Audio System Engineering
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Lecture – 10
Perception of Sound

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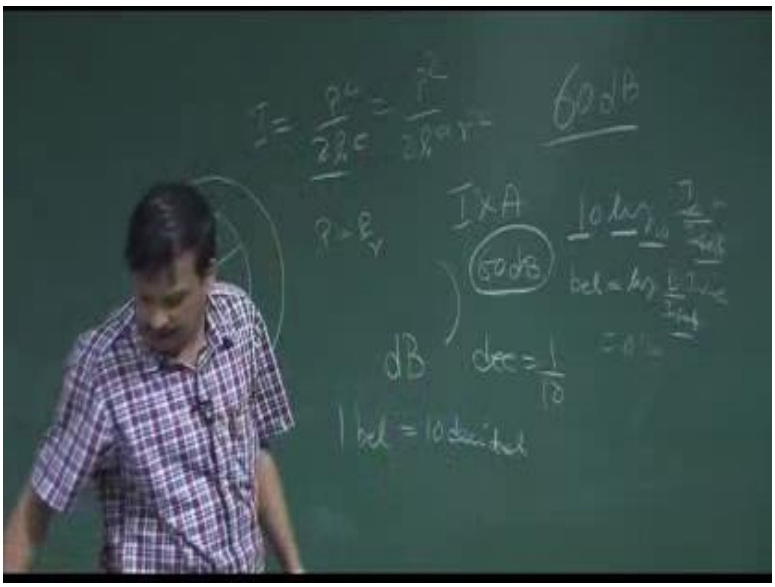

Morning. So, we have seen that spherical wave and linear wave propagation and we derive that intensity equation I, intensity is nothing but a p square by 2 rho 0 C so that is the rho 0 is the density C is the velocity of the sound, p is the pressure of the sound so intensity we derived. And also we seen in spherical wave propagation, if the wave is propagated in spherical in nature, the intensity of the wave depends on the radial distance r. So, since the p is nothing but a p by r so p square is nothing but a so it will be p square by 2 rho c into r square. So, if it is distance is large then the intensity will fall down for the spherical wave propagation.

Now, another things is that when we heard the sound, one is that sound is propagated, it may be audible, it may not be non-audible the frequency may be different. So, those kinds of issues are there, but if you see when you develop any technology, whether it is sound, whether it is vision any kind of technology when we develop for a human perception like microphone, like loudspeaker, music systems, it is basically develop for human perception. Now, we have to know how human perceives the sound.

If I know that then depending on the human perception I can play with the technology so that suppose that I want to I have raise that if the volume of the amplifier if you seen it there is a loudspeaker is playing in a let say auditorium if you raise the volume. are we perceive if I raise the volume double, are we perceive the intensity which I perceive by the human being is also be double. If it is not double then what should be it is. So, the perception of the sound is also an important parameters I am not going details about the perception of human perception, but perception of sound a little bit of touch upon here so that you understand when we are playing with technology frequency, intensity, we should also know how it effect in human perception.

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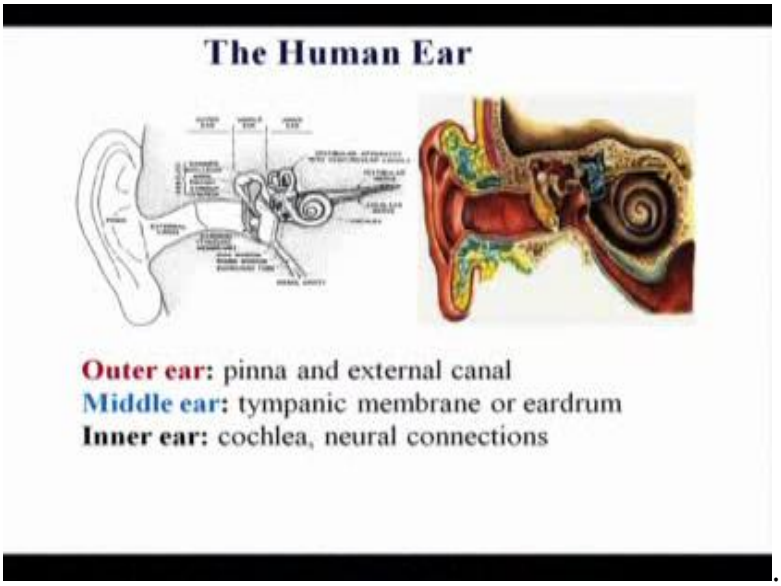

Now, if you see how we perceive the sound, if you see the slides we perceive the sound, basically we have a sensor –sound sensor here. So, ear has three parts, one is called outer ear, this is outer ear, you see this is called pinna – outer ear, middle ear, and inner ear. So, inner ear is basically connected to the nob and that senses going to the brain or perceive. Outer ear is the pinna, external canal; and middle ear is the you know membrane and this kind of arrangement is there details you can see in any internet or any books that this is the (Refer Time: 03:39). So, once the acoustics enters the ear, suppose you are play sound box in this room, the sound intensity will fall in this pinna.

Now, you know if the intensity is I, then what is the energy, energy is nothing but I into area. So, if the area of the pinna is increased the ear intensity, the energy – acoustics

energy received by the ear will be increased that is why sometimes if there is a low intensity sound, we place our hand in here. What you have been, we have increasing the acoustics energy is which suppose to go inside the ear much, because I put a more area in here. So, if I put a area in here, the intensity will be coming here and total area will be multiplied and that much of acoustic energy will go inside my ear so that is it the work of the outer ear is called pinna.

Then what is middle ear, if you see in the middle ear, there is two kinds of bone and one membrane this is you know that this is called membrane one membrane is there. So, once the acoustic energy passes through the canal then there is a vibration is created in the membrane like I put, vibration is created in the membrane. Once the membrane is vibrated that vibration is transfer through a bone conduct cell to the inner ear so that is the human perception things. So, outer ear, middle ear and inner ear, those are the three main parts of human perception.

