Industrial Instrumentation

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Lecture - 34
Smart Sensors

Welcome to the lesson 34 of industrial instrumentation. In this lesson, we will study smart sensor. Now, is the talk of today I mean when you call the smart sensors and suddenly I mean there are sensors. We sometimes we call sensors sometimes we call transducers as a whole sometimes we call instrument. And there was intelligent instruments or intelligent sensor suddenly we started to call it a smart sensor right. Obviously, there is, are differentiation between the ordinary sensors smart sensor and the intelligent sensor. So, in this particular lesson we will look at all those and we more discuss in more details I mean when the sensors can be called as a smart sensor. There are some definitions even though that is not widely expected, but the some people who actually developed some kind of smart sensors. So, well those are discussed they have developed some norm. So, they have developed some terminology I mean on the smart sensors. So, in this lesson we will discuss all this in details. Let us look at the contents of these lesson 34 smart contents.

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Contents; introduction to integrated smart and intelligent sensors there are integrated sensors smart sensors. That means, if we have some sensors if the signal condition is circuitry itself on the chip itself we call it smart sensor I mean we can call it integrated sensor not necessary intelligent one right. So, it starts from there then the working principle of intelligent sensors some examples of smart sensors these are basically we will cover in this particular lesson right.

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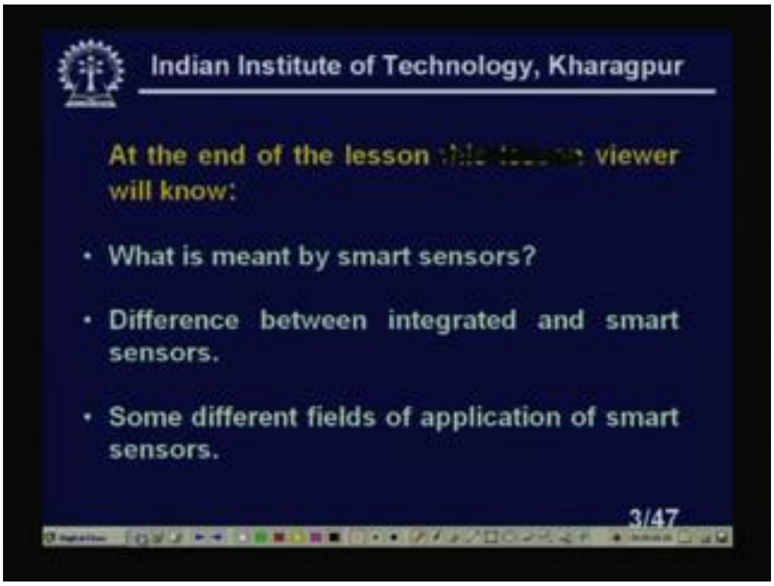

At the end of the lesson, the viewer will know what is meant by smart sensors, difference between the integrated and smart sensors and some different fields of application of smart sensors? I am sorry that there is some error it will be at the end of the lesson the viewer will know. So, this is should note there. So, it should be wiped out like this. So, at the end of the lesson the viewer will know it will like this. Now, integrated smart and intelligent sensor. Let us look at all these in general then we can classify one by one, right

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The successful applications of many types of solid state sensors that means semiconductor sensors solid-states. We are using that is semiconductor sensors has stimulated the market, but led to a demand for either a lower unit cost or an enhanced functionality to improve the market value. You see that if you say some smart sensors and with a huge value nobody will buy. Suppose if you are telling about some temperatures sensors which is based of semiconductor based which have integrated I mean circuitry inside. So, that is a smart sensors with some intelligence functions, but the cost if the cost is extremely high.

So, nobody will buy that type of sensors. So, they will rather use a thermistors and with signal conditioning they will make it outside right. So, the cost factor is very important while you are choosing the sensors or designing the sensor that is the reason we have been calling. The successful applications of many types of solid-state sensors has stimulated to the market, but led to a demand for either lower unit cost or an enhanced functionality to improve the market value. See until and unless the functionality is over suppose it can discard some value which is coming of the range that type of thing it has some decision making functionality.

So, then only if the even if the cost is higher the people can buy or industry can buy industry can install that type of sensor otherwise not. Both of this may be achieved through a higher level of device integrations. Now, all these sensors we are talking about nowadays it is SOC basically system on chip right which is or I mean entire sensors. It is single conditioning circuits everything should be on the chip. Then only we can which is called basically a SOC or system on chip then only we can say that I mean it is a smart or intelligent sensors. If we had some intelligence and. So, large scale device integration is necessary to make this type of sensors.

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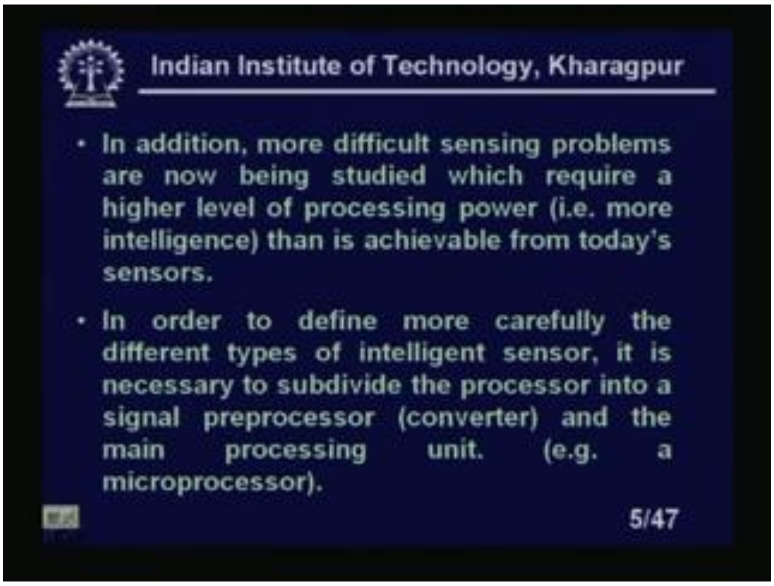

In addition more difficult sensing problems are now being studied which require a higher level of processing power or more intelligence than is achievable from today's sensors. Suppose a simple thermocouples or a thermistor for making a measurements of some sort of I mean the functions which we will get. Suppose a nonlinearity can be removed if there is some signal which is of some other sort of a self test systems inside the sensors. So, that type of things I can say it is intelligence smart.

A sensor output or there is some checking that the sensor is working or not which is very common in the case of thermistor and the thermocouple. You know some sometimes thermocouple is out of order I mean because the junctions, because it is a dissimilar junctions. Sometimes the junctions are out or cut and thermistors sometime fails all those things these things can be. Suppose if you have a built in self test; that means, some testing algorithms or testing mechanism by which I can check the health of the sensor. Then only I can say it has some sort of intelligent this is one form of intelligence sensors or smart sensors I should tell. In order to define more carefully the different types of intelligent sensor. It is necessary to subdivide the processor in to signal preprocessor which is basically a converter and the main processing unit that is a microprocessors.

Obviously, any if I need some computations nowadays. So, I should have some form of I mean CPU or central processing unit is necessary. So, one of the easiest way to use that thing is either microprocessors or a micro controllers. You know 8 bit microprocessors we know that very common form of microprocessors which has quite good. I mean computational power which can which can I mean make some computations it can make some decisions that type of things is possible. And more interesting thing is you see most of the sensors what we are talking about is a is basically a analog I mean in nature. The signals which is coming out from the sensors whether it is a thermocouple thermistors or any RTD's team basically it is a analog in sense. That means the output is continuous whether it is a variations of the resistance or the variations of the current it does not matter right. But if I now incorporate that thing in a digital form that means, if I want to incorporate on a microprocessor; obviously, that comes that the mixed signal circuits right.

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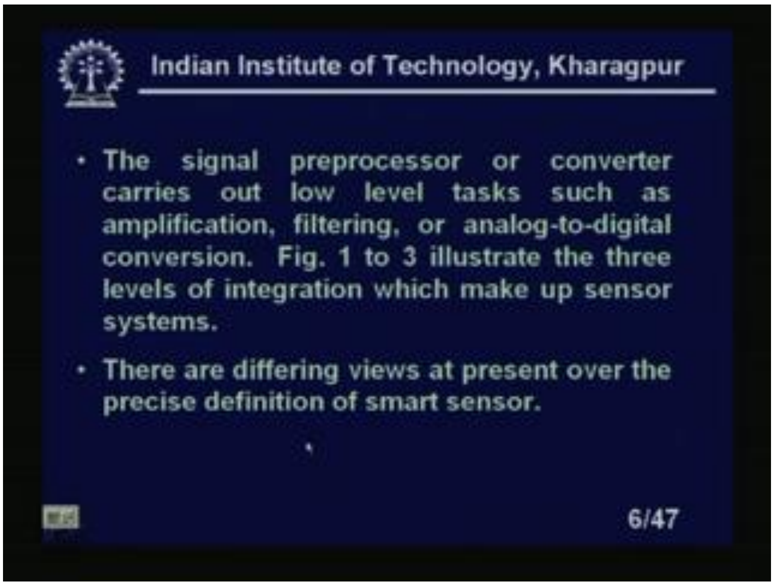

Now, signal preprocessor or converter carries out low level tasks such as these are basically low level tasks. Because I have a amplification filtering and analog to digital conversions like this one, what are this? Let us look at…

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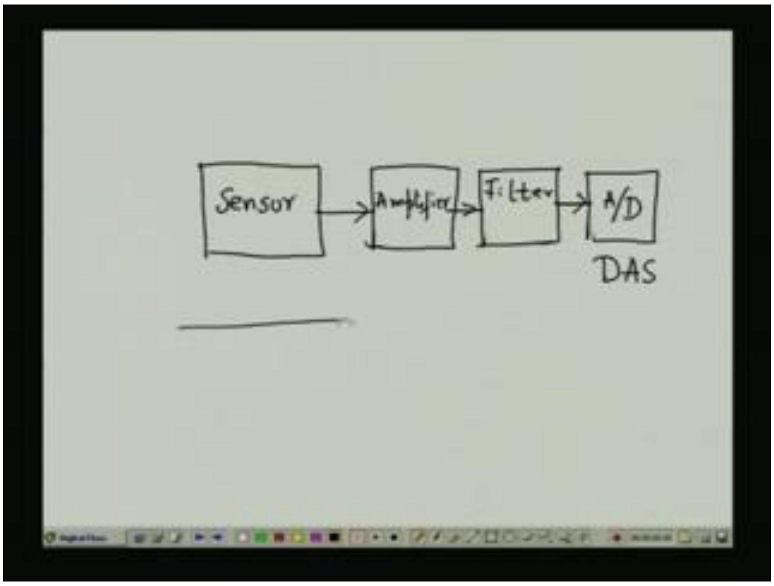

That means suppose I have a signal which is coming from the sensor itself it is generating some signal it might be low in level voltage level. So, I need an amplifications, so I put an amplifier here. Then I may need a filter also if it is AC signals I want to unbound it I mean undesired frequency band is to be discarded. So, I am using a filter then I am using a A to D convertor right. Now, this for this can be a data acquisition card also data acquisition systems or DAS. So, this is the entire systems this should be already incorporated in a single chip right. Now, signal preprocessors or converter carries out low level tasks such as amplification. So, this is a preprocessing it is a filtering it is making A to D conversions; that means, analog to digital conversions.

