

**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**

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

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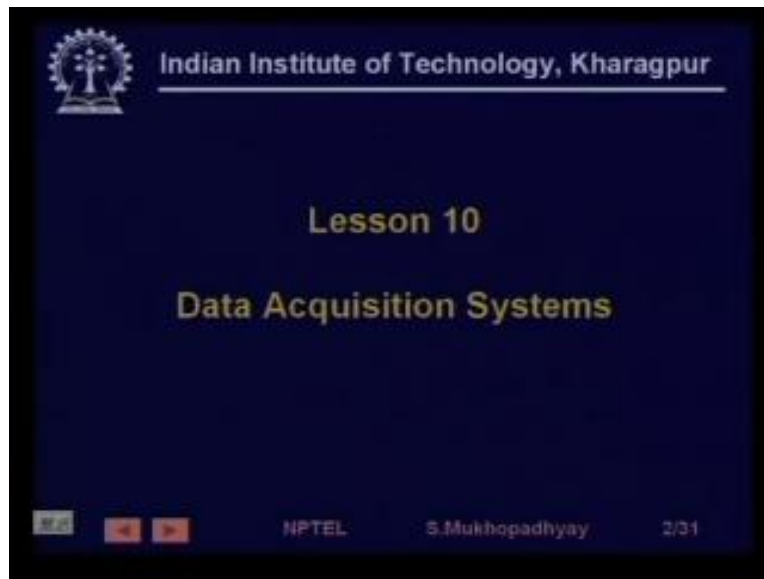
The slide features a dark blue background with white and yellow text. At the top left is the IIT Kharagpur logo. The main title 'Industrial Automation & Control' is in yellow. Below it, the speaker's name and affiliation are listed in white. A small portrait of the speaker is on the left. At the bottom, there are navigation icons and the text 'NPTEL S. Mukhopadhyay 1/31'.

Indian Institute of Technology, Kharagpur  
**Industrial Automation & Control**

 Siddhartha Mukhopadhyay  
Electrical Engineering  
Department  
I.I.T. Kharagpur, 721302, India  
smukh@ee.iitkgp.ernet.in  
www.ee.iitkgp.ernet.in/~smukh

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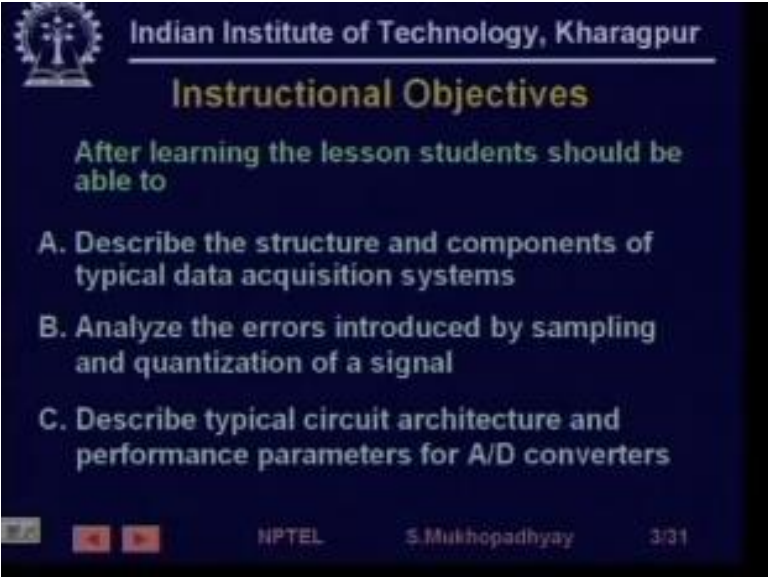
So today we are going to talk about data acquisition systems and before we describe the instructional objectives, let me say a few words about why they are so important you know so far in the course we have first of all in the first two lessons we have seen that the we have seen the industrial automation 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 etcetera 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 floor 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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### Instructional Objectives

After learning the lesson students should be able to

- A. Describe the structure and components of typical data acquisition systems
- B. Analyze the errors introduced by sampling and quantization of a signal
- C. Describe typical circuit architecture and performance parameters for A/D converters

