MEMS & Microsystems
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Lecture No. # 02
Introduction to Microsensors

So, in my last lecture I have introduced the course MEMS and microsystems. So by now, you know that in MEMS and Microsystems, one of the important blocks is the sensor block. And in today's lecture, I will highlight the sensor and I will introduce sensor. Then we will go to the microsensor and different aspects of sensor, its specification required and its technological aspects. All these things I will discuss in today's lecture. And sensor is a very important device and now with in microsystem we use microsensors. And I will discuss what is microsensor and in particular MEMS and microsystem, we normally use semiconductor sensors and again why semiconductor sensors because, semiconductor materials are used in many ICs and VLSI.

So if I can make the sensor out of the semiconductor material, then it will be easy for us to integrate both the sensor part and circuit part together. And that is why lot of sensors are coming out making use of semiconductor materials. And first let us see what sensor means. And sensor basically is a word coming from a Latin word sentire.

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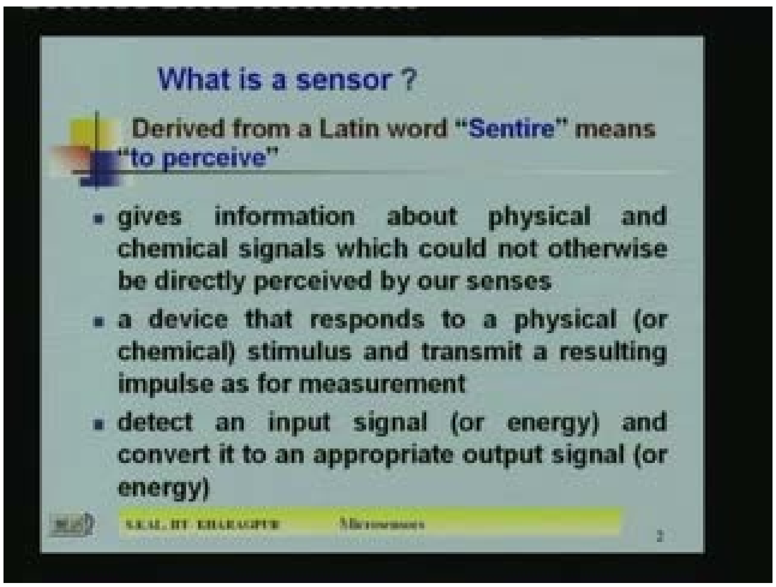

And that means to perceive, that is derived from Latin word sentire and lot of definitions are given for sensors. Basically it gives information about the physical and chemical signals which could not otherwise be directly perceived by our senses. And some people define sensor is a device that responds to a physical or chemical, some stimulus and is transmit a resulting impulse as per measurement. That means some physical thing which cannot be measured; it has to be converted into some measurable quantity. Then only we will understand how the sensor is behaving and how the sensor is sensing. Until and unless we detect and measure the output, then there is no meaning of that particular sensor. It detects an input signal, that signal obviously in some form energy and it convert it to an appropriate output signal which can be measured and which is taken as output. That is the main job of sensor.

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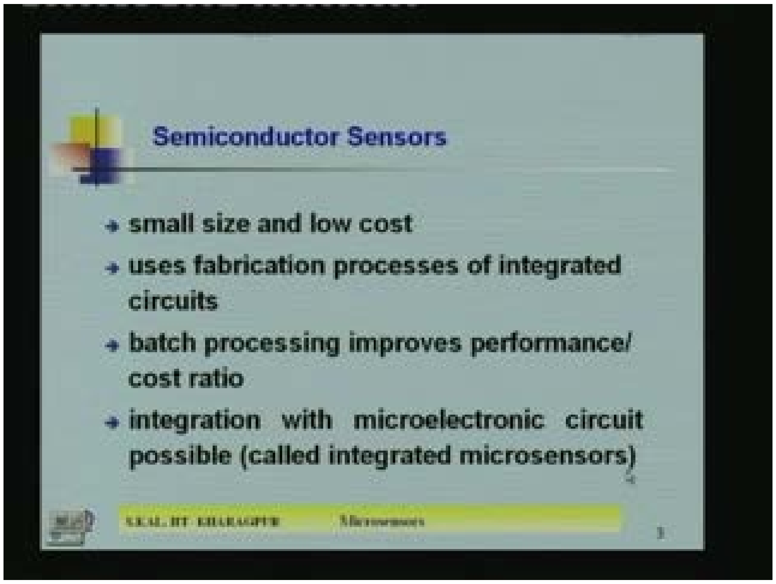

Now, the microsensor and semiconductor sensors, we are dealing with microsensors which are based on semiconductor material mostly they are small in size and low cost. That is one advantage. They use fabrication processes of integrated circuits or VLSI, that is a very good advantage and another thing if the semi as like ICs the semiconductor sensors can be batch fabricated. And batch processing improves performance as well as cost ratio. And that is why people are now giving lot of importance on semiconductor sensors. And at the end, it integrates with microelectronic circuit as I mentioned few minutes back. That is why this is coming up in a big way and then this particular sensor is called integrated microsensors or sometime it is called smart sensors.

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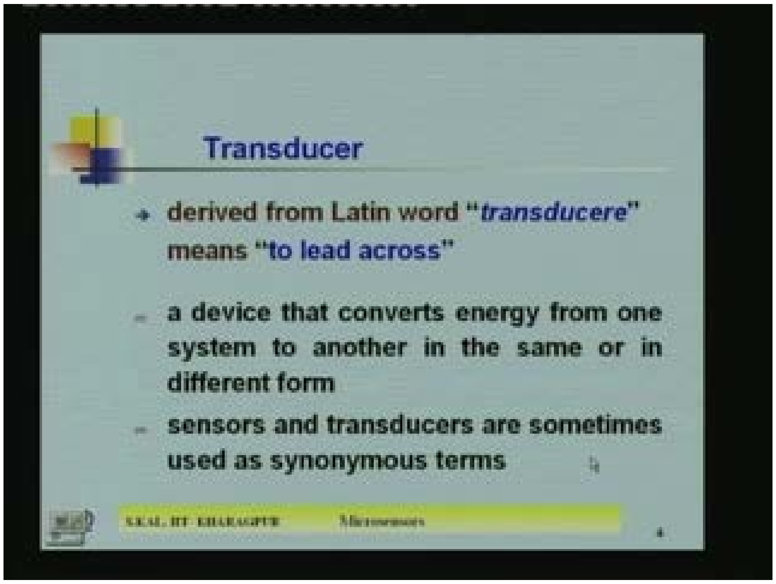

Now, another block which is always sometimes known as the transducer and sometimes some people confuse between transducer and sensor. Basically both sensor and transducer are synonymous form. And transducer word is again derived from another Latin word which is known as transducere and that means to lead across, a device that converts energy from some system to another in the same or in different form. So you see transducer normally transfer the energy from one form to the same form or in another form. That means if the sound, if we apply at the input energy as a sound energy, then transducer output will also be sound energy. Then it is called sound energy of this different magnitude so that we don't call a sensor.

For example, amplifying device, its input signal is electrical signal and its output signal is also electrical signal, so then, the same form of energy is obtained at the output but with the different magnitude. So that amplifier is not called a sensor. But on the other hand, a microphone is called a sensor because there at the input energy is sound energy or acoustic energy and output energy is electrical energy. That means the input and output energy are not same and they are different. So here is the little bit difference between a sensor and transducer. That means on the other hand, we can say all the transducers are sensors. All these sensors are transducer but all transducers are not sensors. Isn't it? So just like if you compare the example of the microphone and also the amplifier then it is clear.

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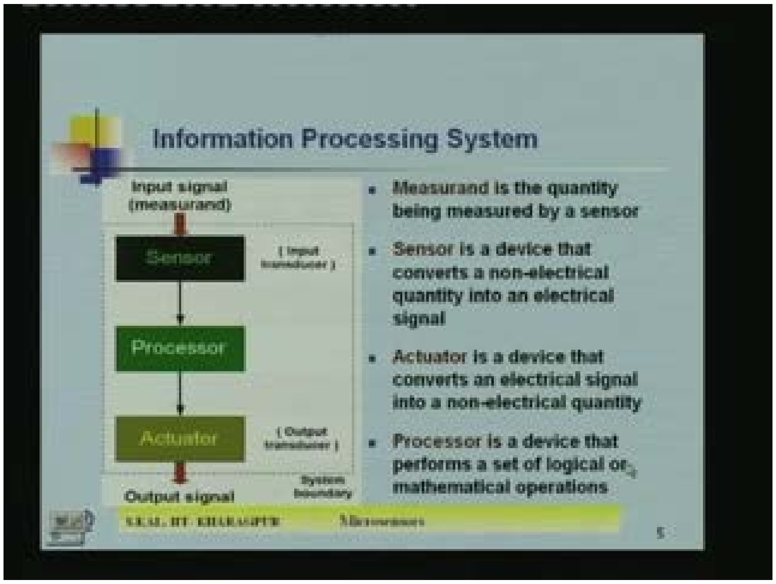

Then a information processing system where sensors are used. So in information processing system, there are three blocks and they are known as sensor, processor and actuator. So input signal which is a measuring quantity, so that is coming to the sensor and that is the input transducer and then the sensor converts the input signal into another form which can be given to processor and that form of energy is to be processed by the processor. So that means, normally processor deals with electrical energy. So the sensor must then convert non electrical energy into the electrical energy. So that in the next block which is a processor block and that block can process the output of the sensor signal. And the other block after processor is the actuator. So actuator is a device that converts an electrical signal into non electrical signal. For example, if the acoustic energy is transmitted in a PS system, then at the end of it you have to get back the acoustic energy.

