Sensors and Actuators

Dr. Hardik J. Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bengaluru

Lecture – 01
Sensors Part 1

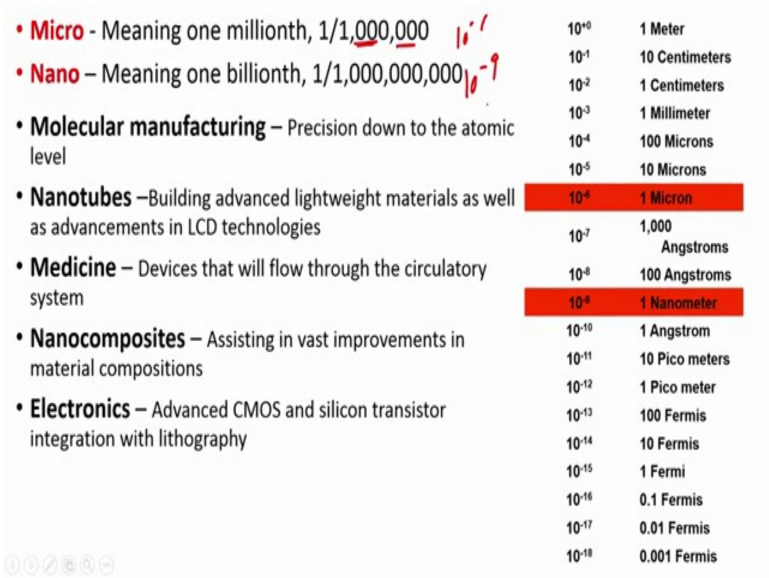
Hi, welcome to this particular course, you already have seen the introduction part where I am talking about what is the importance of this particular course, what you will be learning in this course, how it will be helpful for you to you know use the knowledge from this particular course in the actual you know research domain, as well as for understanding the various sensing principle of Sensors and Actuators.

Now, let us start with the first class of this course and let us understand what the sensors and actuators are and what exactly a sensor is and what is an actuator. So, any tool and component that is within the machine that is responsible for the physical movement of the other parts or for actuating it is that an actuator. While when you talk about sensor; sensor is when it senses the physical or the optical you know physical parameters. For example, let us talk about temperature if you can measure the temperature it is a temperature sensor.

So, a sensor and actuator there is a fundamental difference in the way both the components are defined, when you talk about actuator you can take an example of a valve, when you talk about sensors you can take example of accelerometer temperature sensors gas sensor.

Now, what kind of sensors are there, are the direct sensors, are they indirect sensors what is the principle behind these sensors? So, today we will focus on what kind of sensors are there and what are the mechanism and principle that sensor depends on.

(Refer Slide Time: 02:19)



So, let us see the slide and we will also focus on micro and nano. So, the idea is not just to tell you about the sensor and its mechanism or actuators and its mechanism or as well as application, but also to make you understand how you can design a sensor or actuators and or actuators which are micro in dimensions and sometimes you use the nano material to fabricate or realize the sensors.

So, when you talk about micro, what micro means? Micro means 1 millionth. So, if you talk about human hair it is about 80 to 100 microns. Now, you are talking about 1 micron; 1 micron would be about 10 to the power minus 6 all. So, you can see on the right side of this slide studying from meter we had 10 1 meter, then you say 10 centimeters and you have 1 centimeter, 1 millimeter, 100 microns, 10 microns, 1 micron, then you have angstroms and 100 angstroms, 1000 angstrom, 100 angstrom and then you go to 1 nanometer.

So, what we will be talking about is in this particular range from micro to nano all and then we will see why it is very important to design sensors which are of micro dimensions and same way for the actuators as well. Now, nano like; what I was discussing is about 10^{-9} or you can say it is 1 meaning 1 billionth all, 1 by 1 billion will give you nano which is 10^{-9} you can see that 3, 3, 6, 3, 9 where if you talk about million is 1 by 1 millionth which is 3 and 3 6. So, it will be 10^{-6} this will be 10^{-9} that stands for your micro and nano.

Now, when you talk about molecular manufacture it is like precision down to the atomic level you have several systems which can help you to deposit the layer atom by atom. So, molecular manufacturing stands about depositing the precision down to atomic level. Nanotubes were building advanced lightweight materials as an advancement in LCD technologies a lot of advancement you can see that from the CRT to the LCD that we are used today that is a huge you know improvement particularly because of the lightweight materials and advanced technologies.

Same way when you talk about medicine there are devices that will flow through the circulatory system, they are all micro and nano devices lot of research is going on in this particular domain as well. We talk about nano composites is about assisting in various improvements in material composition, but when the word electronics you are talking about advanced complementary metal oxide semiconductor and silicon transistor integrated with lithography or integration with lithography.

So, when you talk about just sensors and actuators it does not mean that you know you are just talking about the phenomenon or mechanism you are also understanding how you are going to fabricate those sensors and that is the goal of this particular lecture as well as the course is to show it to you what kind of sensors are there, but also to explain you how can you fabricate those sensors.

When I talk about fabrication there are several you know techniques that you will be learning during this particular 30 hours course, and then we will see that when you talk about lithography like we just discussed in the first slide that when you want to design an electronics. For example, the complementary metal oxide semiconductor I want to design the sensors or 2 silicon transistors then you need to rely on the lithography. So, we will be discussing about lithography we will discussing about the systems and then we will see how we can design using the micro technology processes different sensors and actuators.

(Refer Slide Time: 06:55)

Now, when we discuss about this you should understand that we are not only going to discuss about this, but we will be looking at how the sensors looks like. For example, if I show you a sensor right in my hand you can see the sensor. So, this is a sensor that we will be talking about, now these sensors are from Taguchi is a Japanese company, but what we are, what you want to understand is what is there within this particular sensor within the casing and what is the role of having x number of pins below the casing, what is sensing material that this particular sensor is using and finally, can we fabricate this sensor? .

