Acoustic Materials and Metamaterials
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Lecture – 08
Sound Signal Analysis – I

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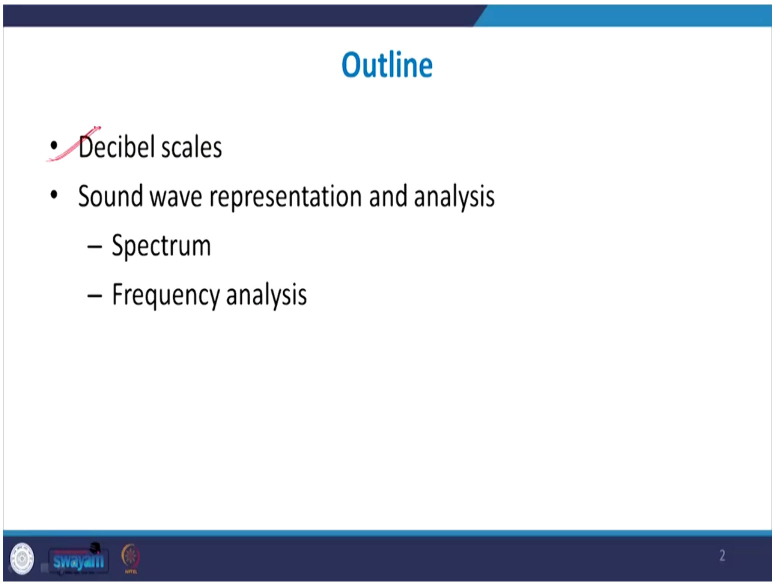

Welcome, to lecture 8 of this series. This lecture is on Sound Signal Analysis. So, the outline over the lecture is that will first discuss about the decibel scales so, this is a very important scale. So, usually decibel scales are used to represent sound waves for noise control applications and then we will see: what are the various ways of representing sound waves and analyzing the sound waves. So, we will study about thing called spectrum and frequency analysis.

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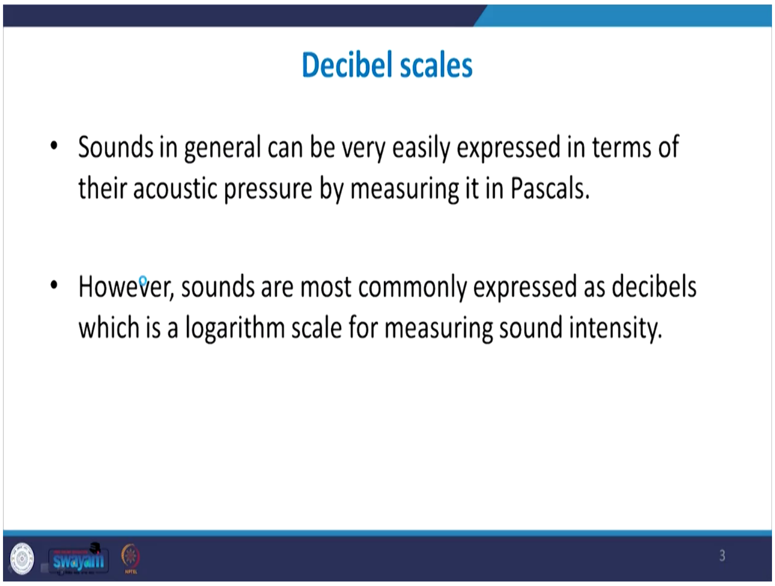

So, let us start with decibel scales. So, now, you know that an acoustic sound waves, they can be represented simply as a function of the acoustic pressures. So, we can so, any sound wave can be represented as some p x y z comma t. So, it is a complex pressure function which have some expression.

So, we can represent any sound wave as its acoustic pressure value and this acoustic pressure can be measured, as in the terms of Pascal's. So, when we already have this particular quantity called Pascal's to measure sound waves; then why do we need some additional scale for measuring or representing sound waves?

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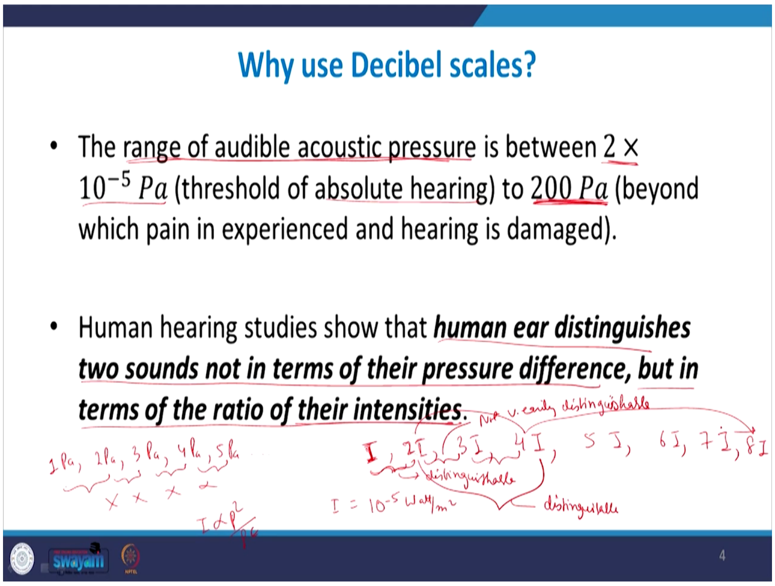

So, the reason for this is that, first of all so, we already have the commonly used scale called Pascal's, but we represent it using decibel scales which is a logarithmic scale. And the reason for this is that; firstly, the range of audible acoustic pressures for a human ear is between 20 micro Pascal's, where the hearing begins to 200 micro Pas, to 200 Pascal's where suddenly the pain is experienced and hearing is damaged.

So, as you see even in the very beginning of this lecture I said that, the mean atmospheric pressure which is of 10 to the power 5 Pascal's, but the fluctuations even as small as micro Pascal's or some 10 to 100 Pascal's are heard as very loud by the human ear. So, even very very small fraction of fluctuation on the mean acoustic; on the mean pressure of the medium can give you very very large loudness or sound sensations.

