Engineering News

ALTEC LANSING

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TECHNICAL LETTER NO. 196

CALCULATING AND USING CRITICAL DISTANCE

By Don Davis©

The concept of critical distance (D_c) was discussed in Technical Letter No. 182, "Engineering Loudspeaker Locations". D_c is defined as the maximum critical distance in feet from the loudspeaker to the listener for obtaining equality of direct-to-reverberant sound. Greater accuracy in calculating acoustic gain is possible if D_c is calculated and used as a limit on the following distances:

- D_1, the distance between the proposed microphone location and the nearest proposed loudspeaker location.
- D_2, the distance between the proposed loudspeaker location and the most distant listener location.
- D_s, the distance between the proposed microphone location and the proposed talker location.
- D_o, the distance between the proposed talker location and the most distant listener location.

Formula for D_c

At ALTEC, D_c is calculated with the following formula (see Figures 1 and 2):

(eq 1)

$$0.34\sqrt{S \cdot \bar{a}} = D_c$$

Where 0.34 is a constant that includes a 7-dB directivity factor (typical of multicellular and sectoral horns commonly used in high-quality sound reinforcement systems),
S is the total surface area of the space (end walls, side walls, floor and ceiling), and
$\bar{a}$ is the average acoustical absorption coefficient of the total surface area.

Calculation of $\bar{a}$

Use the following procedure to determine $\bar{a}$:
Measure the surface area (s) of each portion of the total surface area (S) having a different absorption coefficient, multiply each value of s by its respective absorption coefficient (a) to get the number of absorption units (sa) in sabins for each s measured, add the values of s to get S and add the sa numbers to get total sabins, then apply equation 2 to get $\bar{a}$.

(eq 2)

$$\frac{s_1a_1 + s_2a_2 \cdots\cdot s_na_n}{S} = \bar{a}$$

Tables I and II contain typical values for "a" frequently required for these calculations.*

EXAMPLE

Assume a room 100 feet long, 50 feet wide and 40 feet high with carpeted floor, plaster ceiling, end walls covered with acoustic material, side walls of hard plaster and 2/3 of the floor area containing 600 heavily upholstered theatre seats. S and sa can be compiled for calculating $\bar{a}$.

Surface	s in ft^2	a	sa
Ceiling	5000	0.05	250 sabins
Floor	5000	0.25	1250 sabins
2 end walls	4000	0.87	3480 sabins
2 side walls	8000	0.02	160 sabins
	S = 22000		sa = 5140 sabins
		600 seats at 3 sa/seat =	1800 sabins
		Total sa =	6940 sabins

Then $\bar{a}$ is derived by substituting S and sa values in equation 2:

(eq 3)

$$\bar{a} = \frac{250 + 1250 + 3480 + 160 + 1800}{22{,}000} = 0.32$$

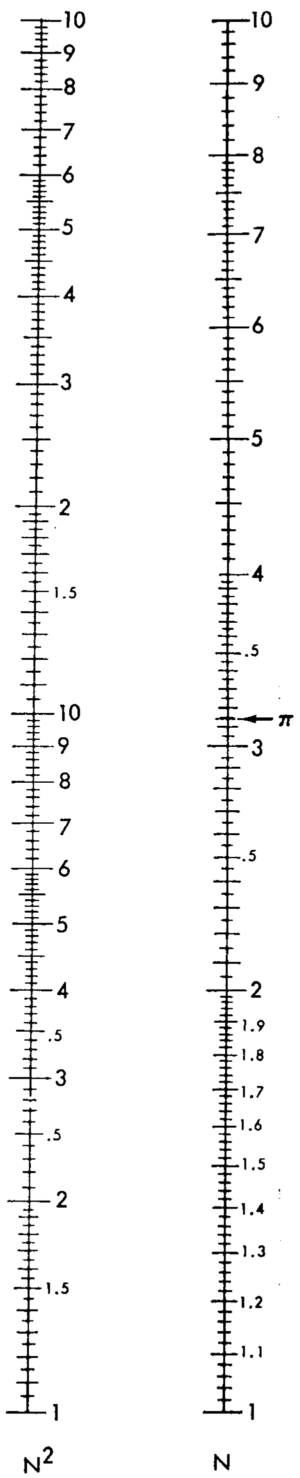
D_c is derived by substituting S and $\bar{a}$ values in equation 1:

(eq 4)

$$D_c = 0.34\sqrt{22{,}000 \times 0.32} = 28.5 \text{ feet}$$

*Sound absorption coefficients of acoustical materials may be obtained from Acoustic Materials Association, 59 East 55th Street, New York, New York 11022.

Litho in USA CP-79-0.75K



TO FIND N^2

FIND N ON N SCALE. N^2 IS DIRECTLY OPPOSITE ON N^2 SCALE.

TO FIND $\sqrt{N}$

FIND N ON N^2 SCALE. $\sqrt{N}$ IS DIRECTLY OPPOSITE ON N SCALE.