So, the answer is yes, we can fabricate the sensor and I will show it to you how to fabricate the sensor and how to make the casing. These are one just giving one example of the sensor, we will show several examples I will show it to you several examples of different kind of sensors.

(Refer Slide Time: 07:48)

Let me show you one more sensor I have; I will show you a few of the sensors. This is another sensor that I am holding in my hand and these are all gas sensors these are all gas sensors there is a pin on the back side and the front side you have the mesh through which the gas can pass and then within it is a sensing layer when a particular amount of gas is passed there is a change in the resistance value. I will tell you why there is a resistance initially and how the resistance value changes when a gas comes into contact with the sensing layer.

So, we are talking about another sensor that I am holding here which is again a gas sensor and then in gas sensor when talking about there are VOC sensor as well. So, what you understand by VOC? VOC stands for Volatile Organic Compound.

(Refer Slide Time: 08:47)

Now when you say volatile and then you say organic compound. So, can you think of some volatile organic compounds? It is very simple, if you think of volatile organic compounds you will see that petrol. So, when you put a drop of petrol is that it will immediately evaporate at room temperature. Same thing when you talk about acetone can you please see on my hand the sensor that I am holding.

(Refer Slide Time: 09:13)

So, when you talk about acetone, it is again a volatile organic compound, when you talk about ethanol is a volatile organic compound, when you talk about methanol is again a volatile organic compound, when you talk about IPA Isopropyl Alcohol is again volatile organic compound, when we talk about butanol is again volatile organic compounds, there are lists of volatile organic compounds . So, the sensors that I am showing it to you is not only a gas sensor, but it is also a VOC sensor Volatile Organic Compound, VOC.

Now, you will ask it what the use of this sensor is, why to measure VOCs. So, there are a lot of applications of VOCs all one is ethanol sensor. For example, drunk and drive drinking and driving is not good. First of all, you should try to avoid drinking, but at least if you are drunk you should not drive very simple. The point is it is injurious to your health alcohol as well as smoking and you all know I am just telling you once again, the idea is to make you understand that if you want to know what is the blood glucose concentration then you can measure the amount of ethanol from the breath using ethanol sensor .

So, this sensor can be used as an ethanol sensor; ethanol is volatile organic compound. So, this is again of VOC refrain yourself from having any kind of you know bad influence, bad habit like I said sensors and actuators we are learning, but we can learn everything only when our sensors and actuators are working well. See we have eyes optical sensors, we have acoustic sensor, we have a sound vocal sensor we have taste buds, we have force sensor, we have touch sensors everything is sensors.

And this will get deteriorated over a period if you are if you keep on having bad habits such as drinking a lot of alcohol or have smoking you know tobacco it is not good. So, try to you know be away from such kind of habits, but at the same time you should know that what is the effect when somebody drinks alcohol, how it is converted or mixes with the blood and how it comes to the breath. So, that a person can be identified under the influence of alcohol through the breath by using alcohol sensor and alcohol sensor is nothing, but the ethanol sensor.

So, these are another sensor that I am holding in my hand and you can see there are four pins in the bottom what are the what is the role of this four pins at the bottom I will teach you in some other class, this is another sensor that I am holding this all sensors are from Taguchi.

Now, there are CO_2 sensors, there are ethanol sensors, there are methanol sensors, there is a humidity sensor. So, a lot of sensors are there some sensors come with electronics embedded, some sensors that does not come with electronics.

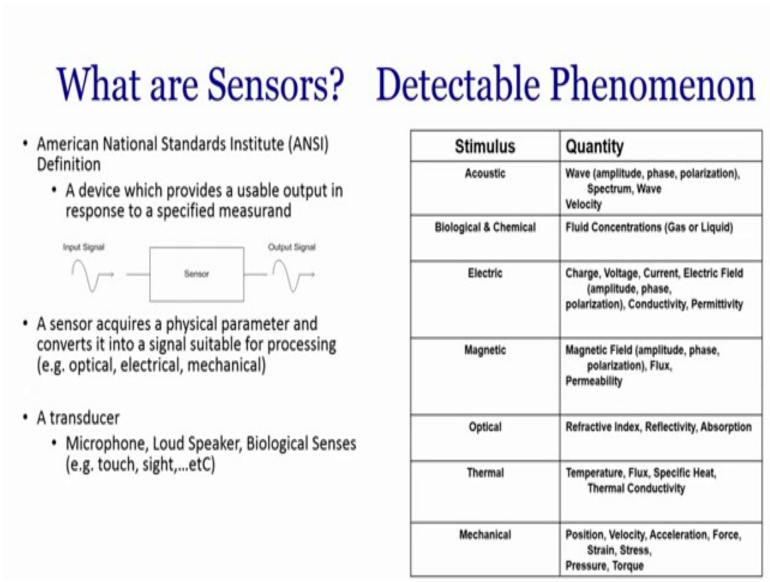
(Refer Slide Time: 12:31)

Now, this is a sensor that comes with electronics right in the back side as you can see here all right front side is your sensor, back side is your electronics. So, how to use it? You are just there are pins to connect the sensors and you can immediately use it for measuring a particular gas.

So, let us first understand before. So, this is just like I am giving some examples that we these are all gas sensors, but the sensors are of several types from like I said from temperature sensor, accelerometer, light sensor, magnetic field sensor, we have photo gate, we have CO_2 gas sensor, we have ultrasonic sensor and so on, so forth .

So, let us understand today sensors and then like I said we will continue with that actuators. So, if you see the slides our focus of this particular lecture is to understand, what are sensors? Then we will look at what is the detectable phenomena or what is a mechanism? Physical principles that is how do sensor works? Need for sensors, choosing a sensor, what kind of application you are targeting and what kind of sensors you have to choose for that application and then we will see few sensors and their applications from temperature sensor to CO_2 gas sensor alright.