So, acoustic pressure in general is a very small fraction of change in the mean atmospheric pressure. And, this is the range for it and the second fact we know is that so, first of all we know that, this is a range of human hearing. And, it has also been found from the human hearing studies that a human ear it distinguishes two sounds not in terms of their pressure difference, but it distinguishes them in terms of the ratio of their intensities. Which means, that suppose we have a human and we give them sounds of 1 Pascal's, 2 Pascal's, 3 Pascal's, 4 Pascal's, 5 Pascal's and so on.

So, if we give the, if we expose them one by one to 4, 5, 6 different sounds on the linear scale. So, 1 2 3 4 5 a linear scale of pressure, then the human ear may not be so, able to distinguish these sound. So, it may be able to distinguish these sounds, but to a human ear this difference will not be the same. So, it will not sound as distinguishable; on the other hand let us say the intensity is roughly proportional to p square by rho c.

So, it is somewhere is proportional to p square so, let us say now, instead of that we are exposing it to sounds of intensity I 2I, 3I, 4I, 5I, 6I, 7I, 8I and so on. So, we are exposing them and where I is some standard sound intensity; you can start with let us say the value of let us say 10 to the power minus 5 Watts per meter square. So, you can give any standard value of you are starting with the sound of one particular intensity, then you are doubling it, tripling it and so on.

So, we are increasing it linearly, but the human ear will not be able to distinguish them as well. For human ear this sound, when the intensity doubles will be easily distinguishable. So, they can distinguish between these sounds, but this sound will not be, not very easily distinguishable. And, similarly, this may not be very easily distinguishable, but 2 to 4 I may be distinguishable and so on.

So, it has been found that the human ear it actually compares the sound. So, 1 to 2, 2 to 3 it may not be easily distinguishable, but 2 I by I is it this is increasing twice. Then this again is increasing twice and this again is increasing twice. So, for a human ear I, 2I, 4I and 8I they appear to have the same difference in loudness. So, this is how the human hearing is, it is usually that once the intensity doubles or triples then there since then only they are able to distinguish the difference between two sounds.

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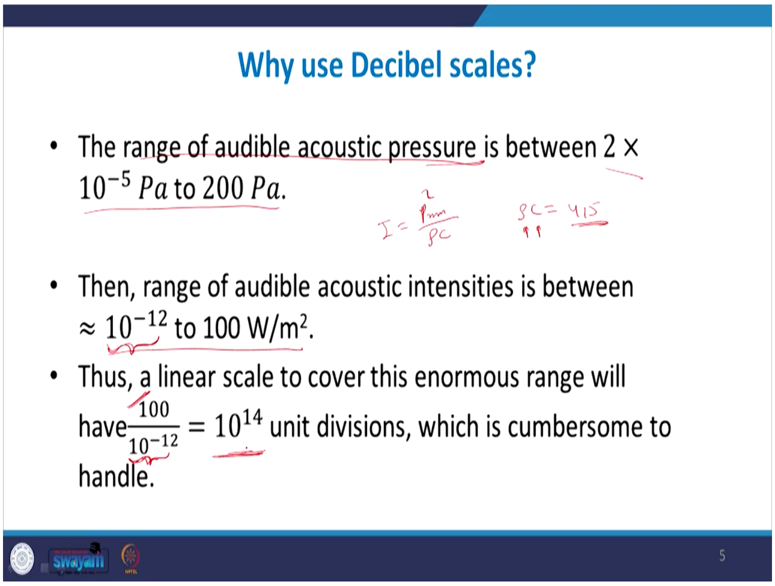

So, we have these two facts known to us. So, let us say, the range of audible acoustic pressure is given to be 20 micro Pascal's to 200 Pascal's. If we then the range of audible intensity is corresponding to them comes out to be somewhere here; where I is simply whatever is the rms pressure square by rho c and rho c for here is approximately 415 putting the density and the speed of sound values.

So, corresponding to the audible pressure we get some audible range of acoustic intensities, if we have to make a linear scale to represent all these intensities then in that scale; let us say we taking the maximum value as 100 after which hearing is damaged, but this is the minimum value which is heard. So, one unit division should be at least as big as this one. So, in that scale the total number of divisions will come out to be 10 to the power 14 unit divisions. So, this becomes a very large and cumbersome scale with so, many divisions.

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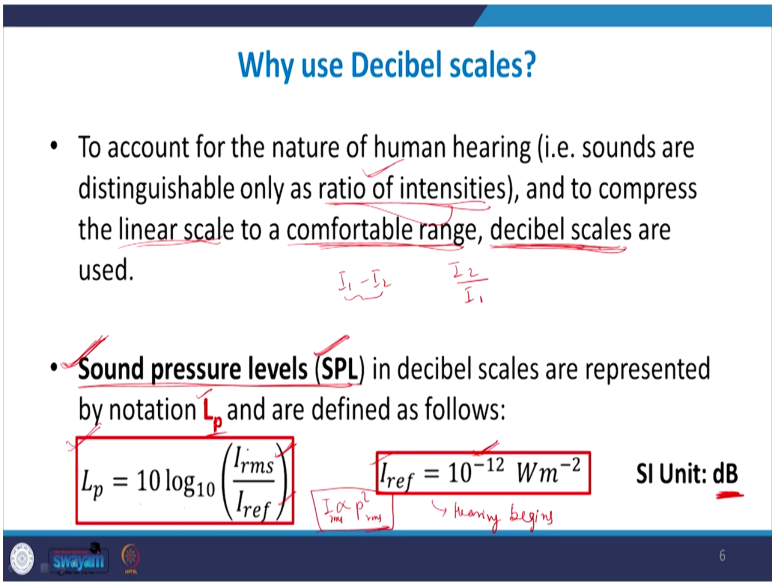

So, a reason for using a logarithmic scale is to compress the scale and make it more comfortable to handle. So, that is why, that is how the decibel scales are introduced; it is to come it compresses the linear scales by using this logarithmic value and it converts them into a comfortable range and moreover, the way the decibel scales are the value for decibel scale is calculated only the ratio of intensities is taken into account not the difference.

