Analog Circuits
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Week - 01
Module - 01
Introduction

Hello, welcome to the first lecture of this course analog circuits. I am your Prof. Jayanta Mukherjee from the electrical engineering department of Indian Institute Technology, Bombay. So, this first lecture will be purely an introductory lecture and here we will not be discussing the technical details of the course or the detailed mathematical derivations or the detailed circuits but instead this lecture, I will try to understand and make you appreciate the importance of analog circuits in electronics.

So, let us start with this lecture, the first question that comes to mind is why (()) (01:03) analog?

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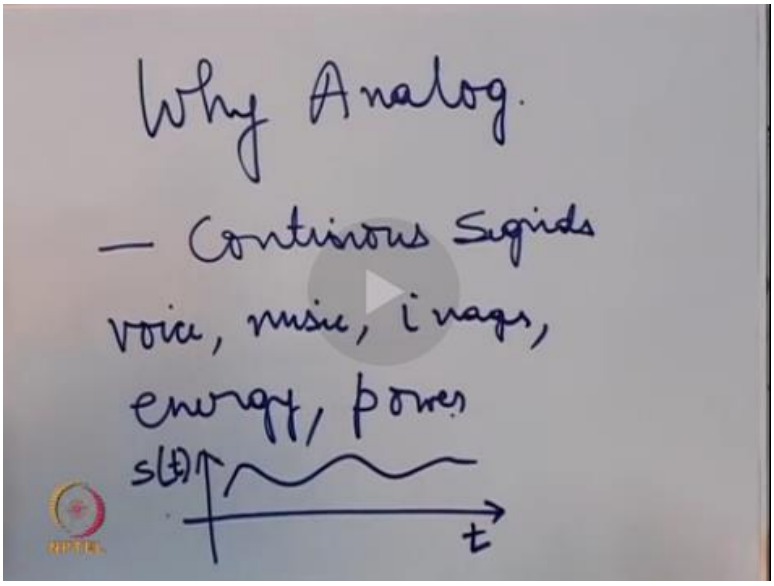

So, why analog? Now you see that most of the signals that we know in our daily life they are analog signals unlike digital signals which are discretized, you know which have definite values at discrete time instants analog signals are continuous, so 1 basic property of analog circuits or analog signals is that the signals are continuous. So, for example voice or say music or say

images, energy, power, now as you can see all these signals have our analog in the sense that they are continuous.

If I plot say the signal St is St represents the signal and the X axis is represented by time and these signals are continuous, there is no break between them and this is what happens in nature, so in one basic thing about this analog circuits is or analog signals

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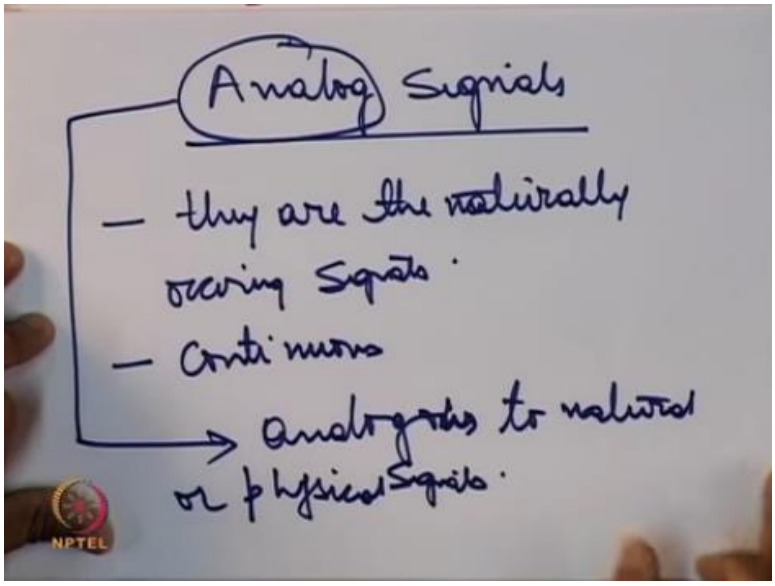

Let us first start with analog signals, before going to analog circuits, let us talk about analog signals is that they are the naturally occurring signals and again I will just repeat this point they are continuous. As I had said in the so the reason this word analog comes in is used is because they are analogous, the signals are analogous to natural or physical signals so what are some examples of analog signals which we have already discussed on the other hand the other types of signal that we use commonly in electronics they are the digital signals.

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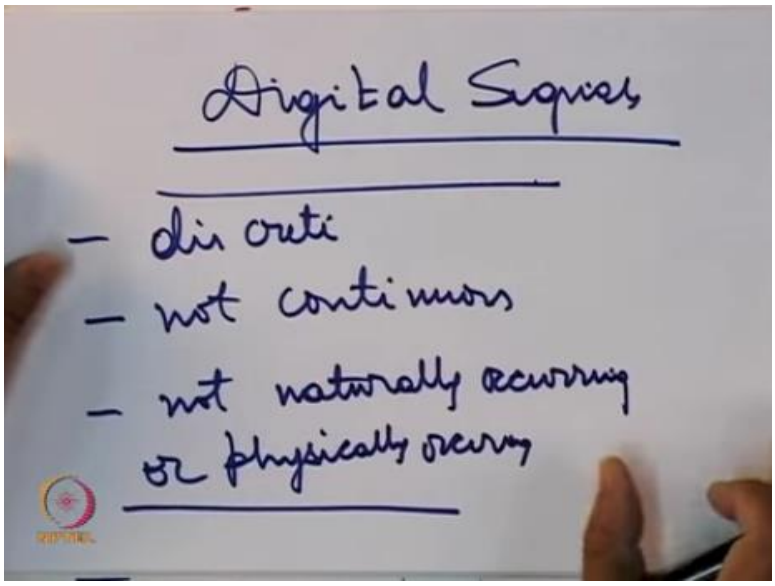