(Refer Slide Time: 14:00)



So, when you talk about sensors. So, the American National Standards Institute definition is a device which provides you usable output in response to a specific measurand. So, a sensor is nothing but a device that can give us an output for measuring a measurand. That means, that a sensor acquires a physical parameter and converts into a signal suitable for processing for example, light then optics. So, can I see the intensity of this light and convert it to a phenomenon or to a now output signal that can be useful. For example, can I convert this light to resistance. So, all light to current light to voltage whatever does not matter.

Some measurable output, what is the measurand here, the light intensity. So, it can be optical, it can be electrical, it can be mechanical. Suppose there is a cantilever assume that what is cantilever, I will give you example of a cantilever you have sink diving board diving board is in a swimming pool. So, the diving board on which a person stands and dives so, that itself is a cantilever it is held from one side like this. So, when you press it bends like this; so, every cantilever head is operating at its natural frequency or vibrating and natural frequency.

Now, if you consider this as a cantilever, if I press this cantilever and if there is a piezo resistor embedded into this cantilever what will happen when I press it there is a change in the resistance. Why there is change in resistance? Because piezo resistivity is a phenomenon why when you apply when you apply a pressure there is a change in resistance. So, if there is an embedded resistor piezo resistor into this cantilever assuming that the pen that I am holding is a cantilever, the piezo resistor is right over here when I apply a force because of the strain there is a change in the resistance.

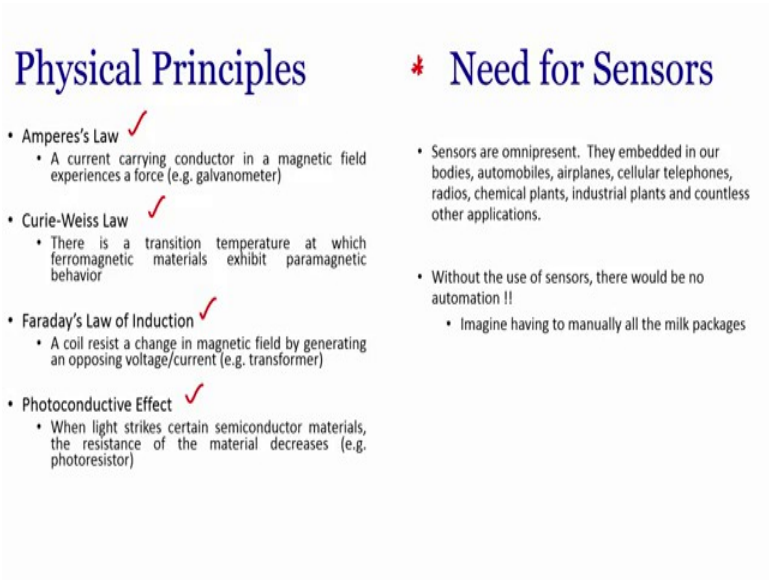
So, now the force that I am applying is the signal, is the measurand and the resistance that I am looking at is the output. Is if my output is in the detectable range or usable range then I can say that this cantilever is nothing but a sensor that is just giving an example.

So, a sensor like I said acquires a physical parameter and convert it into signal suitable for processing or while when you talk about transducer and transducer is like microphone, loudspeaker, biological senses, example touch, sight etcetera. So, transducer transduce the signal; for example, loudspeaker like whatever we speak it amplifies the signal.

So, that is the transducer when you say about detectable phenomenon; that means, that what is the stimulus and what is the quantity. For example, if we talk about acoustic stimulus, then we can have wave there is amplitude, phase, polarization, spectrum, wave velocity. We talk about biological and chemical kind of stimulus, then what is our quantity? Fluid concentration such as gas or liquid.

So, we talk about electric, then what is the quantity? Charge, voltage, current, electric field, amplitude, phase, polarization is the conductivity and permittivity. When the word magnetic, then you have magnetic field which is amplitude, phase, polarization as well as flux and permeability. While optical the quantity is refractive index, reflectivity and absorption. For thermal it is temperature, flux, specific heat and thermal conductivity well for mechanical it is position, velocity, acceleration, strain, stress pressure, force, torque. So, these are the stimulus and the quantity can be defined.

(Refer Slide Time: 18:12)



Now, let us see physical principles and then we see need for sensors, when you talk about physical principles there are several laws that we need to understand. First law is Ampere's law, where a current carrying conductor in a magnetic field experiences a force for example, galvanometer. While when you talk about Curie Weiss law then there is a transition temperature at which ferromagnetic materials exhibit paramagnetic behavior there is a Curie Weiss law that at a particular temperature which a transition temperature your ferromagnetic materials will behave or exhibit paramagnetic behavior.

While when you talk about Faraday's law of induction most of you should know it is a coil resist a change in magnetic field by generating an opposing voltage or current. For example, a transformer; transformer are several types we know there is a step-up transformer, step down transformer and then each of them has its own core. So, that it comes in the transformer section we are not focusing on that, but I am just giving an example that the Faraday's law of induction works for transformer, then we talk about photoconductivity effect.

So, photoconductivity effect is when the life strikes the certain semi-conductor materials, the resistance of the material decreases for example, a photo resistor. So, what we do not understand is that every or most of the sensor they operate on certain principle either can be Amperes law, it can be Curie Weiss law, it can be Faraday's law, it can be photoconductivity effect so on and so forth all . So, if you see the slide these are the physical principle like I said Amperes law, Curie Weiss law, Faraday's law of induction and photoconductivity effect.

Now, when you talk about need for sensors; what is the need? So, the need for sensors is sensors are omnipresent. The embedded in our bodies automobiles, airplanes, cellular telephones, radios, chemical plants, industry plants and countless other application. I told you sensors are everywhere; you talk about your body your body is full of sensors. I just give you full few examples we have a temperature sensor, we have a optical sensor, we have a touch sensor, we have a four sensors, we have tactile feedback and then we have acoustic sensor, we have transducer, we have amplifier how like amplifier, I can increase the amplitude of my signal and decrease it based on how I want to delivered my lecture .

