Data Communications
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Lecture # 03
Data and Signal

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Hello viewers welcome to today's lecture on data and signal. This is the third lecture on the series of data communication. In this lecture we shall cover various aspects of data and signal. On completion of this lecture the students will be able to explain what is data, distinguish between data and signal, distinguish between analog and digital signal, explain the difference between time and frequency domain representation of signal, specify the bandwidth of a signal, explain the bit interval and bit rate of a digital signal and here is the outline of today's lecture.

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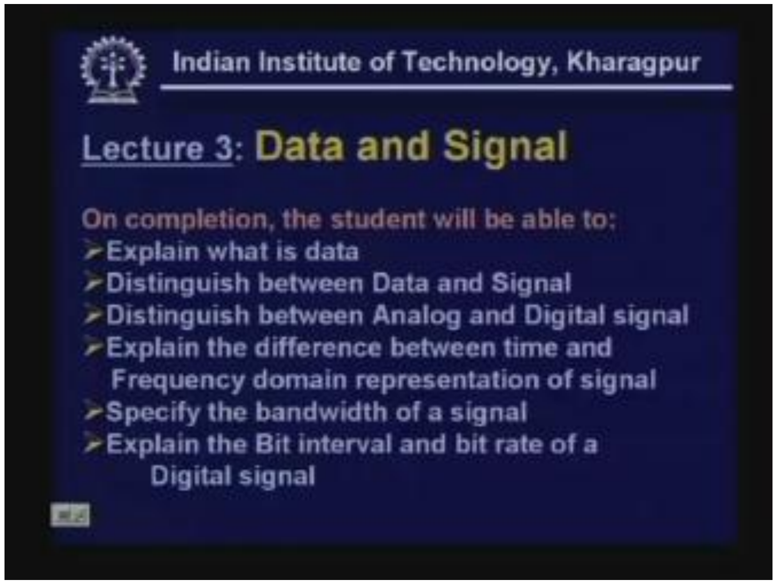

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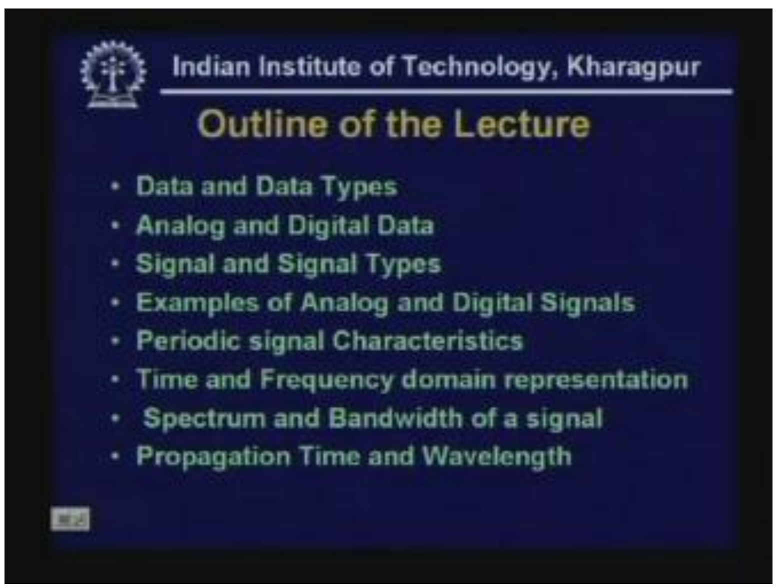

First we shall consider data and data types, analog and digital data, signal and signal types, examples of analog and digital signals, periodic signal characteristics, time and frequency domain representation of signal, spectrum and bandwidth of a signal and finally the propagation time and wavelength.

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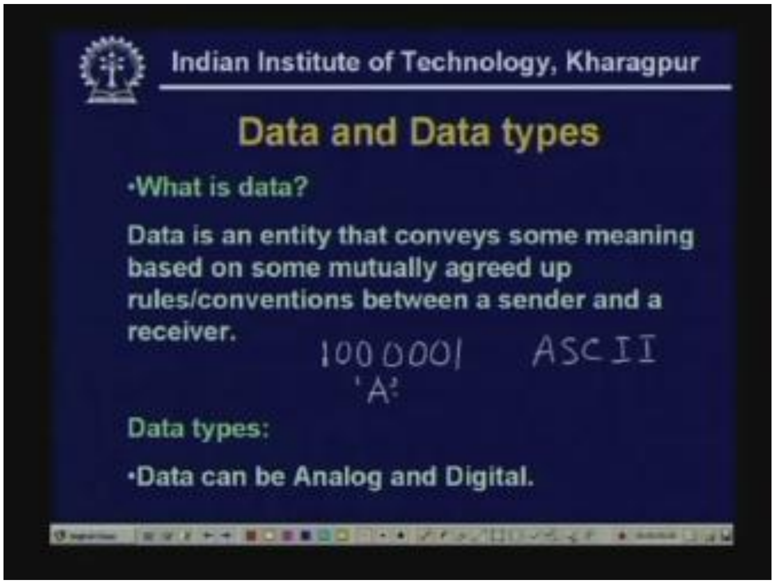

First let us consider what data is. As we have seen that we have to send data through some communication media and we have to understand what we really mean by data, data is an entity that conveys some meaning based on some mutually agreed upon rules, conventions between a sender and a receiver. That means for sending the data the sender has to follow some mutually agreed upon rules and convention at the receiving end. The receiver also has to follow mutually agreed upon rules and convention to interpret the data.

Let us take up an example say the sender has sent some data say 1000001 that has been sent by a sender. Now as such this bit sequence has no meaning and the receiver cannot really understand what it is and what for it has been sent. But once it is told that an ASCII character has been sent as you know ASCII stands for American Standard Code for Information Interchange and whenever the sender informs that this is a ASCII character then the receiver will know that an ASCII character has been sent which is nothing but the character code for the character A. That means A has a seven bit code 1000001 so now it has become a data until it was able to be interpreted the receiver is able to interpret it is no longer data.

For example we hear many noise disturbances from the environment but we do not interpret every thing as data. But whenever we hear a music or song then we can interpret it and we can understand the meaning of that song and that can be considered as data. That means uncorrelated incoherent signal or information whatever we receive is not data. But what we can interpret obviously that interpretation is based on some knowledge of the data that means some standard norm or some mutually agreed upon convention. So this is your significance of data or meaning of data.

Now the question is what are the different types of data that are possible? Data can be either analog or digital in nature.

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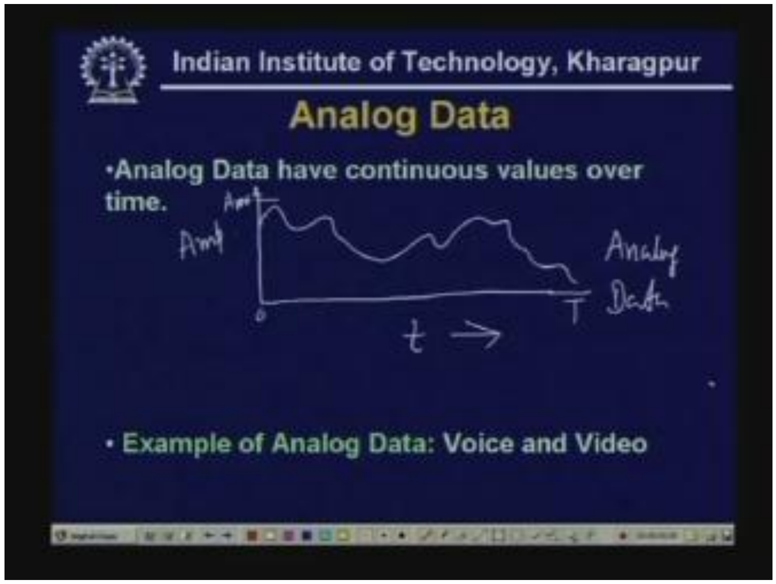

Analog data have continuous values over time. That means suppose this is the time domain representation of some data and say. So it has continuous values over time so this side is the time and this side is the amplitude in this case. So whenever this is being sent then this has continuous values that means it has got infinite number of values within this range then we will call it analog data. Here within this duration say time 0 time t a large number of values or infinite number of values have been sent that means the signal levels can vary from 0 to some range say A_{max} any value we can get so we call that range the analog data. So this is the example of analog data. For example, voice and video are analog data that is being commonly sent over medium. First let us consider audio as an example of the analog data. For example if a person is speaking then someone is listening to it. So this is the mouth and this is the ear.

