DESIGN AND SELECTION OF APPROPRIATE SOUND REINFORCEMENT SYSTEMS IN LECTURE HALLS.

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Abstract

The study looked into the design and selection of appropriate sound reinforcement systems (SRS) in lecture halls using the Multi-purpose Hall (MPH) and the Mathematics/Computer Science Lecture Hall (MCSLH) of Federal College of Education (Technical), Omoku as case studies. Various acoustic parameters such as frequency; directivity factors, room constant; critical and limiting distance were used to determine whether the sound from the source gets to all the seated listeners in the lecture halls. Also determined was whether the existing Public Address System (PAS) used in the lecture halls could provide the required audio - power. The results revealed that, comprehension of sound from the source was only possible between the sound source and limiting distance of 8.2m and 9.2m for the MPH and MCSLH respectively. The audio - power of lOOw of the present PAS in use is less than the required audio - power of 240w and 203 w for the MPH and MSCLH respectively. The findings were discussed with the selection of the Central System (CS) for the MCSLH because it has a slipped floor and the seated students had a direct line - of - sight. The Distributed System (DS) was selected for the MPH because it has a flat or level floor and seated students do not have a direct line - of- sight.

Introduction

Sound Reinforcement Systems (SRS) in lecture halls are required to obtain loudness and good sound distribution from the source (lecturer) to the listeners (students) to augment the natural sound transmission. This happens when the lecture halls are not designed acoustically and constructed with carefully chosen materials that shall provide the required sound reinforcement and good sound distribution. In this regard, they only become mere large rooms provided to accommodate as many students as possible. Invariably, the speech from the lecturer may not get to audience or listeners at the back seats of the lecture hall (Doelle, 1972; Burberry, 1979; Newman, 1983; and Amasuomo, 1994). The main objective of sound reinforcement according to Sprinkle (1983) is therefore:

> To permit the audience to hear well and create an illusion (hat the sound emanates directly from the talker and that a sound system is required whenever the acoustic power of the talker is unable to create adequate sound levels.

Furthermore, the floors of most lecture halls are usually level or Hat. In this circumstance, the students in the front row seats tend to obstruct those students at the back row seats. Invariably, there shall be sound attenuation, reduced hearing; and impaired sight line for vision or direct line - of - sight. On the importance of good sight line, Templeton and Saunders (1987) said:

> In the case of rows of seating in auditorium, a good sight line also lead to reasonable sound reception. The senses act together, that is, it is easier to follow and comprehend speech if one is watching the speaker mouth the words. In terms of recall, sound cannot compete with sightline - people are vision oriented in education. We learn 11 percent by listening and 83 percent by sight and remember 20 percent of what we hear and 50 percent of what we see and hear.

A SRS consists basically of four elements: microphone, signal processing equipment, amplifier and loudspeakers (Klepper, 1992). The microphone is a device that converts the sound into electromagnetic waves which are fed through a signal processing equipment to an amplifier that amplifies the electromagnetic signals. The amplified signals are finally led into the loudspeaker which converts the amplified signals back to sound as shown in figure 1. Although, the SRS is to produce speech but the speech so produced by the audio power of the system is expected to have a lairly uniform output frequency characteristics. This frequency characteristics should cover as wide a band as possible for the speech to be heard audibly at the low (100-200Hz): medium (500-100Hz); and high 2000 - 2500hz) frequencies respectively. This should be so because, at the low frequencies, the speech is mostly vowel while at the medium to high frequencies, the speech is mostly consonant sounds (Templeton and Saunders, 1987). That is why, when a SRS covers a wide range of frequencies, the vowel and consonant sounds could be heard audibly at all the frequencies.

Statement Of The Problem

The Multi-Purpose Hall (MPH) and the Mathematics/Computer Science Lecture Hall (MCSLH) are two lecture halls that are used for large lecture classes. Because the normal human speech could not be audibly heard by students at the back seats, a public address system (PAS) is used to transmit the sound from the source to all the students in the lecture hall. But there are still some inherent sound transmission problems. These are:

1. Unintelligible and distorted sound from the system as a result of acoustical singing or hum, hiss, crackles and other noises that come from the loudspeaker. This is because of the absence of equalization devices to filter and flatten out the acoustical responses for a smoother sound to be heard by the students. This distracts the students during quiet periods.
2. The audio power of the loudspeaker is 100 watts which appears to be relatively small compared to the size and audience capacity of the lecture halls.
3. The loudspeaker is on the same ground level as the listening students. This means the sound propagated from the loudspeaker is likely to be attenuated by the sound absorptive audience. When this happens., the students seated at the back seats shall receive less sound energy.
4. The microphone in the present arrangement does not afford the teacher to move about with it to the chalkboard or chart to illustrate a point without unknowingly detaching it from the teacher's mouth. This could create loss of speech transmission to the students.
5. The students do not have access to their own microphone during question and answer sessions since there is only one microphone which is for the teacher alone. This could create a psychological separation between the teacher and the students.