Or then figure 1 to 3 illustrates the 3 levels of integration which make up sensor system; that means, both the normal sensors intelligent sensors smart sensors. So, this 3 things are I mean we have discussed in the we will in the following slides 3 slides what are those actually means actually we want to meant right. There are different differing views at present over the precise definition of the smart sensor. As I have told you it is a very new thing and which is coming up there is no precise definition I mean why should I call it a smart sensor? So, there are different views from one one differs from the other. So, this is you see a typical sensor system without any intelligence without any smart test.

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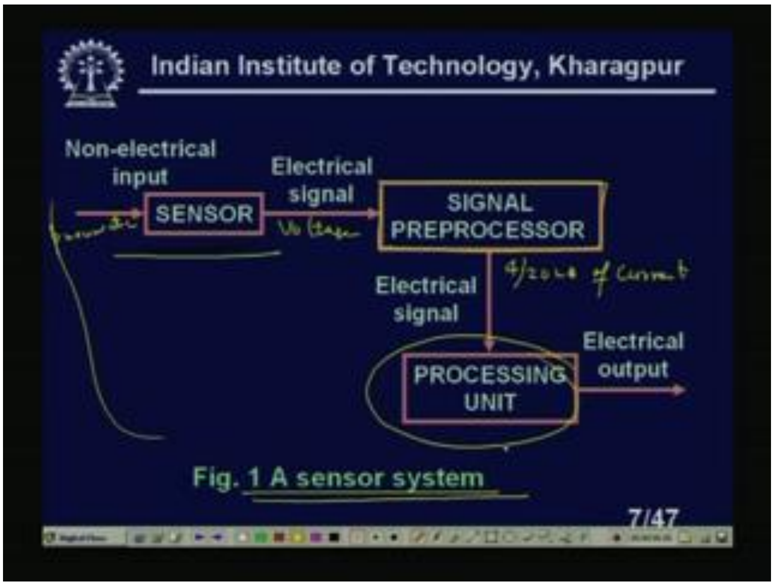

So, I have a, you see I have a non-electrical output. Let me take a another type of pen. I have a non-electrical output see it might be pneumatic signals also this signal might be pneumatic is not it? This I am signaled through pneumoelectric converters I am converting to electrical signals right. Suppose in the flow measurements we have seen in details in the flow measurements that is in pneumatic signals which is coming from the differential suppose differential sensing devices. Now, we want to convert that to 4 to 20 milliampere. Electrical signal is coming now signal processors because this is basically this output will be voltage.

Now, signal processor you see it is a entire unit right I am talking about just now I which I have drawn; that means, it has amplifier it has filter that type of thing. Now, processing unit not necessarily it can be inside the computer itself. So, this current usually this will be 4 to 20 milliampere of current this will come. Then I have a processing unit processing unit what will do it will convert to the digital domain it will take some decisions I mean some it will display and all this things. So, there is no as such there is in the entire scheme if you see there is no sort of any sort of intelligence or any sort of smartness in this particular sensor scheme. These are basically sensors or I should say not necessarily conventional sensors many modern sensor modern day senor might be.

Suppose a very extreme brand new a micro Do 2 sensors; that means, where I want to measure the oxygen contents in human tissue which is very sophisticated sort of very small in size I want to know that type of things. It is a very new type of devices, but not necessarily that will be intelligent or smartness smart sensor. In that type of situation the entire things I can define any sensors I should say can be defined by this particular diagrams. These particular diagrams I can I mean sense any particular I mean any typical sensors right. Now, this is integrated sensors in a sensor system.

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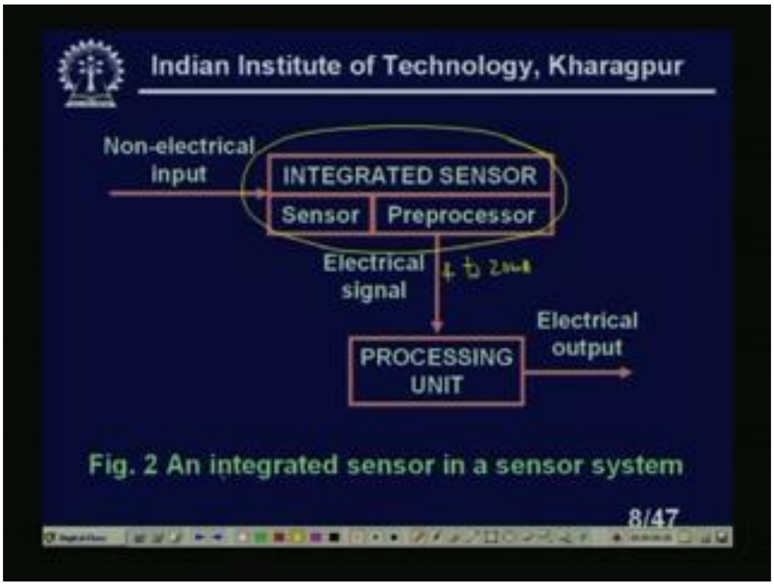

Entire thing as a whole I can I am calling it sensor system because while I am calling it sensors only. That is actually I am getting some measurement right on the particular parameters might be pressure temperature flow. Now, when I am making the excuse me when I am making the single conditioning when I am making a single conditioning that times I can say that it is a as a whole sensor system right. So, here you see the sensors we have non-electrical output input, because not necessarily from the all the sensors we are getting electrical input right that might be non-electrical input. So, I have integrated sensors I have a sensors preprocessor then electrical signals and processing unit and electrical outputs what I am getting right.

So, there are preprocessors and sensors you see in a one. So, this is some for sort of integrated sensors you can look at right. So, I have sensor unit I have a preprocessing unit before though it is a current. Now which is sent to the processing unit or might be the CPU of a computers through the data acquisition. And because at the data acquisition card usually this is as I told you earlier it is a 4 to 20 milliampere of current. This is to be converted in the voltage domain and processed through the data acquisition card this signal will go the computers and the computer will process and I will get a electrical output right. So, as such it is I should say it is integrated sensors; that means, the sensors and the preprocessors on a single chip right. Now, a smart sensor or integrated an intelligent sensors looks like this.

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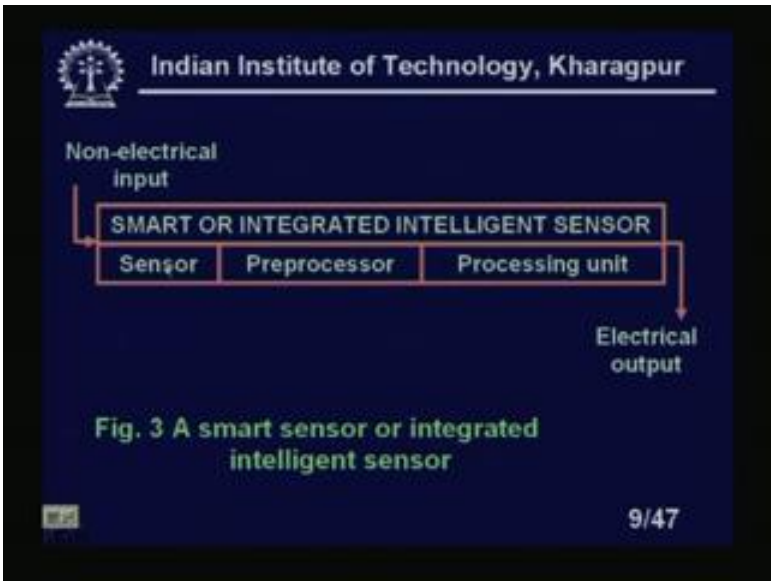

You see the sensor preprocessor processing unit, are all in single chain. So, this type of sensors I am calling it smart sensors. Obviously this processing unit has some decision making I mean functionality that there should be there otherwise I should not say a smart sensor right. It can discard suppose a signal say I mean some data is coming which is out of band. So, the system should be in a position to discard that signal not shown in the electrical output right. That type of decision making algorithms or root functionality should be there in the, but as a whole this is a smart and integrated sensors.

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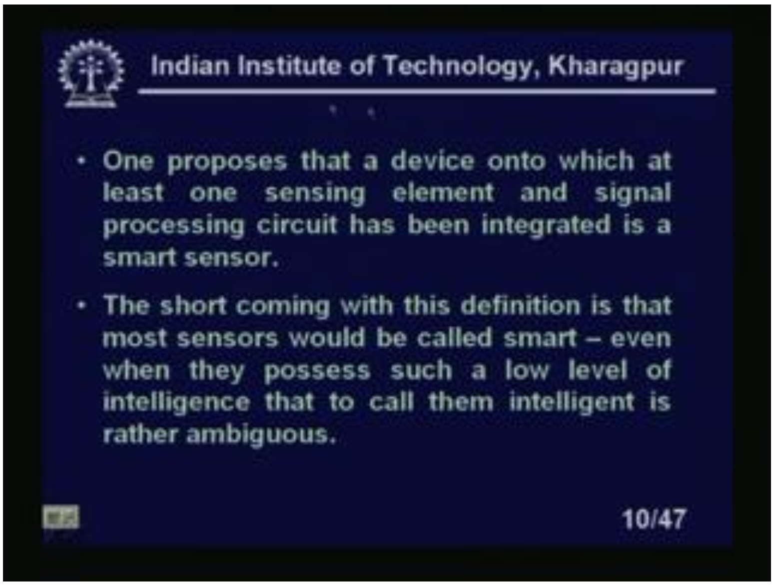

One proposes that the device on to which at least one sensing element and signal processing circuit has been integrated is a smart sensor. Not necessarily, because when the, it started people as started to define. Like that that one proposes that a device on to which at least one sensing element and signal processing unit circuit has been integrated is smart sensor where this definition is little vague I should tell. Since it is a newer devices; obviously, you can understand that the, this is just developed definitions is not very I mean well accepted I should say right.

The short coming with this definition is that the most sensors would be called smart even when they possesses possess such a low level of intelligence that to call them intelligent is rather ambiguous. Because this I cannot say I mean it is just a I mean a sensors which is signal conditioning something I should not say intelligent. Because it is not a intelligence it is a part of signal processing I should not say it is a intelligent sensor right. So, if this definitions is not well accepted if you see you can say integrated sensor obviously, but not necessarily you can say intelligent sensor.

