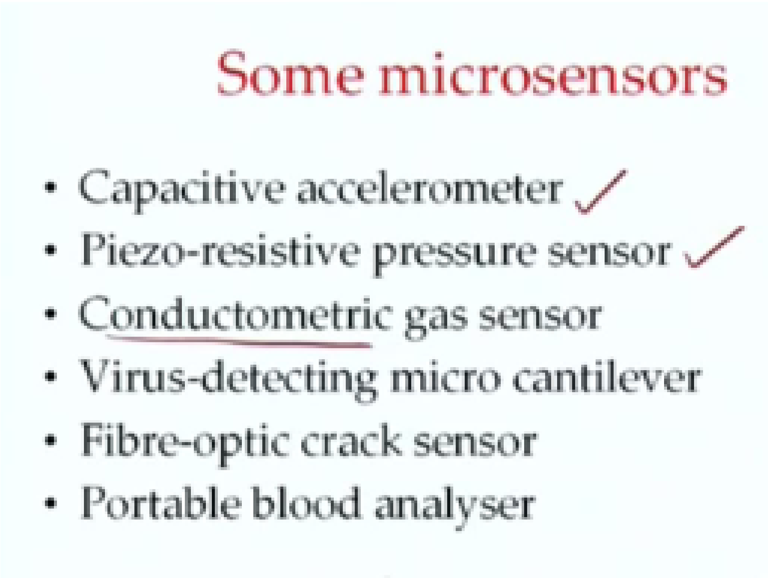

So, there are lot of ways where you can use a same physical element and measure a number of things that another term to remember; the same physical element may be able to sense multiple things. Let us now look at having discussed the basics of sensors in general. Let us look at few specific examples and we are going to discuss a little bit more detail about capacitive accelerometer, piezo resistive pressure sensor, conductometric gas sensor and a virus detector and a fibre optic crack sensor and portable blood analyser.

These examples covered as you can see a number of different fields and also a number of different transduction techniques; transduction technique is the way a sensor measures something. First one is capacitive, second is piezo resistive, third is conductometric metric and fourth is for a detection of virus which uses a different sensing technique, fibre optic crack sensor is different and portable blood analyser works in a different principle.

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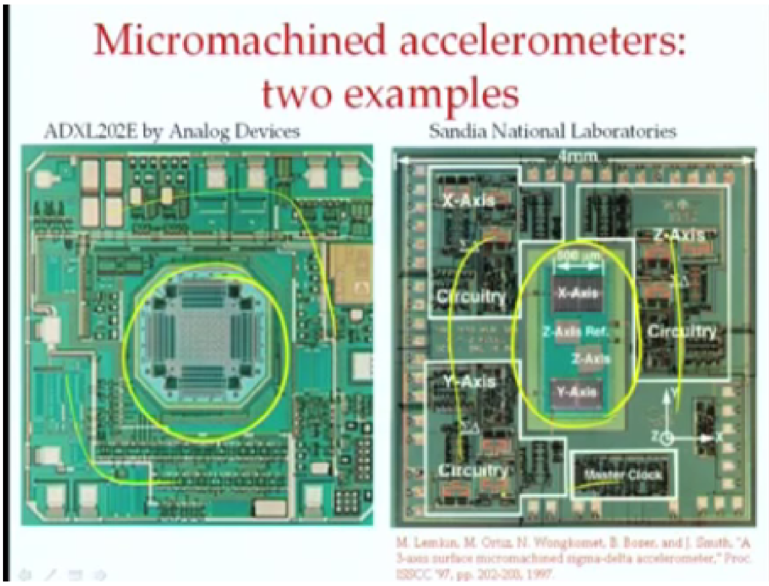

Let us look at all of these one by one. Here, you see the photographs of micro machined accelerometer, one is a commercial one by analogue devices, I have a small sensor here of that it is made by analogue devices.

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So, here you see this chip is an accelerometer made by analogue devices that you can buy commercially and there is also anther one which is much smaller than this which is a gyroscope, it measures the angular rate. If you mount it on a car, it will tell you how much roll over the car has at what rate and how it is; at what rate it is turning and so forth. While we are looking it, let us also look at another sensor which is made by Bharat Electronics Limited which is a pressure sensor.

This pressure sensor, there is a small hole here which when subjected to pressure from outside, it gives you at these electrical leads at a certain output and you can measure the pressure. So, you can compare with the 1-rupee coin here, how small all of these sensors are, that is why they are called micro sensors. That chip that is inside all of these might look like this, in fact this is analogue devices chip where there is a sensor element; there is a sensor element over here.

Similarly, another one made by Sandia National Laboratories, the sensor elements are here, these are the mechanical sensor elements, this is a 2 axis accelerometer, this is a 3 axis accelerometer and there is all this electronic circuitry surrounding that, all of these are in a chip and this has to be packaged to make a sensor that looks like what we saw in the real chip. How does it work?

