Architectural Acoustics
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Lecture – 27
Electro – Acoustics – II

So, good morning, students. Welcome, to the NPTEL course on Architectural Acoustics we are in the week – 6 and the second lecture of the week – 6 that is the lecture number 27 is on Electro Acoustics II. This is the second series of lecture of on electro acoustic.

So, if you remember in the first lecture on the electro acoustics what we have discuss is the total three basic components of the system of electro acoustics and what are the basic parameter that is actually we deal with the electro acoustical system.

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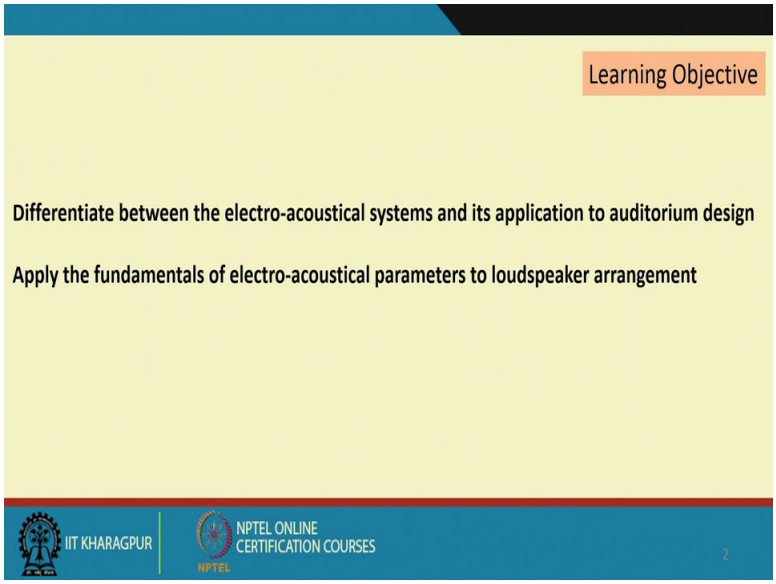

So, today the learning objective of this 27th lecture on architectural acoustics will be the we actually need to differentiate within the application system of the electro acoustics, particularly focusing to the auditorium design or that kind of a principles. And, also we will apply those fundamentals of electro acoustical parameter to some extend of the loudspeaker arrangement also. So, from these two learning objectives let us move forward.

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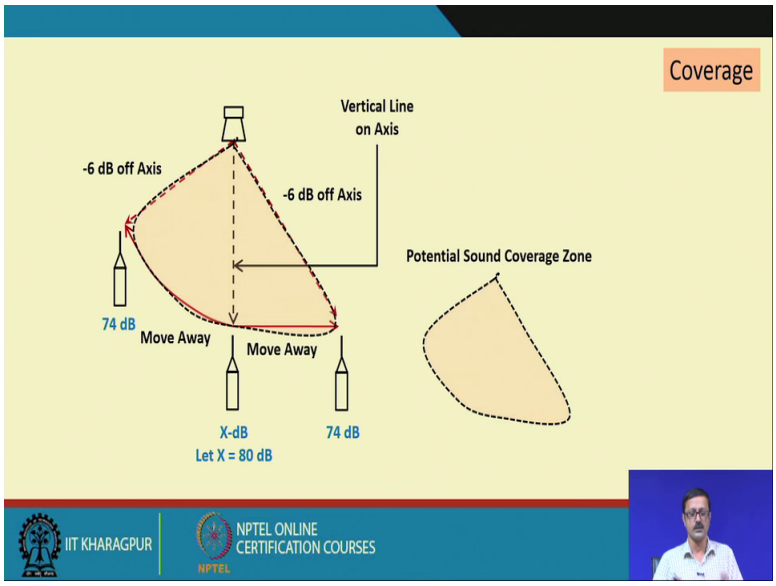

In the last lecture, we have seen that the directivity of the loudspeaker which is essential as the loudspeaker of various frequency behave differently and the throw is short for the low frequency sound and this throw of the loud speaker is higher or the long for the high frequency sound. So, here in this power point presentation in this slide what I have drawn is that I have kept a loudspeaker in the ceiling and just below that at a certain distance I have kept a the dB meter that a sound recoding dB meter.

Now, suppose the it is a reading is X and X is almost suppose the 80 dB or so. So, this particular axis is on axis or vertical axis just below just 90 degree the perpendicular to that particular center point of the loudspeaker to the any point below is the on axis or the vertical line.

So, now if I move this loudspeaker in the left or may be in the right side I will definitely record some change in the reading in the dB meter and definitely the reading will be less than 80 dB and let us move it let us move it further and now move away to this particular point and suppose the at this particular point is 74 dB the record is 70 it is record 74 dB. So, there is a 6 dB decrease from the on axis point and this line if I draw will line from the against center point of the loudspeaker to that particular point, where I recorded at 74 dB is this inclined line is called the minus 6 dB off axis line.

It can be again do you can again do this sometimes some way you can go radially of or may be in the radially of also in this on the right hand side also. So, just to show this two

type of axis I have one side I have drawn a flatter movement or the horizontal movement and another side I have drawn a circular movement. So, by virtue of this circular movement suppose at this particular point again you record 74 dB which was actually 80 dB at the on axis. So, again I can joint this two line the midpoint of the loudspeaker and this particular point and that is also called minus 6 dB off axis.

So, I can say why virtue this particular area this particular shaded area a is called as within the zone of minus 6 dB off axis zone and this is the potential sound coverage zone and that is the that is the coverage of loudspeaker. So, the loudspeaker will be design, sorry loudspeaker will be placed or arrange in such a way that we will actually the effective area of the coverage of the loudspeaker we will deal with this particular length or a vertical cross section areal point of view this particular circular area will not bring to tell me some sound of course, but this as it is away from the off axis minus 6 dB will not take care of that particular area into consideration of our loudspeaker arrangement design or layout design.

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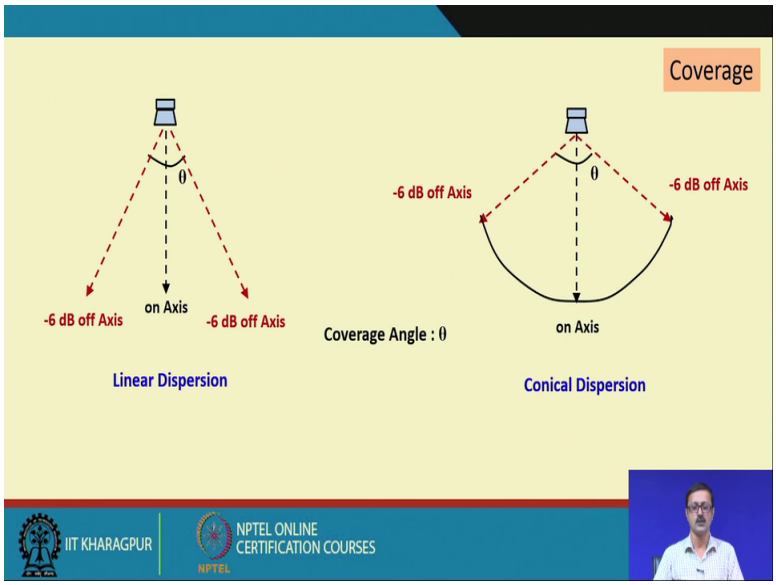

So, there are two type of dispersion; one is called linear dispersion where you goes straight horizontal and get the 6 dB off axis line and sometimes we go conical dispersion when you go the circular in left and right side and you got the minus 6 dB axis line. So, there are two type of dispersion possible and as is this two dispersion in between this two lines of this two minus 6 dB axis inclined line the angle that in between this two lines are

called coverage angle and it is represented by theta. So, this coverage angle is very important in the loudspeaker design or the arrangement of the loudspeaker design in any format of electro acoustical arrangement and being a architect to we must know some of the principle the design fundamentals of that.