So, it does not take into account I1 minus I2 whatever the difference, but rather it compares the sounds ratio wise. So, the definition of such decibel scale is this is the most common term used which is sound pressure level. So, now we know why we use decibel scales, first of all to be more aligned with the data of human hearing as well as to get a more comfortable scale with less number of divisions.

So, the sound pressure the acoustic pressure, when it is represented in a decibel scale then it is called as sound pressure level or SPL and this is the term which you will very commonly encounter in any noise control application. So, in decibel scales so, it is also represented by the symbol L p which means, the level of the pressure or the sound pressure level and, the way it is defined is that it is 10 times the log 10 of I rms by I reference.

So, if you are given any particular sound wave, we calculate what is the rms intensity of that sound wave. And, then we compare this rms intensity with a reference intensity and what could be the reference intensity? It is the minimum intensity that is audible. So, that is 10 to the power minus 12 Watts per meter. So, this is where the hearing begins, hearing begins here for a human ear.

So, this is the minimum value of the intensity which we take as reference and then any sound wave the acoustic intensity of that is compared with this reference intensity and then it is converted into a log value. And, the units so, when we use this formula whatever we get value it can be 40, 50, 60, it is expressed as decibels. So, this is the most common way of measuring sound waves for noise control purpose.

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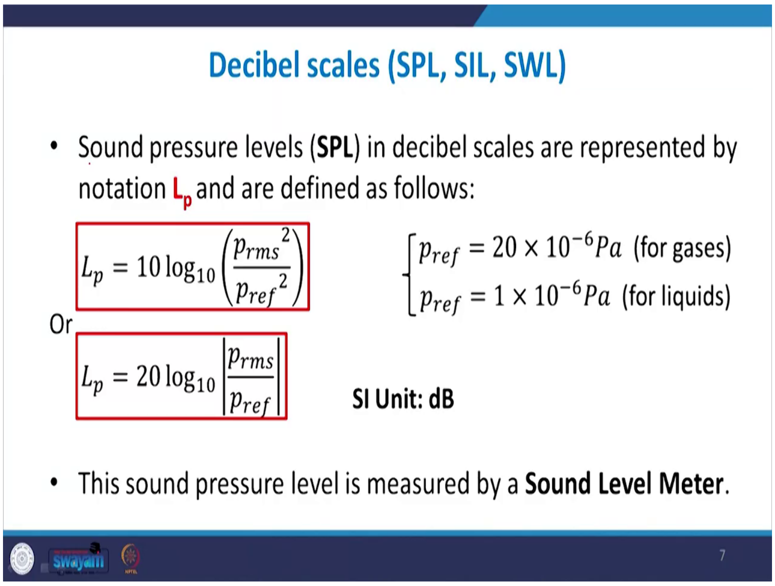

Now, another definition of sound pressure level is there, which is called as what is L p is. Now, we know that 10 log 10 is, 10 log 10 of I rms by I reference and if the medium is the same for both the waves. Then I will be directly proportional to p square or, I rms will be proportional to p square, intensity is proportional to the pressure square. So, replacing this by their respective pressures we get 10 log 10 p rms square by p reference square, where p references the minimum audible pressure. So, for gases it is, 20 micro Pascal's for liquids it is 1 micro Pascal. So, with the same standard equation we have now, replaced intensity by the pressure squares.

So, you take this 2 out it becomes 20 log 10 mod of p rms by p reference. So, this becomes yet another way of defining sound pressure level and the value which we get is expressed in the units of decibels or dB and the equipment used to measure this is a sound level meter in our in subsequent class, when we study about noise controller principles of noise control; we will study what is this equipment. So, these are the two standard definitions of sound pressure level.

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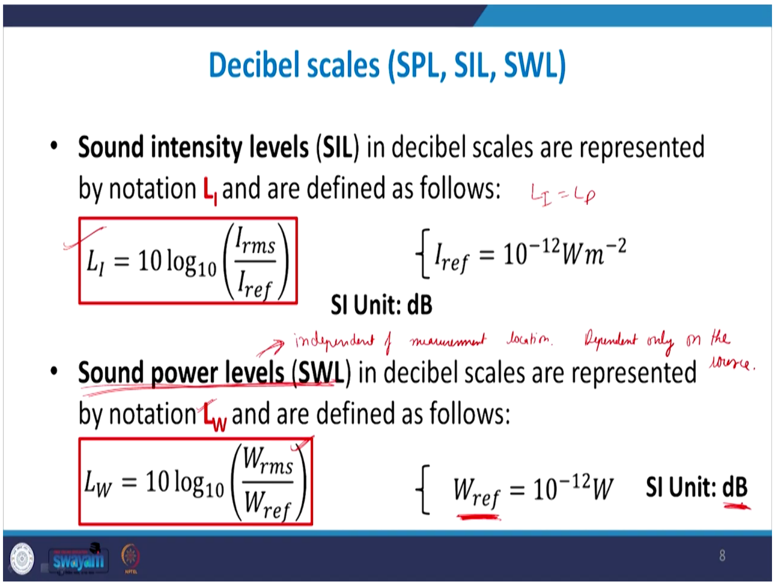

Then there are other levels such as sound intensity level, it is simply defined as L of I or the level of intensity which is 10 log 10 I rms by I reference. Now, as you see here this is the same definition as L p. So, L I is just the definition is different, but the values are always same L I is equal to L p, sorry here L I is equal to L p. Then we have another way of another quantity called as sound power level

So, sound intensity level and pressure level they are used to measure what is the particular sound at a particular location. Then we have a quantity which is used to measure the source, which is generating the sound and that is called as the sound power level. So, this value will be as we as you recall sound power is independent of the space; it only depends on the source so, it is independent of the space, it is only dependent on time.