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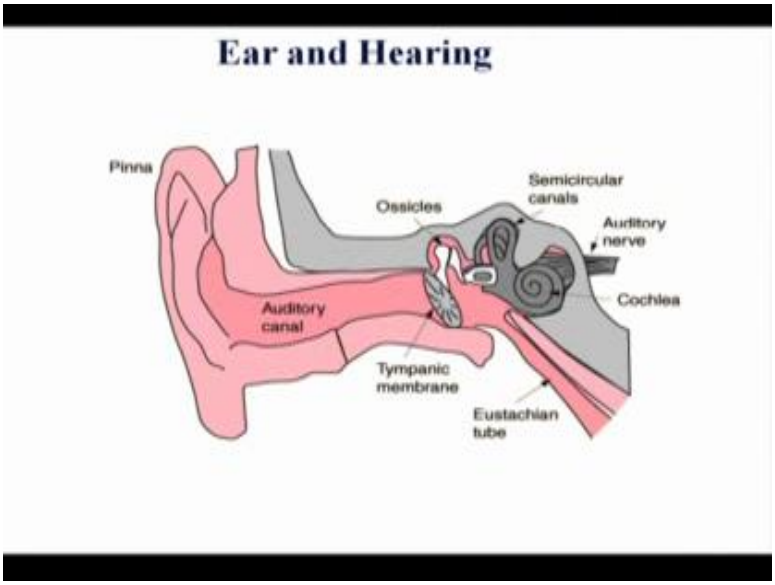

Now, if you see that schematic diagram, so it is nothing but a pinna, auditory canal then there is a membrane then there is a bone structure is attached with the cochlear. This is the semi-fluid liquids are there for human perception.

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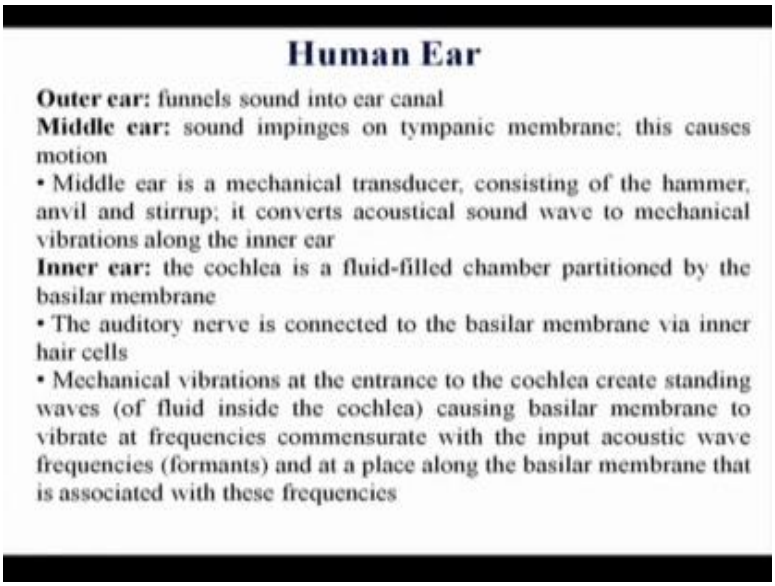

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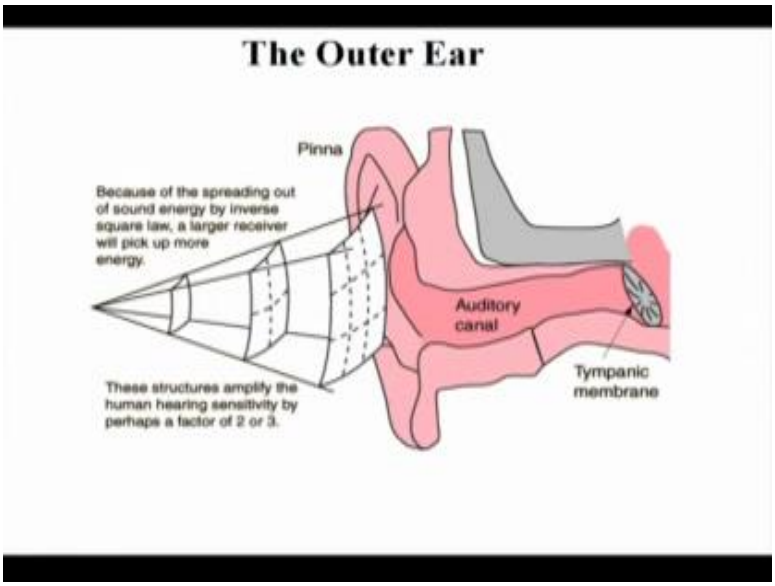

Now, I am not going details. So, acoustic intensity will be gathered by the pinna, converged to the vibration by the membrane then transfer to the bone to the inner ear. So, before that inner ear, if I see that how it is look like that response there is one kind of you know every system has a frequency response.

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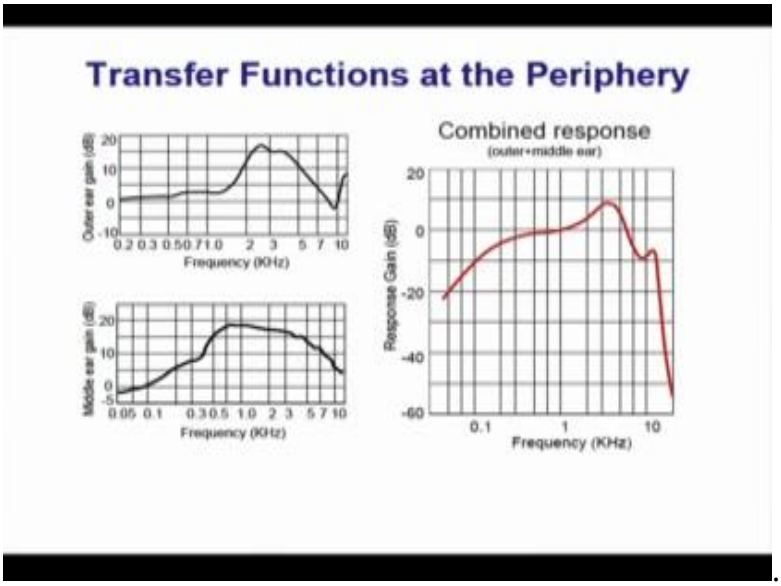

So, it is said it is experimentally prove that that the frequency if I prove the frequency versus outer ear gain how much the frequency response of the outer ear this pinna is like this way, if you see this curve. So, all the frequency is not equal to sensitive. There is some (Refer Time: 06:33) frequency outer ear is much more sensitive.

