INDIAN INSTITUTE OF TECHNOLOGY
KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and
Control

By Prof. S. Mukhopadhyay
Department of Electrical Engineering
IIT Kharagpur

Topic Lecture – 07
Data acquisition systems

Keywords: AD converter, Signal conditioning, data acquisition systems, anti-aliasing filter, sensors.

Welcome to lesson 10 of the NPTEL course on industrial automation and control.

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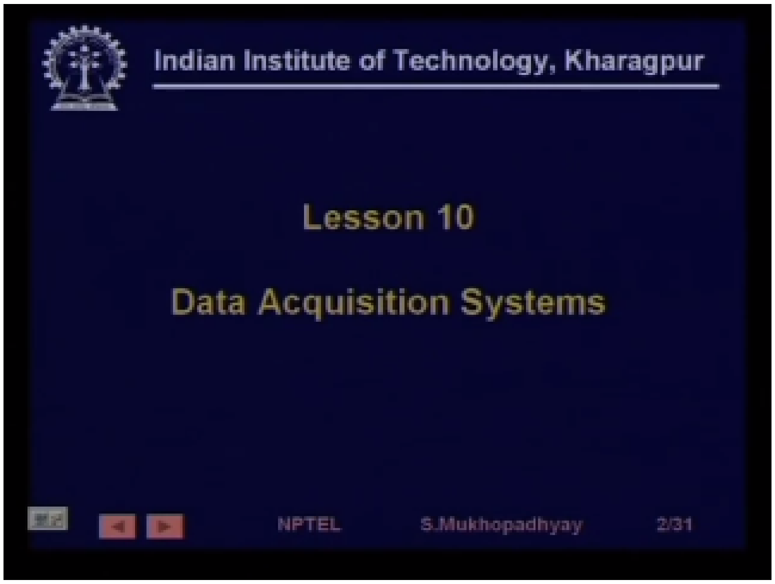

So today we are going to talk about data acquisition systems and before we describe the instructional objectives, let me say a few words about why they are so important, you know, so far in the course we have, first of all in the first two lessons we have seen that, the we have seen the industrial automation pyramid right, so we saw that one of the, one of the major features or characterizing features of advanced automation is that there is a lot of data flow up and down that is data actually gets into the into computers and it's all about computers because there are computers at every layer of the automation pyramid of various types which do a lot of real-time computing right and they do control optimization etc, and that is how the benefits of industrial automation are actually realized.

So there is a lot of dataflow from one level to the other, right and now all this data which is actually basically acquired from the plant flow where the, where the actual machines are from the plants, from the, from the, from the industrial equipment they are, they actually get into these computer systems through the sensors, so we have studied sensors that how these process quantities are sensed and today we are going to end our sensor module by looking at the data acquisition systems which will interface to the sensor on one side.

And to the computer on the other side, so through these systems the data will, the analog data usually analog there can be some digital data also, so the analog data will come through the sensors get converted from their physical forms into some electrical forms and then through the data acquisition systems will get into digital form into the computers and then they are going to flow, them they are going to be utilized by the various algorithms residing at these computers and they are going to get communicated to other computers after various processing and get utilized at the various levels of automation.

So what we are going to study today is how the data which is fine, which is coming from the sensors gets into the computers or how digital data is going to be acquired, right, so that is the subject of the lesson today.

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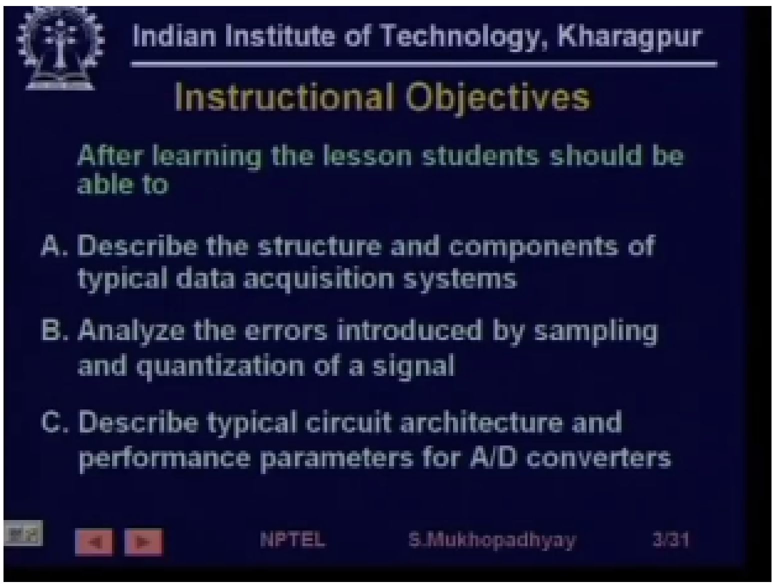

