Digital Speech Processing
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Lecture - 17
Speech Perception - Part II

Now last class we were discussing about the Basilar Membrane.

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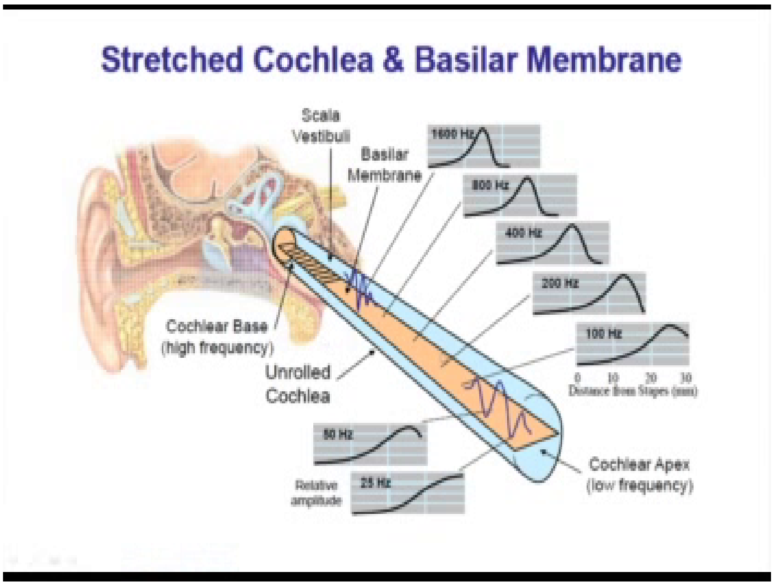

So, if you see this picture this is the basilar membrane which is inside the cochlea. So, the cochlea is full of liquid and basilar membrane is floated there. So, you can see the basilar membrane divided into the cochlear in 2 part, one is called a upper and lower part now this is the beginning part and this is the end part of the basilar membrane. So, this is the apex and this is the base. Along the cochlear membrane there is a some you can say the there is some kind of normal arrangement that is called if you see it is a there is a we call inner hair cell.

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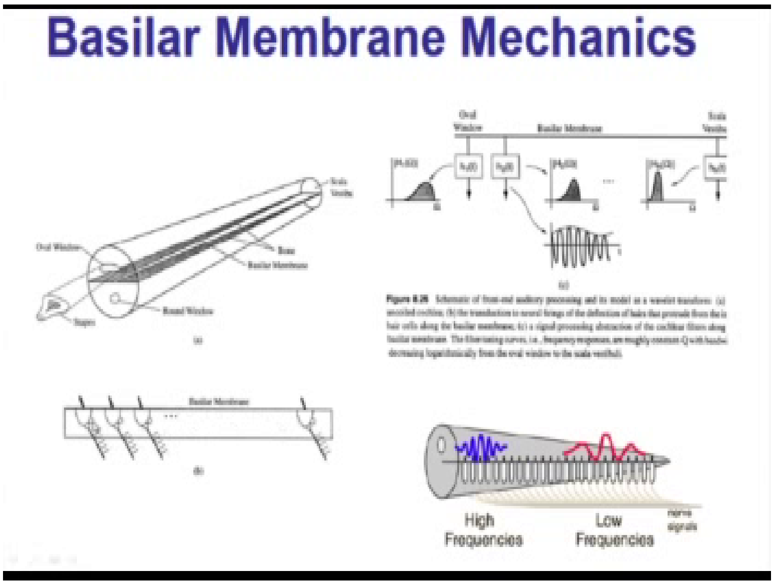

So, there is a inner hair cell, basilar membrane there is a this kind of you can say the narwhal sensor, let us think about narwhal sensor there is a sensor kind of things in there. So, if I see if I all along the basilar membrane and it is response on the high frequency sensing are present in here and low frequency are here. Why because if you see in speech production side due to the radiation load.

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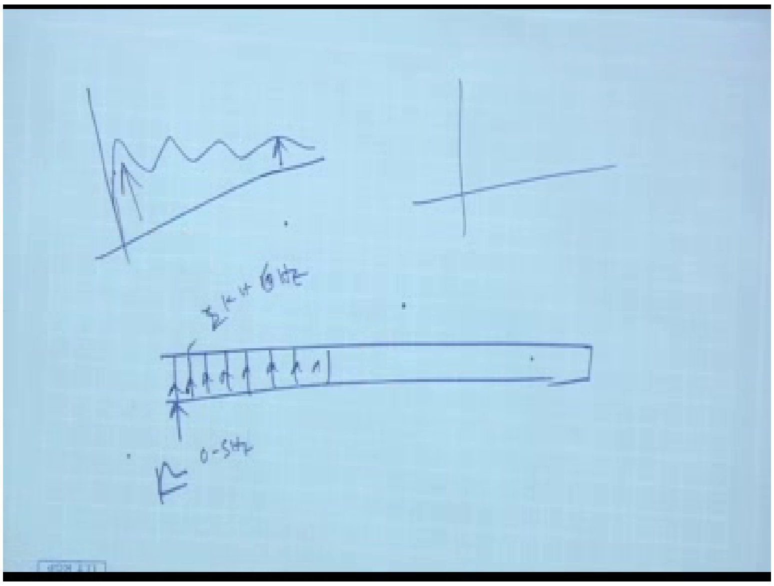

The low frequency signals are high amplitude frequency or high amplitude compared to the high frequency. So, the acoustic wave which is preach away which is coming that has a high frequency or less amplitude compared to the low frequency sound. So, the mechanical motion or high frequency mechanical motions are amplitude are less.

So, that is why this this high frequency sensor are in the beginning and in the apex are the low frequency sensor. Now it is this kind of sensor acts as an responsible for a particular frequency range. So, I can say let us this is the basilar membrane let us this divided with a this is the sensors, all each of the sensor is responsible for particular frequency band. So, let us this perceive 0 to 5 hertz, let us this perceive 5 hertz to this 10 kilohertz or you can say 2 hertz to 10 6 hertz. So, there is a overlapping frequency band is perceived by each and every sensor.

So, I can see the basilar membrane is nothing but a output of a different filter bank, if I think in engineering model I can think the human conversion of acoustical signal or you can mechanical signal to the narwhal signal is nothing but a sensor are nothing but a tank circuits or which is a particular filter or tank circuits or you can the sensor is active for a particular band then it is called tank circuit.

