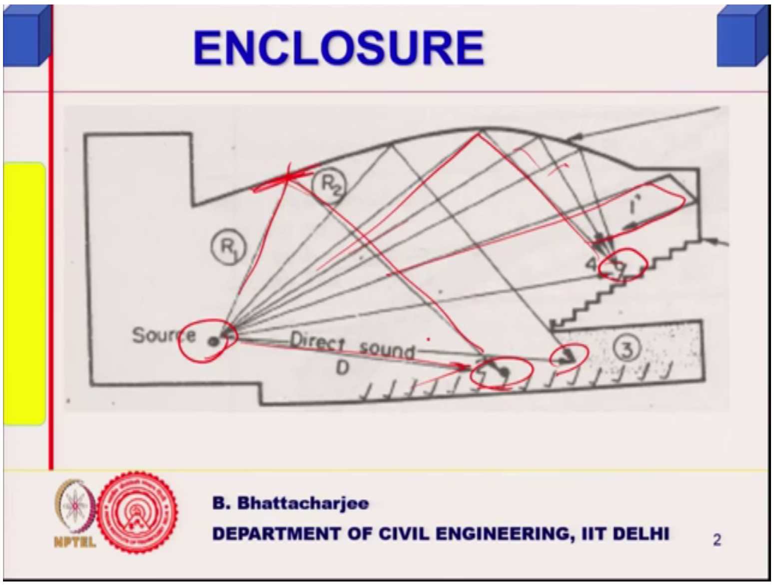
Energy Efficiency, Acoustics & Daylighting in building
Prof. B. Bhattacharjee
Department of Civil Engineering
Indian Institute of Technology, Delhi

Lecture – 36
Sound within Enclosure

(Refer Slide Time: 00:23)

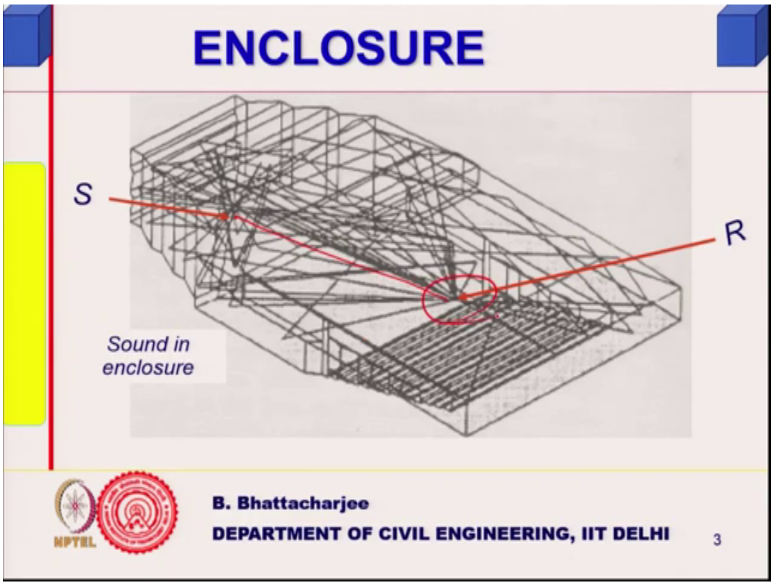


Sound within enclosure. So, sound within enclosure is slightly different than what we have looked in open. See, if you see this is an auditorium, now this is the source, this is the source, this is a source. And let say this is my receiver this there can be another receiver another receiver etcetera I mean just to explain what is the sound within enclosure we have taken this.

So, what will happen is direct sound comes there, but there can be reflection, there can be reflection. And if you see this source, how many reflection, this reflection, this reflection, this reflection and there can be some reflection like this multiple reflection reaching to the receiver.

So, we got to take account of the reflected sound also. And there are infinite number of reflections actually there are infinite number of reflections in within an enclosure right within an enclosure. Now, here the absorption is important just as we are talking about, because whatever is not reflected we consider is absorbed by the enclosure itself whatever is not you know. So, if have a have a opening here, let us say if it is opening here, reflection would have been 0, it would have that ray would have gone out, so that is sound within an enclosure. So, we got to look it into this manner right.