So moving on, we have, as instructional objectives to get familiar with the structure and components of typical data acquisition systems and to understand the basic mechanism of the process of sampling, you know, by which data sampling and quantization because when we have digital data we do not have all the points on the, on the continuous process but we have points, values of the signals which are at close intervals or at intervals of the sampling time and it is not only it is a, it is not a because we are going to manipulate it in the computer and the computer although it has a large number of bits and usually quantization may or may not be an issue but nevertheless there is a quantization issue as well and that whether it is important or not that depends on the computer, so if it is an 8-bit computer then it could be important, if it is a32-bit floating point computer it may not be important.

In any case we will take a look at the basic concept of sampling and quantization and finally we will see some typical circuit architectures and actually, physically how is it that the analog electrical signals get converted to, to digital signals which are interface with the computer hardware, so we will look at that, so these are the basic objectives.

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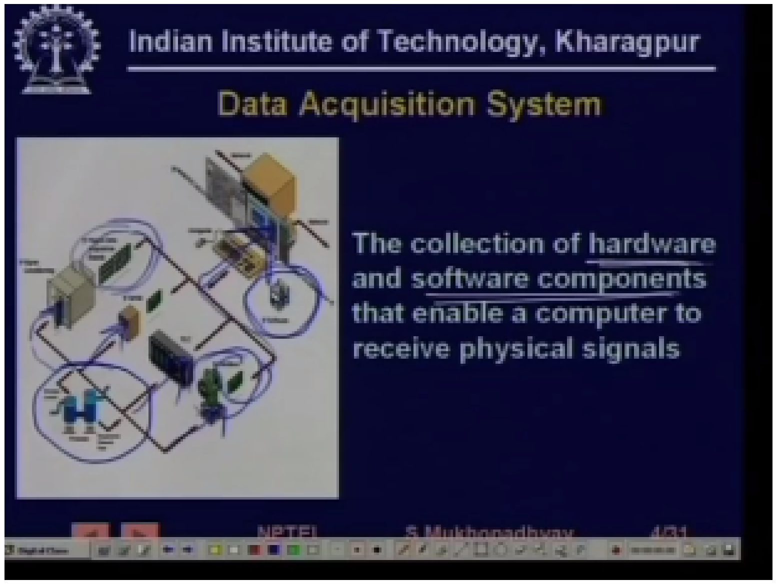

Coming on to a data acquisition system, what this figure, we want to define it first, so we define it as follows that it is a right. so it is a collection of hardware and software components, let me, let me choose, so it is a collection of hardware and software components that enable a computer to receive physical signals, so you see this is what this picture says that this is the process, maybe I have to change my pen, again so this is the process then and there are various, you know hardware, for example data is, may first enter through signal conditioning modules, it may, it may be serial data also sometimes, it may go to go to go to PLCs or it may go through you know these are some actuators, for example this looks like, this looks like a valve something like a motorized valve and finally, so from all these equipment there are through data acquisition processes it actually gets into a, it gets into a computer.

So once it gets into the computer through this sort of you know electronic boards and there is some software residing in the computer, so this software does two things, it firstly helps to, helps these cards to transfer the data into the computer or other interfaces and secondly it may help in, you know the actual usage of the data, that is in terms of display, in terms of decision making, trending, alarm generation, what have you, so some of it may be utilized at that computer itself where it is being acquired and some of it may actually be transmitted to other parts of the system through computer networks.

That, so at that point it becomes pure computer communication. So, we are primarily going to look at this part of the system where from various equipment on the plant, the data gets into the computer right, so.