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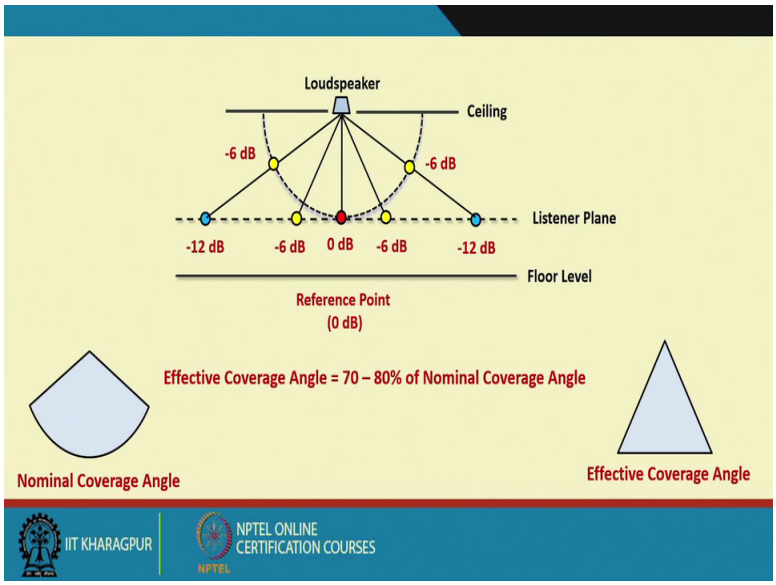

So, the next one is that, suppose I am providing a loudspeaker in the ceiling. So, this is the ceiling and this is the floor level and this circular line is that line where this is the conical dispersion line and this is the listener plane the listener plane if I actually some sitting for kind of a category it is 4 feet and if it is a standing kind of a listen listener category then it is 5 feet. So, mostly it is sitting in case of auditorium.

So, we actually take as this height as a 1.2 meter or 4 feet and in that there are lines of minus 6 dB line. So, this is for the dispersion which is a linear dispersion lines and this is for the conical dispersions line. So, all these four dots of the yellow dots are minus 6 dB dots, one follow the linear and other follow the conical and the central this red dot are 0 dB because it is the on axis line and this is the reference point of 0 dB which is actually the one of the strength axis or the of the acoustical strength axis you can say.

But, this point if we extend towards this the listener plane then you can say this two blue dots are also available which is tentatively, tentatively is minus 12 dB. So, the difference is dB level from here to here it is minus 12 d dB or so. So, that can be also taking into account in some kind of overlapping scenarios.

So, by virtue of this we can say that this if you go with a conical dispersion this you will get two such angles one is this angle which comes under the conical dispersion this angle and one is the triangular or the linear dispersion which is this angle. So, it has actually both two type of coverage angle. So, one called the nominal coverage angle which is higher which is a conical dispersion kind of scenario and one called effective coverage angle which comes from the linear kind of a scenario.

So, if you take the effective coverage angle and design your system will be little bit of conservative side and if it is a nominal kind of a coverage kind of angle it will be kind of a non conservative zone also it is much more wider much more economical in that sense. So, effective coverage angle if you see it is almost like 70 to 80 percent of the nominal coverage angle.

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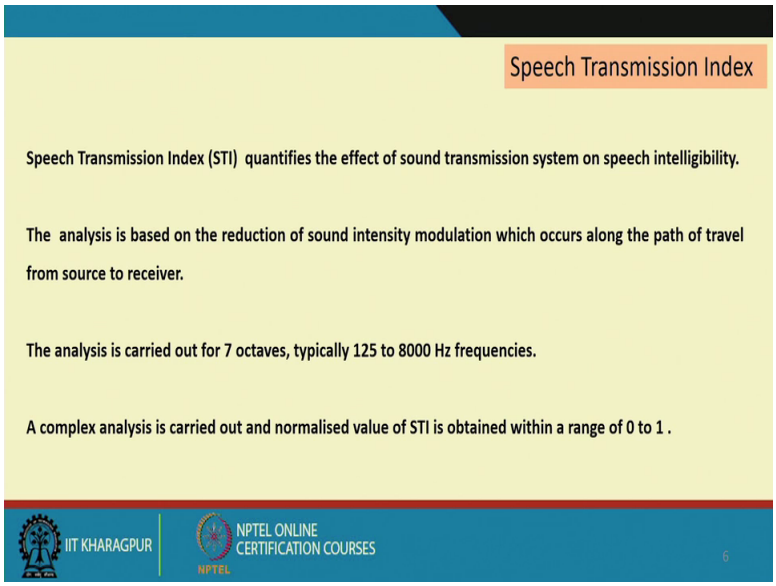

Now, next is let us go to the speech transmission index which is another a another fundamentals in the electro acoustics or any kind of acoustics, where it talks about the how a particular speech is actually go from one from the source to the listeners or maybe and during this particular travel or this particular the movement this particular sound may be going to decay down. And due to this decay this speech which is from the listener to the particular, sorry from the source to the particular listener is weakened and what will be the particular modulation of the particular speech when listener actually here particular that.

So, it is farthest particular analysis, it covers almost 7 octave, 125 to 800 hertz octave and it has carried out in a very complex kind of a scenario and it is given a kind of a range within 0 to 1.

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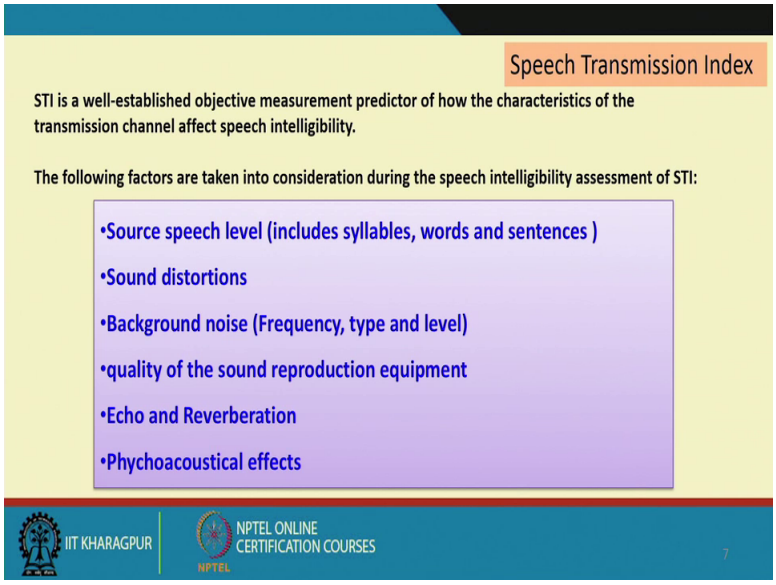

So, a speech transmission index or STI will have these following points which will actually encounter while they will device this 0 to 1 this kind of index, what are those points the source speech level and that will be actually going to take care of the syllables word and the sentence of a particular speech. Sound distortion if any, background noise if any; there are frequency type and level of the background noise also what are the background frequency of the background noise types and level.

The quality of the sound reproduce by the equipment suppose there are some speech which is actually reproduced by the some equipment or the electro acoustically equipment the what is the quality of that particular sound. The presence of echos and the reverberation in a particular field and a psycho acoustical effect that is a another thing that is how a particular person perceive a particular speech, whether he can understand the speech or she can understand the speech in a thoroughly or thorough manner which probably not that much problematic if he and she is any very first row. But that particular understanding of the speech may be a bit of problematic when he or she in the last row because of the distance things are decay down, the syllables, the word and sentence are not very much proper in terms of hearing.

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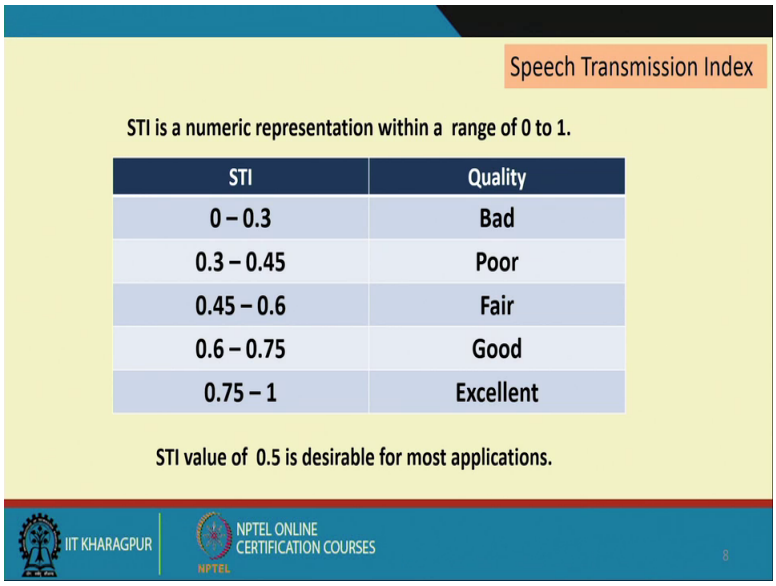

So, based on this all 1 2 3 4 5 6, 6 parameters and with complex kind of a calculations provide a table or provide a chart, where SIT is starts from 0 to 1, and what is a low numbers SIT means it is bad or poor, and if it is a higher number of SIT is good or excellent. So, always it has been it always it is desirable to have the SIT value more than 0.5 definitely the should be more fair towards the good also providing a very good or excellent kind of the SIT sometimes it is difficult.