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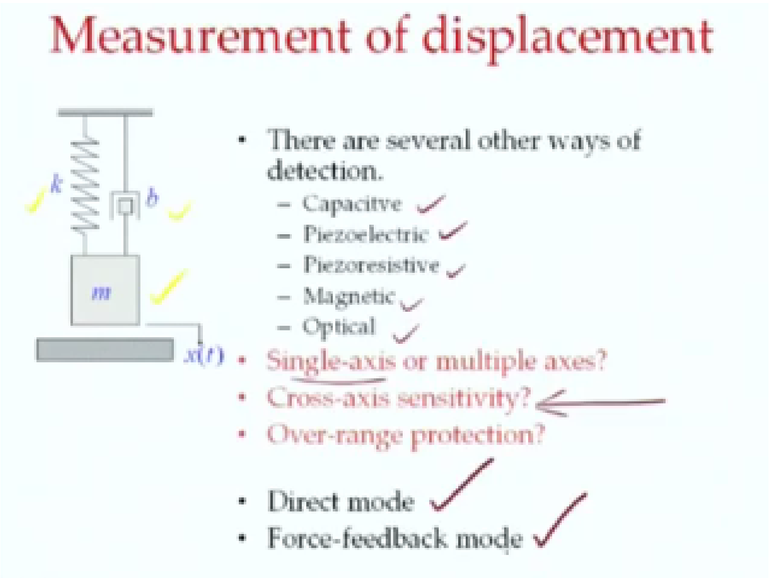

How does this accelerometer of analogue devices or Sandia National Laboratories or any other accelerometer work? All you need to have is a mass and a spring and a damper, so if you have these, you have a sensor in your hand. The mass; a proof mass as it is called and there is a spring, meaning that there is a beam that restricts the motion of the mass and that is the spring and there will be some damping which is shown as a dashpot here.

So, this is a very informative and very useful model of an accelerometer. One can make a model as complex as we wish but this captures the essence of an accelerometer. The motion or the mass in the presence of acceleration can be detected as we already saw in the multiple ways; capacitive, piezo electric, piezo resistive, magnetic, optical and many other ways and we may want to measure only acceleration along a single axis or multiple axis.

We have to worry about one more thing in the case of an inertial sensor that is the accelerometer which is cross axis sensitivity. If there is an acceleration in one direction, we do not want to detect or get an output when there is an acceleration in the other direction and that is cross axis sensitivity and that is very important because if you want to define that my sensor has this much of resolution then the cross axis sensitivity also becomes very important.

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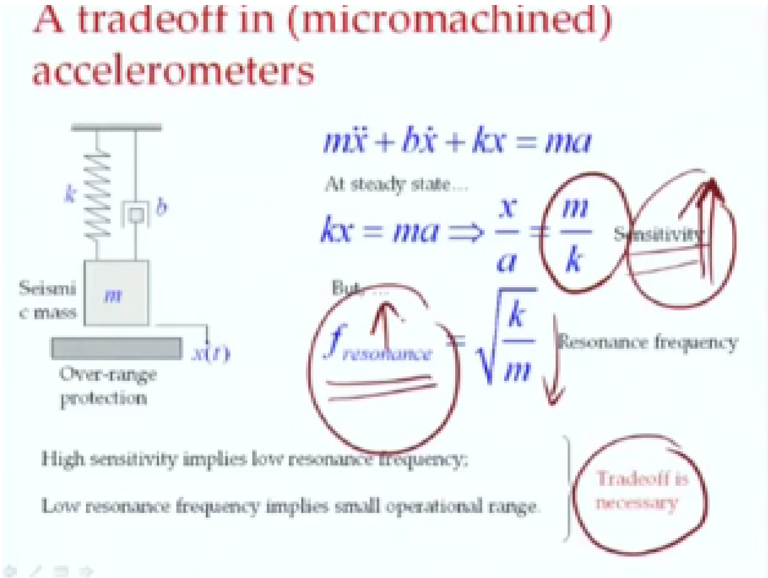

Because we do not want to detect the acceleration that happens in another direction as opposed to the one that we want and as we already discussed a sensor can act in a direct mode or a feedback mode that is open loop; this is an open loop direct mode, feedback is the closed loop mode. In the design of sensors, there will be lot of trade off like it happens in any design.

In the case of accelerometers, the sensitivity is defined by the ratio m over k because m times a is a force acting and if you divide that force by k which is a spring constant of this spring which is expressed as newton per meter that gives us how much displacement we have elected to the acceleration applied x over a will be m over k, if you want signal which is here the x and a is the measurand, if you want to have this to be very large we need to have a large mass and a small spring that makes sense.

Because where given acceleration mass is large, they will get a lot of force on it, if the spring constant is low it will move a lot of distance, if distance is what we are measuring we want it to be very high for high sensitivity. So, this has to be very high but then we have the natural frequency for the simple model which is square root of k over m, radiance per second, so when you want to have a large enough frequency, because if the frequency is large, the bandwidth will be more.

Meaning that; we will be able to measure acceleration over a large range of frequencies, so we want this to be also very high. But as you can see we have m over k be wanted to be high then this also which is the reciprocal of m over k, this will go down, so there is conflict between the 2, but ideally we would like to have this to be large and this to be large and that is not possible and that is why there is a certain trade of that one needs to do in the case of sensor.