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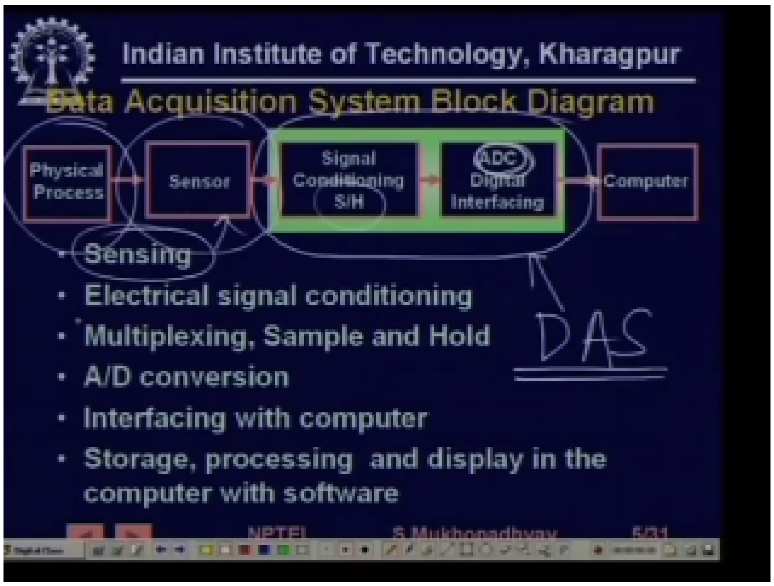

So let us first look at a block diagram and see the major functionality, I'm sorry, I Don't know what is happening here, yeah. So, this is, in this block diagram, we have this physical process change of pen again, this is the physical process and then this is the sensor, up to this we actually understand, now from the sensor, now the, as we have understand, as we have learned, the sensor itself we have some signal conditioning but at the same time there may be further signal conditioning required or in some cases if the sensor signal conditioning, if you know if it is not possible to put signal condition electronics at the sensor sometimes, the sense the signal condition electronics by things like amplification can be put as part of the data acquisition card itself, so you have such signal conditioning here which is typically analog signal conditioning.

And then you have a sampling and hold circuit which is, which is put means we will see what it does and then finally it gets into digital domain through a, through a circuit which is typically referred to as the analog to digital converter or the ADC this is a very well, well used term and then so at the output of the analog to digital converter you have bits, so you have a number of bits which represent the value of the analog signal at a particular sampling instant.

And then, that those lines are those bits have to be transfer, transferred to the computer, so you need an interfacing mechanism by which the computer can accept the digital data, so these are the typical, you know, this is the part which is called the data acquisition system, this is the data acquisition system which will sometimes refer to as the DAS, so this overall process, what, does it, the sensing part is comes from the sensor which is typically not a, not part of the signal conditioning.

And then there is electrical signal conditioning then there is, that, then there could be multiplexing sample-and-hold, multiplexing means that, you know, time division multiplexing that is looking, if you have a number of analog sensor very quickly you scan the channels so first see this one convert this to digital then see that one convert this to digital and so on so that is called multiplexing and then sample and hold, so sampling and holding the signal for that small interval of time when it is being converted then ADC conversion the process of converting it to digital and interfacing with computer.

And then finally this is also not strictly a part of the data acquisition board but the, but sometimes it is a part of the real acquisitions is considered to be a part of the data acquisition system because generally data acquisition vendors will not only give you this sort of components they will also supply you with the software which works with these, this data and can you know display it, can scan it, store it, can trend it, analyze it. So, various functionality of software are also provided for ease of use. Okay, so that is what you do in atypical data acquisition system.

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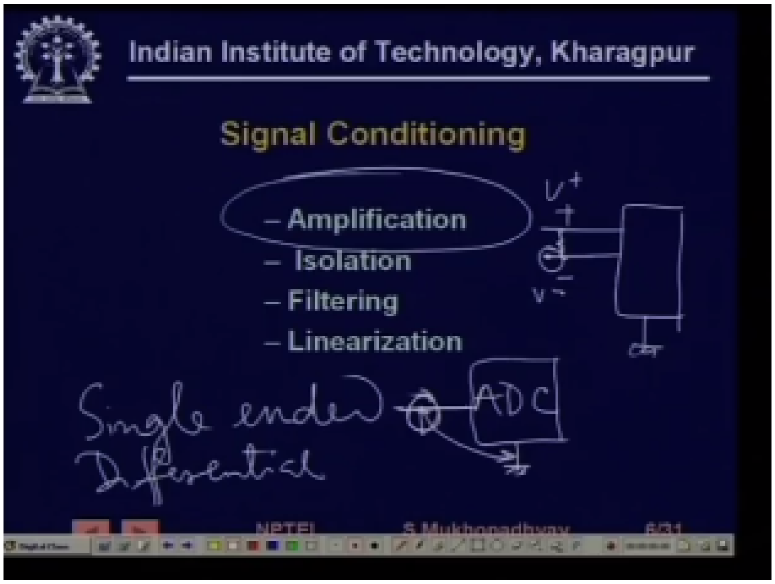

So what do we do in signal conditioning oops yeah! so what we do in signal conditioning is, go to amplification, is very important because as we will see detail, is important because every AD converter has what is called is dynamic range and it is important that the analog signal that you are sort of presenting at the input port of the AD converter, is utilizes the dynamic range of the ad converter otherwise you are going to have approximation errors, larger approximation errors than are necessary, so it is important to amplify the signal to increase resolution, isolation is typically required because the field signals can be sometimes be at high, big, for example you know these analog channels generally come either as single-ended or as differential.