So in between you can process the acoustic signal by different blocks and those building blocks or electronic blocks like amplifier, like mixer, like filters, those are there to get back the original energy. That is say acoustic energy into again acoustic energy but in amplifier fashion or free of noise etcetera. So then, the actuator means, always it is at the output side of the information processing system and it gives the output signal and that output signal is perceived by the people. That means, sensed by the people and from there they will understand the quality of the input energy. So now, these block sensor processor and actuator together, they form information processing system or sometimes it is also known as a microsystem.

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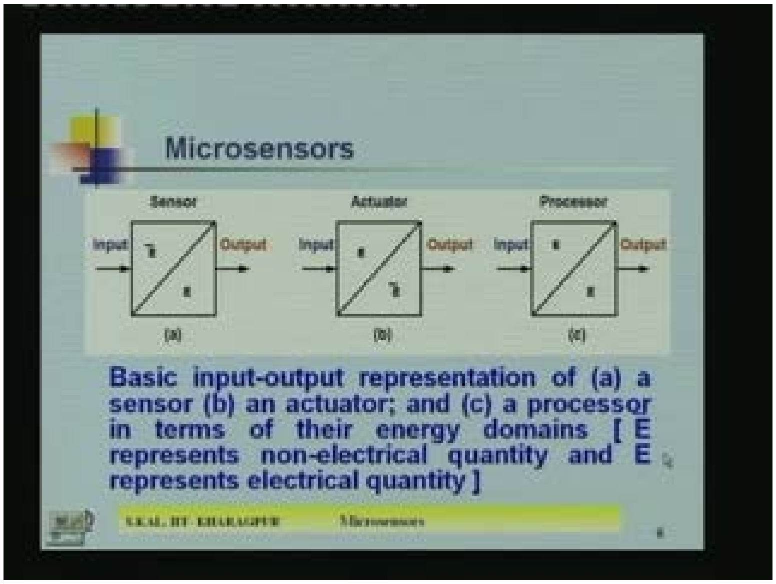

Now the microsensors, if you look into the building block of microsensor, then we can say here. You see sensor input and output, there are two parts. Here you can see the E, is the energy one form of energy, E bar is another form of energy and E bar represents the electrical quantity and E bar represents the non electrical quantity and E represents the electrical quantity. So the sensor basically converts the non electrical quantity into its electrical quantity. Then another block is actuator. The actuator input is electrical again and output may be non-electrical. Non electrical means it may be mechanical energy, it may be acoustical energy, it may be optical energy, it may magnetic energy. So input is electrical, that is the actuator block and the other one you see here is the processor block. There you can see the input is also electrical and output is also electrical. So a processor changes input which is electrical form to output which is also in electrical form, but, may be the amplitude or may the frequency change at the output. Depending on the block which you are going to use it, so these are the three blocks we transform some quantity of energy into other form of energy.

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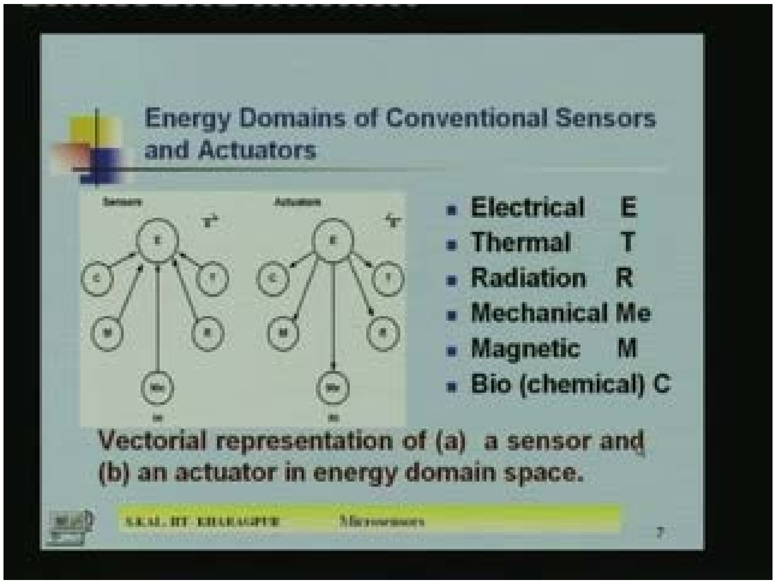

Now, again what are the different forms of energy, the sensors and actuator deals? They are mainly the electrical, thermal radiation, mechanical, magnetic and biochemical energy. Now the electrical, here is denoted by the word E, thermal is a T and R is a radiant energy, Me is a mechanical energy, M is magnetic energy and C is biochemical energy. So all these energy is at input and they transformed into electrical energy that is the job of the sensor. Now on the other hand here, vectorial representation of actuators is shown in the figure b. So here, the actuators get electrical energy then it converts it into either chemical energy or you see magnetic energy or mechanical energy or radiation energy or thermal energy. This is the vectorial representation of sensors and actuators.

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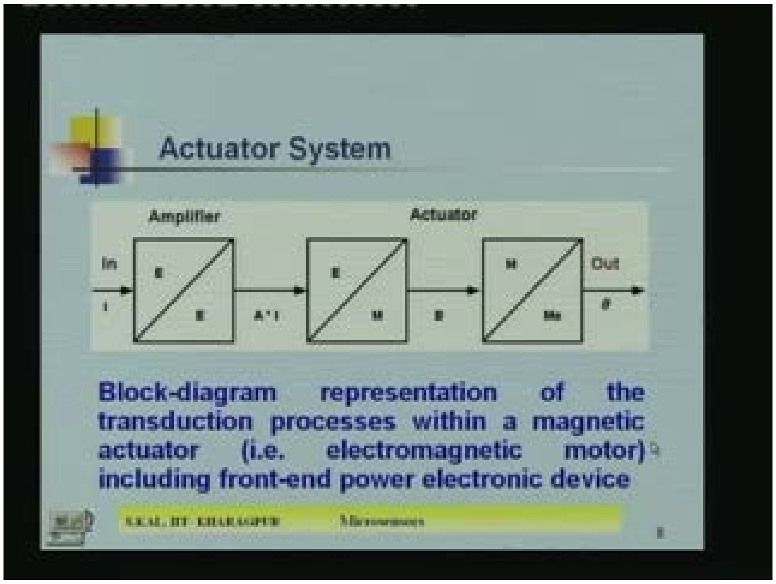

Now, the actuator system is shown in this particular diagram. So in the actuator system, the actuation means it will act something, some either mechanical or some motion or movement or some colour change or light intensity change something will happen there. So for that first the whole system is again can be sub divided by different blocks. For example, first block is an amplifier where the input is also electrical energy and output is electrical energy. If I is the input so output you are getting A star I. A is the amplification or gain. So now this is fed into another block which A star 1 is basically electrical quantity, so the electrical quantity is getting but output is getting magnetic energy. So electrical to magnetic, it changes. Now these magnetic energy is fed, that is the B is the magnetic flux so that is fed into another block which takes it to the magnetic energy. But its output is a mechanical energy with vibration or motion or displacement or whatever it is.

That means from electrical to basically the mechanical motion displacement from vibration, that conversion sometimes it needs another block which changes from electrical to magnetic energy. In some cases, there are certain materials which directly from electrical can be converted into mechanical vibration and most on those you know is a piezoelectric material. So input if you apply the electrical energy, electrical field and output you will get the mechanical motion or vibration and in this short of crystal, but not always. If you do not use piezoelectric crystal, then you have to use some intermediate block which can converts into a magnetic. And then magnetic energy can easily converted into vibration or displacement something like that. So that is the block diagram representation of the transduction processes within a magnetic actuator.

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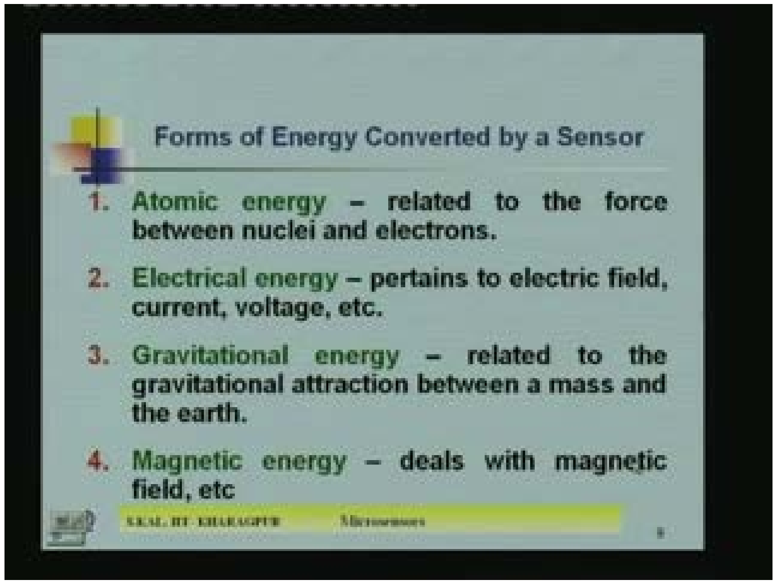

Now, what are the difference forms of energy converted by sensor? Those forms of energy are many. One is atomic energy, electrical energy, gravitational energy, magnetic energy and so on. So atomic energy relates the force between nuclei and electrons. So, that is the atomic energy. Electrical energy pertains to electrical field current or voltage. Gravitational energy it is related to the gravitational attraction between a mass and the earth. Similarly magnetic energy deals with magnetic field.