(Refer Slide Time: 01:59)



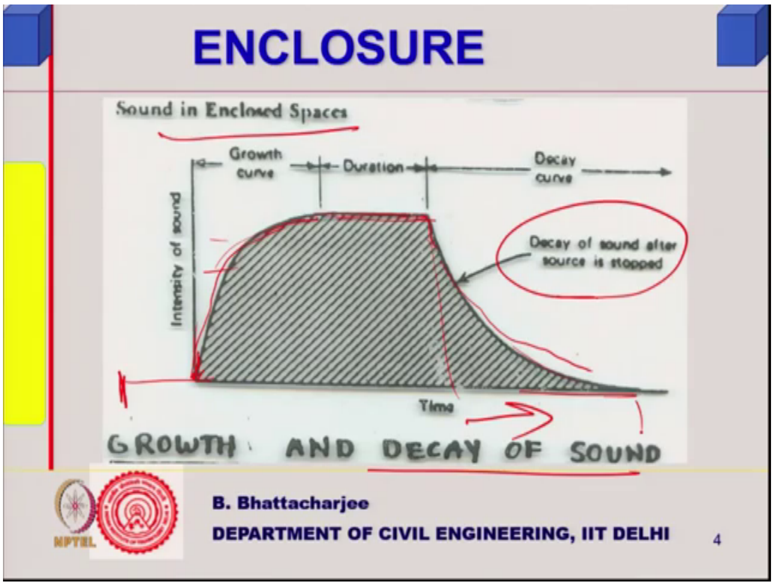
So, it is in fact, this is what the source you know. So, you have a source, let us say source, the receiver and what is happening there is only one direct sound, one way of direct sound. And there are infinite rays of reflected sound which can be one reflection after first only one reflection, where after n refraction right. So, actually if you see sound travels different path direct sound travels least path. While reflected sound travels longer paths, so they will not reach at the same time. Reflected sound will reach somewhat later then the direct sound right in time frame.

So, in enclosure, this aspects has to be taken into account, because sound will be reflected, and they will contribute to the I mean either good sound or noise level. If you do not like it then it is noise, but the diagram that I am showing so far they are all auditorium or similar sort of situation, you would like that to reach actually. You know more sound to reach at the rear of the auditorium, and the back side of a classroom I would like that maximum sound reaches there.

So, sound actually since it is now is a function of time. The intensity that I will reach it would be found to the at the receiver end, intensity of the receiver end will be a function of time. It is you know if it is not it is not I mean it is related to the time which time it will go on changing the moment I from the time I have put on the source. It is a constant source let us say having say not a human voice, but a source generated at kind of a source I generate through a bit frequency oscillator sounds you know I have I have and the speaker system.

So, basically electronic oscillators can generate electronic signals which can be converted into sound through transducer and speaker is something of that kind. So, I have a speaker which generates constant power at a constant frequency ideal condition what you call pure tone single frequency pure tone. And then I just kept it in position. Now, if I measure the time verses level at a point, I will find that is varying with time it is not the moment I put on the switch to sometime it will not be constant it will take some time to reach a steady state.

(Refer Slide Time: 04:40)



So, this is how it behaves. So, with time growth and decay of sound it is something like this sound in an enclosed space spaces. So, intensity of sound if I measure, it will increase because during the first space only directly sound will reach quickly, then there are infinite number of reflected sound.

Because one travels list after just one reflection that will reach next depending upon a distance it travels and some sound will come much later. So, it will take some time to built up a steady level. And if I keep my switch source on then finally it will attain a steady value. So, this is the steady duration of the sound, since it is growth then it becomes steady.

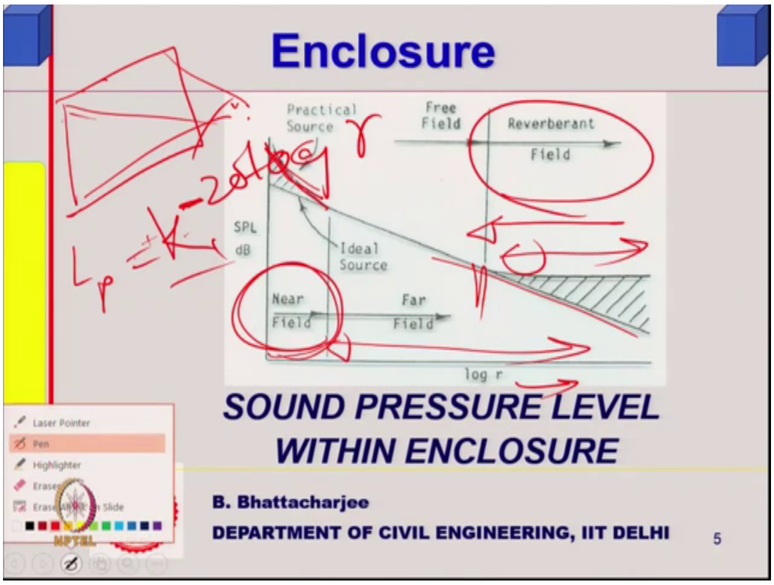
And if I put it off then also what will happen direct sound will go away first. So, therefore, there is a quick reduction of the direct sound which is maximum. The reflected sound will go on reducing, so decay of sound after source has been stopped, so it will go like this. So, if this is the behavior of sound in an enclosure unlike the unlike the you know unlike the so noise in outside, where there I put it on there is a phase like right and then that sound increases and if I am keeping the source on it will just study value no reflected sound just it will reach you know so it might be a step function all of thing.

