ALTEC TRAINING MANUAL

DESIGN OF DISTRIBUTED SOUND SYSTEMS FOR ROOMS WITH INCLINED FLOORS AND CEILINGS

Introduction

Occasionally it is desired to install a distributed system in a room whose floor and ceiling are not parallel. There are two approaches to the design of such a system. One is to retain a constant loudspeaker density in loudspeakers per −6 dB coverage circle area in the listening plane and hence approximately the same uniformity of coverage throughout the listening area. The second is to maintain a constant loudspeaker unit cell size at the ceiling for simplicity of design. This second method requires that each loudspeaker receives the same input power.

The advantages of the second method are:

1) Simplicity of design with worst case non-uniformity of coverage at the lowest ceiling height.

2) The same power to each loudspeaker.

3) A lower power requirement for loudspeakers at the maximum ceiling height.

The disadvantage of this method is:

1) More loudspeakers of the same type are needed than for Method 1. This is partially compensated for by advantage 3) above which allows the use of a lower power loudspeaker type.

Altec Design Method 1

The basis of this method is a set of four design sheets for each loudspeaker type used for distributed systems. Each sheet has lines at angles drawn symmetrically either side of an axis drawn along the sheet in the longest direction. These lines represent different parameters in different sheets and are:

1) for sheet one, the angles of coverage for the minimum SPL in the listening plane approximately equal to the number of dB shown on the lines. These dB values are relative to the axial level of a single loudspeaker for the 2 kHz one-third octave band.

2) for sheet two, the angles to give the values of $L_{max} - L_{min}$ shown on the lines in the listening plane for the 2 kHz one-third octave band.

3) for sheet three, the same as for sheet one but for the 4 kHz one-third octave band.

4) for sheet four, the same as for sheet two but for the 4 kHz one-third octave band.

Each sheet also has lines inclined to an axis running across the page. The positions of these lines indicate the rotations needed to offset the radiation up the slope for a floor inclined at the angles shown relative to the ceiling. The manner in which these design sheets are used to step off loudspeaker positions in the direction of the slope and across the slope is best shown by example. Examples are given later.

When the positions along the slope have been determined, it may be decided that there is too much overspill into a given area, e.g. onto a stage. To minimize this, the fraction of a coverage circle by which this overspill should be reduced is estimated. The layout along the slope should then be repeated with the same fraction of a coverage circle as overspill at the starting end. The actual distance displaced by each loudspeaker will vary with local ceiling height.

For a system designed to satisfy a particular value of one criterion (L_{min} or ΔL) at one frequency (2 kHz or 4 kHz), the other design sheets can be used to estimate both criteria at both frequencies. Hence L_{max} can also be estimated at both frequencies. These additional estimates are made by comparing angles on the design sheets.

The relative powers required by speakers in different rows for the same direct SPL in the listening plane at the different ceiling heights can be calculated from the inverse square law. Taking the power to a speaker at the lowest height as 0 dB, the power (W_i) required by a speaker in the i^{th} row is given by

$$W_i = 20 \operatorname{Log} \frac{h_i}{h_1} \text{ dB} \qquad (1)$$

where h_1 and h_i are the heights at the lowest row and the i^{th} row respectively.

Method 2

Using the minimum ear to ceiling height, the method given in TM-11 for parallel ceilings and floors should be followed exactly. All speakers should receive the same power. In addition to the advantages given earlier, this design method is well suited to rooms with the floor or ceiling (or both) changing its (their) level in a non-systematic manner.

Articulation Loss

For a distributed system, the maximum articulation loss (AL_{max}) is the smaller of

$$AL = 9T\% \qquad (2)$$

and
$$AL_{max} = \frac{656\ V\ T^2\ N}{S_c^2\ Q_o\ 10^{0.1\ L_{min}}}\ \%. \qquad (3)$$

The minimum articulation loss is the smaller of (2) and

$$AL_{min} = \frac{656\ V\ T^2\ N}{S_c^2\ Q_o\ 10^{0.1\ L_{max}}}\ \%. \qquad (4)$$

where V is the room volume in cu. ft., T is the reverberation time in the frequency band of interest, S_c is the ceiling area, N is the total number of loudspeakers and Q_o is the axial directivity factor of a single loudspeaker. For Method 1, AL_{max} and AL_{min} are each approximately constant throughout the listening plane and are approximately equal to the values for an equivalent parallel floor and ceiling case, (i.e. equal listening plane density). AL_{max} and AL_{min} can be calculated directly from (2) or (3) and (2) or (4)