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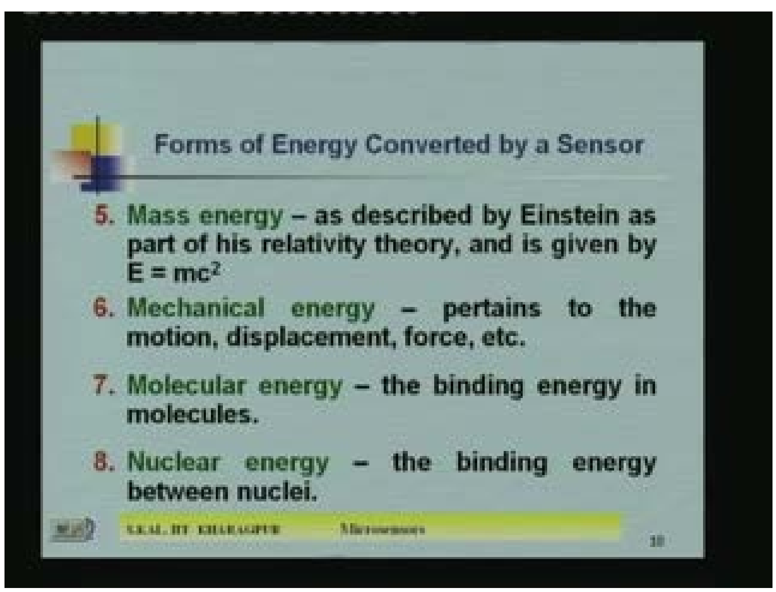

So other forms of energy are mass energy, mechanical energy, molecular energy and nuclear energy. So mass energy described by Einstein and you know if mass is m, so energy equivalent of m is mc square, where c is the velocity of light is the same as Einstein equation E equal to mc square. And mechanical energy pertains specifically to the motion, displacement and force. So those are mechanical energy. Molecular energy is basically the binding energy between the molecules is known as the molecular energy. So nuclear energy is the binding energy between two nuclei. So you can get the distinction between molecular energy and the nuclear energy. So molecule to molecule, that binding energy is molecular energy. And nucleus to nucleus, that binding energy is called nuclear energy. And atomic energy is electrons with the nucleus. So those three energies little bit slight difference, all are related to the molecule structures, means atoms, nucleus or molecules.

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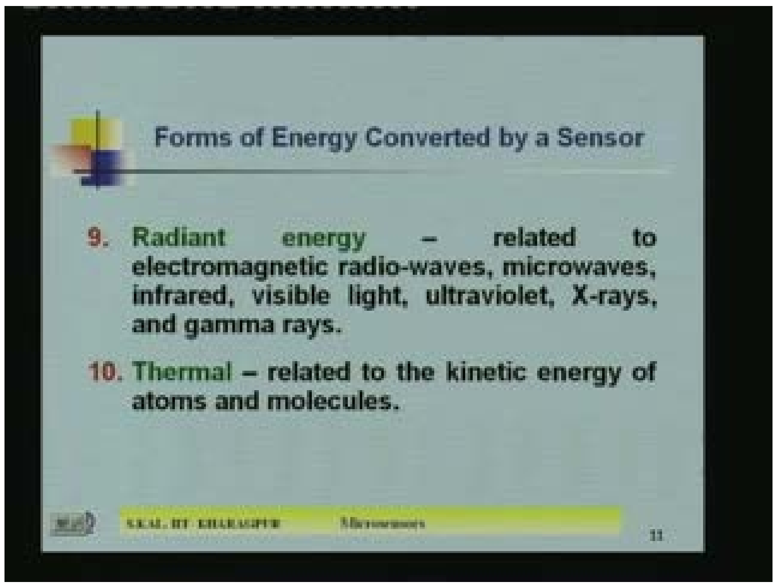

Now, other forms are also there; radiant energy and thermal energy. Radiant energy related to the electromagnetic radio waves, microwaves, infrared visible light, ultraviolet, X-rays and gamma rays, those are radiant energy. Many of these energies are available in space. So radiation, some sensors are required infrared detectors or nuclear radiation how much is coming from the space. So we have to know what are different forms of radiation available in space. Accordingly, utilizing the physical property of the materials we can design the sensor. And the last form which is shown here is a thermal energy. Thermal energy related basically to kinetic energy of atoms and molecules. You know the kinetic energy increases means its energy in kinetic increases, means the temperature of that body also increases. So it is directly related to the kinetic energy. Thermal energy is related to the kinetic energy and with the absorption of the radiation or absorption of light, the kinetic energy may increase and as a result of it, the reflection is temperature of that body increases. So these are the difference forms of energy we come across and accordingly, we have to make sensors depending on or based on the properties of different materials.

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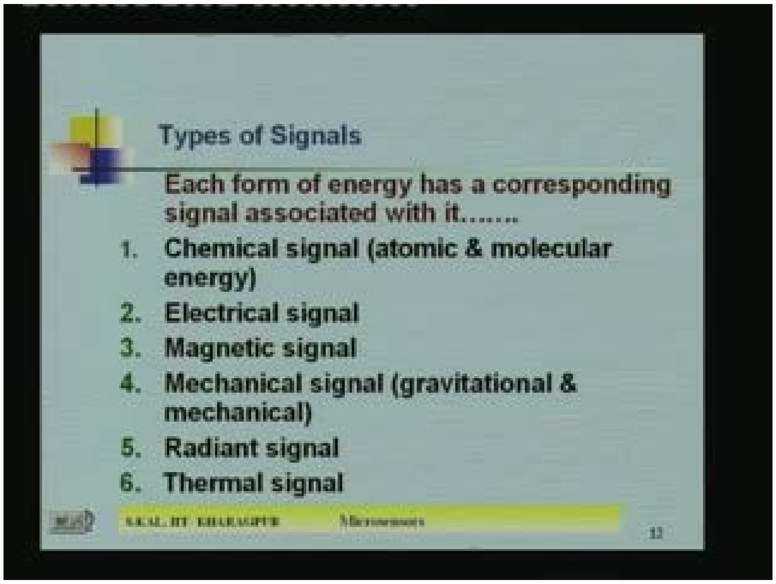

Now, what are the different types of signals we deal? Each form of energy has a corresponding signal associated with it. And those are chemical signal that is basically atomic and molecular energy, electrical signal, magnetic signal, mechanical signal which are gravitational and mechanical, radiant signal, thermal signal. So these are different signals we are getting and those signals are fed into your sensor system.

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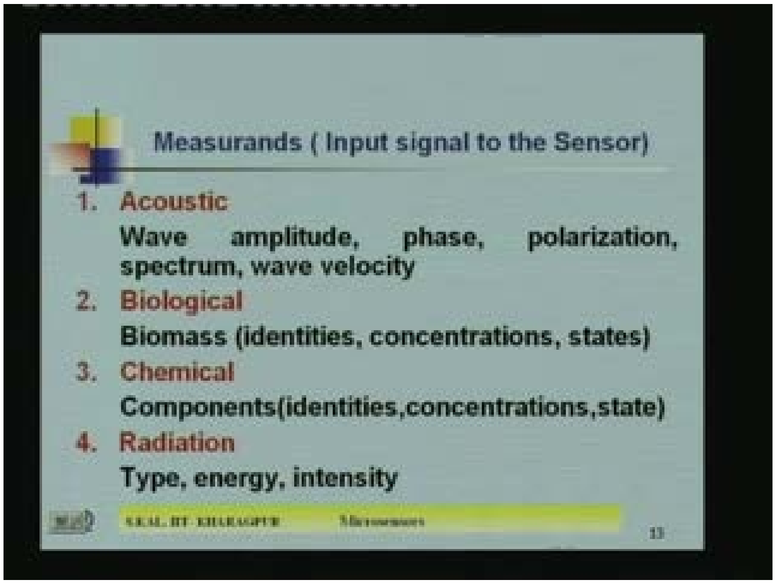

Now, what are the measurands that is the input signal to the sensor? The measurands are acoustic level of the acoustic, energy you want to measure sometimes. And what you mean what basically parameter of the acoustic energy you are going to measure? Those parameters are many. Those are basically wave amplitude of the acoustic signal, phase of the acoustic signal, polarization spectrum and wave velocity. These are the various parameters of the acoustic signal. Any of the parameters you can measure in your sensor. You can measure the amplitude, you can measure the phase, you can measure the change of polarization of that particular signal or you can change the wave velocity or the frequency change which is basically coming from the frequency spectrum.

Now another form is a biological measurands and what is the biological measurands? That is basically the biomass. Biomass means that is, its identity that is in a biological material put at the different components, there that is its identities, then concentrations. For example in a biological blood, lot of constituents is there. They are how much is your fat or cholesterol, that is the identity, how much is a creatinine, that is an identity, how much is your sugar that is another identity, what is your urea; those are basically the biomass identity. Then concentration what is the level of that particular identity, that means in a 1 milligram, how much is that particular amount or what is the concentration of that particular chemicals into a identity in a biomass, that is the concentration and what state it is lying there in the biological body. So those are the few things which we have to measure either all of them or any one of them. So that accordingly your sensor is to be designed.

Then third one is a chemical. Chemical again the components like the biological that is identities concentration and state. That means the identities means whether is an alkaline in chemical whether it is alkaline or is acidic. So if is alkaline, how much it is alkaline? If it is acidic, how much it is acidic? So those are the concentration or in a particular chemical solution what is the concentration of the solution. For example KOH solution which is frequently used in MEMS and micromeasuring labs MEMS laboratory and how much percentage of KOH your are taking that without that is not the composition of individual identity. That means the water and that particular the material in what ratio it is mixed into the solution and which state this particular chemical is lying. So, all those things are to be known before we are going to use those particular chemical in either the sensing or actuation or in any processing side.

So other is the radiation and radiation means which type of radiation and its energy and intensity. Type of radiation means whether it is a alpha ray or beta ray or gamma ray or it is ultraviolet ray isn’t it? or it is infrared ray. These are radiation, its type energy and intensity that means how strong is the radiation. And that is the intensity you are getting. Then from that particular intensity how much energy you can get. So the energy is and intensity is different. For the same intensity the energy may be different. So that is why the type energy intensity, these are the different components of any radiant signal or radiant energy.