Then there is a middle ear frequency response curve. So, if combine the outer ear and middle ear, the response curve will be look like this. So, this is the frequency scale and this is the response in db. What is the meaning of this curve? If I want to explain the meaning of this curve, if you see the sensitivity of the middle ear and outer ear is varies according to the frequency. If you see at the lower frequency sensitivity is less, at the higher frequency gain is very high; that means, no intense sound within this frequency range I can heard. Same intensity like that suppose this is 0 dB, 0 dB or lets 0 dB of 1 kilo hertz sound, and 0 dB same intensity db of 20 hertz sound, I cannot heard this 20 hertz sound, but I heard that 0 dB of 20 kilo hertz sound.

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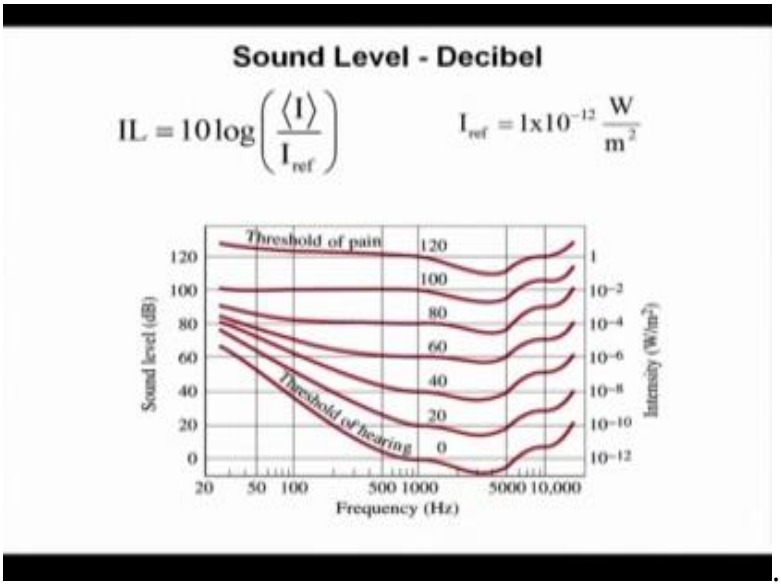

So, there is a connection that just if I say the efficiency of my ear is nothing but a reverse of this curve, efficiency of this ear is nothing but a reverse of this curve. So, I will come that that point I will come. So, if I say that auditory or you may say the sound perception is a human phenomenon, but sound is a physical phenomena. Sound if you say the sound wave is travel in the air, sound wave travel in this room, so this is the physical phenomena, but perception is a bi variable phenomena by a human being.

So, I can say sound or auditory has a two dimension, one is called perceptual dimension, another is called physical property of that sound. So, if you heard that that you know that that perceptual dimensions are pitch, loudness and db; and physical dimension fundamental frequency, intensity, spectrum or (Refer Time: 08:53) or composition of that sound. So, what is the difference? Physical phenomena, I can measure, but in perceptual phenomena I can only observe. So, if I say that intense what is the difference between loudness and intensity. If I say this microphone speaker produce the intensity of 60 dB, I know there is value of intensity, I can measure it physically.

So, what is the physical property, or if I say this sound is louder than the previous sound that is my perception, this is my perception. After hearing the sound, I thought that this sound is louder than the previous sound, so this is perceptual dimension so that can be observed only. Similarly, you heard about that pitch and fundamental frequency. Pitch is a perceptual dimension, what is pitch. If you see, if I play the same node, same node

means same fundamental frequency (Refer Time: 10:00) harmonium or guitar, even if you are close your eyes, you can identify which instruments are producing which sound, but fundamental frequency is same. So, pitch is the perceptual skill, perceptual parameter, but if I say the fundamental frequency, fundamental frequency which can be measured within that pitch is a physical parameter. So, this is the difference between the perceptual parameter and physical parameter.

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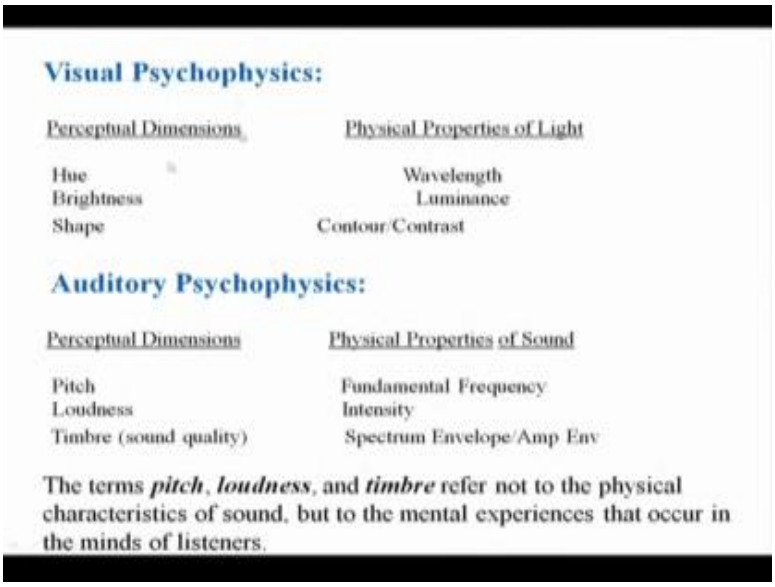

Similarly, visual dimension also we know that hue, brightness and shape, and wavelength, luminance, color contrast all you know that this is the auditory, this is the visual and this is the auditory. Timbre, I am not explaining.

