Phonetics and Phonology: A broad overview
Professor Shakuntala Mahanta
Department of Humanities and Social Sciences
Indian Institute of Technology, Guwahati
Lecture 08
Acoustic Phonetics

Welcome to the NPTEL MOOCs Course in Phonetics and Phonology: A broad overview. Today we will move to our next section, that is Unit 2 Acoustic Phonetics. Before that, let us quickly recap what happened in the last few classes.

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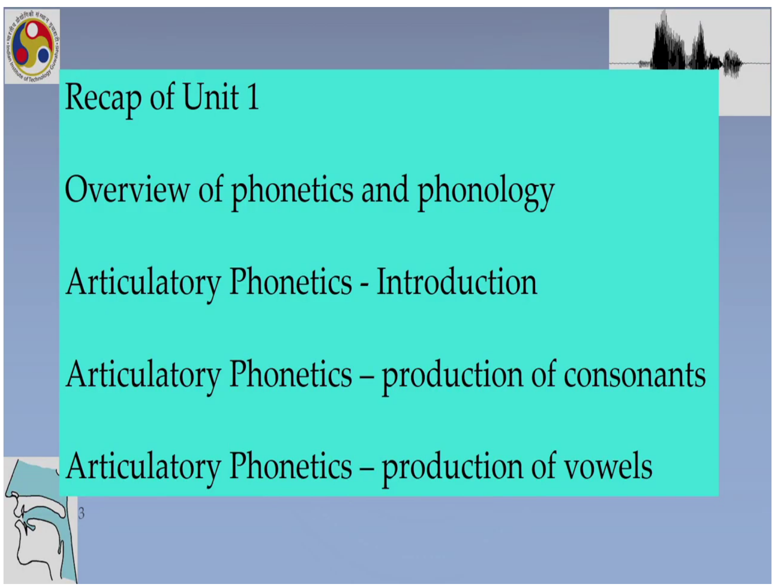

In Unit 1 we had a brief overview of phonetics and phonology. After that we looked into the various aspects of articulatory phonology, production of consonants and production of vowels. In overview of phonetics and phonology we went through some basic terms like phoneme as a unit of abstract representation, and then also other units like phones and allophones. And then we saw how phonetics deals with the physical manifestation of sounds.

So, for instance in articulatory phonetics which we went through in the second two sessions we saw that production of consonants and production of vowels involves a different vocal tract mechanism; for the production of vowels is always a free air flow, for the production of constant there is always an obstruction inside the vocal tract.

In the last class we looked at how vowels are produced. And as I have just mentioned it was with the free air flow. And then we looked at vowel distinctions and we looked at the vowels of English mainly, and we saw how we can divide the vowel inventories of different languages into certain categories depending on where the tongue is and where the narrowness occurs inside the mouth and whether the lips are rounded or unrounded. With articulatory phonetics we have looked at the basic aspects of this part of your course. And then now we move on to acoustic phonetics.

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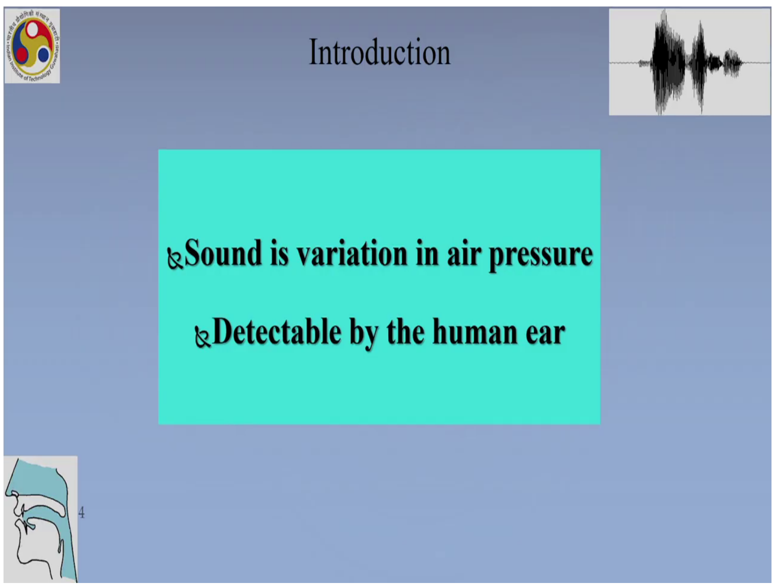

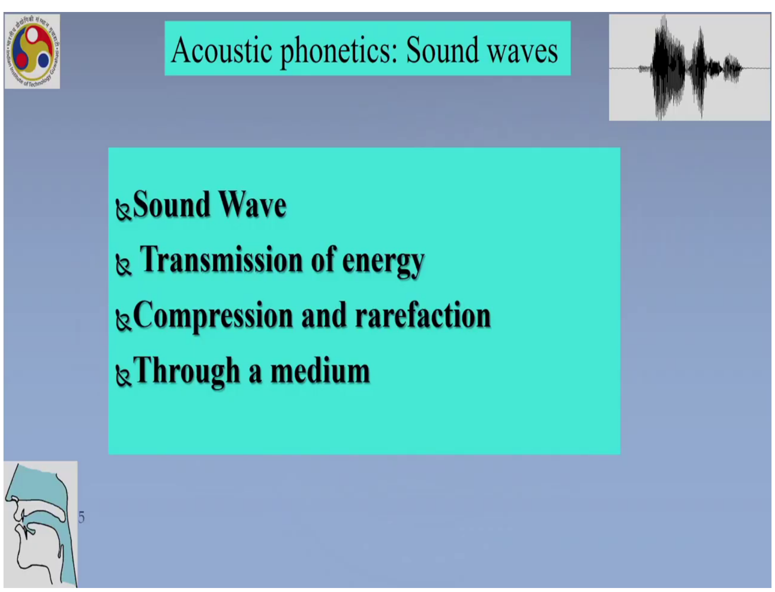

So when we study acoustic phonetics we study the physical, again the physical properties of how sounds are produced; the acoustics of these properties. So what happens when sound is produced? Sound is nothing but variation in air pressure. And it is air pressure which is detectable by the human ear. So variation in air pressure which is, which the human ear can detect and that is which reaches the hearer's ear as a sound, as a speech sound produced by another person.

So sound waves are characterized by transmission of energy. And this transmission of energy happens in the form of compression and rarefaction through a medium. So sound wave, so as we just saw that it is variation in air pressure which must be detectable by the human ear. And that is the result of a transmission of energy. So the way that it will be detected by human ear is the transmission of energy which happens in the form of compression and rarefaction which, which will require a medium. So sound is a form of traveling air fluctuation. So this compression and rarefaction can be imagined as a traveling air fluctuation.

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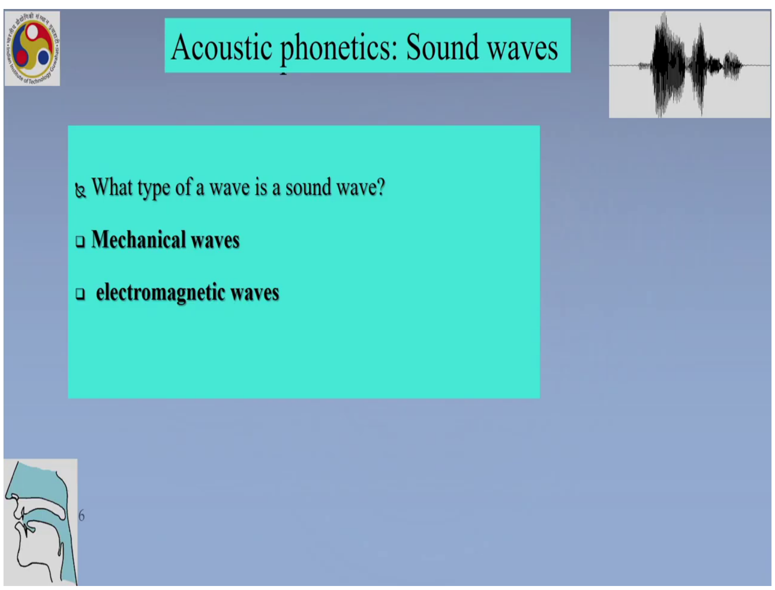