Suddenly you will find that it is reached there is no reflection, it will be just as a time lag it reaches and remains constant there of almost f function like scenario. But here is gradually increases because some of the path will be very long many reflection and every path at every point, there will be loss. So, there is a reduction you know the delta values would go on changing, every time because after reflection the reflected sound because there some absorption will be the boundary wherever it is reflecting.

So, some absorption is occurring and second reflection more absorption will occur every reflection, there will be some loss of the sound at the boundary, and finally, you can so we can we can now estimate it actually very simply you can estimate it model it. So, this is how the physical behavior of sound within an enclosure right.

So, where I want sound to be there what I will do I like to see then even you know this, this continuous for a long time, this persist for a long time. What we have seen is that sound require sometime to go to the level at which a steady level. And when I put it off then also it remains for certain period of time it persist, and this persistence we call as reverberation. This phenomena persistence of sound after I have put off this source is called reverberation, reverberation, and is a is a reverberation.

(Refer Slide Time: 07:38)



So, this is the phenomena is known as reverberation. So, you will have actually you know that is why I coming to something like a reverberation field. So, this phenomena of persistence of the sound beyond I have put in this essentially the reverberation is vibration. How long it persist? Now, supposing you know I have lesser absorption with the boundary, it will require longer time to decay to a nearly 0 level, longer time to decay because in a absorptions at it will like if the absorption is high, after one reflection the values come down to significant value.

But if the reflection is less I mean absorption is high sorry if reflection is high, then it will come down, but if reflection is less, then it will go to second reflection maybe nth reflection and so on and so forth. So, phenomena of persistence is related to absorption of the surface we will see that now there is one more thing yeah

Student: While you are telling (Refer Time: 08:42).

We will come to that, we will come to that now do not shape, but we will see that based shape of auditorium we will see that actually right ok.

Now, there is one more point I would like to mention in when you are looking at noise outside, we are treating most of the time source as point source, because the distance of the receive will be relatively large compare to the source. And I said that it should be six times or so. In a space enclosed space very close to the source is actually near field. If I plot with log r, log r, you have seen that 20 log r, 20 log r. So, near field is where the source is not point source. For point source L p is you know so many things equals to so many things minus 20 log r minus 20 say some constant k 1 minus 20 log r that is what we have seen.

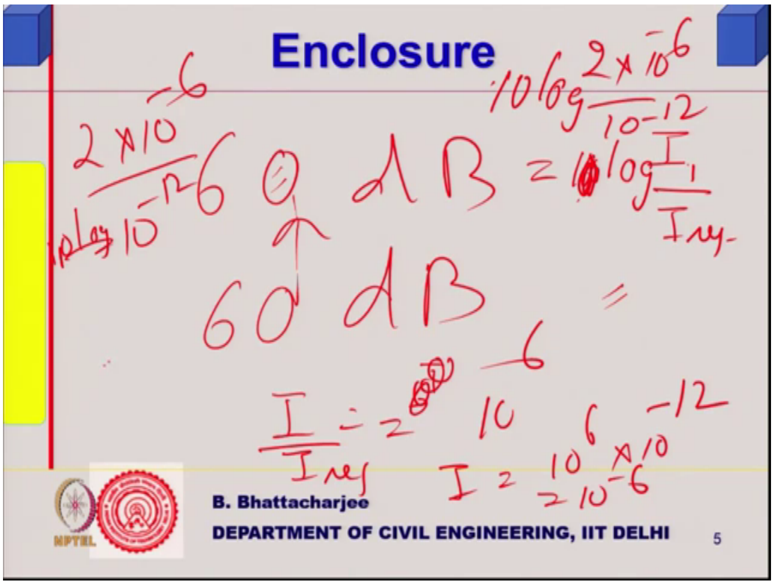
So, it readily if I plot against log r for a point source, it will be linearly very good log r right, but practical sources so for example, if it a you know large surface, this is surface and close distance sound will come from all the points, then it will higher then more than that you would have got otherwise if it was a point source.

So, for a line source, planner source or anything practical sources you will have some higher values right. So, this field we call as near field, near field in a enclosure this you know sources can be near. While in noise usually sources are far off places, but if it is near then you will get normally higher than what you have talked about earlier that it is equals to L w plus d i minus 20 log r minus 11. Now, it will be more than that actually this is what is it.

So, this we call as near field. Then beyond this is all are far field where I can treat it as a where I can treat as point source beyond that is far field, where I can treat you as a point source. And in the far field, log r it is proportional to log r, but if I go with their the distance beyond which reverberation sound that is if it an within an enclosure reverberant sound actually overtake the direct sound. If the source and receivers are very close, if the source and receivers are very close, if the source and receivers are very close, if the source and receiver are very close right, source and receiver are very close, if the source and receivers a very close, direct sound will be dominant, value of direct sound will be much higher than the reflected sound reflected sound.