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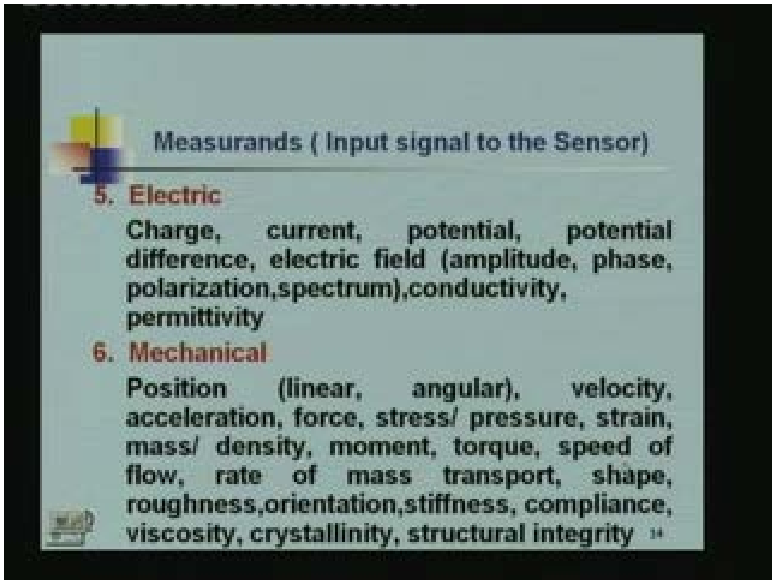

Now, another one is electric. So electric means there a lot of measurands in electrical energy. What are those measurands? Those measurands are charge, current, potential, potential difference, electric field means its amplitude, phase, polarization spectrum, and spectrum means here frequency is also there in spectrum then conductivity, permittivity. Those are the different measurands in an electrical signal. Your sensor can measure or can identify the chart, your sensor can measure the current, your sensor can measure the frequency change of that particular electrical signal or it can measure the conductivity or permittivity.

So these are the different measurands and all are electrical say all belong to the electrical signal but measurands are different. And another one is the mechanical energy or mechanical signal. It has got enormous number of the measurands like position means what do we mean by position? Position means it is a linear moment or angular both called as a position, then velocity acceleration, force, stress or pressure, strain, mass or density, moment, torque, speed of flow, a rate of mass transport, shape, roughness, orientation, stiffness, compliance, viscosity, crystallinity, structural integrity, so all these are the measurands. So those all belong to the mechanical signal or mechanical energy all are.

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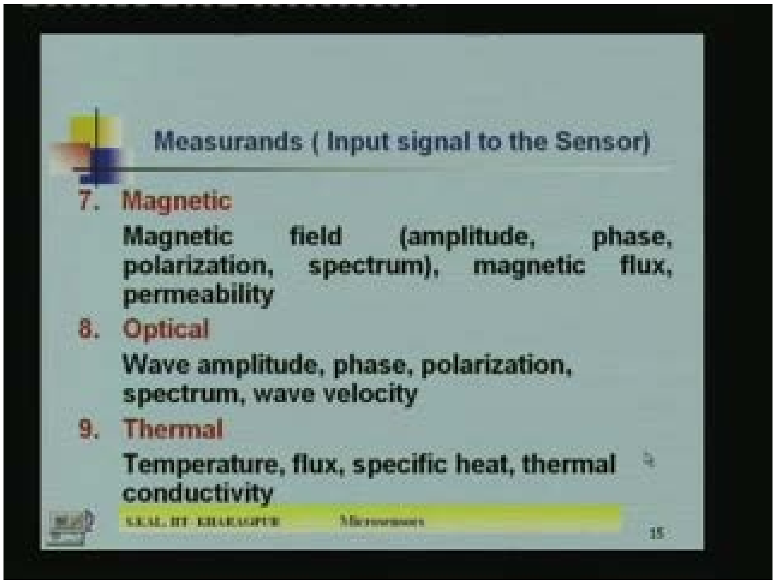

Now, magnetic what are the measurement measurands? Those are the magnetic field means again coming the amplitude, phase, polarization and spectrum, magnetic flux and permeability. Next one is optical and what are the measurands in optical signal, wave, amplitude, phase, polarization spectrum, wave velocity. Those are the various kinds of optical signal and many of the optical sensor they the show the change of polarization. Many of the optical signal they show the change of frequency, optical frequency, optical sensor, and many of the optical sensor they show the optical intensity.

So there are certain optical sensors are available when the intensity of the input signal is beyond a certain limit, then some activation will be done some switch is on. And and if it is below that level the switch is off that is one kind of that we depends on the intensity. Another is the optical signal as soon as is it incident on particular sensor then what will happen? It will say photo detector. So optical signal is there and at the output you can get some electrical signal that electrical signal can be used for some other controlling or some other activation. So these are signal, the input is optical but what you are using there, that is optical amplitude. Whatever the amplitude is it is falling there it works. And phase is also used sometime thermal and a thermal energy, its measurands are temperature flux specific heat thermal conductivity these are belong to a thermal energy.

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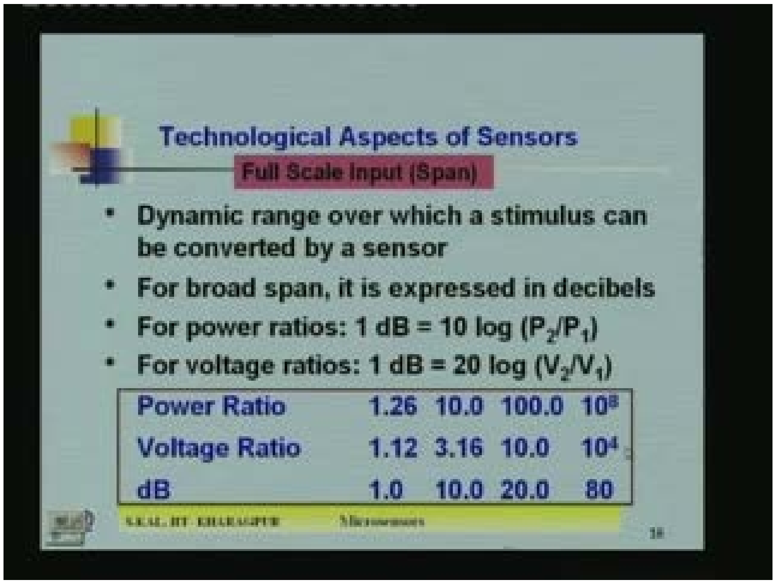

Now, the technological aspect of the sensor is a very important and there are lots of parameters which specify a particular sensor. And these parameters but it basically qualify a sensor whether it is good or bad. That means when you will choose a sensor for your particular application, you have to find certain parameters and you have to judge from that parameters whether that particular sensor serve your purpose or not. So those parameters, how these are control? How those parameters are defined? And how their parameters are achieved in fabrication? Those things have to be kept in mind when you are going to design a sensor and or when you are going use a sensor. And one such parameter is full scale input. Another is full scale output and another parameter is offset, linearity and stability, hysteresis these are the different parameters one is to look into before selection of a sensor.

Now let us discuss little bit on full scale input or span. And here is basically the dynamic range over which a stimulus can be converted by a sensor. For broad span it is expressed in decibels. That means full scale input means what is the range of the input which the sensor can sense or output you can get it. That is the full scale input or its known as the span and normally it is expressed in decibels if for power ratio you know the definition 1 dB is still log P 2 by P one for voltage ratio is 1 dB is twenty log V 2 by V one. For example if the power ratio is 10, so we have the decibel it will be 10 dB and is a power ratio is 10 to the power 8, so the decibel it is 80 dB. So that it’s come from this relation if the voltage ratio is 10, so the decibels it will be 20 log V 2 by V 1 that is 20 dB. This is the normal unit by which a full scale input is expressed.

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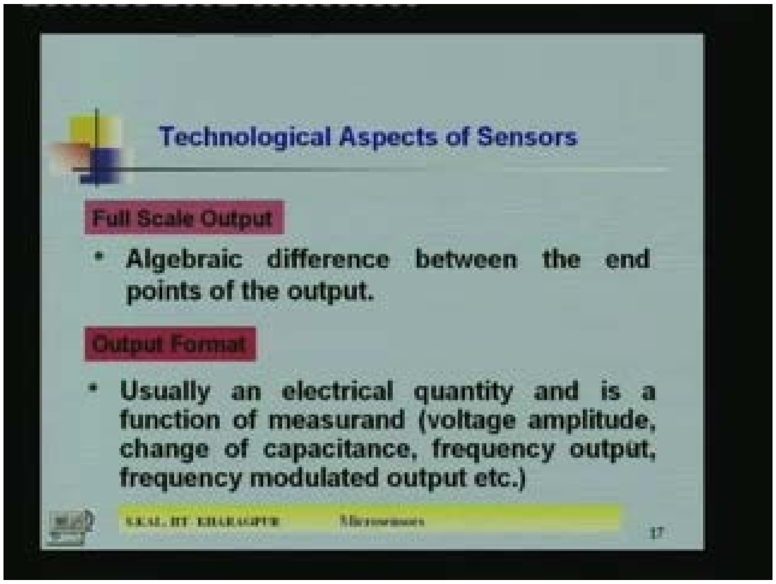

Now the second technological aspect of sensor is full scale output that is basically the algebraic difference between the end points of the output. That is the full scale output and output format also you have to see what is that? That is usually an electrical quantity and is a function of measurand that means whether the output format is in voltage, it may be in voltage amplitude, change of capacitance, frequency output or frequency modulated output. So these are different output formats you can get it a from a sensor and the full scale is the minimum to maximum output you can get that is the total full scale and that is also a parameter which you have to look when you are selecting a certain sensor for certain application.