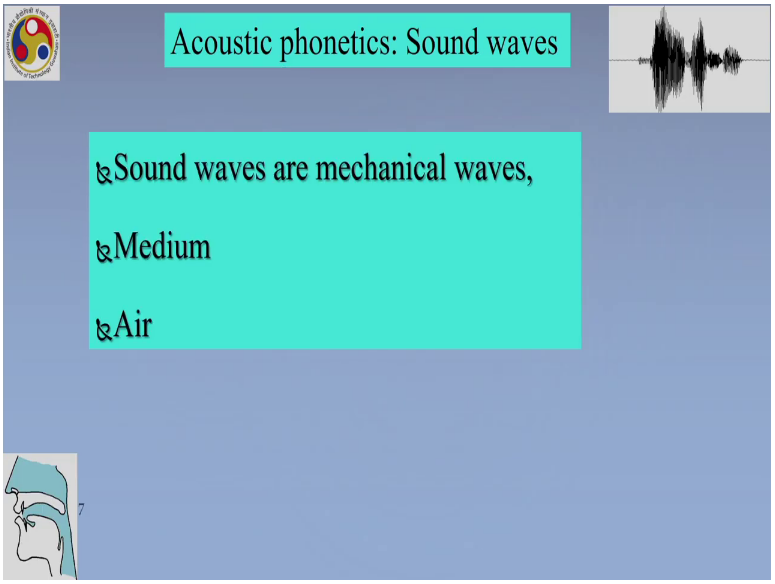

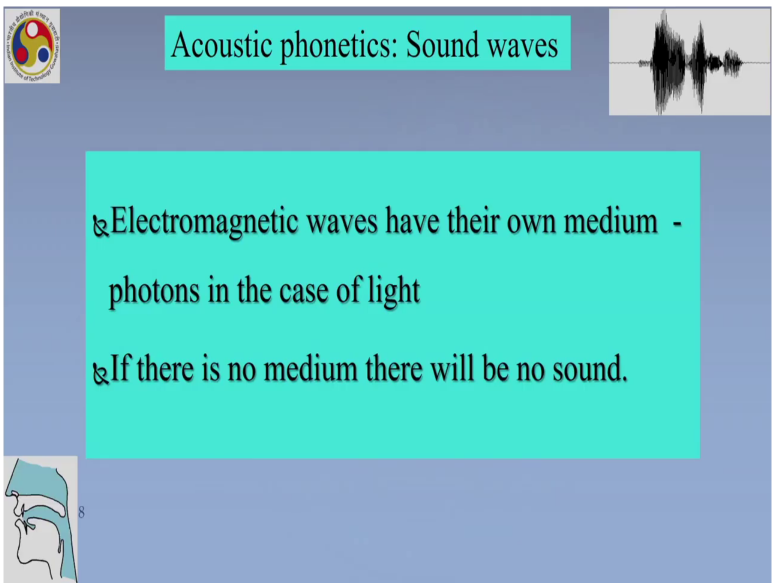

So what type of a wave is a sound wave? So there are two types of waves, mechanical waves and electromagnetic waves. And sound waves are mechanical waves. Sound waves are mechanical waves because they need a medium which we just talked about, a medium for the travelling of that fluctuation of the air a medium is required. And that medium is air. And sound waves therefore rely on the availability of movement of particles.

So the movement of particles is extremely important for sound to be heard by human ear. And unlike mechanical waves like air there other kinds of waves like electromagnetic waves which have their own medium, for instance photons in the case of light. However if there is no medium there would be no sound.

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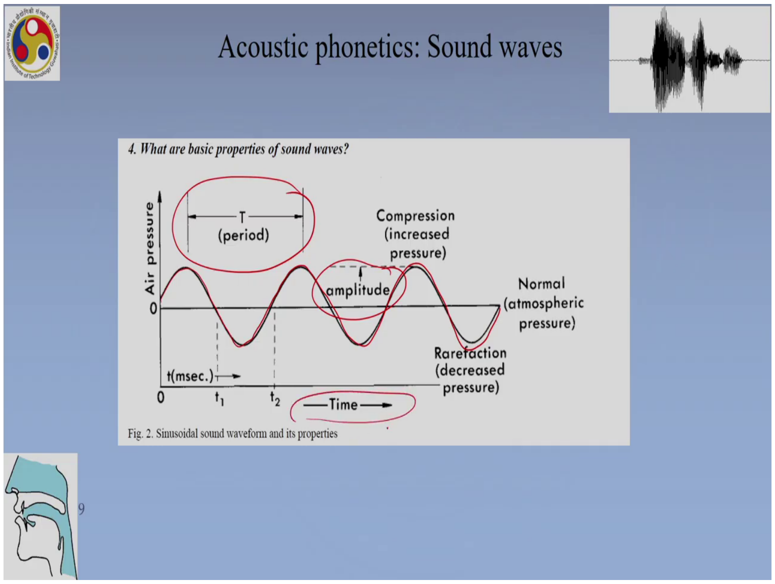

So this is the compression and rarefaction that we talked about; compression, rarefaction; compression, rarefaction; compression. This is the fluctuation on which the air, the travelling of air depends on. So we will now study what is a period, what is amplitude and what is the relationship between time and all these other things.

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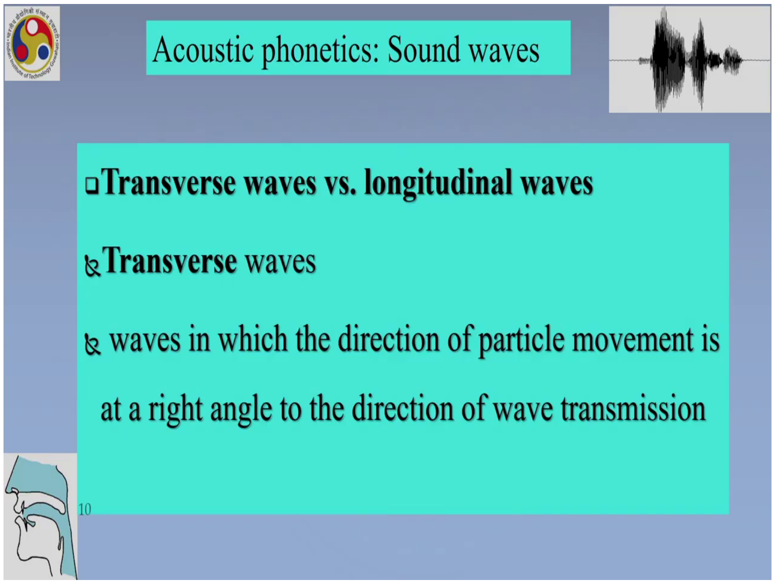

So when we study sound waves we have to understand how sound waves are different from other types of waves. We just now saw that sound waves require medium, and that is why it is a mechanical wave which is different from an electromagnetic wave. Now the other kinds of waves like transverse waves versus longitudinal waves. So what are transverse waves? Waves in which the direction of propagation of, the direction of particle moment is at a right angle to the direction of wave propagation. So the movement is at a right angle.

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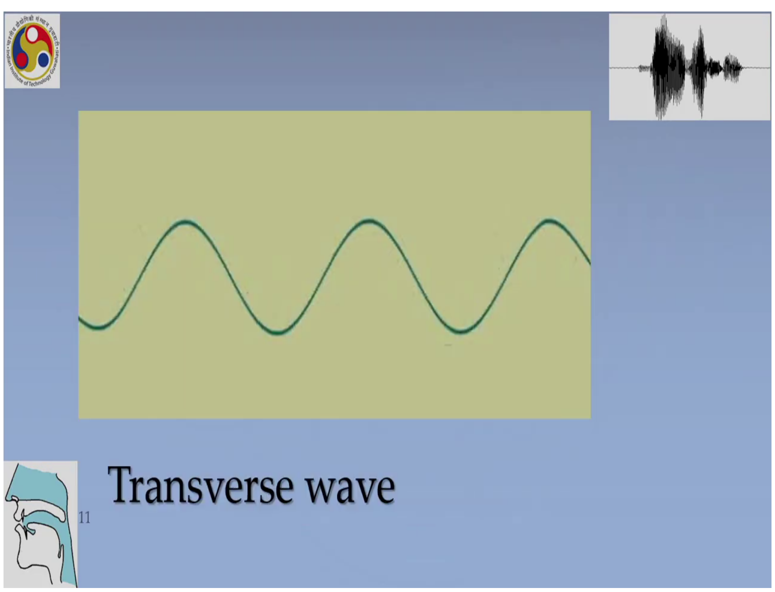

And let us see an example of something similar to a wave created on water. So when you throw a pebble on water you have a transverse wave and it is something like this. So its movement is at right angle wave to the direction of propagation of the wave. So when you throw a pebble into the water you see ripples created in the water. That is a transverse wave. Are sound waves like that? No. Sound waves are longitudinal.

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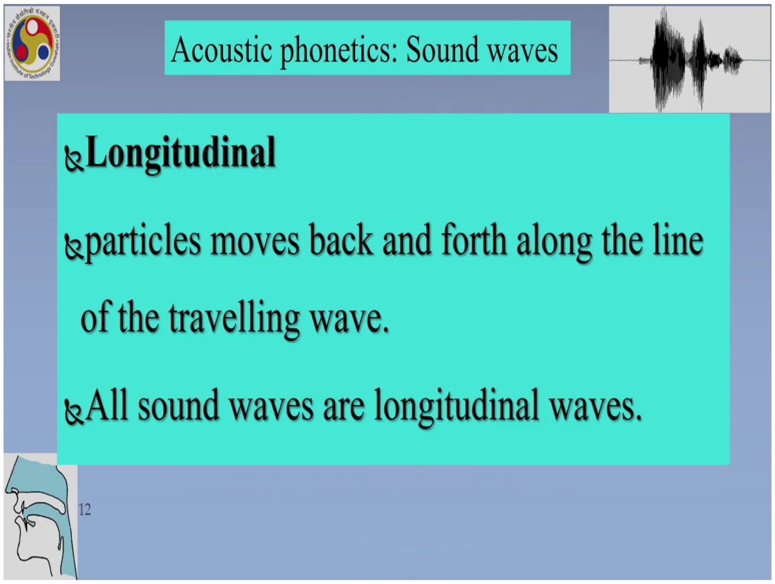

So what happens in sound waves is not the, what we just saw, 90 degree to the wave movement, particle movement at 90 degrees to the propagation of the wave. Here the particles move back and forth, back and forth along the line of the travelling wave. So sound waves are longitudinal waves.