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Instead we will use the term integrated sensor to describe this type of low level smart sensor where most of the preprocessor is integrated as shown in the figure 2. We have already shown in the figure 2 that this all the preprocessing unit rather the preprocessing units are integrated within the sensor itself. That mostly this type of things; obviously, comes in the case of semiconductor sensors right instead we will use the term integrated sensor to describe this type of low level smart sensor where most of this preprocessors are indicated as shown in figure 2. We have shown already in figure 2 we can go back this is the figure 2 right some sort of preprocessing is done you can see here some sort of preprocessing is done right fine right. The term smart is reserved to denote the integration in part or full of the main processing unit which adds the intelligence. That means say when I am calling it smart; that means, it will be either part or fully preprocessed. So, a smart sensors already we have shown in the figure 3, right.

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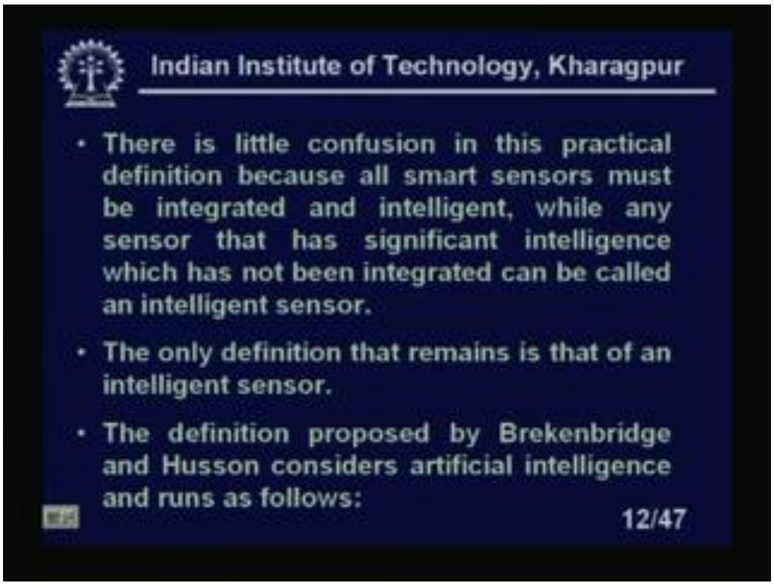

There is little confusions in this practical definition because all smart sensor must be integrated and intelligent. While any sensor that has significant intelligence which has not been integrated can be called an intelligent sensor. So, smart sensor must be must integrated sensors, but a smart sensor; if they are some sort of intelligence. But it is not integrated I we just simply call it integrated sensor or intelligent sensors I am sorry. The only definition that remains is that of an intelligent sensor the definition proposed by Brekenbridge and the Husson considers artificial intelligence and run as follows.

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They are telling the sensors itself has a data processing unit with automatic calibration automatic compensation function in which the sensor detects and discards abnormal values or exceptional values right. That I told you several times it incorporates an algorithm which is capable of being altered. And has a certain degree of memory function and further desirable characteristics are that the sensor is coupled to other sensors adapts to change in environmental condition and as a discrimination function. All this thing should be I mean this should other sensor there is a combination protocol all those thing then we can call it intelligent sensor.

Not necessarily; that means, suppose I have a DMM a digital multi meters it can nowadays digital multi meters in auto ranging auto zeroing. All those facilities are there, but I should not call it a smart sensor or like that I should rather call it a not also intelligent sensors. I can call it only the integrated sensors right because it cannot discard the values which are coming I mean out of range and all those thing which I have just talked about. You see here in the algorithm which is capable of being altered has a certain degree of memory functions compensations abnormal values. Or exceptional values can be discarded only then I can call it a intelligent sensor.

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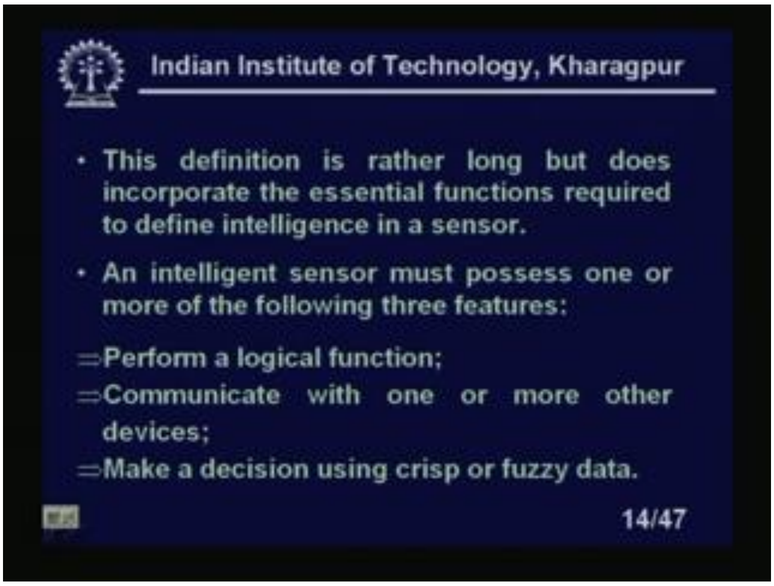

This definition is rather long, but does not incorporate the essential functions required to define the intelligence in a sensor. What are the how will I call a sensor intelligence that is will define in particular this definitions right. An intelligent sensor must possess one or more of the following 3 features an intelligent sensor must possesses one or more of the following features 3 features what are those? Perform a logical function, number 2; communicate with one or more other devices. Perform a logical function communicate with one or more other devices and make a decision using a crisp or fuzzy data.

That means too hot or hot too cold like this fuzzy data it can take some decisions right only. Then I will call it intelligent sensor and also it should have communication facility with the other sensors also not necessarily only one sensors. I should if there are ten sensors you should have a communication facility and perform a logical functions that should be all; that means, some form of arithmetic computation should be there. Obviously I need a microprocessor or micro controller for doing this then only I should say a intelligent smart sensor.

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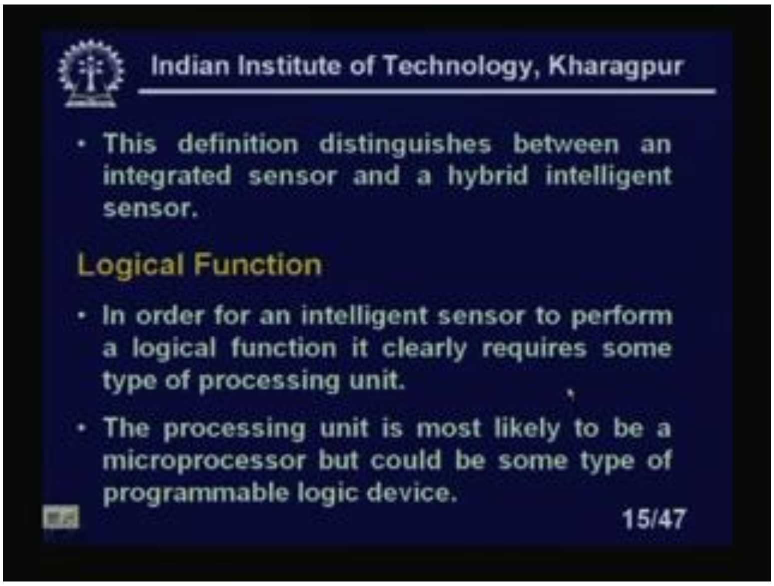

This definition distinguishes between an integrated sensor and a hybrid intelligent sensors. It might be it is a hybrid in the sense that it is some form of intelligence is there or may not be there. Now, logical function what are those logical functions I talked about, because I said already that it is a should be a logical function perform a logical functions. So, what is that logical functions? In order for an intelligent sensor to perform a logical function it clearly requires some type of processing unit. Any logical function as you know it is a whether it is a I mean adder subtracter. So, I need a some form of logical I mean if you want to do I need processing. What is the simplest processing unit available? It is a microprocessors not necessarily very large I mean very highly computational processors.

Most of the applications we have seen in the instrumentations; that means, it is a 8 bit microprocessors will solve our purpose. So, either microprocessors like Intel 8085 which is a 8 bit processor as you know Pentium is a 32 bit microprocessors. When we call it 8 bit microprocessor 32 bit microprocessor please note actually we are referring to the resistor size. Because all the, I mean in all processing in all this logical functions and all this when you perform we are have to shift a load all the manipulations actually we do in a resistor itself. There are several resistors depending on the complexity of the microprocessors and these resistors. Actually the if you look the resistor size we can tell what type of bits I mean how many bits?

When we said the 8085 Intel 8085 is a 8 bit microprocessors we can look at the resistor size we will find all the resistors are 8 bit. Whereas, when I call the Pentium processor is a 32 bit processors if you look at the resistor size of the pentium. Number I do not consider there are several numbers there are or the number of resistor differs from the 8085 8086 and a and the pentium processors. But this size of the resistor will tell whether it is 8 bit processor or a 32 bit processor. But most of the instrumentation applications we will find that this 8 bit processor will suffice right. And if you need some peripheral chips in most of the cases we need some peripheral chips we can go for a micro controller micro controller is.

Difference between the microprocessor and the micro controller is that it has some in built chip which is necessary because in 8085 a microprocessor a processing unit cannot work until and unless it has some peripheral chips. Some sort of RAM to a minimum RAM is necessary 2 kilo RAM is necessary 2 kilo byte RAM is necessary some ROM is necessary. This is a minimum thing is necessary in the microprocessors I may need some counter or timer or counter. These all those things are incorporated in a 8 bit microprocessors like 8051 or 8091 this are basically Intel based microprocessor. This is a 8 bit microprocessors it has 120 byte of memory RAM very small, but most of the applications you will find that is enough right.

So, that is the logical function in order to for an intelligent sensor to perform a logical function it clearly requires some type of processing unit. The processing unit it most is most likely to be a microprocessor, but could be a some type of programmable logic devices. PLC also we will do, but that will reduce the cost, but nowadays as you know microprocessor cost is not very much. So, instead of programmable logic controller you can use it, but the microprocessors in most of the cases will work very fine. Because we know how to programs and all this things microprocessor has some language that will simplify the process.

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The integration of the processing unit with the sensor then requires a significant electronic design effort. So, this basically most of the sensors I talked about the intelligent smart sensors is basically electronic sensors or a semiconductor sensors and effort perhaps through the use of application specific integrated circuit or ASIC which is called applications specific integrated circuit technology. So, lot of integrations are necessary, if you want to make a intelligent or smart sensors.

An intelligent sensor may be able to communicate with it is operator. So, provide valuable information about the problems etcetera. Alternatively an intelligent sensor may communicate with the another device. So, modify it is own behavior right. Intelligent sensor may be able to communicate with it is operator and. So, provide valuable information about the problem etcetera. Alternatively an intelligent sensor may communicate with the another device. So, modify it is own behavior.