So, digital signals, you know they are discrete not continuous and not naturally occurring or physically occurring, the question is then why does this digital signals exist? The reason digital signals exist, so let us say the advantages. 1, they are easy to process, so what does this mean easy to process? This is the they are easy to process.

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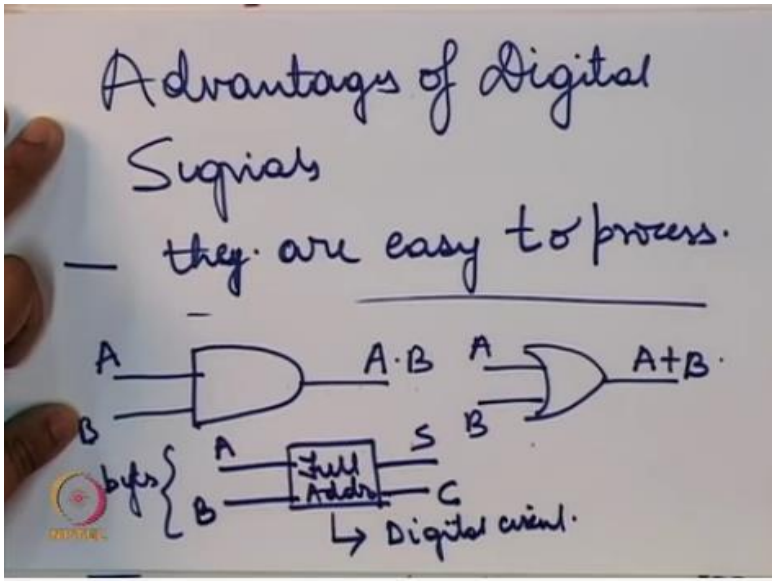

So, as you all know that digital operations, for example a simple AND gate. So, you have 2 signals A B and the output is A.B and or you have the OR gate output is A not A sorry this the OR gate I beg your pardon the output is A or B now here what you see is that, if we try to do the same operation using analog signals it would have been much more difficult or say you know.

Let us consider a full adder circuit if you have two bytes A and B here this A and B are bytes not bits then the output will be a sum and the carry, now this same operation of say you know adding 2 signals in analog domain would have been much more difficult as compared to the ease with which you can achieve in the digital domain, so this is a this full adder is an example of a digital circuit.

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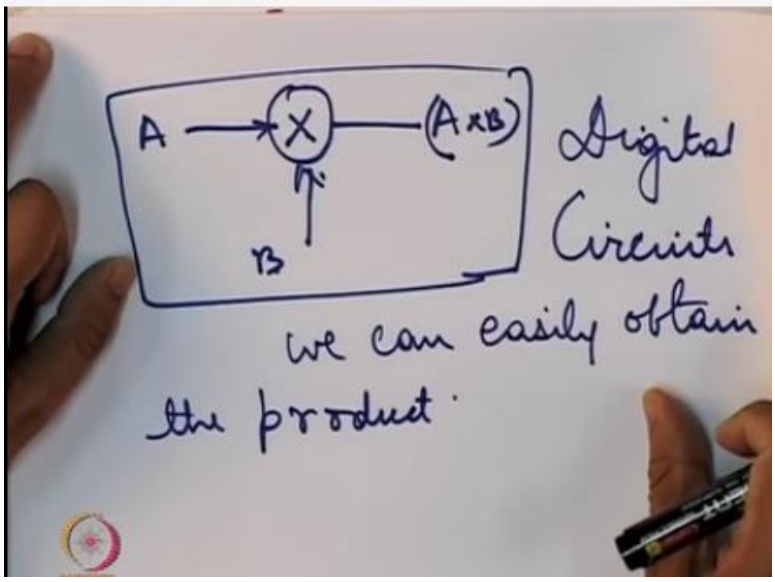

Then let us for example, if we go for more complex processing, for example say multiplying 2 signals you have A and B and the product you have to get is the product of A and B signals, here also we have a very well established mechanism for achieving this product using digital circuits. So, using digital circuits we can easily obtain the product, so this is the first advantage that is of digital circuits that is they are easy to process.