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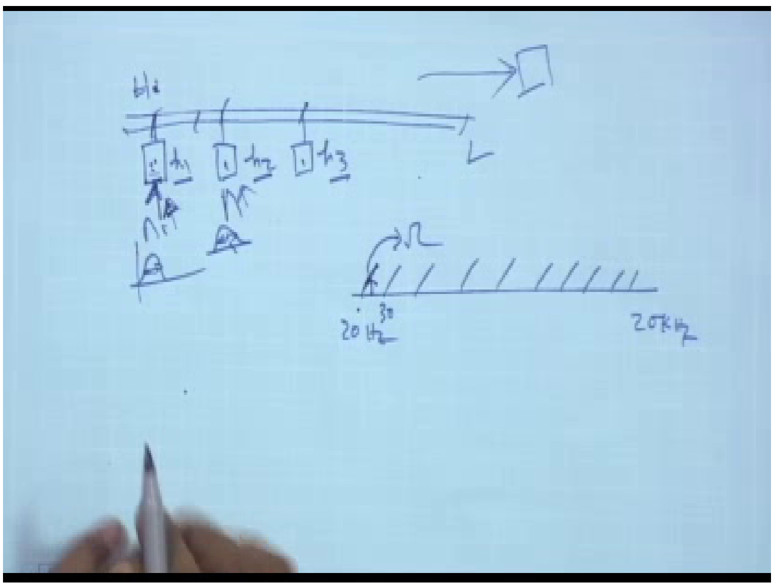

So, it is a tank circuit this is h 1 sensor, there will be a h 2 sensor there will be a h 3 sensor. So, h 1 h 2 h 3 is nothing but a band pass filter I can consider. So, I can say it is nothing but a filter bank analysis by the human basilar membrane whatever the input signal come, it passed through a particular band of filter and ultimately response of the each band is the neuron signal and that goes to the central vein system. So, that it can process for human cognition ok.

So, how it is convert mechanism is called inner hair cell, there a lot is a like the inner hair cell each in each of that sensor, there is a 10 to I think 10 nerve fiber each of the different diameter one inner hair cell consists of 10 fiber auditory not fiber. So, that converts that thing. So, now, come to that we know that how human being perceived the sound, how human basilar membrane convert that mechanical motion to normal motion now think about an engineering model we said. So, basilar membrane responds maximally to different input frequency, frequency tuning occur at basilar membrane. So, I can say that each of the 10 circuit is responsible for a particular frequency band which is a constant q filter. So, I can say let us this is particular frequency band, this is also responsible for particular frequency band then I want to know if this band are linear or is this band are non-linear.

So, bandwidth of the each of the particular filter is it linear overlapping or non-linear overlapping how do you define that, how do you I do know that things whether it is a non-linear and linear. So, we can do some experiment and later will come. So, these bands are called you can say that bark scale. So, I will come later on what is bark scale. So, physiologically I can say human perception or human the frequency which is heard by the human being or sound which is now sense by a human being is down on the base basilar membrane well it is as a different frequency tank circuit and bandwidth of non-linear then we will come later on that what is how do you define this non-linear scale.

Then how do you perceive the frequency? We said each on one is the particular band if it is band then how do you perceive the frequency because this is nothing but if it is this is a particular where this is a knob fiber if I say this is the high frequency and this is for low frequency then or this suppose I said I have a frequency respond 20 hertz to 20 kilohertz, there is a 100 tank circuit.

I know the bandwidth of each tank circuit, now suppose I want to perceive some. So, is it is 20 hertz, it is 30 hertz like that way or non-linear way and whether this fiber how this fiber is responsible particular frequency that I want to know. So, this there is a 2 theory one is called temporal frequency which is called temporal theory and another is called place theory.

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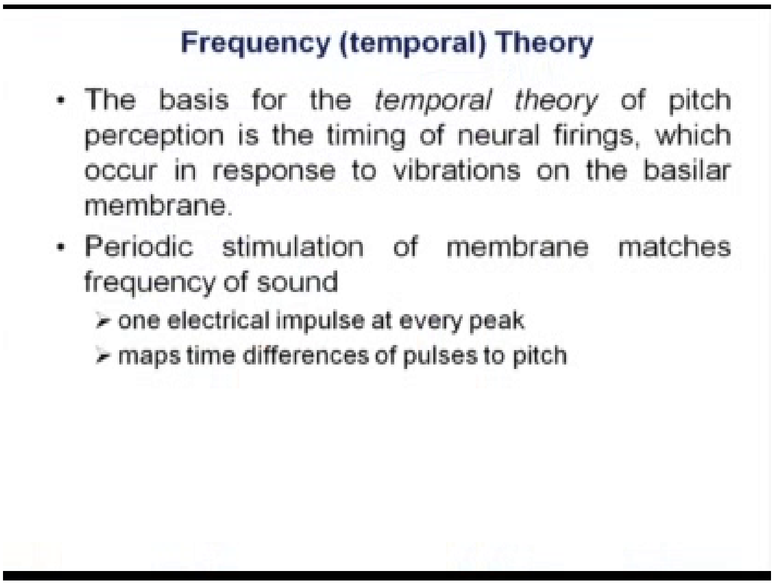

So, be first theory say that the basic of the temporal theory of the pitch perception is timing of neural firing, which occur in response to vibration of the basilar membrane. Timing of the neural firing is perceived as a frequency. So, periodic stimulation of membrane match frequency of sound.

Once electrical impulse at every week every peak next one is called place theory.

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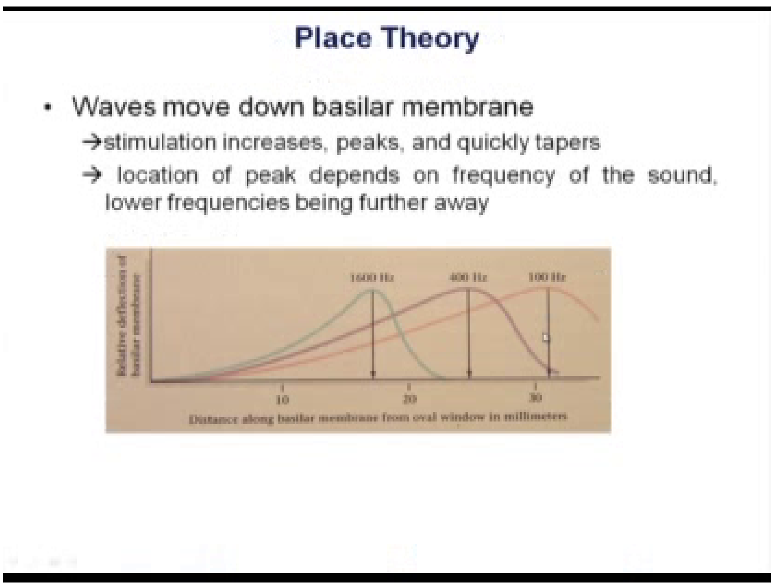

Where move down basilar membrane, stimulation increase increases a peak and peak quickly taper location of the peak if you see if the simulation I have stimulated the cochlear and that increase the peak motion is. So, I can say let us this is my basilar membrane this is a. So, if I wave this mechanical wave is stimulated, then this will be loop like this why we moving like this along the basilar membrane in a wave.

So, stimulus increases the peak and quickly taper if I say this portion is increased and taper increases and taper. So, increase and taper and increase it this kind of motion will be happen. So, location of the peak depends on frequency of sound lower frequency mean farther away. So, if the peak is occur in here, location of the peak if occur in here then it come it perceive the frequency. So, there is a one is called timing, another is called location of the pin. So, that is why because local place theory another is called frequency or temporal theory frequency theory ok.

Now, human being perceive the sound. So, I have I can say that human perception of an input sound has 2 part, one is the perception of the frequency another is the perception of the amplitude. So, if I produce a you can say the let us 500 hertz acoustic signal it has an frequency it has an amplitude. So, human being perceived frequency and also perceives as well as perceived the amplitude of the particular frequency. So, 2 perception things is here. Now I have to know how accurate we are in perception of amplitude and frequency what do you mean by accuracy? You can say think about the resolution ok.