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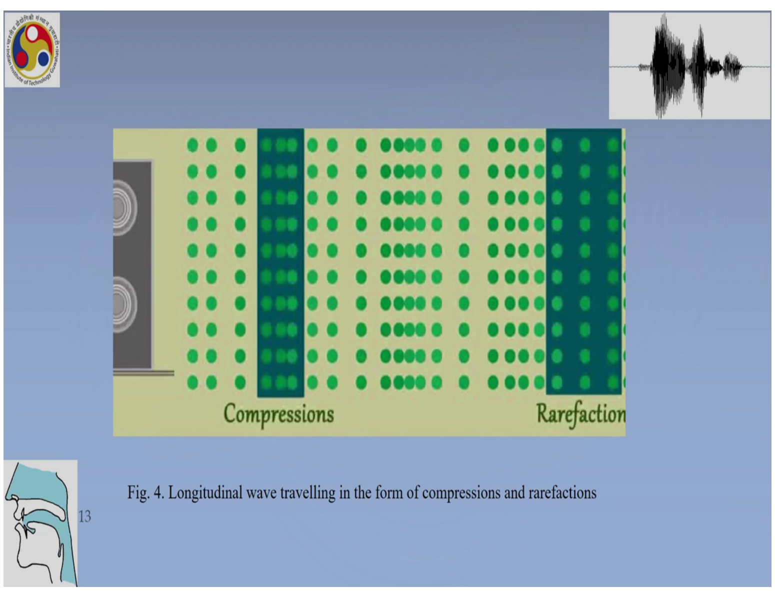

Now let see an example of what we mean by back and forth. So once I stop you will see that; let us look at this again. We will see that, suppose these, we have a player here and we have sound coming out of that player. What is happening here? So what is happening is that there is transmission of energy, and transmission of energy is happening through the movement of back and forth; which means the particles move and again come back to the original position. So look at this closely again.

So they move and come back and move and then it sets the other particles into movement and again come back. So now when that happens you have a compression and rarefaction, where a place of high energy and a place of low energy; place of high energy, low energy which keeps transmitting the energy so that the sound wave travels along that line of movement.

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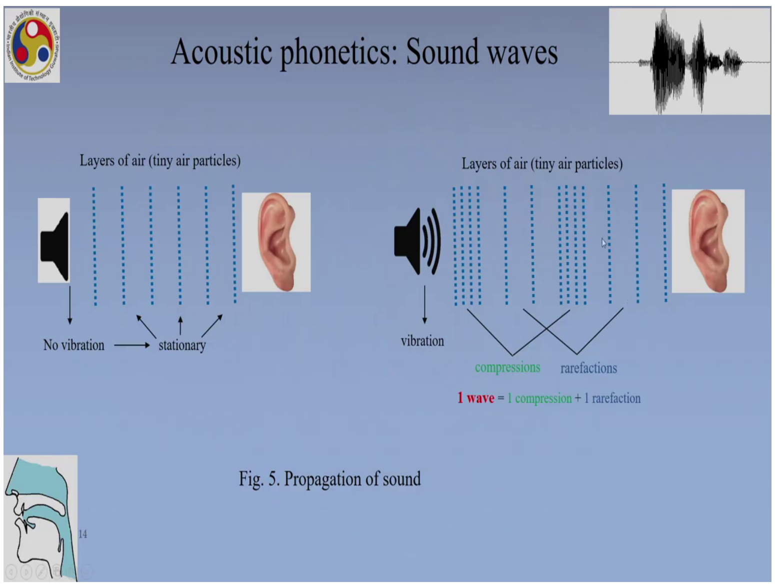

So when the air particles are stationary there is no vibration. There is no propagation of sound, unlike here when you have a compression and a rarefaction; the compression, high energy moves forward and then creates energy and comes back to its original position and then you have these positions, you have these places of high energy and low energy as a result of which is the sound wave can travel.

Now let us study the properties of sound waves. We have learnt a couple of things; that sound wave is characterized by transmission of energy in the form of compression and rarefaction, so high energy, low energy and movement of back and forth, back and forth as a result of which the wave will be moving along the line of its propagation. So therefore relying absolutely on the movement of particles, air particles. When there is no movement of air particles then there is no sound.

Having learnt that let us look at the properties of these compressions and rarefaction which leads to the special characteristics of the sound wave. So as you saw that the movement of air particles is represented in a uniform sort of a cycle on a plane. So that cycle is called the period. The period is a time taken to complete one cycle.

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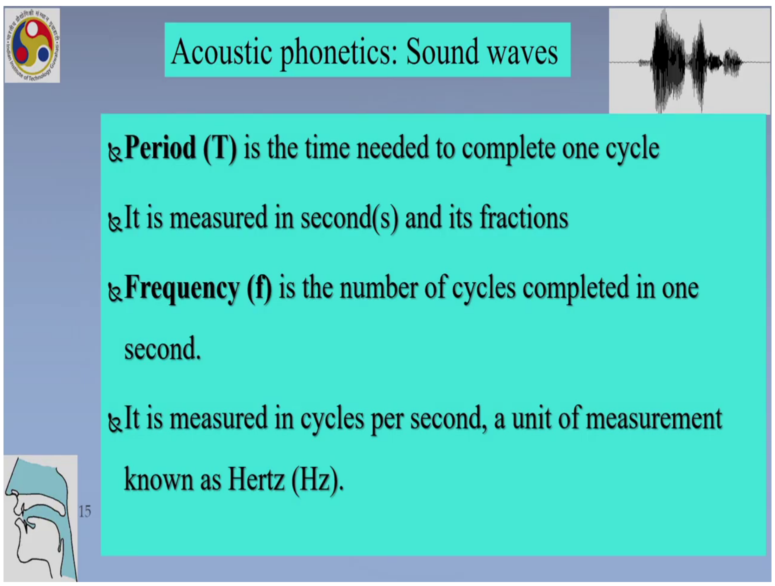

So period is measured in seconds and its fractions. So the time taken to complete one cycle is called the period. So the other important, very important term while learning about sound waves is frequency. Frequency is the number of cycles completed in one second, cycles per second. Frequency period is time taken to complete the cycles. So period is about the time and frequency is the number of cycles completed in 1 second. So frequency is measured in cycles per second. Unit of measurement of frequency is called Hertz.

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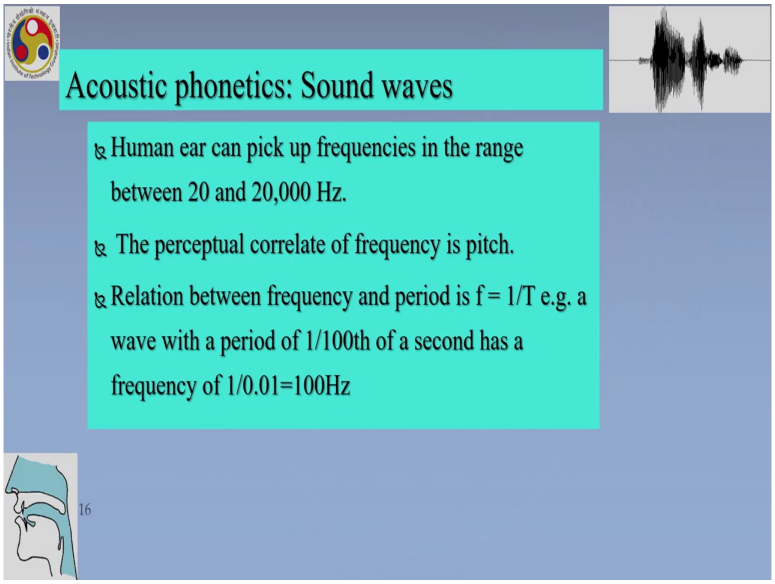

So human ear can pick up frequencies in the range of 20 to 20000. There may be variations depending upon your age and other, and if you have ailments so you might, your hearing range may be different so some people have higher hearing range some can hear as low as 20 Hertz while others may not. But generally it is as low as 20 Hertz can be picked up by the human ear and as high as 20000 Hertz.

Frequency, which we just talked about cycles per second, so number of cycles completed in a second. That is heard in psycho-acoustic terms perceptually we hear that in terms of pitch. So when we hear a low pitch and when we hear high pitch we normally hear the differences between the pitch. And it is a psycho-acoustic correlate frequency is pitch. And the relation between frequency and period is frequency is equal to 1 by the period that is time taken to complete, and to complete the cycle and a wave with a period of 1 by 100th of a second has a frequency of 100 Hertz. So that is the equation.

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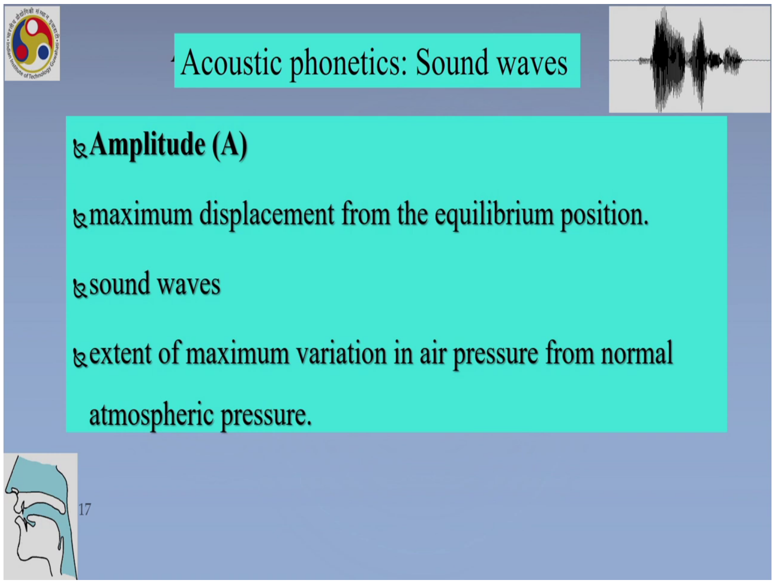

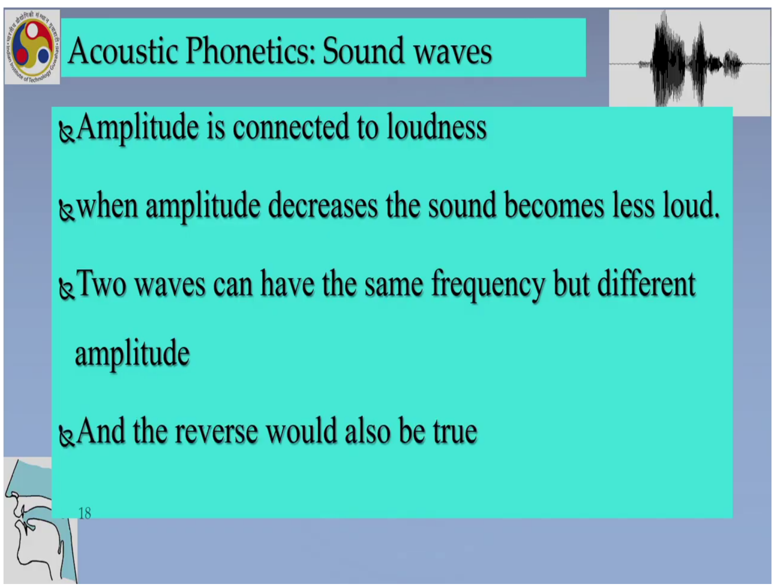

The other important term that one would have to know while studying sound waves is that of amplitude. Amplitude is also called the maximum displacement from the equilibrium position. So what is the maximum displacement? It is the maximum variation, in terms of sound it is, it is called the maximum variation in air pressure from normal atmospheric pressure. So amplitude is connected to loudness.