So, the sound Watt level or the sound Watt level we call it or some power level, this will also be independent of the measurement location. It will vary only with the source dependent only on the source, and it is defined as it is represented by this symbol and it is defined as 10 log 10 W rms by the W reference. So, we have a reference minimum sound Watt.

So, this corresponds to the minimum sound power which can be heard, then the sound power of any new source is then compared with this and a logarithmic scale is applied to it and the unit is same as dB. So, this is how we convert the general acoustic variables into decibel scales or dB scales. We first of all compare them with we divide whatever is the rms value with a reference value which is the minimum audible quantity and then we apply 10 log 10 to it.

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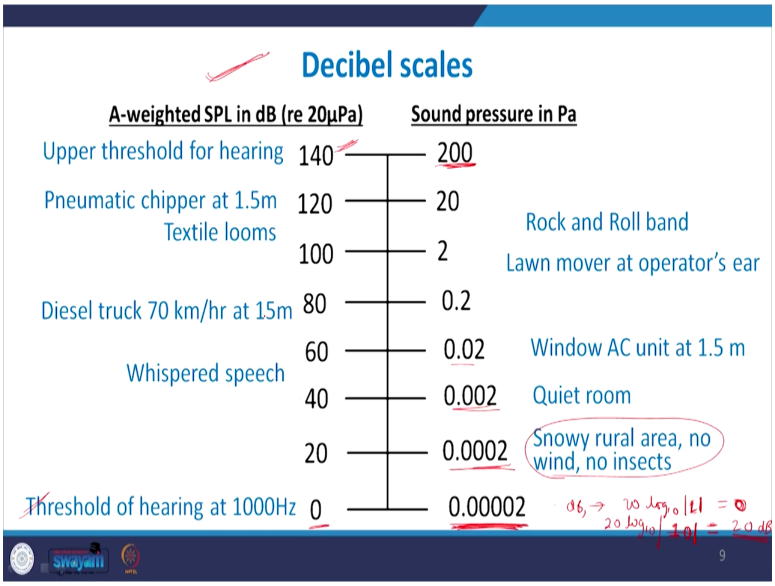

To give you a general idea of how the various common sounds they lie in this spectrum of decibels and Pascal's let us see this figure here. So, as you can see this is the minimum audible pressure which is 20 micro Pascal's.

So, this will correspond to how many decibels? So, you take the definition here. So, 20 log 10 of now, if 20 micro Pascal signal is given to you and this is also 20 micro Pascal so, numerator and denominator are same. So, this will equal, this will equate to so, the dB corresponding to this will be 20 log 10 of 1 because, the denominator is also 20 micro Pascal. So, it will come out to be log 1 is 0 so; it will come out to be 0 decibels.

So, the minimum audible pressure when converted to decibel, it converts into 0. So, the scale starts with 0 decibels and as you increase it 10 times. So, here I am increasing this 10 times at every level. So, as you increase it 10 times, how will the dB vary? It will be 20 log 10 the reference value remains the same and the upper value is increasing 10 times. So, the increment will be 20 log 10, which will come out to be log 10 is 1.

So, it comes out to be 20 dB. So, once the pressure values is increased 10 times which means, it come we converts into only 20 dB increase. So, as you see the scale is now, getting compressed the differences are now, getting compressed. So, the increment 10 times is now, just 20 dB's. So, this big range from 20 micro Pascal's to 200 Pascal's reduces to a range of 0 dB is to 140 dB's and so on.

So, we get a compressed and more comfortable range of values to handle. So, this is where is called as the upper threshold of hearing, after which hearing damage happens this is called as the lower threshold where the hearing begins and then we have various sounds which lie in between them. So, for example, in a rural area when you have no insect sounds, no wind nothing it is approximately twenty dB a quiet room is approximately 40 dB.

The general conversations from whispered speech they lie somewhere between 40 to 60 dB then we have some heavy duty vehicles like a diesel truck and all they lie around 80 dB. Then lawn movers they are very noisy, they lies and the operator is operating the lawn mover he is just standing next to the lawn mover so, here the levels will be more than 90 dB.

Then we have so, it shows you where the various common noise source lie in terms of dB. The textile looms they are more than 100 pneumatic chipper is 120 the jet aeroplane when it takes off to the people in the at the ground, it will sound 130 dB and so on and beyond 140 hearing can be damaged.

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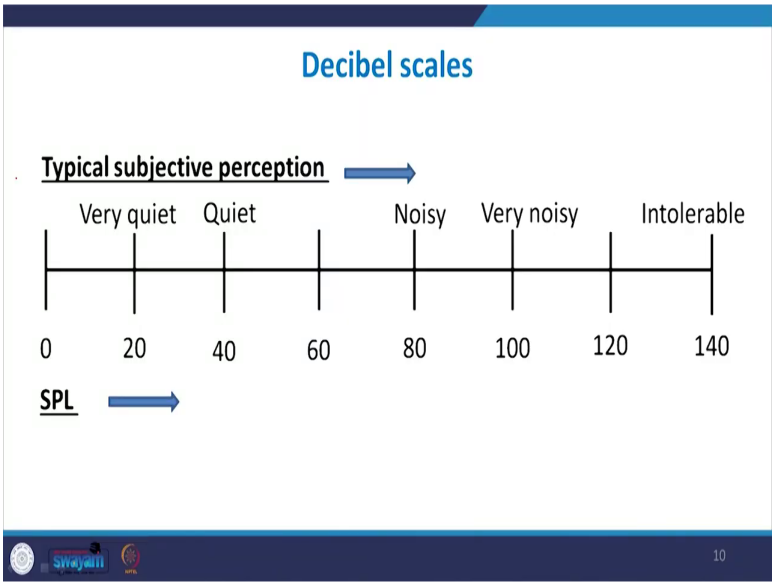

So, I to show you give you an idea of how the decibels are perceived. So, this is a scale where we have 0 20 40 and so on till 140 dB's and to show you how the human ear subjectly perceives it. So, usually the sounds over this range are perceived as very quiet, then quiet this will be normal loud noisy begins here then very noisy and then sounds 140 plus are intolerable and so on. So, this is how you can compare the SPL with how loud or quiet it sounds to the human ear.