So, the designer the sound engineers and the designers actually keep the particular things SIT value very near to 0.6 around 0.6, 0.65 or so for their design of the speech are those kind of activity area like lecturer room or conference room or so.

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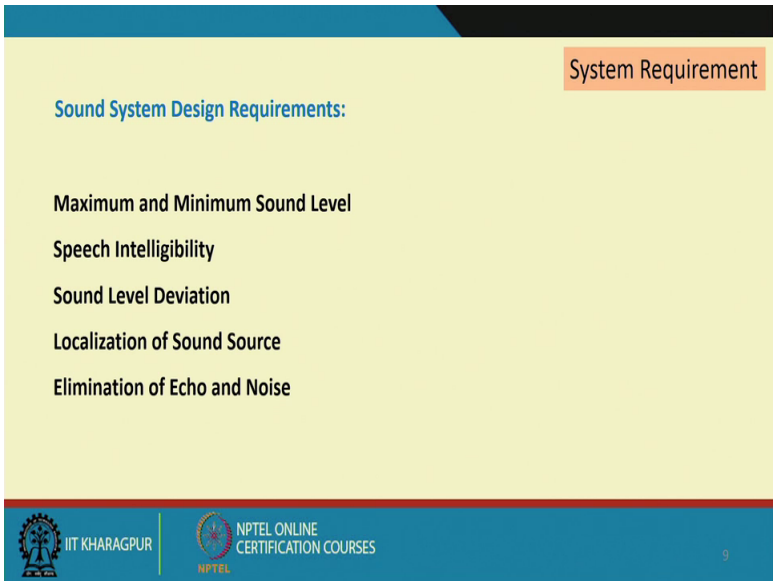

Some reinforces reinforce system design and what are the requirement of that. Those are the requirement we required a maximum and minimum sound level you have to check and this two should not the very high and that will give you a un-equality or the non uniformity. Just I have told about the speech intelligibility that is the how a speech is going to be captured by a person in various points of the auditorium and how it will actually behave and how it is going to give you that kind of a understanding on the speech. Sound level deviation which comes from the first point the maximum minimum of the sound level deviation or so.

Localization of the sound source, sometimes because of the faulty character of the electro acoustics there are some kind of a localization of the there are some points where you get a very high level sound and which is also bothering. And maybe some other point that is a level of sound is very low which is again give a problem of the speech intelligibility or so, we cannot actually purely you enjoy the music or the speech. Localization of the sound source that I have just cover the elimination of the echos and the noise the that is on of course, one of the issue at the this particular system should eliminate all the echo and all the noise as concerned.

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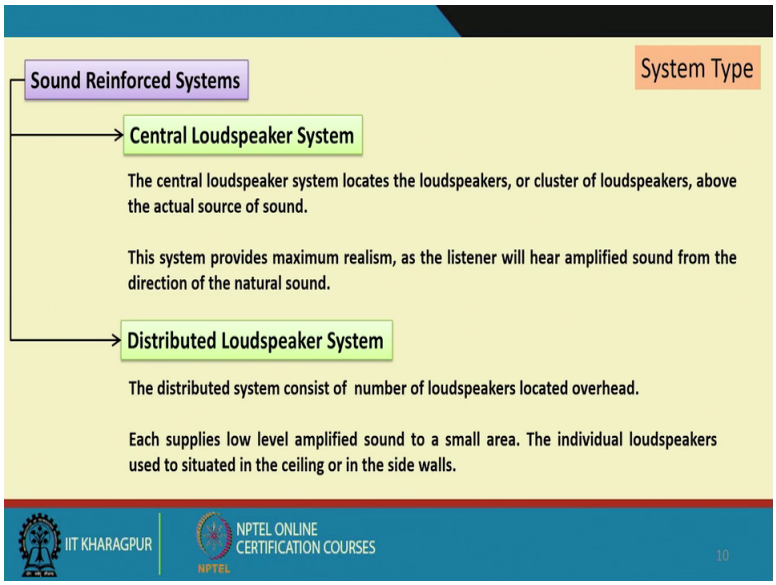

And, what are the system the sound systems or sound reinforce system, there are two. One called the central loudspeaker system where a cluster of loudspeaker is located in a central place and it is very near to the stage or very near to the actual speaker or the actual performer and that gives a 100 percent or the maximum realization of the particular sound because it is comes from the very near to the point where the actual sources are located. So, it is a single cluster a group of cluster which are very focused and centrally located in a particular auditorium.

And, a second one called a distributed speaker system where it is distributed; distributed in a small area or may be a distributed in a larger area of the hall or the auditorium. Where in each distribution loudspeaker a low level amplification is made and it is captured or it is provide the sound reinforcement in a smaller smaller area and that gives a particular uniformity and that gives a particular the reinforce in the sound in a particular space.

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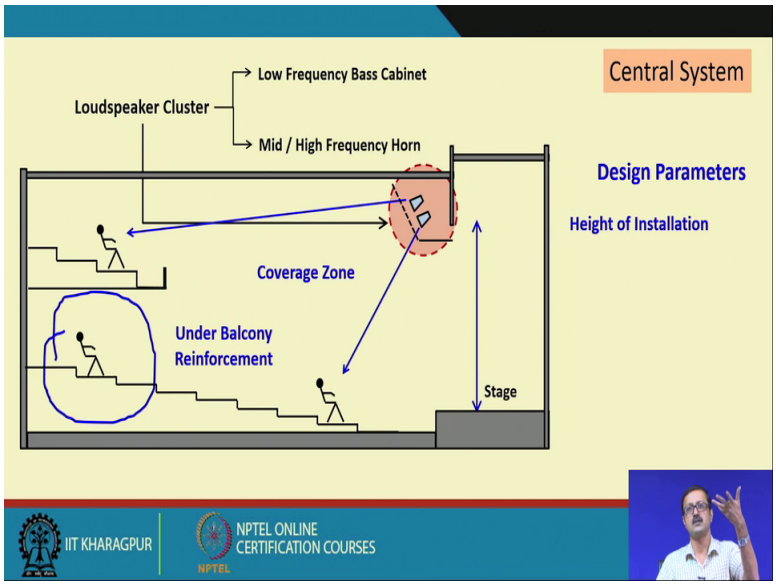

So, this particular ppt slide gives you a cross section of a cross section figure of a auditorium and I am talking about the central systems now, where you see a loudspeaker cluster is actually placed on the top at the top just above the stage. So, there is a the source directivity; directivity in the sense of that the performer and the loudspeaker are in almost same vertical level and within that particular zone you can have a low frequency bass cabinet or may be the high or mid frequency horn kind of a the loudspeaker.

And, from here we have to see the what is the coverage zone, we will discuss in details how to manage the coverage zone from the very first sitting audience to the last seat and maybe also in the balcony. You also has to see the under balcony situation sometimes is under balcony is not going to receive the sound from this cluster and we have to see the what is the height of this installation as the height of the installation is high your distribution potential is also going to be high.

So, this height is one of the character or the one of the basic design parameter of the whether you will going to use a central systems system or not, that is one of the height is one of the design parameter.

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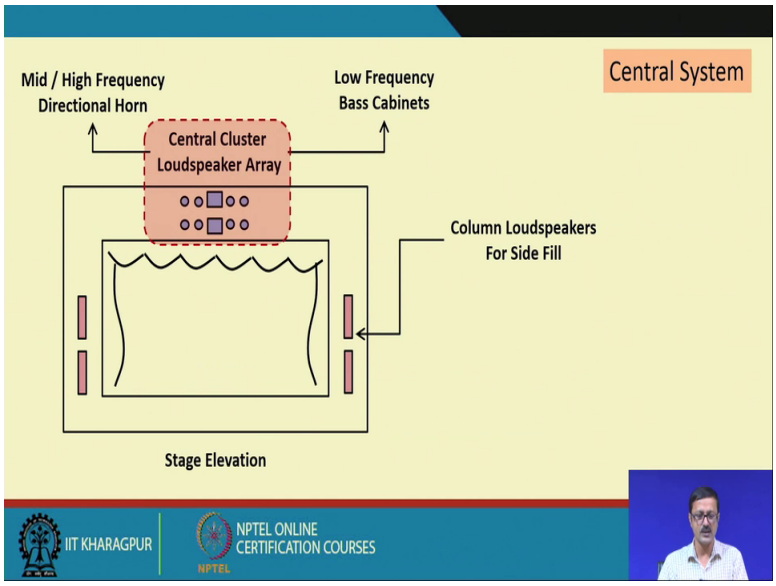

So, if I take a stage elevation point of view so, this cluster of the arrays of the loudspeaker it is placed at the central part of the stage the above the stage where there are some low bass and some directional kind of a high mid or high frequency sound loud speaker and sometimes there are some column loudspeaker are also placed in the sites which is required for the same kind of a side fill.

