Signal Processing Techniques and Its Applications
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Lecture - 02
Signal and its type

So, welcome to the lectures on Signal Processing Techniques and its Applications. So, today, we will talk about Signals and its types. So, we talk about what a signal is because before we start signal processing, we have to know what a signal is and what signal processing is.

So, today, we will talk about signals; what is a signal? many people are asking what is a signal, what is a signal? Signal anything you can go to the traffic, the traffic signal. There are many kinds of that; you wave your hand, giving a signal to your friends. So, what are signals? If I ask you to define signals.

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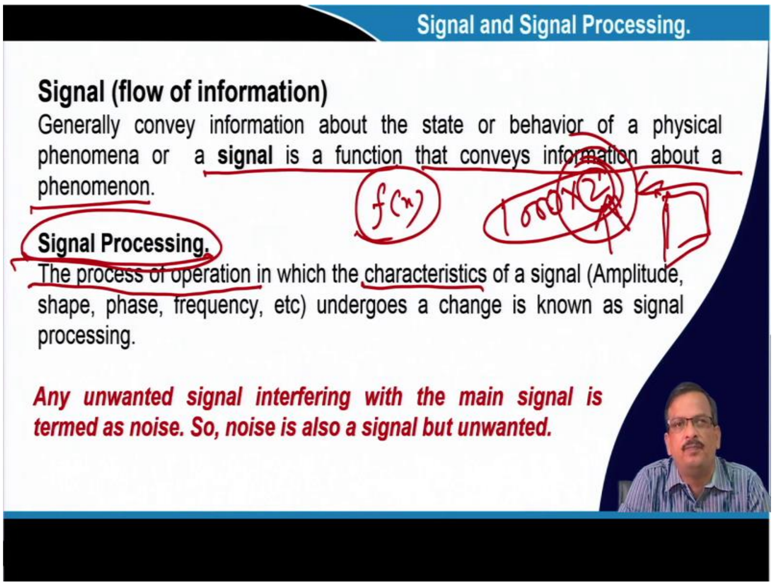

So, if I want to define the signal, the signal generally conveys information about the state or behaviour of a physical phenomenon. So, any physical phenomenon where states or behaviour of the phenomena is represented by a signal. So, if you are calling your friend by waving a hand, it is a signal.

So, you are conveying information to your friend that you are calling, so that is a signal. Now, if I go for the mathematical definition, I know ok. So, any physical state or behaviour of a physical phenomenon is called a signal. Now, when I define mathematics, in that case, I can say that a signal is a function that conveys information about a phenomenon.

So, when I say a signal, it is nothing but a function. So, in mathematics, I can consider a signal to have some information. So, how do I represent it? It can be represented by vectors. So, as you know, the vector has an amplitude and a direction. So, I can say a signal is nothing but a vector, and f(x) is a vector.

So, it may be f(y) or f(z), so a signal is represented by a function that has an amplitude or which has, you can say that value, and it has a direction. So, anything about a phenomenon or state of a physical phenomenon is a signal. Then many people ask, is noise a signal? Yes, noise is also a signal. So, in context, if you see in a context that the signal is unwanted, then I call that signal a noise.

Suppose I am speaking to you, so, while I am speaking, the signal which is coming out from my mouth is a signal for you, but suppose somebody is playing the box while I am speaking to you and that playing a song, or that will be playing a music that music is also a signal, but it is noise to you because it is unwanted in that context.

So, noise is also a signal. So, the signal is nothing but a physical behaviour or state of physical phenomenon. A noise is also a signal but is unwanted in a context. I can give you another example. A lot of you have already studied that information in data. If I ask you what information and what data are?

All of you have already gone through that information data; this is so much data; 3 GB data is required, internet data and when you say information, then what are the differences between the information and data? Data is evidence of phenomena, and information is meaningful evident is information.

So, when I say noise, noise is also a signal, but when it is unwanted in a context, I call it noise. Then, what is signal processing? It may be analog; it may be digital. Signals can be processed in the analog domain and digital domain. So, I call digital signal processing when I process in the digital domain. When I process in the analog domain, suppose you design an analog amplifier and give an analog signal. The amplifier will amplify the signal. So, this is also processing; this is analog signal processing.