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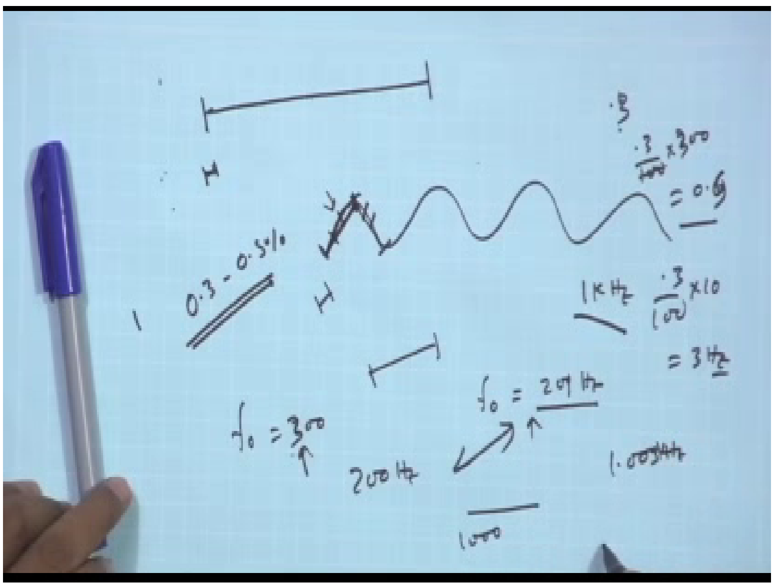

So, suppose I have a straight line and I want to measure the straight line in a some small scale or I say there is a line which is like this, if I want to measure in a scale small scale. So, I put the scale along this line, now if I scale this larger then I put the scale here and again I put the scale here. Now if you see if I approximate it long section then I may lose some area or my introduce some error so; that means, how accurately I can perceive the sound. So, either a human being perceive every hertz of the sound, if it is possible that the human being will perceive 1 hertz, 2 hertz, 3 hertz, 4 hertz, 5 hertz, 6 hertz, 7 hertz and that like that way or for a particular frequency in a band.

Similarly, if I increase the intensity are we able to linearly perceive the in the intensity increase or in which scale, whether I able to differentiate between the 2 dB and 2.5 dB or 2.11 2 dB or not. So, that is the resolving power of the human being I have to know; how good an estimation of the fundamental frequency.

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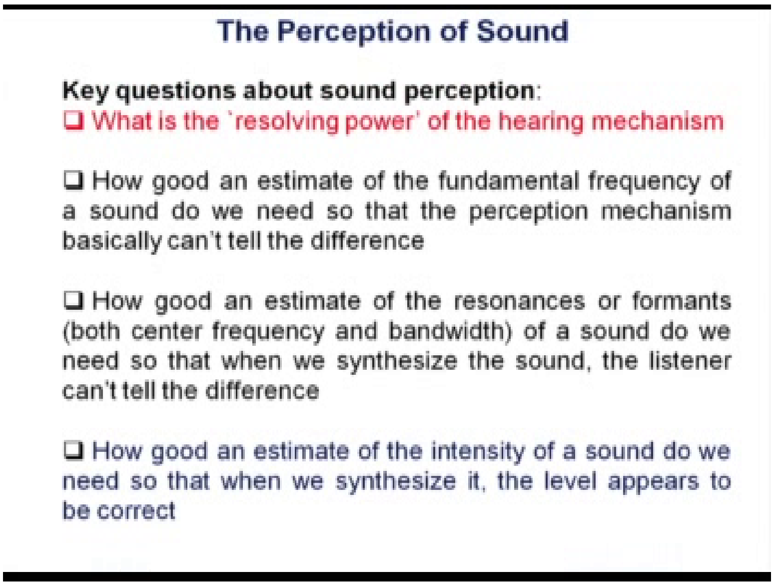

So, in the frequency domain and intensity domain there is some parameter. Fundamental frequency the resolving power is 0.32 0.5 percent. So, if I say my f 0 is 2 hundred hertz and somebody's f 0 is less 2 201 hertz whether can I am able to differentiate between these 200 hertz and 201 hertz it said it is 0.3 to 0.5 percent; that means, if the difference is lie between this range we cannot differentiate that 2 frequency. So, we cannot separate them.

So, let us point 3 let us point oh 0.3. So, 0.3 percent means 0.3 divided by 100 into 200 place; so it is 0.6. So, if it is let us if it is 4 the 300 hertz 0.9. So, I can say approximately 2201 hertz frequency and 200 hertz frequency I cannot differentiate. If it is 1 kilo hertz then 0 point 3 by 100 into 1 k it is nothing but the 3 hertz. So, if I say the perception of the frequency is different in different frequency range. So, this is not a linear scale it is a non-linear perception.

So, how do you perceive? If it is a high frequency the difference the perception will be more rough I can say the bandwidth will be perception bandwidth will be a larger. So, I can say that initially for the low frequency my resolving power is very high, but at high frequency delivering power is very low so; that means, at high frequency I cannot separate the 2 lists 1 kilo hertz and 1.100 1.03033 hertz then I cannot slue hertz I cannot separate.

But at low frequency almost one hertz difference I can understand. So, low frequency level human perception resolution power is much more, high frequency level we do not have that much of resolution power. So, in high frequency accuracy; so suppose a suppose I want to copy an instrument. So, I can say high frequency details informations are not that much of required because human being cannot perceive the high frequency in a high resolution.

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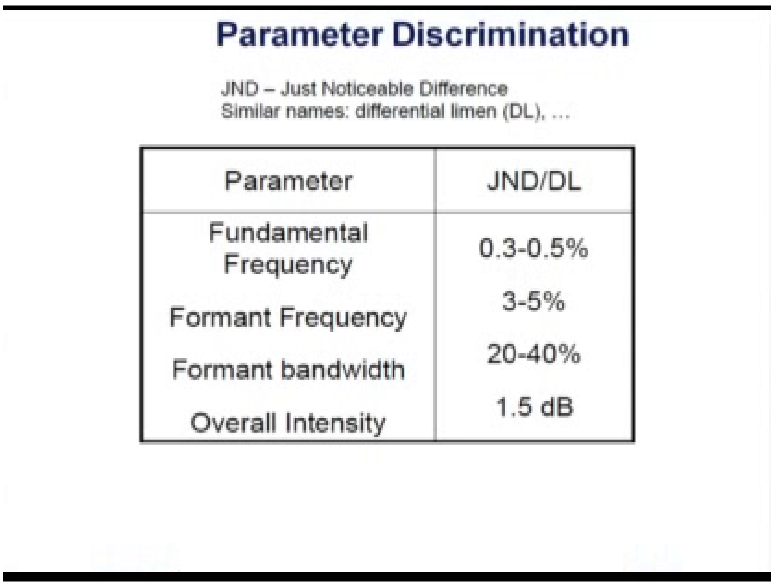

Parameter	JND/DL
Fundamental Frequency	0.3-0.5%
Formant Frequency	3-5%
Formant bandwidth	20-40%
Overall Intensity	1.5 dB

Fundamental then the formant frequency, you know the formant frequency is nothing with a formant position in the speech; so first formant around 500 hertz. So, if it is uniform to you 500 hertz. So, almost 500 around 500 around 500 as will be first formant.