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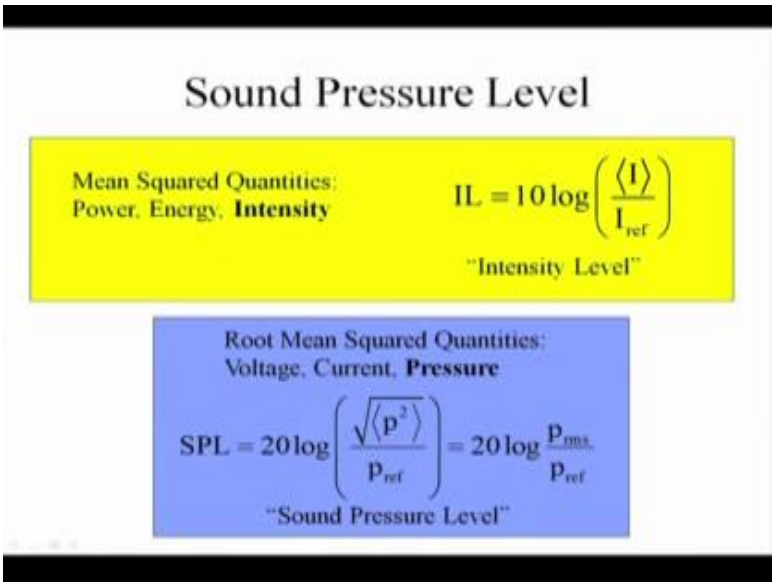

Now, if I say why I have to know this all kinds of perceptual things, yes, because if we study the sound system engineering let say given an example, Pollution Control Board said that 60 dB should be the sound limit for maintaining the environment pollution. I cannot produce a sound which is more than 60 dB; because it can it may harm to up to the human being. So, now 60 dB, what do you mean by 60 dB, I write 60 dB, what is the meaning of the 60 dB, 60 dB is nothing but a intensity, I said the intensity of the sound must be 60 dB. What is the meaning of the dB? Everybody is known dB is nothing but a 10 log output by input, we know that; that output by input 10 log 10 is the dB.

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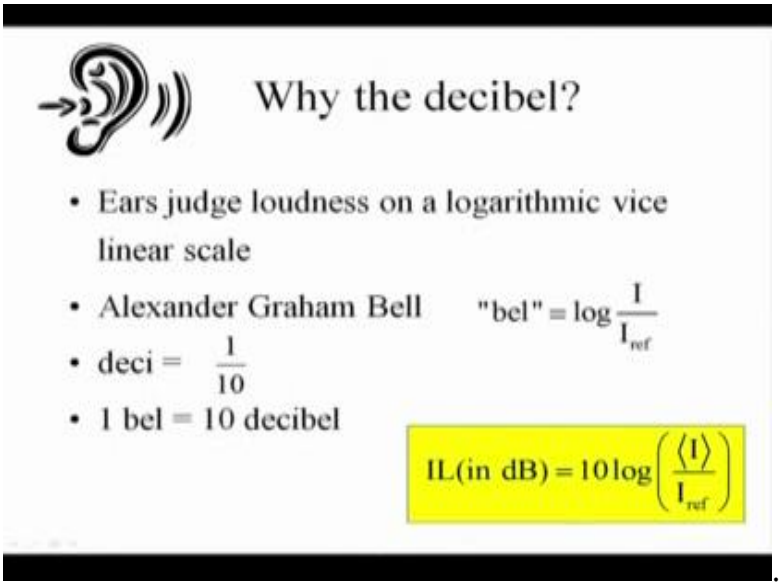

Now, if you say Bell – Alexander Graham Bell had said that in case of sound, one bell means log I divided by I ref. What is I ref is the reference sound of human being. What is the reference sound, the intensity of the sound for which I just heard the sound is called I ref. So, at I ref that if I equal to I ref then it is nothing but a 0 bell, what is dB – deci bell, what do you mean by deci, deci means ten, so decibel deci if it I say deci, deci is nothing but a 1 by 10. So, deci bel, so one bel is equal to 10 decibel. So, I multiply this decibel, it is 10 log 10 I by I reference input.

What is I reference, I reference is the intensity of that sound for which a human being can normal audio spectrum of the human being, normal human being can just heard the sound. So, in the value that reference value that 0 dB, so that is called 0 dB. So, I ref, I ref is nothing but a 0 dB, because ref, ref is 1, so it is nothing but a 0 dB. So, 0 dB of sound is that sound of intensity of that sound for which human being can just audible level of that sound. I just heard that sound; a normal human being just heard the sound which is called 0 dB. So, 0 dB is nothing but a 10 to the power minus 12 watt per meter square is I reference for normal human being.