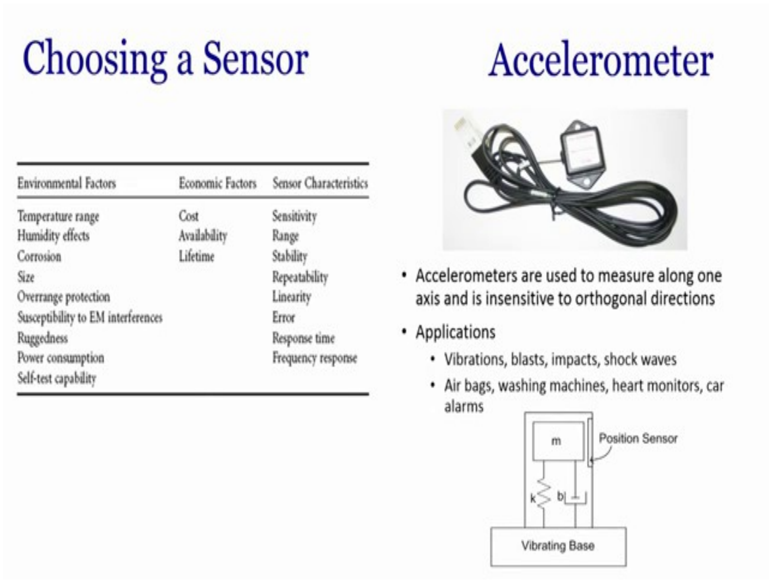
So, you have full of or a human body is full of plenty of sensors and that is how we try to mimic some of these sensors in real time whatever we feel for example, force like if I am holding a pen I know how much force, I had to apply I can get up feedback as how much force I am applying tactile feedback I also can have haptic feedback.

So, without sensors you see that there can be no automation. For example, see all the airplanes if you see in flight when you take a flight or you go you sit in a bus or travel in an auto rickshaw or travel in a car or travel in a train or even your motor bicycle everywhere there are sensors and the importance of the sensors are tremendous .

So, for example, let me give you a very simple example which you can correlate with our daily activities. If you see you may have used milk in a package, but the milk that goes to a package the packaging of that 1 liter or half liter of milk occurs through an automation system, where there are lot of sensors involved. Can you imagine serving milk in terms of like package milk to these many people if the phenomena if the if the process is done manually, it will take hours.

Now, because of the automation, because of the sensors this time is reduced tremendously. This is just a given an example of sensors in our real-life packaging of milk for example, you can correlate with several examples. So, without the use of sensors there will be no automation.

(Refer Slide Time: 22:47)



Now, let us understand choosing a sensor. So, environmental factors are one of the things that we need to understand, we must understand economic factors and then we have to see what the sensor characteristics are.

So, if we talk about environmental factors, then what are the factors that we have to consider? For example, what is a temperature range. how the humidity will affect the sensor, what kind of corrosion is there a corrosion is there, what is the size of the you know measurand, over all overrange protection, susceptibility to you know electromagnetic interference that is called EM interference ruggedness, how to get your devices, power consumption is the device capable or sensor capable of you know using less amount of power.

So, power consumption is very important phenomenon, then your self-test capability, repeatability lot of things are there which you got about any environmental factors, but when you talk about economic factors you know that it should be low cost devices, should be available, the life time should be extremely high suppose I get a sensor to measure the temperature in my home .

Now, the lifetime of this temperature sensor or the system is just 1 year, and the cost is like 15 k then I cannot buy it because the lifetime is extremely small, but if I say that it will be lifetime warranty. So, assuming that human life average, human life is above 70 years, then 70 years the sensor would work for 50 k, then it can be one can give a thought about that. However, if you say that for self instead of 50,000, I give it to you for 5,000 and give you lifetime warranty, then you will immediately buy it.

So, the economic factors are very important the when you make a technology; technology can be the while devising the technology you have to invest lot of money, but once the technology is ready it should be at a lower cost except that it is specialized technology. So, cost will be in lifetime these are economic factors, when you talk about sensor characteristics. What are the sensor characteristics? It can be sensitivity can be range, it can be specificity, can be stability, can be repeatability, it can be frequency response, it can be response time, it can be error, it can be non-linearity.

So, several sensor characteristics are there that we need to take care when we design a sensor. How linear my sensor is? That means, that with increase of temperature sensor; with increases temperature if my output is in terms of resistance is my output linearly decreasing or increasing? Then I can correlate that for 1 degree change I will have 10 degree or 10-ohm resistance change for example, if it is a linear it becomes easier for you to design the signal conditioning systems. So, linearity (Refer Time: 25:42).

How sensitive it is for 0.1 degree can I see the change sensitivity, how specific is it is, how repeatable it is. He goes to 34, he comes back to 25 again goes 35 again comes 25, how well it follows the curve. How stable it is, if the room number says 24 is my resistance stable, stability. What are the errors? , when I go from 24 to 30 back to 24 back to 30, back to 24, what kind of errors I have in terms of resistance, am I getting the same resistance every time when I reach 24 degrees centigrade, am I looking at the change in resistance every time when I reach 30 degree centigrade, what is the error or what are the errors that is another point that you do understand .

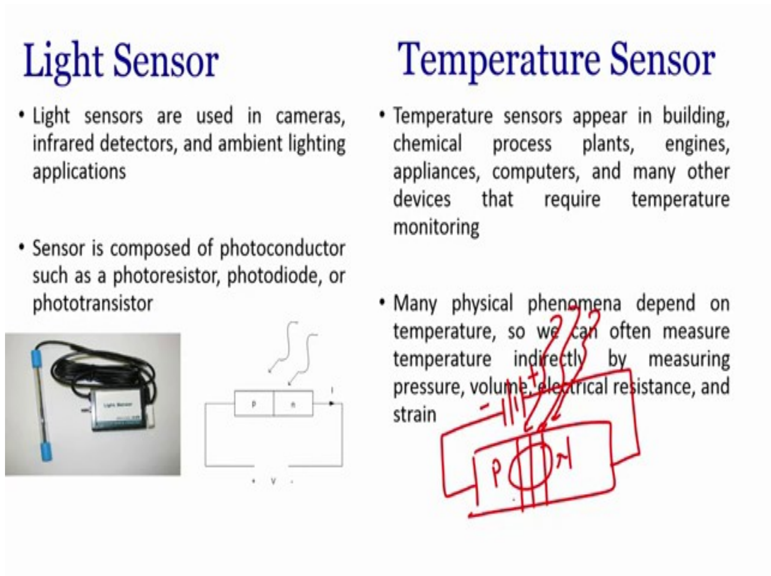
Response time how fast it changes? 0.1 degree change suddenly can I see the change in resistance. How much time is it milliseconds few seconds few minutes it is microseconds how fast is response time? So, these are some sensor characteristics. So, when you talk about choosing a sensor you do consider all three parameters environmental factors, economic factors and sensor characteristics three things, cool.