So, I can say 3 to 5 percent. So, if it is 500 hertz.

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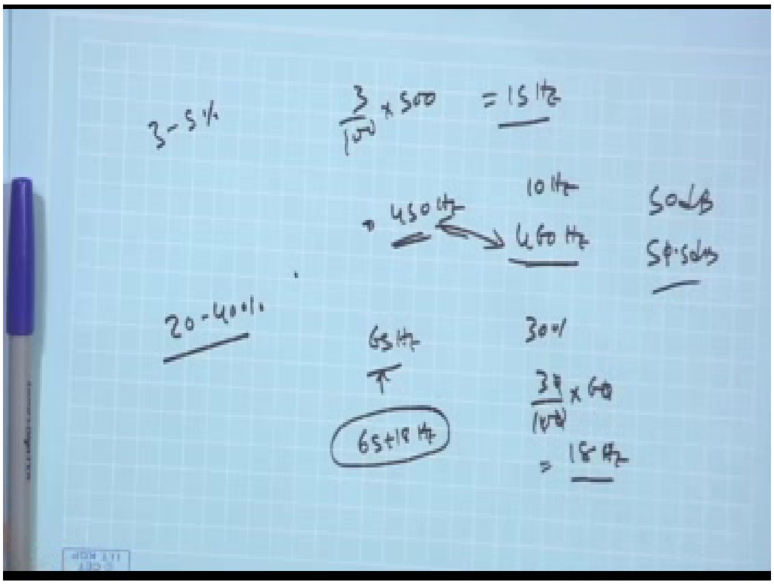

Then 3 divided by hundred into 5 hundred. So, almost 15 hertz error informant human being cannot differentiate. So, suppose I extract a formant frequency of a particular vowel let us 3 450 hertz if it is differ by of 10 hertz instead of 450m if it is 460 hertz then also human being cannot distinguish the difference because we do not have resolving power of this formant position, then formant bandwidth 20 to 40 percent error. So, suppose [FL] let us [FL] has a formant by a first formant bandwidth.

Let us 65 hertz even if instead of 65, we if it is 20 percent error. So, 20 to 40 percent variation we cannot distinguish. So, let us 30 percent variation we cannot distinguish. So, 30 divided by 100 into 65 18 hertz difference. So, instead of 65, even if it is 65 plus 18 hertz then also we cannot see any difference that is called just noticeable difference JND. So, due to the limitation of human perception, we cannot distinguish if the range is within this limit intensity 1.5 d b over all, if it is 50 dB and if it is let us fifty point 51.5 dB no difference for the same frequency if the 2 50 dB and 51.5 dB we cannot perceive the differences.

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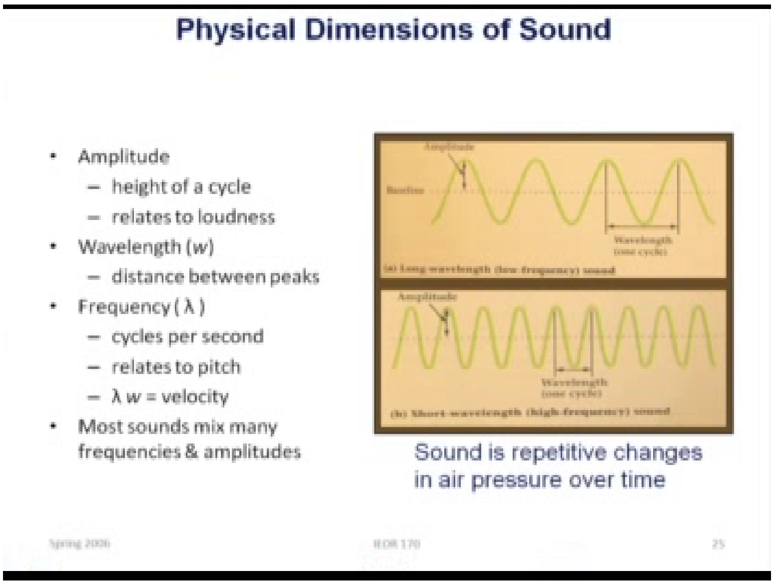

Now I come to the physical dimension of the sound and physiological or you can say the cycle over perceptual dimension of the sound.

So, that is obvious you know that that height of the amplitude frequency wavelength and their property, you know that now I auditory perception.

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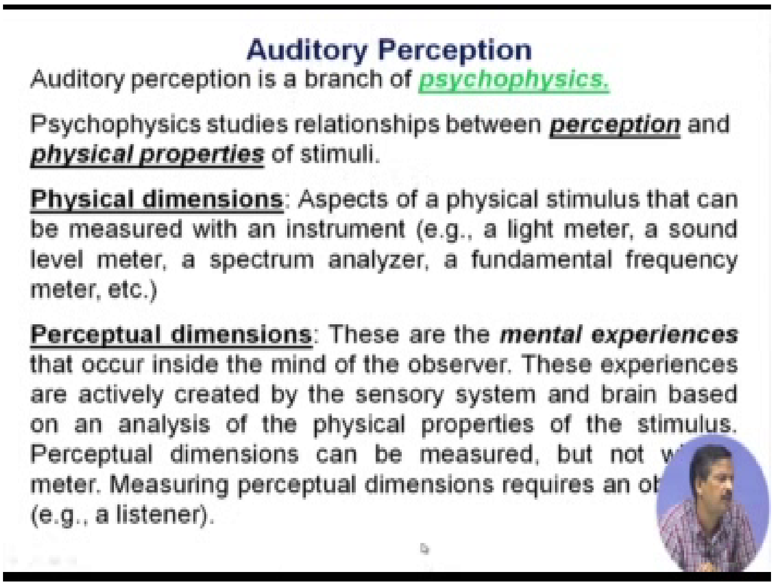

So, auditory perception is branch of psychophysics you know that, so perception and physiology physical property of stimuli. So, physical dimension as we have said is the measurable, but perceptual dimension is the mental exercise on you physiological output if I excited by a physical stimulus, what kind of output I observe based on that characteristics I can measure the perceptual dimension parameter.

Now, if it is sound wave.