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A type of intelligence can in it is simplest form provide a warning of abnormal operating conditions or more cleverly provide a feedback control mechanism. That I told you; that means, suppose a thermocouple is not working. So, a temperature sensor is not out of order. So, intelligent sensor should be even in the position to tell that the sensor is not actually working right. That means a some sort of test mechanism should be there in the inside sensor itself or in the integrated chip itself. Intelligent sensor may provide a good level of control such as via digital controllers that is possible if you use a feedback systems and all those things. An intelligent sensor may have some form of high level adaptive control strategy that permits the control parameters to be automatically updated with time. So, you know the controller parameters those who are studying control you know. So, you can update automatically. So, that type of situation should be there. It will have some I mean it will predict something or it will get some those data from as the time changes. Then only it will update those controller values then only I will call it intelligent sensors.

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The implementation of a sensor which can warn it is user or adapt to environmental conditions requires some decision making capability right. Now, it is very difficult suppose I have a Wheatstone Bridge, we have studied that suppose I have I am measuring the I mean load by a strain gauge right. Now, as you know the strain gauge is basically resistive based sensors. Now, if the temperature changes environmental temperature changes usually what we do? We connect the, that with a strain gauge in a Wheatstone bridge either a single strain gauge or 4 active strain gauge it does not matter. Now, if you have a single strain gauge as the temperature changes environmental temperature changes there is a change of resistant, but I am no I do not want that.

Because the unbalanced voltage of the strain gauge of the Wheatstone bridge will be different. What I want that the output will be only it should be dependent on the unbalanced voltage of the Wheatstone bridge and basically that depends on the change of the resistance in the strain gauge itself right. So, simply how we will do we use an an ambient temperature we use another strain gauges. So, for ambient temperature compensation, but that I should not say intelligence sensors. Just it is one to one correspondence that if that the both the resistor changes due to temperature change that will be nullified. Some sort of the decision making system algorithm should be there in all the intelligent sensors. Though I am saying to adapt a environmental condition requires some decision making capability there should be some decision making capability there.

Traditionally sensors use a parametric data to make a decision. For example, the signal from a diode can be used to provide a overload protection to a device which exceeds it is normal operating temperature. Diode can be used as you know I mean it is a used in many places we have seen for overload protections, because in the op-amp also, as you know in the op- amp the output is, if you accidentally connect the op-amp output to the ground. It is not that op-amp output will op-amp will burnt out there is a short circuit protection in the op amp right. Because with a diode and as you know that in a series regulators we are also protecting the junction which is they are costly transistors series transistor by diodes also. Because if you bias the diodes always you will get across the diode point seven volt, right. So, that can be utilized to protect your circuit right. So, traditionally sensors use parametric data to make a decision for example, the signal from a diode can be used to provide an overload protection to a device which exceeds it is normal operating temperature.

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However, more intelligent sensors of the future may use a nonparametric methods such as artificial neural networks and or expert systems which relies upon fuzzy data. Expert system as you know is a program and is based on an IBS program it has some form of form of decision making algorithm. But as you know this when you are this is all basically a program it is not necessary it is a software when you want to I mean connect it to a hardware devices to a sensors. So, I have to make it some microprocessors or some micro controller where this decision making algorithm like neural network. Neural networks also as you know it is very it is not very cost effective. If you want it is cheap over it will extremely high if you want to realize a neural networks in the wafer.

So, if you want to I mean use the neural networks synthetically or artificially neural networks; obviously, I need some form of computations or some form of CPU. So, microprocessor are best thing which you can give that the definition of an intelligent sensor used here includes any sensor system that contains a discrete microprocessor unit right. Either a discrete microprocessor unit, because you see that is a SOC or mixed signal circuits. Because mixed signal circuit is a circuit where both you have a digitals and analog on the same chip right.

Now, it is very talk of today as you know this mobile phone and all this things are basically a mixed signal circuits, but it is quite expensive also. So, if I take out this microprocessor unit I mean then we can call finally, it as a intelligent sensor, but in future; obviously, we will try to make the microprocessor units with digital circuits some analog sensors also at the same chip. So, that it will lead to a a mix signal smart sensor. Consequently there are a large number of instruments that are classified as intelligent sensors.

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A few is examples of intelligent sensors and their applications are listed in table one examples of intelligent sensor system radiant. The sensor class the sensor class principle intelligence and monitors the special Fourier transform of the retro reflected light from a surface is basically machine tool control.

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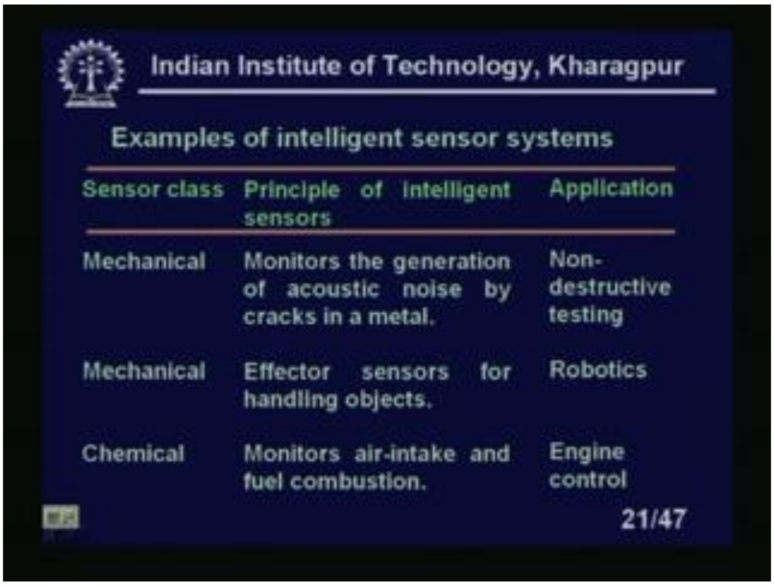

Sensor class mechanical monitors the generation of acoustic noise by cracks in a metal the non-destructive testing. Sensor class is mechanical effect or sensors for handling objects for robotics it is for robotics. Chemical monitors air intake and fuel combustions in engine control right.

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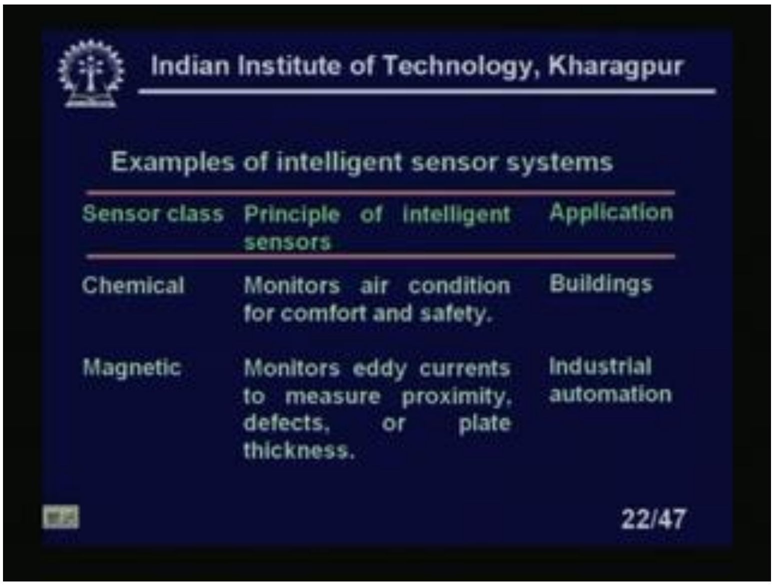

Sensor class chemical monitors air condition for comfort and safety in buildings. Magnetic monitors eddy currents to measure the proximity defects of plate thickness is industrial automations. Now, integrations of signal processing.

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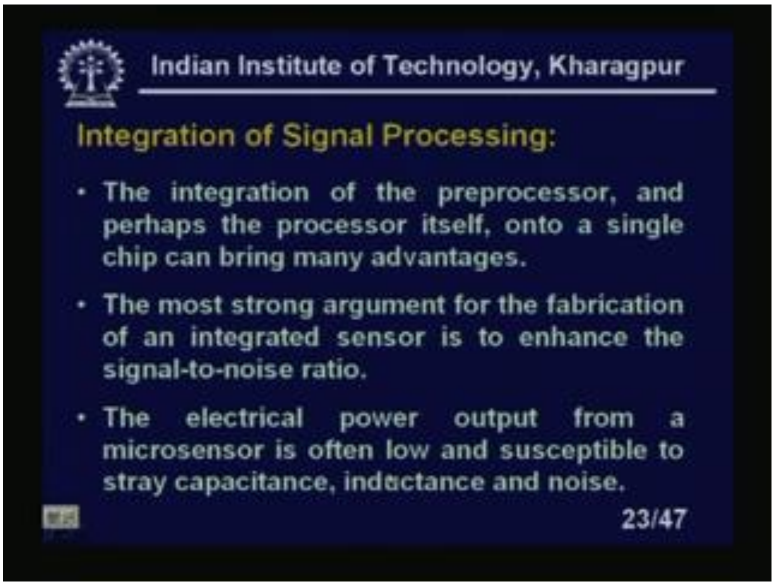

The integration of the preprocessors and the perhaps the processor itself on to a single chip can bring many advantages. Why we are calling it I mean willing to go for intelligent sensors it looks like this. The most strong argument for the fabrication of an integrated sensor is to enhance the signal to noise ratio. Obviously, if you want to transmit this signal to the outside world or to 2 separate chip signal to noise ratio will not be very good. But on the same chip if you may figure obvious a signal to noise ratio or it is an R which is called which is usually expressed in db 20 log 10.

So, it is; obviously, better. The electrical power output from a micro sensor is often low and susceptible to the stray capacitance inductance and noise. You see these microsensors are very, very small in natures and one of the one of the greatest problem is the capacitance. So, if you want to connect to an external world by wire. And all those things that will be in the capacitance of the wire itself will play a picture, because those values of the sensors of the capacitance sensor is extremely small.

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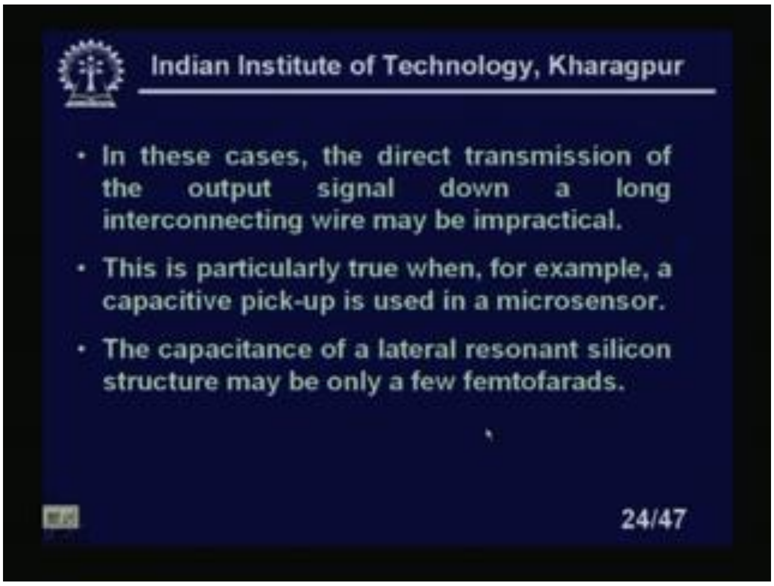

In this cases the direct transmission of the output signal down a long interconnecting wire may be impractical, right. If you want to do, because it is a microsensors that is say it has a very small value of the capacitance change might be. If you want to transmit that signal to some bridges for measurement of the capacitance change or accordingly some voltage change it will be very impractical. This is particularly true when for example, a capacitive pickup is used in a micro sensor.