So, now, let us now, that we have come to know about the decibel scale, we will now discuss how to use, how are the sound signals processed for further analysis. Now, till now, whatever sounds we studied they were in general having only one frequency component. So, we use the Fourier's theorem and we saw that any general sound can be decomposed into a sum of sines or sum of cosines.

So, let us take a general solution which is a sine or a cosine form and study that. So, all the equations we derived was for a sinusoidal wave. So, these waves which have only one component, one frequency component they are also called as tones.

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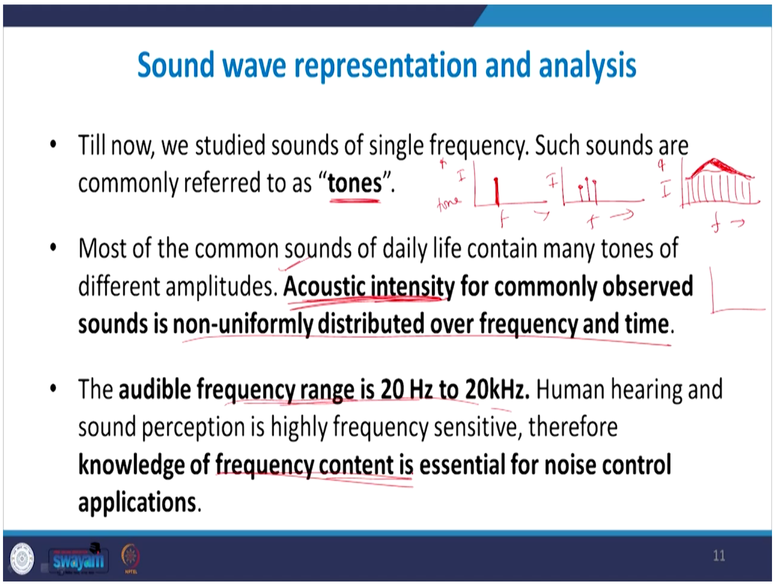

So, in general term these are called as tones. So, they have only one frequency component, but most of the common sounds that we hear they do not have only one frequencies, but they are a combination of many frequencies. So, usually what they are they do not have one tone, but they are a combination of different tones of different amplitudes, at different frequencies all combined together to give you a general sound.

So, a way of representing so, usually how do we so, to analyze such sounds what we do is that, we observe how the acoustic intensity. And, usually whatever sounds we encounter the acoustic intensity is usually non-uniformly distributed over the frequency and time; which means, that suppose this is a tone it will only have one frequency and this is the intensity and this is the frequency.

So, this will be the graph like of a tone. So, it just has acoustic intensity at one frequency. If we combine 2 3 tones it can be something like this. Intensity at different frequencies, but a general sound is something like this is frequency this is acoustic intensity it is something like this.

So, what it has is that the acoustic intensity; we have some intensity at almost every frequency for a common sound, but the magnitude will be non-uniformly distributed for most of the common sound, some common some sounds can have more intensity at low frequencies, some can have more intensity at high frequencies. For example, if you see whistle or a sharp whistles whistling sound it will have it is a high intensity sound.

Even the sounds that the dolphins make its a high intense, its a sound with a high frequency. So, it is a sound where the acoustic intensity is higher at higher frequencies. So, it has more high frequency component. Whereas the typical machinery sound the graph of that is that it has got more magnitude in the lower frequencies and less magnitude in the higher frequency. So, it has more low frequency components.

And, the human hearing is very much frequency dependent so, the knowledge of knowing how the intensity is distributed over different frequencies is very important for noise control. Because, for example, for a human ear usually the frequencies around 1000 to 4000 Hertz are very sensitive it can be easily, it can easily here those sounds whereas, the sounds at extremely low frequency below 100 below 100 Hertz hardly audible.

So, the sensitivity of a human ear is highly frequency dependent and even the sounds that we encounter they have different distribution over different intensities. So, the study so, we cannot study these sound signals just as a time waveform; we need to study what are the components so, how the intensity is distributed over the different frequency for noise control.

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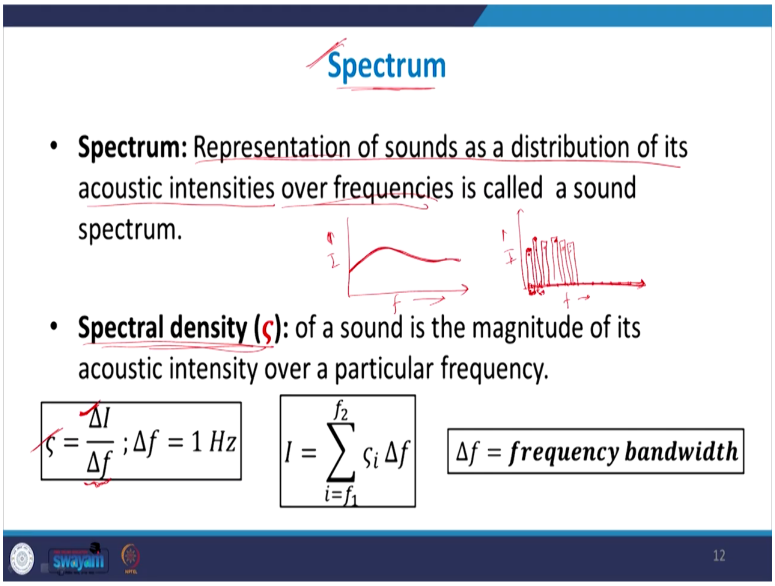

So, that is the basis for sound wave representation and that is the basis for spectrum analysis. So, I am introducing a term here spectrum this term simply means, that it is the representation of sounds as a distribution of its acoustic intensities over frequencies. So, here we are representing how the acoustic intensity is varying over frequency. Now, if the frequency scale was continuous and we represented this suppose some graph we obtained here so, it shows you how with increase in intensity, how with increase in the frequency the intensity is varying it could be a continuous graph, but most of the measuring instruments they use digital signal processing.