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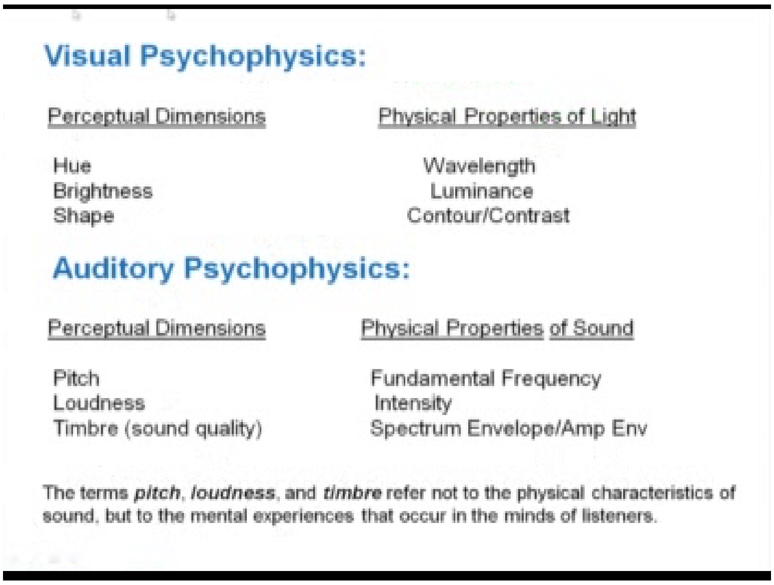

I have not detailed discuss about the human visual auditory system usual psychophysics auditory psychophysics pitch loudness timbre are called perceptual dimension of the speech or (Refer Time: 18:08) a sound wave or sound perception of the human being pitch loudness timbre physical properties fundamental frequency, intensity spectrum envelope or amplitude envelope you can say. So, what is this it is a pitch sometime you see that many the many of you may be practices music you say that somebody is from guru said that you said the harmonium at plat b scale; because your pitch will be around let us 200 hertz of flat b or 180 hertz plat b.

So, that is nothing but the average pitch we say average speech, but pitch in your perceptual parameter. So, 180hertz is nothing but a fundamental frequency average fundamental frequency of that single not the pitch plane. Sometimes we say the pitch example is that suppose I play a Tanpura and a harmonium and a say guitar let [FL] and with the same frequency harmonium [FL] has 200 hertz tanpura [FL].

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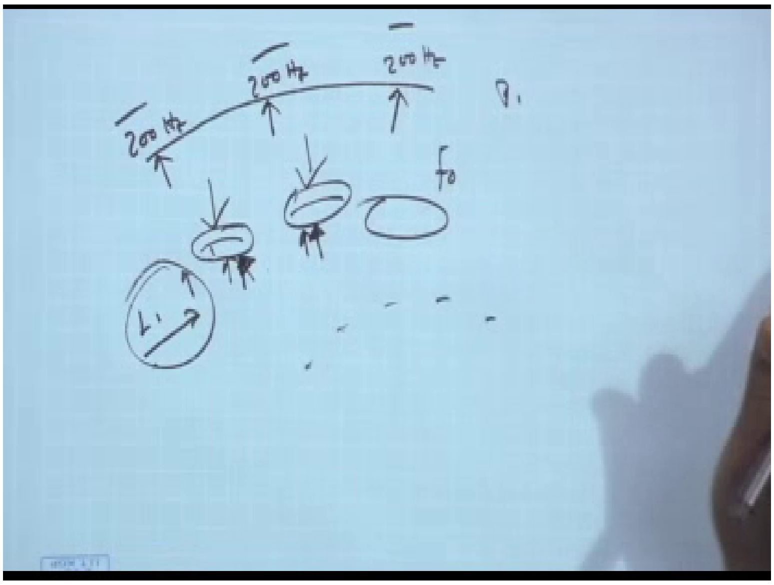

Also has a 200 hertz also let us the tanpura harmonium and guitar 200 hertz, all instrument or producing [FL] of the same frequency same frequencies [FL], but even if I closing my eyes I can identify this sound is coming from harmonium this is for tanpura this is for let us guitar.

So, how do we find? All if the all pitch are same if I say the fundamental frequency is the pitch. So, pitch is in perceptual parameter it may include something else, for which we can understand this is the source of the sound is different although they are produces in the same fundamental frequency. So, that is the pitch in perceptual domain. So, main parameter physical domain parameter of pitch is called fundamental frequency or f 0. Many places I refer to f 0 also f 0 fundamental frequency of that sound. Then loudness intensity physical parameter is intensity I can measure the intensity 5 dB 6 dB 7 dB, but loudness is in perceptual parameter I can say this is louder sound compared to previous sound this is louder sound compared to previous sound.

So, loudness is an perceptual parameter intensity is an physical parameter timbre or sound quality if you see I can give an example. Some musical grammar some lyrics is generated from a 2 female speaker, let us not ominous curve use the same lyrics same musical note position and his same. So, he song the (Refer Time: 21:38) discussing a song record a song. Same lyrics same musical grammar is followed by some other things singer also, let us he does not make any mistake and also produce the same song, but we can able to distinguish this song I i say if we perceive it we say this song is better than this why? Because if I control this thing then I can say the movement of the speech of the singing grammar is same he also followed the same note same position same duration also then why this speaker this is better than this because of the timber complexity of the speech, if this complexity I may like much more compared to this speech complexity.

So, the production mechanism that complexity whether or you can say physical dimension is called spectral structures we say it is spectral structures. So, our timber or complexity of the speech is an perceptual dimension. I can say this complexity, but if I say how do you measure it one of the procedure is spectral envelope spectral composition of this segment and this segment will be different. So, pitch loudness timbre perceptual dimension, fundamental frequency intensity and spectrum envelope is the properties of physical dimension of the sound ok.

Similarly, you can see that there is a huge hue brightness and sharpness not shape sharpness and then a wavelength luminance contrast all kind of things are there in perceptual dimension also how human being is perceived a picture that is called visual perception of the human being. So, we have again limitation in human perceptions perception of visual dimension also. So, speech dimension I have a limitation. So, I have to find out that limitation and you can say the visual dimension there is a limitation. So, there is experiment to find out those limitations now I am not describing this thing again now human range of hearing.

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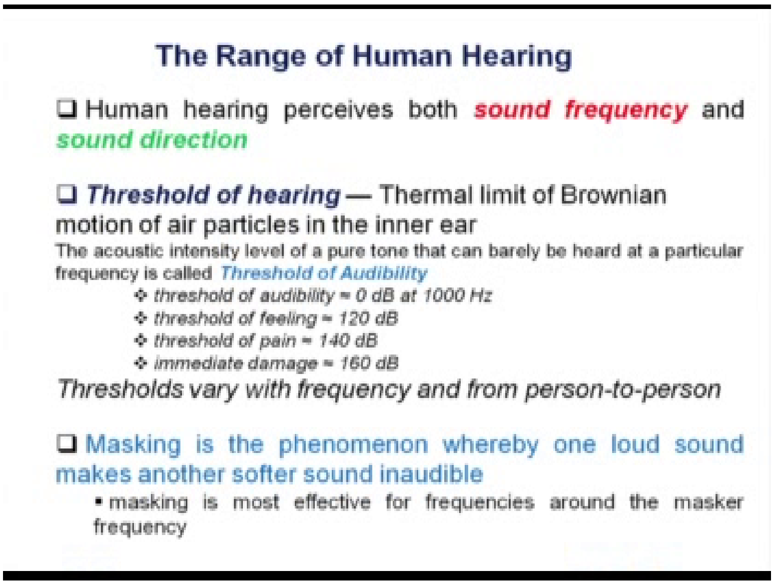

Sound frequency and sound direction both sound frequency and sound direction threshold of hearing. So, there is a human threshold of hearing.