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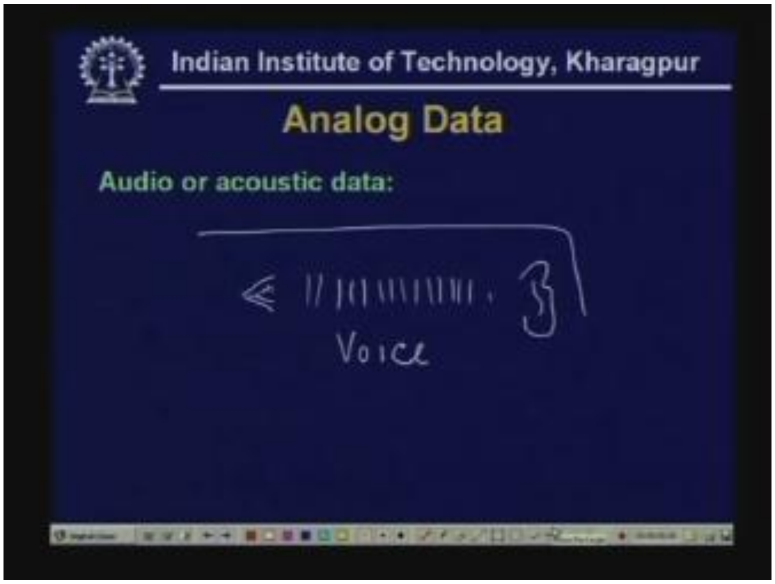

Now through air the voice travels to the ear. That means from the mouth the vibration is made and that vibration leads to some compression and decompression as you know the waves and that waves compresses the data to the ear and it gets some sensation in the eardrum which makes us hear. So this is your audio or acoustic data. Now if we represent it on time domain or instead of time domain let me represent it frequency domain.

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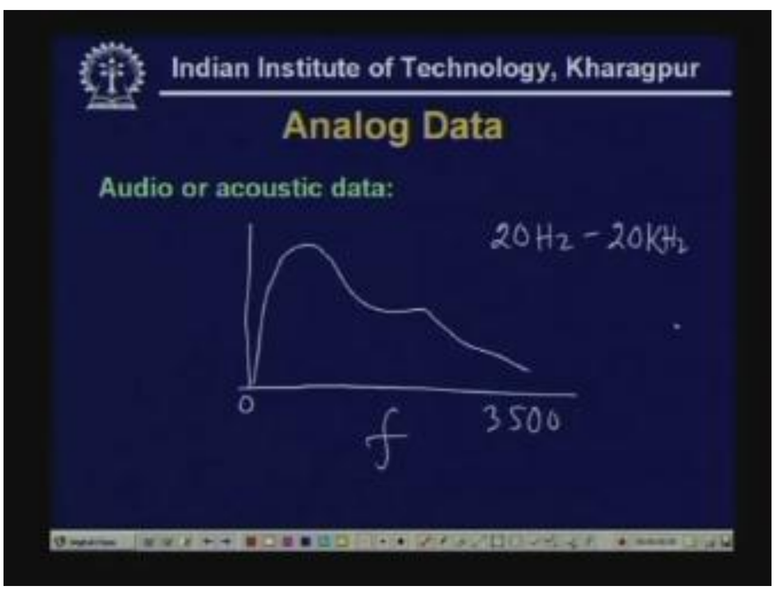

So here we write in frequency domain and the signal strength usually lies in the range of may be 0 to 3500 so the significant portion of the signal lies in this frequency domain. However, as we know a voice or music can have any signal in between 20 Hz or 20 KHz.

However, our ear is more sensitive to this range of the signal that means 0 to 3500 and most of the voice communication takes place within this range. So this is the analog data or audio data that can be communicated usually through air.

However we cannot send it electronically so to send it electronically we have to do something which we shall see later. So far as the video data is concerned we are familiar to viewing image on TV. The video data can be best explained with the help of what we see on TV.

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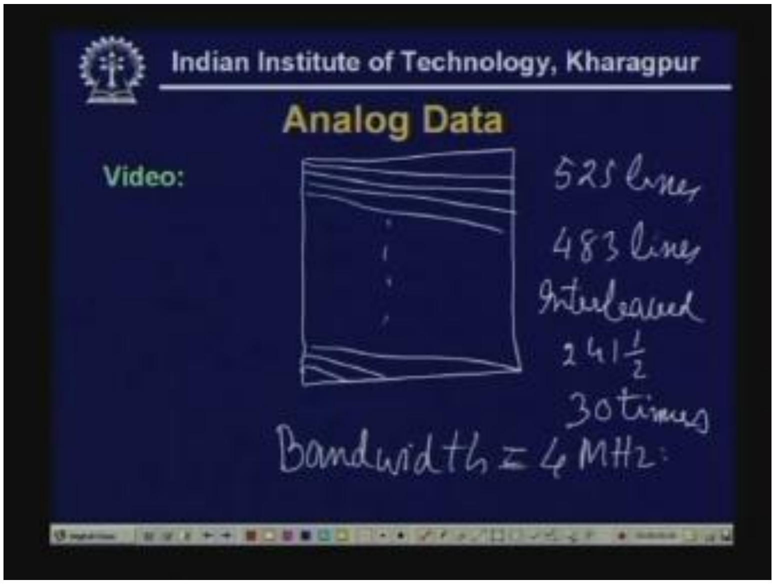

As we see on TV a raster scan moves, an electron beam moves from this end to the other end a large number of times and that's how a frame is created and the number of lines is about 525 lines of course all of them are not visible but of which 483 lines are visible the other lines are blank and it is done in an interleaved manner. That means 241 ½ times it is repeated twice and it is repeated thirty times in second to make it visible on the screen. That means for the sake of retentivity of the eye the repetition rate should not be less than thirty times otherwise the image will not appear to be stationary.

So, whenever we do this the bandwidth requirement of this video data is about 4 MHz of course this is excluding voice and color, if we include that it will be more than this. So this is the example of video data that we receive through a television network and we see that it has got much higher signal components having bandwidth of 4 MHz, this is an example of another analog data.

Now let us consider the third type of analog data that is physical parameters. Physical parameters are essentially various parameters that we encounter in environment. The world that you belong to is in analog domain. That means all the physical parameters are analog in nature.

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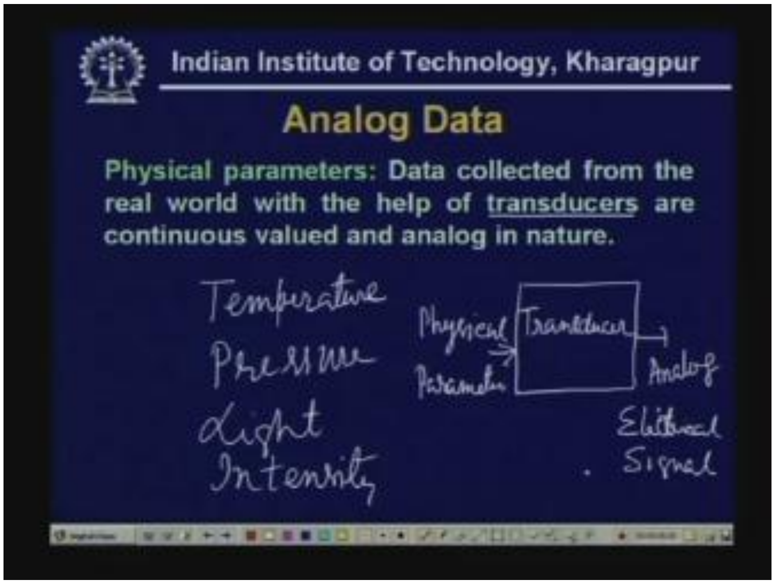

For example temperature, pressure etc are all analog in nature and these analog parameters are usually converted to electrical form with the help of transducers. Transducers are essentially some kind of energy conversion device so on this side we apply physical parameter it can be temperature, pressure, light intensity and on this side we apply that on this we get some electrical signal voltage or current so this is your transducer. And transducer produces here an electrical signal which is also analog in nature usually. That means we get continuous values of the electrical signal corresponding to the physical parameter on this side for anyone of the parameters I have mentioned earlier. So these are the examples of analog data.

Now let us consider digital data. Digital data take on discrete values. Discrete values so again in terms of time we are representing then it can have 1 0 1 1 so these are the discrete values. That means two distinguished voltage levels, here it is 0V and it can be said 5V it is represented by two different voltage levels. So 0 1 1 1 then it can be again 0 and one so as you can see it has got two different voltage levels.