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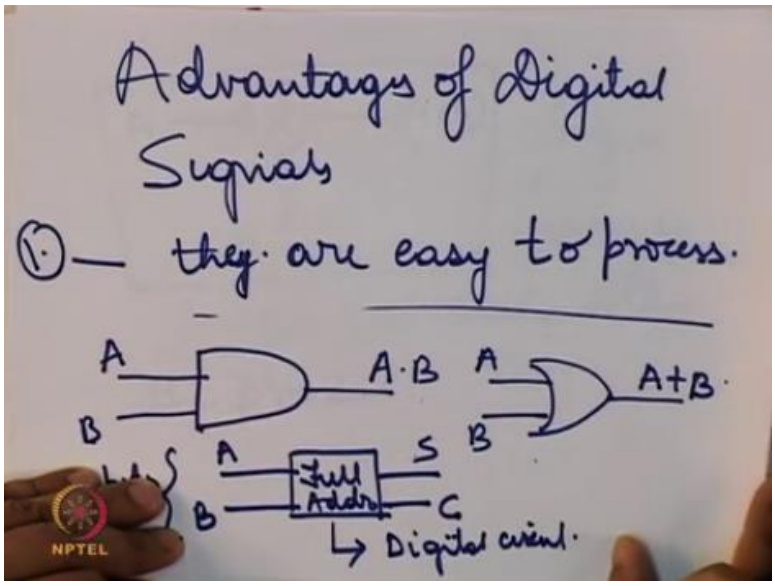

I will put this as point number 1, they are easy to process what is the second advantage of digital circuits or digital using digital signals or digital circuits, the second advantage is that they are much less sensitive to noise.

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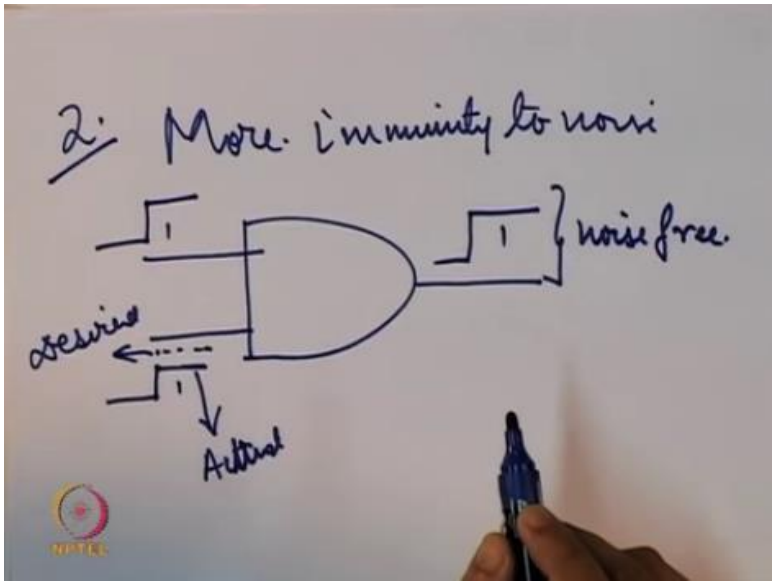

So, the second advantage is more immunity to noise what does this means, for example suppose you have let us say you have an AND gate say the first input is 1, so this is 1 but the second input is a little less say ideally the level desired signal level should have been this but what you are actually in putting is a little less than the total amount of voltage required at the input.

However the output if this signal is still of sufficient amplitude and the (amp) output you will continue to get an output like this, so this is 1 this is also 1 but then as I said earlier that this level is a little below than what is ideally desired. So, what you see is that even if there is a slight variation in the input the output can still obtained and the output that is obtained is noise free that is no amount of this imperfection at the input is transmitted to the output.

So, this is one big advantage of digital circuits or digital systems is that they have very high immunity to noise even if there are some errors in the input they will be corrected at the output and third important advantage of digital circuits is that they are easily reproducible.

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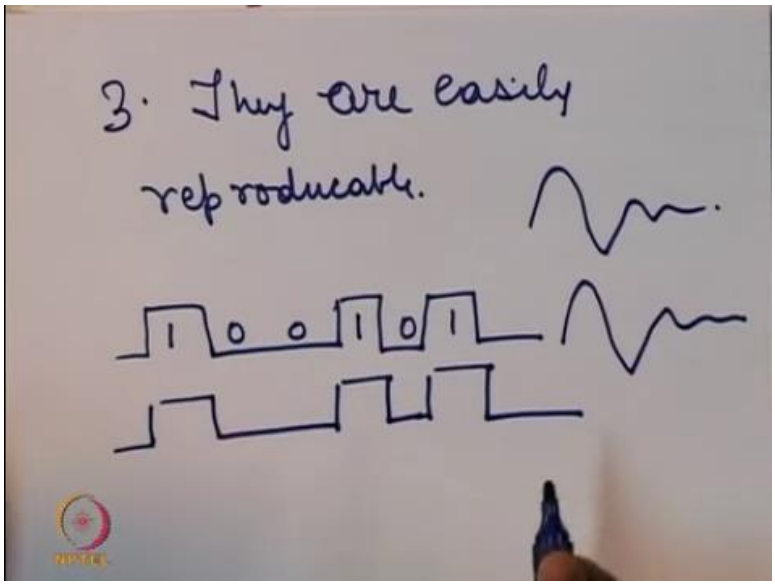

What I mean is, suppose you have a stream of bits like this, so this represents a 1 0 0 1 0 1 it is very easy to produce this signal. Because all we need to produce is another stream of 1's and 0's, however for analog signals on the other hand suppose you have a signal like this to exactly reproduce it that is I want an exact copy like this that might become very difficult, because this when you try to reproduce the signal you have to ensure that the signal is same at each and every point at each and every time instance and that becomes difficult, so that is another big advantage of digital signals that they are easily reproducible.