Capacitive pickups is used for many as you know for the one talk that is our capacitor microphone is there capacitance are used for level sensing. And so many thing capacitance are used for the differential pressure measurements in all this, but if the change of the differential pressure is very small. So, capacitance change also will be very, very small usually these capacitances are order of femtofarads. So, any I mean stray capacitance which is coming of the same order that will totally I mean change the value of the output voltage. The capacitance of a lateral resonant silicon structure may be only a few femtofarads.

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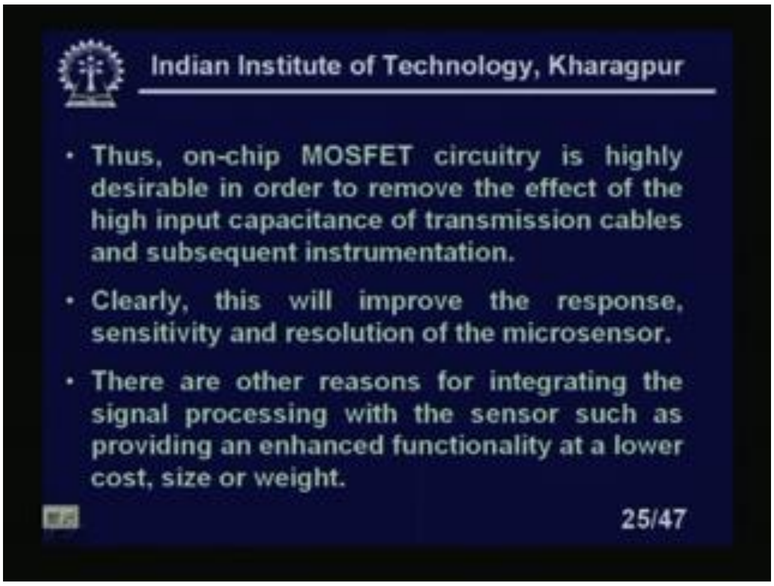

Thus on chip MOSFET circuitry is highly desirable in order to remove the effect of the high input capacitance of transmission cables and subsequent instrumentation. So; obviously on a chip itself, if you can do it; that means, MOSFET circuits remove the effects of this all this interconnecting problem or the interfering of the parasitic capacitance will be immediately removed. Clearly this will improve the response sensitivity and resolutions of the microsensors.

Resolutions means the smallest detectable values which can detected as output smallest change of the parameters which I am going to measure which will make a detectable output right. So; obviously, this will because if the entire thing is I mean I the entire thing is camouflaged by the noise itself . So, that is I would not get the output. There are other reasons for integrating the signal processing unit with the sensor such as providing an enhanced functionality at a lower cost size and weight. Cost will not be that low obviously, but the size and the weight; obviously will be much, much low.

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Now, self calibrating microsensors this is another important thing for the smart sensors we will look at. Most sensors have a at least 2 parameters that need to be set during the manufacturing process this is offset and the sensitivity or gain. Usually we do any sensors if it is not simply passive type of thing, suppose a ammeter or the voltmeter. Then; obviously, we offset if there offset off set might be the zero offset also usually we do we set it before taking a reading and adjust the gain also. If it is a active sensors; that means, it has some signal conditioning circuitry along with the sensor. So, that type of cases we can adjust the gain. A gain is basically as you know we have defined in the first class it is also sensitivity. In the mass production of a sensor the process of calibration individual sensor is expensive and undesirable, but often essential right. So, individual calibration is not possible, but it is sometimes it is very essential specially in the case of semi conductor sensors.

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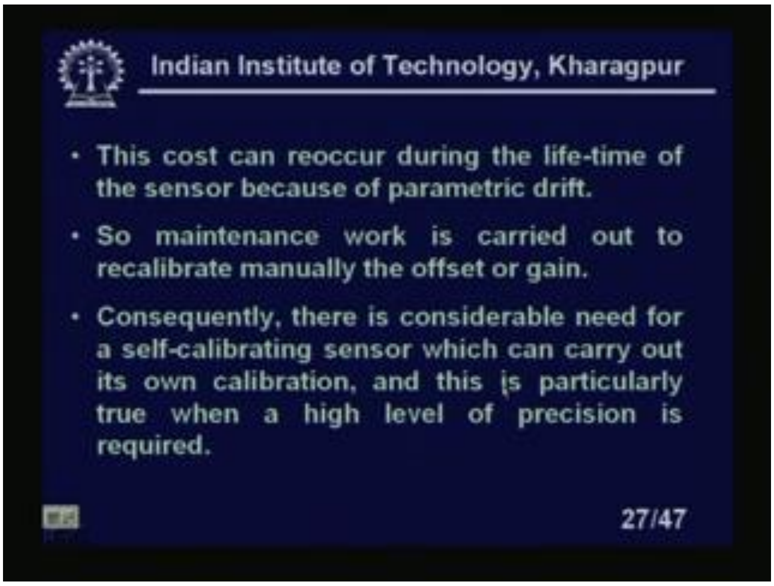

This cost can reoccur during the lifetime of the sensor because of the parametric drift, because this if the parametric drift. From there if you have; obviously, and specially it is very difficult in the case of as I mean integrated sensors where you do not have much provision to change any I mean parameters right. So, you have to either you have to through it out that is the only thing, but you must know whether you have sensors are perfectly working or not. So, some sort of testing unit should be there inbuilt. So, that by which I can know the health of the sensor itself, whether the calibrations which I have done at the initial stage of the sensors that is now still valid or not otherwise entire erroneous I can throw it out.

But the thing is first of all I must know whether that calibration whether I which I did are still valid or not. So, maintenance work is carried out to recalibrate manually the offset or gain right. So, it must be laser trimming that type of thing which is very difficult to do consequently there is considerable need for a self calibrating sensors which can carry out. It is own calibration and this is particularly true when a high level of precision is required when a high level of precision is required. So, this is true even though that is are quite costly.

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The conventional calibration of a sensor may involve the laser trimming on integrated resistors. Integrated resistors to get a typical values. So, I can laser seam it to change the values. So, that the, suppose due to drift suppose the resistance value changes. So, I can make laser trimming to bring it to the value. So, that my calibration will remain valid this means that the resistor film and the patterning process must be comfortable with the IC and the micro sensor technology. Typically resistor films like chromium and nickel chromiums are vaporized from the substrate by a YAG lasers in controlled cuts or trims. So, that I will get the precise value of the resistance.

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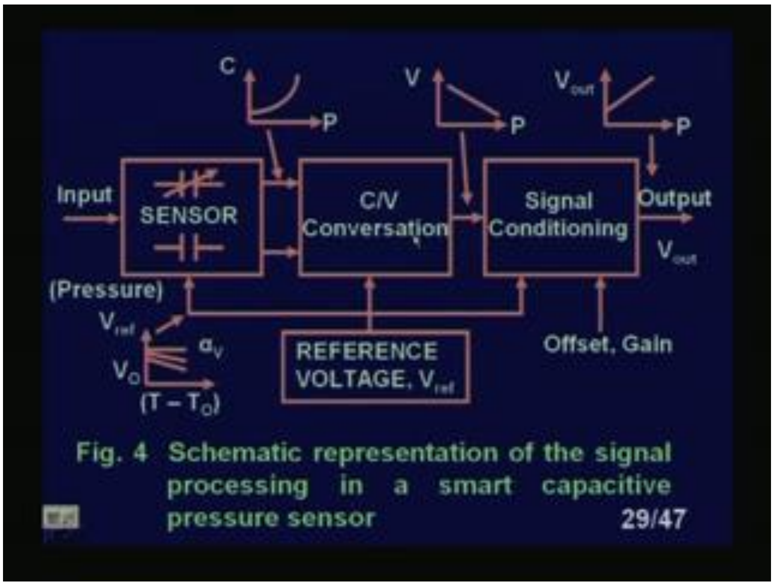

Now, schematic representation of the signal processing in a smart capacitive pressure sensors. That you see what I have a sensor unit here which is variable I have a capacitance to voltage conversions basically it will be capacitance to volt. Because all capacitors ultimately if you measure you put one bridge I will get a unbalanced voltage. So, this is a bridge circuit, so capacitance of voltage conversion I have a signal conditioning. Now, I have V reference voltage you see here see any sensor. So, in this I will create a smart sensor this entire thing I should say this entire thing I should say a smart sensors. This I should say a smart sensors only if I have the capability of changing this calibrations of this all this 3 units. So, for that reason there should be some sort of intelligence for the measurements of the output voltage. From time to time I should check accordingly I will change this parameters.

So, that the whatever the output desirable output for a particular change in capacitance will remain same as before only that time and that time I could call it a smart sensor. So, that is the thing reference voltage some sort of you see I am changing here offset and gain of the signal conditioning circuit. If there is already due to drift this that it has changed I will change the offset I will change the gain. So, I must know whether my calibration is still valid or not right. Figure 4 shows a block diagram of the signal processing that takes place in the capacitive sensor and it is associated electronic circuitry. That is we have just shown let me see it again schematic representation of the signal processing in a smart capacitive pressure sensors. You know the pressure sensors also we have seen that thing; that means in the differential pressure, because why we have we have seen that we have in that I mean we have a differential pressure sensors.