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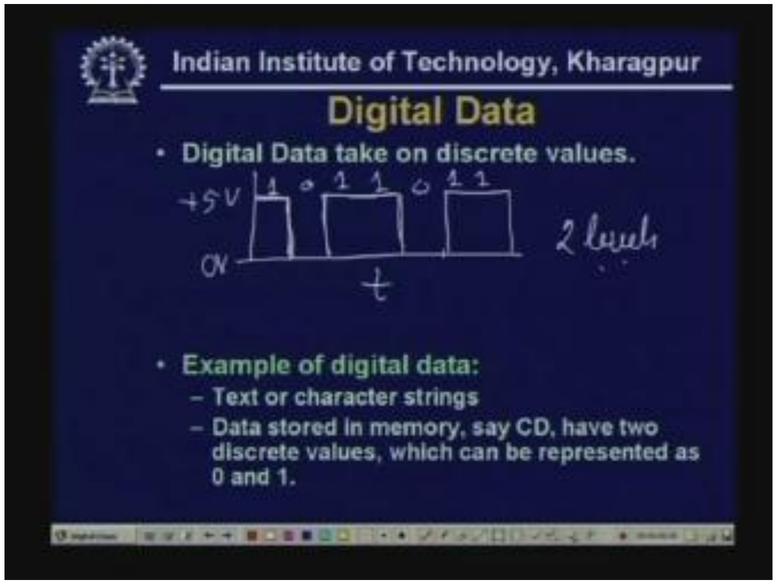

So here it takes on some discrete values. It is not absolutely necessary that it should have only two voltage levels it can have more than two voltage levels but in general we are more concerned with digital communication so it will be essentially of two levels as we shall see in most of the cases. An example of digital data is text or character strings.

As we have mentioned that ASCII characters are of eight bit here we see is an example of some ASCII characters. So American Standard Code for Information Interchange ASCII codes are seven bit codes and some of the codes are given here.

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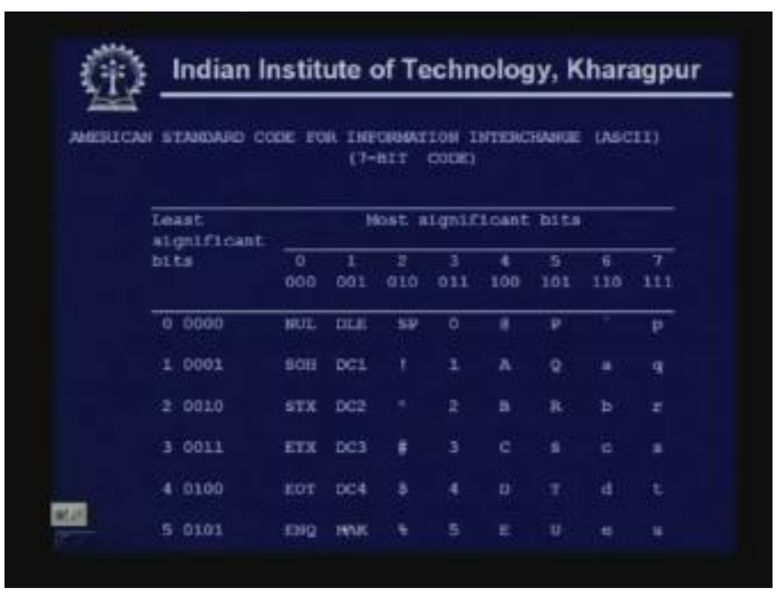

For example 0 is 0 0 1, 0 0 0 0 then one is your 0 1 1, 0 0 0 1 that is the ASCII code for 1. That means in the computer whenever we press the keyboard and press the character essentially 1 0 0 0 0 0 1 is sent to the computer. That means keyboard senses the character code 1 0 0 0 0 0 1. Thus some of the ASCII characters examples are given here and this is an example of digital data.

Another example of digital data is data stored in memory say CD has two discrete values which can be represented at 0 and 1. For example inside the computer the information that is stored is stored in the form of 0s and 1s and inside the digital computer it is essentially digital domain and nothing else exists other than 0s and 1s. So whenever some information is stored in the memory or hard disk or CD it is stored in the form of 0s and 1 and it is stored in that way.

Now comes the question of signal. So far we have discussed about data and explained what data is. We have seen that whenever data has to be sent over some communication media it has to be converted into signal. Data cannot be sent as it is through the transmission media. We have to transform it into signal before sending over the communication media.

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So what is signal? A signal is nothing but it is electric, electronic or optical representation of data which can be sent over a communication media. That means we are converting into some form which can be either electric electronic or optical. It depends on through which medium they are trying to send. That means when we are trying to send through a pair of wires it has to be electrical voltage or current.

On the other hand whenever we are trying to send through an optical fiber cable it has to be converted into optical signal or light. Then that light can be communicated through the optical fiber medium or sometimes we send in the form of magnetic field so we can say it has to be in some form which can be electric, electronic, optical or some electro magnetic signal.

Again as we shall see signals can be of two different types analog and digital. It can be either analog or it can be digital. An analog signal has continuous values over a period of time or you can say the infinite number of values over a period of time. For example here this is an example of an analog signal.

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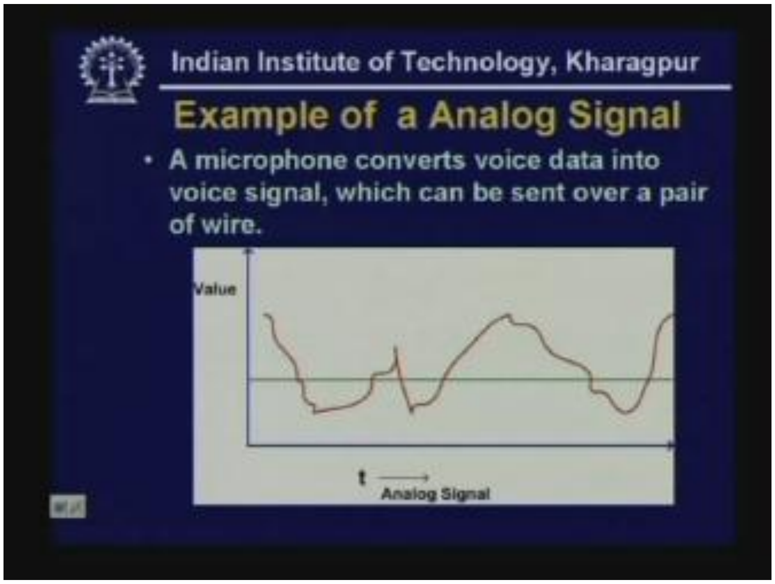

As you can see a microphone converts voice data into voice signal. As we have seen whenever somebody is speaking or singing he makes some vibration in the air. So that audio data can be converted into audio signal or electrical energy with the help of microphone, that microphone is essentially a transducer which converts that vibration or pressure on the microphone into electrical signal generating voice signal which can be sent over a pair of wires.

Here is an example say t and as we can see here you have got the electrical signal with different amplitude values as it is shown on this side. This has got infinite number of values so it is analog in nature. Similarly digital signal can have only limited number of defined values usually two values 0s and 1.

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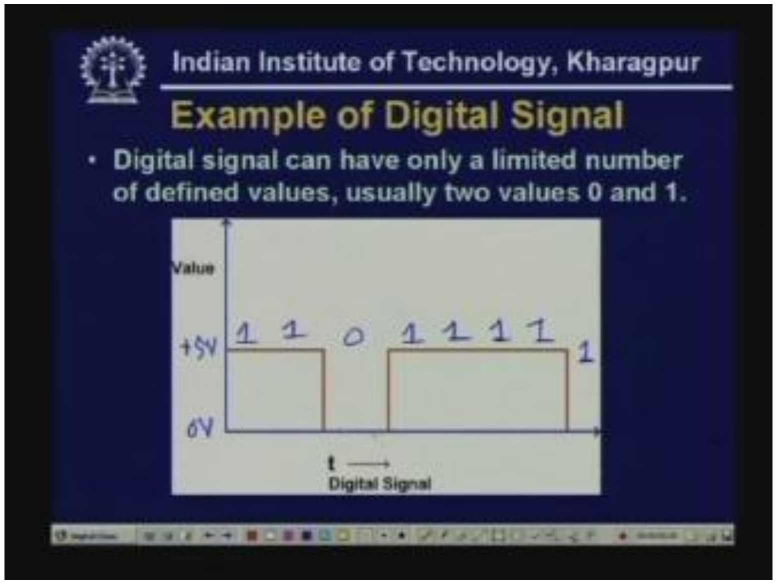

For example, this is a 0V and here it is plus 5V. The 0V can be considered as 0 logic level and plus 5V can be considered as one logic level. So here as you can see the signal has got two distinct values either one so here let it be 1 1 0 1 1 1 and 1. So in terms of 1s and 0s the digital data is converted. So in digital data we are having only two different values.