So when you have single-ended it means that, this line this value that is going to be the value of the analog voltage is actually with respect to the ground electrical ground of the AD converter, so the AD converter is also an electrical circuit that has a ground, so when you are applying it in a single-ended mode this voltage will be measured by the AD converter with respect to its own ground and then convert it that value, on the other hand when you when you give it a differential input then what happens is that there are two inputs provided to the AD converter, so there is a plus and there is a minus terminal and the difference in these two signals are provided right, so this so this the potential of this can be quite different from the ground, so now the voltage difference V Plus and V minus actually the signal value that you will get will be proportional to V plus minus V minus now this v plus v minus can be at pretty high voltages.

If they are coming from let us say a motor winding suppose you want to measure a motor winding temperature, so it's not, in fact if you connect such high voltages to the AD converter electrically it might, it will get, it might get damaged, so therefore what you do is, you put an isolation circuit such that the input side is actually galvanically isolated with the output side, you have various mechanisms of isolation like optical like, you know, capacitor based or transfer transformer based inductive coupling etcetera.

Then you have filtering, filtering is required for noise removal, as we will see it is also required for a phenomenon called anti-aliasing, so and we could do some linearization in the signal conditioner itself or you know, sometimes you can do the linearization as one of the, one of the benefits of digital data acquisition is that you can do that in linearization probably much more easily in software so.

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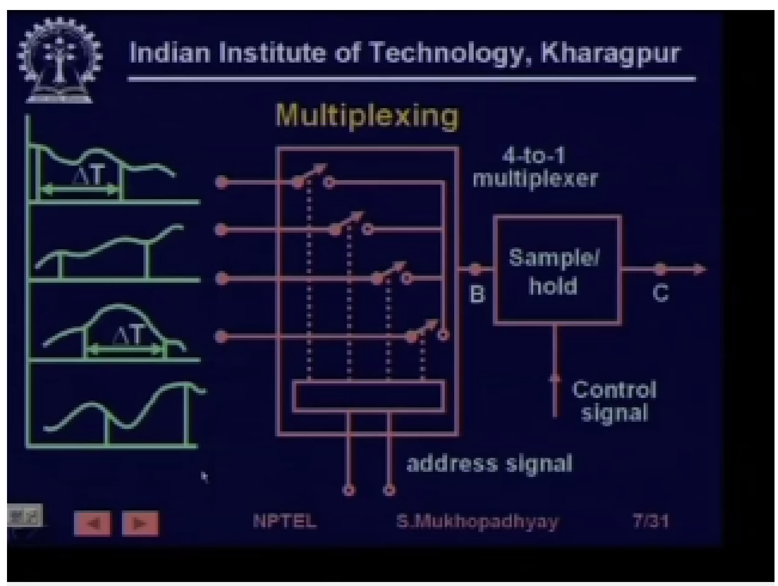

Now you have, so this is how you, condition the each analog channel before you present it for AD conversion, right, now it turns out if you see, if you see any standard data acquisition system that they typically will specify that they can take eight analog channels simultaneously, apparently simultaneously, now how do you get eight analog channel simultaneously, so typically it is the conceptually, the scheme is something like this so it is done through a process called multiplexing, so typically you have, you know, let us say these four channels of analog signals are being presented at these four inputs right, so what you do is, if you, these are, you know, electronic switches which can be put on or off depending on this address signals, so maybe this address is 0 0 this is 0 1this is 1 0 and this 1 1 right.

So what happens is that if you close this switch then this signal gets connected, actually this is a not connected here this connected and goes to the sample-and-hold and goes to the AD conversion on the other hand if this signal is connected, this will go, so actually so, if you connect these four switches in quick succession then overtime interval let us say the overall time interval is delta T now within this delta T if you divide delta T by 4 and then apply these switches on, at these one after the other within that overall time delta T then every delta T interval you will get four values of these signals.