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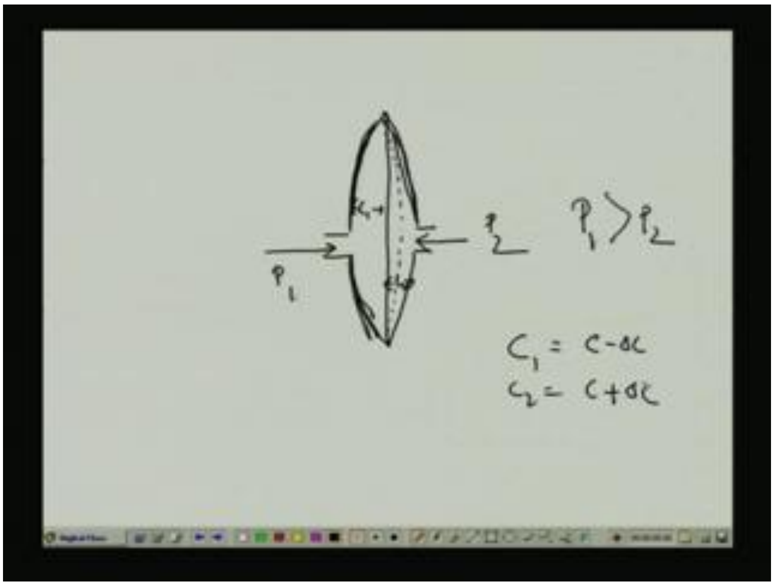

Let me take a black pen. I have a still diaphragm this you have already discussed right still let me just make a recapitulations. So, this pressure is P one this pressure is P 2 if the P one is greater than P 2 the still diaphragm will move like this one, is not it? And this inner side is coated with some metal preferably gold and that type of things inner side it is basically is section of a section of a sphere this is a section of a sphere. So, this inner coating and this plate will make one capacitance. So, if there is a change of capacitance. So, there is a change of the capacitance differential capacitance because this at the middle it will be C.

Now, when it is moved like this one. So, this is if I say that this is C 1 and this is C 2, so C 1 will be previously C. Now, so if the D is increased, so what will happen if D is increased capacitance will be decreased say delta C and C 2 will be C plus delta C is not it? So, this is our actually you see that capacitance to voltage. Now, if I put on a this in a Wheatstone bridge this 2 sensors in a Wheatstone bridge. Then what will happen? I will get a unbalanced voltage. So, this is a capacitance to voltage conversions. So, and also, from pressure to capacitance from, then capacitance to the voltage, so from pressure differential pressure to capacitance, change from capacitance; change to voltage change.

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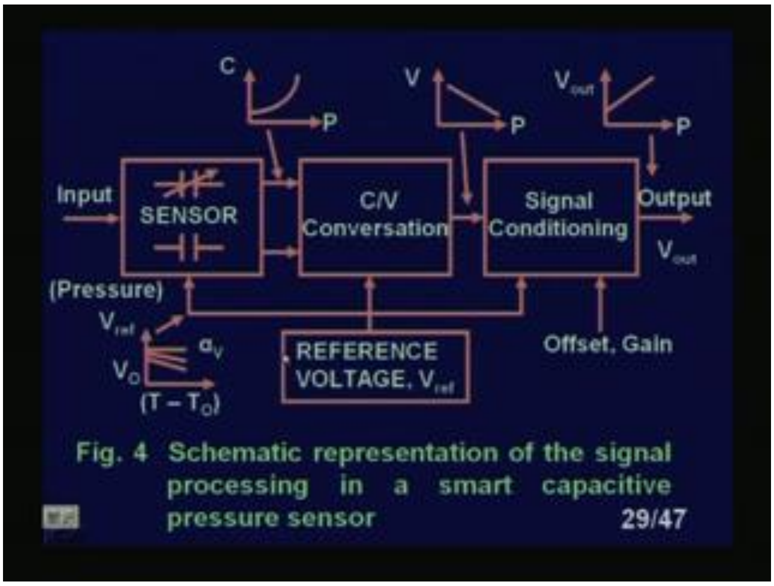

This capacitance this is the capacitance change to voltage change this one. This is one is basic sensor which I am giving pressures I am getting a signal which is you see the 2 signals are coming because there are differential in nature. So, the I am getting a signal which is corresponds to the measure. So, I am getting a change in this capacitance which corresponds to pressure right.

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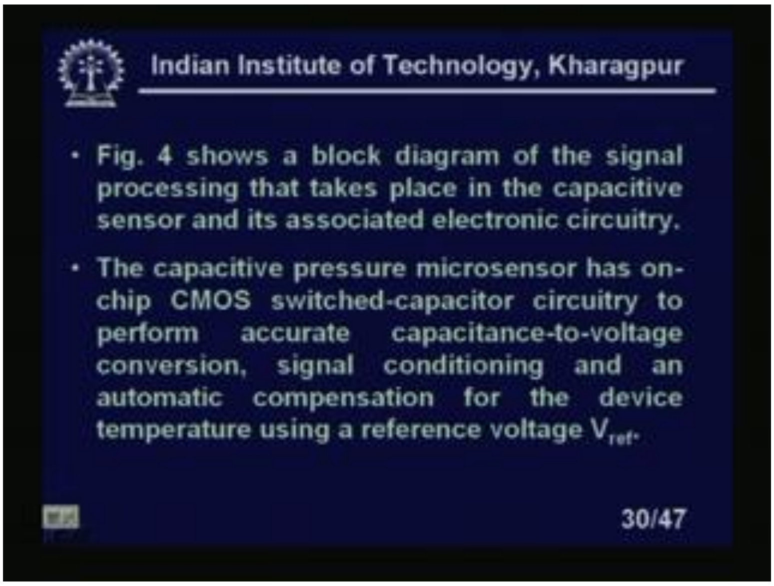

The capacitive pressure my pressure micro sensor has an on-chip CMOS switch-capacitor circuitry to perform the accurate capacitance-to-voltage conversion, because you know that this can be done with a switch capacitor circuits also. Accurate capacitance to voltage conversion signal conditioning and automatic compensations for the device temperature using a relative voltage. The advantage of the switch capacitor circuit it is performance depends totally on the ratio of the capacitance rather than the absolute value of the capacitor that is the reason switch capacitor circuits are preferred. Though there are some limitations of the switch capacitor circuit like parasitic capacitance. But we have some configurations where I can use the switch capacitors in a parasitic insensitive structure right. Basically function is something like this that I have a I can take a blank page.

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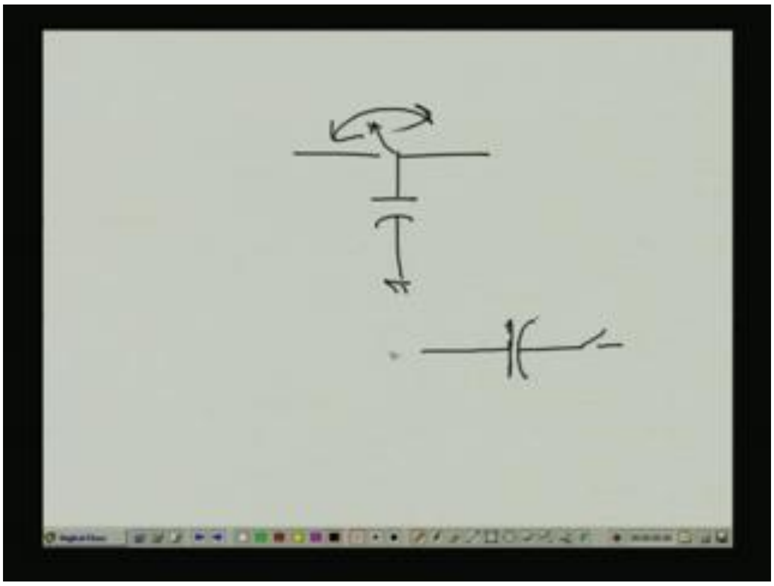

If I have a switch a capacitor like this sorry if I have a capacitor like this one and I have a switch which is toggling between this 2. So, this resistance this capacitance can be replaced by a resistors. So, the resistors can be simulated by a capacitance and 2 more switches clear. So, this will give you the resistor simulation. The advantage of this now this is a parasitic sensitive I can have a I mean in parasitic insensitive if I have a structure like this one if I have a structure like this one this is parasitic insensitive structure right. We can have parasitic in I mean I mean I mean we can have the switch capacitor integrator also I am not going to that details about those things. That is you see the CMOS switch capacitor circuit to perform the accurate capacitance to voltage conversion signal conditioning and the automatic compensation for the device temperature using a reference voltage V reference. By changing the V reference I can change the automatic temperature compensations and all those things.

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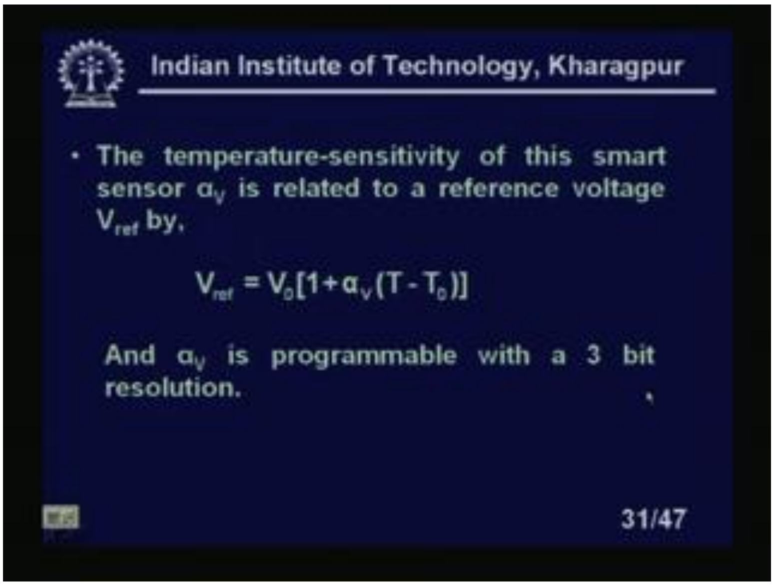

The temperature of this smart sensor d alpha V is related to the reference voltage V reference by the relations V reference V naught 1 plus alpha v T minus T naught and alpha v is programmable with a 3 bit resolutions. Now, self testing microsensors.

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The ability of a sensor to test the functionality is highly desirable right whether it is working properly. As you know I do not know whether I mean that when you switch off when you switch on a microprocessor or you switch on a Pentium processor usually the Pentium tests all the, I mean logic conditions by a built-in self test systems. Which will tell you which will it will load all the accumulators with all zeros if it does not load then you know there is some problem in the chip itself. So, it do it usually do it very fast with a nanosecond. So, you would not be it is not realizable to you, but actually this is they are doing this is called the built in self test. Recent developments in the in the field of smart sensors are leading to sensors with some limited diagnostic capability. This is basically an ability of a sensor to determine whether it is a functioning normally or not.