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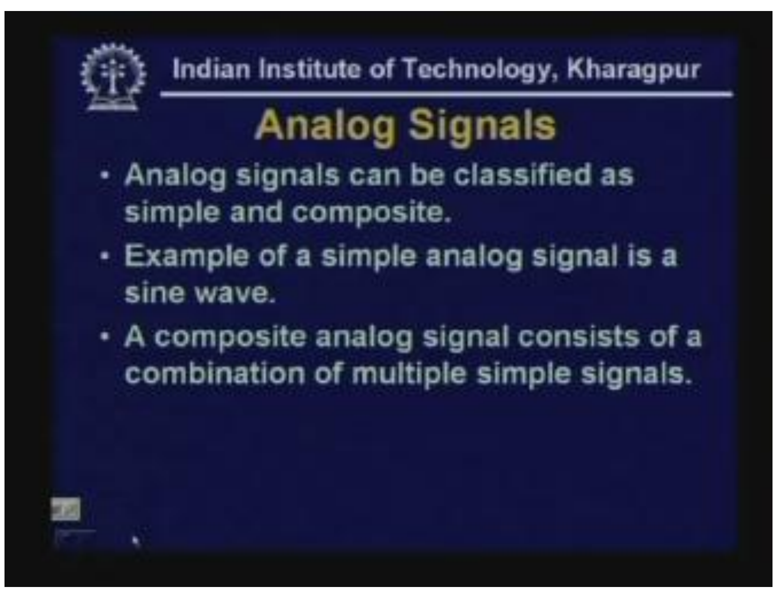

Now we can focus more on the analog signal. Analog signal can be classified into two types. First one is simple, second one is composite. Example of a simple analog signal is sine wave. Sine wave can be considered as a simple analog signal and as we shall see a composite analog signal is essentially a mixture of multiple simple signals as we shall see very soon.

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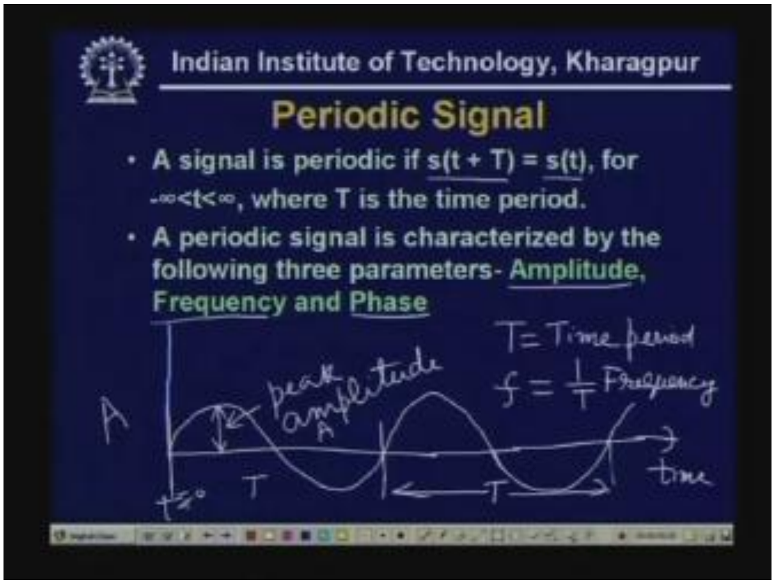

Again these simple analog signals usually are periodic in nature for example a sine wave. Let me draw a sine wave. For example, this is a sine wave I have drawn. Now this sine wave is repeating as you can see after this time (Refer Slide Time: 24:45) this time t is known as the time period where t is equal to time period. That means after time t the signal will be same as the previous portion. The same thing that is this part will be repeated here so this is another t. So mathematically as you can see when s(t) plus t is equal to s(t) for the range minus infinity to plus infinity of time that means it is starting from any time, it has started long back and it is generated continuously then we call it a periodic signal and it is a time period t, this T is the time period (Refer Slide Time: 25:47).

Now a periodic signal can be fully characterized by three parameters. What are the three parameters? The three parameters are amplitude, frequency and phase. What is amplitude? As we can see on this side we have plotted time and this side we plot amplitude and this one is known as the peak amplitude A.

So we have seen peak amplitude A and that frequency f is represented by one by t. That means if t is the time period then frequency is essentially is 1/t so f is equal to 1/t that is your frequency, this is actually the frequency. Now there is another parameter phase. Phase is actually expressed between two different signals, the relative appearance of a signal with respect to another signal.

For example, let us assume this is time T is equal to 0. Here the signal value is 0 so we can say phase is 0. Now let us discuss in more detail about amplitude, frequency and phase.

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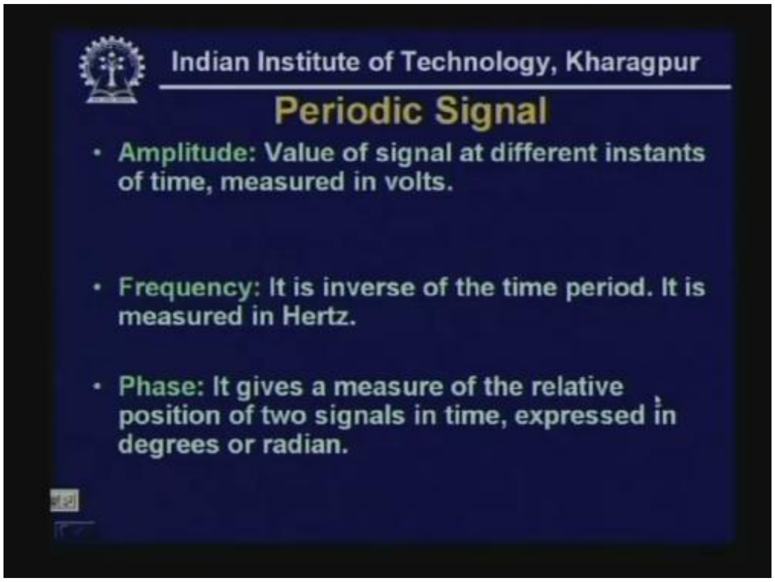

Amplitude is the value of the signal at different instants of time measured in volts. And for example let me represent a sine wave, amplitude frequency and phase. So, if we consider a sine wave say let me represent this signal s(t) is equal to a sine 2 pi ft plus phi. This is the representation of a sine wave and as you can see here A is the peak amplitude and obviously with time this amplitude varies. For example, as we have seen earlier it varies like this. Although this is the peak amplitude that means with time it is varying because of this factor multiplied with this. so this is known as the amplitude varying with time. And frequency it is the inverse of the time period and usually it is measured in hertz.

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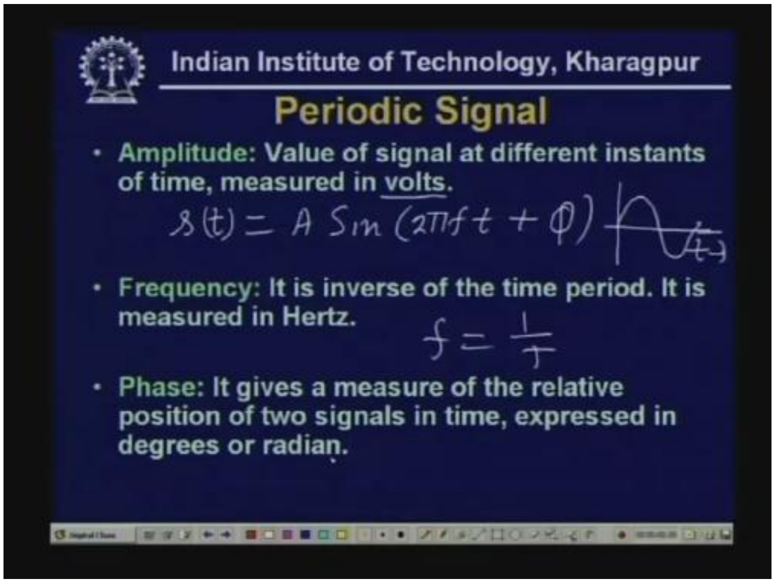

This amplitude is measured in volts as you can see here. Of course as we shall see there are other units that also we use. Frequency for example it is inverse of the time period that we have seen f is equal to 1/t and it is measured in hertz. On the other hand phase as I told it gives a measure of the relative position of two signals in time expressed in degrees or radian. Let us see examples of signals with different amplitudes, frequency and phases.

For example this particular signal (Refer Slide Time: 30:49) as you can see has got peak amplitude 1V so A is equal to 1V, this part is 1V, this is 1V and within one second we can see that one complete cycle is completed. So it has got frequency f is equal to 1. And as I told in time 0 the phase is 0 so phi is equal to 0. Now here is another signal.

Here amplitude as you can see the peak value is 0.5 and with respect to this we can compare so this is 0.5. So A is equal to 0.5, the frequency is same it is repeated after one second and here also phase is 0. Here on the other hand as you can see within one second there are two complete cycles. So here frequency f is equal to 2 although amplitude A is equal to 1 and phase phi in this case is 0. So here we have got amplitude equal to 1, frequency is equal to 2 and phase is equal to 0.