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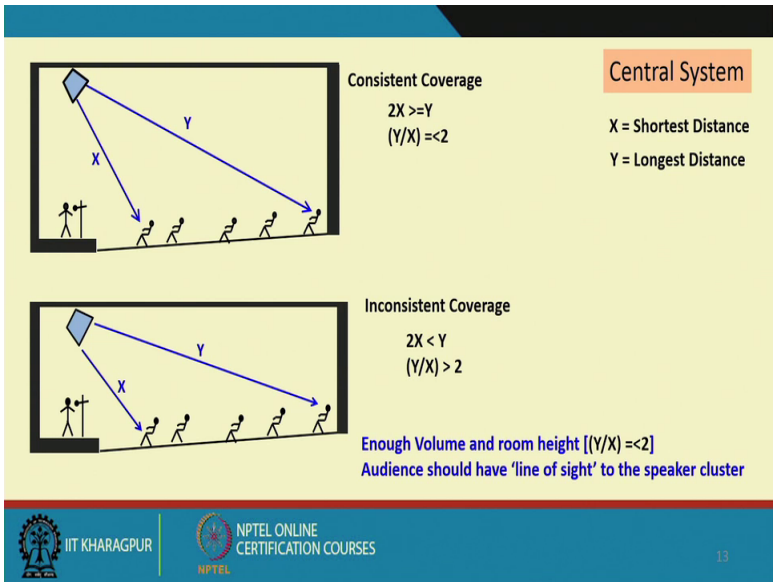

So, now let us consider Y in the central system you required a huge amount of volume or huge amount of height. Suppose, if you see this particular cross section where a

particular cluster from that if I draw a straight line to the first audience and also the last audience and this will be measured this X and Y if the Y is twice of X are something like that or more than twice of that or maybe the Y by X ratio is more than, less than equal to 2, then it is gives a consistence kind of a coverage; where the X is a shorter distance the first are the first row distance from the cluster the central cluster and Y is the last row distance from the cluster.

But, if I reduce the height of the auditorium and I place the same cluster then I will if I draw the line X and Y, I will get two different dimension and there probably this Y by X will be greater than 2. So, the X will be smaller and the Y will be larger and this ratio will be greater than 2 and if it is greater than 2, then it will give a very inconsistent kind of a coverage. So, better not to go with the central type of system when the auditorium ceiling is low or there is this X by sorry Y by X is greater than 2 kind of a scenario. We can just draw two simple lines in our fractional drawing in autocrat or may be any kind of a the software and check the what is the dimension between a ratio of the dimension Y and X and then you can decide that this particular systems can be applicable or not.

Sometimes may not be for suppose this auditorium is quite a large or the height of the auditorium is large, but because of the placement of the false ceiling the apparent height of the auditorium is bit low, come down to a bit low and then we can say that this X by Y ratio may not be adequate may not be give you a consistence kind of a coverage. So, the enough volume and the room height so, the Y by X ratio should be less than 2, otherwise can be a problem kind of a the consistency problem and audience should have a line of sight to the speaker cluster. So, the audience last audience here should see that if can he or she can see the cluster there is a direct sound can become and propagate from that point to the last row.

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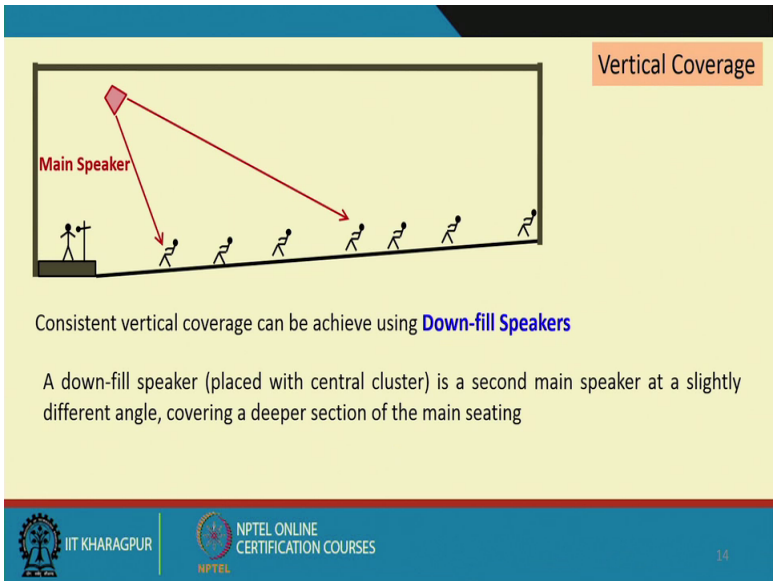

So, as I told a particular cluster of speaker I may be a particular line of cluster of speaker may not be sufficient to cover the entire area. So, you need some kind of downfall kind of a speaker. So, a down fall speaker is another cluster which is given in some different angular orientation and that will going to cover or the in the some other part are the maybe the front or maybe the rear part of the auditorium, auditorium and the seating. So, maybe one or two such down fill the speakers can required to cover the entire zone from the point of view of the clustered or the central distribution system.

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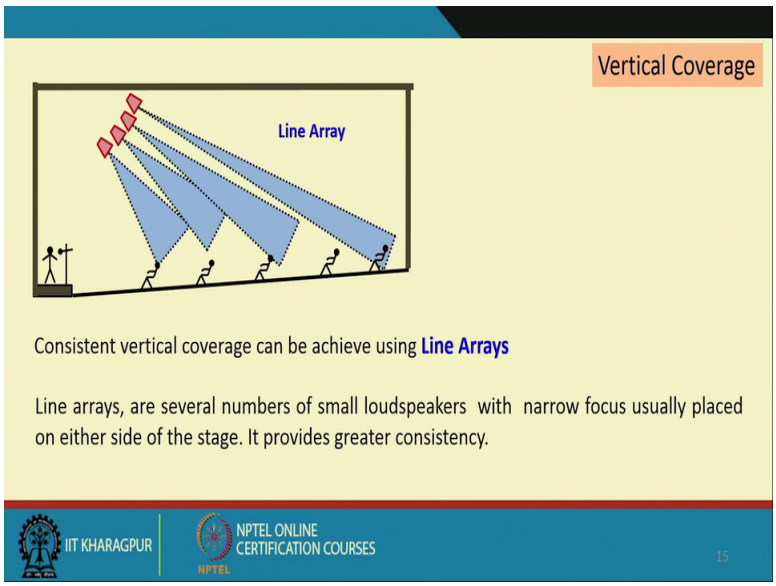

Sometimes in that kind of a consistency to provide some kind of a consistency in the larger auditorium when the auditorium is very very large the rows of speakers are provided like this, the array the line array is provided like that. So, it is not one or a particular it is a kind of a, you now say that a particular clustering systems the central systems now gradually move from the central cluster system to the distributed system. But the principle adopted here is central cluster because it is started from that very top and it is focusing towards the various part of the auditorium in a special directivity and the sound reinforcement principles point of view.

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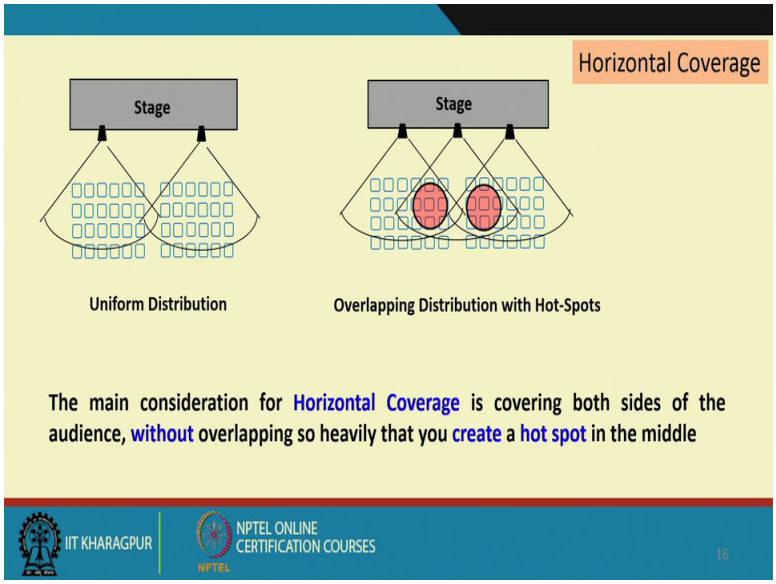

So, in nutshell what we can say that the coverage and the particular areal the distribution of the sound from the vertical point of view it is very very important.