So, they analyzing the sound at every frequency in a continuous scale is very very cumbersome it means, infinite values we have to observe infinite such values. So, usually, what we do is that rather than observing it in a continuous scale we have a digital scale so, the same frequency scale is sort of broken into small bands and the intensity distribution over these bands. So, between these to this what is the intensity here; between these to this what is the intensity and so on. So, between this small digitize the small cut up bands the individual intensities are observed.

So, what happens here is that now, we do not have to deal with infinite number of values, we can divide the audible frequency range into some finite number of values and observe the intensity distribution over those values. And, we can get the idea of how these spectrum looks like. So, that is where we introduce the term spectral density; the spectral density is simply, what is that small amount of acoustic intensity which is contained within a small frequency band. So, here we have divided the scale into small bands.

So, within this small del f what is the amount of intensity contained within this small del f what is the amount of intensity that is contained this is called as a spectral density and if you sum the entire thing up you will get the total frequencies.

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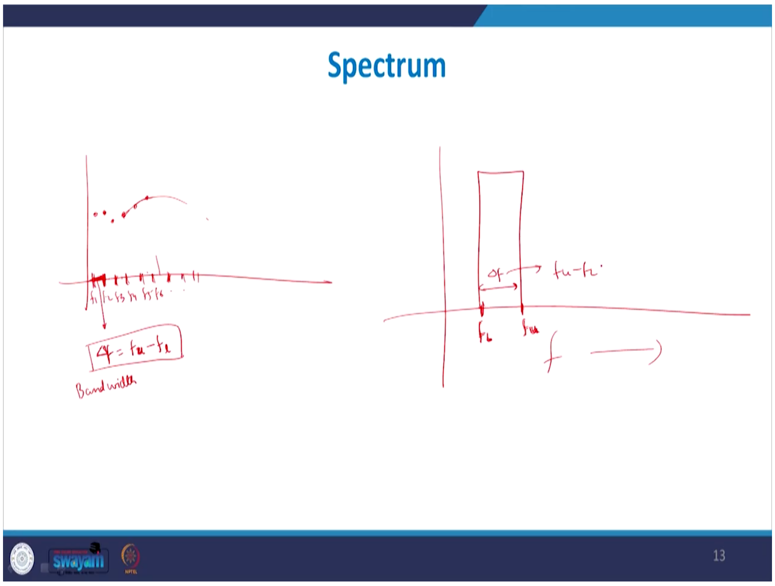

So, frequency band divided into certain small values and within those bands, we are observing what is the intensity value here, what is the intensity value here and so on. And, we are getting some graph so; the net total intensity will be what it will be the summation of intensities over the entire frequency range that we have observed.

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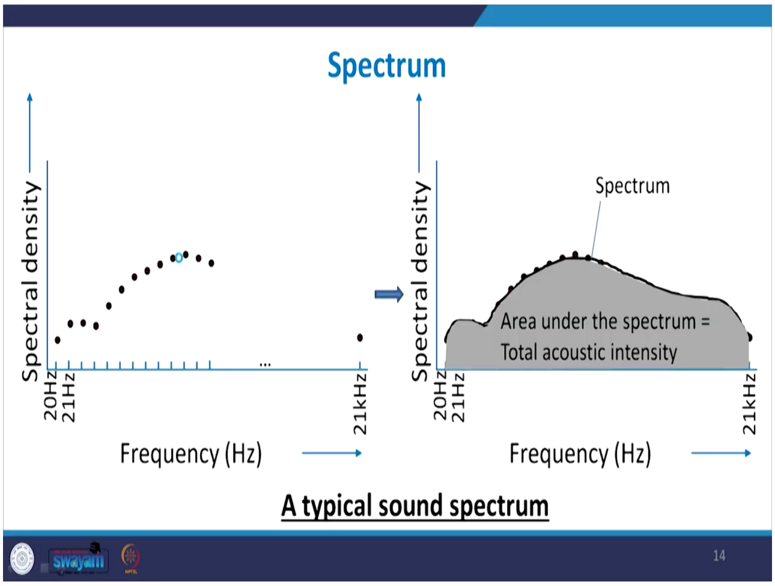

So, this is how it looks like so, we can cut this continuous frequency scale into small bands observe the individual intensities and the net integration of the integral of this graph or simply the summation of the area will give you total acoustic intensity. So, this is the common way of representing any sound wave for analysis. So, we get some sound wave we obtain some wave form as a function of pressure, we get some pressure function pressure wave that is a function of space and time.

Then we do some analysis and convert that pressure wave not and represent it as a function of frequency. So, how is the intensity varying with frequency? So, that is called as the spectrum or frequency spectrum. Now, in that spectrum or frequency spectrum as I told you earlier, we are dividing the frequencies into small units. So, let us say this value is f 1 this is f 2 f 3 f 4 f 5 f 6 and so on.

Then these are the individual bands and this difference del f or the width of a frequency band is also called as the bandwidth which is simply the upper value of the frequency minus the lower value of the frequency. So, in general it is the upper value minus the lower value. So, every band is characterized by 3 quantities. So, whenever we have a frequency scale and we have some frequency band. So, it will have some upper frequency value and it will have some lower frequency value and the width of that will be del f or the bandwidth which is f u minus f n

So, you can so, you can vary the width of the band to do analysis; if you have wider bands which means, you can do a more quicker analysis because, then you will have to observe less points, but the data will not be very fine. You may miss certain details and if you have finer bands. So, if the bandwidth is smaller which means, f u minus f n is smaller. So, there this means that now, the same frequency scale is getting divided into more number of bands.

So, now, the observation point will increase so, computation time will increase, but you will get a more detailed analysis of sound.