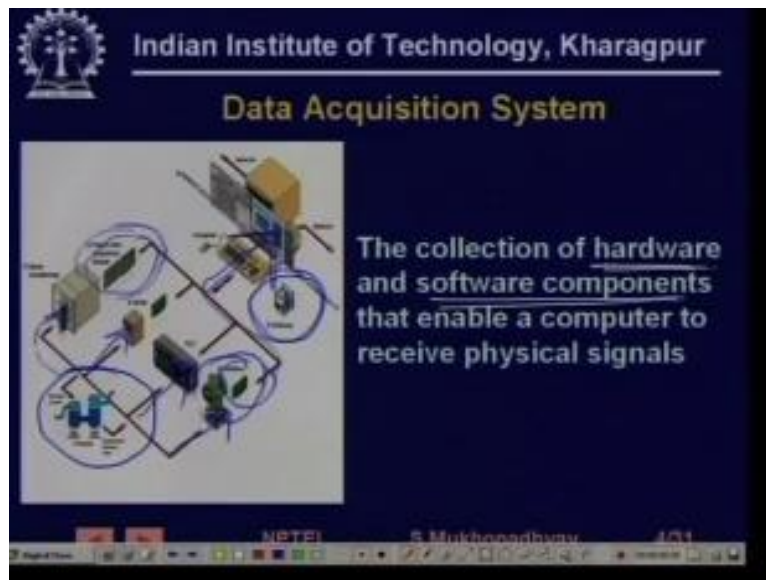
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So moving on we have as instructional objectives to get familiar with the structure and components of typical data acquisition systems and to understand the basic mechanism of the process of sampling you know by which data sampling and quantization 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 a 32-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 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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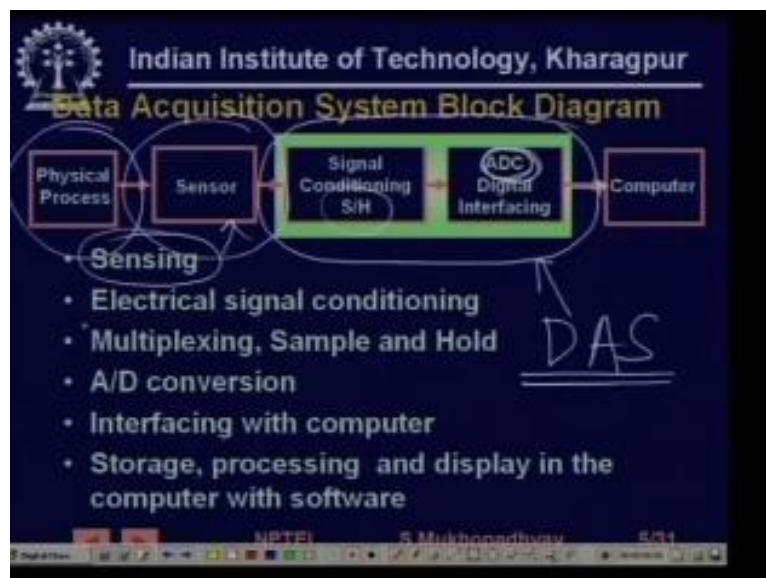
Coming on to a data acquisition system what this figure we want to define it first so we define it as follows that it is a right. so it is a collection of hardware and software components let me let me choose so it is a collection of hardware and software components that enable a computer to receive 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 my 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 help 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 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 Don't know what is happening here yeah so this is in this block diagram we have this physical process change of pin again this is the physical process and then this is the sensor up to this we actually understand now from the sensor now as we have understand that 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.

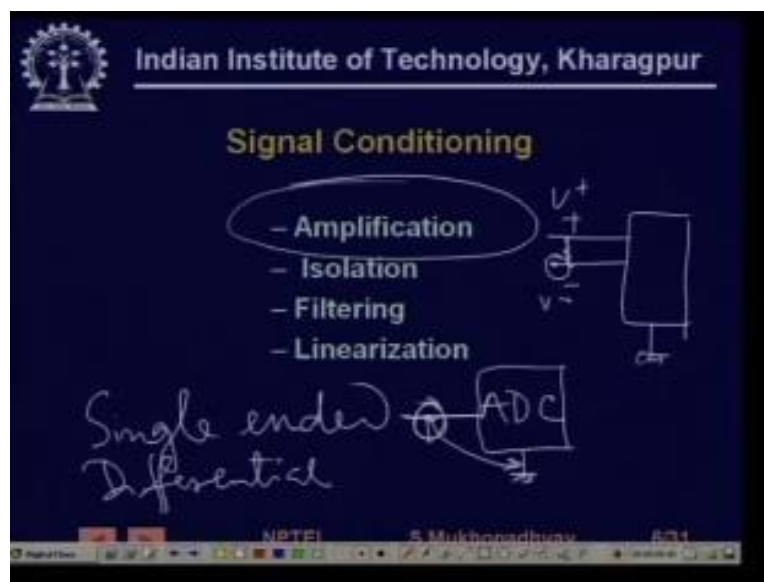
And then you have a sampling and hold circuit which is which is put means we will see what it does and then finally it gets into digital domain through a through a circuit which is typically referred to as the analog to digital converter or the ADC this is a very well well used term and then so at the 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 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 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 equal 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.