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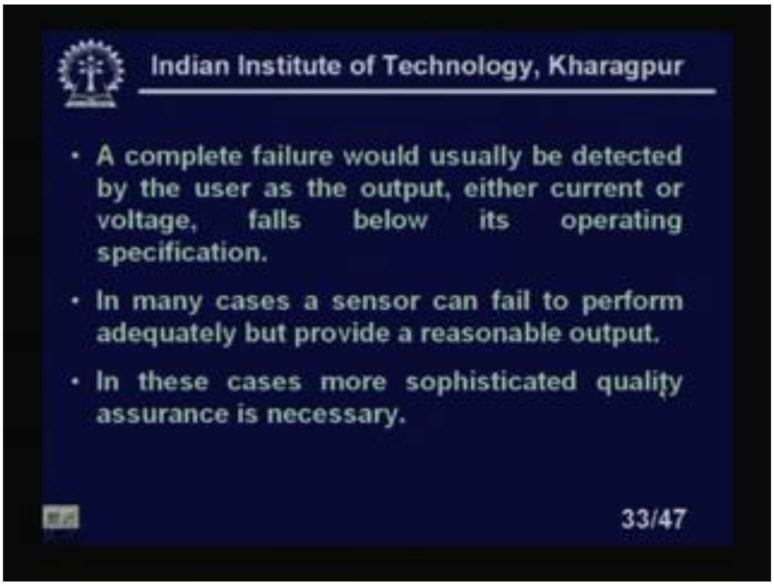

A complete failure would usually be detected by the user as the output either current or voltage falls below the operating specifications. So, this is another saying I mean we have we should have some mechanism when it falls below some values. So, we can say there is a failure. There are various scheme of determining this type of failure of the sensors it is a different testing scheme of the sensors or functionality testing of the sensors. Suppose when you buy a sensor; obviously, we check something for this voltage whether it is showing this current or for particular temperature it is showing the proper value of the current. If it is 4 to 20 milliampere output all those things these are I mean parametric testing right functionality testing. In many cases a sensor can fall fail to perform adequately, but provide a reasonable output many cases I may fail to perform, but provide a reasonable output right? In these cases more sophisticated quality assurance is necessary, because it may not it is giving some output for particular cases or it may not get the correct output if it fails. I mean it may not get for some other value of the sensor input, right.

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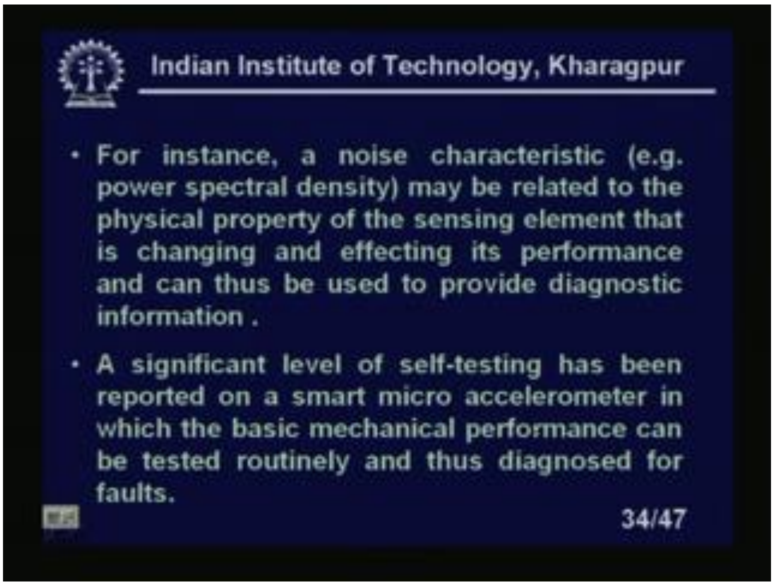

For instance a noise characteristics power spectral density may be related to the physical property of the sensing element that is changing and affecting it is performance can thus be used to provide diagnostic information. So, diagnostic sometimes you know that I mean one of the thing that in a integrated circuits; that means, the bias current changes. Where the bias the current of the circuit changes abruptly then I can say there is some problem in the circuit this is some sort of diagnostic informations which you can get. We can continuously monitor this bias current of the circuit and predict whether the, your circuit is healthy or not. A significant level of self testing has been reported on a smart micro accelerometers in which the basic mechanical performance can be tested routinely and thus diagnosed for the faults if there is some faults. So, I can detect it.

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Now, built in self test will be incorporated in future microprocessor. Built in self test; as I told you microprocessor Intel from 80386 onwards till Pentium processor they have a BIST or built in self test where you have the on chip devices which you check the health of your or test of your devices. Here in the case of micro I mean sensors it will there should be some mechanism by which or built in systems on the same chip by which I can check the whether the, my sensor is or not. Multi-sensing smart sensors often improve their performance through the use of other sensors to monitor undesirable dependent variables multi-sensing is another form it is a redundancy basically. So, if the sensor is not giving correct output if the nine sensors giving correct outputs. So, I can say this that this particular sensor is not correct. With all the nine sensors are giving somewhat I mean similar input output of this; obviously, I can say the sensor number 10 which is not giving some abnormal output this is some sort of redundancy.

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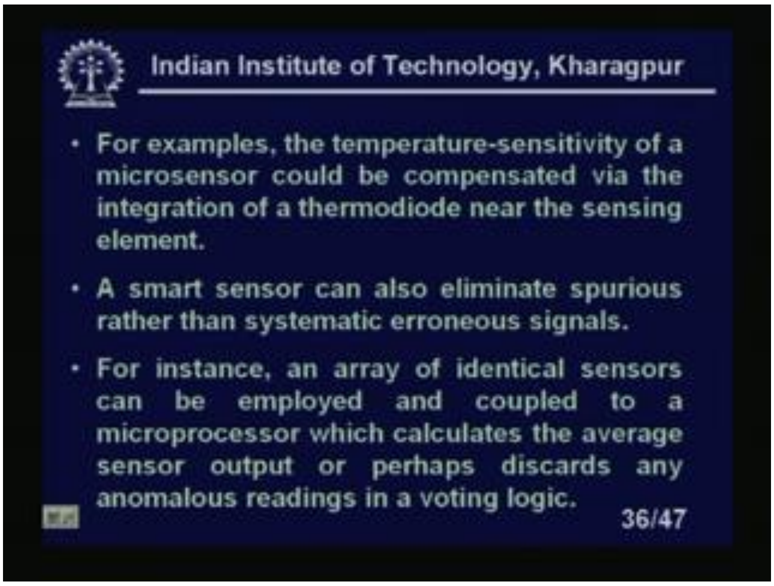

For example, the temperature sensitivity of a micro sensor could be compensated by integrations of a thermo diode near the sensing element. A smart sensor can also eliminate spurious rather than the systematic erroneous signal. For instance an array of identical sensors can be employed and coupled to a microprocessor which calculates the average sensor output or perhaps discards any anomalous reading in a voting logic that we can also incorporate. In a if you have microprocessor computation mechanisms I can do it with the proper program.

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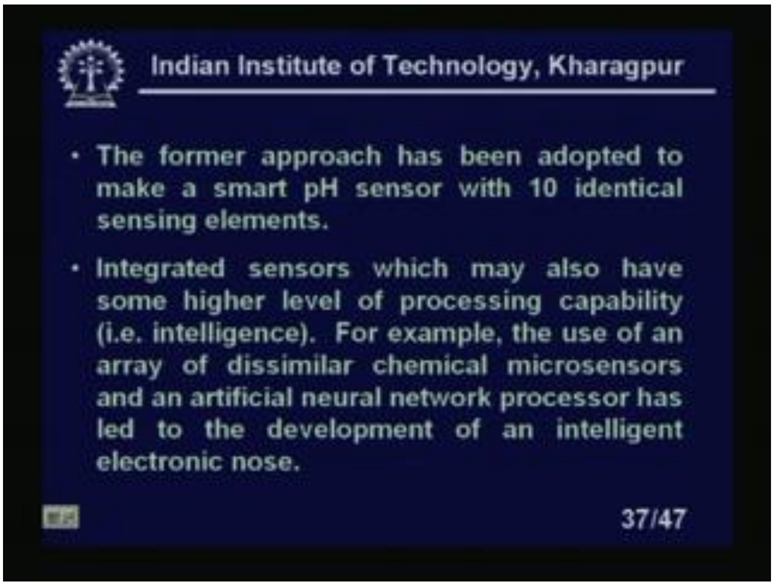

The former approach has been adopted to make a smart pH sensor with 10 identical sensing element. Integrated sensors which may also have some higher level of processing capability or intelligence. For example, the use of an array of dissimilar chemical microsensors and artificial neural processors which can be incorporated by a microprocessor has led to the development of intelligent electronic nose. Electronic nose means it can smell. So, this basically will give you the, I mean some form of intelligence.

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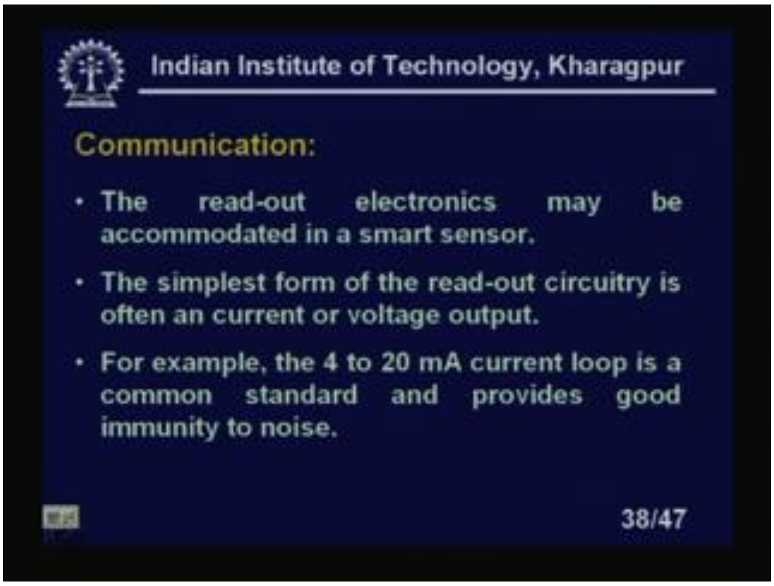

Communications the read out electronics may be accommodated in a smart sensors. The simplest form of a read out circuitry is often an current or voltage output. For example, the 4 to 20 milliampere current loop is common standard and provides good immunity to noise. You know the voltage in most of the, I mean the instrumentation cases we will find always we convert this voltage to current because it is immune to noise. So, the noise immunity is very important while you are communicating from one sensor to other communicating from the sensor to the, your PCs or computers. From the sensor to the transmitter usually all the transmitter transmit current not the voltage right because voltage will be easily corrupted by noise.