So, let us talk about the horizontal coverage, this as a plan of a stage and there are the audience. I have placed two such loudspeaker in this to very uniform points or the symmetrical points and it is gives the uniform distribution. Sometimes if the larger the size is larger than we can go it is some kind of a in filler or some kind of a overlapping scenarios. And if you go for those kind of overlapping scenarios those two red colour zones of course, this red colour zones a little larger than the circular are come under a typical overlapping scenario and this typical overlapping scenario are actually creates some kind of a sometimes make create kind of a hotspot.

So, the powered output from these has to be little low with compare to this two to create or minimize that particular kind of a hotspot that is one.

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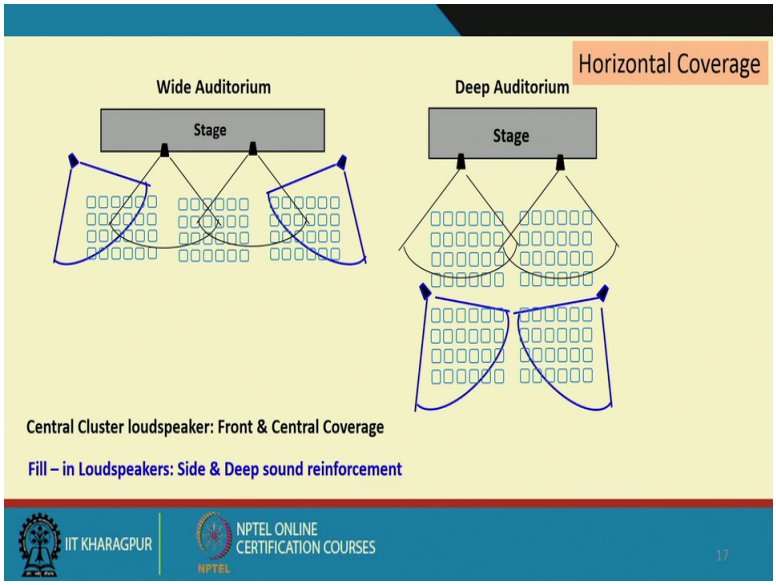

And, number two: sometimes it is essential to go some additional kind of a loudspeaker because if I say this is a Y type of a auditorium where there are aisles and there are seatings like this. So, there are some area where actually this particular two cannot be adequate. So, there are some area is here it is deep. So, this area the back benchers or the back seaters are not adequately taken into the sound reinforcement category or the sound reinforcement atmosphere.

So, you need some kind of a speakers which is in the sides, which is in the world mounted which will going to take care of your those area where you have not taken attention from the central cluster. So, those are called the fill-in loudspeaker. So, those fill-in loudspeaker are also go along with you are the central loudspeaker system, where there is a requirement of filling, if the loudspeaker or the central loudspeaker or not adequate to covered the entire wide or the entire deep zone of your audience.

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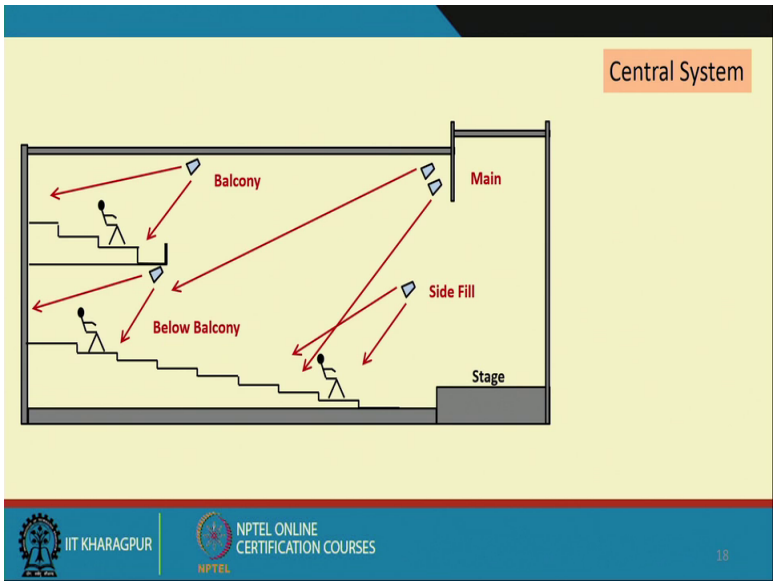

So, now let us see the what are the possibilities. The possibilities are the main cluster is definitely is a important one because this is the actually backbone or the actual fundamental need of a central system, but you required some kind of a side fill. Why side fill, because sometimes the audience are in a larger or the wider the spectra. So, the left and the right side of the corner or the world side audience should have equality from the particular the sound reinforcement system point of the adequate side fill that just now we have discussed in the last slide.

And, then this is also may not be adequate you have to go now rear part and the rear part you may require a special attention from the balcony. Of course, you have to give a another cluster in the balcony just to take care of the balcony, you have to see the what is the sound level here and the what will be the actual output sound level here with respect to this, because sometimes if these two are mismatch the there will be some kind of hearing confusion over this particular people who are there in the balcony. And there may be some kind of a strengthening point or the loudspeaker has to be provided the below balcony area. Because, it is sometimes say are many times it has been notice that this central cluster cannot reinforce the sound below the balcony.

So, in nut nutshell what happened is that we have two layers; one side fill and the main layer for the front and the mid zone of the people and one is for the balcony or the rear part of the people.

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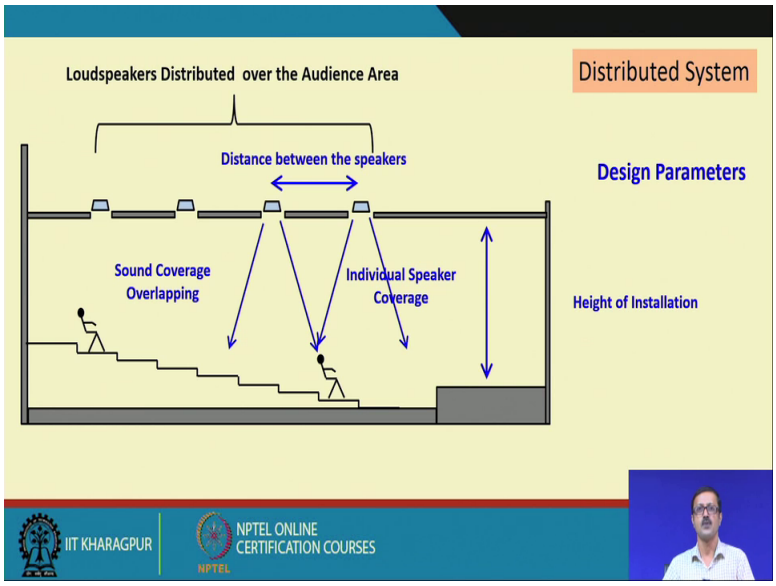

So, let us let us go to the second type of system which is called distributed system, where I have drawn a sectional view of a particular auditorium which is low the ceiling is very very low. So, a central cluster can give you a this X and Y mismatch, the Y by X ratio is more than 2 so, it is better to go for a distributed system. So, ceiling mounted things or maybe the wall mounted things will be provided and this will be given some kind of a individual coverage of the speakers and we have to check that total coverage of the speakers and all those are in a particular way that it gives a uniformity all over. Again, height of installation is one of the major parameter to design this particular system.