In the case of Method 2, the greatest value of ΔL occurs at the lowest ceiling height. This is therefore where both AL_{max} and AL_{min} are to be found. AL_{max} is the smaller of (2) and

$$AL_{max} = \frac{656\ h_1{}^2\ T^2\ N}{VQ_o 10^{0.1\ L_{min}}}\ \%. \qquad (5)$$

Also, AL_{min} is the smaller of (2) and

$$AL_{min} = \frac{656\ h_1{}^2\ T^2\ N}{VQ_o 10^{0.1\ L_{max}}}\ \%. \qquad (6)$$

where h_1 is the lowest ear level to ceiling height.

Programmable Calculator Aids

More convenient and faster design alternatives are available in the form of Altec design calculator programs. Most cases of Method 1 can be handled with the information in Programming Note CP-9A. Method 2 designs can be carried out with CP-19A. Articulation loss calculations are included in these Programming Notes.

Examples

Method 1

Example 1

Figure 1 shows a scale drawing of the longitudinal section of a room, preferably on semi-transparent paper. Let it be supposed that a sound system is to be designed with $L_{max} - L_{min}$ equal to 2 dB at 4 kHz, using 403s. The ceiling is inclined at 10° and the floor at 30° giving 20° between them. The appropriate 403 template is taken and the scale drawing superimposed over it as shown in Figure 1 with the loudspeaker inclined to point up the slope such that the 20° line across the template is colinear with the ceiling. The drawing is then slid along until the 2 dB line passes through the corner at the rear wall and ear level plane (point 1). The loudspeaker row position (S_1), the approximate centre (A_1) of the contour pattern and the lower 2 dB point (point 2) can all be marked on the scale drawing. The drawing is then slid along until point 2 becomes the upper 2 dB point for the next speaker row. The next speaker row position

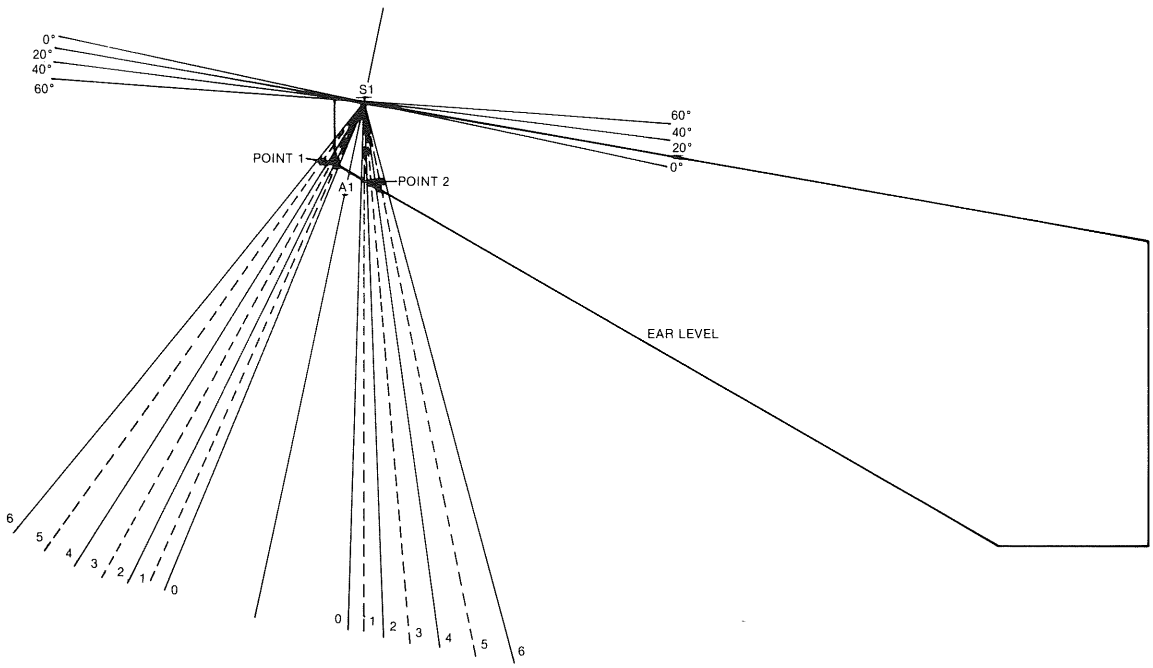

Fig. 1. Longitudinal section of room with template.