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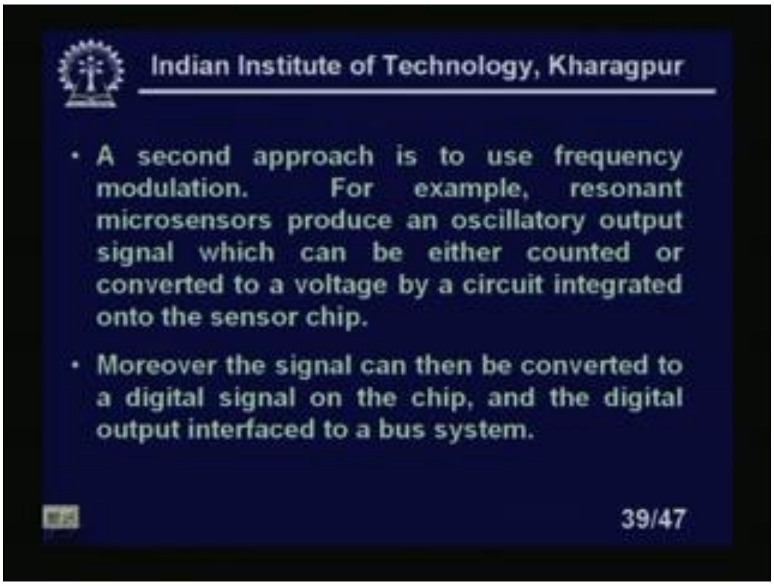

A second approach is to use a frequency modulation because frequency modulation will be totally different. At the out dissipating end also will be I will receive frequency. So, there is a chance of, because even the amplitude is getting I mean corrupted or I mean or it is totally camouflaged by the noise it does not matters. Because at the output at the receiving end I will look at the frequency and keep them high if I have a demodulator there I can get the actual signals right. For example, resonant microsensors produce an oscillatory output signal which can be either counted or converted to a voltage by a circuit integrated on to the sensor chip itself right. Moreover the signal can then be converted to a digital signal on the chip and the digital output interfaced to a bus systems. Because these all you see that is I am talking about a mix signal circuit; that means, they and the same processors I mean everything should be there. That means, the digital circuit is there analog sensors will be there.

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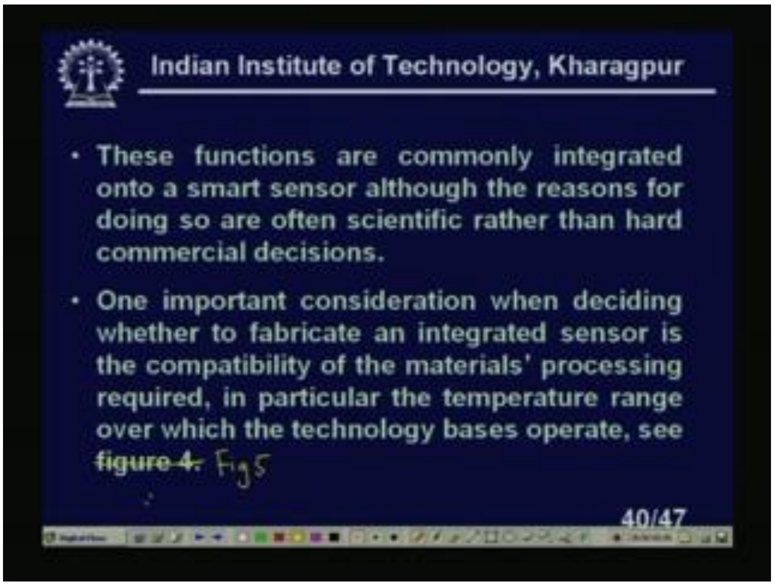

These functions are commonly integrated onto a smart sensor although the reasons for doing. So, are often scientific rather than the hard commercial decisions. It is not very I mean it is acceptable by the industry and people if you make that type until and unless you are well justified. Because the cost is a great factor for making such type of sensors you have to look at the market potentials also. One important considerations when deciding whether to fabricate an integrated sensor is the compatibility of the materials processing required in particular the temperature range over which the technology bases operate. Which is shown in the figure 4 sorry it will be figure five rather I should tell. So, it is not a figure 4. So, this will be this will be figure five rather this will be figure 5, I am sorry.

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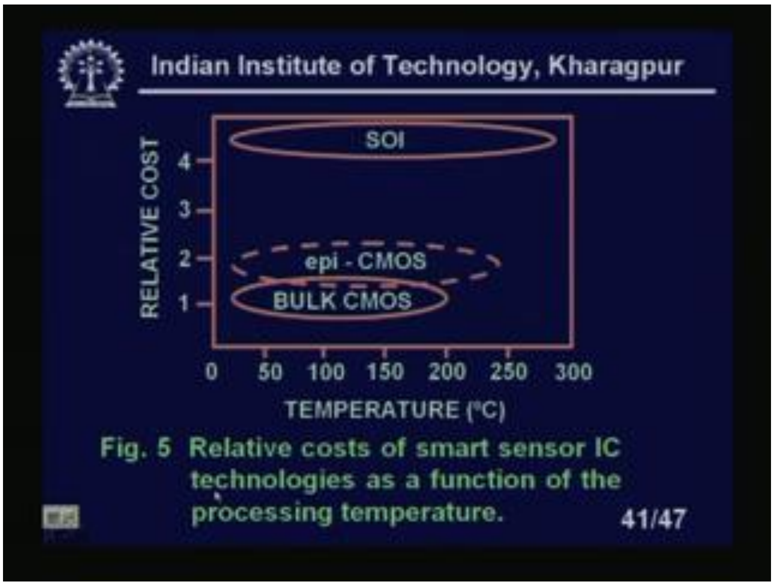

Relative cost of the smart sensor IC technologies as a function of the processing temperatures right. Nowadays, you know you need to always I mean a very wide temperatures I mean devices some sometimes some people needs however, if the sensor can work in a range of minus 50 to 150 degree centigrade or minus 190 to kinetic temperature that type of things. So, this all demands I mean various wide temperature functions. So, relative cost of the smart sensor technology as a function on the processing temperature.

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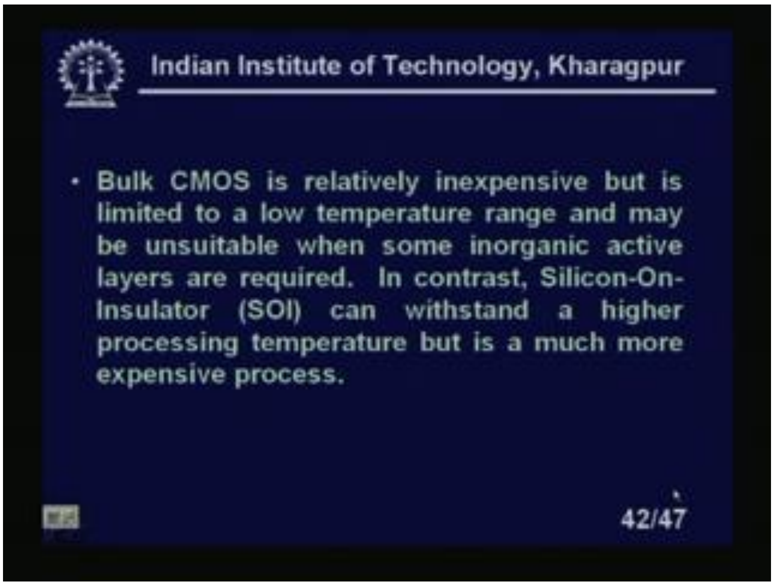

Bulk CMOS is relatively inexpensive, but it is limited to a low temperature range and maybe unsuitable when some inorganic active layers are required. In contrast silicon on insulator SOI can withstand a higher processing temperature, but it is a much more expensive process. Now, applications of smart sensors.

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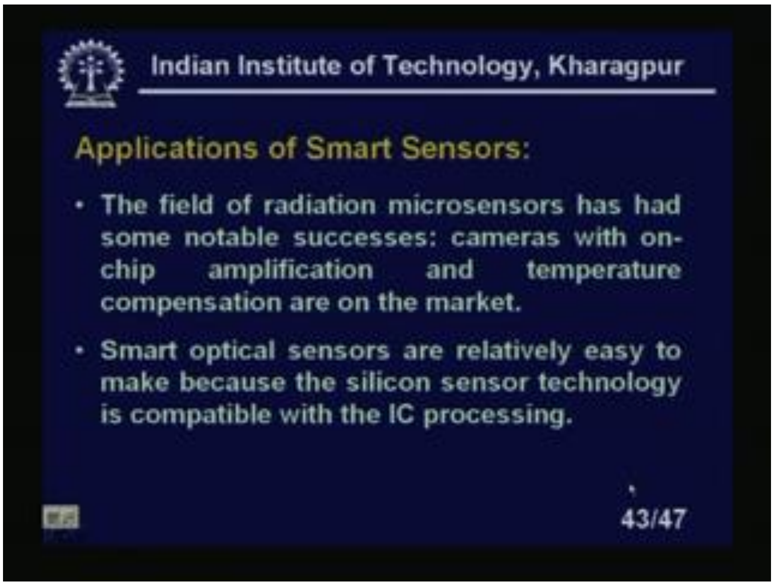

The field of radiations microsensors has had some notable successes cameras with on chip amplifications and temperature compensation are on the market. Smart optical sensors are relatively easy to make, because the silicon sensor technologies compatible with the IC processing.

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CCD images image sensors with integrated image intensifiers have also enjoyed some commercial success such array sensors are; however, very expensive. Smart mechanical sensors such as pressure sensors were initially fabricated at a relatively high cost and in low volumes. However, the interest of the automotive industry in the low cost microaccelerometers for the air bags has changed this situation now you can make it. Even though the cost is quite high, but it does not matter because automative industry needs that type of air bag which can deceleration which can sense the high speed deceleration. Because whenever there is a there is an accident or there is a I mean there is a crash between crash between the cars with another car or anything or any other hard object. So, there is a tremendous amount of deceleration. So, there should be some sensors which will decelerate and activate the air bags. So, that the persons who are driving who are sitting in the front seats or sitting or driver as well as co-drivers. So, they can save their life.

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Smart silicon Hall Effect devices have been fabricated include a built-in offset for the null voltage and internal temperature compensation. Perhaps the most difficult, but potentially most rewarding development in the field of smart sensors will be in the chemical and biological sensing.

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Traditionally chemical sensors suffer from the various problems such as drift in any offset parameters degradation of sensitivity due to poisoning interference from humidity and other chemical species. The design and the integration of the intelligent processing unit algorithm biochemical sensors micros could correct these deficiency and would create large markets in fields such as environmental monitoring and mechanical diagnostics. With this I come to the end of the smart sensors.

Thank you.

Preview of Next Lecture; lecture number 35; Chromatography. Welcome to the lesson 35 of industrial instrumentation. We will start to discuss the chromatography in general actually we call it gas chromatography though it is more popularly known. But it is actually it is a chromatography because the chromatography is both for the gas and the liquid. So, in this lessons and subsequent lesson; that means, lesson 36. We will consider the gas chromatography we will consider the chromatography. Let us look at the contents of lesson 35.

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Contents; we will basic have a introduction to the systems what the actually chromatography look like. What is the packing material is used and what is actually where it is used? All those things we will discuss. Now, the chromatography is basically the separations of the fluids, because in many industrial situations as well as in the chemistries we need this type of situation when there is a mixture. So, we want to know it is a very difficult to know the content of the percentage content of the mixture of the 2 gases.

Thank you.