So the variation in terms of the air pressure from the normal atmospheric pressure that would be your amplitude, you would hear it in terms of loudness just the way frequency perceptually is pitch, the perceptual correlate of amplitude is loudness. So when amplitude decreases the sound becomes less loud. Two waves can have the same frequency but different amplitudes and vice-a-versa.

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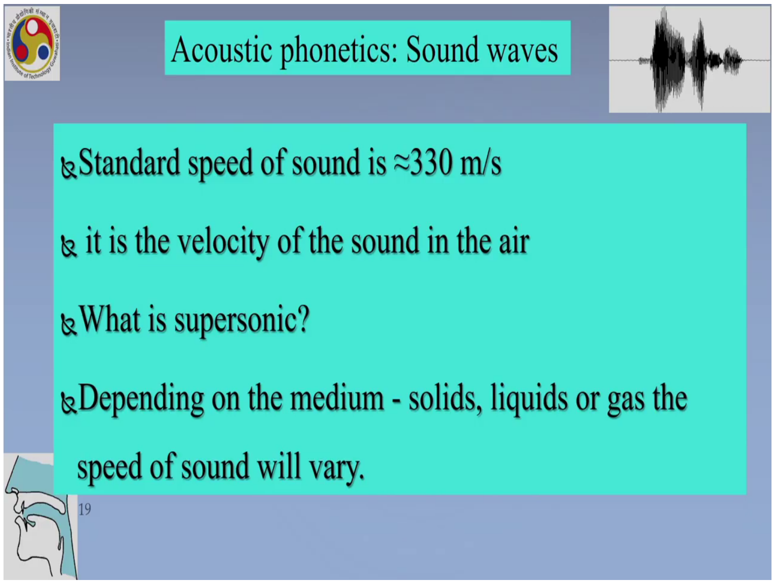

The standard speed of sound is around 330 meters per second and it is the velocity of the sound of air. Anything which is above that velocity is called supersonic. So the other important aspect of sound is that depending on the medium, so we learnt this very early in the lecture that sound will always needs a medium. And depending on the medium the speed of sound will vary. So depending whether it is solids can also have the frequency, for instance this table or this pen, they might all have different frequencies. And gas, liquid in water also sound can travel but the speed of sound will be different.

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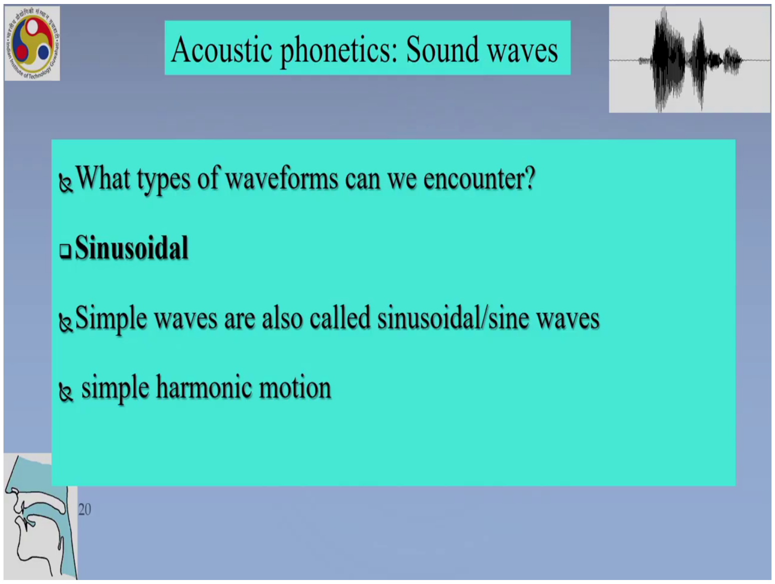

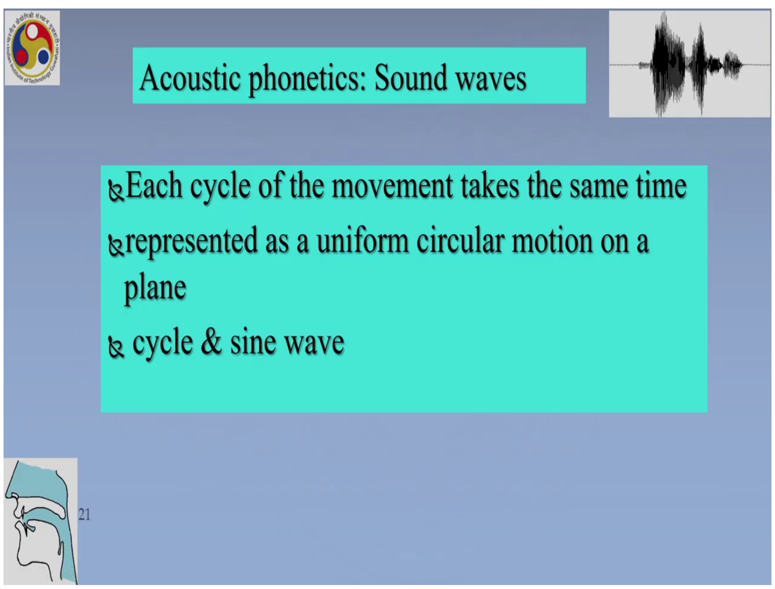

So we learnt a bit about sound waves, that they are mechanical, that they are longitudinal. And now we are studying how we are looking at the characteristics of the sound wave. And you have just seen that there is something called frequency which is this, the time taken to complete one cycle, the cycle of compression and rarefaction that we first talked about, based on which the sound is perpetuated, based on which the air fluctuation which happens in terms of compression and rarefaction and, the properties therefore are such that sound can have very, very typical properties.

So let us see what would be a typical property, what would be the property of human sound, speech sounds and what are the other types of sounds which we encounter? And that will all depend on the sound wave, the compression and the rarefaction.

So one type of sound wave, need not necessarily be a human speech sound, is a simple wave or is called a sinusoidal or sine wave. Now sinusoidal waves have a simple harmonic motion. So what does it mean to have a simple harmonic motion? It means that there is just one frequency component. Remember we talked about 100 Hertz, that is, then we will talk about relationship between frequency and period, so if a sound has just one frequency component of 100 Hertz or just one frequency component of 200 Hertz that that will be your sinusoidal wave.

So just one frequency component, just a simple harmonic motion. And now what is a sinusoidal wave? Each cycle of the movement takes the same time. So each cycle of compression rarefaction will take the same time. So it is represented as uniform circular motion on a plane. And it is also called sine wave and a cycle.

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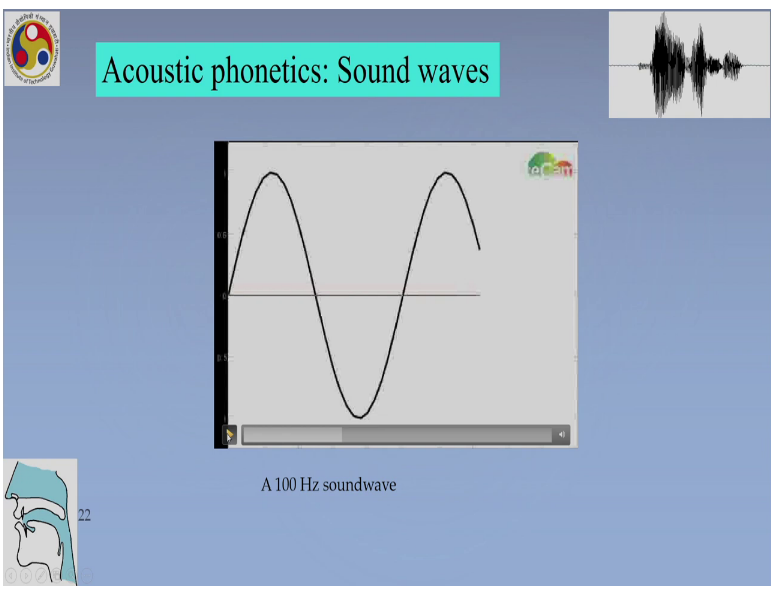

Let us see an example of 100 Hertz wave that we try to generate. So it is difficult to stop at exact point where the compression and rarefaction ends. So this would be your one cycle, a simple sine, sine wave. Now if you have another one, yes, this would be your simple sine wave, two cycles here; one compression one rarefaction, another compression another rarefaction. Two sine waves and both the cycles take exactly the same amount of time. So this is a simple sine wave.