   Thus, the PAS does not seem to transfer information effectively from the teacher to the students in either a flat or raked floor.

Purposes Of The Study

The purpose of the study is to design and select appropriate SRS for lecture halls to enhance hearing. To achieve this purpose the following steps shall be taken:

1. Ascertain the floor configuration of the Multi-Purpose Hall (MPH) and the Mathematics/Computer Science Lecture Hall (MCSLH)
2. Establish the average absorption unit and the existing and expected Reverberation Time (RT) of the two lecture halls.
3. Establish the surface area of the materials used for the internal construction of the lecture halls.
4. Evaluate the criteria for determining the design and selection of appropriate SRS in terms of

i. the room constant;
ii. the directivity factors;
iii. the critical and limiting distances;
iv. the types of SRS;
v. the number of loudspeakers required and the spacing/location;
vi. the arrangement of the loudspeakers; and
vii. the audio-power requirement.

5. Evaluate and select appropriate sound reinforcement systems.

Research Hypothesis

The following hypotheses were formulated based on the purpose of the study:

1 The extent of normal speech transmitted from the lecture shall not get to all the students especially those ones seated at the back rows without a sound reinforcement system.

2 The existing public address system (PAS) in use shall not provide the audio-power that shall transmit audible and illegible sound to all the students in the lecturer halls without a carefully designed and selected sound reinforcement system.

Methodology

Choice of Lecture Halls: The MPH and MCSLH of the Federal College of Education (Technical), Oinoku, Nigeria were selected for the study. The two halls are used for large lecture classes. They have a student capacity of 272 and 210 students respectively. The choice was also made because from an earlier study, the two halls did not produce the required reverberation time (Amasuomo, 1997 and 2000). That means the sound from the lecture diminished before it got to the listening audience at the back seats.

Also, a mobile PAS in form of a central system is an oblong loudspeaker with a built-in amplifier and a microphone connected to it with a long cord. It has a tripod stand and is usually positioned on the floor in front of the seated students. It has an audio-power of 100 W.

Features of the lecture Halls MPH has a flat or level floor. The seated students do have a direct line of sight on the sound source. That is, the students in the front seats are likely to obstruct the views of those at the back seats.

The MCSLH has a stepped floor. The seated students have a direct line-of-sight on the sound source. Therefore, the students in the front seats are not likely to obstruct the views of those at the back seats.

Data Collection: The data to be collected shall include:

i. The average sound absorption units for the two halls at the low, medium and high frequencies.

ii. The surface areas of the internal spaces of the two halls. The collt ted data are presented in Tables 1 and 2.

Table 1: Acoustical Data on MPH and MCSLH

Multipurpose Hall (MPH)				Mathematics/Coinput sr Science 1) Lecture Hall (MCSLF		
Frequencies (Hz)	Low 100-200	Mediu 500-100	High 100-2500	Low 100-2500	Medium 500 1000	High 2000-2500
Average absorption unit[2]	0.17	0.25	0.21	0.19	0.27	0.23
Existing reverberation time (second)[2]	0.9	0.4	0.3	0.85	0.50	0.75
Expected reverberation time (second)[2]	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5	1.0-1.5
Directivity factor	4	3	2	4	j	2

Table 2: Physical Data on MPH and MCSLH

Size of lecture Halls"	Length - 1 8.5m Width - 12m Height - 3.5m	15 m 13m 3.8m
Surface Areas[2]	657.5m"	602.8m
Effective floor Area¯	222 m[2]	195 nr
Floor - ear distance'	1.2 m	1.2m
Ceiling - ear distance[2]	2.3 m	2.5 m

Sources: 1 Templeton and Saunders (1987), and Porges, (1977) 2 Amasuomo, (1997 and (2000).

Data Analysis The data for the study shall be analyzed using the works of Sprinkle (1983) to determine:

The room constant
_ . Critical distance
' Limiting distance
4. Loudspeaker spacing
5. The number of loudspeakers
6. The arrangement of loudspeakers
7. The audio-power requirement.