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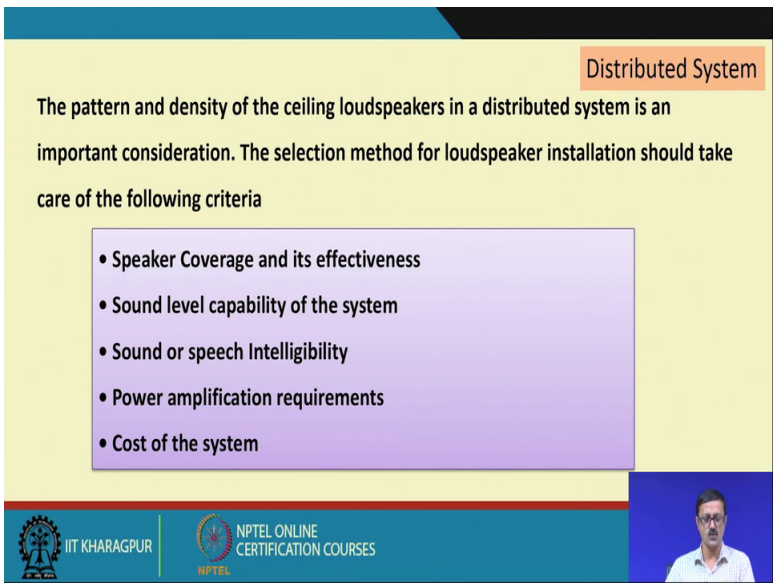

The pattern and the distribution system is important and for the this particular selection method and any kind of a criteria and what are those criteria for the selection methods and design of any loudspeaker or speaker coverage angle and its effectiveness, sound loud sound level capability of the system, sound and speech intelligibility the power amplification quality and the of course, the cost of the system.

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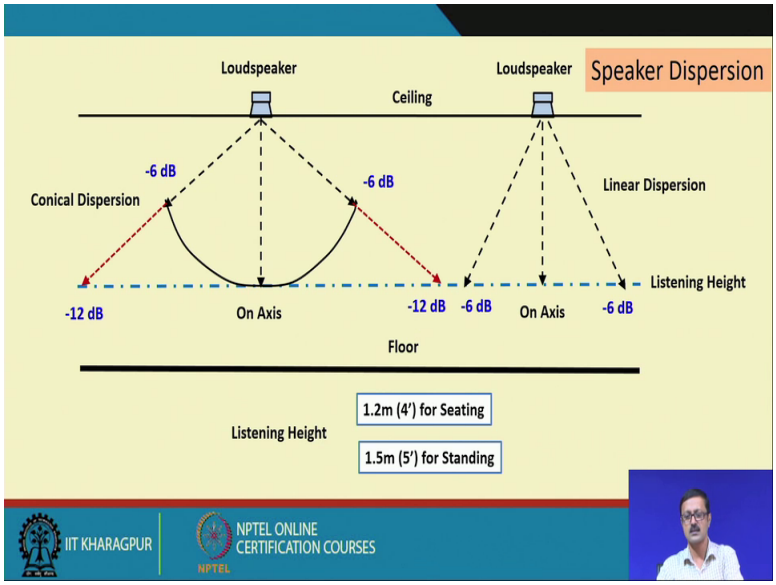

So, let us we will discuss about the how the speaker can be arranged in distributed system. So, we have just now completed the two type of systems that is distributed and the central and now, let us again discuss about the dispersion which is conical dispersion and the linear dispersion which we are were discussed in the 26th lecture and the listening height I have told you that is 4 feet for the seating which is 1.2 meter listening. So, this height the floor to a height of our ear, standard ear and 5 feet for standing or 1.5 meter for the standing.

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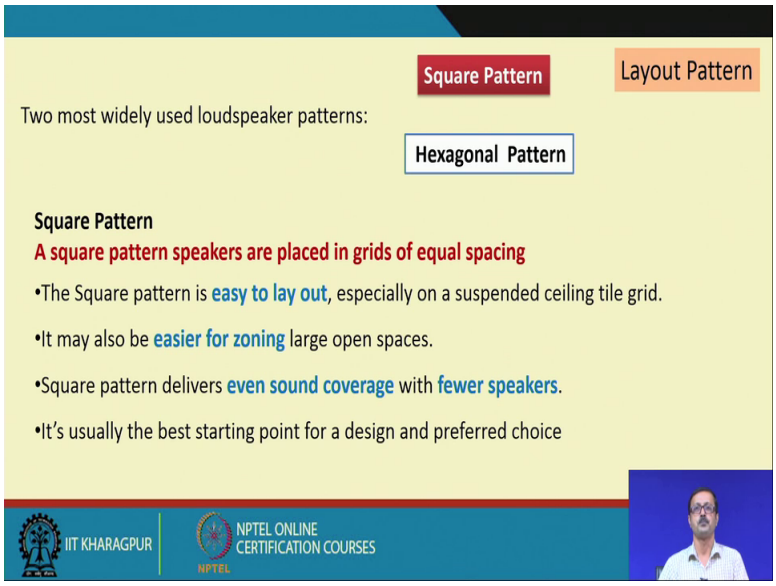

So, there are two type of pattern; possible one is the square kind of a pattern and one is hexagonal. In the square pattern it is very easy and square pattern is that it is very easy to layout the square pattern because it is in squares and it is space in the equal grids of a square. And the easiest part of it that if some kind of a straightening is record in some localized zone or the zoning is very easier in case of this the square pattern kind of a the distributed system is gives you almost even kind of a coverage with less number of speaker which is economical and usually this is the starting point of any kind of the coverage for a distributed systems and also that is preferred choice. So, there are different way I can cover it up.

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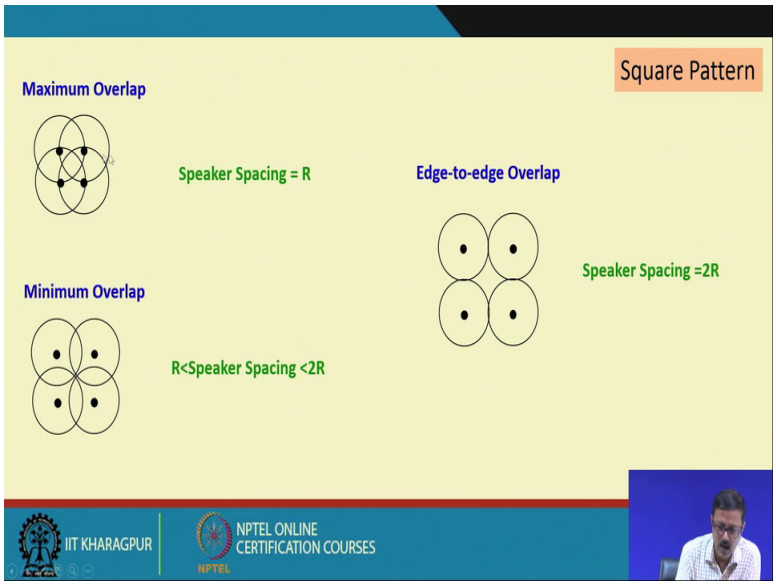

So, if I so, this black dots are the speaker points in the top and this circles are the coverage at the particular the listener the level. So, if I placed it is so closed and it is called the minimum overlap, now if I just move it a bit then it is called the minimum that was is the maximum overlap sorry and this is called the minimum overlap and there are third type of overlap also possible which is called edge to edge overlap.

So, if we see in the minimum case, maximum case this area there is a possibility of a hotspot and the speaker spacing is equal to R; R is the radius of this coverage at listener level. Here in the edge to edge there is a potential area which is not taken into account or the not considered at all which definitely gives a cold spot or a drop of sound level and where this distance between the speaker to speaker is R plus R equal to 2R. In case of a minimum overlap this distance is in between R and 2R something like 1.5R or 1.75R something like that.

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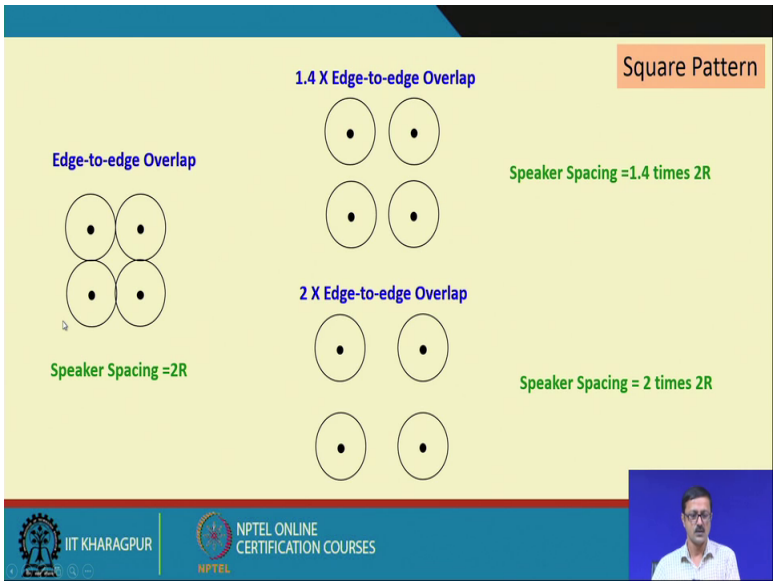

Let us go to the next slide and see sometimes this edge to edge overlap is also go into different extension. There are possibilities of 1.5 times edge to edge; that means, this length is 1.5 times of this 1.4 times of this lengths, sorry and 2 times of edge to edge is that this length are the distance or the spacing of the speakers are 2 times of the spacing of the speaker which compared to the edge to edge.