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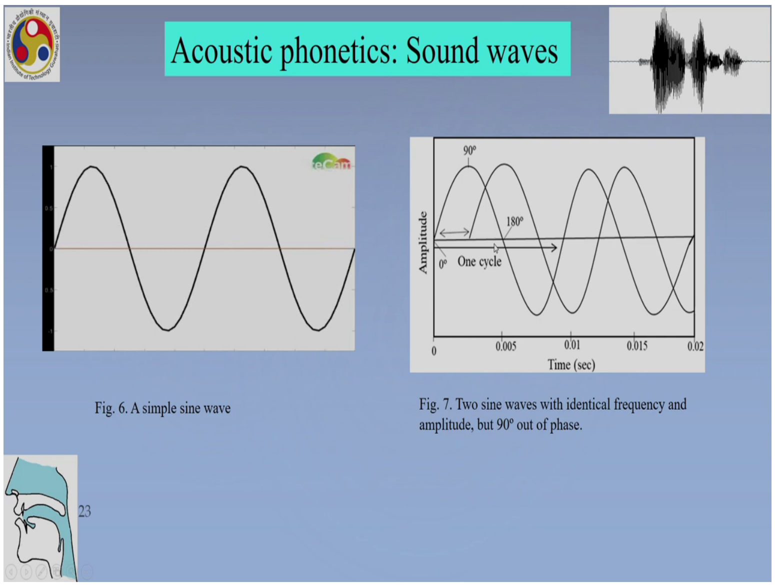

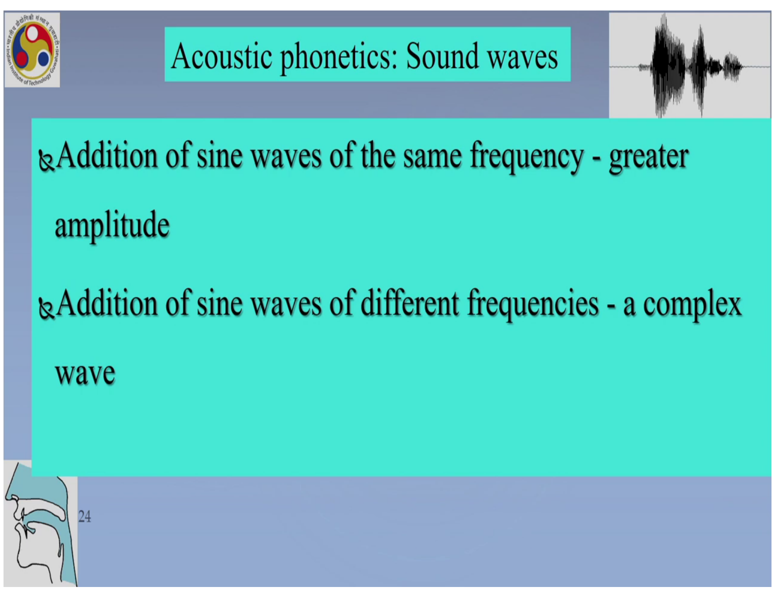

So if we have two sine waves with identical frequency and amplitude we would just have a louder sound and we would not have a complex sine wave. So if we add a sine wave of same frequency we have greater amplitude. And addition of sine waves of different frequencies we have a complex wave.

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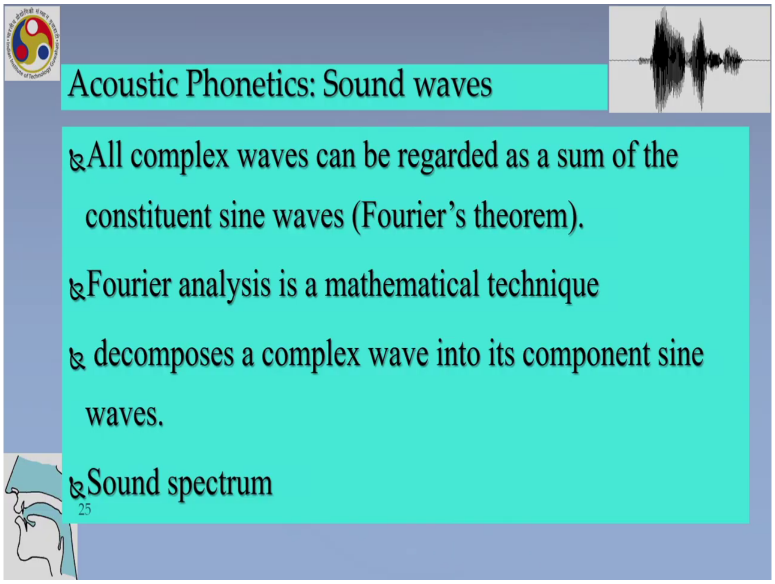

So we will study complex waves more where we study human speech sounds as human speech sounds are almost always complex waves and the way they are studied as, as sum of constituent sine waves. So they are decomposed into their constituent sine waves. So remember that each wave has a frequency component. We saw the sinusoidal wave where each cycle takes the equal amount of time.

Now if you combine frequency components, various frequency components you would get your complex wave instead of a sine wave. So Fourier analysis is a mathematical technique where the complex waves are decomposed into their component sine waves. So that is how we get a sound spectrum of human speech sounds.

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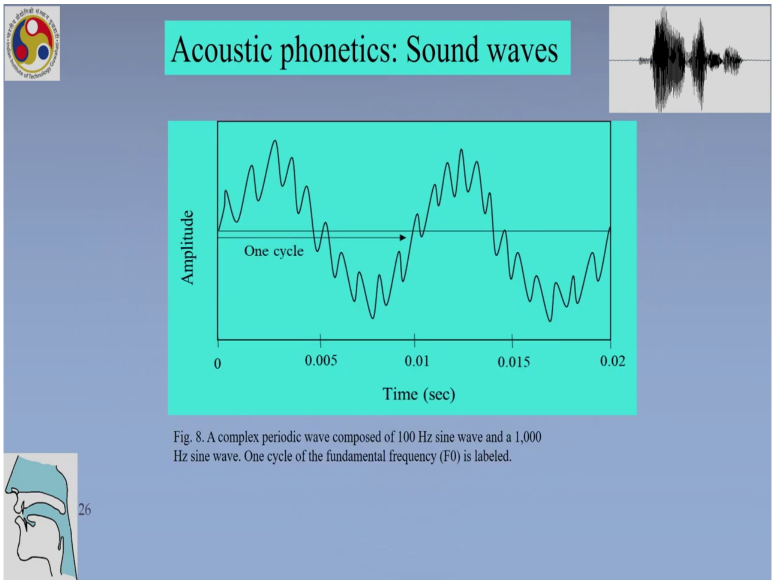

Now this is what complex periodic wave would look like. So here is a period, complex periodic wave composed of 100 Hertz sine wave and a 1000 Hertz sine wave. And you can see that it is not like the uniform circular movement that you saw before. It has two component waves and it is shown by the sort of jagged line here, that there are two component waves here. However the two component waves will finish the cycle at the same time. And again the cycle starts or finish. So that is how you have complex waves.

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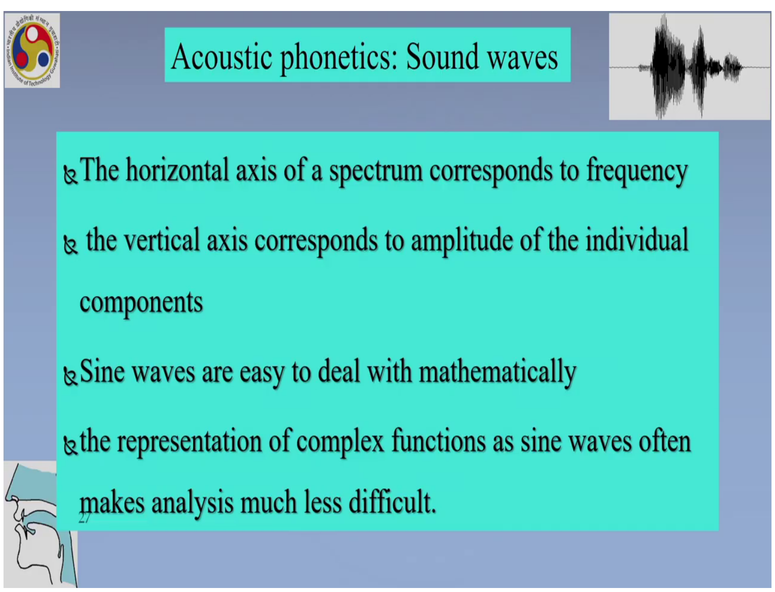

How are these different aspects of a sound wave, how are they represented in a graph? You have seen that in the horizontal axis we have the frequency; in the vertical axis we have the amplitude. And sine waves are not very difficult to deal with mathematically and the representation of complex functions as sine waves often make analysis less difficult. And we will see that when we look at the component waves in human speech sounds like that of vowels.

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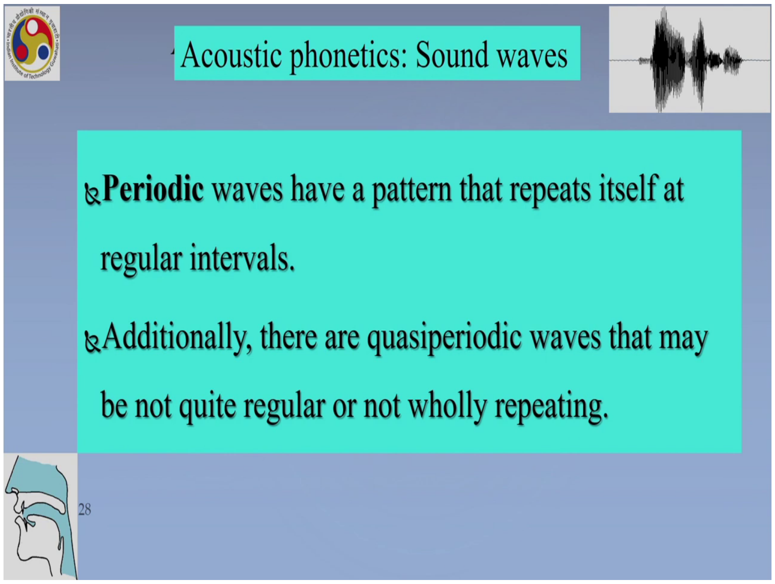

So periodicity is very important when we study human speech sounds also. Periodic waves have a pattern that repeat itself at regular intervals. So for any human sound to be periodic this characteristic must be there, that the pattern must repeat itself at regular intervals. Additionally there are quasi-periodic waves that may not be quite regular or not wholly repeating. So human speech sounds maybe quasi-periodic also.