If the source and receivers are sufficiently large distance, then direct sound will reduce, but reverberant sound might be say because it is coming from after infinite reflections, it is coming after infinite reflection. So, what we call this field were this point we call as room radius I will define this later on. This field where reverberant sound is more or comparable to the direct sound we call it reverberant field, we call it reverberant field right, we call it reverberant field, we call it reverberant field ok. So, this idea is fine this idea is fine ok. So, this is how some definitions of the field etcetera.

(Refer Slide Time: 12:23)

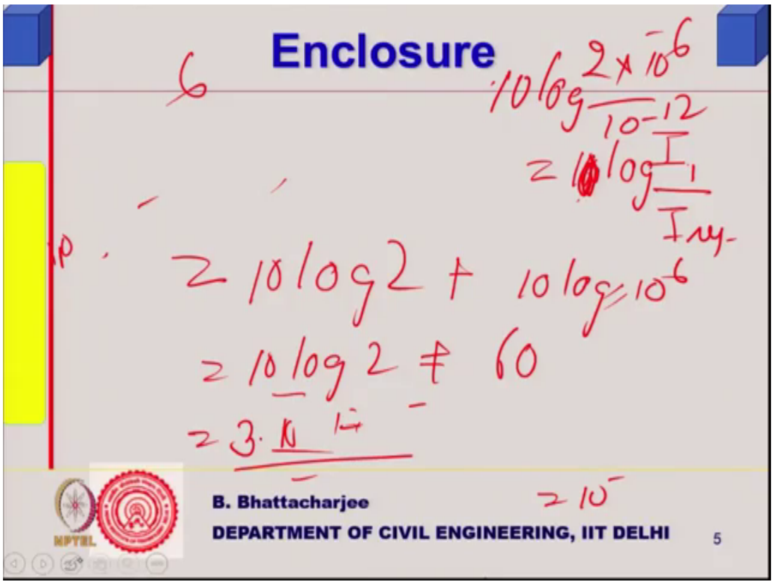


Supposing I am adding 60 dB plus 60 dB sound two sources are there from one I get 60 dB from another I also get 60 dB. How much will be the total noise level? It will be actually how much let see it will be 63, how? Because 60 dB would corresponds to 10 log if it intensity or pressure level does not matter intensity level divided by I ref. So, intensity corresponding to this and this is 10 log. So, I 1 let me call it.

So, I 1 is equal to I 1 by I ref will be equals to you know 10 divided by so 6, 10 to the power 6 am I right? Because 10 log it was 10 log 10 log. So, I by I ref reference would be how much 10 to the power 6, 10 to the power 6, am I right, 10 to the power 6. So, how much is I then 10 to the power 6 into 10 to the power minus 12. I can you know this is nothing but 10 to the power minus 6.

So, if such two such sources are there what will be the total intensity twice into 10 to the power minus 6 divided by 10 to the power minus 12 is I ref 10 log of that 10 log of that you take 10 log of that. So, 10 log of 10 log of 2 into 10 to the power of minus 6 divided by 10 to the power minus 12 will be nothing but 60 dB plus 10 log 2 60 dB d b plus 10 log 2 right I am I right 60 dB plus 10 log 2 you know all this I can erase now. Let me put like this right, so which is which will be equals to I can write it like this, I can I can write it like this.

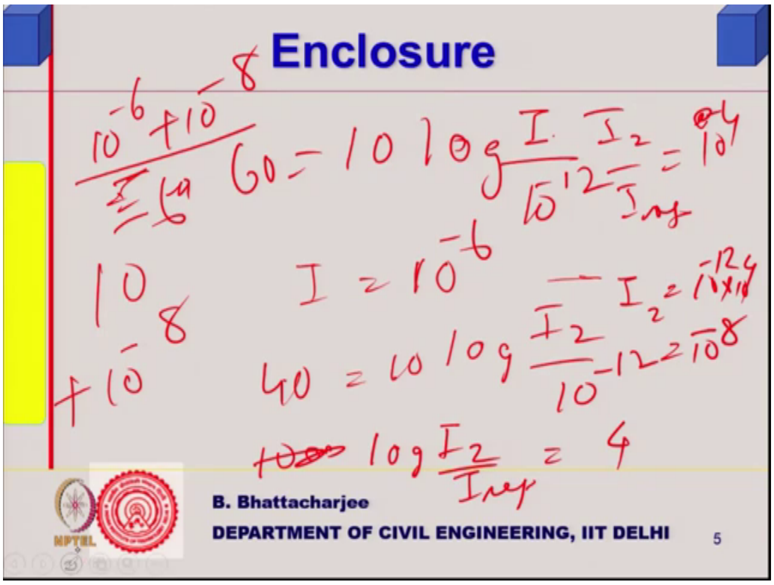
(Refer Slide Time: 14:20)



This will be equals to 10 log 2 plus 10 log 10 to the power 6 because minus 12 will go up there so which is nothing but 10 log 2 plus 60 dB this is 60 dB because if you take this and this is what three point you know 3.0 what, what one zero or whatever it is so about 63 dB. So, if you say you know double dB it is only increase by 60 dB. So, when you are calculate, you know this plot was related to this plot was related to db. So, I am writing SPL dB.