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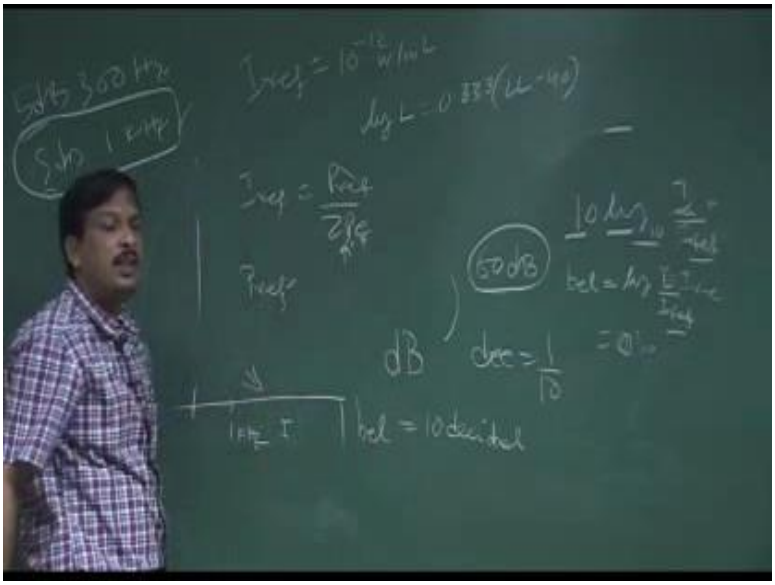

If I produce 10 to the power minus 12 watt per meter square intensity then that sound is just audible. Now, there is another things, is this power I should be for any frequency, I just said the frequency response of the human ear is not linear, it is has a change, human response to the frequency. So, it is not; 10 to the power minus 12 watt per meter square

intensity cannot produce a a sensation for different frequency, only for 1 kilo hertz frequency. If the pure tone is 1 kilo hertz sound or sound frequency is 1 kilo hertz and intensity is 10 to the power minus 12 watt per meter square that sound only can produce a sensation for a normal human being means which is just audible.

So, for different frequency the amount this I will be different, so that is why we make a curve. If you see this curve, this is called threshold of hearing; that means, if I produce a 60 dB sound of lets 20 hertz then it is just audible. But I can the 1 kilo hertz 0 dB sound will be audible for 1 kilo hertz. So, if I say if I produce a sound of 5 dB, 5 dB sound of 300 hertz and 5 dB sound of 1 kilo hertz which will be louder in case of sensation, 1 kilo hertz. Because the frequency response sensitivity of my ear at 1-kilo hertz is much higher, so I can heard the sound is louder. So, the loudness, when I say the sound level or loudness of the sound is a perceptual parameter. But one is say the intensity of the sound is a physical parameter. I can measure the density of the sound, but loudness is a perceptual parameter.

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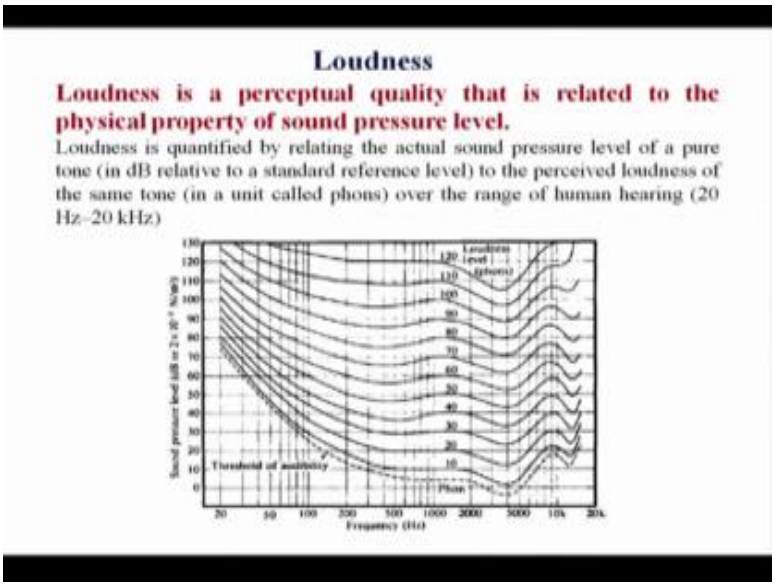

So, loudness is a perceptual quality that is related to the physical property of sound pressure level. Now, I want to correlate the loudness versus sound pressure level or intensity of the sound. So, loudness is quantify by relating the actual sound pressure level of a pure tone in dB to the perceive loudness of the same tone over the range of human hearing. So, if I say this is the frequency response, this is the sound pressure level.

So, this curve the below is black line this is the same loudness curve; that means, if travel along across this curve, if I change only the frequency, if I produce suppose for 20 hertz, I produce a sound for 90 dB. And if for 1 kilo hertz if I produce a sound of 90 dB curve if you see the 90 dB curve around forty dB will be equally loud, so that is why this each curve is called phone curve; phone curve, which line is equal loudness in this line.

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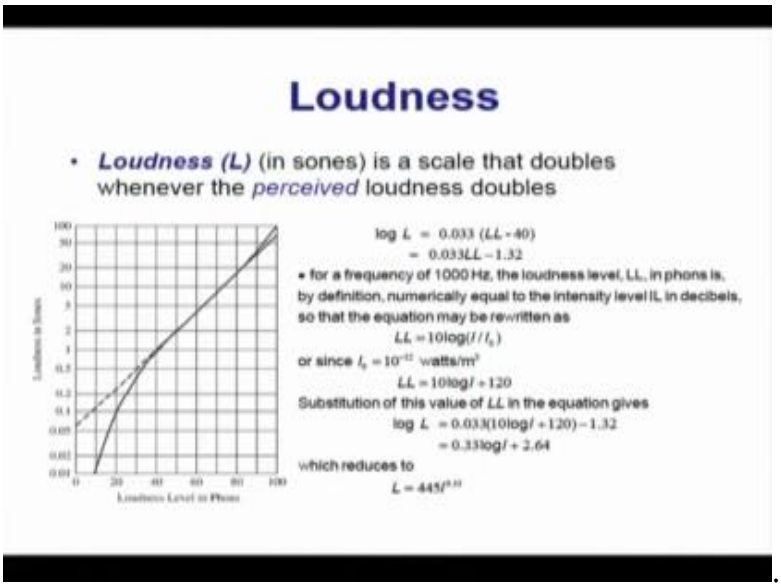

Then loudness in term of intensity, I can convert L is nothing but a so this is you can see this slides and you can see that mathematical deduction, which is loudness converted to the intensity. How do you done, it is very simple experiment. Suppose, you loudspeaker on for a particular frequency let us for 1 kilo hertz, then you produce a sound let us you produce a sound for 5 dB. Then you increase the volume increase the gain then you produce the sound of 6 dB, 7 dB, 8 dB, 9 dB and you told the listeners when you perceive the sound is loudness is double than the previous, you raise your hand.