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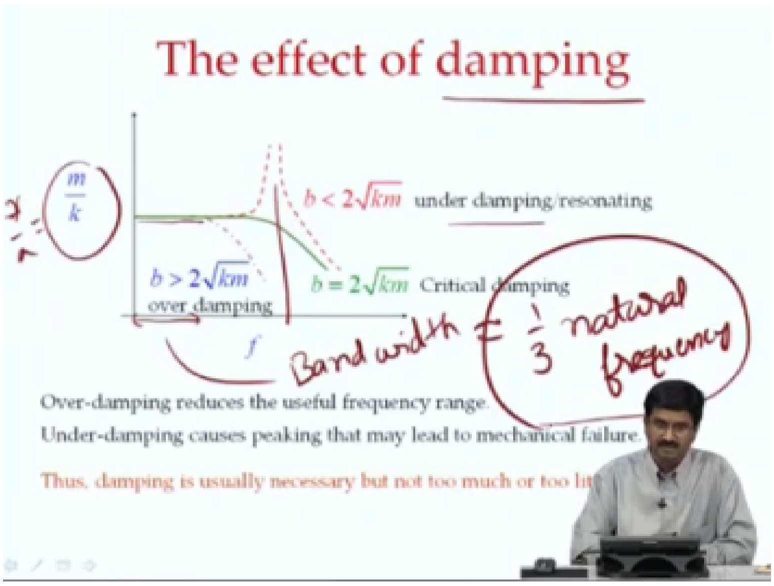

This is true for not only for accelerometer but true for most of the sensors, high sensitivity if you want you have to probably sacrifice something or use any innovative method to get high sensitivity and high band width or a high natural frequency. Let us look at the effect of the damping term which we have shown as a dashpot here, so there is a spring of spring constant k and the damper of damping coefficient b what is the effect of that?

If you look at the frequency response this also tells you about the band width that we talked about. Depend on the value of the damping that you have, if it is under damped, that is damping is not very high, the frequency response; this is m over k that you are going to measure that is equal to as we saw x/a for a given acceleration how much is the displacement of the spring that mass as a function of frequency in the log-log plot.

You will have something like this, if it is a red dashed line that is under damped there is not much damping but it is nonlinear, we do not want a sense to be nonlinear and if it is critical damping, it will be flat over a long lot of region and then it will go down. In the case of over damping, it will be constant and then it will go down like this. So, depending on what you want you can have over damping or under damping.

Normally, under damping is not preferred, over damping is not preferred, you want something reasonable and you can see that for this range of frequency the signal is constant right. For a given acceleration, we have x over a here that is constant irrespective of the frequency and that we call as a band width and that good thumb rule is that band width is roughly = 1/3 of the natural frequency; resonance frequency.

Here, natural frequency is this way because resonance; at resonance where the frequency of the applied measurand the output is going to be very high and we do not want to operate here because this is nonlinear we want to be in the region where the x over a or the thing that you are measuring, output divided by the measurand has to be constant for a range of frequencies and that is the band width.

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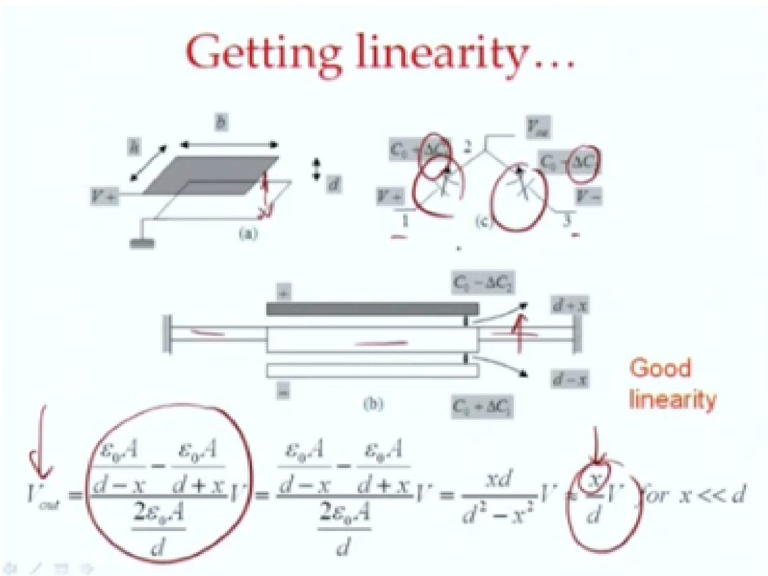

If we take this as the thumb rule, you can design sensors with predicted band width. How do you get linearity? That is a different game depending on the transduction technique that we have the linearity has to be adjusted with clever design. In the case of capacitive accelerometers, we had seen this figure earlier, there is a moving plate there are fixed plates and at top and bottom.

In this particular case, we can have, if you want only capacitive change, only the top plate or only the bottom plate but then we have both, what it gives you is that; if you were to use this capacitor formed by the top plate and the top surface of the moving plate and the bottom surface of the moving plate and the bottom plate, if you take these 2 as 2 different capacitors which I shown by comparing their capacitance, let us say because of acceleration this moving plate moves up.

Then this capacitance is going to increase because capacitance is inversely proportional to the gap in fact, inverse portion to the square of the gap, so this capacitance will increase, whereas this capacitance will decrease. So, you look at those changes that is c0 c0, when it is perfectly balanced and then you have delta c1 and delta c2 by using those and doing signal processing with electronic circuitry, we can actually see the output voltage that we get.