So, db if this is you know the intensity is much easier it will not by adding say 50 dB to 60 dB is so good because it will be still 60 points something 60 and 60 is 63, 60 and 50 might be 61, and 60 and 40 would actually mean so whichever is higher that dominates, because 10 to the power minus you know 10 to the power. We said 10 to power minus 6 was intensity I 1 right, because I ref I divided by I ref was 60.

(Refer Slide Time: 15:29)

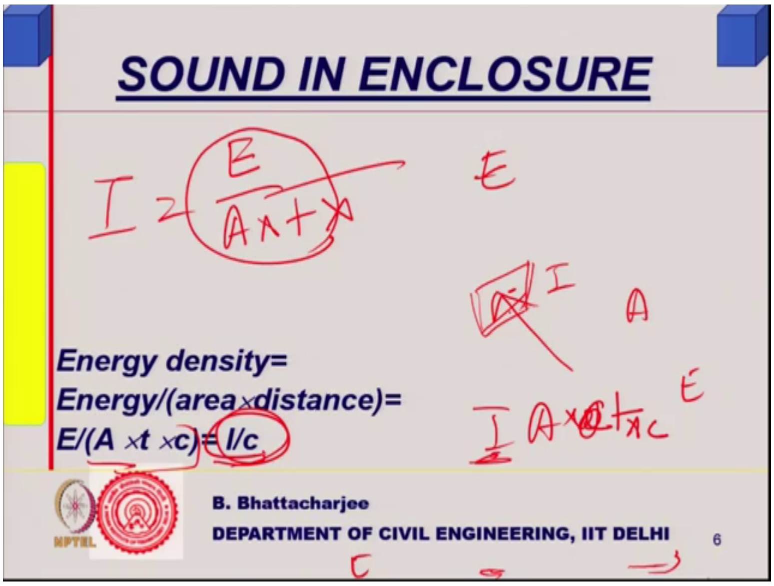


So, 10 to the power minus 6 you will get now we have this 10 to the power minus 8. So, if it is if it was it makes no sense actually it hardly any addition would be there. So, dB addition higher one always dominates you know that is what I saying let us let me do it again supposing I am adding 60 dB to 40 db 60 db will be 10 log I divided by 10 to the power minus 12 right and this was 60. So, I came out to be 10 to the power minus 6, you remember 10 to the power minus 6 right, 10 to the power minus 6, because this will be 10 to the power 6 and this is minus 12 so comes out to the 10 to the power minus 6. And if it is 40 dB, it will be 10 log of I 2 divided by 10 to the power minus 12.

So, this is 10 to the power you know log of I mean basically log of log of I 2 by I ref is equals to 4 right because 40 divided by 10 is 4. So, I 2 is how much I 2 by I ref will be equals to 10 to the power four and I ref is 10 to the power minus 12 10 to the power minus 12. So, this as to be you know I 2 will be 10 to the power minus 12 multiplied by I mean 10 to the power 4 it was. So, I 2 will be then equals to 10 to the power minus 12 into 10 to the power 4, which will be equals to 10 minus 8.

Now, you add I to the power 10 to the power minus 6, 10 to the power minus 6 plus 10 to the power minus 8 actually this value will be quite small compared to this value you know. So, therefore, if you divide this by I ref now I ref now effect of this one is practically not there. So, if you had 60 to 40, it will be 60 plus very small value, so that is what is happening here as well. Since, you have plotted against since we have plotted you know decimal values reverberant field if it is much higher than the direct field, it will be practical showing a constant value, it will be practically showing constant right practically showing constant value so that is what it is.

(Refer Slide Time: 18:06)



So, that is what now let us look at this scenario. We define a term called energy density. Reverberant field, what is reverberant field? Let us understand reverberant field reverberant field means is there anywhere in the room the value is constant that is what we are assuming multiple infinite number of reflection. So, if I take any point in the space within the room within the enclosure, sound will reach after multiple I mean I just for the sake of it let us say I kept the direct sound out.

So, put a sort of a you know like reflected sound at diffuser around the speaker diffuser around the speaker. So, it goes all around the place all around the place, no direct sound is reaching. Then if I take any point or another point ideally speaking it will show same decibel level, because every point only the infinite reflected sound will come and infinite everywhere. Therefore, this reverberant field has largely a constant value it is reality it will not be reality will find where there are you know absorptions are not same at all surfaces, but there is less absorption actually you might find the fields slightly decibel level slightly higher where there was higher absorption it might be somewhat lower.