Data Analysis And Results

Before the data are analysed and results are determined, the following parameters for speech transmission shall be considered. '

1. **Frequency Range** The frequency range of particular importance considered for speech intelligibility in room space are 100-200 Hz, 500-1000 Hz and 2000-2500 Hz for low, medium and high frequencies respectively (Tempteton and Saunders (1987); and Porges, (1977) as shown in Table 1. This is because the natural human speech has a frequency range from 100-10,000 Hz (Mackenzie, 1964).
2. **Directivity' Factor:** The directional characteristics of the human voice affects the intelligible reception of words (Driscoll, 1980). Also, the frequency and intensity range of human voice does not give the whole picture of sound transmission. Therefore, how the sound waves coming from the mouth are distributed is governed by the "directivity pattern" (Mackenzie, 1964). Directivity according to Sprinkle (1983) is “the ratio of sound intensity in a given direction to tht at the same point if the same source were radiating in all directions”. The directivity factors given by Templeton and Saunders (1987) as shown in Table 1 are 4, 3, and 2 for low, medium and high frequencies respectively.
3. **Room Constant:** The room constant is referred to a value in square metres, when the sound from the source is kept fairly constant after the initial delay when the sound source has stopped. T his is produced by the reflections of the sound waves from the source by the walls, ceilings, floors and objects in a room. The value of the room constant shall indicate whether the room space is “very live” (long reverberation time and low absorption) or treated (short reverberation time and high absorption).
4. **Critical and Limiting Distance:** The critical distance is the distance from the sound source at which the sound levels of the direct field and the reverberation fields are equal. Conversely, the limiting distance is the greatest distance from the source where comprehension is possible (Sprinkle, 1983).

Determination of the extent of speech transmission from Lecturer to the Students

In determining the extent of normal speech transmission in the two lecture halls, the following steps shall be followed; (all the equations used are from Sprinkle, 1983 in conjunction with the data in Table 1 and 11).

a. Multipurpose Hall (MPH)

I. Room Constant

R Sa/(1 -a)

Where R Room Constant

S Surface area of materials - 657.5 m^2

Average absorption coefficient for the materials of construction in the room space-0.17, 0.25 and 0.21 at low, medium and high frequencies.

At low frequency,

R (657.5x0.17) / (1-0.17) = 134.7m2

At Medium frequency,

R (657.5x0.25)/(1-0.25) = 219.2 m2

At I ligh Frequency,

R (657.5x0.21) / (1-0.21) = 174.8m2

Critical Distance

Dc 0. 141 QR

Where Dc = critical distance

O directivity factor - 4, 3 and 2 at low, medium and high frequencies, room

R constant — 134.7 m2 , 219.2m2 and 174.8m2 at low, medium and high frequencies.

At low' frequency,

Dc 0. 141 4x134.7 3.3 m

At medium frequency,

Dc = 0.141 3x219.2 3.6 m

At high frequency,

Dc = 0.141 2x174.? 2.6 m

3. **Limiting Distance**

D| = 3. 16xDc

Where D| = Limiting distance

Dc = critical distance - 3.3m, 3.6 and 2.6m at low, medium and high frequencies.

At low frequency,

D, = 3.16x3.3 10.4 m

At medium frequency,

D,. = " 3.16x3.6 11.4 m

At high frequency.

Di = 3.16 x 2.6 5.2 m

h. Mathematics/Computer Science Lecture Hall (MCSLH)

I. Room Constant Hall

R Sa/(1 -a)

S Surface area of materials - 603. 8 m

A Average absorption coefficient - 0.19,0.27 and 0.23 at low medium, and high frequencies

At low frequency,

R (602.8x0.19)/(I -0.19) 141.4 m

At medium frequency,

R (602.8x0.27)/(1-0.27) 223.0 m

At high frequency,

R (602.8x0.23)/(1-0.23) 180.1 m

2. Critical Distance

Dc = 0.141 OR

O directivity factor— 4,3 and 2 for low, medium and high frequencies room
R constant - 141.4m, 223m, and 180.lm at low medium and high frequencies.

At low frequency,

Dc = 0.141 4x141.4 3.4 m

At medium frequency,

Dc = 0.141 3x223 3.6 m

At high frequency,

Dc = 0141 2x181.1

2.7 in

3. **Limiting Distance**

D,. = 3.16x Dc

D, = critical distance - 3.4m, 3.6m and 2.7m at low medium and high Frequencies.

At low frequency,

D,. = 3.16x3.4 = 10.7 m

At medium frequency,

D,. = 3.16x3.6 = 11.4m At high frequency,

D,. = 3.16x2.7 = 8.5 m

Inference from the Results:, From Table 1, the average absorption units for the **MPH** at low, medium and high frequencies were 0.17, 0.25 and 0.21 with corresponding reverberation time (RT) of 0.9, 0.4 and 0.3 seconds respectively. Also, for the **MCSLH,** the average absorption units at low, medium and high frequencies were 0.19, 0.27 and 0.23 with corresponding RT of 0.85, 0.5 and 0.75

seconds respectively. This means, the speech from the teacher decays or diminishes between 0.3 and 0. 9 seconds while the expected RT for the two hall is between 1.0-1.0.50 seconds for the three frequencies.