It will be some voltage times the change in capacitance, this is a function of the electronic circuit that you have, if you work out the details here assuming that the displacement or the mass is x. If you consider that x is much smaller compared to the gap initially that is d is an initial gap between the 2 plates here, this is the moving plate, this is the top plate, this is the gap between these 2 here.

If that is very small, you can get this to be x over d times, v source volt that you are applied for these 2 capacitors, then you can see that the output here which is the voltage is linearly proportional to the displacement x and that in turn is linearly proportional to the acceleration as we saw, provided the mechanical element it has these springs here which are beams, if that is also linear then will have a linear sensor here.

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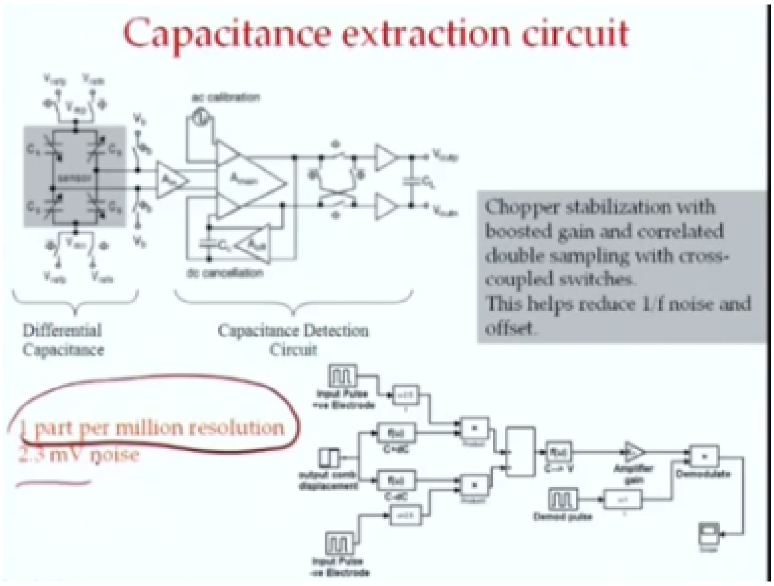

So, in order to get linearity, you have to use some clever techniques in your sensor and we need lot of electronics to convert that change in capacitance we saw into N output voltage, there are lot of different types of techniques that you will learn in another lecture that focus on electronics. Here we can use chopper stabilisation with boosted gain and correlated double sampling all these are electronic capacitance extraction circuit terms.

And that will tell you how in the presence of noise, we can reliably sense acceleration. For example, this particular thing says that you can actually measure the capacitance one part per million, meaning that if you have certain capacitance, certain farad, 10 power - 6 times that farad we can detect and in the presence of noise which may be in our output 2.3 millivolts, we can still have a reasonable accelerometer.

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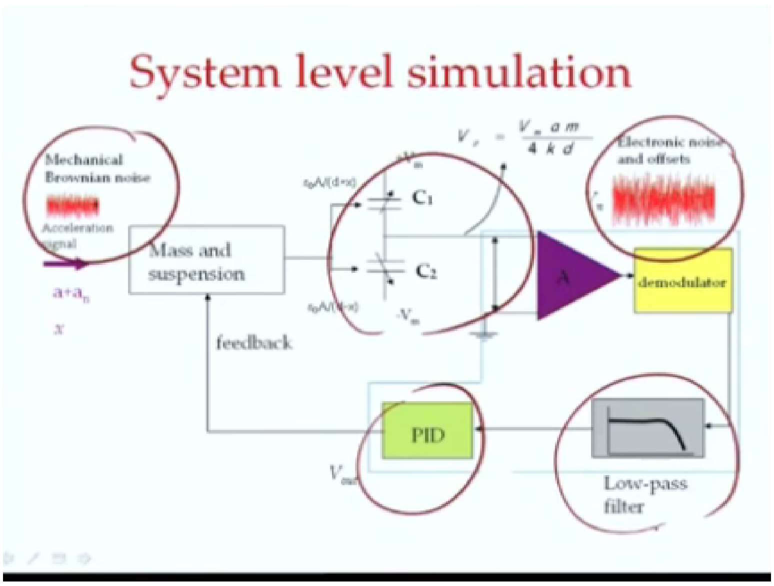

This system level stimulation, it shows here the mechanical noise that is there in the mechanical element as well as the electronic noise, you have to take this mass and suspension that is the spring and this in a closed loop, there is a PID controller, if you want to use a close loop sensor, and there is an electronic circuitry here and you put in the noise and there is further electronic circuitry for filtering certain; for signal conditioning.