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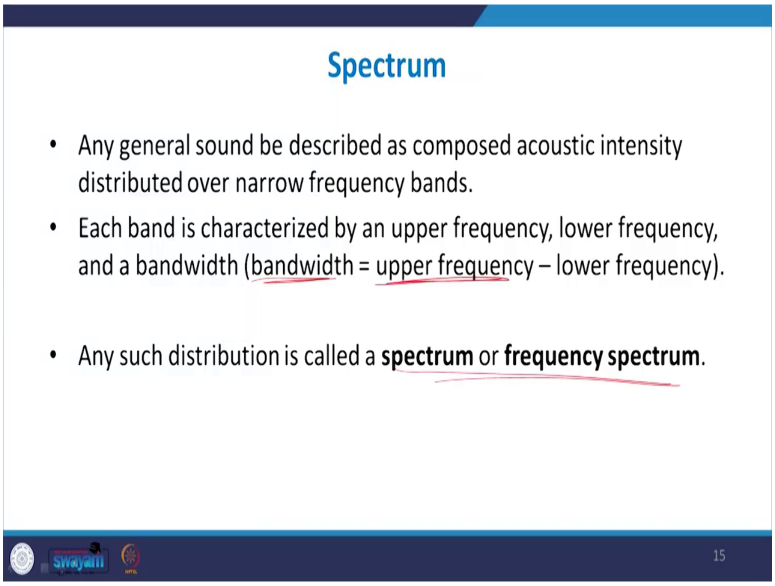

So, this is how the bandwidth is defined as I said upper frequency minus the lower frequency

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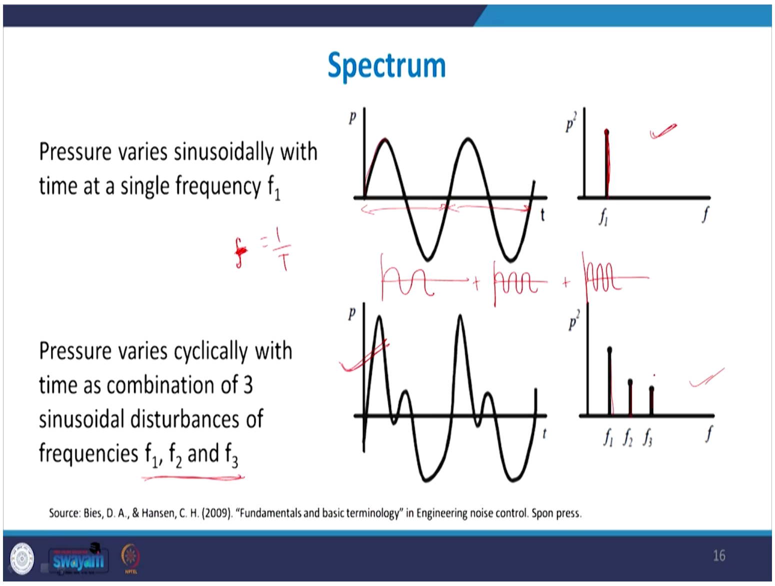

So, let us see how the spectrums look like. So, here the pressure suppose, we have a typical sinusoidal wave. So, here as you can see the frequency is fixed. The time period here is same as the time period here so, at any point the time period is constant and f is equal to 1 by time period. So, the frequency is fixed it only has one frequency. So, this is how the spectrum looks like all the acoustic intensity is only in one frequency.

But, now, let us see super impose 2 to 3 different sine waves of different frequencies and different amplitude; we get something like this. So, here this particular wave has got 3 individual components. So, this is simply a superposition of 3 different sine waves with different frequencies and different amplitudes let us say, when you combine it you get some wave form like this the spectrum can be it will have distribution over 3 different frequencies.

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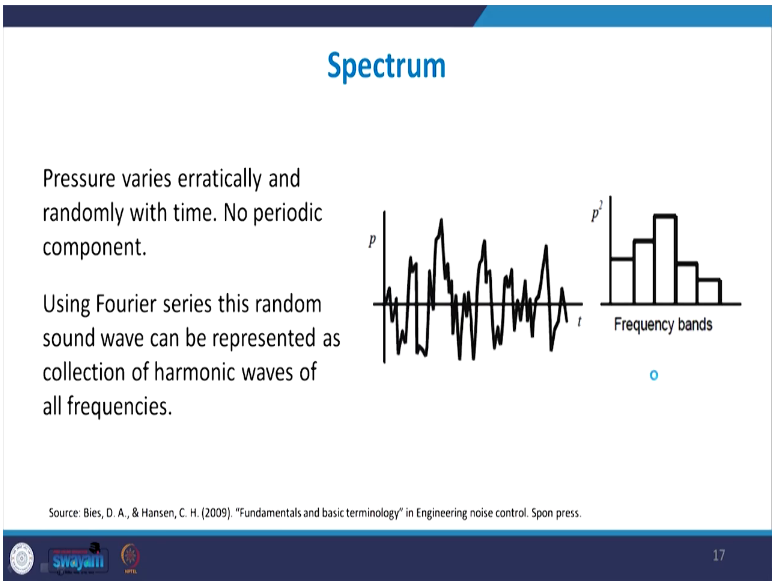

Now, if you have a non-periodic signal so, it is completely random and you cannot find any periodicity. So, how do you represent such wave in a spectrum? Then according to the Fourier's theorem again; even a non-periodic signal can be represented as a sum of periodic waves. So, you can represent it as a sum of sinusoidal waves over the entire range of frequencies.

So, you will have a continuous band. So, here we had some individual bands depending on how many frequencies are there, a random wave we can have, we can assume it to have some intensity at every frequency. So, this will be a general representation.