So, everything put together ideally we assume that reverberant field is constant, uniform. So, we call it diffused uniform diffused field, uniform diffused field because it is diffused come from any direction not specular. Specular means what like you know yeah something like a mirror in angle of incidence is equals to angle of reflection that will get clear we also talk of lighting and elimination little bit. So, this is diffused means coming from any direction any direction anyway.

So, you take any speed any point in the space that will have for example, any space point in the space anywhere in the space, it will have same reverberant field that is what ideally we are resuming. And value of this intensity values related to reverberant field will be constant that is what we say. So, therefore, we can talk in terms of energy density of the reverberant field which is energy per unit volume energy per unit volume.

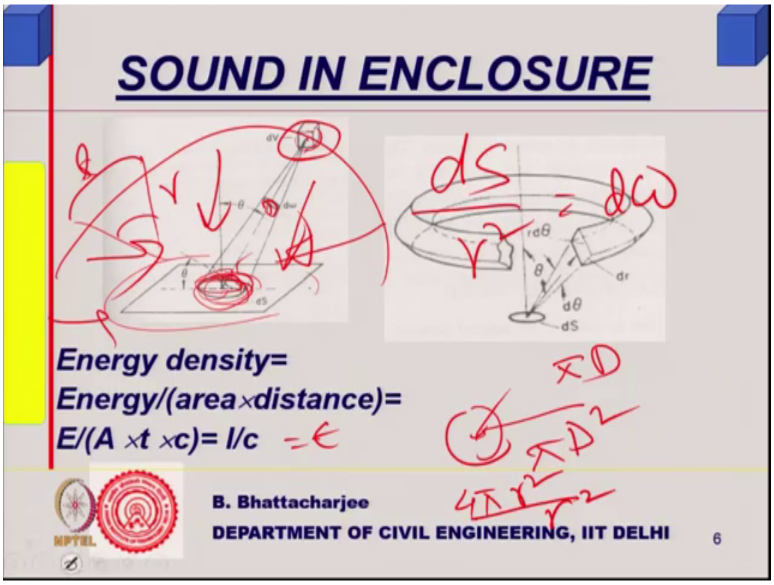
Now, supposing I consider unit area unit area unit area right, so energy content in unit area. And sound is travelling normal to this sound is travelling normal to this right. So, energy density will be energy area and the distance. Now, energy density is defined in this. So, intensity here is I which means the power per unit area energy that is passing through this area A in unit time unit time right that is intensity unit time 3 that unit area.

So, if area is A, I into A is a energy that will pass through this area in unit time right, so that multiplied by you know energy density is energy per unit volume I am saying I into A into C sorry I into I is what. So, I want to find out joules per meter cube. So, this is actually watt per watt means joules per second. So, multiplied by t travelling through t time and c is the distance which it travels in t into you know it can it can be related to I into t is in one second actually yeah per second you know. So, how do you define I, I was essentially energy per unit area per unit time right per unit time, so energy per unit area per unit time right.

And volume if I want to find out in unit time that is what is a volume in t time, volume it as covered through t time t into c. So, basically the length would be c. So, I you know energy density energy per unit area per unit volume because t into c is the distance it has covered through t time. This distance multiplied by the area is the volume. So, energy contained E divided by that will give you per unit volume.

So, from that it follows that E A t c is I by c is actually energy density I by c is energy density. I is watt per meter square right and c is meter per second. So, watt per meter cube into joules per meter cube, c is the velocity of sound. So, this is energy density we define a term energy density we define a term energy density right.

(Refer Slide Time: 23:30)



And now any point if I consider that can be treated as a source, any point in the reverberant field I am dealing only with the reverberant field now. So, any point in the reverberant field or in the space anywhere say somewhere at the building I mean somewhere in the space I can consider a dB volume and that can be treated the source.

So, small dB volume if I take multiplied by the energy density which sometime we define in terms of a epsilon or E sometime we might define it terms of epsilon some books will define in you know so I think that is what I am doing further. So, this should be this should be the this should be you know energy density multiplied by this is the energy content in that space small dB volume, energy content in the space in small dB volume in a constant reverberant field.

Now, from this source it I want to find out how much of it will actually from the reverberant field, how much of it will reach the periphery wall. So, I consider a small portion of the wall ds element in the wall or ceiling or wherever it is somewhere in the boundary, somewhere in the boundary.

So, this is dB element, somewhere in the boundary it reaches right and I can define say this is ds is ds area of this is known. So, I can define something called it will reach over a how much it reaches over the boundary area I want to find out. So, I can define something called you know we knows something called solid angle. So, the if this is making in solid angle right, angle is for an arc divided by distance. Arc divided by distances is you know like if you call it length divided by arc angle is given by that.