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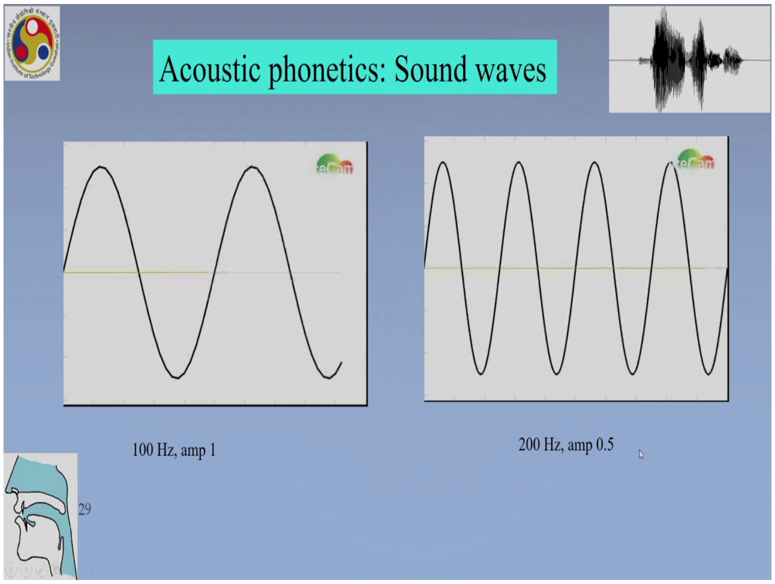

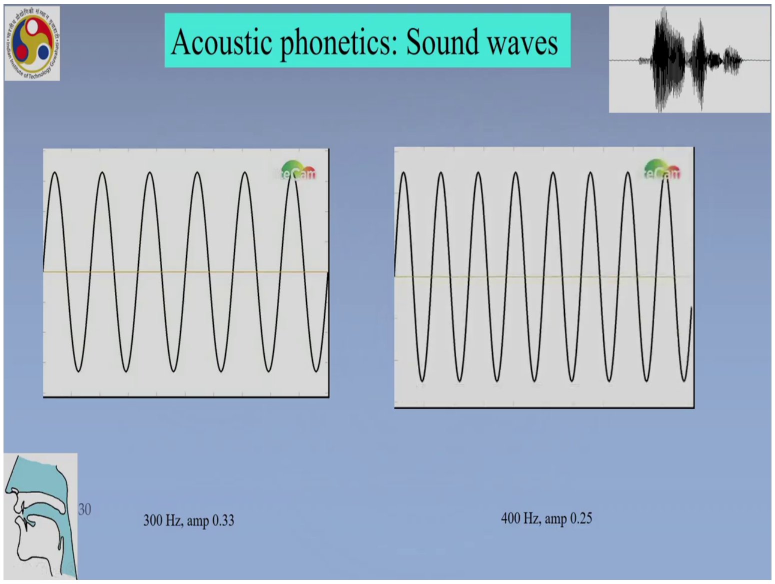

Let us again look at sound waves, how you can have a 100 Hertz. You can see that moves very fast. Here is a 200 Hertz. It has amplitude of 0.5. So if you have all these, this is 300. And this is 400 Hertz. Now if all these are component waves in a complex wave then you can imagine why the complex wave looks the way it does.

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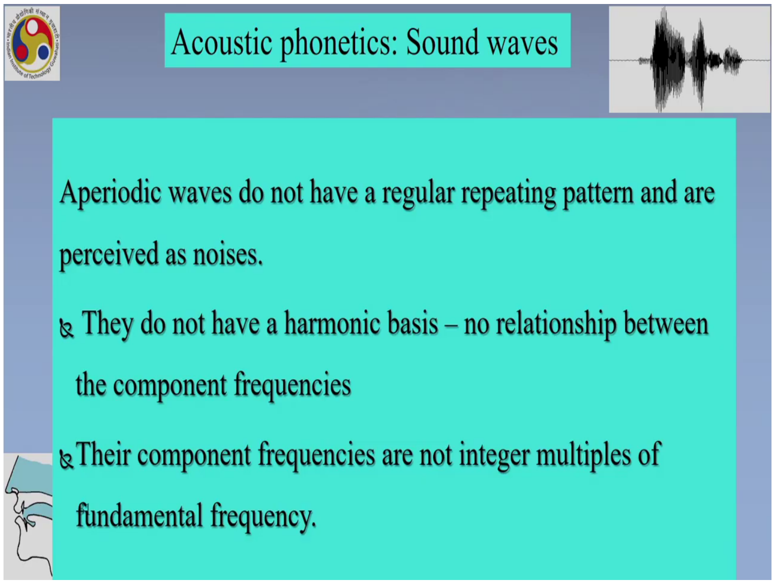

Coming back to aperiodic waves. Aperiodic waves do not have a regular repeating pattern and are perceived as noises. And they do not have harmonic basis either. And they do not have relationship between the component frequencies. And the component frequencies are not integer multiples of their fundamental frequency which is the characteristic of harmonic sound patterns.

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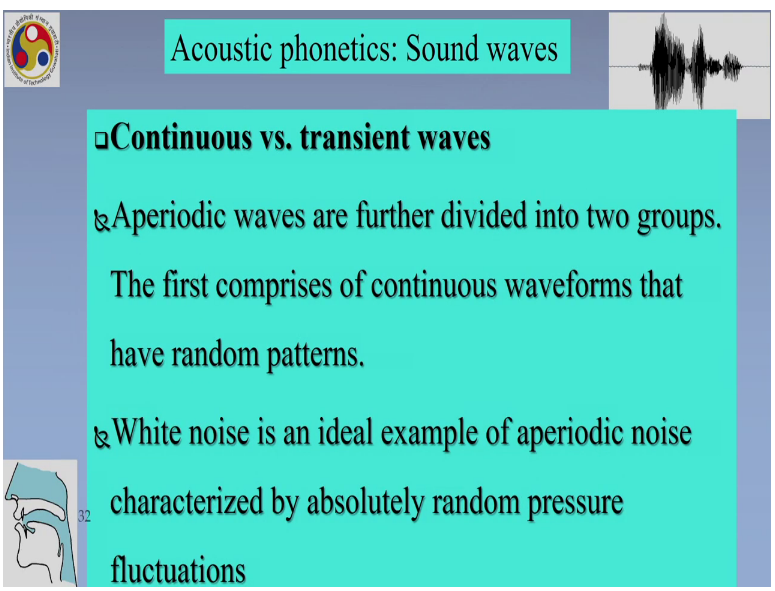

Even there you can have, even among aperiodic waves you can have two types, one which is continuous versus one which is transient. So even in sound which is noisy you can have two types; one which is continuous and transient. So continuous waves can also have random patterns but there is a continuity. So white noise is an example of aperiodic noise characterized by absolute random pressure variations.

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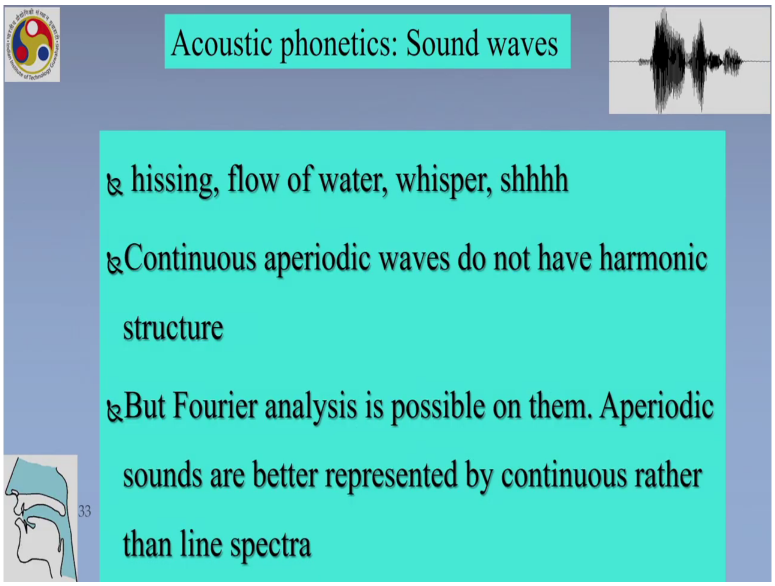

So some sounds are your typical continuous aperiodic waves. So you have, for instance when you say shhhh or a hissing sound or a whisper, these are all continuous aperiodic sounds. They do not have harmonic structure, so but Fourier analysis is possible on them.

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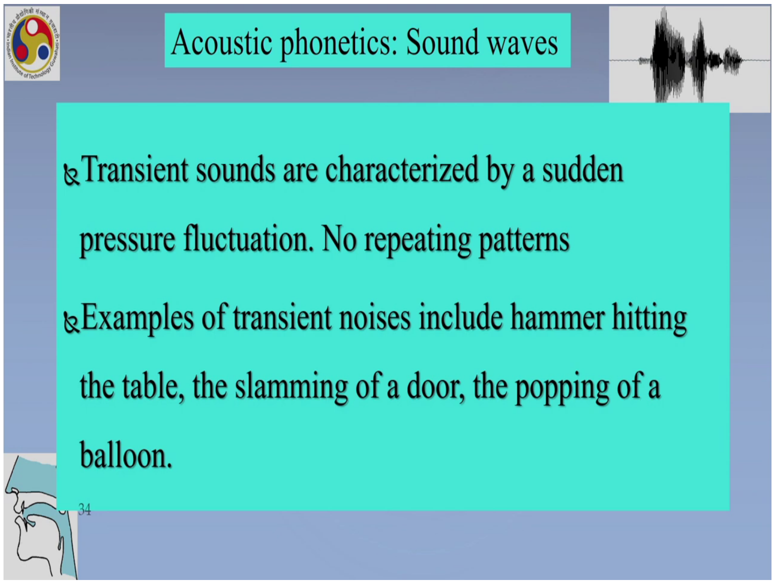

Again transient sounds are sudden pressure fluctuations, sudden noises are transient sounds.