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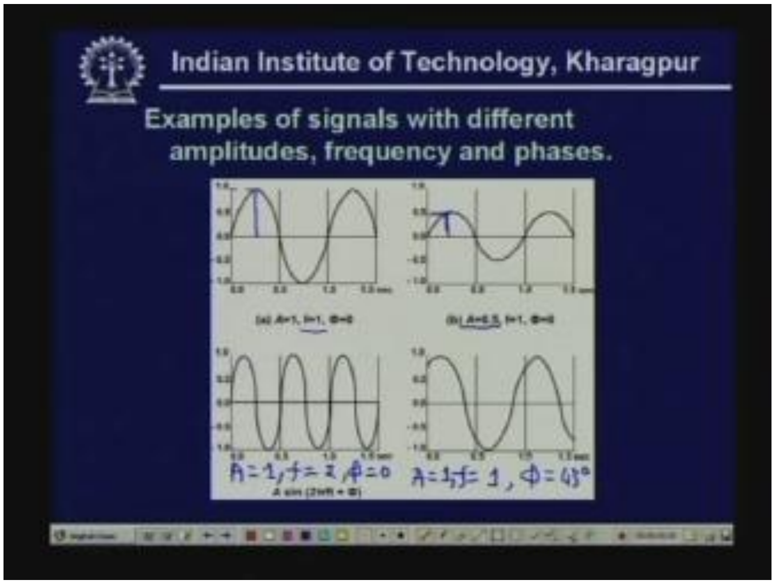

Now in this diagram (Refer Slide Time: 32:39) we have got phase as you can see with respect to this. Everything is the same with respect to this expect phase. So it is not starting with 0 that means 0V is not at 0 point and there is a phase shift of about 45 degree and phase is expressed in terms of degree or radian as we shall see. So in this particular case A is equal to 1V, f is equal to 1 Hz where 1 means 1 Hz because in one second again one cycle is completed and phase is equal 45 degree. So here we have taken example with different amplitude, frequency and phases.

Now, for different parameters that we have discussed amplitude, frequency and phase let us consider the other units that are commonly used.

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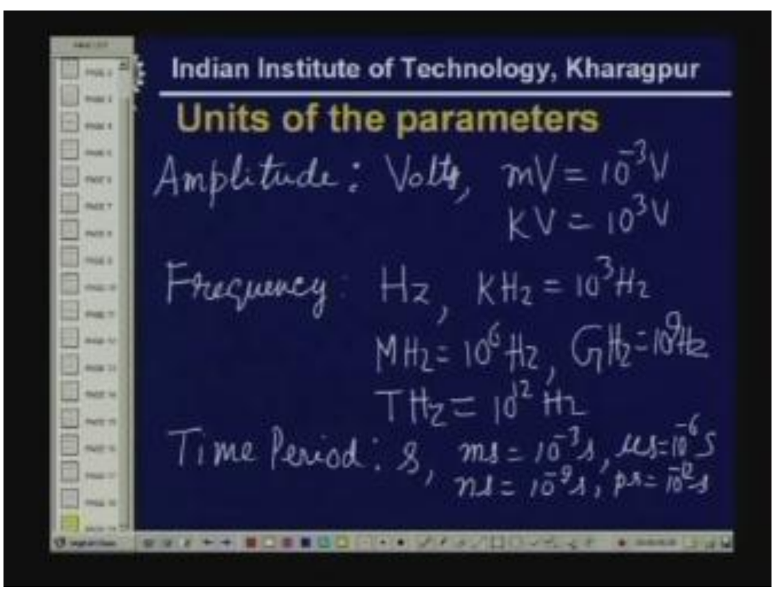

For example, let us consider first for amplitude. So it is in volts but sometimes the voltage can be of very small so in such case we can call it millivolt then we write mV millivolt that means something which is equal to 10 to the power minus 3V or sometimes we have to represent high voltage then we can say that it is KV that means it is 10 to the power 3V.

Similarly we call frequency as hertz. But sometimes the values can be very large or sometimes the frequency can be very high then we say KHz kilohertz that means 10 to the power 3 Hz or it can be MHz megahertz that means 10 to the power 6 Hz or it can be GHz gigahertz that means 10 to the power 9 Hz or it can be THz terahertz that means 10 to the power 12 Hz and so on. Hence we are dealing with very large frequencies nowadays.

Similarly for time period or sometimes we call it period so the basic unit is second which we represent by S but sometimes we have to deal with very small time or very long time. If we have to write millisecond that is equal to 10 to the power minus 3 second or micro second that is equal to 10 to the power minus 6 second millisecond, microsecond or nanosecond 10 to the power minus 9 second or it can be picosecond sometimes we have to write very small time picosecond 10 to the power minus 12 second so these are the various units for amplitude, frequency and phase. Similarly we can have units for phase.

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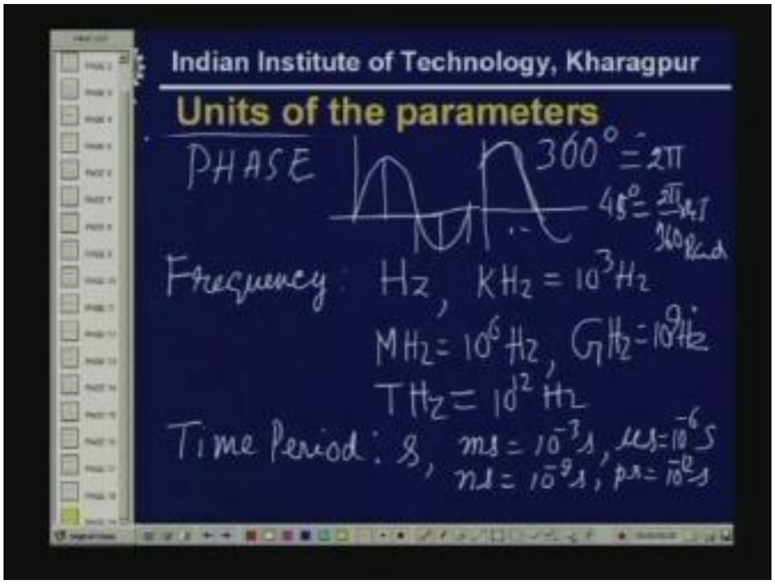

We have seen that for phase within one cycle that is within this range the phase can vary at 360 degree. So from here to here (Refer Slide Time: 37:43) that means this is 90 degree, this is 180 degree and this is 270 this is 360 or we can express it in radian and in that case it is 2 pi. Suppose the phase has been shifted by another signal like this that means here the phase is about 45 degree. So in that case it is 45 degree which can be written as 2 pi by 360 into 45 in radian.

So we have seen the various units used to represent the important parameters such as amplitude, frequency and phase for a signal. And later on we shall see that these are the parameters that we shall vary for the purpose of communication through medium.

Now we have discussed about the time domain representation of the signal. On the x axis we have plotted time and the amplitude variation with time we have shown and this can be visualized with the help of the oscilloscope. Oscilloscope is the equipment that is normally used to have visualization of the time domain representation of the signal and we are very familiar with that.

However, whenever you vary the amplitude phase or frequency it becomes a composite signal and that composite signal whenever it is shown on the oscilloscope does not convey much meaning to us so in such a situation it is better to have frequency domain representation of the signal.

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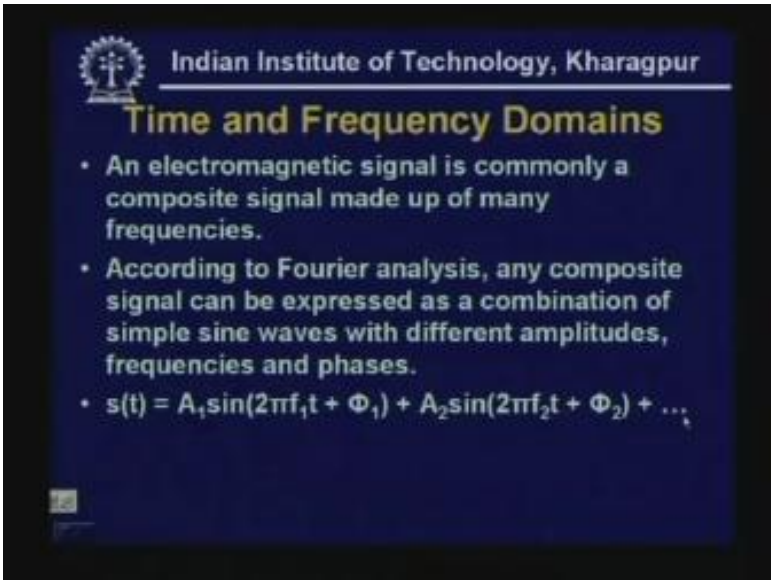

And whenever a signal is complex by virtue of the variation of parameters like amplitude, phase and frequency with time then it becomes a composite signal and that composite signal according to Fourier analysis any composite signal can be expressed as a combination of simple sine waves with different amplitudes, frequencies and phases. That means we can express any composite signal in terms of sine waves having frequency f_1, having frequency f_2, having frequency f_3 so it's an infinite series of many frequencies. Now here is an example.