So now, if you, if you are willing to ignore this slight difference between the timings that is if the, if the time is close enough compared to the rate of variation of these signals then you can kind of, kind of implicitly assume that they're all signals, which are, which these are the four channels and after sampling this four channels you would get into the computer four values, so you can, for your future purpose you can assume that those were the values of the signals all the four which existed at some time at the beginning of delta time, delta T without differentiating between this, you know, delta t by 4 and all that. So this is called multiplexing.

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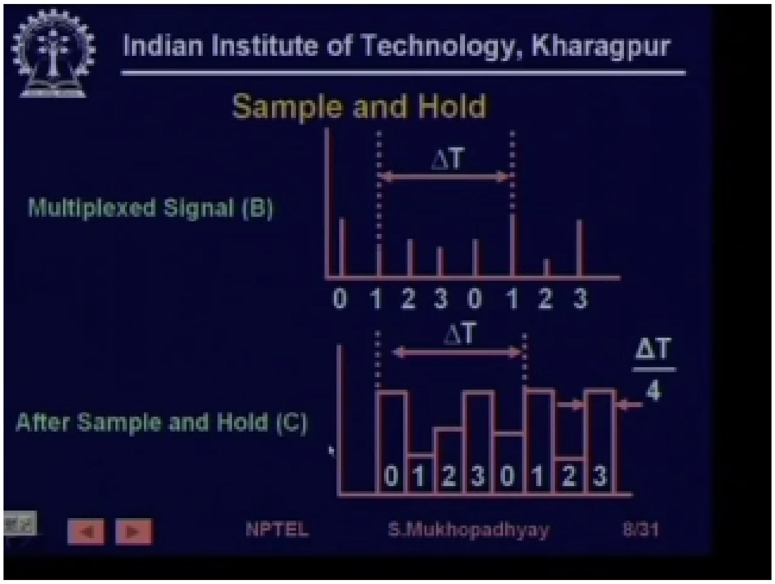

Then we have sample and hold, so why we have hold is that while the AD converters converting the signal, the signal it is sometimes necessary that the signals maintained at the input but, for but that maintaining need not be done by the switch because you see the switches take finite time for getting switched on and off, so you just, so you put another additional circuit such that you put on the switch, so let this voltage be sensed by that circuit and then this circuit is, this circuit is called the sample and hold circuit the circuit is such that it will hold that voltage value.

Now you can open the switch again but this value will be held and so the AD converter will actually see this held value, even if the switch has been opened, so this opening will take some time and it will be ready to close the next switch after let us say another delta T by 4 right, so this is called the sample-and-hold procedure where a particular time instant value is told and held for a small interval within a circuit, right, this is called sample-and-hold.

So while at the switching point. you may, you may close the switch for very small points of time, so you get these values, of the various see, these are the samples, while this could be for channel number one, channel number two, channel number three and channel number four and then again channel number one, so you have these four channels, but at the output of the hold circuit, you will find that this value zero is being held up, till the value is sense to, again the hold circuit is instructed that, now you release that held value and now acquire new value so by the time can the next channel switch has been put on and the value has stabilized there so now the hold circuit senses the new value and then again holds it for the next interval, so it holds it for the next interval then again it senses the new value and then again holds it, so this is what happens by a sample-and-hold right.

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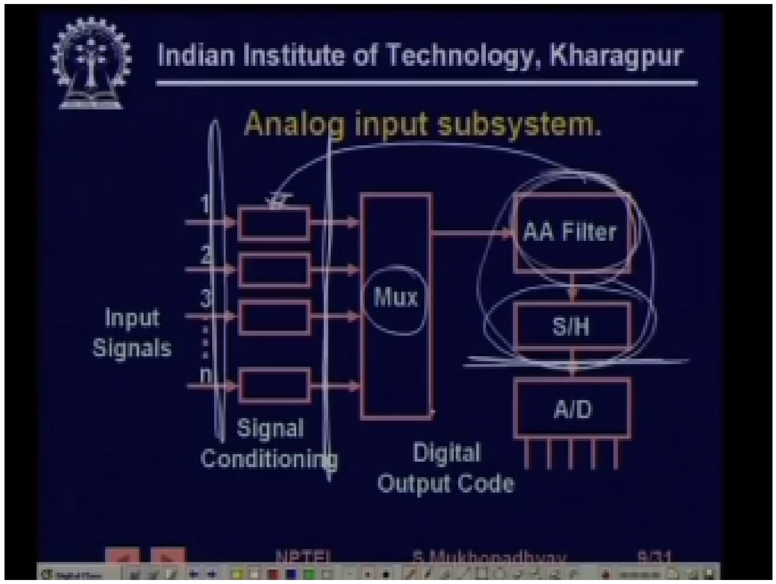