So, what will get that you are saying this is the loudness curve, this is the loudness level, and this axis is the intensity I. So, loudness level in phone, phone means for particular frequency let us for 1 kilo hertz, 1 kilo hertz sound I produce a particular intensity I, then I said ok, this is my I. Now, I said the persons that when you perceive the loudness is double who raise your hand. So, let us once I increase the intensity, person raises his hand like this way. So, then I get a curve, that curve indicate the loudness perceived loudness of that person with relation to the I, so that is why the curve is represented like

that that log L loudness is nothing but a 0.033 sound level intensity minus 40. This is the curve; they experimentally find out and put this equation. Now, you that L in dB, and you find out that relation.

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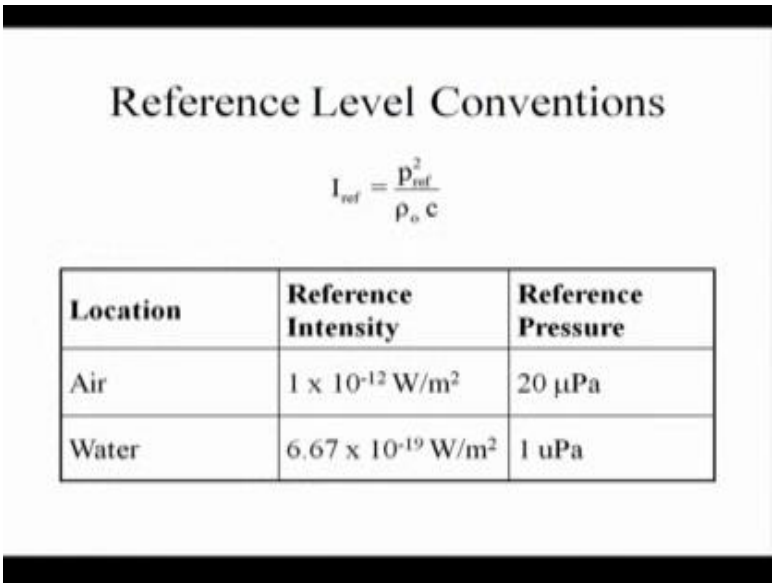

Now, there will be several kinds of things that I reference for human being is 10 for 1kilo hertz 10 to the power minus 12 watt per meter square, it is I. Then what is the P reference, so I reference is nothing but if I say I reference, so I reference is nothing but a P reference divided by 2 rho c. If I know the velocity of the sound, and density of the medium then I can calculate what should be the P reference. If you see this table, I said the P reference, P reference for air, it is I reference 10 to the power minus 12 watt, P reference is 20 micro Pascal; we will use it.

So, when we convert pressure in dB, let us I say I produce a 1 Pascal pressure, what is the dB in term of human perception. So, it is a 1 Pascal means 10 log 1 Pascal divided by P reference. What is the P reference? Pascal divided by 20 micro Pascal, now I convert this ting and find out how much dB is the sound. So, providing sound level pressure Pascal in Pascal, I can convert it to dB by way using the P reference for air. Similarly, if the sound is propagated in water, then water is 1 micro Pascal, reference is 1 micro Pascal. Then if it is water, let 1 Pascal, then it is 10 log 1 Pascal divided by 1 micro Pascal, P reference will be different. So, this kind of calculation will be used many times in our tutorial analysis.

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Source	Intensity (W/m^2)	Sound Level
Jet Plane	100	140
Pain Threshold	1	120
Siren	$1x10^{-2}$	100
Busy Traffic	$1x10^{-5}$	70
Conversation	$3x10^{-6}$	65
Whisper	$1x10^{-10}$	20
Rustle of leaves	$1x10^{-11}$	10
Hearing Threshold	$1x10^{-12}$	1

This is for your information, you can get it from anywhere jet plane that intensity and sound level. So, sound level means pressure level; so you say intensity means I it is nothing but a P. So, I is 100 dB, sound pressure level is 140 dB. Pain of threshold then all things you can get it.

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Decibels and Percentages

$$\% \text{ change} = 100\left(1 - 10^{\frac{-dB}{10}}\right)$$

$$\% \text{ change} = 100\left(10^{\frac{+dB}{10}} - 1\right)$$

$$dB = M \log_b\left(1 - \frac{\%change}{100}\right) \quad \text{Below Reference}$$

$$dB = M \log_b\left(\frac{\%change}{100} + 1\right) \quad \text{Above Reference}$$

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Then there is another example that how you convert the dB and this is nothing but a mathematics simple mathematics. Suppose, somebody said that some percentage change, how it is converted to the dB, so percentage change is nothing but a hundred into one

minus 10 to the power minus dB divided by ten. If it is decrease, if it is increase then 10 to the power plus dB divided by 10 minus 1. It similarly percentage to dB, and dB to percentage, so these equations you can remember and then use.