So, now let us see the first sensor which is our accelerometer, if you see on the slide accelerometer are used to measure along one axis and is insensitive to orthogonal directions. The applications of accelerometers are in vibrations, blast, impact, shock views. In airbags, washing machines, heart monitors, car alarms.

So, this is just an equivalent circuit of the accelerometer you can get accelerometer readymade and you can measure the vibrations like I said it is placed in the air bags in your car, it is there in the washing machines, it is there in the heart monitors and it is also there in the car alarms. When you see that you are suddenly I if you are seen certain places if there is a car and if somebody tries to open the lock of the door of the car suddenly there is an alarm.

So, that alarm also sometimes includes the accelerometer. Your air back in the, car air bag in any system when there is an impact the air bag comes out accelerometer. So, blast, impacts, vibration, accelerometer is used cool. So, accelerometer we have seen now let us see light sensor.

(Refer Slide Time: 28:24)

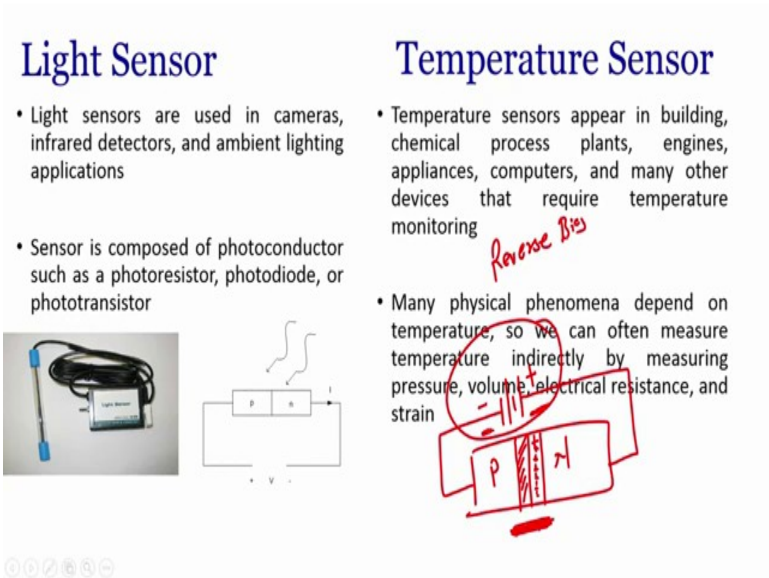


So, light sensors are used in cameras in particular we are talking about infrared detectors and ambient lighting applications. So, there is application of light sensor. Sensor is composed of photo conductor such as photo resistor, photodiode or photo transistor.

Now, let me explain you this is a there can be many ways of designing of photo diode. For example, if I want to design a photo diode and if I take of P and N junction. P N junction is what? P is your semiconductor; N type is another semiconductor. In P type you have holes as a majority carrier, in N time you have electrons as majority carrier. Now, if I apply a negative bias to my P type and positive to N type minus to P type positive 2 N type. What will happen? The depletion layer will increase; the depletion layer will increase.

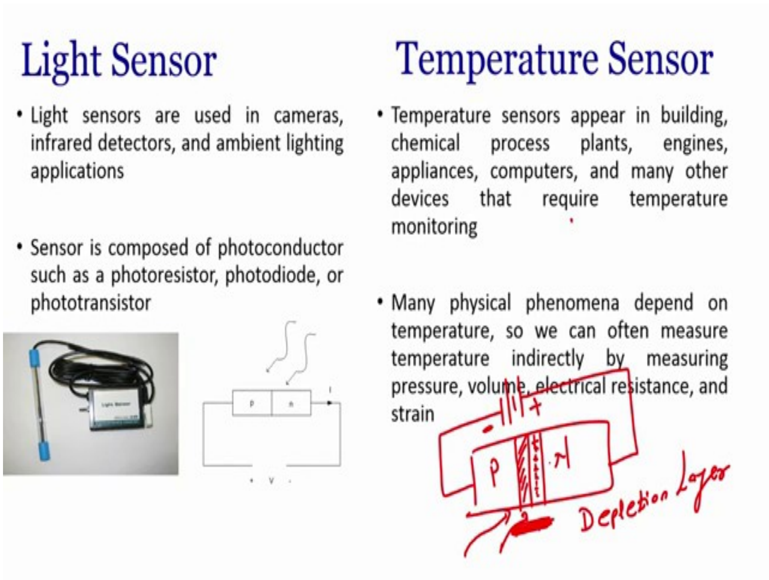
So, when I have depletion layer increased and if I externally if I incident a light, what will happen the electrons will be donated, and this depletion layer will start decreasing what I am saying let us understand again.

(Refer Slide Time: 29:53)



So, if I have P N kind of semiconductor; P N kind of semiconductor, what will happen? That when I apply a negative to P and positive to, then there will be a depletion layer, when there is a depletion layer if I incident an external light onto this depletion layer. So, what is this one, what kind of biasing is this? These are reverse bias you all know this reverse bias. What is forward bias? Forward bias if I want to see forward bias what I will do, I had to apply positive to P and negative to N it becomes forward bias.

