ALTEC LANSING ENGINEERING NOTES

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SOUND DISTRIBUTION ON A PLANE NORMAL TO A LOUDSPEAKER AXIS

By
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Introduction

For certain applications, particularly the design of distributed systems, it is desirable to know the distribution of sound on a plane normal to the axis of a loudspeaker. A further advantage is gained if this distribution can be expressed as simple equations with known constants for each speaker of interest. Of particular interest are the angles and radii of coverage on the irradiated plane to -6 dB.

The Equations

In the configuration shown in Figure 1, the sound pressure level (L_p) at P relative to the on-axis value can be taken from a measured polar and can be corrected to the level (L_T) on the plane OR at T by

$$L_T = L_P + 20 \log \cos\theta \text{ dB} \qquad (1)$$

as shown in Appendix 1. This procedure can be carried out at different values of the off-axis angle (θ). Examples are shown in Figure 2 as X. For the various speakers treated in this way, attempts at best-fit equations were made for different types of equations. The overall best equation type was found to be

$$L_T = -a\,\theta^b \text{ dB}. \qquad (2)$$

An example is shown as the solid line in Figure 2. Values of a and b are tabulated in Appendix II for a number of Altec speakers for the 2 kHz and 4 kHz one-third octave bands. The values obtained from (2) show good agreement to about -12 dB (sometimes better).

Letting OS = h and OT = r (the radius of the circle at L_T),

$$\frac{r}{h} = \tan\theta \qquad (3)$$

or $$\theta = \tan^{-1}\frac{r}{h}^{\circ}. \qquad (4)$$

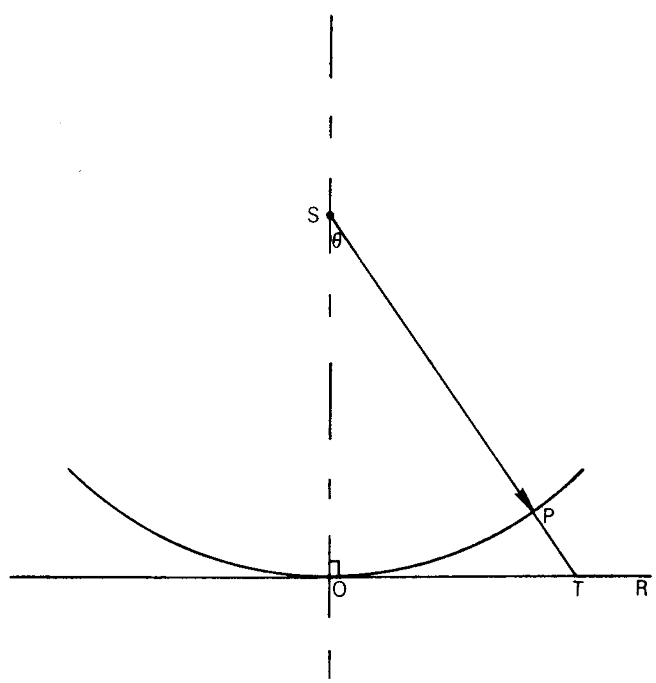

Figure 1.
Loudspeaker (S) Radiating Onto a Plane (OR) Normal to the loudspeaker Axis (OS)

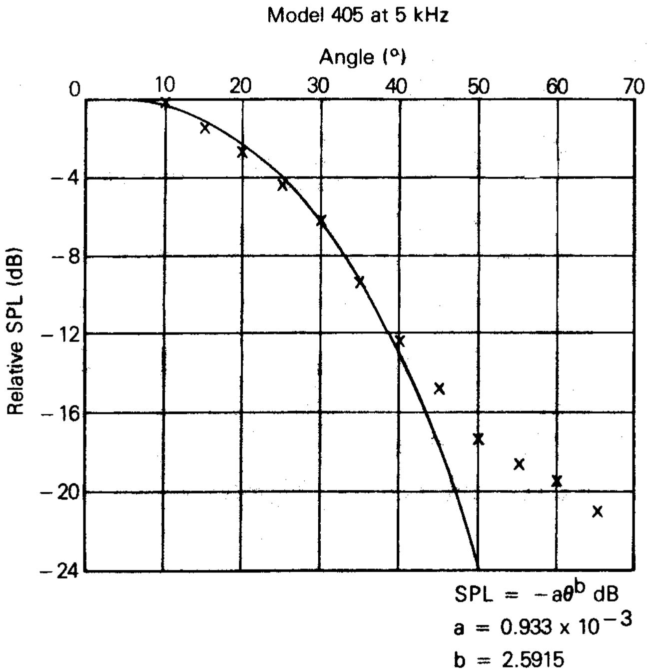

Figure 2.
Example of SPL Values From Polar Curves Corrected to Radiation on a Normal Plane (Indicated by X) and Best Fit Power Curve (Solid Line)