Furthermore, the limiting distance of 10.4m, 1 1,4m and 8.2m at the three frequencies are far less than the effective room length of 18.5 (Table 1 1) for the MPH. Also, the limiting distance of 10.7m, and 8.5m for the MCSLF1 is less than the effective room length of 15m (Table 11). The implication is that adequate comprehension of the speech from the lecturer can only be heard audibly and intelligibly by the listening students at distances not further than the limiting distances for the three frequencies in the two, lecture halls (not further than 8.2 and 9.2 for MPF1 and MCSLH respectively). Any other student seated after the limiting distance is not expected to get adequate comprehension of the speech from the source (figures 2 and 3) in a relaxed listening situation (Templeton and Saunders, 1987). Consequently, a sound reinforcement system (SRS) is required to provide adequate loudness and good sound distribution from the source to all the listening students in the lecture halls. The first hypothesis is therefore accepted.

Determination of Audio-Power Requirement for Sound Reinforcement Systems (SRS) in the Lecture Halls.

Before, the audio-power requirement for SRS in the lecture halls are determined, the loudspeaker spacing and the number of loudspeakers required shall be determined first (all the equations used are from Sprinkle, (1983) in conjunction with the data in Fable I and 1 I).

a. **Multipurpose Hall (MPH)**

I. Determination of Loudspeaker Spacing

D = 1.15 (H-d)

Where D = distance apart of loudspeakers-m

H = floor - to-ceiling height. 3. 5 m

D = floor - ear height of seated students - 1.2 m

D = 1.5(3.5-1.2)m = 2.65 m

2. **Determination of Number of Loudspeakers**

The number of loudspeakers required is determined by dividing the effective audience area by the coverage area or spacing of one loudspeaker.

Given that (Table 11).

Effective audience area (EAA) = 222nr

Coverage diameter of loudspeaker (CDL) = 2.65 m Coverage area of one loudspeaker (CAL) = T T (CDL)“ m ~

2

$3.14\ (2.65)^2 = 5.50\text{m}^2$

2

therefore, the number of loudspeakers required is;

EAA = : 22 - 40

5.50

b. **Mathematics/Computer Science Lecture Hall (MCSLH)**

D = 1.15 (H-d)

11 = 3.8 m

D = 1.2 m

D = 1.15(3.8-1.2)m

= 2.99 m

3. **Determination of Number of Loudspeakers (MCSLH)**

Given that (Table I I):
EAA = **195 m^2** CDL =
2.99 m CAE = 3.
$14(2.99)^2$

2

7.0 m^2

Therefore the number of loudspeaker required is:

195 = 29 7

c. **Audio-Power Requirement For The Two Halls** The power requirement could be determined by the audio - power loudspeaker performance curve (Sprinkle. 1983) using the data in Table I I with the following steps.

i. **For the MPH.**

a. The ceiling-ear distance (Dee) = H-d where 11 = floor-ceiling height - 3.5m

D = floor - ear height of the seated students - 1.2 m

Dee = (3.5-E2) m

= 2.3 m

b. From the performance loudspeaker curve in figure, 4, the ceiling - ear distance of 2.3 m shall given a sound level of 91 dB. That is, 1W of audio-power produces about 91 dB. To get lOOdB at 2.3m, a power of 9dB (100-91 dB) is required. If the sound intensity of 6dB equals 4W per loudspeaker (Sprinkle, 1983), then 9dB will give a power of 6W per loudspeaker. Thus, the total sound output (audio - power) required is 240W (6Wx40 loudspeakers) to produce an audible and intelligible sound (speech).

ii **For the MCSLH.**

a. The ceiling - ear distance (Dee) = Hd

Where H = floor - ceiling height - 3.8m

D = floor - ear height of seated students - 1,2m Dee = (3.8m-1.2) m = 2.5m.

b. From the cure in figure 4, the ceiling - ear distance of 2.5m shall give a sound level of 89dB. That is, 1W of audio - power produces 89dB. To get lOOdB at 2.5m, a power of 11 dB (IOO-89dB)is required. If the sound intensity of 6dB equals 4W per loudspeaker, then

1 IdB will give a power output of approximately 7W per loudspeaker. Thus, the total sound output (audio - power) required is 203W (Wx29 loudspeakers) to produce an audible and intelligible sound (speech).