(Refer Slide Time: 30:32)

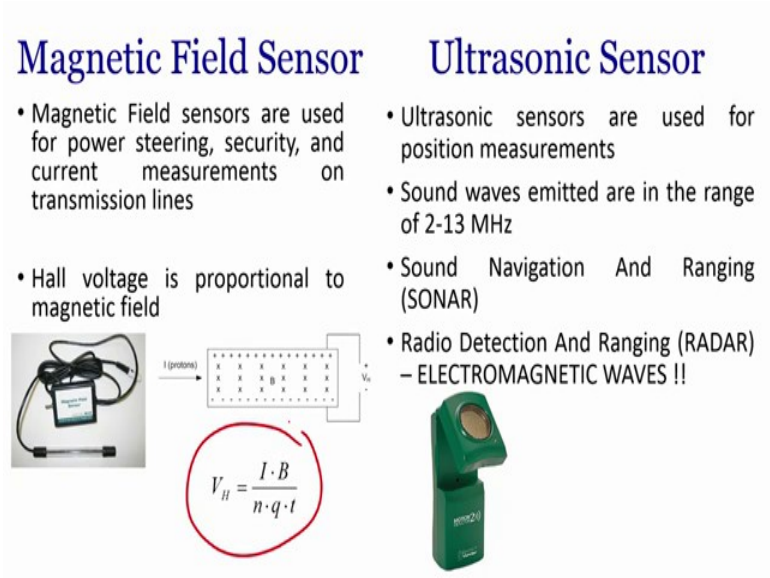


But I had to create a depletion layer that is why I am applying negative to P and positive to, when I do that there is a creation of depletion layer; depletion layer. And when I incident a light onto this particular depletion layer, what will happen the depletion will be reduced because of the electrons form because of the intensity of light and then what will happen the reduction in this depletion layer can be measured with the help of the current flowing through this particular semiconductor. Thus, this is the phenomenon of any photo diode or a photo resistor or a detector. So, that is what it is.

Now, when you talk about temperature sensors, then you see the temperature sensors appears in several applications including chemical process plants, engine applications, computers and many other devices that require temperature monitoring. Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, we can measure temperature by indirectly measuring volume, we can measure temperature indirectly by measuring electrical resistance as well as strain.

Now, you talk about chemical plants they require to be at certain operating temperature. Engines if it gets too much heated it is not correct, computers we require to keep it you know active at certain temperature if it is too much heated the electronics will be destroyed deteriorated and say many other applications.

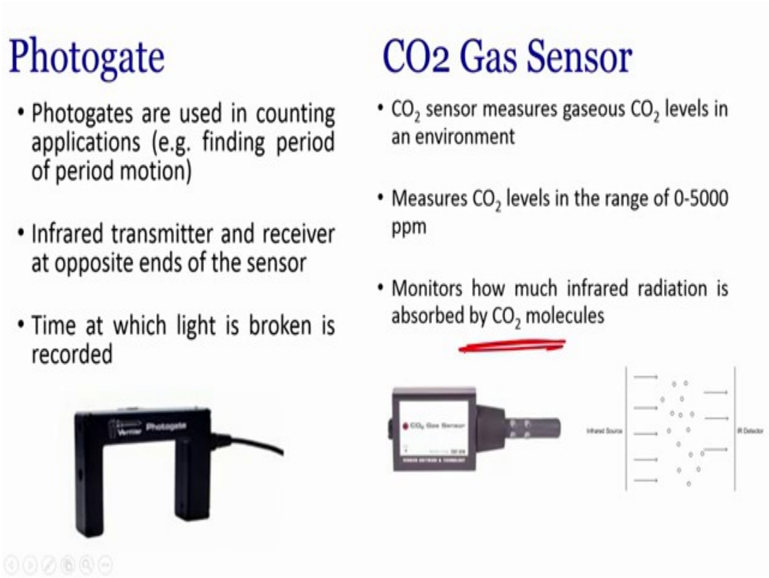
(Refer Slide Time: 32:10)



Where did you talk about magnetic field sensors? The magnetic field sensors are used for power steering, it can be used for security and current measurements on transmission lines and in the way the magnetic sensor works is based on the hall voltage, which is proportional to the magnetic field.

So, I have given an equation. So, this is the equation on which the hall voltage can be measured. When you talk about ultrasonic sensor, then ultrasonic sensors are used for position measurements. Sound waves emitted are in the range of 2 to 13 megahertz. Sound navigation and ranging which is on sonar and radio detection and ranging which is radar both are electromagnetic waves and there is a use of the ultrasonic sensor in this kind of application.

(Refer Slide Time: 33:06)

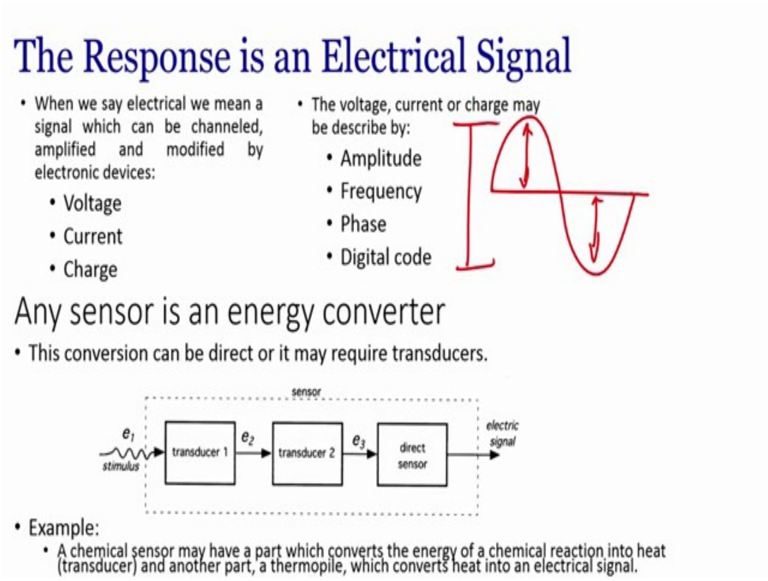


When you talk about another sensor which is your photo gate, then photogates are used in counting applications, example finding period of a motion and also it can be used for infrared transmitter and receiver at opposite end of the sensors. The time at which the light is broken is also recorded with the help of photogate.