But solid angle is given as area divided by distance square. We can understand that because how do you define actually a if the angle came from a circle make pi into diameter pi D, phi angle. So, ratio of the total perimeter divided by diameter is constant that is pi that is pi you know so that is what you call as angle. Therefore, you take an small arc you can define the angle in some ratio of the pi right pi by 2, pi by 4, pi by 6, etcetera, etcetera that is how this angle basically came into being.

Now, if you look at sphere we are talking circle sphere equal distance from the point then it has got pi d square, pi d square right pi d square is a surface area. So, if you know all 4 pi r square is a surface area right. So, we call 2 pi angle is made by the you know because sphere circle makes 2 pi angle, we called it 2 pi.

By same token we divide by r square the 4 pi solid angle is subtended at the centre of a sphere 4 pi is a solid which is constant. So, surface area of a sphere divided by the radius square is a constant and that is 4 pi and that 4 pi is a solid angle subtended by a sphere at its centre we call it 4 pi ster radians, ster radians instead of radiance instead of radiance.

So, from this one, if I assume a take a small ds angle, you know that that kind of a conical volume which is there through which the sound will actually reach here. Sound will be you know this will be emanating sound and it will reach here to solid angle, all the sound wave that is travelling through that solid angle will be reaching here right. Earlier we have seen this spherical wave front. So, we took a point point source and it goes around all 4 pi. So, distributed by surface area same thing that is why you take the area part here. So, this is almost we can treat as a point source and this is a ds area.

So, what is the solid angle it will be subtending ds divided by the r square ds divided by and this we call as all d omega. So, d omega is nothing but ds divided by r square you know ds area divided by r square the distance square is nothing but omega d omega is a solid angle small solid substances right.

And how much of the how much of the sound will yeah how much of the sound will how much of the sound will reach here actually that I can find out. Consider this kind of a surface, because there are you know there are if I look at this all those I mean I am interested in how much sound reaches here. Now, I have taken a point, if I larger area, instead of point, small db volume I take larger volume and integrate, then I will get the total amount of sound incident on it or impinging over it, total amount of sound impinging over it.

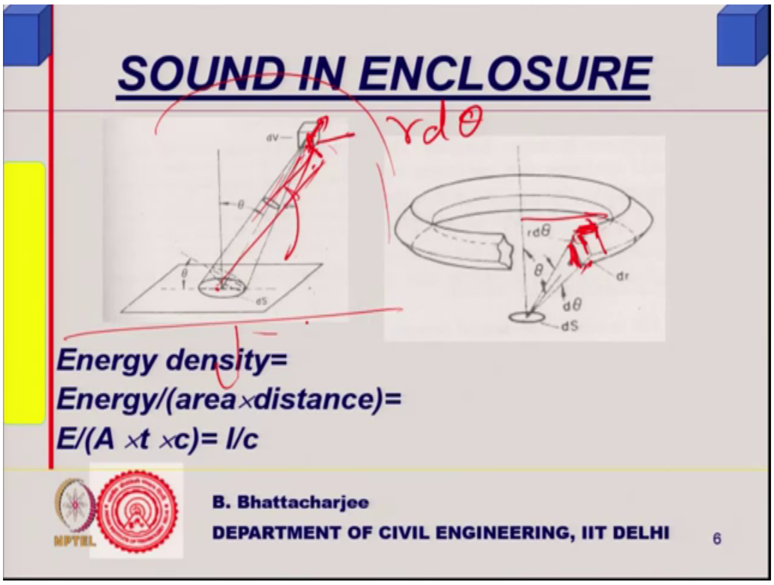
Now, what to do is we do not take you know like all rectangle areas, but it is coming from one direction radially from this direction, that direction, etcetera, etcetera readily from all directions. So, what you do is we take a hemispherical situation right hemispherical volume. If I am interested in t time, then diameter of that radius of that hemispherical one will be t time I said c into t. So, I can integrate from 0 to c into two that is a sound that will reach anything beyond will not reach, because it will come radially from all direction.

So, to do that what you do is we simply take a torus volume of this kind we take a as volume of this can consider the chord circle considered the chord circle you know there is a large sphere hemisphere around it because bottom side is not there. So, I am talking a hemisphere. Take a chord circle. And a small element in the chord circles right small element in the chord circles. This is the radius of this one.

This is the d r, because it is going outwardly, d r is going outwardly right. This is d r. This I can find out knowing how much angle it makes will you will come to that again. So, this is d r this value I can find out and I can actually take if I take a small volume then this dimension also I should be taking. So, this dimension d phi I call it d phi, this is d theta, because it is making an angle theta here this one you know.

This is my ds I can consider it is making an angle theta here d theta. So, d theta into one-dimensional will be d theta into you know this one would be one-dimensional will d theta this will be d r this will be d r will be readily outward this is vertically down. So, if this angle is theta this height will be r d theta.