So, more immunity so again to recap first advantage was that they are easy to process, so I said give an example of a simple OR gate or AND gate or a full adder circuit and I said that if the

same operation of addition would have to be performed in the analog domain that would have been much more difficult than they have more immunity to noise, that is even if there are some imperfections at the input they can be corrected and output the same thing would have been much more difficult in the case of analog systems.

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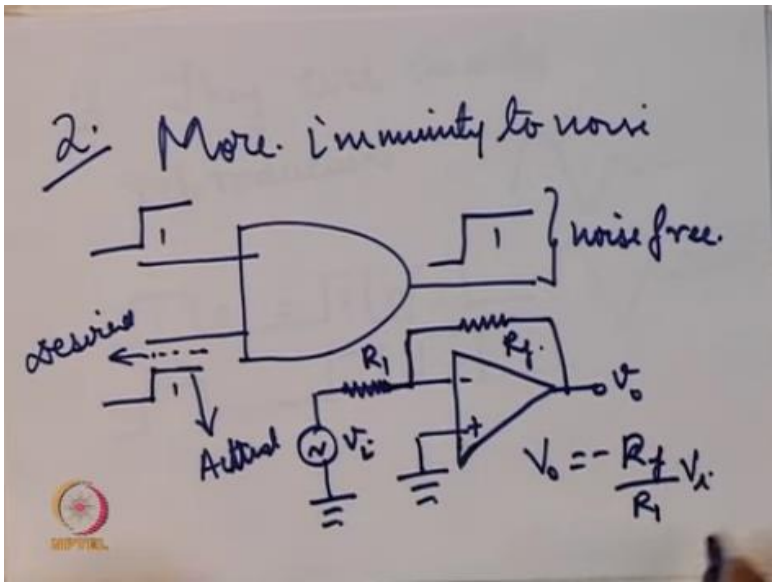

For example if this is an op amp and say the positive terminal is grounded and suppose we supply the negative terminal with a source. So,, say this is in a inverting configuration this is the output this is the input this is the resistor 1 and this is the feedback resistor so we know that VO here will be equal to minus RF upon R1 times V, of course we will go into the derivation of these relations in too much detail later on.

But this is for now just understand that this is a analog circuit with an input VI and the output voltage VO is given by this relation minus RF upon R1 multiplied by VI where RF is the feedback resistance and R1 is the series resistance, now here suppose we change you know there is some disturbance in VI that will not be corrected at the output, see according to this relationship whatever imperfections are there in VI that will be directly transmitted to the output.

So, that this circuit is much less tolerant to noise or imperfection at the input and then finally I discussed the third advantage that they are much easily can be the digital signals can be very

easily reproduced which the analog circuits cannot, so these are some very important advantages of digital circuits because of which we find that there are many digital circuits present.

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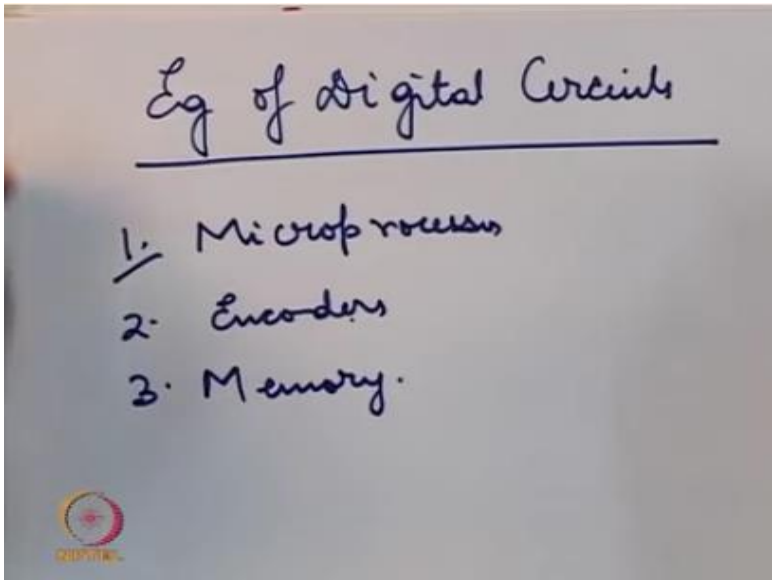

For example the most common digital circuits that come into mind a microprocessor, encoders, memory elements and so on every day you know the any digital computer you take up you will see these chips or similar digital circuits, so now we have dilemma that we have 2 kinds of signals or systems.