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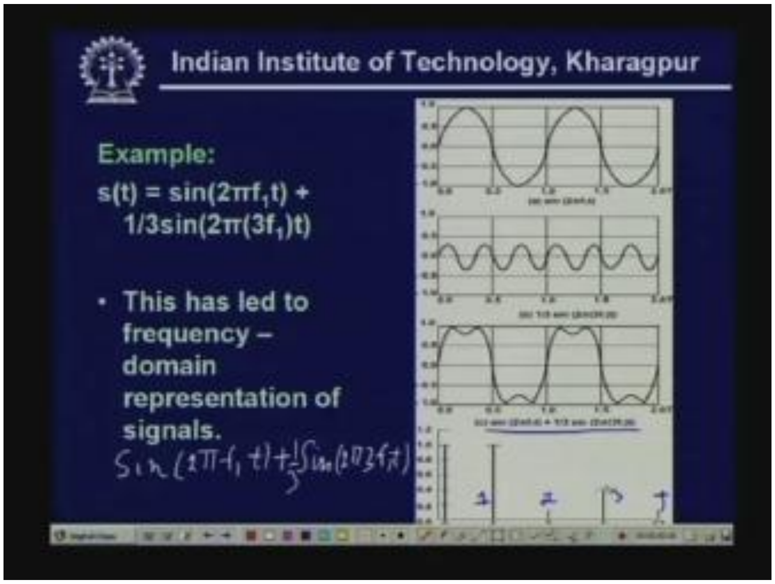

So here we see this is a sine wave, sine 2 pi f_1 t having frequency f_1, this has got frequency f_1. Here is another signal, as we can see within this we have got three cycles so it has got frequency $3f_1$ so this frequency is three times of that. Now if these two are added that means suppose we have sine 2 pi f_1 t plus 1/3 as the amplitude is 1/3 sine 2 pi 3 f_1t assuming that phase is 0 for both then if we combine these two we get a signal like this as shown here. That means here as you can see we have got combination of these two sine 2 pi f_1t plus 1/3 sine 2 pi 3 f_1 t so if we combine this and if we see it on the oscilloscope in the time domain we shall get this kind of diagram. This is the diagram we shall get in the time domain.

However, if we analyze it with Fourier series then we know that it has got two frequency components one of f_1 and another of $3f_1$. So here we see that on the frequency domain representation on this side you have got f and this amplitude corresponds to the amplitude of this frequency and here we have 2 and 3 so here it is 2, here it is 1 and here it is 3. So here you see that the waveform with three amplitude has got frequency $3f_1$.

How we can see this? This can be visualized with the help of special equipment known as spectrum analyzer. So spectrum analyzer is an equipment which can give us frequency domain representation of the same signal. Now this frequency domain representation as you can see gives us the information about the different frequency components the signal has got which is sometimes very useful to us. So, now let us consider several examples of time domain and frequency domain representations.

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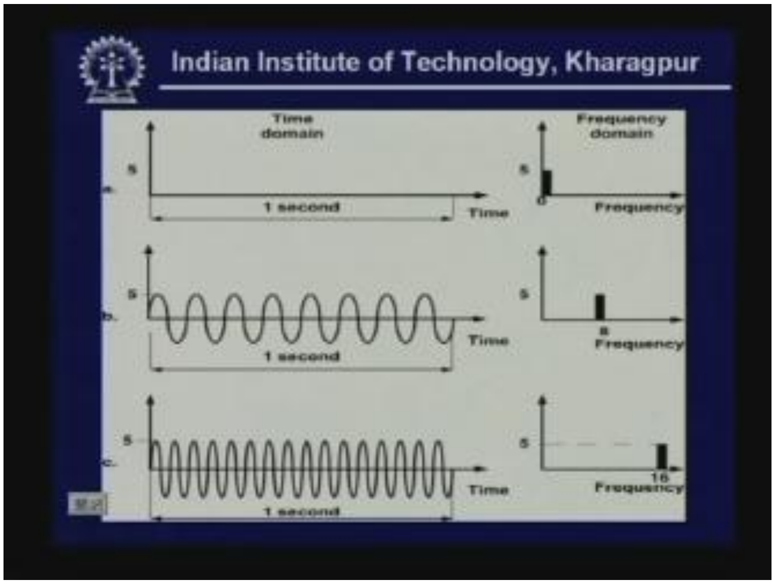

So here we see, this diagram A gives you a signal having one second and within one second how many pulses are there? There are 1 2 3 4 5 6 7 8 so there are eight pulses. So it has got frequency f and time period is equal to 1/8 second. And this corresponds to 5 units may be 5V so if we have a look at the frequency domain representation we get a line here at frequency f is equal to 8.

On the other hand here is another signal which has frequency 16. If you count you will get sixteen full periods within one second, this is one second. So it has got time period 1/16 second. And as you can see here frequency domain representation is given here (Refer Slide Time: 45:11) and we get a line of the same voltage with amplitude 5.

Now, whenever we are considering particularly a digital signal or a composite analog signal as we have seen it comprises many frequency components and that is expressed in terms of frequency spectrum. And frequency spectrum of a signal is the range of frequencies a signal contains.

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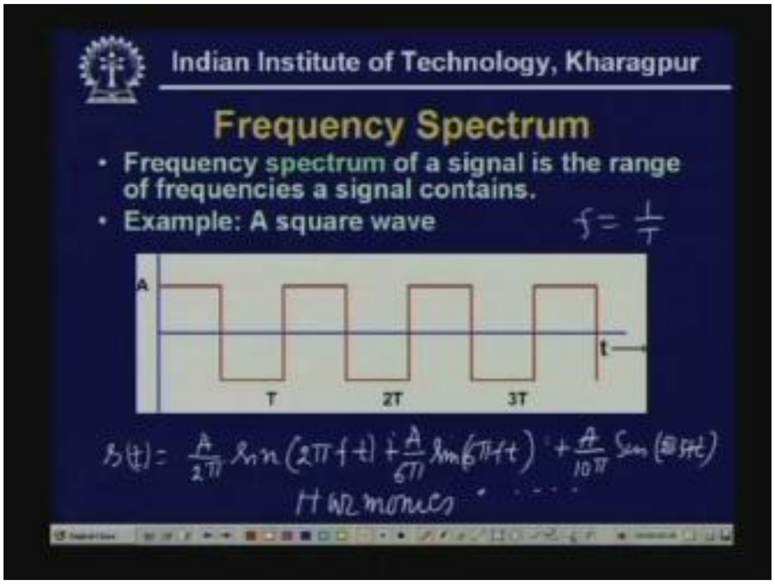

For example, here is a square wave and this square wave has time period t and frequency f here say f is equal to 1/t. Now this square wave if we expand it with the help of Fourier series it will have the representation s(t) is equal to A where A is the amplitude that means it will have the amplitude A/2 pi sine 2 pi ft plus A/6 pi 1/3 2 pi 3 f1 that is 2 pi into 3 ft which means the frequency is three times plus A/10 pi sine 2 pi into 5f into t. So here actually it will be A/6 pi sine 6 pi ft. So in this way it will have all the frequency components say frequency component of 3f, 5f, 7f, 9f and so on. However, as you can see here the amplitude is gradually decreased as A/6 pi, A/10 pi, A/12 pi so it will keep on falling but however it will have a frequency component of infinite frequencies. So it will have all the frequency components starting from f to infinite components. However, the frequency components of higher frequencies will be lower known as harmonics.

So this is the third harmonic, this is the fifth harmonic, it will have seventh harmonic, ninth harmonic and so on so increasingly of lower amplitude. Now, whenever we are representing a signal we have seen that the frequency spectrum can be very large. However, most of the frequency components having very small amplitudes are of not much use that's why there is another parameter known as bandwidth that represents the frequencies over which most of the signal is contained or this bandwidth can be the effective bandwidth of the signal.

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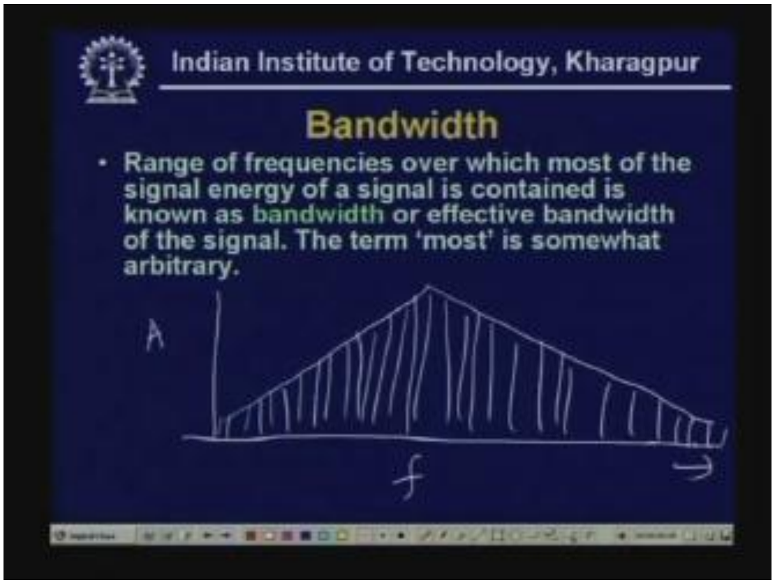

Here the term that means the range of frequencies over which most of the look at this term most that means so here is the information about bandwidth.