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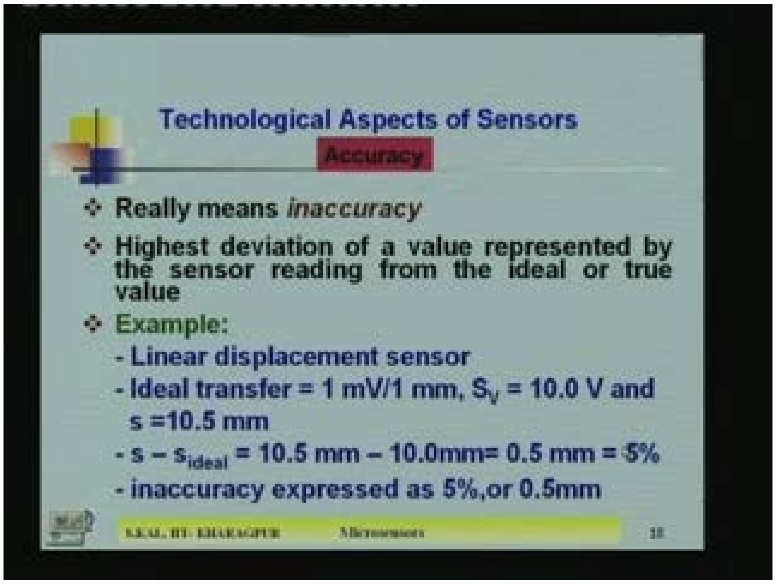

Now the other one is accuracy. How much how accurately a sensor can measure the input measurand. Basically it is in inaccuracy, although we had calling it in the accuracy of sensor, is basically the highest deviation of a value represented by the sensor from the ideal or true value. And an example is given here. For example you are going to measure the linear displacement. An ideal transfer is 1 millivolt 1 millimeter. For example, for 1 millivolt if we apply the displacement is say 1 millimeter that is the ideal transfer. Application of 1 millivolt, the displacement is 1 millimeter. Now if we apply in a certain sensor, the input voltage is 10 volt and your observed displacement is 10.5 millimeter. So in that case, what is the difference between the observed and an ideally you should get 10 volt means you should get 10.5, but 10.5 minus 10 is a 0.5 millimeter is the deviation so 0.5 millimeter in 10 millimeter so that means it is 5 percent. So inaccuracy is here 5 percent. So now inaccuracy is expressed as 5 percent or 0.5 millimeter. That is basically how the inaccuracy or its other word is accuracy is defined in percentage.

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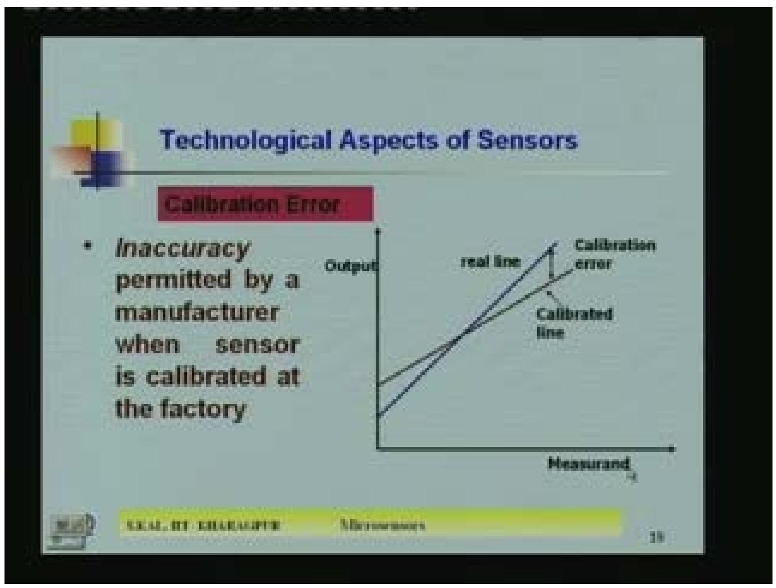

So now the other one parameter is a calibration error. So calibration error is basically the inaccuracy permitted by a manufacturer when sensor is calibrated at factory. You look from this curve where the real line is here which is basically given by the supplier from the factory. Now here if you calibrate it with some known signal at your laboratory, you are getting this line. So obviously, it deviates from the real line. So from the real line to your measured at the laboratory. So that is the calibration error. So whatever calibration has been made at the manufacturer side is not same when you are going to measure it. Why because, during the transportation or during the packaging or during the aging, so that calibration error may change, calibration line may change and that means it is not highly stable. So that means when you see the calibration curve at your laboratory it deviates from your original which has been made at the manufacturer side, may be long time back.

So that is the calibration error that you have to measure before you put the sensor in your system. And let us now see what are the other parameter which you look, that is hysteresis. Hysteresis is another important parameter. So hysteresis the word is familiar where you have studied in the magnetism, magnetic hysteresis as you know it. Similarly, the hysteresis is also there in any form of energy, in any form of sensor. That means when you go on measuring the measurand by a sensor and if you go on increasing the input measurand, so you are getting the output in an increasing way. Now you come to a limit, what is the maximum limit you got it, and then you decrease the measurand and see the output. And you will find the curve will not follow the same path. When increasing mode and when you are coming in the decreasing mode it different path follows. If you plot the input and output curve the difference of path gives the measure of the hysteresis.

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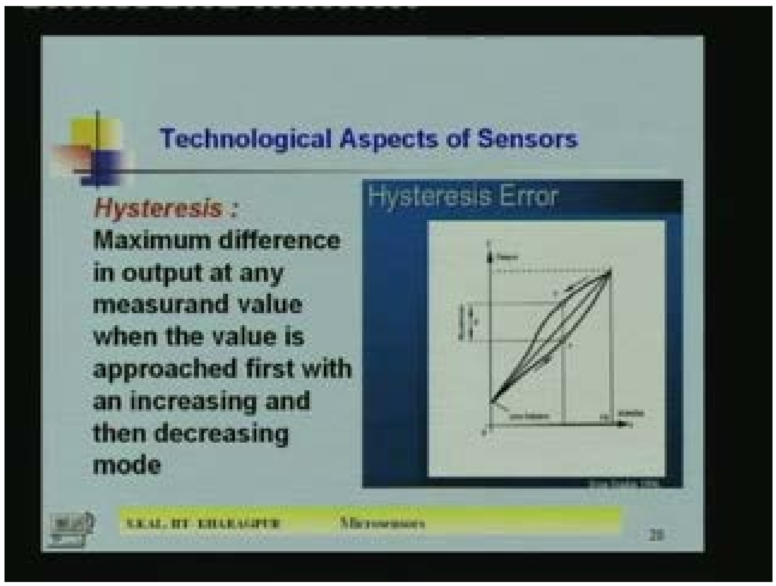

And here if you look into the picture, there you will see here, this is the curve which follows if you go on increasing the stimulus from low value to high value. Similarly if you from high value from full scale is here, this fs means full scale point, if from the full scale point if you reduce it the stimulus then it follows a different path. Now if you take the difference for the same stimulus you see, it is the same stimulus is here. Here is the point x and here is the point y, difference between the x and y which is the hysteresis. So this hysteresis for an ideal sensor is not desired. Here, I may have mentioned that different this hysteresis is a property of material. Different material has got difference hysteresis property.

For example, silicon has got minimum hysteresis. That is why silicon is one of the chosen materials for sensor. For magnetic material, so manganese, so iron or nickel there, this hysteresis quantity is more. So you have to take care of that problem because, always a sensor does not work, the stimulus will increase in always, some time you have to measure when stimulus input stimulus is decreasing also. Then is already the sensor in some other higher state so then it will not give you the actual reflection of the input stimulus. So that is why it is very important.

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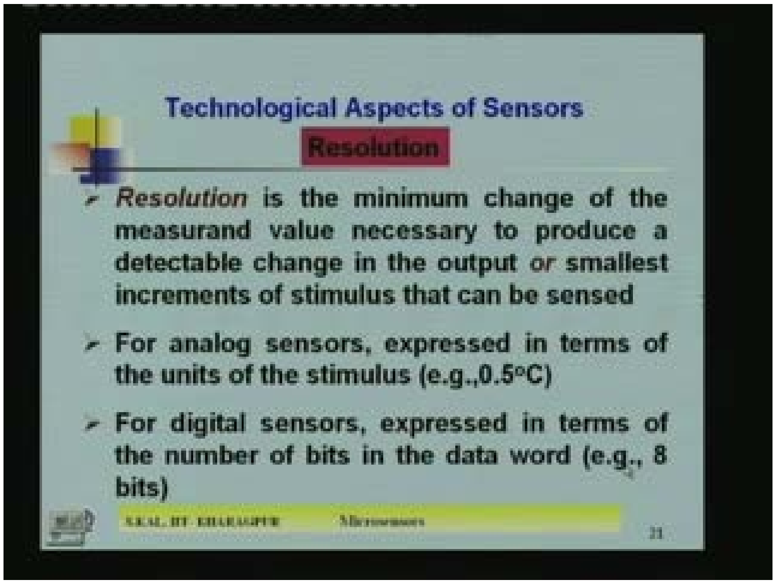

The other parameter which you have to take care is the resolution. So resolution is the minimum change of the measurand value necessary to produce a detectable change in the output or smallest increments of stimulus that can be sensed that is the resolution. What is the minimum amount of input signal which can give you a detectable output at the desired energy level which you were looking for? So that is the resolution. So, resolutions for analog and digital sensors are different. Obviously for analog sensor this resolution is expressed in terms of units of the stimulus. For example, in a thermal resolution may be 0.5 degree centigrade or 1 degree centigrade or may be 0.2 degree centigrade. In case of the electrical, it may be resolution say few micro volts or few millivolt like that. But if you look into the digital sensor, then the resolution is expressed in number of bits in data word. For example say 8 bits or 10 bits like that. So that is the resolution in case of digital sensor.