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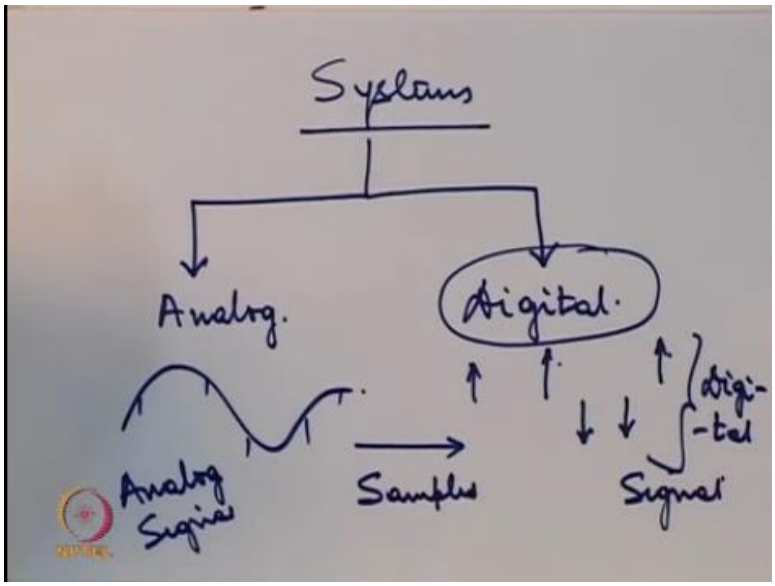

Broadly that can be classified as analog, which are analogous to the signals that we see in our day to day life and digital which are sort of discretized that is if we have a signal like this then if

we sample at various instance the values that we get they are the digital signal. So, this is when you sampled, so this is the analog signal sampled and this is the digital signal, ok the dilemma that I was mentioning is that which one to choose to choose the analog or the digital signals.

So, for digital we already saw some advantages, so it might be logical to think that let us digitize everything from the analog to the digital and let us do everything in the digital domain. Unfortunately that is not possible, everything while it is true that digital systems offer some advantages there are also some problems.

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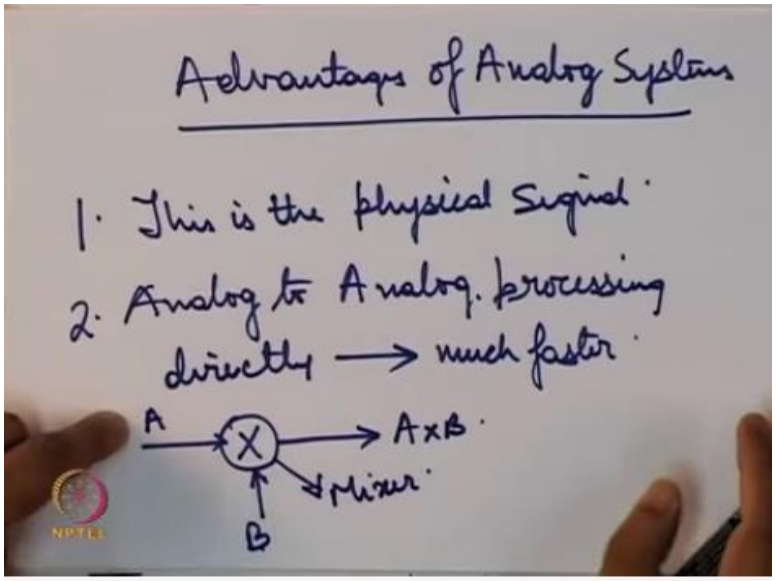

So, let us see the advantages of analog system, first a big advantage of analog systems is that this is the physical system or physical signal that is at the end of all signal processing we ultimately have to even, if we do our signal processing in the digital domain finally we have to convert everything to the analog domain because these signals actually represent the physical signals and since we as human beings understand only the physical signals which are analog and even if we work in the digital domain we have to ultimately convert it back to the analog domain.

The second important thing is, since we as human beings understand only the analog signals, so analog to analog processing ultimately as I said we human beings understand only analog signals, hence if we could do this analog signal to analog signal processing directly that would be much faster ok.

So, for example, while we can do a multiplying action as I said I gave in the previous example that this multiplication action can be done easily in the digital domain using some set algorithms it would have been much faster if this operation could be done in analog domain okay, so the same multiplication action of 2 signals A and B in the analog domain is much faster, if you do directly in the analog domain as compared to the digital domain.

So,, for example in the case of a receiver we do such an operation in a mixer, a mixer is a device that multiplies 2 signals and gives an output A multiplied by B also another big advantage of analog systems is that they can handle a much wider dynamic range and a much wider bandwidth.

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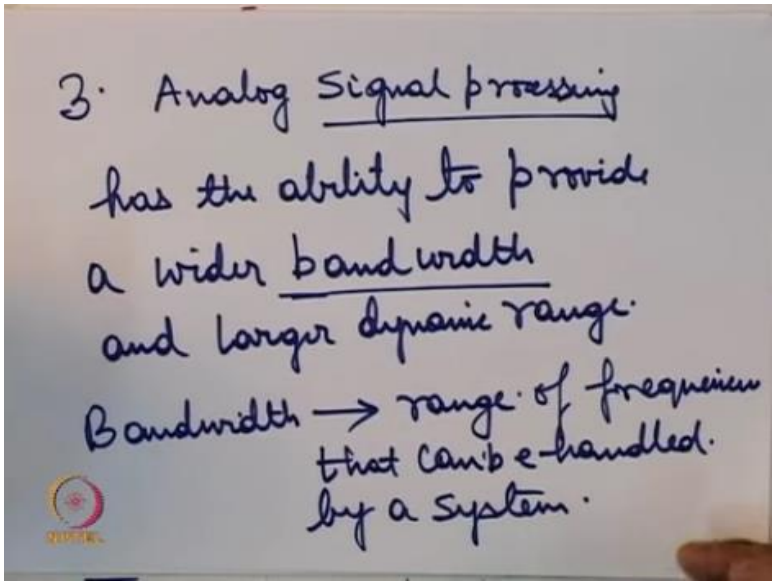

So, the third important advantage is analog signal processing, I am using the word signal processing which means that this term signal processing means that converting signal from one form to another. So, here analog signal processing means processing signals that is taking one analog signal and converting it to another analog signal, so analog signal processing has the ability to provide a wider bandwidth and larger dynamic range.