So, if I define signal processing only then, then I can say the operation process in which the characteristics of a signal undergo a change known as signal processing. Suppose I said I have an analog signal; I want to amplify it by 3dB. So, I design an analog amplifier; I apply the signal in the input and output I get that amplified signal; the signal is amplified by 3dB.

So, I am changing the amplitude of the signal. So I can change the characteristics of the signal. That is why this is called signal processing. Similarly, I said digital signal. So, a digital signal I want to amplify. So, a digital signal is nothing but a number. The amplification means I want to multiply by something that is digital signal processing.

So, people may ask, what is the advantage of digital signals? Why do we go for digital signal processing? If I do analog signal processing, then why should I go for digital signal processing? What is the requirement of digital signal processing? So, in digital signal processing, what is the benefit or what is the requirement?

If you want to buy a music system, then people will say the sales girl (Refer Time: 07:10) says signal processing is inside, and digital signal processing is inside the system. What do you mean by digital signal? What advantage is there? Just giving an example. If you have a radio in your home or an old tape recorder in your home, then if you see after 5 to 10 years or 5 years that the radio quality of the sound is decreased, you can say while you are tuning, your radio tuning is not that perfect.

So, what is the problem? The problem is the tolerance of the component. So, your radio also uses components; that means, when I design an analog amplifier, let's say analog amplifier, I use resistance, I use capacitance, and every component has its tolerance and also changes along the timeline because components in a capacitor can be developed a leakage. So, the value of the capacitance will be changed.

So, component tolerance is an important issue in the case of analog signal processing. Now, when I go for the digitization and then amplification, what is the meaning of amplification? Suppose I have a number called 1000. I want to amplify by 2 times; that means I want to multiply by 2. So, in the digital domain, the amplification is nothing but an algorithm where I amplify the number by a number. So, it is an algorithm. So, the algorithm will run on a processor.

So, the algorithm does not have a component tolerance. So, today, if I design an analog filter, maybe after 2 years, due to the component tolerance or component leakage, the 1kHz filter base becomes to change. Now, if I design a digital filter, it is an algorithm. So, the algorithm will never change.

Designing complex processing in the analog domain is a very difficult task, but in the digital domain, it is a very easy task, but people may say, then, why not all that processing and signal processing in the digital domain? Why is that still analog signal processing? You know that RF amplifiers cannot be designed in the digital domain; why?

So, the problem is that any real-world signal is an analog signal. If I want to suppose I am speaking, it is an acoustic signal, and when I use a microphone, when I convert it to an electrical signal, it is an analog signal. I am coming; what is an analog signal? I am coming. So, it is a continuous time and continuous-valued signal, which is why it is called an analog signal. So, now, if I want to process it in the digital domain, then the first step is that I have to convert this analog signal to a digital signal.

So, I cannot convert; that process of conversion has complexity. I cannot convert a high-frequency analog signal to the digital domain. I will explain it when I talk about analog to digital conversion. So, there are certain requirements for analog to digital conversion, which requirement are so specific that if that signal is very high frequency, the digital conversion is very troublesome. So, we cannot sometimes, and it is also not possible.

So, if it is not possible, then I cannot process in the digital domain. So, both analog and digital signal processing exist. Digital signal processing advantage is that it is nothing but an algorithm that will not change, it will not change with temperature, it will not change with tolerance of the component, and it is also not so expensive because if I design an amplifier, the specification is fixed.

But if I design an amplifier and I want to change the gain in the case of a digital, it is nothing but a change in the multiplication number. Suppose I design an analog filter, and for 1kHz, I want to make it 2kHz. Just I change the algorithm, nothing will change, but in the case of the analog system, I have to change the entire system.

So, those are the advantages and disadvantages of analog and digital processing. So, since digital processing has so many advantages, that is why people are talking about digital signal processing. Again, it has a limitation. The limitation is that high-frequency signal we generally cannot convert in the digital domain. That is why digital signal processing is restricted to a certain frequency range and why I will explain when we talk about analog to digital conversion, ok.