Inference from the Results: It has been established that the SRS in the MPH and MCSLH should have an audio - power (sound output) of 240W and 203W respectively. These values are more than the 100W audio - power of the mobile Public Address System (PAS) used in the lecture halls. This means that the PAS in use is not capable of providing adequate sound loudness that will be audible and intelligible to the listening students. This calls for selection of appropriate SRS that shall give an audio - power of 240W and 203 W for the MPH and MCSLF1 respectively. The second hypothesis is therefore accepted.

Discussion Of Findings

The results of the findings established that the normal speech from the lecturer is not adequately transmitted and distributed to the listening students especially those seated at the back-row. This was confirmed by the calculated minimum limiting distance of 8.2m and 9.2m for the MPH and MCSLH respectively. This means a SRS is required to obtain adequate loudness and good sound distribution from the source to the listener to augment the natural sound transmission (Newman, 1983).

Furthermore, the mobile PAS with a sound output of 100W did not provide the required audio-power that shall transmit audible and intelligible sound to the listeners. It means that the PAS does not seem to transfer information effectively from the teacher to the students. That is, the PAS has failed in its mission of adequate information transfer. In this regard, Sprinkle (1983) noted that;

> A sound system is really an information device, whereby information from the talker is transmitted to the listeners who must understand the speech if the massage is to be received. If this condition is not achieved, the sound system has failed in its mission.

Selection Of Appropriate Sound Reinforcement Systems

Sound Reinforcement Systems: Basically, there are two types of SRS used in lecture halls: Central System (CS) and Distributed System (DS).

Central System (CS): The central system consists of a cluster of directional horn loudspeakers supplemented by a number of low frequency loudspeakers and usually located above the actual source of the sound in front of the hall to give coverage to specific areas of the seated students. This arrangement is more effective where all the listeners have a direct “line-of-sight” on central loudspeakers (Newman, 1983) and where the sound levels from the cluster of loudspeakers are individually adjusted to give the required directional characteristics.

The CS also gives high realism and the listeners can readily localize the direction of the sound source since the amplified sound comes from the same direction as the original sound and give the listeners the impression of increased loudness or clarity, not that of an artificial sound. In this regard, the horn type of loudspeakers are much used for public address purpose, one advantage being that they are directional (Green, 1995).

Distribution System (DS): The distribution system uses a large number of loudspeakers located within baffles or containers in the ceiling and distributed uniformly over the listeners like “down lighting’'. It is used to provide highly intelligible sound in many difficult situations, especially where the ceiling height is low and the listeners cannot have “line - of - sight" on a central loudspeaker.

The size of loudspeakers used in any container or baffle varies between 200mm and 420mm depending on the height of ceiling which may also vary from 4m above. For the highest quality and uniformity, the 60° coverage angle loudspeakers are more appropriate (Sprinkle, 1983).

Selection of Appropriate Systems:_ From the foregoing, the Central System (CS) is selected for the MCSLH which has a stepped floor since the seated students shall have a direct line-of-sight on a central loudspeakers. Also the speech from the lecturer is not likely to be attenuated by the seated students because there shall be no obstruction of students at the back seats by those in the front seats. Therefore, the cluster of loudspeakers in the CS should produce a combined sound output of 203W as already calculated. Figure 5 shows the CS loudspeaker arrangement.

The DS is selected for the MPH because it has a flat or level floor and the seated students may not have a direct line-of-sight on a central loudspeaker. Also the speech from the lecturer is likely to be attenuated by the seated listeners since the listeners in the front seats shall obstruct those at the back-row seats. In this regard, the DS with loudspeakers distributed in a “down lighting” manner within the ceiling above the listeners is more appropriate. Figures 6 and 7 shows the location of the DS, while figures 8 and 9 shows typical arrangements of DS. Also figures 10 and 1 1 shows the two types of geometrical presentations. It should be noted that, loudspeakers are not to be located along the side walls of the lecture halls to avoid “cross firing” since this may cause listeners to hear multiple time delays thereby reducing intelligibility (Sprinkle, 1983).

Microphones: The microphones used in SRS are omni-directional, unidirectional and bidirectional (Klepper, 1992; and the World Book Encyclopedia. Vol. 13, 1992). The omni-directional microphone has no real directional pattern and picks up sound from all directions. It has a smoother frequency response then the unidirectional or bi-directional type but may not effectively discriminate against room noise. The unidirectional type is most sensitive to sound arriving on an axis perpendicular to it and least sensitive to sounds arriving from the back. They can discriminate against room noise (Sprinkle, 1983). The bi-directional type is used for sound coming from the front and from behind, but not from the sides (The World Book Encyclopedia Vol. 13, 1992). It also cannot discriminate against room noise effectively.