What does this word bandwidth? So, bandwidth of course we will be discussing this later on, range is a roughly means range of frequencies that can be handled by a system. So, this is a very

brief definition there is there are much stricter definitions of bandwidth which we shall study later on, this bandwidth is kind of the range of frequencies that a system whether it's analog or digital can handle.

Now in analog processing, since you are directly dealing with the analog signal without digitizing it, you can achieve at the same cost a much wider bandwidth as compared to the digital systems. One problem with digital systems is that you have to sample the signal from the analog signal domain is not it, that is what I said that analog ultimately all physical systems are analog, so if you want to go to the digital world you first sample them and convert from analog signals to the digital signals and to do that.

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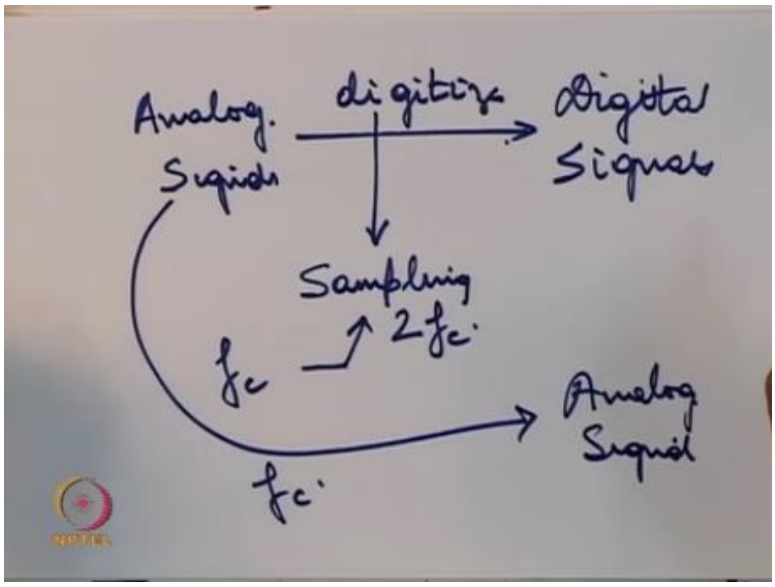

You need to sample, so you have an analog signals on one side which you have to convert to digital signals, you have to digitize it that is digitization involves a step called sampling and for to achieve say a bandwidth fc or say by fc bandwidth. fc I mean the range of frequencies that will be handled by the system is still fc you need to sample at a frequency which is twice at least twice of fc.

So, you see that you need a system to digitize an analog signal which is twice the maximum frequency that is present in the analog signal on the other hand, if you do an analog signal to analog signal processing you only need a system that has a bandwidth of fc, that is the one big

advantage that analog systems provide over digital system similarly the concept of dynamic range.

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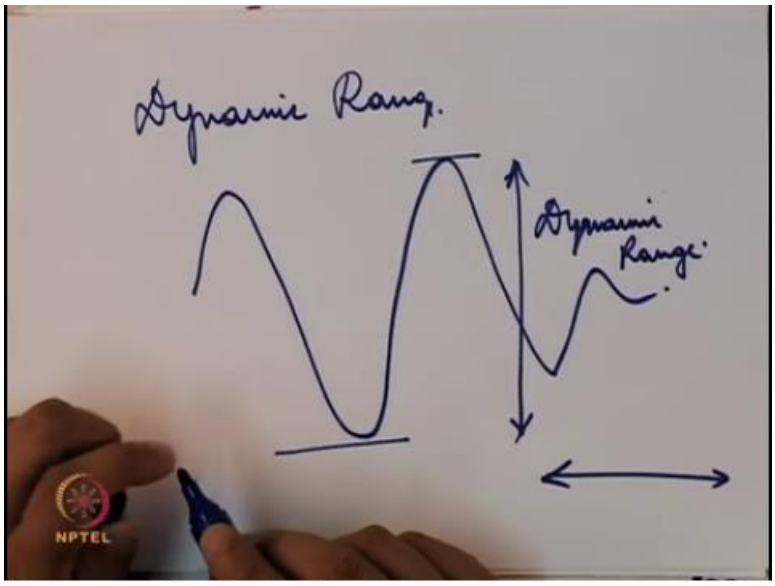

What does this term dynamic range mean? Suppose your signal is like this then dynamic range kind of gives the range of suppose the signal is a voltage then the range of voltages that are applied to the system that is the dynamic range, so the maximum to the minimum values of the voltage or any of the or whatever analog signal you are giving the maximum to the minimum values of that signal the entire range of signals between the maximum and minimum value is called a dynamic range.

In an analog system the dynamic range will be given by the properties of the device or circuit that is being used, but in a digital system in order to have a large dynamic range you also need to have a large bit length is not it in order to provide sufficient resolution to the signal at each and every point at the same time having a wide dynamic range.