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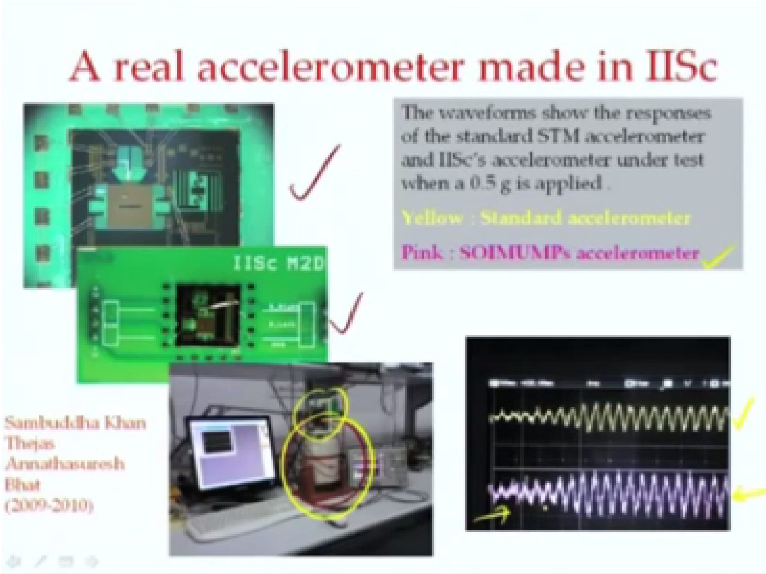

Overall, we can get much better performance in the close loop mode. Let us look at a real accelerometer that was made in IISc, these are the pictures, these are the real accelerometer, a photograph of the accelerometer is using silicon and the electronic circuit put on a PCB and tested on a vibration shaker because it is important to calibrate an accelerometer that is shown here. In this portion which in a vibration shaker and we have to compare with something commercial.

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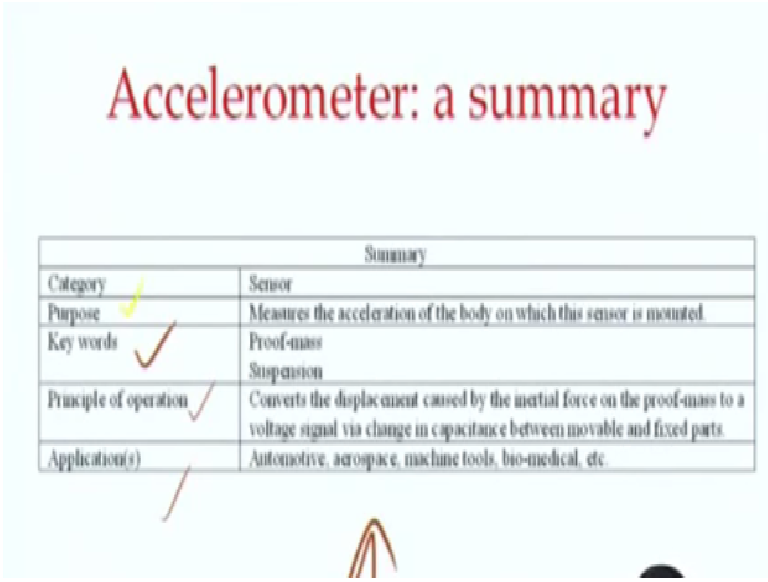

So, this is a commercial accelerometer and what you see here is this one; is the trace of the accelerometer made in IISc, this pink colour here corresponds to the IISc accelerometer and these 2 wave forms have to correspond with each other, then you can know for sure that your accelerometer is working properly. If you look at a sensor, in this case we have talked a lot about accelerometer, you can summarise all of that saying that what is the purpose?

What does it do and what are the basic terminology; related to that and how does it work and what are the applications? Accelerometers needed in automotive applications, aerospace application, machine tools, biomedical applications and a number of other areas, it is a very generic sensor. Similar chart we can make for any other sensor that you study because there are lots of different kinds of sensors and one cannot discuss all of them in detail.

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But if you are interested in a particular type of sensor, we can make a summary chart like this and you can see; what are the different characteristics of the sensor. For example, if I look at a commercial accelerometer made by Honeywell Company. This is when packaged, it looks big but they give you the input range, the bias, scale factor, full scale output we have discussed, resolution in this case it says less than 1micro g, band width we say 300 hertz and lot of things.

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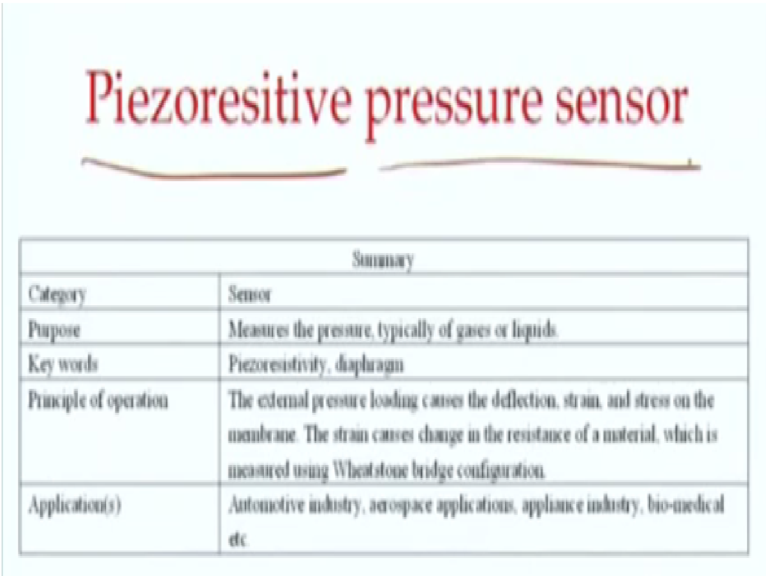

Summary	
Category	Sensor
Purpose	Measures the pressure, typically of gases or liquids
Key words	Piezoresistivity, diaphragm
Principle of operation	The external pressure loading causes the deflection, strain, and stress on the membrane. The strain causes change in the resistance of a material, which is measured using Wheatstone bridge configuration
Application(s)	Automotive industry, aerospace applications, appliance industry, bio-medical etc

The size, what it is made of, under what environmental conditions it will work, so this is the kind of information that you would want to know when you are using a sensor especially micro sensor. Now, let us look at a piezo resistive pressure sensor, a different kind of sensor, so here again we have to study that sensor in detail and make a summary chart like this. What is it measure?