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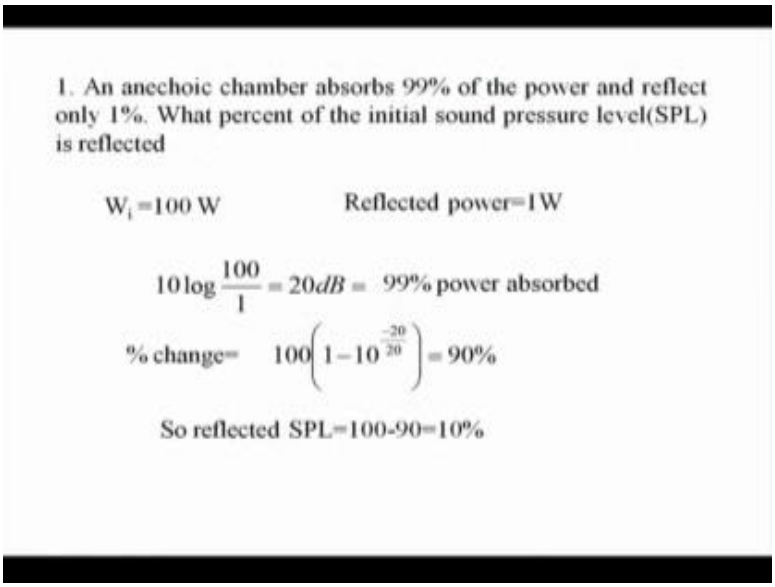

Like, let us do this kind of mathematics; anechonic chambers absorb 90 percent of the power and reflect only 1 percent. What percent of initial sound pressure level is reflected? So, this kind of question may ask by the society. An anechoic chamber, I have to design, it is 90 percent power is absorbed and reflect only 1 percent, so what percent of initial sound pressure level is reflected.

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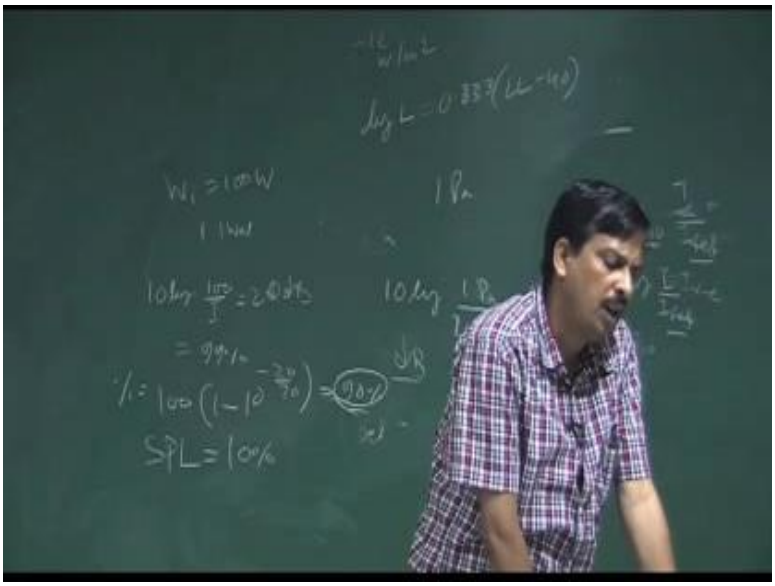

So, let us W i, you may see that W i is equal to 100 watt, if I produce a 100 watt sound, so reflected power is 1 watt; 99 percent is absorbs and 1 percent is reflected. So, if it is 100 watt, then I said 10 log 100 divided by 1 is equal to 20 dB, 100 by 20 dB, so it is nothing but a 99 percent. So, percentage change is nothing a, it is decrease, so it is nothing but a 100 into 1 minus 10 minus 20 divided by 20 is equal to 90 percent. So, reflected sound pressure level – SPL. Reflected sound pressure level is 10 percent; 90 percent of the sound pressure level is absorbed and 10 percent is reflected.

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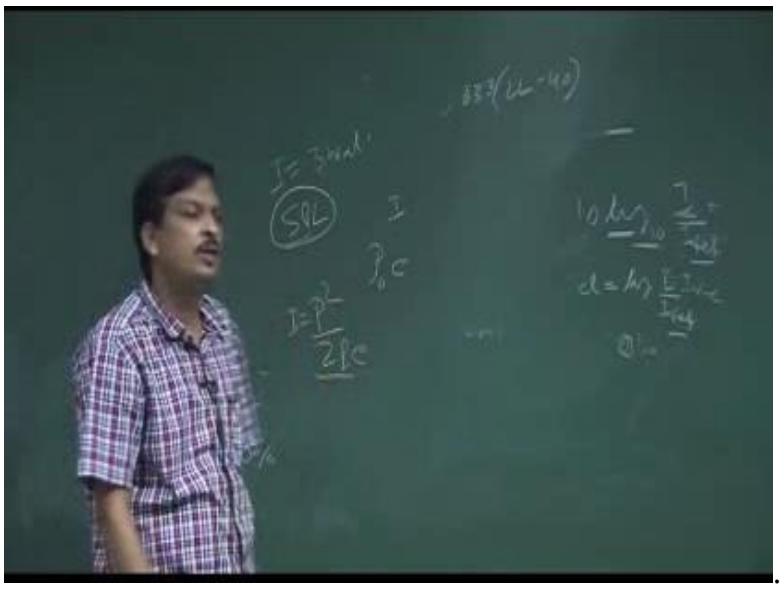

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Similarly, you can do for other mathematics for other kind of things that if it is 5 percent, if suppose somebody said I play a loudspeaker and its gain is raised by lets 3 dB. You do it in home; I said the gain is increased by 3 dB, how much sound pressure level will be change if I heard it. Percentage change of the sound pressure level in perception, you can convert it. So, this kind of mathematics will be done in practical cases will be used this kind of frequency, mathematics for dB to percentage, percentage to dB and convert that sound in dB. Similarly, somebody can say I have somebody ask you that Pollution Control Board said that I cannot produce a 60 dB more than 60 dB sound. So, if I want to limit the sound pressure level 60 dB, what should be the output power of my amplifier? limit of the output power of the amplifier.

So, if I say convert this to in watt, I can convert, how much. If I want to produce a 60 dB sound, then how much energy is required? So, I reference, it is nothing but a 60 dB is equal to 10 log I divided by I ref is 10 to the power minus 12 watt per meter square. So, from there, I can calculate I how much watt is I require to produce that sound. Similarly, if I say I have an amplifier, I have an amplifier with the gain of let us 10 dB is the gain of my amplifier, I want to restrict the amplifier to produce only 60 dB sound, what should be mixing maximum input voltage to the amplifier. So, gain is 10 dB, so I have to produce 60 dB, so input is 6 dB only. So, 6 dB, I can convert to the reference; with respect to reference, I can convert to how much power is required.