That is because we need to hold it because otherwise sometimes the AD conversion can get into error, if the signal if, while is a converter is converting the signal vanishes from the input terminal then the AD converter can get into problems, so, now, so we need see basically between the in between the signal conditioning input and the AD converter input, there is this block which actually does two things first it will multiplex several channels and second it has to do sample-and-hold, now this which can do in two ways and which one you will choose depends on, depends on how fast your signals are varying and how fast is your sampling frequency okay.

So this is a case where you see that, so we first present this architecture, this is analog input subsystem right, so here is the AD converter, so you are seeing between these input signals then signal conditioning then this is the AD converter input, so here in this case what you are doing is that, you have put a multiplexer on each channel and then you put, you know, anti-aliasing filter this can be also, this can also be a part of this filter if you want because the anti-aliasing filter may be different for different channels and then you put, if that is not required to have different different anti-aliasing filter and if the transient response of the anti-aliasing filter is fast enough then you can actually have, you can actually put one anti-aliasing filter.

And then one sample and hold amplifier, so you see that this channels, you put a, you are saving costs because you are putting only one anti-aliasing and filter and one sample and hold circuit and for all the let us say four or eight channels, so the assumption is that, now what happens is the remember that, so the difference is that now we will get this for values at the end of delta T remember that these four values are actually sample delta T by four times later.

So they are actually not samples, are the same theoretically at the same accurate instant of time right, now in, that makes that if that does not make a difference to you then having one filter and one sample and hold is okay and that is cheaper right, so you go for this architecture but if it does make a difference to you then you have to look at the next architecture.

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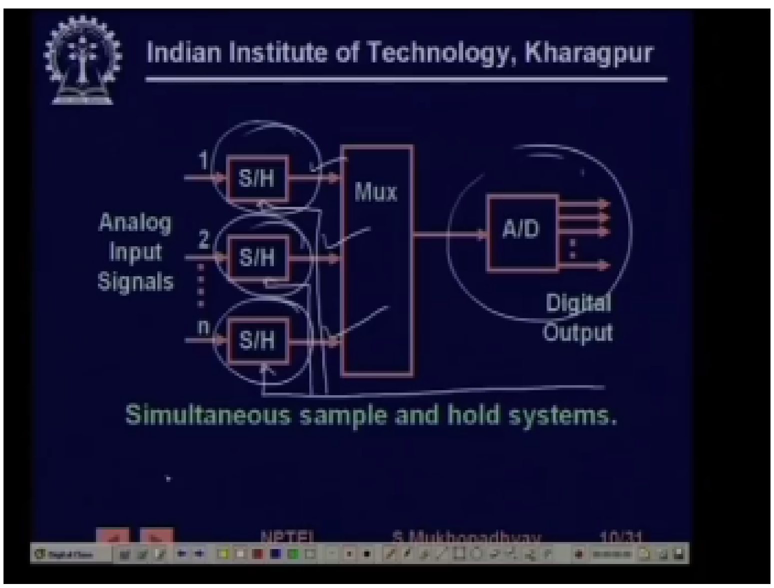

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Which is called the simultaneous sample and hold circuit, where after signal conditioning you have this sample and hold, at for all channels, individual sample and hold and a, what I have not shown, but what exists is that there is a control signal which will go to all these sample and holds, so that each sample and hold will simultaneously sample all these channels that is possible now because you have, because you have put separate sample and hold circuits, so they will use so they will, now this so they will hold the values, so now remember that the values which are being held here correspond to samples at the same instant of time, see they are going to be read into the AD little bit later but they are time synchronous, in the sense that the, those four values represent values of process variables at the same instant of time.

So the sampled simultaneously and held it simultaneously and then read it serially because you are having one AD converter, if you had different AD converters then probably you could have gone for simultaneous AD conversion also but that is generally hardly necessary because the AD converters are quite fast and because we are talking about processes, physical processes, so their dynamics would be complete quite slow and the ad converter speed is more than accurate so you and AD converter is expensive, so you don't want to have more than one AD converters rather than have more than one sample-and-hold channels right, for simultaneous.