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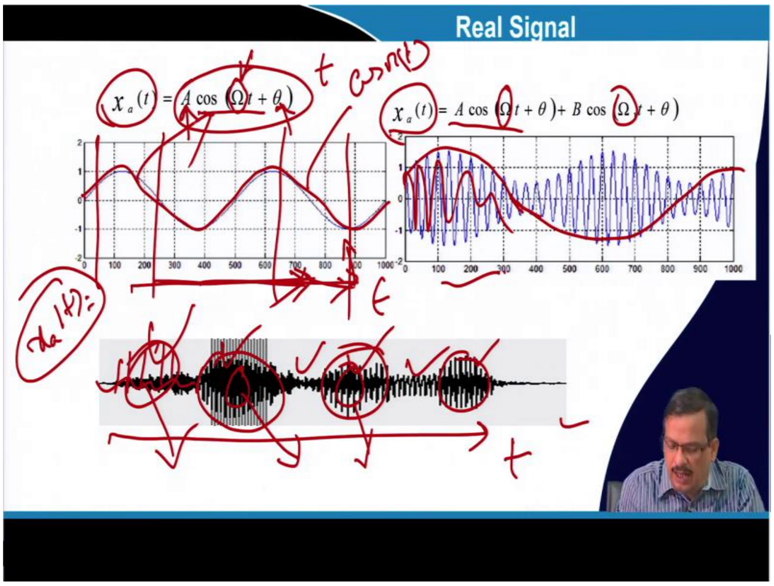

So, now I come to the signal. So, you said signal; signal is a function. So, a signal is a function of something that is varying. So, let us say a signal:

$$x_a(t) = A\cos(\Omega t + \theta)$$

I can say the signal, which is a time-varying signal along the timeline, the value of the cos will be changed. You know the cos curve will look like this along the timeline, and the value of $x_a(t)$ is real.

So, I can say this is a real signal, and this Ω is called analog frequency, or I said radian per second is the analog frequency; you know what frequency is. So, radian per second is the analog frequency, which is why $(\Omega t + \theta)$, θ is called phase, and A is called amplitude.

So, this signal has a particular frequency. I can say that I have a signal that is a combination of two frequencies; one is Ω, and the other one is Ω_1. It will look like this. So, I can say there is a global variation. You can say there is a variation that looks like this. So, there is some variation like this. So, I can say that it is a composite signal.

So, if the value is real, I say the real value signal. Similarly, let us say the speech signal. When I speak, if you record using your microphone and display it, it will look like this. There will be a different speech event at different positions, and the values are real, not complex. So, then, it is called a real signal.

Now, if you observe this curve, these three curves if you see along the timeline, suppose I take the signal from here and I take the signal from here also it is $\cos(\Omega t)$, and here also it is $\cos(\Omega t)$, but if I take the signal from here and if I take the signal from here and here the signals are different. This is a sibilant, vibration kind of signal; there may be a periodic signal, and there may be again a sibilant signal.

So, along the timeline, if the signal does not change its property, it is called a stationary signal or time-invariant signal; along the timeline, the signal does not change its property. So, I said that along the timeline, it will always remain $\cos(\Omega t+\theta)$; it will always remain $\cos(\Omega t)$, and oscillation will be Ω only.

But in the case of the speech signal, the beginning may be a sibilant; there may be a vowel, there may be a consonant, retroflex or trill consonant, there may be an again vowel, there may be a voiced consonant-vowel. So, signals are changing their properties along the timeline. So, it is called a time-variant signal or non-stationary signal; the stationary signal, non-stationary signal. Along the timeline, if the properties of the signal change, we call it a non-stationary signal change if it is not changed, we call it a stationary signal.