So, similarly this sound pressure level I can also said if it is dB is if it is in air, I value of I is given 3 watt. What is SPL, SPL means sound pressure level. If in air, rho and c will be given then I know I and then I can calculate P, because I is equal to P square by 2 rho c, so I can calculate P. So, that way we can calculate do the things, many things we can do. not going details to the frequency perception by the human being because that is not included in here that yes, you have to know it, you can read it from other source, because frequency response is also so why that will be the why I do not required a flat frequency response of an loudspeaker. Because human perception of the frequency is not flat, we do not perceive the frequency in linearly. If I produce a sound of 100 hertz pure tone and then I produce a sound of 100 just 1 hertz a human being cannot distinguish between these two sounds. A human being will say that the sounds are same, but physically they are different.

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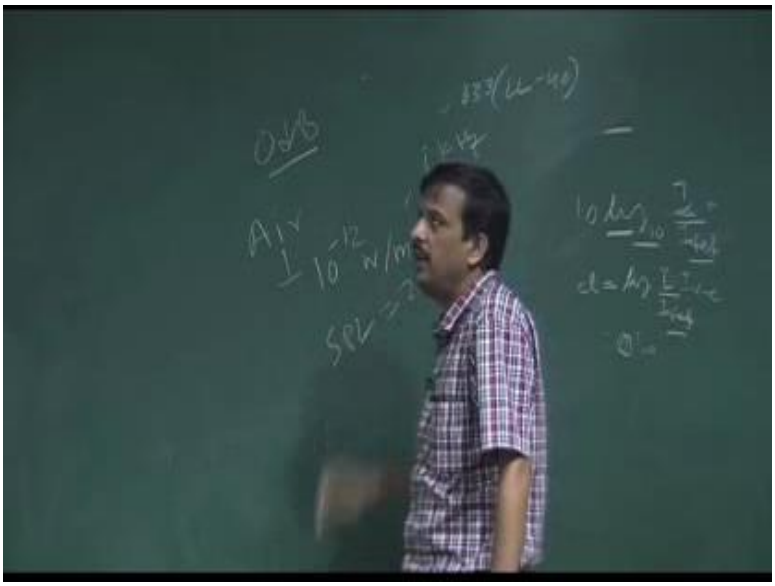

So, the human perception of the frequency is also important that is that scale is called male or box scale, you can say box scale is the that is there, box scale male scale is there. So, if you wanted then I can if you raise some questions on this area here, I can take another class on frequency range frequency perception of the human being. But you should know that what is dB and how it is converted, so those kind of things I will deal with some tutorial, I will give some assignments, so where you can find out. So, then somebody asking what do you mean by 0 dB sound, 0 dB sound means intensity of the sound is 10 to the power minus 12 watt per meter square. And SPL is if in case of air, 0 dB in air 10 to the power minus 12 watt per meter square for 1 kilo hertz pure tone.

Similarly, in that case, the pressure the SPL is nothing but a twenty micro Pascal twenty micro Pascal for 1 kilo tones, but if it 20 hertz tone, (Refer Time: 29:54) may be shifted to somewhere else. So, for the low frequency, we perceive our efficiency of the ear is very less and also high frequency efficiency is less so that is why our ear if you see that this is hears curve hearing. So, if you see the low frequency threshold of hearing is high; high frequency also threshold of hearing is increases. At the mid range frequency, threshold of hearing is very, very good so that means, we can perceive, we can differentiate between the 1 kilo hertz slightly higher frequency, we are very perceptive means we are very sensitive of the intensity of those frequencies. So, at high frequency, very large amplitude has to be produce to hear it. Low frequency very large amplitude has to be produce to hear it.

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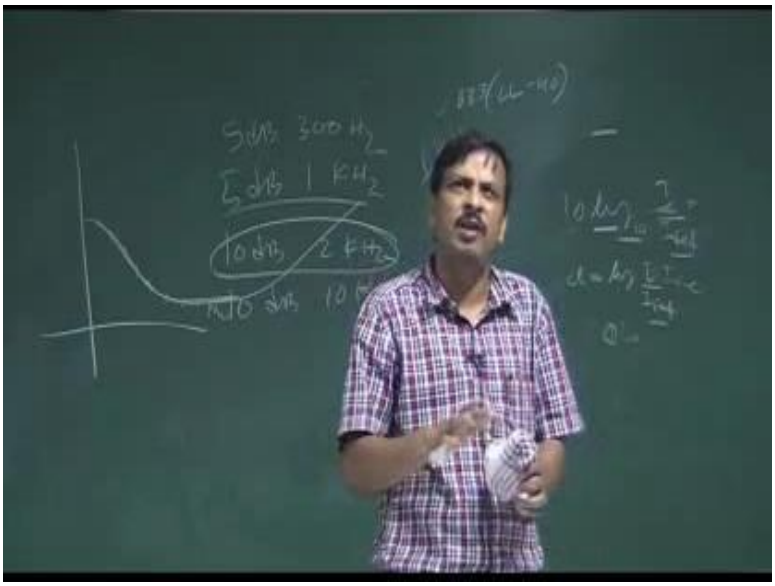

So, somebody may ask you suppose I produce a pure tone, 5 dB pure tones of 300 hertz and 5 dB pure tones of 1 kilo hertz, which will be louder, 1 kilo hertz. Similarly, somebody tell 10 dB pure tone on 2 kilo hertz 10 dB pure tone on 10 kilo hertz, which one will be louder, 2 kilo hertz will be louder. And the curve, frequency response curve of the ear, the equal loudness curve if I go through this direction equal loudness, loudness will be equal that is called phone curve. This is called equal loudness curve. And this high frequency also it will be increases; it depends on the human perception. I am not going many, many details of that reasons. So, then will do some tutorial and it will be completed.

Thank you.