The lavaliere microphone of any of the three types is recommended for the lecturer since it is cordless, light, unobstructive and give adequate voice pick-up. It also has the advantage of being attached to the lecture's dress and allows the lecturer free movement all over with the microphone to either the chalkboard or chart to illustrate a point without the microphone detached from the lecturer's mouth. There is no loss of speech transmission to the students.

Provision Talk-Back Microphones: These are microphones that are either fixed to the ceiling and dropped with cord or are fixed to the seats of the students. It enables the students to talk back during question and answer sessions. These pick-up devices should be placed relatively close to the students. This arrangement also bridges the psychological separation between the students and the lecturer.

Equalization Devices: An equalization device should be provided to control acoustical feedback, hiss and crackles so that the potential acoustical gain of a given installation may be realized. Equalization filters and flatteners out the acoustic responses of a sound system a and smoother sound is heard by the audience. This contributes to the naturalness of the sound system (Klepper, (1992).

The Operator: If an operator is available, he should be located towards the rear of the seating listeners for him to hear the system as it is heard by the listeners. At other times, the operator is placed in the audience (Klepper, 1992).

Installation Every sound system should be installed in a rack cabinet. There should be a conduit system for microphone wiring, a separate one for line power level and a third one for loudspeakers wiling. All conduits should be ferrous type for magnetic shielding.

Conclusion

The provision of SRS in lecture halls for effective teaching - learning entails a careful analysis of the use of the system, the spatial relationship between the sound source with respect to the listeners; the choice between central or distributed systems; and the choice of microphones. When these are analysed and the appropriate system is carefully selected, a conducive lecture hall environment shall be created. This also assures the production of intelligible and undistorted sound from the lecturer to the students. Therefore, the absence of sound impairment means the effective transmission and good sound distribution to all the listening students in the lecture halls. This not only creates a conducive environment but also makes teaching-learning more meaningful.

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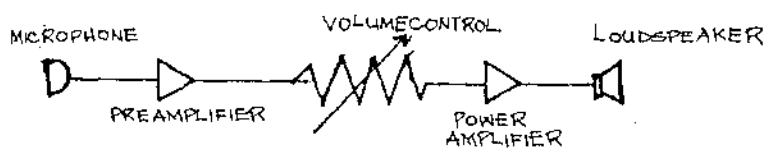

FIGURE 1. BASIC SOUND-REINFORCEMENT SYSTEM

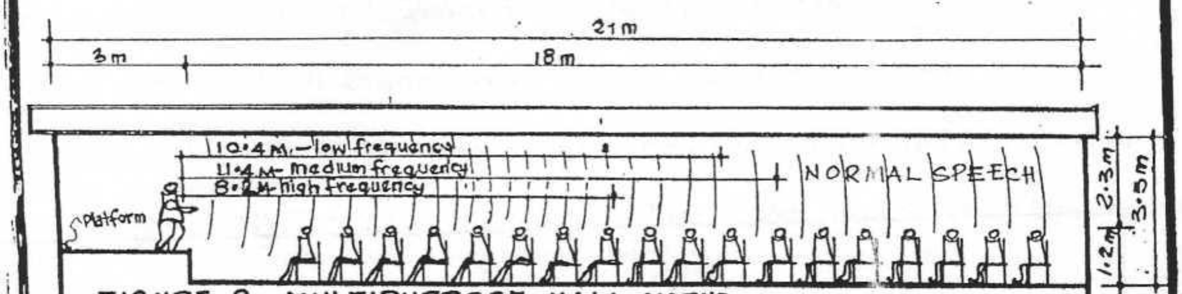

FIGURE 2. MULTIPURPOSE HALL (MPH)
Limiting distance of sound at low, medium and high frequencies.
No direct line-of-sight and sound is attenuated by the audience