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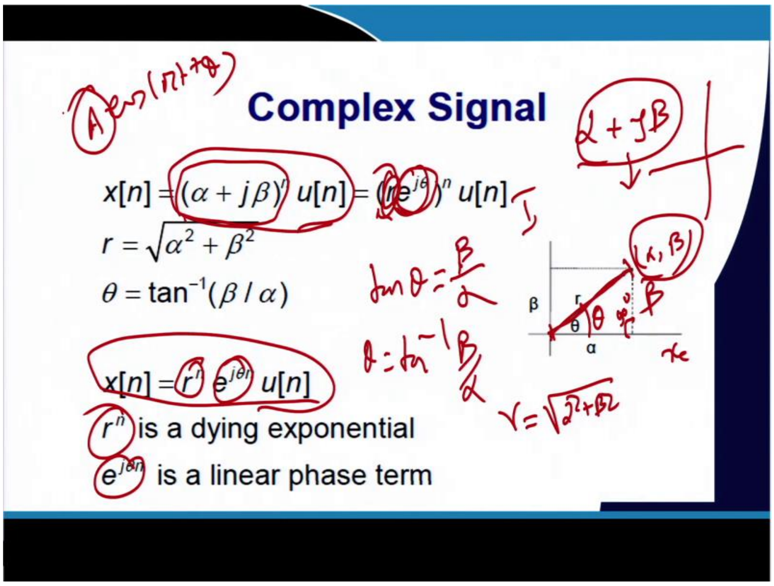

Now, I come to the complex signal. So, if the signal value is real, I say it is real, and now I come to the complex signal. Let us say I have you all. You know the complex number α+jβ is nothing but a complex number. So, it is in a complex plane; this is the real axis, and this is the imaginary axis. So, this coordinate is α and β, ok. So, this is a complex signal

$$x[n] = (\alpha+j\beta)^n u[n]$$

What is u[n]? I will come later on.

So, what is there? Now (α+β), the value of the signal is not real; it is complex. So, I know any complex number can be represented by its magnitude and direction; this is a very important issue. Often, when you go for signal processing, whether digital or analog, we always represent a signal with an amplitude and a phase; phase is represented by $e^{j\theta}$ and r is called amplitude. So, (α+jβ) can be represented by r, which is the amplitude. So, this is α, this is β. So, I can say

$$r = \sqrt{\alpha^2 + \beta^2}$$

because this angle is 90°. So, that is the distance. How far is it from the origin? So, I can say, as you know, any Cartesian coordinate can be converted to the polar coordinate. So, here (α, β) is a Cartesian coordinate in I real axis and imaginary axis coordinate system.

So, It can represented by a polar coordinate, which is r and θ angle with the axis. So, if the angle with the x-axis or the real axis is θ, then I know

$$\tan\theta = (\beta/\alpha)$$

so $$\theta = \tan^{-1}(\beta/\alpha)$$

So, any complex signal in the form of $(\alpha+j\beta)$ can be retained in the form of amplitude and direction $e^{j\theta}$, and θ is known r is known.

So, I replace $(\alpha+j\beta)^n$. So,

$$x[n] = r^n e^{j\theta n} u[n]$$

So, this is called phase term, and this is called amplitude term, but in the case of a real signal, it is A cos $(\Omega t + \theta)$, which has a real amplitude, understand. So, the real signal and complex signal.

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Now, I come to the multi-channel signal and multi-dimensional signal.

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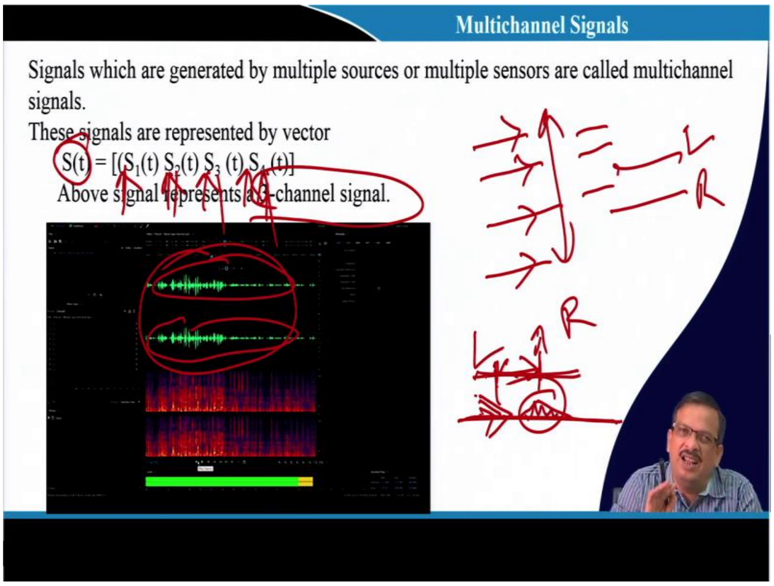