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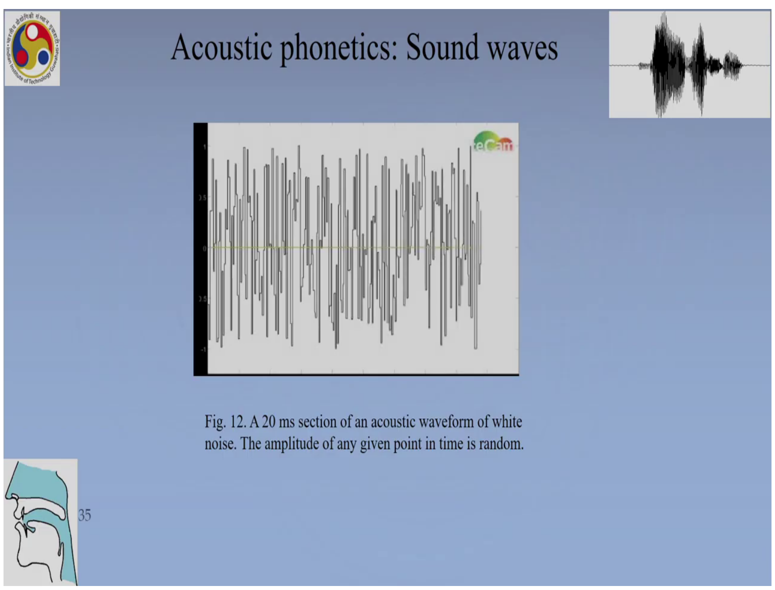

This is your white noise. As we just said white noise is aperiodic continuous sound.

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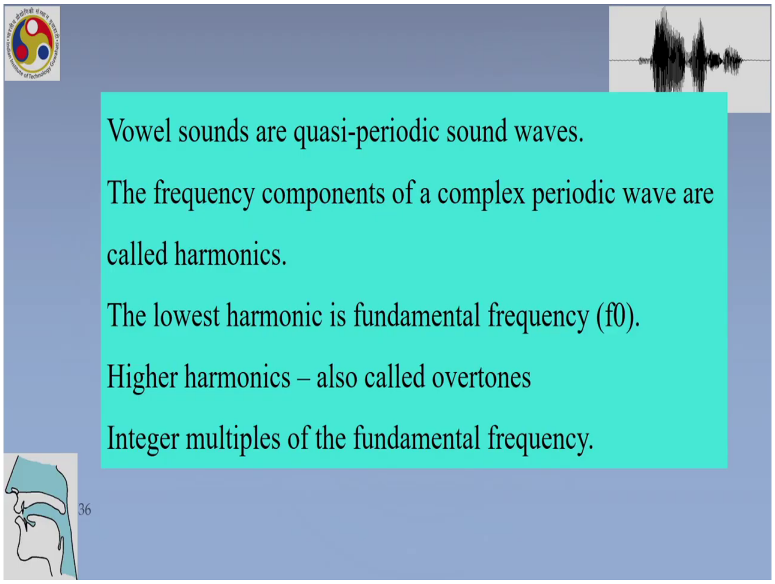

Now, when we talked about periodicity we talked about quasi-periodic sounds. What are quasi-periodic sounds? So the frequency components of a complex periodic wave are called harmonics. So suppose there is a frequency, there will be multiples of that frequency which are called harmonics. And these are always integer multiples of what, we have the most fundamental of those frequencies called the fundamental frequency. And above the fundamental frequency there are higher harmonics which are called overtones, and which are integer multiples of the fundamental frequency.

So vowel sounds are typically like this and then there is always fundamental frequency and then there are, among these harmonics, few of the strong ones stand out and these are called formants. And this is how we understand vowels in acoustic phonetics. The harmonics which have the most energy are the ones which stand out in the characterization of vowels and these are called formants and we will study in the next class.

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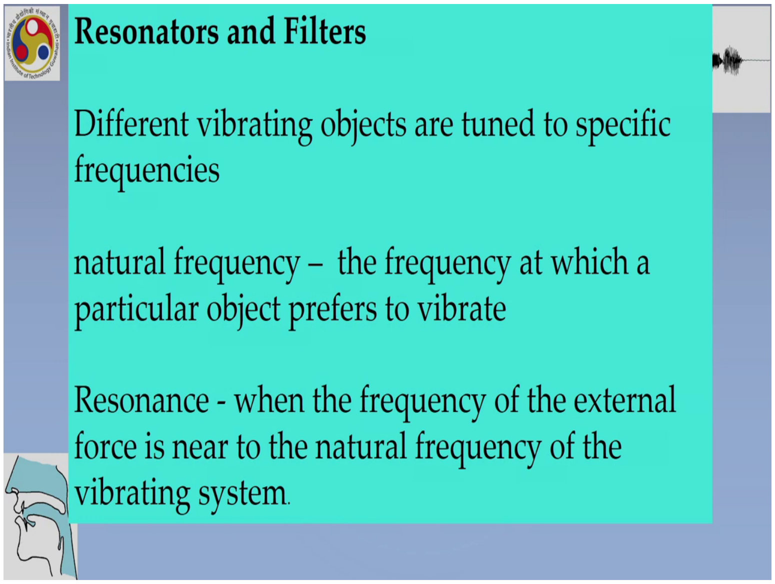

While talking about sound waves and also because we just now talked about vowels, something very important which will have to be mentioned is that of resonators and filters. So we talked about how sound needs a medium and, for the transmission of energy. So it is a travelling air fluctuation, travelling air fluctuation. And then, so when air particle moves there is always some resonator which sort of attenuates, sort of weakens or increases the properties of that sound. So, apart from the medium, you also have resonators.

So, for instance in the production of speech sounds we have the vocal cavity. So that will be your resonator. And that is, apart from the air which is pushed out from the lungs which is given various shapes by the vocal tract. Now the vocal tract itself is like a resonating chamber which gives particular characteristics to the sounds that are produced.

So each of these resonators are tuned to specific frequencies. So the natural frequency, the frequency at which a particular object prefers to vibrate. For instance this wooden desk would like to, has a certain frequency. It has the natural frequency. It prefers to, the sound that you hear as I slightly, lightly tap on it is the natural frequency of this wooden table.

So when the frequency of the external force is near to the natural frequency of the vibrating system you have what is called resonance. So the both must come together, which means the frequency of the external force, the driving force and that of the resonating system; there must be a match between the two. And then you have what is called the resonance.

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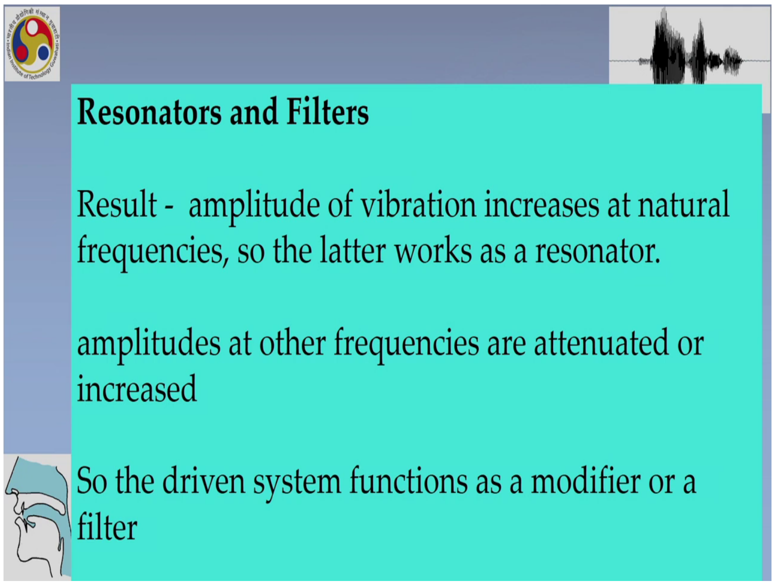

So the result of this is that the amplitude of vibration increases at natural frequencies. So it works as a resonator. So they are attenuated or, so either, so there is modification of the amplitudes of other frequencies. So the system functions as a modifier or a filter.

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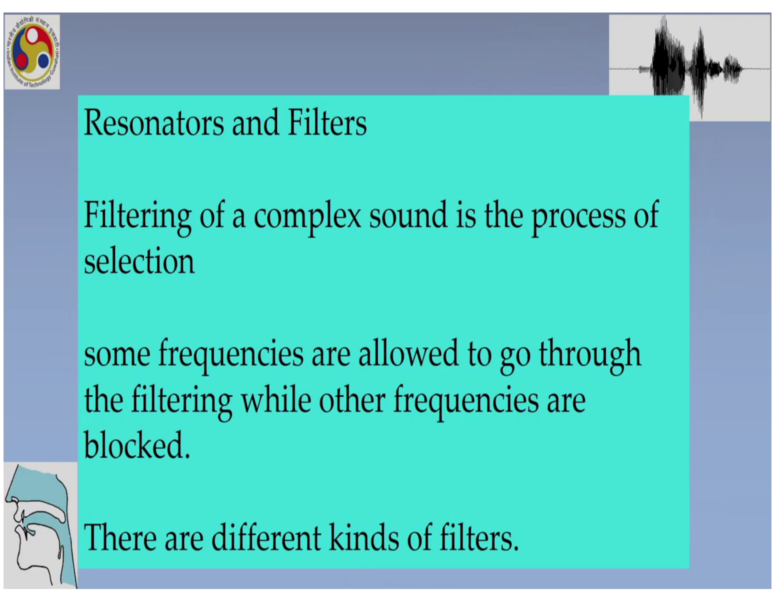

So sound is studied as a source filter system which we will talk about in the following classes on acoustic phonetics. Resonators and filters; filtering of a complex sound is a process of selection. Some frequencies are allowed to pass through while others are blocked. So some frequencies are preferred over some other frequencies. So that is the purpose of a filtering system, of a resonator. And there are different kinds of filters.