For example, you are interested in representing the bandwidth. Suppose this is the frequency domain representation and this side essentially signal strength or amplitude has got infinite frequencies in this range. Obviously the frequency of this spectrum of the signal is spreading over from lowest to highest frequencies. However, for all practical purposes we can remove this, (Refer Slide Time: 51:35) similarly from this side so if we remove this portion of the spectrum then we can say this is the bandwidth. So this is the bandwidth of the signal. From this part to this part is the bandwidth of the signal.

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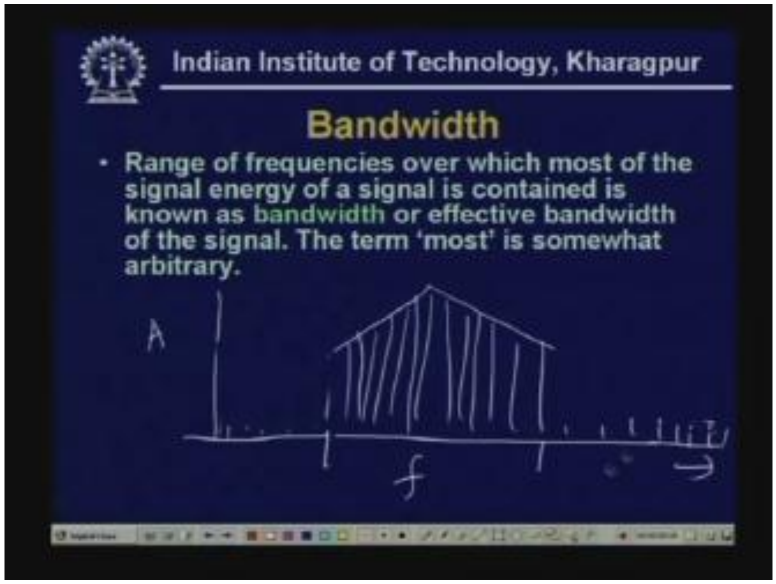

This is where the major part of the frequency components or energy is lying so we call it the bandwidth of the signal. Now in case of digital signal as you have seen it can be aperiodic in nature it may not be periodic in nature like the simple analog signal like sine wave. So in such a case it can have infinite number of frequencies. Now in the context of digital signal there are two parameters known as bit interval and bit rate which we have to discuss. For example bit interval is the time required to send a single bit.

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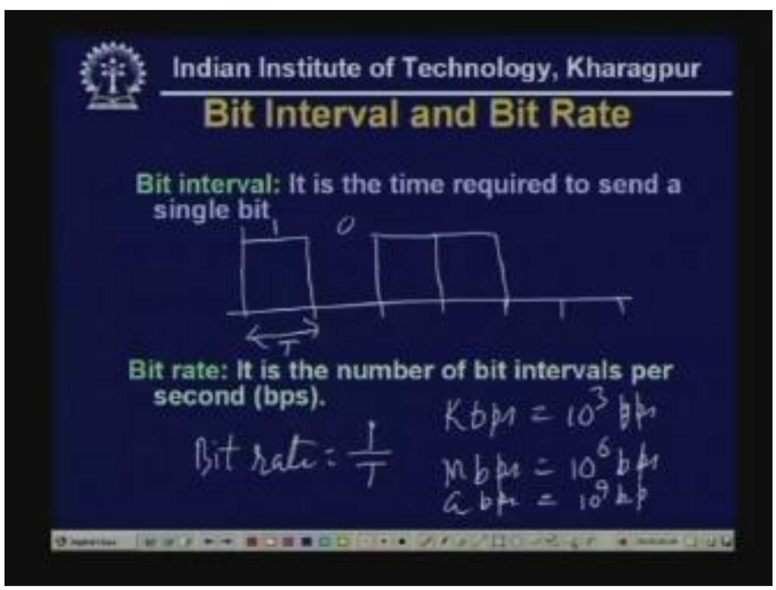

For example this is a digital signal say this is one and these are the intervals say 1 0 and then it can be 1 1 and this interval is essentially the bit interval say this time t is the bit interval. And if bit interval is t then the number of such bits can be sent in one second which is essentially 1/t and this is known as the bit rate the number of such symbols that can be sent in one second and it has the expression bits per second, obviously it can be extended to kilobits per second whenever you are sending 10 to the power 3 bits per second or it can be megabits per second then we are sending 10 to the power 6 bits per second or gigabits per second 10 to the power 9 bits per second and so on. So these are the bit rates that are commonly used.

Whenever we are sending analog digital signal then the bandwidth is restricted within certain range. On the other hand whenever we are sending a digital signal bandwidth is very large. So this can be represented in two forms.

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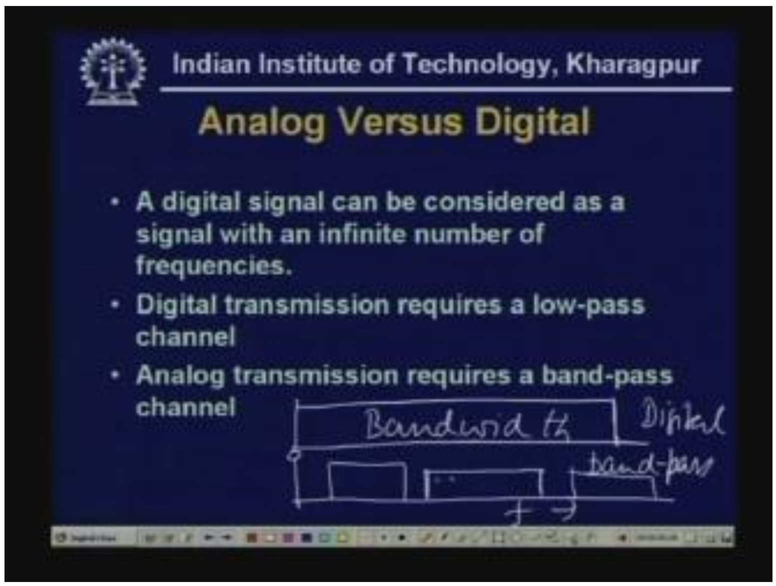

So, for example a digital signal can have spectrum like this. That means this is the bandwidth. This is for digital, 0 to very large frequency. On the other hand for analog signal we may restrict it within certain range so bandwidth is essentially like a band pass. And here it is like low pass as we can see from 0 to certain high frequency. And because of these characteristics through one medium we can send only one digital signal and on the other hand we can send several analog signals like say another analog signal, another analog signal and so on so in this way we can say in a frequency division multiplexing manner. So this is the frequency and several such signals can be sent through the media. On the other hand digital signal cannot be sent this way.

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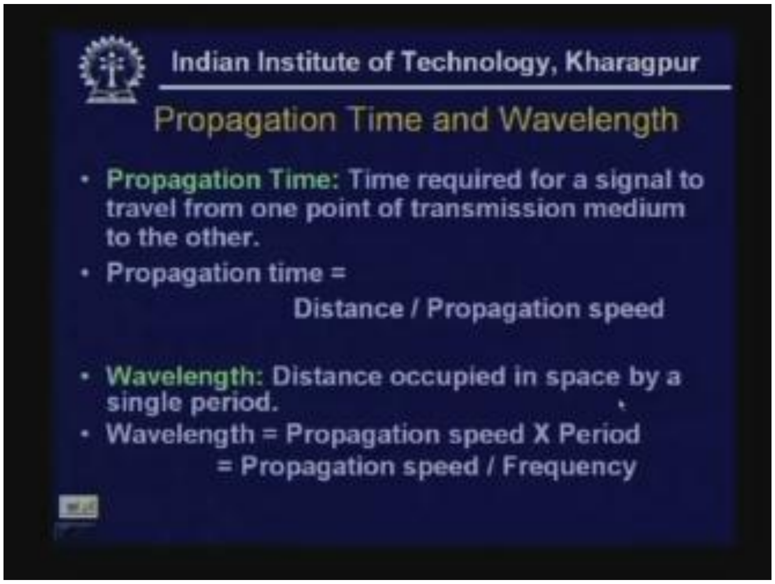

Now there is another important parameter that is propagation time. It is the time required for the signal to travel from one point of transmission medium to another. It is essentially the distance by the propagation speed. And there is a related parameter wavelength it is the distance occupied in space by a single period. Obviously there is relationship between the two where wavelength is equal to propagation speed into period or propagation time into frequency. Let me explain with the help of some example about the speed and frequency.