(Refer Slide Time: 30:38)

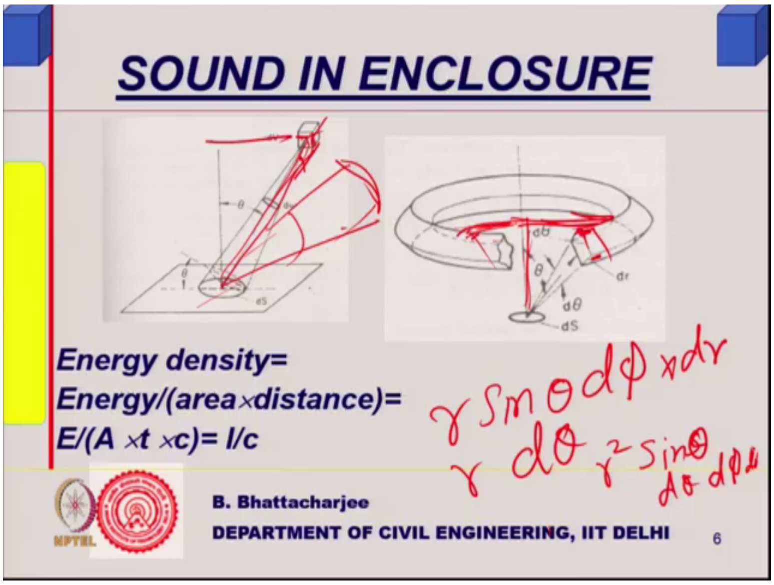


This height will be r d theta. D o you agree with this? If I take a cubical volume let me just again erase this out quickly, erase this out quickly. So, this height will be nothing it will depend upon what a angle it is making here. This distance is r this angle. If it is elevation angle is altitude angle you know remember if it is theta then it will be r d theta r d theta right. So, this height will be r d theta right is clear. Radially going outward is d r and this one will be how much it will be d phi you know along in the plane if I put it in the projection onto the ground projection in the ground like azimuth angle.

So, one angle will be a azimuth, another is kind of something synonymous to my altitude angle, and third one is d r. So, I can actually find out the volume in terms of r, d theta, d phi right and d r. Now, d phi will be how much because it is this is. So, any distance I take here would be basically I am calling it as in you know d phi multiplied by this radius I am taking from a torus.

So, this distance any distance here part of or any distance along this line if I know this radius now this radius is nothing but if this the distance is r then r yeah, so depending upon the theta. So, I can find out in terms of r, this will be r is this is r. So, this is vertical one will be up to the centre will be r cos theta r r sin theta it would be right it will be r sin theta because opposite to the angle.

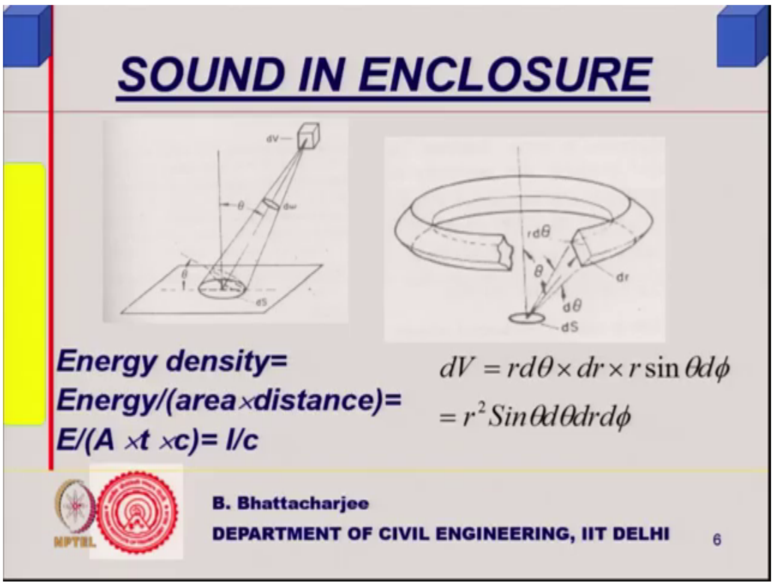
(Refer Slide Time: 32:26)



So, r sin theta r sin theta by one term, this is related to d phi r d phi I was talking about you know r sin theta d phi. And then another one will be simply dr and another will be r d theta you know this vertical height will be simply altitude angle changing by d theta.

So, if you look at this product, it will come as a r square sin theta d theta r square sin theta d theta d phi d r right. And if I integrate it from 0 to c t or one second c 5 minutes zero to c that is all the sound that will be rest here we will derive this we will look at this again in the next class from this point only right.

(Refer Slide Time: 33:21)



So, we will start from here again. So, you find the dB is equals to same thing that I was talked about. So, we will start from here r square.

So, we have to stop here.