You need a system the digital system should be capable of accommodating such a large number of bits that can represent the entire dynamic range with sufficient resolution, so that becomes a problem in some digital systems in where the number of bits of the system is limited you cannot have a very large dynamic range or you cannot have a very fine resolution, so here on the other hand analog signals are just limited by the maximum to minimum values of the signal.

They are not limited by the bit length by the byte length or the resolution of the bits so that is why analog systems tend to have a wider dynamic range and then you know as I said again I am repeating this concept again and again that all systems have all physical systems are analog in some cases.

For example, say if you want to measure the heart rate or the ECG signals that the ECG signals that appear on us on the on our body are very low amplitude that is they have a very low value, but then to make them useful for signal processing for the ECG monitor you have to amplify them and then do some other signal processing steps before they are actually usable and you can actually view those signal.

So, here also you see to transfer convert a lower level signal to a high level signal, you need a lot of analog signal processing. So, even among analog signals before the step of digitization you have to process the analog signal, so that it is capable of being digitized so there also you need a lot of analog circuits for amplifying or frequency conversion or level conversion.

So, for all these things we see that analog circuits are necessary true that digital circuits digital systems have a lot of versatility, but then analog systems also have their own advantages of larger bandwidth larger dynamic range higher speed and also as I said you know to make them capable of getting digitized you also need to do them do some signal processing or signal conditioning, so that this raw signals that you receive is indeed able to be digitized.

Now believe it or not, I will just you have some statistics even though analog circuits in the present day systems like cell phones computers digital set top boxes, you might think that most of the circuits in those systems are digital, but believe it or not even though the number of analog chips or the number of analog circuits are less it takes a long time to design these analog circuits much more than the digital circuit stencils.

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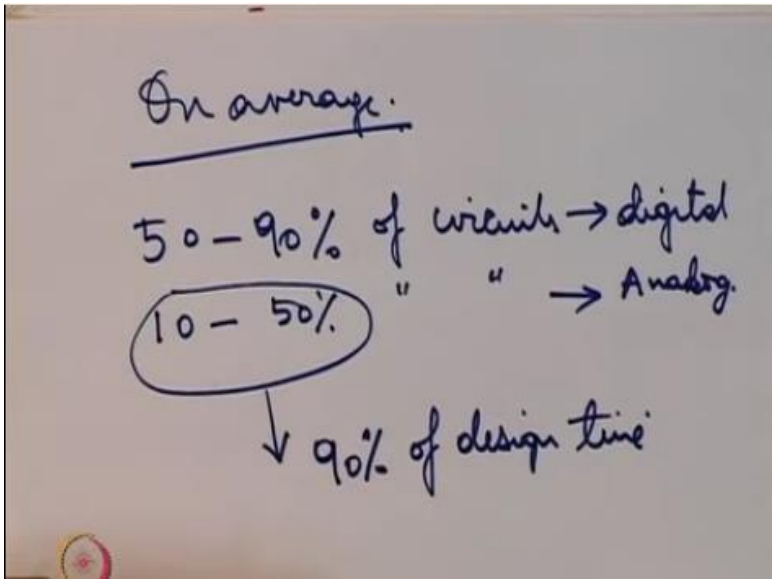

For example on average 50 to 90 % of circuits in present day are digital, so only say 10 to 50 % of circuits are analog but this 10 to 50 % of the analog circuits need 90 % of design time, so you see that designing analog circuits is much more challenging.

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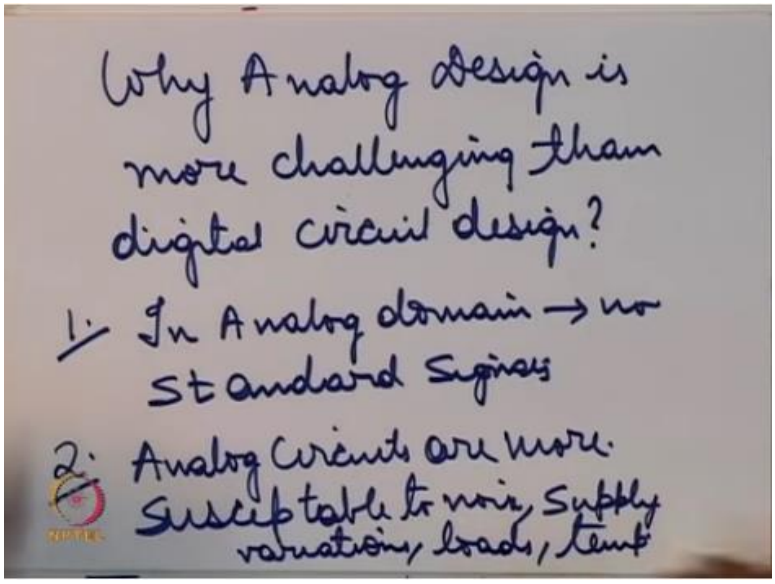

So, why analog design is more challenging than digital circuit design? First point in analog domain, we do not have any no standard signals. For example, in digital systems you have a 1 or 0 which is standard in analog circuits there are no standard signals. Second point, as you saw analog circuits are more susceptible to noise, supply variations, loads, temperature. So, that makes it more challenging because analog circuits unlike digital circuits as I showed that even if there are some errors in the input they can be corrected later on analog signals in analog circuits

cannot be so easily corrected you need some very sophisticated circuits for correcting those errors.