Now, when talk about CO_2 gas sensors; CO_2 gas sensors measures gaseous they CO_2 level in an environment. It measures in the level in the range from 0 to 5,000 ppm. Monitors how much infrared radiation absorbed by CO_2 molecules. For example, it is infrared sensor, if I have a source and if I have a IR detector then depending on the molecules of CO_2 the source and detector that the signal that is sent from the source and signal that is the received by detector would depend on the number of CO_2 molecules in between because that CO_2 molecules or those CO_2 molecules will be absorbed by the infrared radiation.

So, that is one way of measuring CO 2 sensor, but there are several other ways that we will be discussing in the next module, for this module let us see them two more slides. Now, when you talk about these sensors like let us quickly understand that what is the response, if the response is an electrical signal, what do you mean by that?

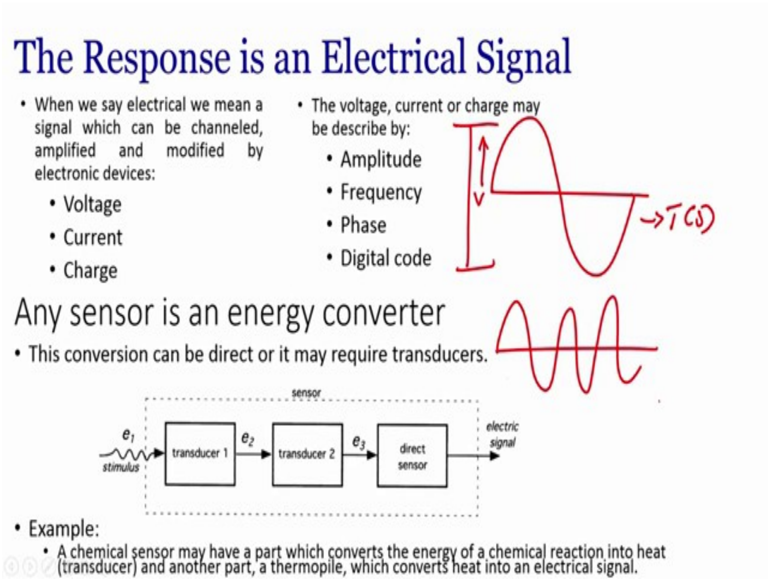
(Refer Slide Time: 34:36)



So, if you see the slide the response in is an electrical signal; that means, that when we say that electrical, we mean a signal which can be channeled, amplified and modified by electronic devices. For example, voltage; for example, current; for example, charge.

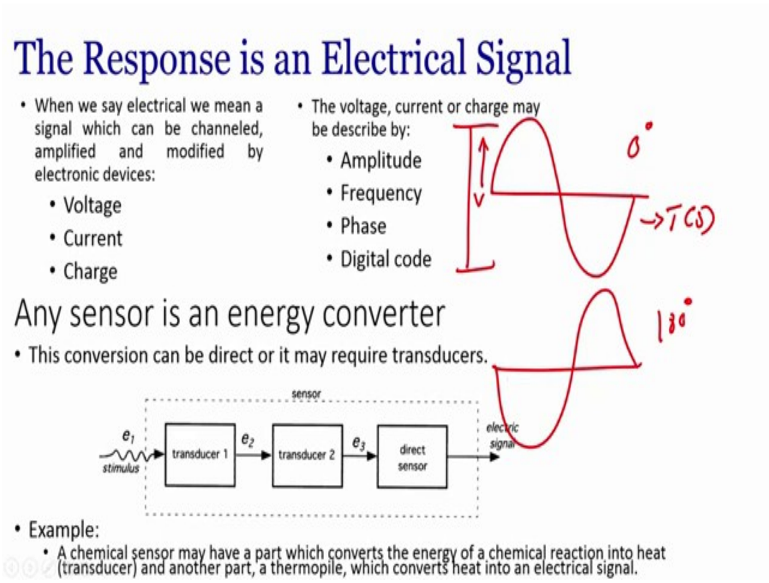
Now, the voltage current or charge may be described by amplitude; amplitude this is the amplitude of positive wave, negative cycle amplitude, total amplitude.

(Refer Slide Time: 35:13)



Now, it depends on frequency this is time, this is voltage time in seconds let us say, if I increase the frequency is higher.

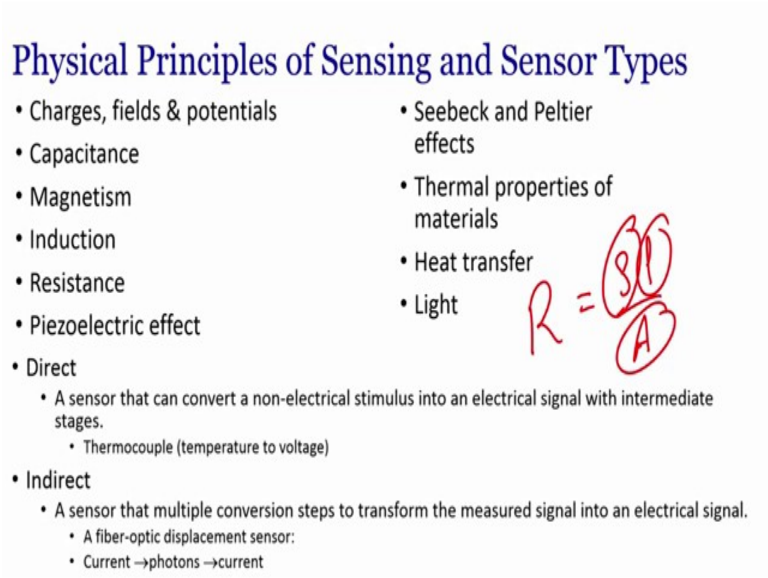
(Refer Slide Time: 35:28)



It depends on phase this is let us say this is 0 degree, then if I have signal this is 180-degree phase when I digital code. So, it did not only depend on the amplitude frequency phase, but also depends on a digital code of the signal any sensor is an energy converter, we have seen that that this conversion can be direct, or it may be may require transducers. For example, if you have a stimulus e 1, can be transducer 1, then we get e 2, then you have transducer 2 you get e 3 and then you are you have direct sensor and then finally, you have a electrical signal.