(S_2), the new contour centre A_2 and the new lower 2 dB difference point can be marked on the drawing as shown in Figure 2. This process can be continued until all possible row positions have been located.

To locate loudspeakers across the room at S_1, a pair of parallel lines can be drawn separated by the perpendicular distance S_1A_1. The drawing is now placed on the template with the 0 degree line colinear with the upper line. S_1, A_1 and the two -2 dB difference angles can be marked on the lines as shown in Figure 2. A plan view of the room is now drawn with lines in the positions of S_1, S_2, etc. as shown in Figure 3. The positions of the loudspeakers along S_1 can be found by measuring the distance between the intersections of the two 2 dB lines and the lower of the two parallel lines in Figure 2. This distance is now stepped off along the S_1 line in the plan view shown in Figure 3. The loudspeaker positions along S_2, S_3, etc. can be located in a similar manner and are also shown in Figure 3. The power levels (W) relative to S_1 can be found from (1) or from

$$W_i = 20 \operatorname{Log} \frac{d_i}{d1} \text{ dB. } i = 1, 2, \tag{7}$$

where d_i is the length S_1 to A_1. These relative power levels are tabulated in Figure 2.

The maximum and minimum articulation loss of consonants can also be calculated. It is first necessary to find L_{max} and L_{min}. By superimposing the ΔL at 4 kHz design sheet and the L_{min} at 4 kHz design sheet, it can be seen that a ΔL of 2 dB corresponds to an L_{min} of 0 dB. L_{max} at 4 kHz is therefore 2 dB. The volume of the room is 274,500 cu. ft. and the ceiling area is 7,819 sg. ft. The total number of loudspeakers in Figure 3 is 90. If the reverberation time at 4 kHz is 0.6 sec. then (2) yields

$$AL = 5.4\% \tag{8}$$

For an axial Q of 14 at 4 kHz, (3) and (4) yield

$$AL_{max} = 6.87\% \tag{9}$$

and

$$AL_{min} = 4.30\% \tag{10}$$

The maximum articulation loss of consonants is the smaller of (8) and (9), i.e.

$$AL_{max}(4\text{ kHz}) = 5.4\% \tag{11}$$

and the minimum loss is the smaller of (8) and (10), i.e.