So, threshold of hearing; that means, the minimum pressure acoustical pressure which can create a sensation in our nervous system is called threshold of hearing. So, suppose I produce a 1 kilohertz

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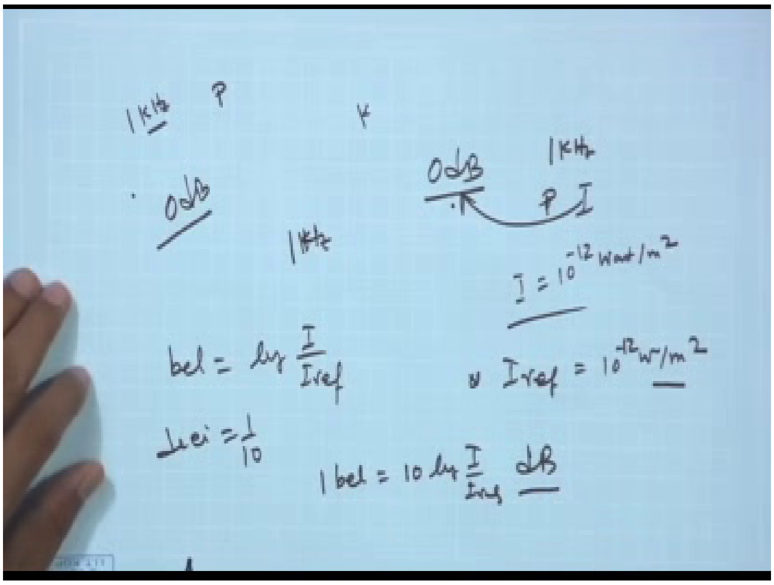

Acoustical signal of pressure P we just create the human sensation in the years, then of normal hearing person the person must be normal hearing person not defect. So, that I mean defect I do not discuss in here. So, for a normal hearing person the required amount of pressure to create just sensation in the human ear is called Threshold of hearing. Now if I if you remember I said the perception or equal to the intensity perception of the human being, but different frequency is different because of the outer ear and middle ear frequency responsible if I draw that.

So, I can say the sensation created the amount of pressure required to create a sensation for 1 kilohertz and create a sensation for 300 hertz signal, may be will be different. So, 300 hertz signal require more power to create the sensation, but 1 kilohertz signal required less power to create the senses. So, if I able to define the threshold of hearing then for a particular you are defining the threshold of hearing for measuring the intensity, I can say let us define the frequency for which I can say threshold of hearing we said it is 0 dB. So, 0 dB is called threshold of hearing decibel for that particular sound play sound intensity which require to create the sensation for 1 kilohertz signal.

So, I can say 1 kilohertz acoustical signal or 1 kilohertz monotone the amount of intensity required to create the sensation in human ear is called 0db. So, one I say 0 dB it is not defined for all frequency 0dB means I take a 1 kilohertz acoustical signal or monotone signal and I want to find out the intensity I we just create a sensation in the human being that I call 0 dB. So, that I is called 10 to the power minus 12 watt I think 10to the power minus 12 watt per meter square. So, this is threshold of hearing. So, that is defined by 0 dB. So, what is dB; what is dB sometimes we said it is dB; dB is called decibel. So, one bel is equal to log of I by I reference where I reference is related to the 10 to the power minus 12 watt per meter square which is defined as a 0 dB decibel.

So, deci means 1 by 10. So, decibel means one bel is equal to 10 log I by I reference decibel dB deci bel. So, if the intensity of the sound is i.

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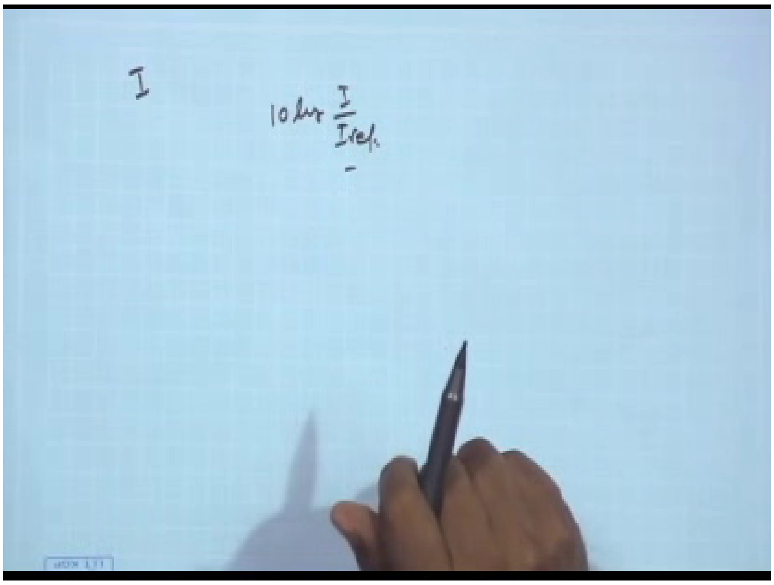

Then I can say convert in dB is nothing but a 10 log I by I reference where I reference is equal to 10 to the power minus 12 watt per meter square.

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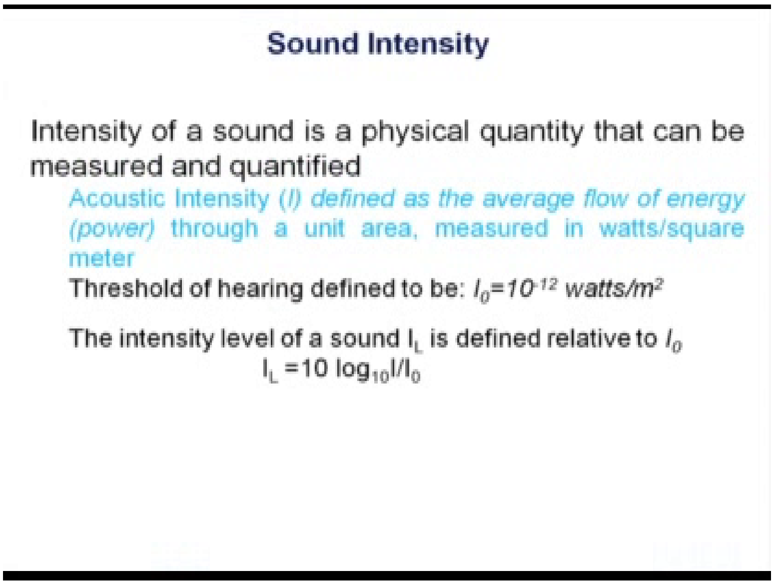

So, sound intensity of a sound is a physical quantity that can be measured and quantified acoustic intensity, I define as the average flow of energy through an immunity air inlet; area you can say the power per unit area or force per unit area is nothing but the intensity power per unit area is nothing but the intensity. So, watt per square meter I by I 0 is 10 to the power minus 12 watt ok.

Now, decibel similarly if it is instead of I, I is equal to p square by 2 rho c or if it is rms wall kind of conversion I can say similarly instead of I, if it is measure in pressure then I can say 20 log p by p reference, where p reference for if you see p reference for air is 20 micro Pascal for water is 1 micro Pascal.

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Reference Level Conventions

$$I_{ref} = \frac{p_{ref}^2}{\rho_o c}$$

Location	Reference Intensity	Reference Pressure
Air	1×10^{-12} W/m^2	20 μPa
Water	6.67×10^{-19} W/m^2	1 uPa

So the p reference intensity in air is minus. So, this is also depends on the conducts the intensity the I said the threshold of hearing is the amount of sound pressure required to create a sensation in human hear for a 1 kilohertz acoustic wave ok.