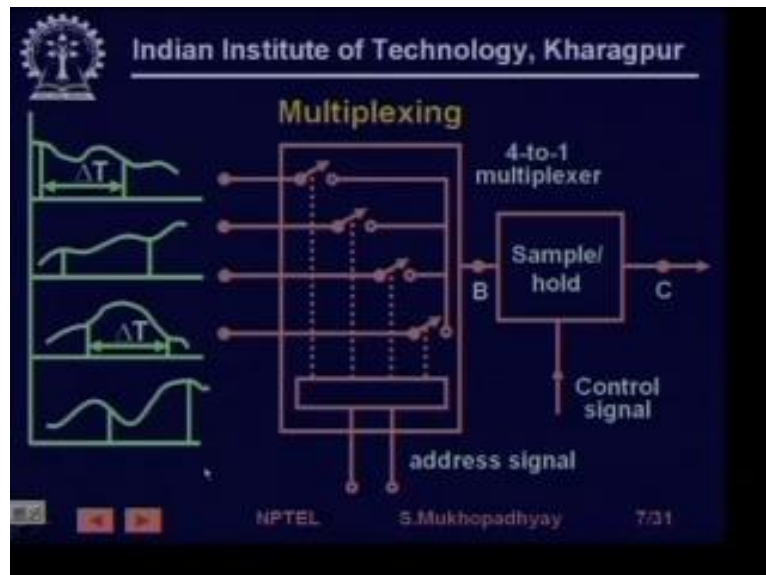
So when you have single-ended it means that line this value that is going to be the value of the analog voltage is actually with respect to the ground electrical ground of the AD converter so the ad converter is also an electrical circuit that has a ground so when you are applying it in a single-ended 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 e 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  $V_{\text{Plus}}$  and  $v_{\text{minus}}$  actually the signal value that you will get will be proportional to  $V_{\text{plus}} - V_{\text{minus}}$  now this  $v_{\text{plus}}$   $v_{\text{minus}}$  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 my if you get it might get damaged so therefore what you do is you put an isolation circuit such that the input side is actually galvanic ally 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 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 benefits of digital data acquisition is that you can do that in linearization probably much more easily in software so.



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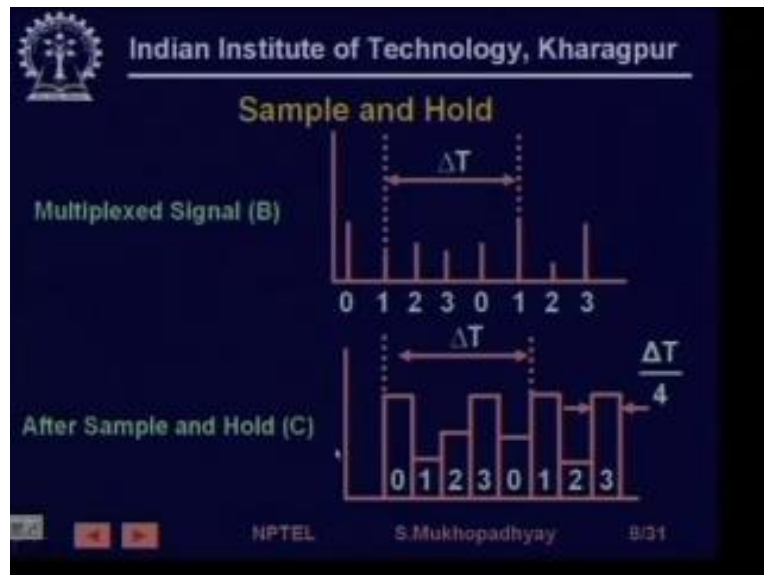