A pressure sensor measures a pressure of a fluid, it can be a gas or a liquid and how does it work? It is there, it is in description, piezo resistive meaning that external pressure will cause a strain in the beam that supports the proof mass and that strain will change the resistance or the piezo resistor element and you measure that change in resistance and then calibrate for the acceleration or a pressure, which is a pressure sensor.

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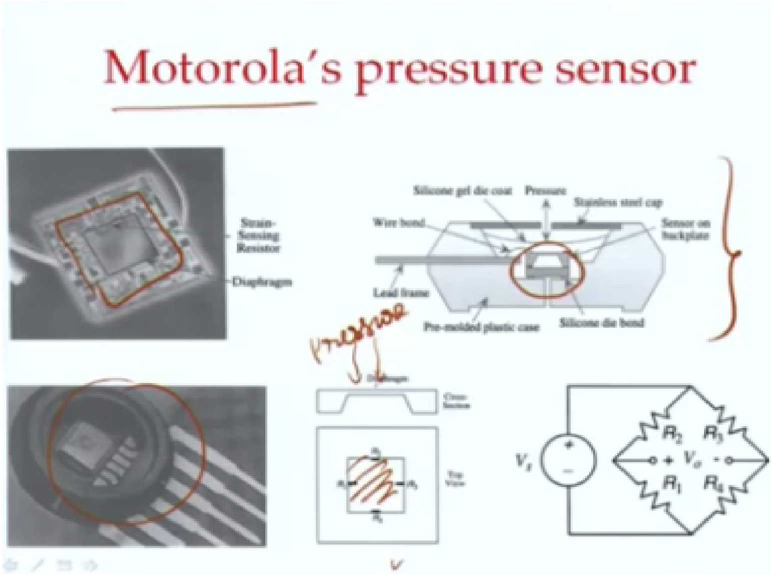

So, you calibrate for as a pressure. It has application again automotive industry, aerospace applications and then you have a chemical industry, biomedical, if you want to measure the blood pressure, we can use this pressure sensor. Let us look at a commercial pressure sensor made by Motorola, this again the chip of this pressure sensor. This is after it is packaged these are electrical leads, so you connect some wires to it.

And connected to where you want to measure the pressure where voltage will tell you how much, these schematic of this pressure sensor, there again the chip is quite small compared to the package and this one if you look at the top view of this shown here. There is a diaphragm here, which is the square thing and there are 4 r1, r2, r3, r4 are the piezo resistors which are mounted at the places where the strain is; strain change is going to be a large.

And if you look at the side view of this, there is a diaphragm which when there is pressure here is going to deform and cause change in strain at these piezo resistor locations which you can detect in the standard Wheatstone bridge and these all there in this chip that you see here and there is a lot of electronic circuitry here to do the signal conditioning and to reduce the noise that is there in the sensor element and electronics.

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Conductometric gas sensor

Summary	
Category	Sensor
Purpose	It detects and quantifies the sources of a gas, i.e., its concentration
Key words	Catalyst, combustible, adsorption, desorption
Principle of operation	The principle is that a suitable catalyst, when heated to an appropriate temperature, either promotes or reduces the oxidation of the combustible gases. The additional heat released by the oxidation reaction can be detected. The fundamental sensing mechanism of a gas sensor relies on a change in the electrical conductivity due to the interaction process between the surface complexes such as O^-, O_2-, H^+, and OH^- reactive chemical species and the gas molecules to be detected.
Application(s)	Environmental monitoring, automotive application and air conditioning in air planes, spacecrafts and houses and sensor networks, ethanol for breath analyzers and food control application etc.

So, that you will get output that can measure the pressure to the lowest extend possible meaning that the smallest change in pressure, let us say a few pascals, a few 100 s of pascals can be measured using this pressures sensor. Let us look at another sensor, in this case it is a gas sensor, you want to detect whether a particular type of gas is present in a particular environment, then you need a sensor.

This here, the principle operation of this sensor again the term conductometric is there that is in the presence of a gas, a certain element will change its conductivity and that happens with a certain technique where a catalyst is used and that catalyst reacts with the gas that is there on a surface and change the conductivity of the sensor element. Let us see the details of it and again whenever you have a sensor that you want to study, it is useful to make a chart like this.