Then the third point is unlike digital circuits, where there is a lot of re-use of circuits like. For example a full adder circuit, if you design a full adder circuit once you can keep on re-using it many times.

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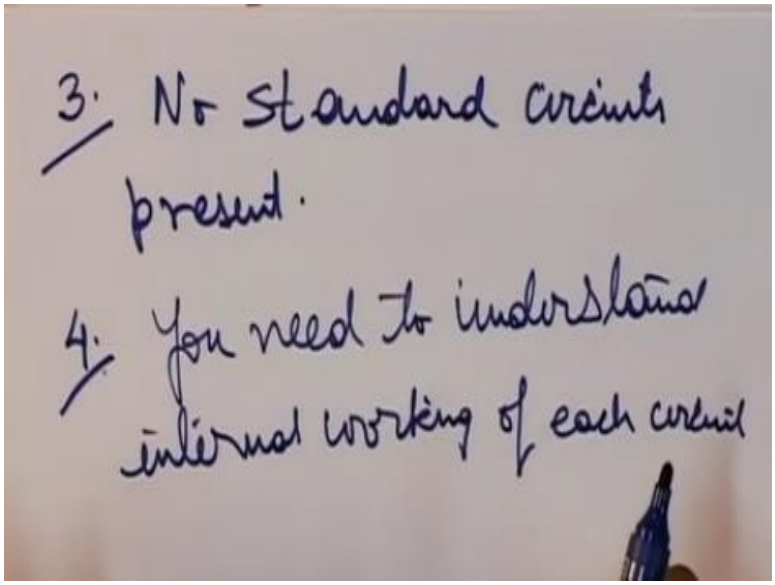

In analog domain no standard circuits are present, so each and every circuit has to be designed individual that makes it very laborious and like digital domain where there is a lot as I said there is a lot of re-use and you can go on building one module, you use it again and again build up a big system, so even though a digital system might look big it actually contains many identical parts, analog circuits cannot be so usually easily used and each and every component has to be designed individual.

And fourth is for example, say in a digital circuit when you have say a digital circuit a very complicated digital circuit you have a many adders in the circuit you do not need to understand the internal circuit of the adder you just need to know what is the property of the other what it does what input it takes and what output in general on the other hand when you actually have an analog circuits and because of its limitation in getting reused you have to know the internal working of each and every circuit.

So, the fourth disadvantage one or fourth difficulty in designing analog circuit is you need to know you to understand internal working of each circuit but then so these are some of the challenges in designing analog circuits, but then what is the joy you get out of ?

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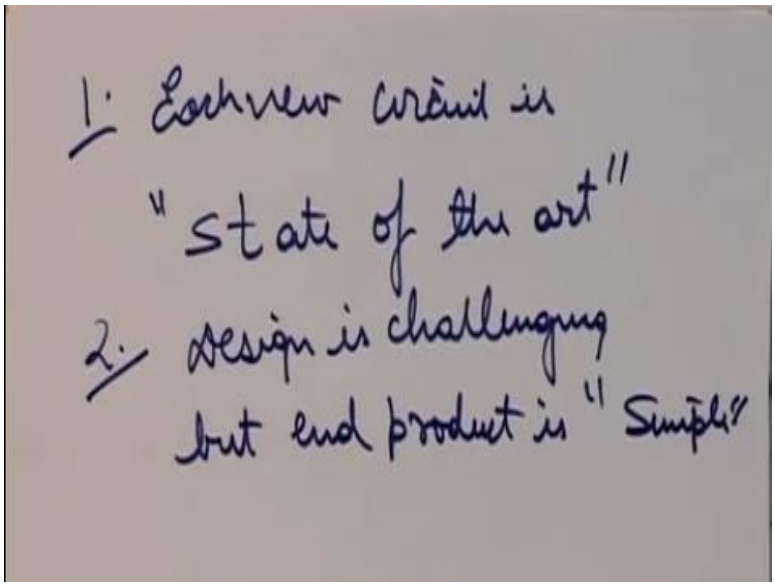

When you design analog circuits the first very rewarding feature of analog circuit design is each new circuit that you design is what we call state of the art. That is every new circuit that you design is something new and that has never been done before, unlike digital systems where there is a lot of time you make a new circuit but functionally that may not be a new that might have been already done by a different method.

Because in analog circuits there is less repeatability and you have to have a good ides of the internal workings of each circuit every time you create a circuit, that gives you some advantage or it produces a new result that is the state of the art and secondly even though the design is challenging the end product that you get is very simple.

So, say you make a better op amp even though you might actually make an op amp, it is a better gain or better noise immunity, the final product is an op amp which is an amplifier. So, the design is challenging but end product is simple, so to summarize this lecture you see that analog circuits are challenging to design.

Digital circuits are the ones that are used more frequently because they have many advantages like noise immunity, they can be used, then they are easy to reproduce, they are easy to process and analog circuits have their some of their own advantages like they are faster, they can give you larger bandwidth, they can give you a larger dynamic range. But the challenging aspect of even though analog circuit is a challenging domain as I mentioned the final output you get is a very simple thing and it is a very rewarding effort.

So, with that I conclude this lecture, but in the form the next modules we will be introducing the basic concepts, we will be starting with op amp and then gradually moving on to the more complex topics, thank you.