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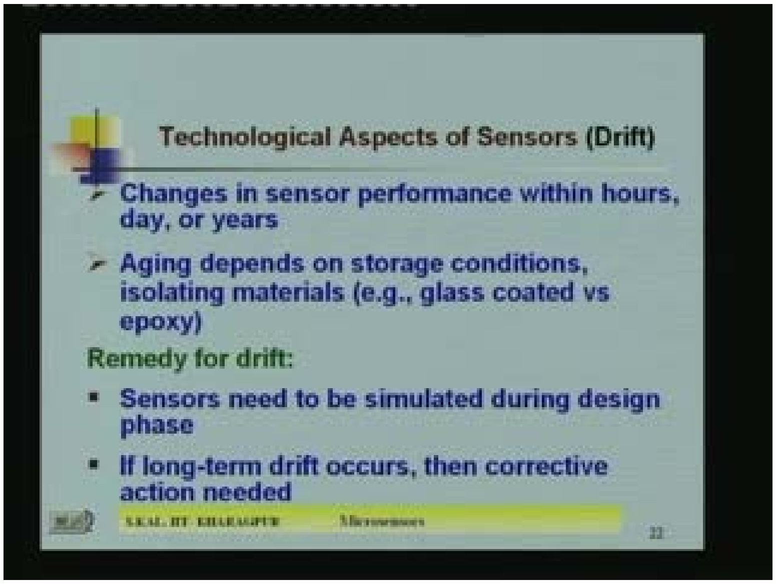

Now, the changing sensor performance within hours on days is also there because performance may change which is known as a drift. So today you measure certain input stimulus using your sensor. If you measure the same input stimulus tomorrow or 1 month later, 1year later, same sensor can give different output. That means that sensor has got drift its property has changed. Also the aging that means it depends on aging, so this aging depends on what? Why after aging after long time the performance is changed? It depends on various parameters. One is a storage conversion and another is isolating material. What is isolating material means, after fabrication of the sensor, if you cover the sensor with, you if you cover means, if you coat or if you put a passivation layer and if the passivation layer if you put a glass or if you put an epoxy, then you will find the aging effect will be different. Because you see with aging your sensor material is coming across the environment.

An environment has got lot of gases and chemical vapours and with those gas and chemical vapour the reaction will take place with sensor materials. And its property may change but if you passivate it with proper material so that it isolates, what isolates the sensor materials and device will isolate from the environmental hazards then the drifting may not take place. So that means one of the cause of drifting is how you are isolating the device. And another is the storage condition. And there are certain senses which are highly sensitive to humidity. Some sensors are highly sensitive to temperature then you have to follow the storage condition. And in some cases the sensors will perform best at certain humidity level and certain temperature level, you have to preserve the sensor in that level. If you do not follow that, obviously the drifting will take place. You cannot prevent it.

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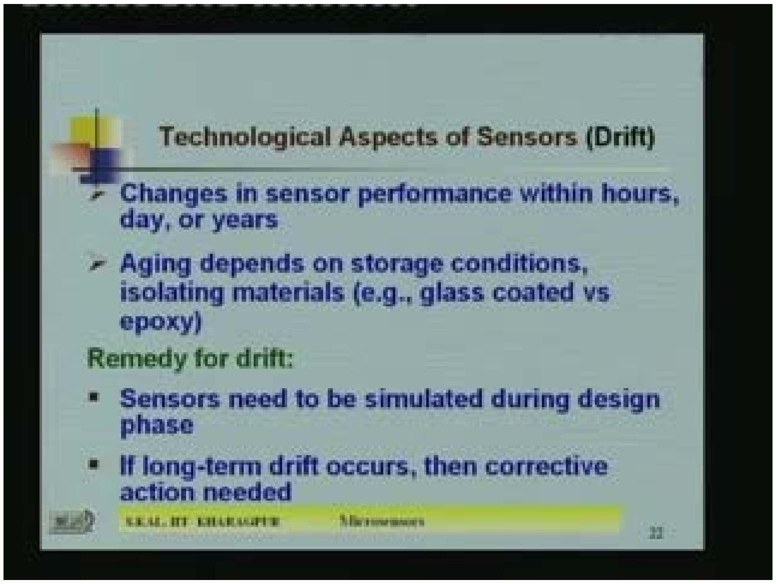

And so obviously what are the remedies for drift? There are few remedies one senses need to be stimulated during design phase, need to be simulated not stimulated the sensor need to be simulated during design phase. That means they are by simulation what are the changes can take place, say little bit temperature rise or little bit humidity rise that you can stimulate. What are the effects of change of temperature and various parameters? What is the effect of increase of the humidity on various parameters? From there you can stimulate its properties, output properties and then you can actual design phase you can change something so that drifting will be less. And if long term drift occurs then some corrective action is needed. That means you have to calibrate the sensor time to time. So these are remedies for drift.

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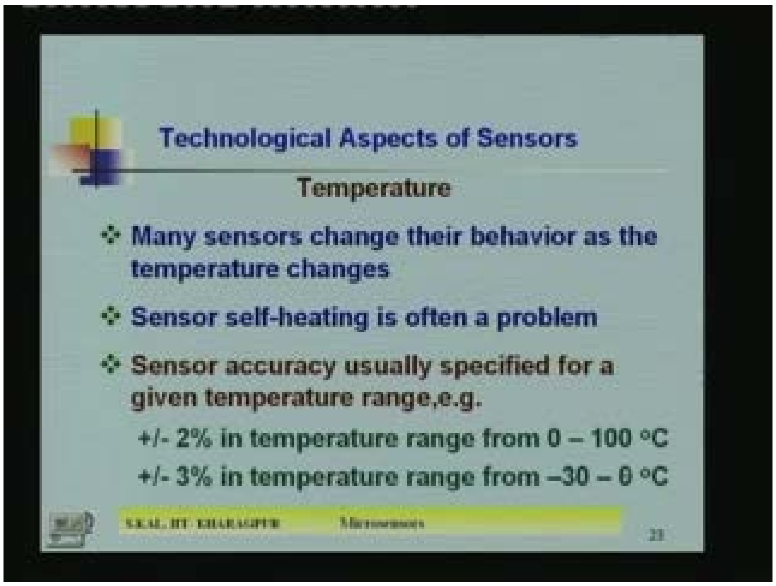

Next one is the temperature. Many sensors change their behavior as temperature changes. Because, many of the materials which are used in sensors, their properties are dependent on temperature. That is why the complete output performance of the sensor changes with the temperature of operation. Another is a self-heating. So, some of the sensor will work if you apply some electrical power. So, if you apply electrical power to the sensor, automatically some current will flow from through different components of that particular sensor, so a self-heating is there. So because of the self-heating the parameter property may change also. So that is, these are the cause which changes the sensor performance. Sensor accuracy usually specified for a given temperature range. For example, for 0 to 100 degree centigrade temperature range, so it may here plus minus 2 percent variation may be there.

Similarly minus 30 to 0 degree plus minus 3 percent variation is there. So that is mentioned when a manufacturer is marketing a particular sensor, what is the temperature variation of those sensor. Here, this example is given to inform you that the temperature variation or the performance of the varia performance change of the sensor is not same in different temperature range. Some sensors are highly sensitive at very low temperature. Fluctuation is more. Some are highly sensitive or its property changes drastically at very high temperature. So, the temperature variation or temperature drifting or thermal drift may vary at different temperature range and that is mentioned in the manufacturers the data sheet of any sensor. Now the other is the reliability. So when you are picking up a sensor for certain application you must look for the reliability how reliable it is.

So that means it will show you the ability to perform a required function under the stated conditions for a stated period. So conditions are known and how do the sensor perform, so that is the reliability. Same conditions if it gives you different performance on different dates or different situation then its not reliable. Specified as a probability the device will function without failure over a specified time or number of uses. That means reliability with respective to time, reliability with respective to use. That means, the reliable to with respect to use means, frequent use if you make and after that if you see is the same input is not giving the same output that means not it a time failure because with time the reliability is lost.

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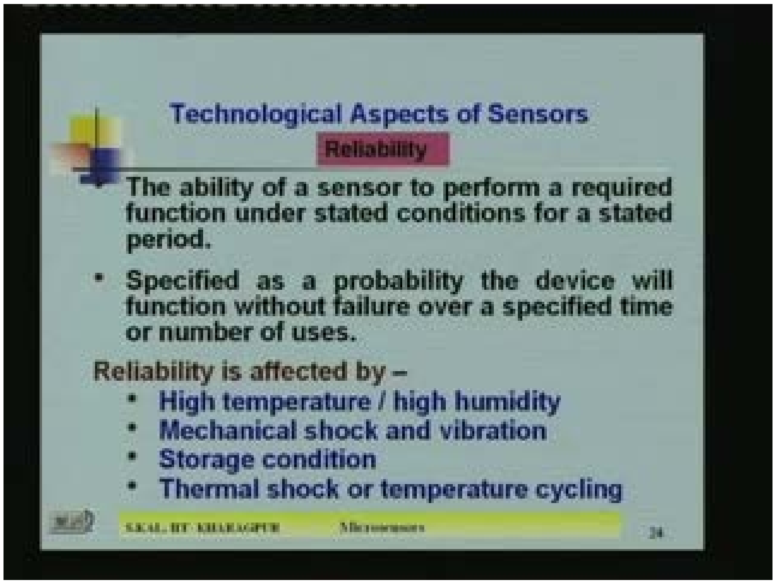

Another is a because it is related specified time and specify use. In some sensor you will not use. If you keep it for a long time, you will find its reliability also goes down. That is also you can say as an aging effect. So reliability is affected by what parameters is affected by high temperature, it is affected by high level of humidity, it is affected by mechanical shock, vibration, it is also affected by storage condition, thermal shock and temperature cycling. So these are the different parameters which affect the reliability of a particular sensor.