So, I can change if it is water then the amount pressure medium is water. So, it required less amount of intensity. So, this I am not going details this is a acoustical apart then conversion of dB to percentage kind of things there is some mathematics also you can say then loudness curve.

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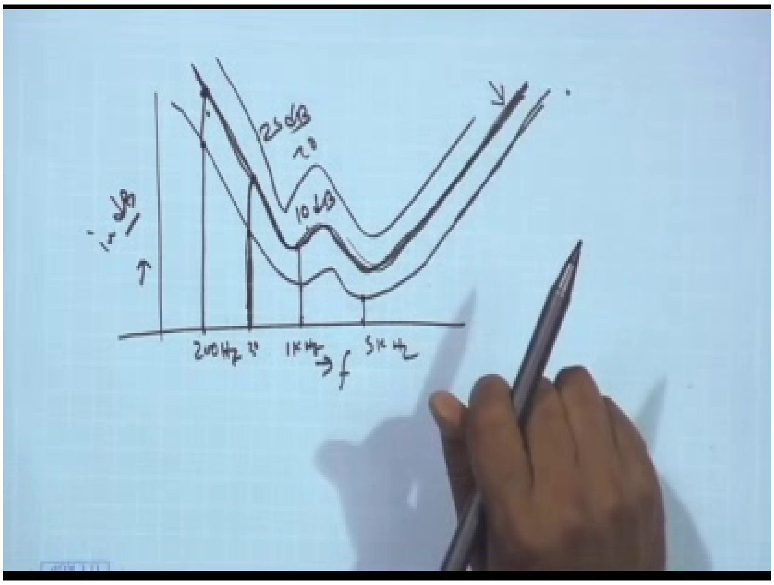

Now if you remember the combined frequency response of the outer air and middle layer, I can say this is look like this. So, this way is the frequency this way is the loudness in dB, reference is t10to the power minus 12watt. now if you see the for this frequency and for this frequency let us this is for 1 kilo hertz, this is 5 kilo hertz, If this is 200 hertz let us.

Now, intense intensity required to create a sensation for a 200 hertz signal, when we require high amplitude. Intensity created for 300 hertz signal let us require high amplitude for 1 kilo hertz this amplitude, 5 kilowatts this amplitude. So, this is called threshold of hearing curve for different frequency. So, this is the minimum intensity required to create a sensation human hear since the frequency response for different frequency. The intensity frequency response of the intensity for different frequency the intensity of the sound perception is different, that is why I said for 200 hertz I require larger intensity sound to create the threshold of hearing compared to 1 kilohertz.

Similarly, I can let us this is a 10 dB curve. So, let us 10 dB at 1 kilo hertz to perceive the same loudness for 200 hertz signal, I require larger intensity. To perceive the 3 hundred hertz signal I require larger intensity, but along this line the loudness which I perceive will be the same. Even from 1 kilohertz 10 dB maybe 300 hertz maybe 20 dB I required intensity, but if I perceive that sound loudness of the sound will be the same. So, I can say if I go along this line the loudness will be same that is why it is called equal loudness curve or sone curve equal loudness curve or sone curve. So, along the line loudness will be equal let us see it is 20 dB curve ok.

So, perception of sound this is the perception of sound, intensity is different intensity for 1 kilo hertz it is 10 dB, maybe here intensity is 25 dB, but perception of the sound is same that is why it is called this line is called equal loudness curve. So, loudness is a perceptual quantity that is related to the physical property level or pressure level of sound or intensity, but it is not direct intensity. So, this curve is called sone curve or equal loudness curve.

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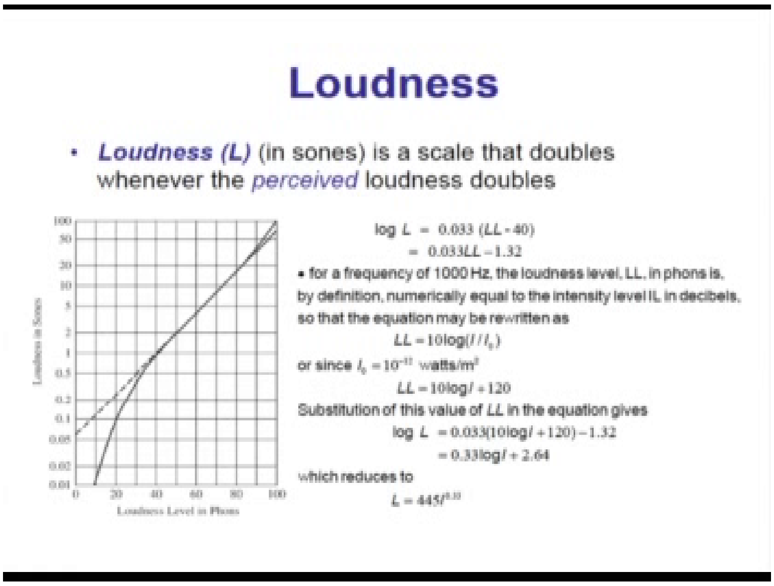

Now how do you then measure loudness in sone sometime it is called also sone, now I want to find out the relations between the intensity and loudness.

How do you do it? So, I can say I design a perceptual experiment, what I take a normal hearing capability sound and this axis I put normal human capability of here normal hearing capability human being I take, I produce loudness in sone.

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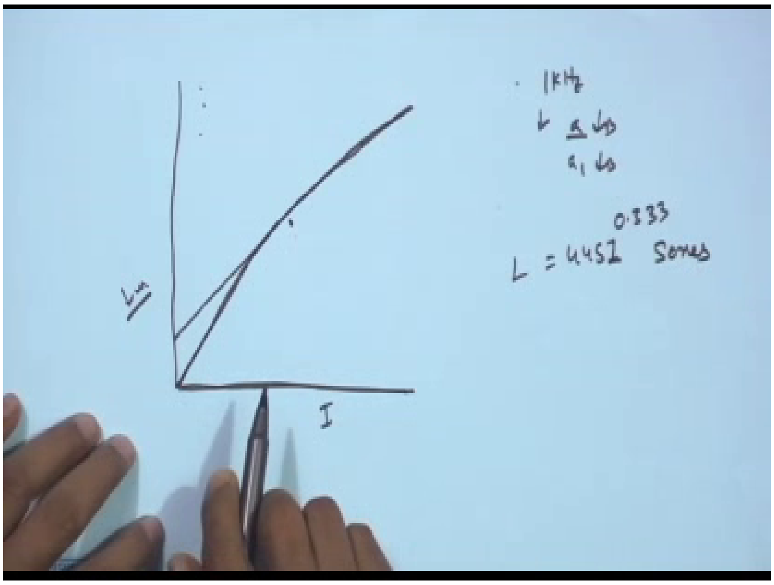

So, I take let us 1 kilohertz acoustical signal I take or equal loudness curve if I then composition overtake. So, let us 1 kilohertz signal.