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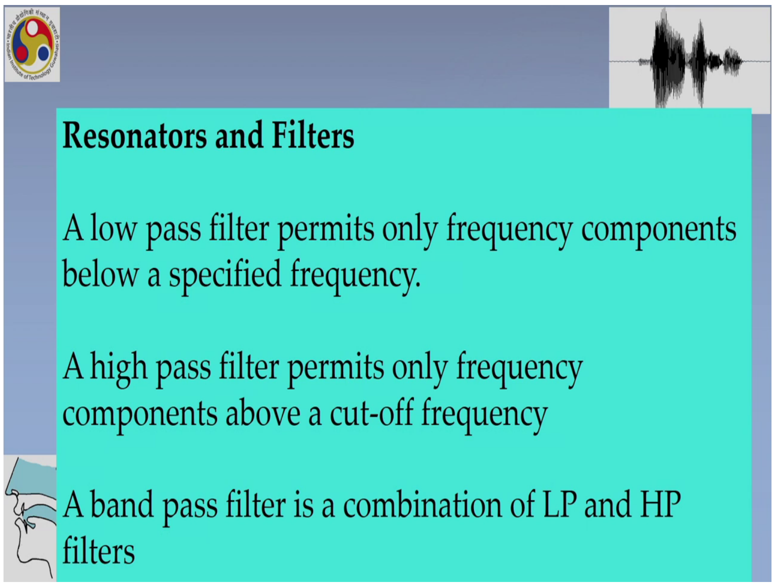

So there can be a low pass filter which permits only frequency components below a specified frequency. There can be high pass which permits only frequency above a certain cutoff. And then a band pass which is a combination of both low pass and high pass and allows.

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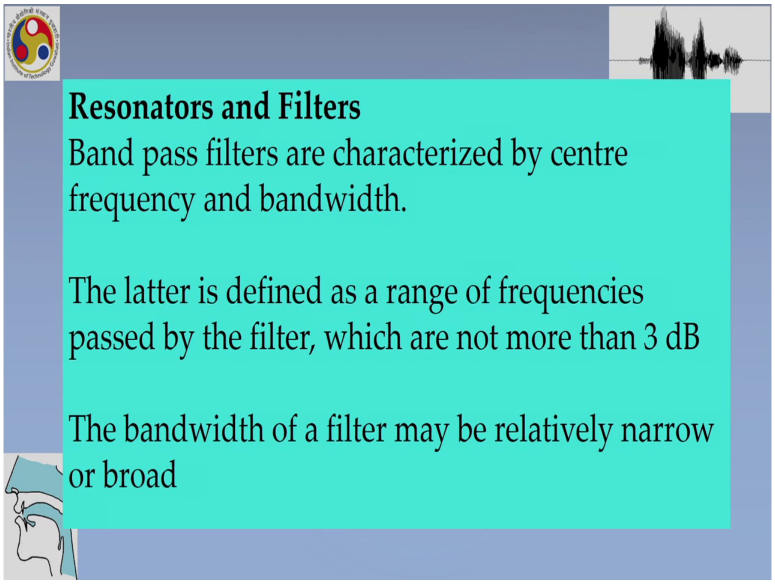

A band pass filters by centre frequency and bandwidth and the range of frequencies passed by the filter which are not more than 3 Decibels. So the bandwidth of a filter may be relatively narrow or broad.

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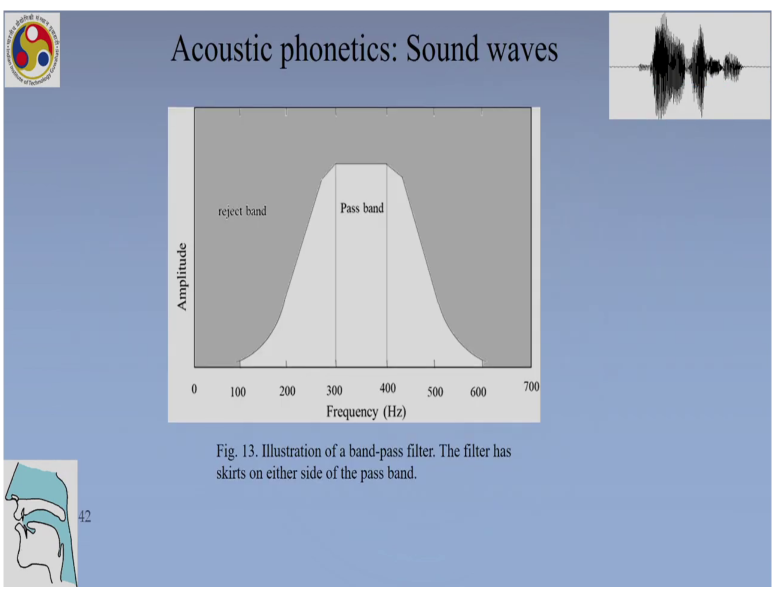

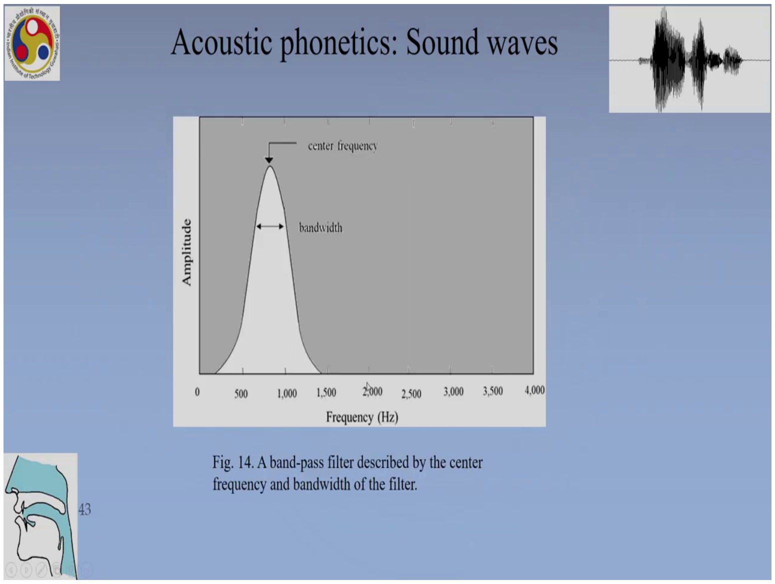

So this is a band pass filter and this could be anything. So when you tune into the radio, so they have band passes and frequencies at various Hertz are allowed to pass through. So you can have, you can have various types of filters. So the human speech system also acts like a certain kind of a resonator and a filter. And this is just to give you an example of how a filter may allow only, for instance, certain, from 300 to 400 Hertz. And then you can have something which is centre frequency and then a bandwidth.

So whereas you can have sounds allowed in that bandwidth all the way from around 200 to 1200, 1300 and then, but the centre frequency which is the central one and then a bandwidth along which various other frequencies can be allowed. So we have come to the end of today's lecture. And we have learnt how speech sounds can be studied in acoustic phonetics, how sound is variation in air pressure and air pressure which is detectable by the human ear.

And then sound wave is transmission of energy through compression and rarefaction through a medium, and sound waves are mechanical waves because they require a medium and mostly that medium is air.

And the compression and rarefaction can be seen in the way particles move back and forth in this longitudinal wave travelling that we showed you how they move back and forth and how energy, sound wave is created by that energy and then the compressions and rarefactions as a result of that air fluctuation is how we hear sound.

And then the properties of sound waves, the period is time needed to complete one cycle and frequency is number of cycles per second. These are very important terms for studying sound waves. And then amplitude which is the maximum displacement from the normal atmospheric pressure.

And then amplitude is connected to loudness, frequency is connected to pitch. And then we also studied how there could be sinusoidal waves where, sinusoidal waves are simple harmonic motion which has just one frequency component, suppose 100 Hertz or only 200 Hertz, so which means each cycle is completed in a second.

So addition of sine waves of different frequencies leads to a complex wave and we can have an infinite variety of complex waves and depending on its component waves which could be decomposed into their sine waves which is Fourier's Theorem. And this is how complex waves look like.

So, also we studied periodic waves repeat themselves and we saw various types of periodic waves and we studied a bit of aperiodic waves also, how they could be continuous and transverse. So like a hissing sound or a whisper can be a continuous transverse sound unlike a big thud or a hammer which could be a transverse aperiodic sound. And we saw that human vowel sounds are quasi-periodic.

There are many frequency components in the complex waves that are produced as a result of the production of vowels. And we also studied a bit about resonators and filters and how the natural frequency of the resonator, if it matches the driving force then that may be highlighted, that may have more energy that resonance. And in human vowel sounds those are called the formants.

So there could be the resonator and filter can modify the air, the air that is passing through and the modifying and filtering can be of allowing certain frequencies to pass through and not allowing certain higher frequencies pass through some filter, certain lower frequency passes through some filters. And then you have band pass filters which allow certain bandwidths. And with that we come to this, to the end of our first lecture on acoustic phonetics. Thank you very much for listening.