Now you have so this is how you condition the each analog channel before you present it for AD conversion, right now it turns out if you see if you see any standard data acquisition system that they typically will specify that they can take eight analog channels simultaneously apparently simultaneously 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 1 this is 1 0 and this one 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 are willing to ignore this slight difference between the timings that is 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 for 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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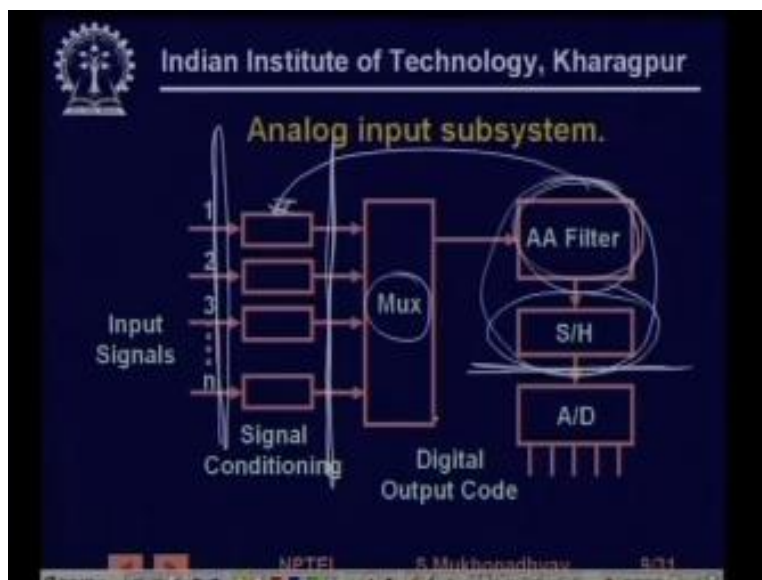


Then we have sample and hold so why we have hold is that while the AD converters converting the signal the signal it is sometimes necessary that the signals maintained at the input but for but that maintaining need not be done by the switch because you see the switches take finite time for getting switched 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 held and held for a small interval within a circuit that is called sample-and-hold.

So while at the switching point, you may close the switch for very small points of time so you get these values of the various see these are the sample while this could be for channel number one channel number two channel number three and number four and then again channel number one so you have these four channels, but at the output of the whole circuit will find that this value zero is being held up till the value is sensed to again the whole 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 whole 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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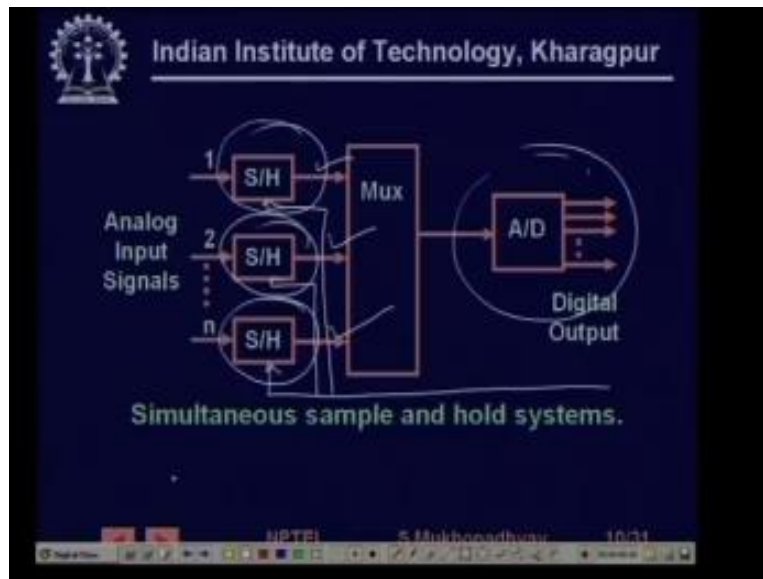
That is because we need to hold it because otherwise sometimes the AD conversion can get into error if the signal if while is a converter is converting the signal vanishes from the input terminal then the ad converter can get into problems so now so we need see basically between the in between the signal condition 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 very 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 puts if that is not required to have different anti-hazing 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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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 sample did 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 any 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 once I'm a sample-and-hold channels right for simultaneous.