$$AL_{min}(4\text{ kHz}) = 4.30\% \tag{12}$$

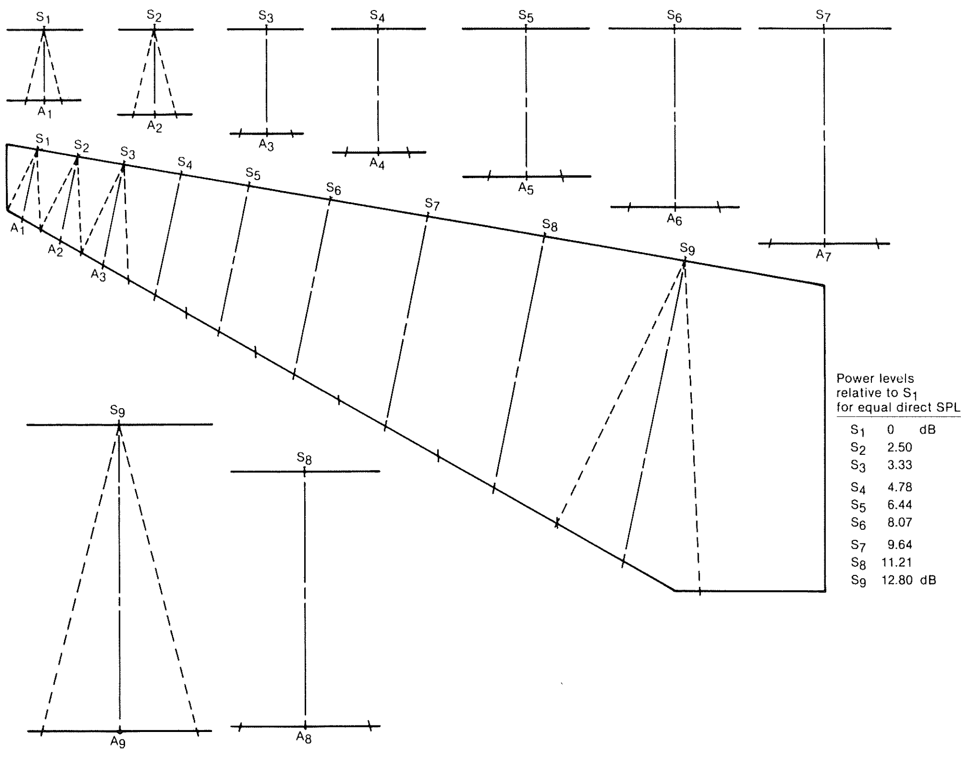

Fig. 2. Longitudinal section of room with loudspeaker row positions.

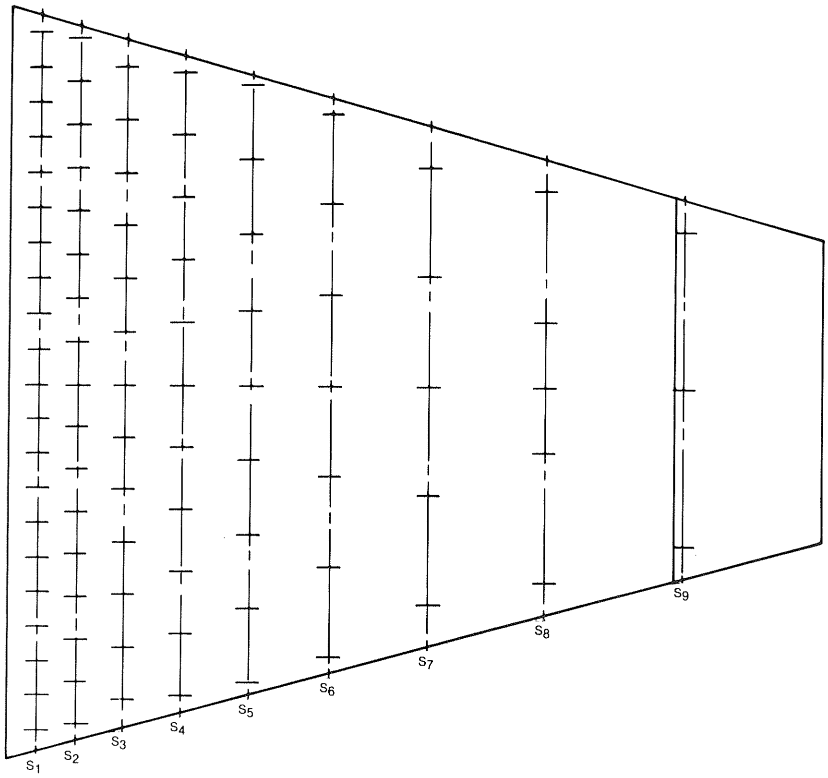

Fig. 3. Plan view of room with loudspeaker positions.

At 2 kHz, superimposing the ΔL and L_{min} design sheets in turn over the ΔL at 4 kHz sheet reveals that at 2 kHz, ΔL is 0 dB and L_{min} is greater than 6 dB. Therefore both L_{max} and L_{min} are greater than 6 dB. For a Q_o of 6.2 and a T of 1.2 sec.

$$AL = 10.8\%. \quad (13)$$

Also $$AL_{max} < 15.47\% \quad (14)$$

and $$AL_{min} < 15.47\% \quad (15)$$

hence $$AL_{max}\,(2\ \text{kHz}) \leqslant 10.8\% \quad (16)$$

$$AL_{min}\,(2\ \text{kHz}) \leqslant 10.8\%. \quad (17)$$

These 2 kHz values are more meaningful than the 4 kHz values.