So, a multi-channel signal means I have a separate source, several sources, and multiple sources of the signal. So, suppose I have recorded the voice two; one is music, and the other is vocalic. Today, if you go to the speech recording studio, you can find a multi-channel recorder. Today, it is not necessary that music has to be recorded during the vocalic synchronous; it is not asynchronous. First, maybe the music was recorded, then maybe the violin was recorded, then maybe the tabla was recorded, then maybe the voice and vocals were recorded.

So, there are multiple channels. So, multiple sources of the signal are represented if I have a multiple-source signal. So, I have a multiple-channel signal. So, I can say multi-channel signal. So, this is a multi-channel signal. Another example is when you said stereo signal. You all know that I initially had a stereo before that 5.1-channel music system. How many of you have a 5.1-channel music system in your home? What is a 5.1-channel music system?

First, think about the stereo system. If you see the revolution that initially came with stereo sound, you have heard about the stereo cassette and mono cassette. So, stereo means I have a left and right channel, left channel and right channel. So, a stereo signal is nothing but a multichannel signal that has two channels: one is a left channel, and the other is the right channel.

5.1 channel audio system. So, if you are playing a recording sound that is not multichannel, it does not give you that effect if you play it in a 5.1-channel music system. So, if I have a multichannel recording system and then play it on a multichannel player, I get that channel's effect.

So, what was that what? Just why did the stereo come? What is the problem with mono? Think about it: what is the problem with mono? What stereo solve? Then what do you mean by multi-channel? Dolby Digital, have you heard about Dolby Digital, the Dolby Digital movie theatre hall? What is Dolby Digital? It is nothing but an encoding system coding system. So, what is Dolby Digital? 5.1 channel. So, it is a multi-channel signal, ok.

So, I will come later on about what Dolby Digital is. You can also think about Dolby Digital. So, a multichannel signal means I have several channels. So, if I represent in mathematics, I have a signal in which there is a multichannel signal combined together. S1 is a channel, S2 is a channel, S3 is a channel, and S4 is a channel. So, it is a 4-channel signal, not 3 3-channel; 4-channel signal S1, S2, S3, S4.

So, during audio editing, why is this multi-channel signal required? If you see it, suppose I have a vocalist and background music. So, I want to reduce the background music when an important conversation is happening. If you see in a movie when an important conversation is happening, the music is stopped, and when it is reaching climax, there is some prominent background music.

So, how do I do that? I put the voicing in one channel and background music in one channel. I can fetch the background music or reduce the amplitude of the background music during that time, and after that, when this is a climax point, I can produce extra music here so that when it is the climax point, then in their background sound will come. So, that is why the multi-channel signal systems come, ok.

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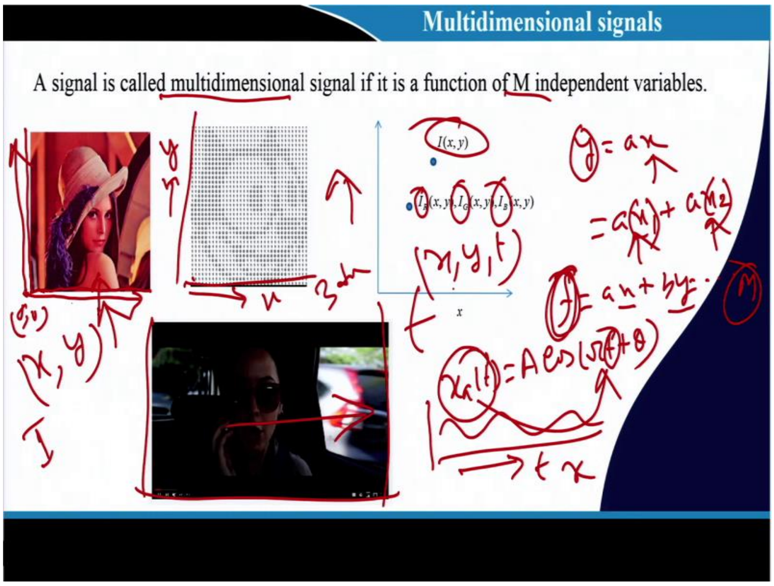