Figure 1. Square Root Scales

Ratio of Direct Sound to Reverberant Sound

Inverse square law attenuation is valid in the example room until the D_c of 28.5 feet is reached. Beyond D_c, the distance from the sound source to the listener can be doubled or tripled and a change of only 1 dB or less in sound pressure level (SPL) will be observed on the sound level meter (SLM), but the direct sound from the loudspeaker to the listener continues to attenuate in accordance with the inverse square law because it has not yet undergone relection. By definition, direct sound and reverberant sound are equal at D_c; then at $2D_c$ the direct sound level will therefore have fallen another 6 dB while the reverberant sound level remains virtually the same as when measured at D_c. At $4D_c$ the direct sound level will again have fallen another 6 dB for a total loss of 12 dB. The resultant ratio between the direct sound level at $4D_c$ and the reverberant field sound level of -12 dB represent the maximum allowable ratio if good intelligibility is to be expressed. Two rules can be derived from these relationships:

> RULE 1: $D_1 \geq D_c$
>
> D_1 should equal or exceed D_c to assure full benefit from inverse square law attenuation while achieving maximum potential acoustic gain (PAG).

> RULE 2: $D_2 \leq 4D_c$
>
> D_2 should never exceed $4D_c$, even though adequate acoustic gain is maintained, because the necessary conditions for good intelligibility will be impaired.

Using D_c in Calculating PAG

Since inverse square law attenuation ceases at D_c, it limits any distance greater than D_c when calculating PAG. Considering this limitation, PAG can be determined:

(eq 5)

$$20 \log_{10} \left[\frac{D_1 > D_c = D_c}{D_s > D_c = D_c} \cdot \frac{D_o > D_c = D_c}{D_2 > D_c = D_c} \right] = \text{PAG}$$

Where

$D_1 > D_c = D_c$ is the distance from the microphone to the loudspeaker. If D_1 is greater than D_c, substitute D_c for D_1. If D_1 is equal to or less than D_c, use D_1.

$D_s > D_c = D_c$ is the distance from the microphone to the talker with the limit at D_c.

$D_o > D_c = D_c$ is the distance from the talker to the most distant listener, with the limit at D_c.

$D_2 > D_c = D_c$ is the distance from the loudspeaker to the most distant listener, with the limit at D_c.

In the example room the following factors are obtained:

D_c is 28.5 feet.
$4D_c$ is 114 feet.
D_o is 85 feet. Since $D_o > D_c$, D_c is used as D_o.
D_2 is 75 feet. Since $D_2 > D_c$, D_c is used as D_2.
D_1 is 35 feet. Since $D_1 > D_c$, D_c is used as D_1.
D_s is 2 feet. Since $D_s < D_c$, 2 is used as D_s.

Then substituting these factors in equation 4, PAG is calculated:

(eq 6)

$$20 \log_{10} \left[\frac{28.5}{2} \cdot \frac{28.5}{28.5} \right] = 23 \text{ dB}$$

Table I. Acoustical Absorption Coefficients of General Building Materials

MATERIAL	Coefficient (a)/Hz		
	125 Hz	500 Hz	2000 Hz
Brick wall, painted	.01	.02	.02
Same, unpainted	.02	.03	.05
Carpet, heavy, on concrete	.05	.25	.60
Same, 40 oz. hairfelt underlay	.10	.60	.80
Fabrics			
Light, 10 ozs. per sq. yd., hung straight	.04	.11	.30
Medium, 14 ozs. per sq. yd., draped to half area	.07	.49	.66
Heavy, 18 ozs. per sq. yd., draped to half area	.14	.55	.70
Floors			
Concrete or terrazzo	.01	.02	.02
Wood	.05	.03	.03
Linoleum, asphalt, rubber or cork tile on concrete	.03	.05	.05
Glass	.03	.03	.02
Marble or glazed tile	.01	.01	.01
Openings			
Stage, depending on furnishings		.25-.75	
Deep balcony, upholstered seats		.50-1.00	
Grills, ventilating		.15-.50	
Plaster, gypsum or lime, smooth finish on tile or brick	.01	.02	.04
Same, on lath	.02	.03	.04
Plaster, gypsum or lime, rough finish on lath	.04	.06	.05
Wood paneling	.08	.06	.06
Acoustic tile, typical	.05-.40	.56-.88	.68-.90

Table II. Absorption of Seats and Audiences in Sabins per Person or Unit of Seating

SURFACE	Sabins (sa)/Hz		
	125 Hz	600 Hz	2000 Hz
Audience, seated, depending on character of seats, spacing, etc.	1.0-2.0	3.0-4.3	3.5-6.0
Chairs, metal or wood	.15	.17	.20
Wood pews	.50	.40	.40
Same with cushions	1.2	1.7	2.0
Theatre and auditorium chairs			
Wood veneer seat and back	.15	.25	.50
Upholstered in leatherette	1.5	1.6	2.1
Heavily upholstered in plush or mohair		2.5-3.0	3.0-3.5

Sabin = sa
- a = acoustical absorption coefficient of a surface
- $\bar{a}$ = average acoustical absorption coefficient of total surface area
- s = any surface area
- S = total surface area

If actual measured values were used to calculate PAG, as in the old method, a different result would be derived:
(eq 7)

$$20 \log_{10} \left[\frac{35}{2} \cdot \frac{85}{75}\right] = 25.9 \text{ dB}$$

The results of this revised method explains those few odd cases where the room was very small (as are most conference rooms) or where the room was very "live" and quite large.