From (2) and (4) L_T can be found for a given ratio r:h, ie

$$L_T = -a\,(\tan^{-1}\frac{r}{h})^b \text{ dB.} \qquad (5)$$

Frequently, it is desired to find θ and $\frac{r}{h}$ for a given value of L_T. From (2),

$$\theta = (-\frac{L_T}{a})^{1/b°}. \qquad (6)$$

and from (3) and (6),

$$\frac{r}{h} = \tan[(-\frac{L_T}{a})^{1/b°}]. \qquad (7)$$

A more accurate determination of θ (and hence $\frac{r}{h}$) for a given L_T can be made by interpolation between points given by (1). The most commonly needed value of L_T is −6 dB. Values of θ at −6 dB [$\theta(-6)$] and $\frac{r}{h}$ at −6 dB [$\frac{r}{h}(-6)$] found by this method are tabulated in Appendix III.

Examples

1) To find L_T (relative to the on axis SPL) for 45° off axis using a 405 at 2 kHz. From (2), using values of a and b from the table in Appendix II,

$$L_T(45°) = -0.372 \times 10^{-3} \times 45^{2.432} \text{ dB} = -3.90 \text{ dB.}$$

2) To find L_T (relative to the on axis SPL) for $\frac{r}{h} = 0.4$ using a 405 at 4 kHz. From (5),

$$L_T(0.4) = -0.0205 \times 10^{-3} (\tan^{-1} 0.4)^{1.6203} \text{ dB}$$

$$= -3.02 \text{ dB.}$$

3) To find the angle (θ) off axis for −3.01 dB using a 409 at 2 kHz. From (6),

$$\theta(-3.01) = (\frac{3.01}{0.5 \times 10})^{\frac{1°}{2.544}}$$

$$= 30.60° = 30° 36'$$

4) To find $\frac{r}{h}$ for −4.5 dB using a 409 at 4 kHz. From (7),

$$\frac{r}{h}(4.5) = \tan[(\frac{4.5}{0.0119})^{\frac{1°}{1.772}}]$$

$$= 0.54.$$

5) To find the angle (θ) and $\frac{r}{h}$ for −6 dB for a 617 at 2 kHz. From the table in Appendix III.

$$\theta(-6) = 42.2°$$

$$\text{and } \frac{r}{h}(-6) = 0.91$$

Summary

The SPL relative to the on-axis value at any angle off axis and on a plane normal to the speaker axis can be found from (2) using values of a and b given in Appendix II. The SPL for any value of $\frac{r}{h}$ can be found from (5) using the given values of a and b. The angle and value of $\frac{r}{h}$ can be found for a given relative SPL on the normal plane from (6) and (7) respectively. All of the above calculations are good for SPL values down to about −12 dB. Values for the off-axis angle and $\frac{r}{h}$ for −6 dB on the normal plane are given for several Altec loudspeakers in Appendix III.

Appendix I

The SPL (L_T) at T in Figure 1 is related to the SPL (L_p) at P by

$$L_T = L_p + 10 \log \left(\frac{SO}{ST}\right)^2 \text{ dB} \qquad (A1)$$

because of the inverse square law.

$$\text{As } \frac{SO}{ST} = \cos\theta, \qquad (A2)$$

$$\text{then } L_T = L_p + 20 \log \cos\theta \text{ dB}. \qquad (1)$$

Appendix II

Speaker	Frequency 2 kHz a	2 kHz b	4 kHz a	4 kHz b
403, 755, 2459	9.064×10^{-3}	1.786	0.0219	1.8787
404, 405	0.372×10^{-3}	2.432	0.02048	1.6203
409	0.5×10^{-3}	2.544	0.0119	1.772
617	0.679×10^{-3}	2.388	0.0651	1.3825
619	0.032×10^{-6}	4.657	0.6776×10^{-3}	2.4912

Table 1. Values for a and b for several Altec loudspeakers for the 2 kHz and 4 kHz octave bands.

Appendix III

Speaker	Frequency 2 kHz $\theta(-6)$ (°)	2 kHz $\frac{r}{h}(-6)$	4 kHz $\theta(-6)$ (°)	4 kHz $\frac{r}{h}(-6)$
403, 755, 2459	38.5	0.80	19.3	0.35
404, 405	53.4	1.35	34.5	0.69
409	39.8	0.83	34.3	0.68
617	42.2	0.91	30.7	0.59
619	58.2	1.61	38.2	0.79

Table 2. Values for the off-axis angle and $\frac{r}{h}$ for -6 dB on the normal plane for several Altec loudspeakers for the 2 kHz and 4 kHz octave bands.