So, example; for example, if you want to understand the sensor as an energy converter a chemical sensor may have a part which converts energy of chemical reaction into heat that is a transducer and another part a thermopile which converts heat into electrical signal through the sensor walls. So, it can be multiple transducer embedded into one particular block.

(Refer Slide Time: 36:22)



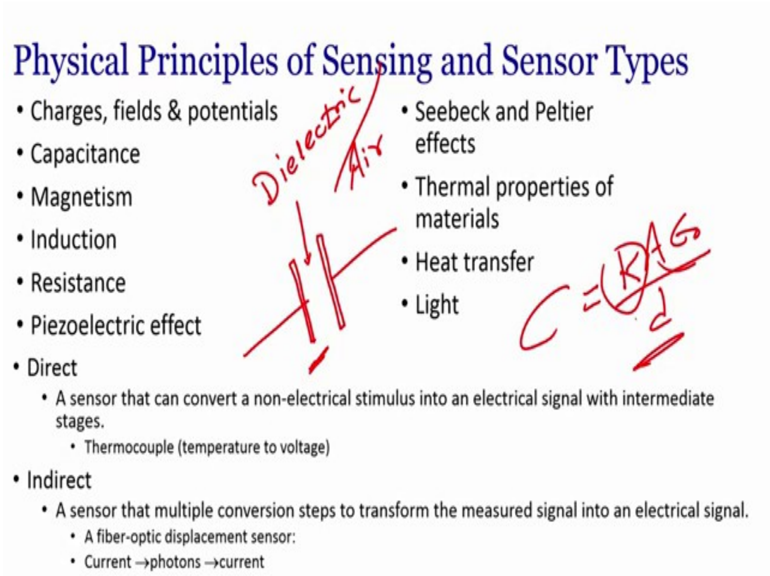
Now, when you talk about physical principles of sensing and sensor types, then there are several physical principles that you need to take care of, and this is a last slide of our lecture this particular module. So, physical principle of sensing and sensor types are charges, field and potentials. There can be capacitance, it depends on magnetism, induction, resistance, piezoelectric effect. It also depends on like we have seen earlier seebeck effect and Peltier effects, thermal properties of materials, heat transfer, light. Seebeck effects you can just see go back and check it. So, everything that I am talking about you please go back and understand what capacitance is, what is magnetism, what is inductance, what is the resistance.

For example, I will just give one example resistance. How you define resistance R equals to what? it is a you can say that it will resist the flow of current, but it depends how it is depending on a material. For example, if you say a resistor R equals rho l by A, it depends on the area, depends on the land, it depends on the resistivity of the material. If the length is higher resistance is higher, if the area is smaller resistance is higher, if the area is larger resistance is smaller, the length is smaller resistance is smaller several things. The resistivity is higher resistance is higher, resistivity is smaller resistance is smaller.

So, so many things just we have an example of a resistance same thing you can understand the effect of piezoelectric; piezoelectric is what we have see there is a difference between piezo resistive and piezoelectric. Piezo resistive is when we apply a pressure there is a change in resistance, piezoelectric is when you apply a pressure that is change in voltage, crystals piezoelectric crystals are there. Piezo resistor materials can be designed by doping is poly silicon with boron there can be design, we can design a piezo resistor.

Thermal properties of material you do not understand, you do not understand heat transfer properties of material, you do not understand how the light will work, how do you understand C capacitance, how capacitance is related for example, I just should give you an example of resistance, how about capacitance.

(Refer Slide Time: 38:41)



For capacitance the formula is C equals to if you see the slide C equals to K A epsilon naught upon d permittivity, area constant K, d is your distance between two plates. What is capacitor? Capacitor is nothing, but two conducting plates separated by dielectric material or air. What are these two things? These are two conducting plates correct.

Now, the distance between these two plates, the area that capacitor covers, the permittivity and constant everything depends on everything defines the capacitance all. Now, when we talk about types of sensors; sensors types there are two types; one is direct sensor and second is an indirect is an indirect sensor. A sensor that will convert a nonelectrical stimulus into electrical signal with intermediate stages for example, thermocouple that is temperature to voltage is a direct sensor.

When you talk about indirect; indirect sensor is nothing, but a sensor that multiple conversion steps requires multiple conversion steps to transform the measure signals into electrical signals. For example, a fiber optic displacement sensor where first is a current, then converts to photons again converts to current.

So, these are the two examples of sensors and let us learn the types of actuators in the next class, in the next module what we have learned here is, what are the kind of sensors available with quick application of sensors, what are the physical principle, when you select sensor what kind of you know environmental parameters you to consider, economic factors you to consider, sensor characteristics you to consider and what are the it can be divided into two paths direct sensors and indirect sensors. In the next class let us understand how the actuator work.

If you are any question always remember that we have NPTEL forum through which you can connect to me through my teaching assistants and whenever you have an equation feel free to ask me through the forum and we will try to get back to you as soon as we can. There please focus on this kind of lectures when you know attain all the lectures with little bit of focus you will be understanding lot of things, because understanding sensors is a very important you know topic since it can not only be used to understand the several physics, principle in physics or, but also to understand lot of you know research problems.

So, if you talk about all the medical devices or most of the medical devices several of those devices, they used lot of sensors, lot of actuators. So, understanding this particular course in detail will help you out with the understanding of lot of tools as well as to come up with a; come out with an interesting problem in the area of research and development. So, I will see you in the next class till then you take care have fun; bye.