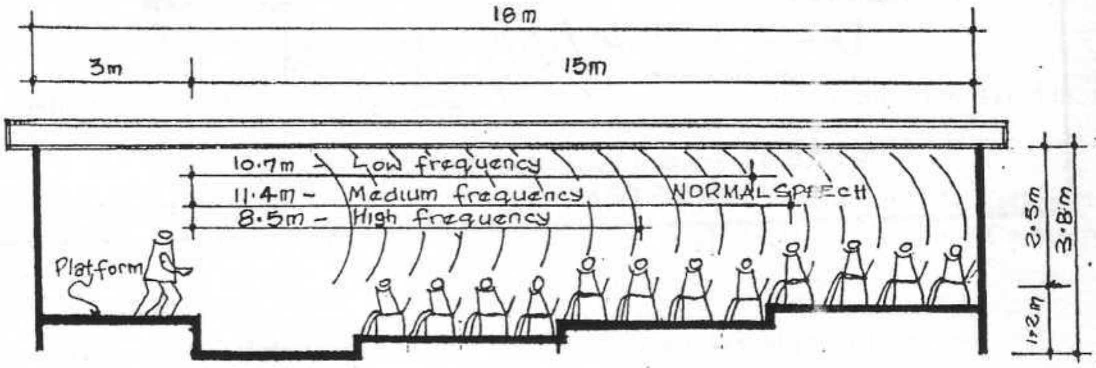

FIGURE 3. MATHEMATICS/COMPUTER SCIENCE LECTURE HALL
Limiting distance of sound at low, medium and high frequencies
There is direct line-of-sight and sound attenuation by the audience is reduced

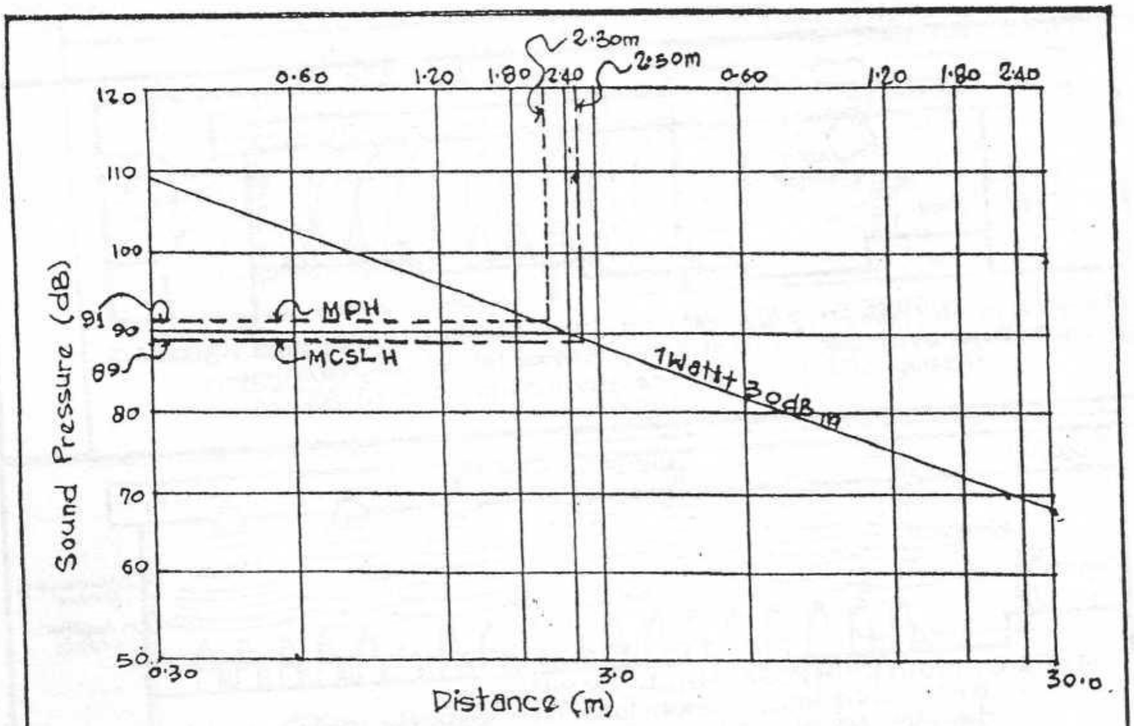

FIGURE 4. Loudspeaker performance curve
SOURCE: Sprinkle, 1983

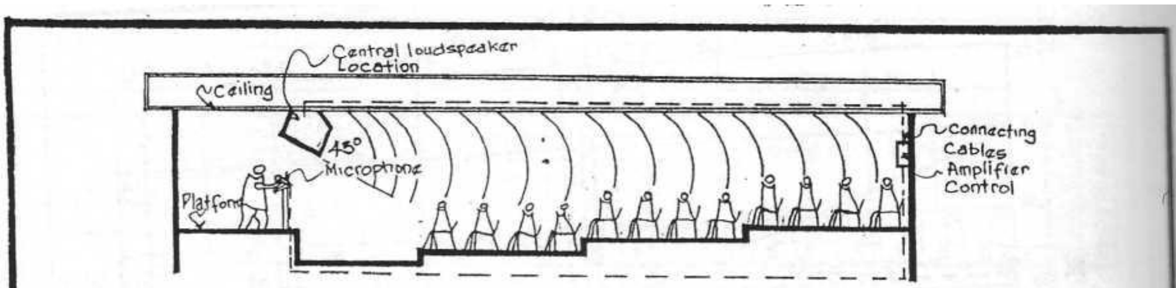

FIGURE 5. MATHEMATICS/COMPUTER SCIENCE LECTURE HALL
Central SRS, Sound is properly distributed, No audience attenuation due to direct line-of-sight