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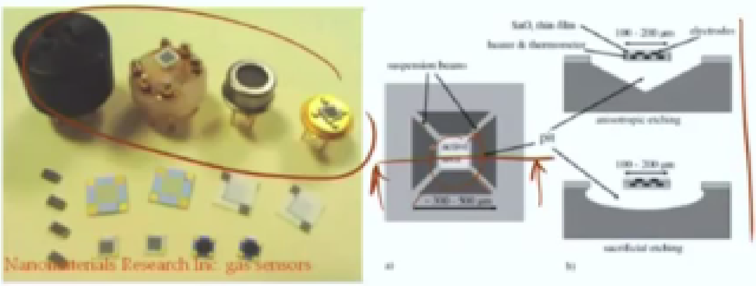
Conductometric gas sensors



Typical materials used: Films of metal oxide like SnO_2 and TiO_2
Sample fabrication process: Gas sensors are fabricated using the single crystalline SNO_2 nanobelts. Nanobelts are synthesized by thermal evaporation of oxide powders under controlled condition without the presence of a catalyst.

So, that the summary will stay in our mind as we compared different types of micro sensors. So, these are certain conductometric gas sensors made by nano material research incorporated. A number of gas sensors, some of these are just the chips; some of them are already packaged here. If you look at one of the chips, there will be a centre area which is active area over which a certain material, for example; either tin oxide or titanium oxide are deposited over this area which act like catalyst.

If there is certain gas that gas will be adsorbed on to this active area and change the conductivity by either introducing electrons into it or removing electrons that in the conductivity of this sensor which you can measure by measuring resistance just as we do in the case of piezo resistive pressure sensor, where this strain change, we measure the resistance.

Similarly, here we measure the resistance and related to the presence of the gas, it just does not say presence or absence, you can also tell you how much is there based on how much the conductivity of this element changes. This is the cross section of this sensor, where there is a suspended, if I take a cross section over here; it looks as if it is floating by just connected by the 4 beams like this.

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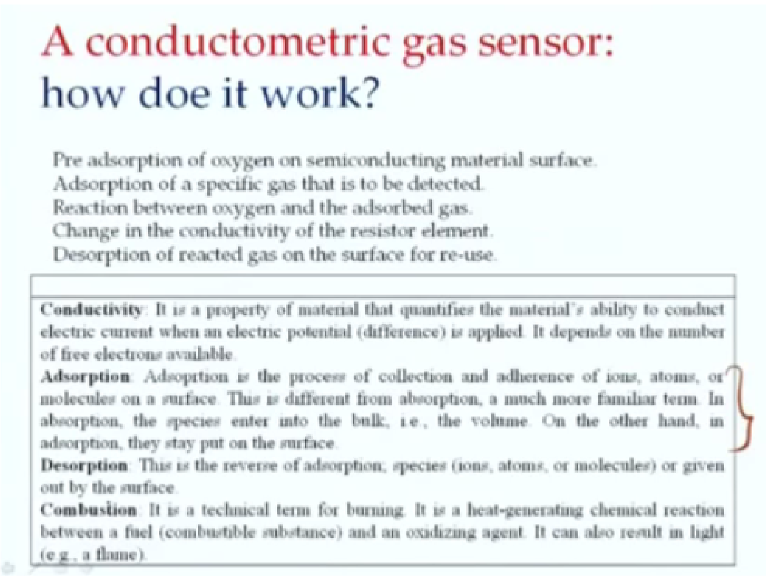

So, that it is isolated from the rest of the chip and depending on whether using anisotropic etching or isotropic etching, this cross section may look different but essentially what we need is an active area over which this catalyst can work and use the presence of the gas in order to change the conductivity of the sensor element. How it works? There are different steps; first in the case of particular conductivity gas sensor you pre adsorbed oxygen.

Adsorption is different from absorption; absorption with absorption is just taking it in; a adsorption is taking it in and keeping it only on the surface that is the term that is defined here adsorption or desorption is giving it away, so that once a particular gas species comes under the surface for it to be reused, it has to give it back, desorption is to remove back whatever was put into the surface.

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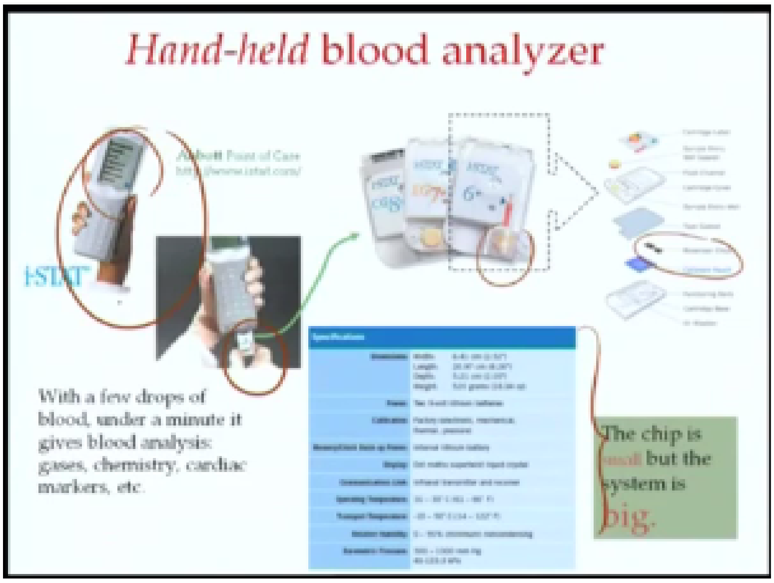

And in this particular case, first the gas gets adsorbed and that change the conductivity, you measure it after sometime, it will just remove it back as soon as the gas disappears the thing will go back into the environment and that is what will make it reusable and we can also have a blood analyser that is shown here which is handheld, we can imagine the size of it, it size of a TV remote.