Then I produce take the let us intensity a dB and I produce the sound listeners perceive it, then again I produce the tech a 1 dB listeners perceive it. I call the listeners when you perceive the sound is twice then this a dB you raise your hand. So, I first produce let us a dB sound to the listeners I told him and next a 1 dB and gradually I increasing the dB and told the listener when you perceive the loudness is double then you raise your hand .then I will can say that here a perceived the loudness is double here a perceived loudness is double here a perceived on this is double then I can draw that curve then I derived the equation of the curve and find out the loudness scale and relation be to the intent this is intensity and this is the loudness.

So, loudness and intensity relation this is the derivation of the loudness and intensity relation I am not deriving it again. So, l is equal to 4 4 5 I to the power 0.333. So, that can say if I know the intensity equal loudness in sone. So, this will be sone, sones that much of sones. So, l is equal to 445I to the power 0.33. So, if it is 5 dB I if I know the intensity then I can calculate loudness. So, this is a loudness sones curve.

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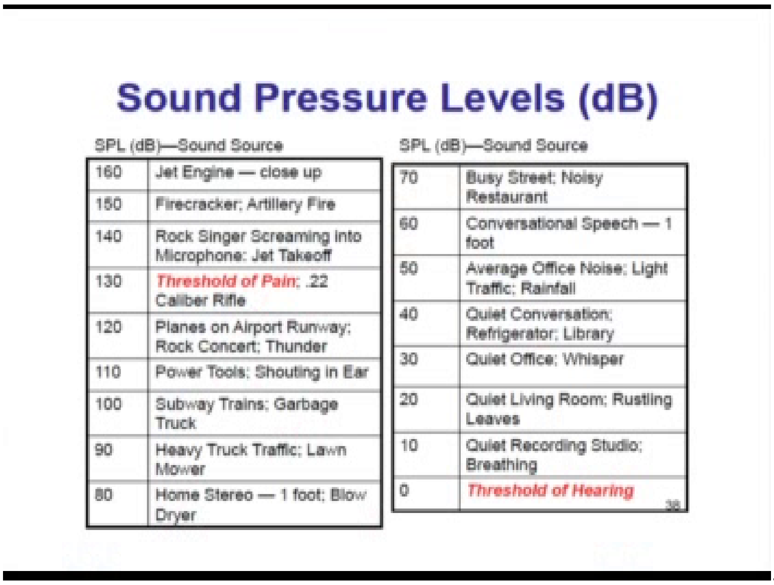
Sound Pressure Levels (dB)

SPL (dB)	Sound Source
160	Jet Engine — close up
150	Firecracker; Artillery Fire
140	Rock Singer Screaming into Microphone; Jet Takeoff
130	*Threshold of Pain*; .22 Caliber Rifle
120	Planes on Airport Runway; Rock Concert; Thunder
110	Power Tools; Shouting in Ear
100	Subway Trains; Garbage Truck
90	Heavy Truck Traffic; Lawn Mower
80	Home Stereo — 1 foot; Blow Dryer

SPL (dB)	Sound Source
70	Busy Street; Noisy Restaurant
60	Conversational Speech — 1 foot
50	Average Office Noise; Light Traffic; Rainfall
40	Quiet Conversation; Refrigerator; Library
30	Quiet Office; Whisper
20	Quiet Living Room; Rustling Leaves
10	Quiet Recording Studio; Breathing
0	*Threshold of Hearing*

Then there is a example this is called sound pressure level for different if it is 160 jet engine close up threshold of pain 130. So, you see this we should not expose to the large amount of sound large or I can say high amplitude of sound, if it is high amplitude it can create pain in our ear ok.

So, threshold of pain is 20 to 130 dB, if I expose to a sound intensity of 130 dB it can create a pain in the ears and also if I expose more than that then my ear permanently can be damaged also. So, then if you see the pollution control board has said that do not produce do not produce the sound which is more than 60 dB. It is more than 60 dB it may cause hearing problem or it not it is not good to expose in a always above 60 dB sound.

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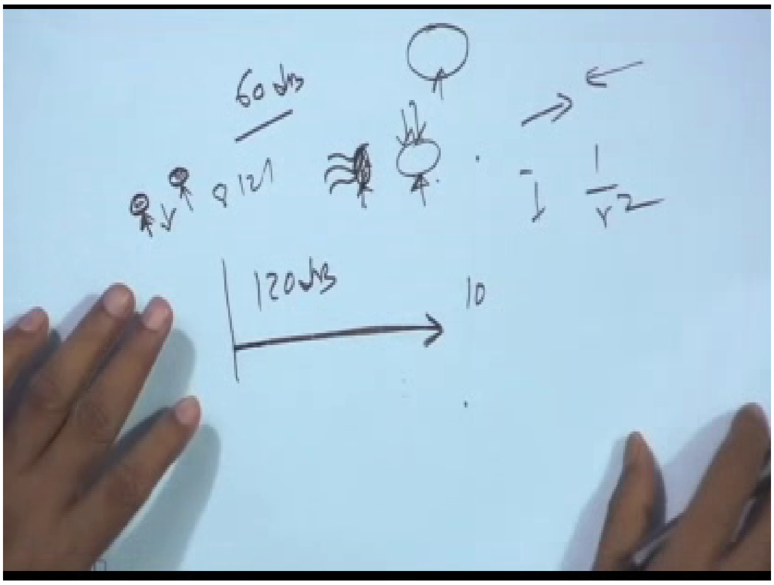

Involvement then you may have some problem in you listening.

Today we if see a lot of people are wearing a headphone many time let that in 24 hour, 8 hours or 12hour day providing the wearing the headphone what is the problem what can effect. So, once is that was you wearing a headphone it lose the sound localization is lost; that means, you wearing a headphone and walking in a road you cannot assume that is why the car is coming on your front or in your back forget about that you just close your eyes you cannot listen that horn also and also car noise also car sound also. So, if you wearing a headphone sound localization happens inside your ear. Now if you expose your ear with a continuous stimulus. So, this is a 24 hour you are listening a music.

So, you are exposed your human hear is exposed to a continuous vibration that can damage the elasticity problem of your middle ear. So, the elasticity of your middle ear may be lost then what will happen that may be response curve will change. So, you may be your distinguishing sound listening capability. So, low intensity sound you may not able to listen or you can you cannot heard the low intensity sound. So, your threshold of hearing will be increased continuous exposure to the sound. So, that is why if you see the person who are working in a factory environment, his threshold of hearing is increased. So, he cannot have the intent low intensity sound you cannot hurt. So, your sensitivity of your ear is decreasing that is the problem.

So, do not expose you or do not you expose your ear continuously in a sound environment, do not expose your ear to a very high intensity loudness or a high loud sound because that can permanently damage your hear. So, do not expose things. So, there is a sound propagation you know that even if your source is produced 120 dB, you may say I am if it is a 10 feet away then you know the 1by r square. So, I is reduced in one by r square form. So, if you distance is double (Refer Time: 41:29) the every doubling the distance 6 dB down.

So, if it is a source away from the source 10 feet, it will reduce the sound intensity, but do not always expose in a large sound so that your ear sensitivity is lost. So, the threshold of hearing threshold of pain all of there, if you see this curve sound intensity level and that this is the black line in threshold of hearing this is the music and this is the speech region loudness of the speech region, contour of damage reeks and threshold of pain is here.

So, next class we will discuss about the frequency perception, ok.

Thank you.