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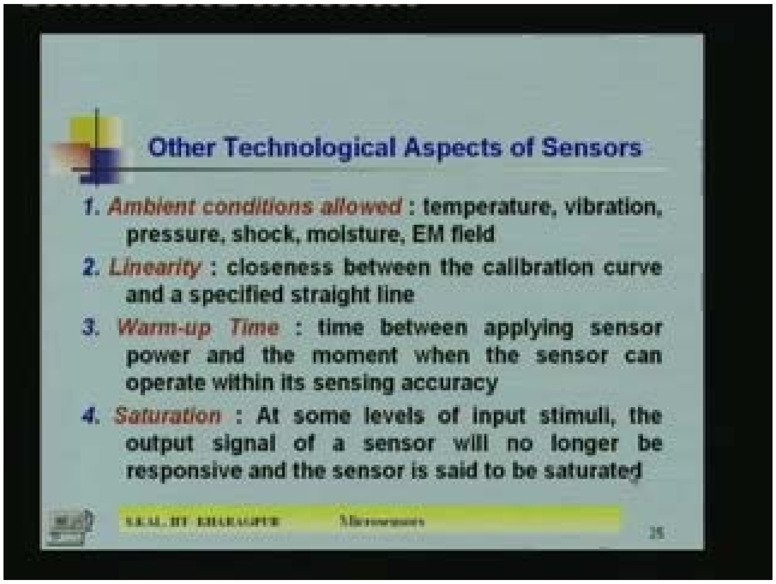

Now the other technological aspects of sensors, those are ambient conditions allowed. That means, what are ambient conditions: temperature, vibration, pressure, shock, moisture, electromagnetic field. That is one important parameter electromagnetic field is coming now a days because of the application of lot of wireless devices. So lot of electromagnetic fluctuations in the there in your surroundings so that means, that is coming as an ambient condition. In addition to their moister is also you know electromagnetic in addition to electromagnetic field moister, shock, vibration, sound level, sound pollution, those are the ambient condition, whether those parameters affect your sensors or not that you have to see. Another is the linearity. Closeness between the calibration curve and its specified straight line that is the linearity. How close your calibration curve with a straight line that is your linearity.

Some sensor shows the linear performance, some sensor does not show the linear performance. So, that you have to know from their physical principle and property, which sensor behaves linear? Which does not behave linear? And which is behaving linear? Then how much is a drifting from the linear? That also is a parameter of a particular sensor. Then warm up time. Warm up time means, as I told you that some sensor works when we apply certain electrical signal or power at the input. So after switching on how much time it is taking to show the or to sense the input stimulus or to change the output with respective to the input, that is known as the warm up time. How much it is taking for full functioning? So that means time between applying sensor power and the moment when the sensor can operate within its sensing accuracy. That is known as the warm up time. So it is important sensing accuracy. As soon you switch on, you may see some sensor you are getting output but output is fluctuating is not stable that we cannot consider.

But it has to be stable and within the accuracy limit, which has been specified by the manufacturer, it has come to that level. Then we call it is and that time we count as a warm up time. And another one is the saturation. At some levels of the input stimulus, the output signal of a sensor will no longer be responsive and the sensor is said to be saturated. If you move on, the input stimulus so output is increasing but after certain limit, the output may not increase. That is the saturation level it has reached and so normal definition of the saturation that is also a technological parameter of a sensor.

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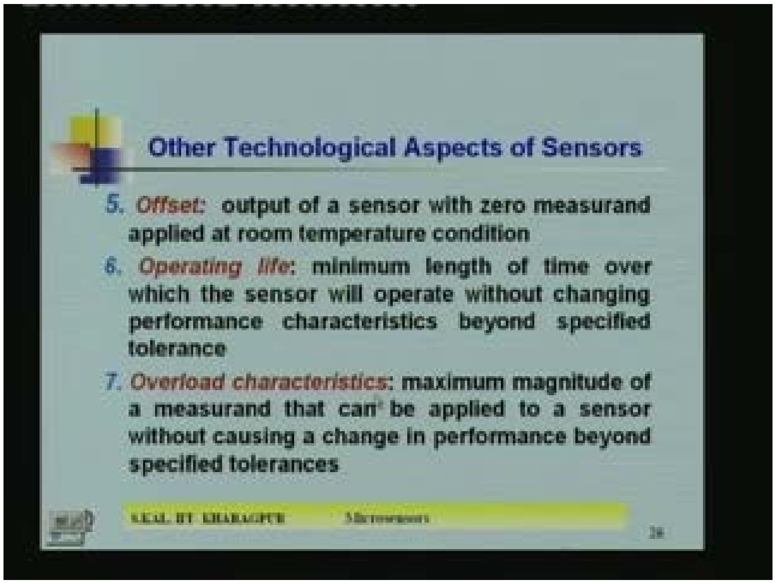

Now other technical aspects of the sensors are offset. That is, output of a sensor with zero measurand applied at room temperature condition. Normally, what we need, the offset is not a desired thing. But in some cases, as soon as you switch on the supply of a sensor, you will get the output signal in spite of absence of the input signal. So a photo detector output is a voltage. So as soon as light is incident on a photo detector, you should get the output voltage or current photo detector normally current is the output stimuli, output measurand. So now, if you do not switch on the light even then if you get some current then it is offset. And in that case it is known as in case of photo detector known is a dark current you will know it.

Similarly in many of the sensor, we will have that property. And that should be as minimum as possible. While you make the calibration curve, or if you package the total complete sensor then you have to see whether you are reducing the offset to a minimum value or not. So that is another one of the important of aspect of sensor when you are choosing it. Next is operating life. Minimum length of time over which the sensor will operate without changing performance characteristics beyond specified tolerance. Because every sensor will have certain tolerance limit. So whether your output exceeds that tolerant tolerance limit or not, that you have to see. If the sensors gives you the output within the tolerance limit, so that till then you use the sensor. If it exceeds you that limit you throw it. So that is the operating life of the sensor.

Next is the overload characteristic. So overload characteristics what does it mean is a maximum magnitude of a measurand that can be applied to a sensor without causing a change in performance beyond specified tolerance. So here is a beyond specified tolerance it should. Maximum input or maximum magnitude of a measurand or stimulus it can sense properly. That is the overload characteristics. So overloaded means you are given if some sensor can, for example acoustic sensor is measuring the output noise level, output sound level. So the sensor maximum can measure say 100 dB noise 100 dB sound amplitude or whatever it is. So now if it is a sound level is so loud it is 200 dB so it is overloaded, so output is not unreliable. It may so the exact value of the 200 dB or it may not. Then that is not reliable. That means it had exceeded your specified the tolerance limit so it behave erratically. So that is why, that is basically overload characteristics is to be known for a particular sensor so that you can use reliably up to that reliable. That is the overload characteristics.

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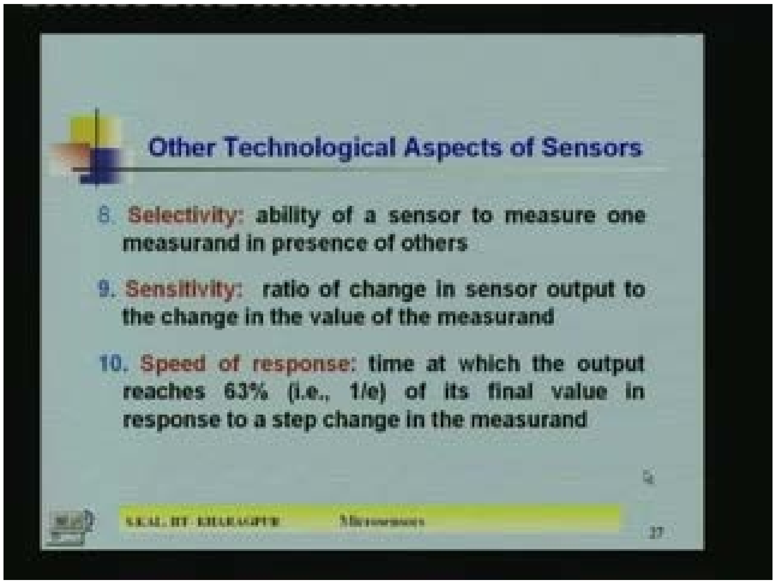

Then comes selectivity, sensitivity and speed of response. Selectivity is again an important parameter. Why? Because, I am giving you one example and that example is again I am talking about the thermal sensor. So you are going to measure the temperature of a particular body. So that temperature can increase by absorption of heat, the temperature can increase when you irradiate that particular body with the optical energy or light. If light is incident, then also its temperature can increase or if you supply some heat, then also it will its temperature can increase. Now your sensor must measure, it is meant for the increase of temperature with the thermal energy supply. Then whatever the optical energy is incident there say from surrounding so from there what is the output that has to eliminated, that means that comes the selectivity. If I want the temperature change due to a certain phenomenon it should select only that phenomena because of other phenomenon the output measurand may change but it will not reflect there that is the selectivity. So that means ability of a sensor to measure one measurand in the presence of others. Then comes the sensitivity.