And in this particular case, if you introduce a few drops of blood into a cartridge, that when expand it looks like this, a small cartridge which is a thumb, so it is about 3 or 4 thumb size and into that, there is a location where you will introduce a few drops of blood and analyse and give you about 50 chemical parameters that are there in the blood that means; that a lot of sensors are integrated into this.

If you were to take this further and explored it the bio sensor chips, a sensor that measures or detects some biological species, will be called a biosensor, that biosensor a lot of parameters can be sensed using this a number of biosensors chips that are there in this and finally that output can be displayed as it is shown here which appears like this on the sensor. For each sensing parameter, you need to define the sensitivity, resolution, the range, the band width all of these things.

And if you do perfectly all of those and package them it becomes a hand held blood analyser. The glucose, potassium, sodium or any other virus all of those can be detected if you put an appropriate sensor element into this system. So, a sensor can be very small whereas the system that you hold can be very big, so the chip is small as you can see here but the cartridge in the whole instrument might be big.

But compared to what we normally have for sensors for blood analysis, this is a hand held one, it still small and this can actually embed wireless elements in it, so you can actually transmit the data wireless means based on just a few drops of blood you put, and you get the data sent somewhere else almost instantaneously, in fact this gives you the 50 parameters within a minute.

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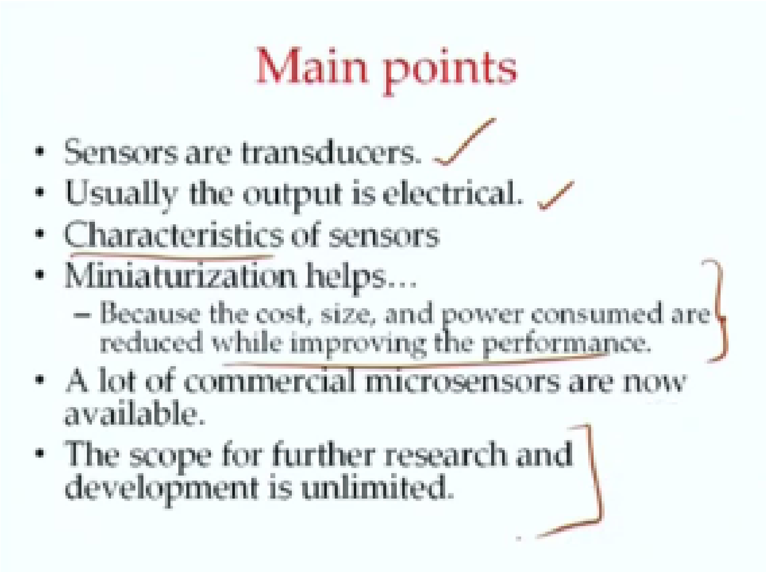

Let us summarise with the main points of today's lecture, where we talked about micro sensors. First, we noted that sensors are transducers, meaning that convert one form of energy to another form usually sensors the output form is electric meaning that we will sends any measurand whether it is acceleration, pressure or the presence of the chemical species or humidity or viscosity, it finally comes down to an electrical voltage or current, that is what we have here.

Another important to note most of the micro sensors, the output in them is electrical and we discussed a number of characteristics of sensors, sensitivity, resolution, range, bandwidth, hysteresis, full scale output and linearity, cross axis sensitivity and so forth, cross axis sensitivity refers to those sensors where the directionality is important. Let us say a microphone is also a sensor.

It senses the sound in which direction is sound coming from is also important. So, in this cases cross axis sensitivity is also important characteristic of the sensor and in all of these cases, one thing that was underlying the stack was that miniaturization helps, how does it help? It helps because when you miniaturization the sensor, the cost will be low because of the same reason that microelectronic circuits have much less cost compared to their macro counter parts.

Because the same process are used, a number of them are made in a single wafer, the cost per chip will come down and the size of course is small because of miniaturisation, so it you want a temperature sensor or a micro phone that goes into your mobile phone can be made very small or into some other instrument if you make the sensor very small is advantageous especially aerospace, you want to have weight reduction.

And there again miniaturisation helps and most importantly we use micro sensors, the power consumed will be very low because the sensor element is small, it does not consume much power in order to perform its function of transduction. It has to convert energy from one form to another form, for that it needs energy and power, that will be very low if you have a miniaturised sensor.

While the performance keeps going up that is another thing that we can achieve with miniaturisation where, when something that is made very small, where the electronics and mechanical element are close to each other, then you can get much better performance by limiting the noise that is there in the sensor element. We discussed a lot of sensors, many of which are commercially available today where they have replaced the macro counter parts.

For example, accelerometer that is used in the cars for deploying air bags in the event of a crash, you need to detect the deceleration when the crash happens or the car suddenly comes to a stop, there you can use a macro accelerometer, which are been around for a long time but micro one is preferred because it is first of all cost much less and has better performance and is not going to add to the weight of the car or in space craft, it is even more important.

And commercial micro sensors are replaced in the macro sensors gradually. A lot of research is needed and the development here, as the scope for research is almost unlimited because just about any sequence if you want to measure, can be done using miniaturisation. Thank you.