So, the signal can be a multi-channel, and the signal can be a multi-dimension. If I say

$$x_a(t) = A \cos(\Omega t + \theta).$$

If you look at the timeline, the amplitude of the signal changes; along the timeline, the amplitude of the signal changes. So, I can say if it has a 1-dimensional signal, ok or not; only this direction signal is changing. So, this may be a t, this may be a x.

So, this $x_a(t)$ value of $x_a(t)$ depends only on t; t is an independent variable. Now, if I say you know that when I say

$$y = ax,$$

you know the y depends only on x. Now, if I say

$$y = ax_1 + ax_2$$

where x_1 and x_2 are independent variables, then I can say y has a 2 dimension, or I can say f function is equal to ax plus by. So, I know the function f has 2 dimensions, x and y, two are the independent variables.

So, if a multidimensional signal, if I have M number of independent variables,, I have a signal whose dimension is M. Example: let us take this picture; how much information is there in the picture? If you see it, let us see the colour picture. So, I know the picture is changing along this direction, and the picture is changing along this direction, too. So, picture this; let us say it is 0, 0. So, the value, colour value is changing along this direction also, and the colour value is also changing along this direction.

So, I can say a picture has dimensions called x and y. So, either colour, if it is a black and white picture, it is only intensity. So, intensity changes along both spatial directions; one is the x direction, and one is the y direction. So, that is why I can say it is a 2-dimensional picture 2-dimensional signal image is a 2-dimensional signal.

So, either colour or black and white, the colour will be a function of x, y, z, or the intensity will be a function of x y z. So, intensity, you know that colour image intensity of R, the intensity of G and the intensity of B that is a function of x, y, and z. If it is a black-and-white image, I is a function of x, y and z. If it is a binary image, I know the value of the pixel will change along the x-axis and along the y-axis.

So, every pixel has a coordinate in x and y. That is why I call it a 2-dimensional signal. Now, when I am watching a movie, it is not a still picture; it is an x and y dimension that also changes over time. When you play a movie, it is nothing, but you change the time. So, it is x and y along with time. So, I can say a movie is a 3-dimensional signal. I have 3 dimensions: x dimension, y dimension and t dimension.

So, I have a multichannel signal and a multidimensional signal. Multichannel is not changing the dimension. The complexity of the signal will be the same in the case of a multichannel signal or may be different, but channel-wise, its sources are different. When I say a multi-dimensional signal has multiple dimensions, the signal depends on multiple M-independent variables.

So, here, the independent variable is x and y and here also x and y; x, y and t. When I say I am speaking, this acoustic signal when it travels in the air if you see how many directions it can travel. So, let us see the pressure wave. So, the pressure wave can travel in the x, y, and z directions.

So, the pressure wave is a function of x, y, z, and t. So, if the pressure wave is a signal, it depends on four independent variables: x, y, z and t. Understand? So, this is the multi-channel and multidimensional signal. If I ask you another important example, let say what is Ohm’s law? What is Ohm’s law? People will say V is equal to I R ok, then there is another condition when all the physical properties remain unchanged.

So, Ohm’s law you have learned in class 8, class 9, class 10 plus 2 and physics,. Sorry, engineering, where is the difference? How does the complexity of I and V change with an induction of different dimensions? I is a signal; current is a signal. So, how has the current signal dimension been changed? Initially, you say all the physical properties remain unchanged.

Now, if you just break that term and add the complexity on the I, so, initially you said I is a function of a t, then you said I is a not only function of t, it is also function of position and time. So, I is a function of x, y, z and t, and V is a function of x, y, z and t. So, you are changing the complexity. So, if I increase the dimension, the complexity of the signal changes.

So, I will stop here today. So, in the next class, I will talk about the characteristics of the signal.

Thank you.