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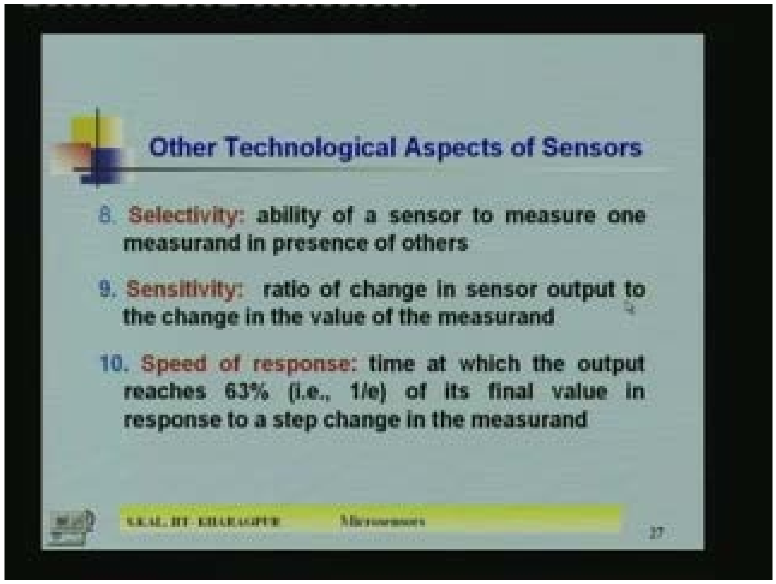

Sensitivity is a ratio of change in sensor output to the change in the value of the measurand. That is defined as the sensitivity. And speed of response is also an important parameter. There may be time at which the output reaches 1 by e which is 63 percent of its final value in response to a step chance in measurand. That is the speed of response. How first because in case of step change of the measurand, you need the sensor respond very fast. And its definition is the time required to reach 1 by e times it is 63 percent desired output so that is the speed of response.

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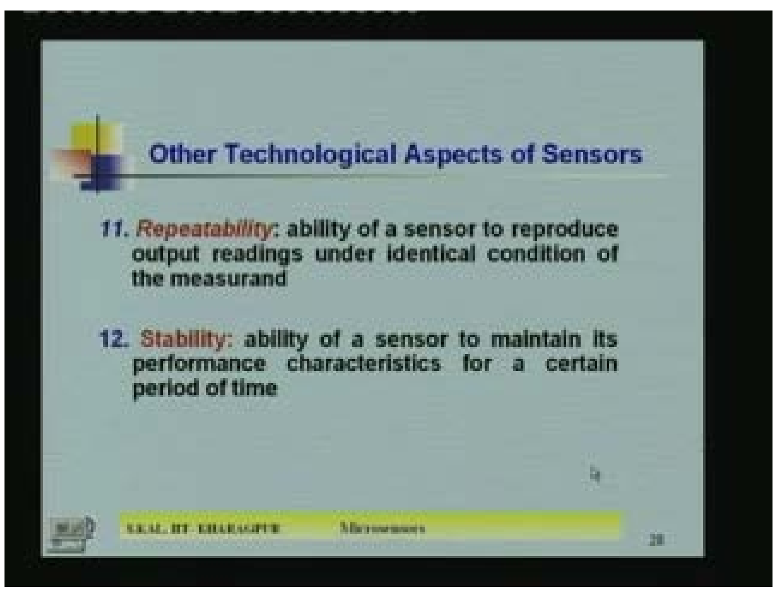

Now repeatability and stability are other parameters which you have to take into account when you are selecting or design a particular sensor. Repeatability means ability of a sensor to reproduce output readings under identical condition of the measurand that is repeatability. Same conditions you are applying, the output of the sensor should be same. If it is not same, is not repeatability. And repeatability may loss because of different problems in your design, different problems your choosing of materials of the sensor and different problems of your environment condition also. And the stability is another important aspect and that is ability of a sensor to maintain its performance characteristics for a certain period of time. So that means how long your sensor is performing well, that is the stability. So with this just I gave an introduction to the microsensors and something I will continue on this topic in the next lecture also. And then I will discuss on the evaluation of this MEMS sensors as well as market survey. Thank you. Let me stop here.

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Preview of next lecture. I will continue for some time Lecture 2 content that is the microsensor introduction. I was discussing on the characteristics of sensor. There are certain parameters which are known as dynamic characteristics of sensor.

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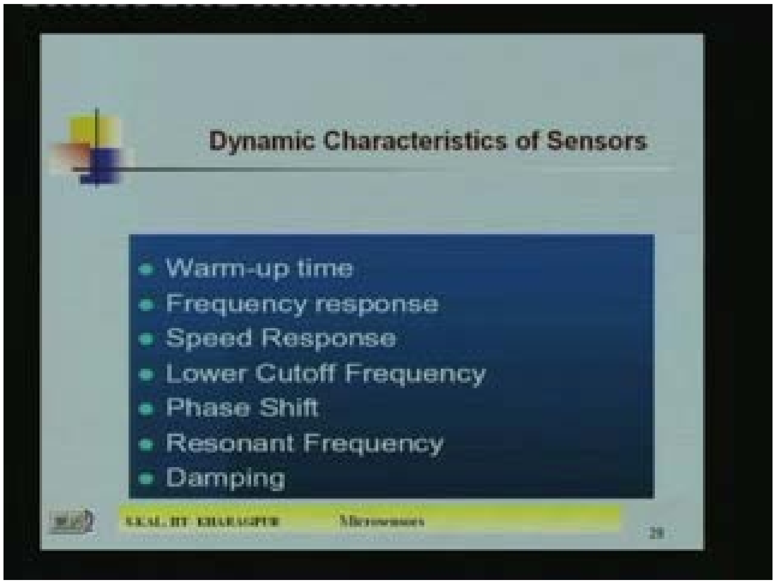

They are namely: the warm-up time, frequency response, speed response, lower cutoff frequency, phase shift, resonant frequency and damping. So these parameters also we have to take care of which are not mentioned in lecture 2. That means a resonance frequency and damping is a critical parameter when we go for designing an inertial sensor. For example, axle meters or gyros. Speed response is important for any kind of transient phenomena if you want to detect, then it's very important. And frequency response is important for any of the sensors which deal with electrical signal. So these are basically the dynamic characteristics and all these characteristics, how the sensor is behaving with all these dynamic parameters that one should know before he use he or she use those sensors in actual application.

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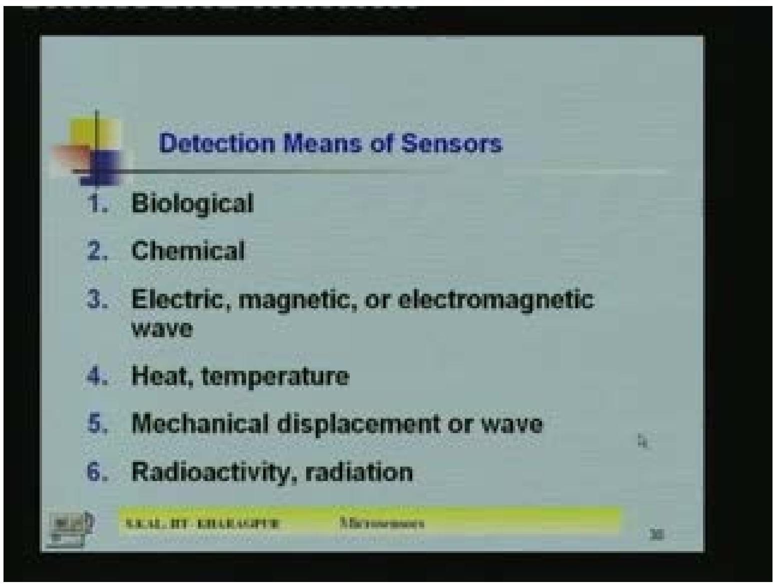

Now what are the detection means of sensors? Detections means may be biological, may be chemical, electric, magnetic or electromagnetic. Detection means may be heat or temperature, mechanical displacement or wave, radioactivity, radiation. These are various kinds of detection means.

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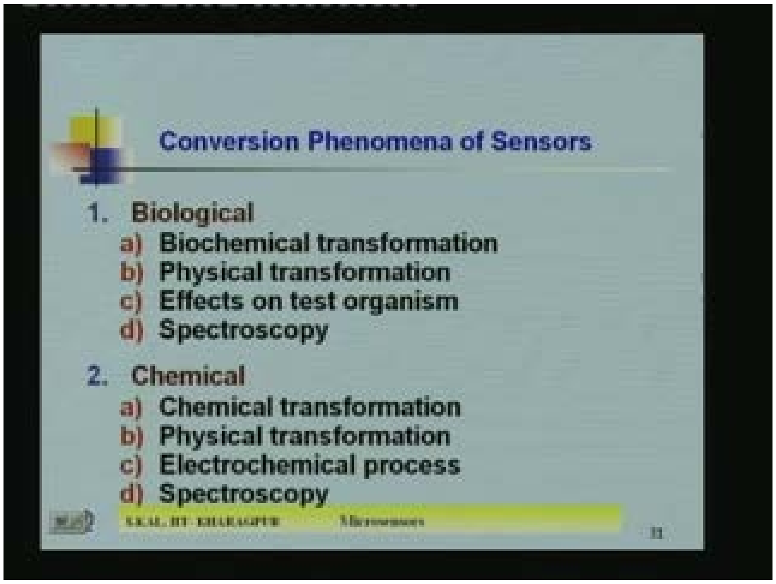

And now the conversion phenomena. So what physical reaction or what physical change is going to take place inside the sensor because of which you are getting output with the variation of the input stimulus. What are those conversion phenomenon? In case of biological, the conversion phenomena may be biochemical transformation, may be physical transformation, may be effects on test organism that means some biological phenomena may take place if we apply certain chemical into that biological species or body. That is the effects on different test organism then, spectroscopy. So these are the conversion phenomenon. In case of the chemical sensors, so what are the conversion phenomena? They are namely chemical transformation, physical transformation, electrochemical process and spectroscopy.