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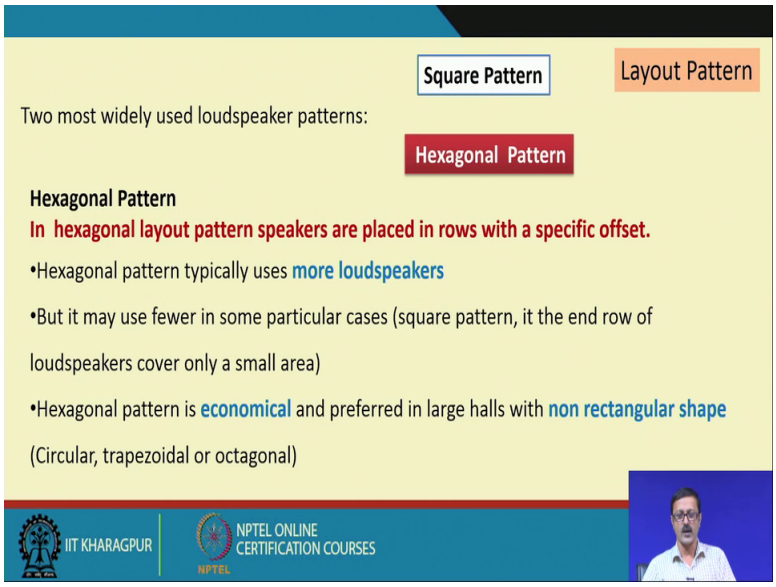

So, those are the square patterns now let us discuss about the hexagonal patterns. In the hexagonal patterns the rows of a specific line and the next rows are having some kind of

a offset with the other and in hexagonal spacings or the patterned you required more number of loudspeaker, but some pattern like a square pattern of the loudspeaker system, in some end rows or in the edge areas there may be some kind of a coverage problem. Then sometimes we have we have to go with a hexagonal pattern in those area, where because some portion may be unattentive in that case or sometimes is this hexagonal pattern also sometimes economical when we deal with some non rectangular space of, suppose a circular auditorium or may be a trapezoidal shape of or octagonal shape of some the lecture hall are something like that. So, all those area a square pattern or the may layout may not be economical, hexagonal will be economical.

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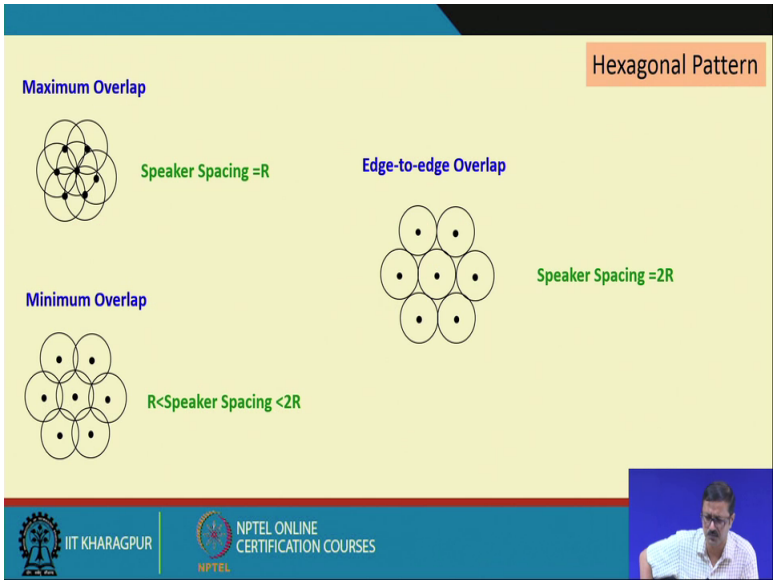

So, there are some hexagonal clustering also. So, if it is very close like those again black points are the speaker points and this circular or the coverage potential coverage circular area on the listening level. So, it can be minimum overlap and the distance between them may be R and there may be a maximum overlap. So, there are overlap, but there is a little bit of way this spacing or little bit of array with respect to the mini maximum and there are may be edge to edge kind of a overlap like that and this particular the on un attentive area with compare to the square is little less it is triangular in that case it was square and this the center to center distance is now become twice of R and in this case of the minimum overlap it is in between.

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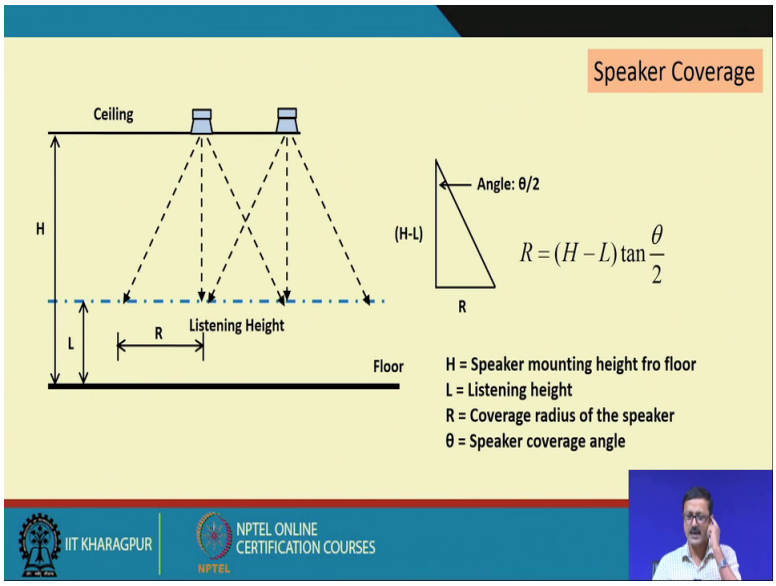

So, we can design also. So, if I just say this R I have to find out which is what is R this is the radius of the coverage circle at the listener height. So, if I know this L this is the listening height which is 4 feet or some something like that and this is the mounting height. So, I know this is as H minus L and this angle is theta by 2 and this is my R. So, with very simple trigonometric functions I can use and I can find out this R equal to this H by L times tan theta by 2. I can found the R and if I can found the R I can found the spacings also, I can found the all the spacings also if just to it know the value of R.

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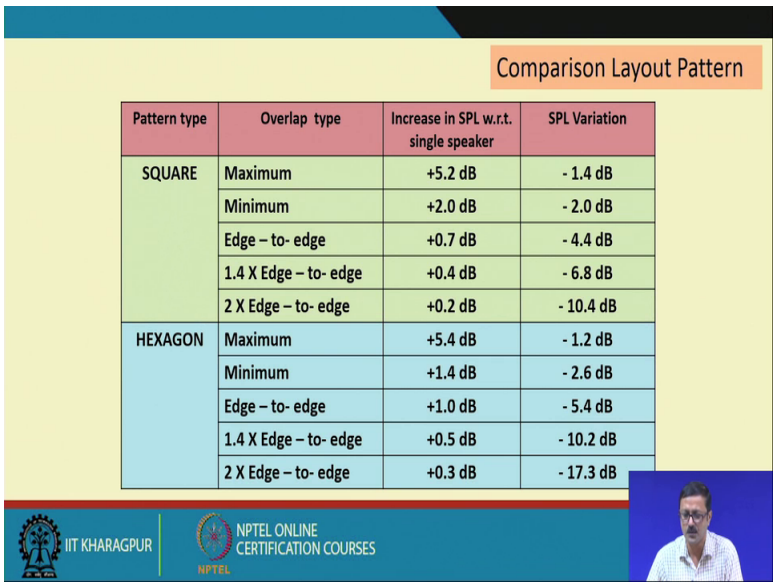

Pattern type	Overlap type	Increase in SPL w.r.t. single speaker	SPL Variation
SQUARE	Maximum	+5.2 dB	- 1.4 dB
	Minimum	+2.0 dB	- 2.0 dB
	Edge – to- edge	+0.7 dB	- 4.4 dB
	1.4 X Edge – to- edge	+0.4 dB	- 6.8 dB
	2 X Edge – to- edge	+0.2 dB	- 10.4 dB
HEXAGON	Maximum	+5.4 dB	- 1.2 dB
	Minimum	+1.4 dB	- 2.6 dB
	Edge – to- edge	+1.0 dB	- 5.4 dB
	1.4 X Edge – to- edge	+0.5 dB	- 10.2 dB
	2 X Edge – to- edge	+0.3 dB	- 17.3 dB

So, if it is a comparison table and for the squares and the hexagonal these are the overlap type maximum minimum edge to edge 1.4 and 2 times edge to edge, so, those are the increase in SPL level for a single speaker, suppose you go for a single speaker and if you go for a edge to edge are maximum levels or so are what are the increment. So, the for a maximum definitely the increment is very high because there are a lot of overlapping, if the minimum overlap the from the single loudspeaker this particular the increases little less and if you if you go for 2 edge to edge 2 times edge to edge is almost like a single loudspeaker because it is the increment plus 0.2 dB.