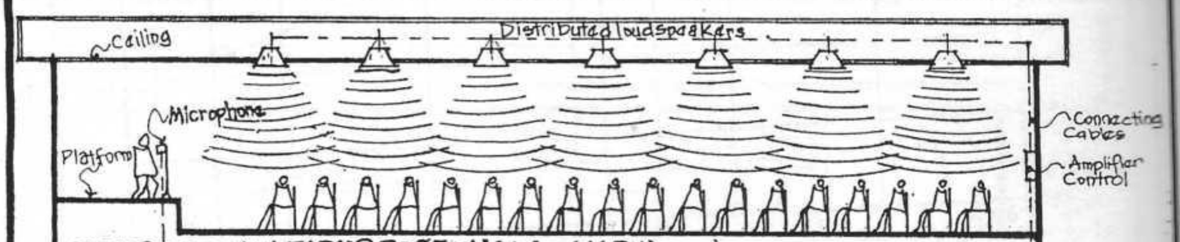

FIGURE 6: MULTIPURPOSE HALL (MPH)
Distributed loudspeaker location – sound is distributed to audience directly. No direct line-of-sight required and no sound attenuation by the seating audience.

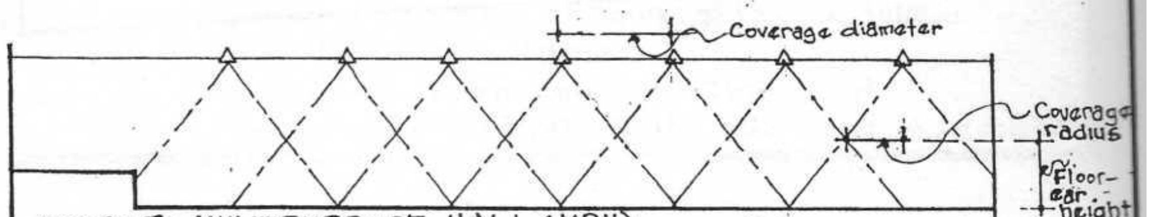

FIGURE 7. MULTIPURPOSE HALL (MPH)
Loudspeaker spacing through cross-section of Lecture Hall

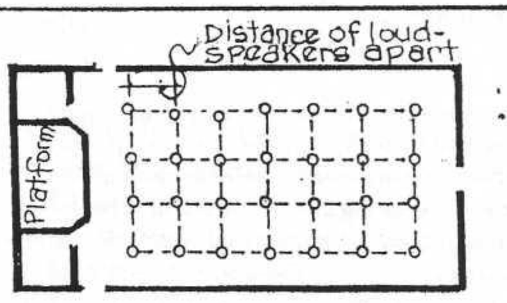

FIGURE 8- Ceiling plan of a typical column and row loudspeaker arrangement

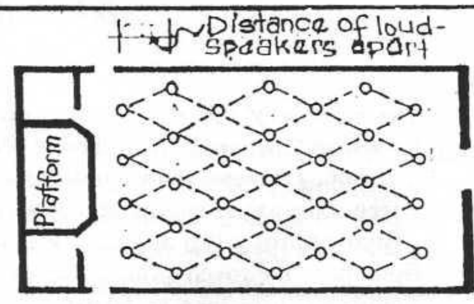

FIGURE 9. Ceiling plan of a typical staggered loudspeaker arrangement

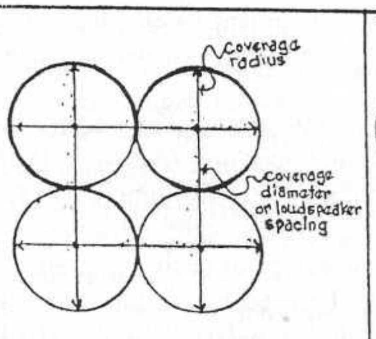

FIGURE 10. Geometrical presentation of column and row loudspeaker spacing

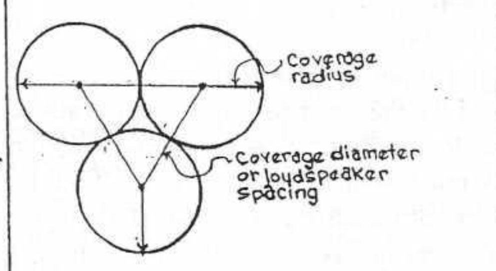

FIGURE 11. Geometrical presentation of staggered loudspeaker spacing