Example 2

Figure 4 shows an auditorium whose seating area and ceiling are generated by rotation of the longitudinal cross section about a point at the rear of the stage area. It is estimated that the minimum direct SPL (System L_{min}) must be 2 dB higher at 4 kHz, than the axial value attainable on axis for a single 619 in the region of maximum ear level to ceiling distance. For this example, the L_{min} at 4 kHz, template is used. In the longitudinal cross sectional view of Figure 4, the angle of inclination for S_1 is 45°, for S_2 it is 20° and for S_3 and S_4 it is 30° in the opposite direction. The remainder of the design procedure is the same as for Example 1 except that S_1 through S_4 are now arcs. S_2' is an alternative to S_2. With S_2' instead of S_2, the positions of S_3 and S_4 would be slightly different.

If it is desired to know the approximate value of $L_{max} - L_{min}$, the ΔL and L_{min} templates can be superimposed. It can be seen that for this particular loudspeaker that an L_{min} value of 2 dB corresponds to a ΔL value of approximately 1 dB at 4 kHz. Articulation loss could also be calculated if desired.

Method 2 Example

The room in Example 1 above is chosen for this example with a width at the rear of 100 ft. and at the front of 40 ft. The length is 110 ft. and the minimum ceiling height (at the rear) is 8.75 ft. Suppose also that it is stipulated that nowhere shall $L_{max} - L_{min}$ exceed 3 dB at 4 kHz, using 409s. It is given that the horizontal section of floor at the narrow end of the room does not have to have good coverage.

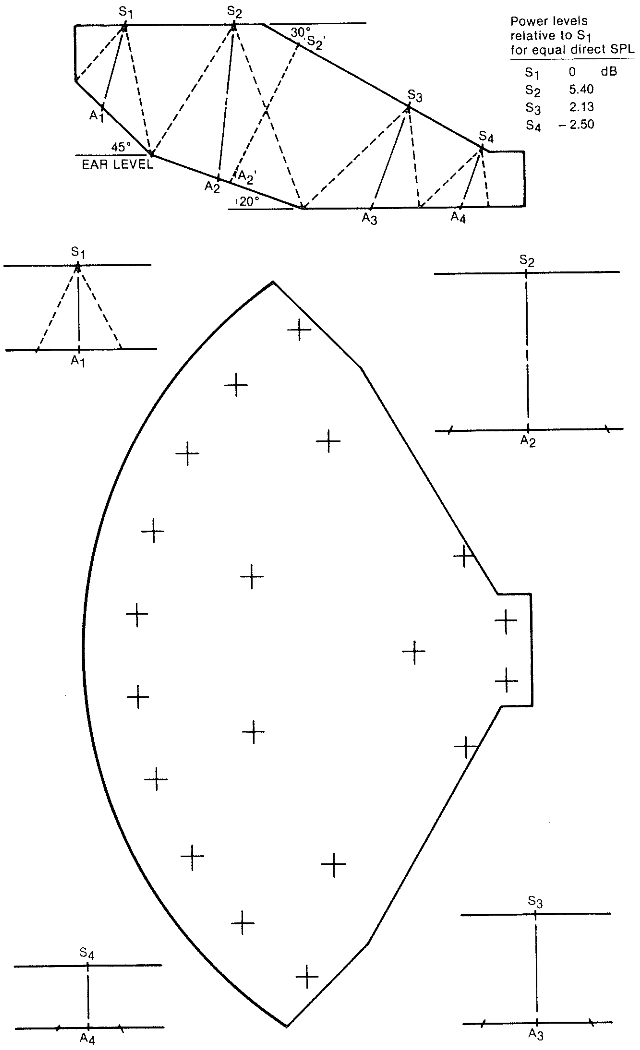

Fig. 4. Room used in example 2.

The perpendicular distance from the rear bottom corner to the ceiling is 8.75 Cos 10° ft., i.e. 8.617 ft. This value is taken as h in the method described in TM-11. The loudspeaker spacing (x) for a square array is given by

$$x/8.617 = 0.63\, e^{3/2.12}$$

$$x = 22.35 \text{ ft.} \qquad (18)$$

This is also the scaling factor for the drawing, i.e. 1 inch represents 22.35 ft.

The hexagonal spacing

$$y = 1.075\, x$$

$$= 23.915 \text{ ft.} \qquad (19)$$

The actual dimensions of the ceiling are:

width at back = 100 ft.

width at front = 40 ft.

length = 110 Sec 10° ft.

= 111.70 ft.