In case of the hexagonal the maximum is almost plus 5.4 dB with respect to a single and if you go to 2 times the edge to edge it is 0.3 dB as good as the single loudspeaker system and in the SPL variation. SPL variation is that what is the maximum SPL and the minimum SPL if you go for a square and the maximum overlap it is minus 1.4. So, it is almost uniform and then if you go for a minimum and all the SPL variation is actually increasing the variation is increasing.

So, this three are good enough. This three are almost good end off you have to actually see the SPL variation should not be more than 6 dB that create a kind of a sound problem the on uniformity sound problems also. So, from that point of view the first three of the square and the first three of the hexagonal gives you a better type of uniformity which are below 6 dB level.

So, these are the comparison between the square and hexagonal and the sound pressure level.

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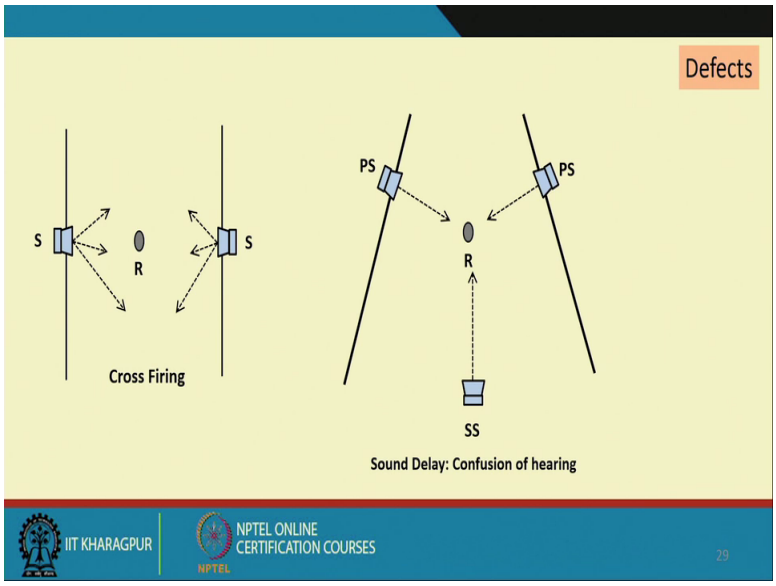

And, in the final let us talk about some 3 defects which encounter in the electro acoustical systems. One is called cross firing, so, if you provide the source of the sound just next to next or the opposite involve and the receiver is actually at the center point it is actually a confusion of the hearing called cross firing. So, it is better to provide the systems not in face to face or directly at the opposite, it has to be some kind of a oblique.

Sometimes a sound delay is also occurs. So, as I discuss that there are some kind of a PS is your the primary source and this is a secondary source will be available from that, the distance is quite urge. So, you will receive this particular receival will receive the sound in a delayed manner, little bit of delay and confusion of the hearing will be occurs. So, you have to check the distances or due to decrease or increase the sound pressure level that do not create that kind of the hearing problem.

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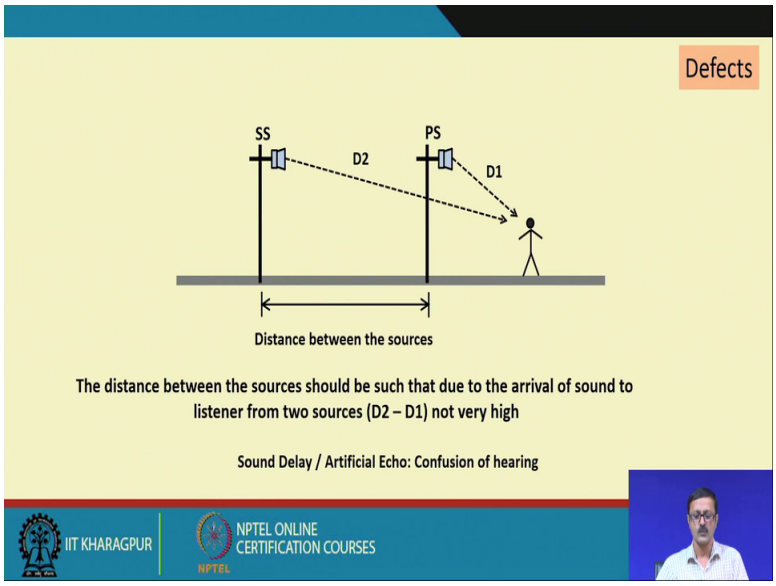

In open hear are may be in kind of some kind of a announcement system this distance is also very important. Because, suppose a particular listener listens a particular announcement from this particular PS primary source at a distance D1 and a secondary source next to D2 and if this D2 minus D1 this path difference is too high it may encounter a artificial echo. Or a it can create a confusion of the hearing particular in the railway station, in the airport or may be in the any public gatherings, any particular rally this kind of the situation may happened.

So, sometimes in the railway station we also kind of a eagerly waiting for some kind of a announcement has to be made for some railway some train and there are some you know some confusion because of this particular fundamentals fundamental problem where D2 is quite height compare to D1 you are listening sound from both. So, the sound comes from D1 reaches you earlier sound comes from D2 or SS is reaches little late and little late means it is not it is more than one tenth of a second late and those to sound are merging with each other in a time lake create a artificial echo or those kind of a problem.

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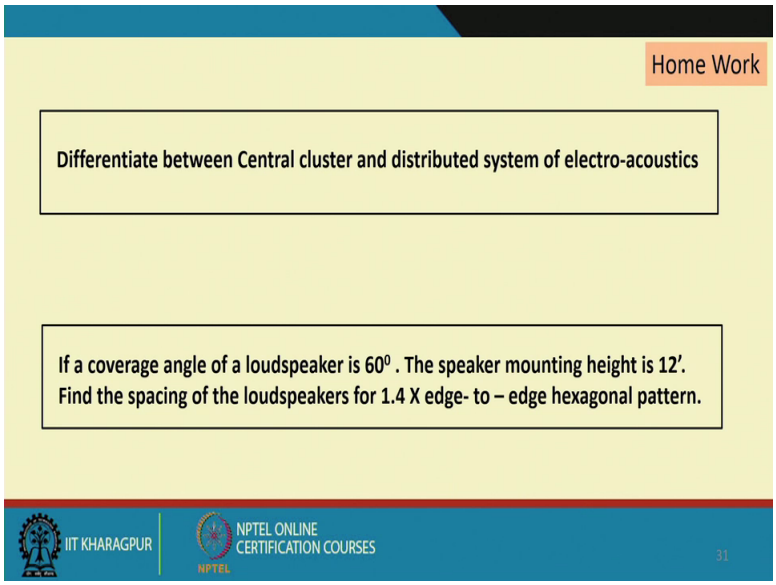

So, that is all for the particular lecture number 27 which deals with the acoustical principles and it is the relation with the systems of acoustics electro acoustics. So, let us have some homework, let us have some homework for your understanding and how you actually learn that this particular 2 lectures and comprehend that through this particular homework. Let us discuss that the let us first one is the something like a again a the theoretical kind of a thing let us differentiate between the cluster system and the distributed system what are the basic need and what are the basic parameters of this two type of system and what are the clustering of the systems, has any difference where in case of the central cluster and in case of the distributed pattern of the loudspeaker, that you have to discuss in the first.

And, in the second one I have given some loudspeaker fundamental properties like 60 degrees the coverage angle and it is suppose 1.4 times edge to edge kind of hexagonal pattern and speaker is mounted at a height of a of a 12 feet and I can you find out the spacing of the loudspeaker seating kind of a scenario.

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So, let us try this two and these are the some of the books which I have referred that is all for the lecture number – 27, Electro Acoustics. In the next lectures in this particular with doctor Sumana Gupta will take you to the outdoor acoustics in the landscape, how it is actually going to effect the outdoor and also the OAT, that is Open Air Theatre design in the remaining three lectures of the week – 6.

So, thank you very much for joining this lecture.