Conclusion

It is hoped that each of you will conscientiously use this new method in your planning and carefully report your results back to ALTEC. It is your field data that makes it possible to determine the validity and accuracy of our methods.

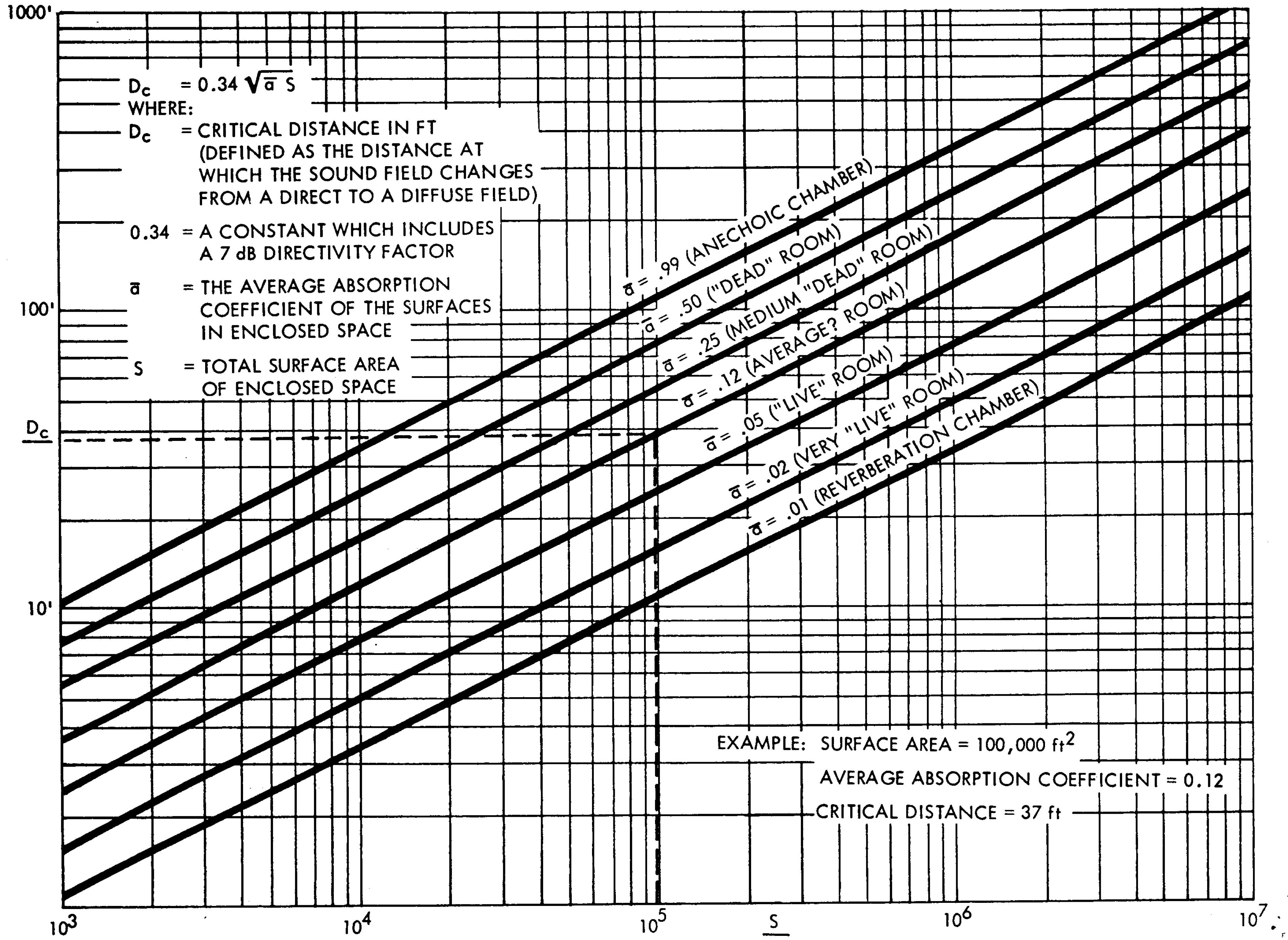


Figure 2. Relationship of Critical Distance Factors