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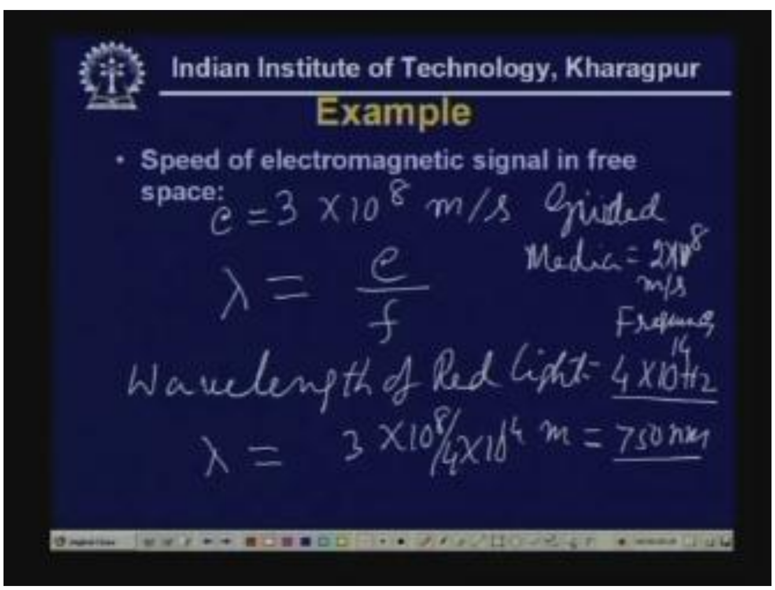

For example speed of electromagnetic signal in the free space is 3 into 10 to the power 8 m per second. Now that lambda that means this is equal to the speed of light; lambda is equal to c by frequency, the speed of light by frequency. For example the wavelength of red light s equal to 4 into 10 to the power 14 hertz, what is the wavelength of this? This is the frequency.

What is the wavelength of red light? Lambda is equal to 3 into 10 to the power 8/4 into 10 to the power 14 m is equal to 750 nanometer. So you see that the frequency is very high but wavelength is small for the red light. So this is how this speed and propagation time can be correlated and this is the speed in free space. Obviously whenever it is sent through some guided media as we shall see then the speed will be smaller will be equal to say 2 into 10 to the power 8 meter per second.

So we have covered different topics related to data and signal.

Here are the review questions on this particular lecture. The questions are distinguished between data and signal.

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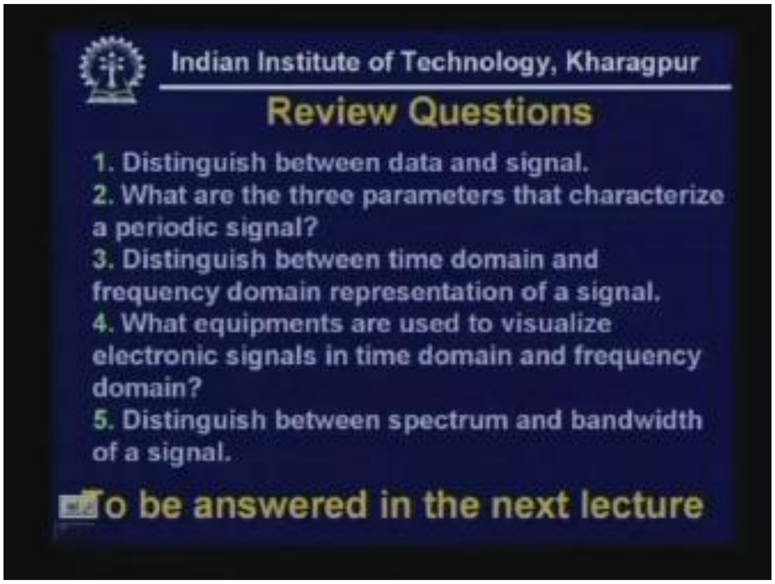

What are the three parameters that characterize a periodic signal?

Distinguish between time domain and frequency domain representation of a signal.

What equipments are used to visualize electronic signals in time domain and frequency domain?

Distinguish between spectrum and bandwidth of a signal.

So these questions will be answered in the next lecture and we end this lecture with the answers to the question of lecture 2.

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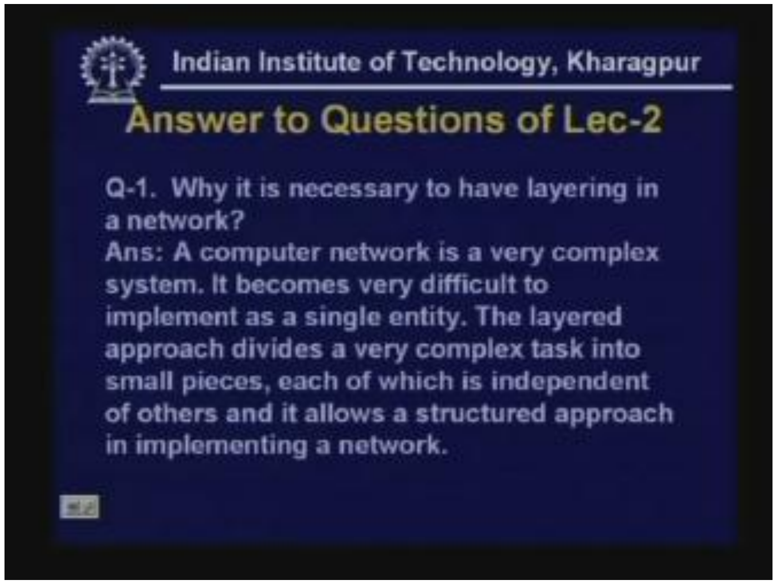

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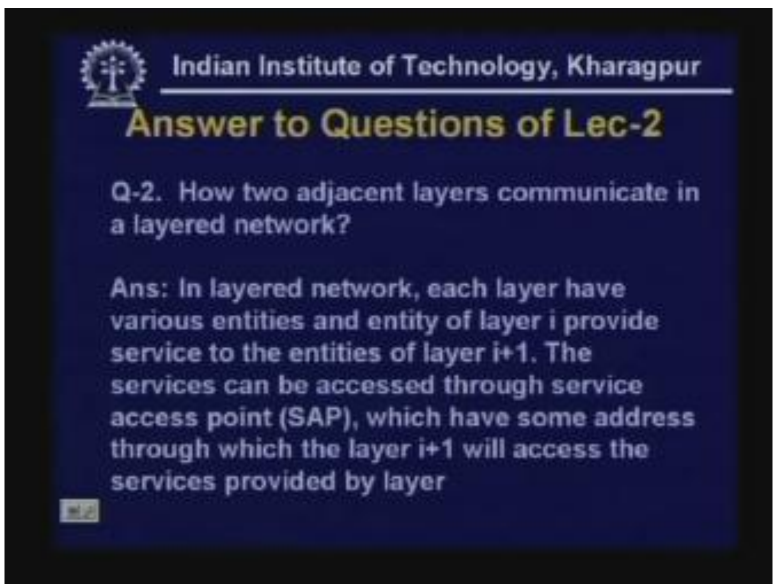

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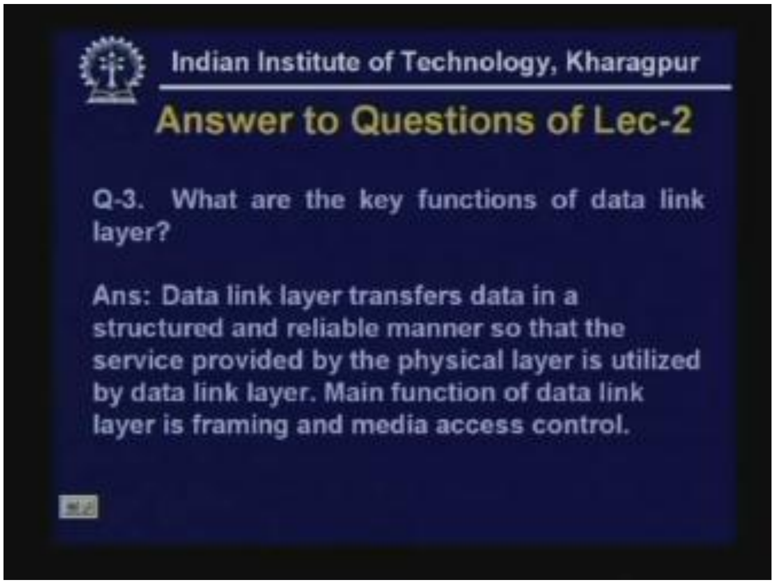

First question is why it is necessary to have layering in a network.

The answer is as we know a computer network is a very complex system it becomes very difficult to implement as a single entity. The layered approach divides a very complex task into small pieces if each of which is independent of others and it allows a structured approach in implementing a network.

This is the answer to questions of lecture number 2. And this is the answer to question 3 of lecture 3, thank you.