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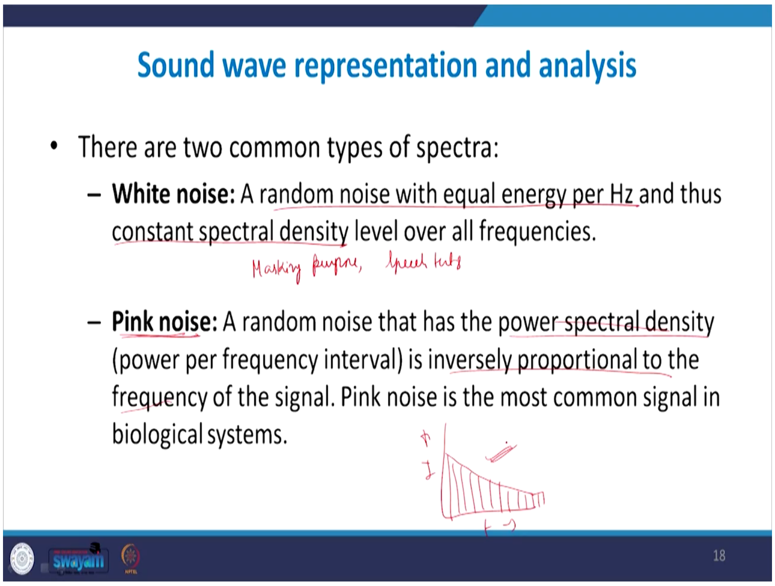

Two specific kind of spectra is usually used in the case of noise control. So, we call them as white noise and pink noise. So, white noise is simply a random noise very equal energy per Hertz or it has a constant spectral density. So, which means, that it is a random noise where the density is almost uniformly distributed throughout the frequency and this kind of noise is usually used for masking purpose and specially in speech tests.

So, this is a general masking noise because, when we are trying to mask some noise then we want to have a random noise which does not bias the results so, we need a uniform distribution. Then another noise we encounter is a pink noise. Now, this is the noise where the power spectral density is inversely proportional to the frequency.

So, as if we represent it as the intensity the spectrum of this intensity versus frequency and it will be something like this, it is inversely varying with respect to frequency. So, this is one of the most commonly encountered noise, where we have in the biological systems it represents more with the common sounds, which human beings or other animal species make.

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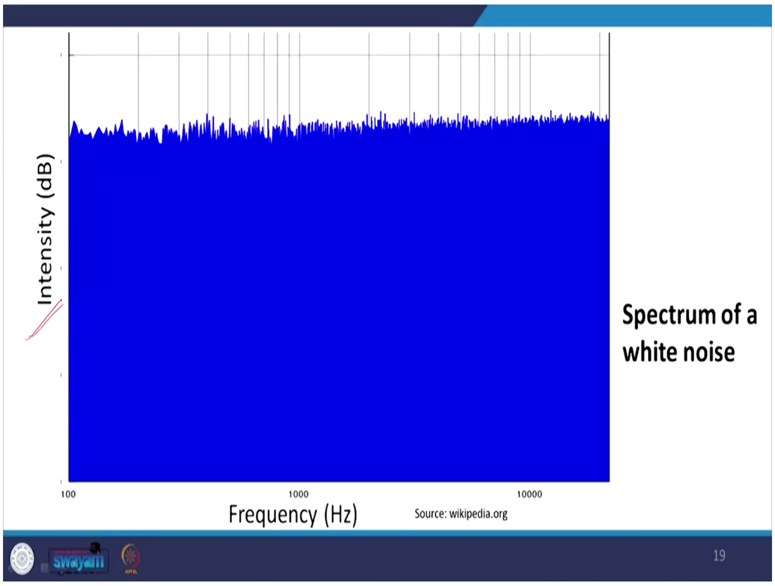

So, this is a spectra, a typical spectra of a white noise. It is almost uniformly distributed throughout the frequency and this is a typical spectra of a pink noise. Ok.

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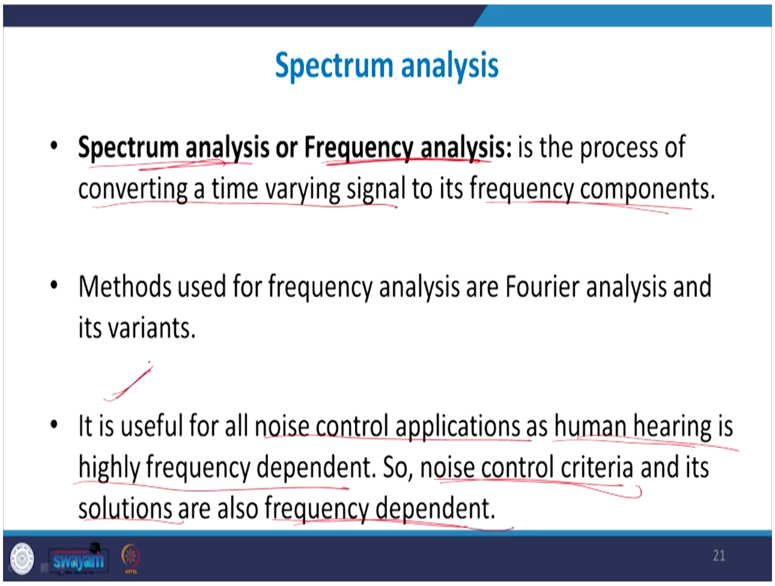

So, usually what so, the main component or the main takeaway of this lecture is that sound, the common sounds they can have many frequency components and the intensity can be distributed non-uniformly throughout these frequency components. But, because human hearing is highly frequency dependent; so, we need to analyze these sounds not as time waveforms, but also as the distribution over the frequency and that is why we need to do frequency analysis or spectrum analysis, which is converting a time varying signal to its frequency components.

And, this is very much important because, all noise control applications they are based on human hearing which is highly frequency dependent. So, the noise control criteria as various solutions is dependent on the frequency and that is why spectrum analysis of frequency analysis of sounds is necessary. So, for example, let us say we have an application; where we have a machinery we want to control the noise of that machinery.

So, we first need to know, how the sound looks like as a spectrum, then we will come to know, this is the region where the maximum intensity is, this is the frequency range. And, then we can apply the noise control accordingly to cut or reduce the noise and that frequency and so on. So, in the next lecture we will study more in detail about, some more things about sound signal analysis.

Thank you for listening to this particular lecture.