This area and the projection of the floor onto the ceiling plane are shown in Figures 5 and 6 drawn to the scale given by (18). Figure 5 shows a square configuration distributed system and Figure 6 shows a hexagonal configuration. In the case of the square pattern it is probably advisable to slide rows 3 and 4 sideways by half of a loudspeaker spacing as shown in Figure 7.

In all of the above cases, the coverage at the edges is actually better than it at first appears because of image sources due to reflections at the walls.

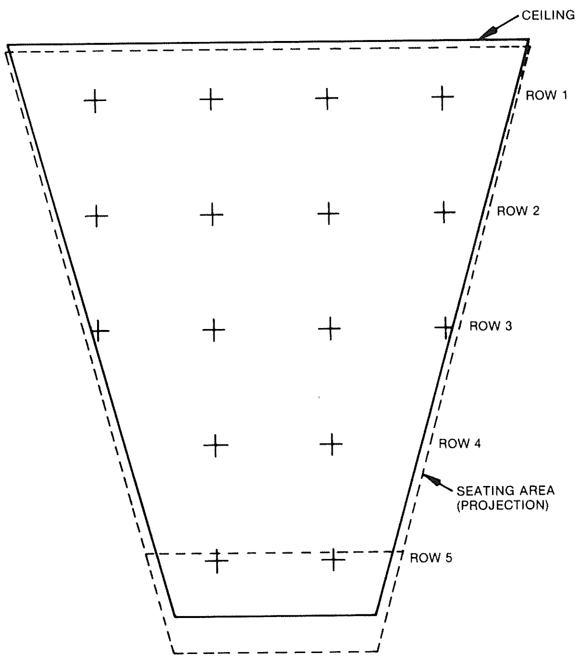

Fig. 5. Perpendicular view of ceiling in method 2 example with projection of seating area and with square loudspeaker pattern.

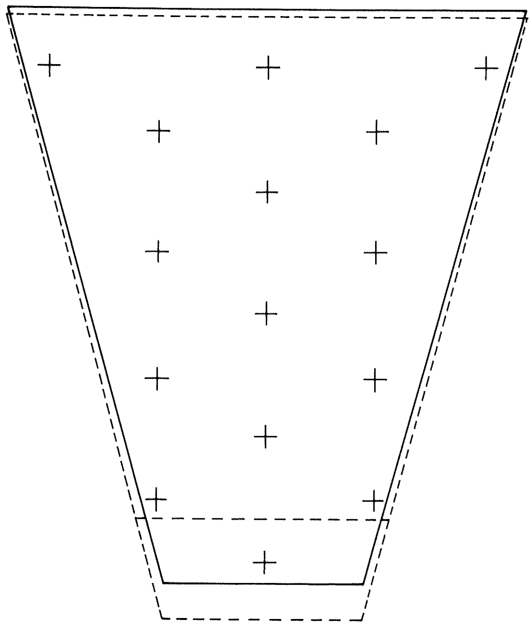

Fig. 6. Perpendicular view of ceiling in method 2 example with hexagonal loudspeaker pattern.

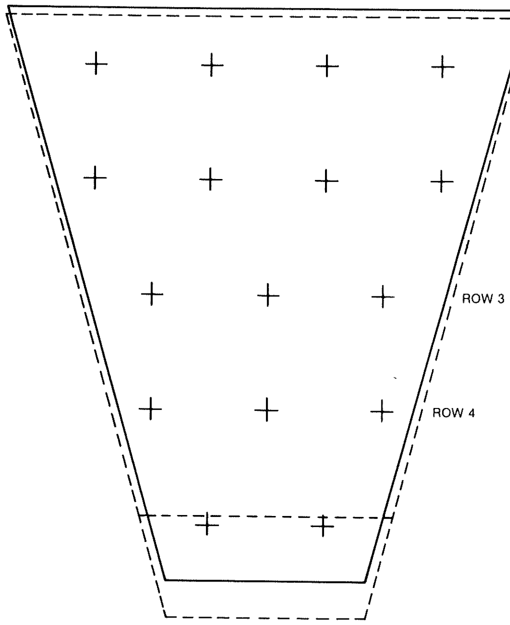

Fig. 7. Square pattern of Fig. 5 with lateral translation of rows 3 and 4 by one-half of one loudspeaker spacing.