6 p

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Standard Test Method for Objective Measurement of Speech Privacy in Open Offices Using Articulation Index[1]

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ε[1] NOTE—Footnote 4 was added editorially in March 2002.

INTRODUCTION

This is one of a series of test methods for evaluating the acoustical characteristics of open office environments and the performance of acoustical components. Other proposed test methods in this series deal with the laboratory measurement of interzone attenuation of partial height space dividers and ceiling systems.

1. Scope

1.1 This test method describes a means of measuring speech privacy objectively between locations in open offices. This test method relies upon acoustical measurements, published information on speech levels, and standard methods for assessing speech communication. This test method does not measure the performance of individual open office components which affect speech privacy; it measures the privacy which results from a particular configuration of components (1, 2).[2]

1.2 This test method is intended to be a field test for the measurement of speech privacy in actual open offices. However, this test method could be used in an environment arranged to simulate an open office.

1.3 This test method could be adapted for use in other open plan spaces such as open plan schools. It could also be adapted for measuring the speech privacy between open plan and enclosed spaces or between fully enclosed spaces.

1.4 This test method relies upon the Articulation Index which predicts the intelligibility of speech for a group of talkers and listeners. While both the Articulation Index and this test method can be expected to reliably predict average speech privacy, neither predicts the specific degree of speech privacy afforded to particular open office occupants.

1.5 The values stated in SI units are to be regarded as the standard. The inch-pound units in parentheses are for information only.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 384 Test Method for Impedance and Absorption of Acoustical Materials by the Impedance Tube Method[3]

C 634 Terminology Relating to Environmental Acoustics[3]

E 1041 Guide for Measurement of Masking Sound in Open Offices[4]

E 1179 Specification for Sound Sources Used for Testing Open Office Components and Systems[3]

2.2 *ANSI Standards:*[5]

S1.4 Specification for Sound Level Meters

S1.6 Preferred Frequencies and Band Numbers for Acoustical Measurements

S1.11 Specification for Octave, Half-Octave and One-Third Octave Band Filter Sets

3. Terminology

3.1 *Definitions*—The acoustical terminology used in this test method is consistent with Terminology C 634. Of special importance are the terms *average sound pressure level* and *arithmetic mean sound pressure level*, both of which are defined in Terminology C 634, and *source point* which is defined in Specification E 1179.

4. Summary of Test Method

4.1 Select two locations in an open office environment,

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[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] *Annual Book of ASTM Standards*, Vol 04.06.

[4] Discontinued. See 2001 *Annual Book of ASTM Standards*, Vol 04.06.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

between which the speech privacy is to be measured. Designate one location as the *talker* or *source* location and the other as the *listener* or *measurement* location. These locations should typify the usual working positions of office occupants.

4.2 All masking sound systems and HVAC systems shall be operating in their usual manner.

4.3 At the listener location, measure the ambient sound pressure levels in each one-third octave-band from 200 to 5000 Hz and the A-weighted sound level.

4.4 Locate a qualified sound source at the talker location and orient it toward the listener location. Drive the source with pink or white noise at a level sufficient to increase the one-third octave-band sound pressure levels at the measurement location by at least 10 dB above the ambient over the entire frequency range of interest. The sound pressure levels produced by the sound source at a 0.9-m (3-ft) reference position for a known electrical input will have been previously established (3).

4.5 Measure the sound pressure levels in one-third octave bands at the listener location with the source on.

4.6 Calculate the level reduction in each one-third octave band, that is, the difference in sound pressure levels produced by the sound source at 0.9 m (3 ft) and at the listener location.

4.7 Determine the speech spectra to be used. The *normal* voice spectrum of male speech peaks from Table 1 must be used; optionally, additional spectra may be used.

4.8 Calculate the one-third octave-band sound pressure levels for the speech spectrum at the listener location. This is carried out by subtracting the measured level reductions from the speech spectrum.

4.9 Calculate the signal-to-noise ratio in each one-third octave band by subtracting the measured ambient and sound pressure levels from the calculated speech levels at the listener location.

TABLE 1 Speech Peaks for Males[A,B]

One-Third Octave-Band Center Frequency, Hz	One-Third Octave-Band Sound Pressure Levels of Speech Peaks for *Normal* Voice Effort (dB re: 20 μPa)	One-Third Octave-Band Sound Pressure Levels of Speech Peaks for *Raised* Voice Effort (dB re: 20 μPa)
200	60	63
250	64	68
315	63	67
400	65	70
500	66	72
630	64	70
800	58	66
1000	58	65
1250	59	67
1600	56	63
2000	52	59
2500	53	60
3150	53	58
4000	50	56
5000	46	52

[A]Speech peaks calculated from rms values given in Ref (4) by adding 12 db, in accordance with (7). Values given in Ref (4) are normalized to 1 m and are used in this test method as representative values for 0.9 m.

[B]The A-weighted sound level and linear sound pressure level of the *normal* voice effect spectrum given in Table 1 are 70 dBA and 73 dB, respectively. The corresponding levels for the *raised* voice effort spectrum are 76 dBA and 78 dB. These may be compared to the levels for the "idealized speech peak spectrum" given in Table 8 of ANSI S3.5, 74 dBA and 77 dB.(7)

4.10 Calculate the Articulation Index in accordance with Section 11 using the one-third octave-band signal-to-noise ratios.

4.11 Report the Articulation Index to two decimal places as the measure of speech privacy.

5. Significance and Use

5.1 The speech privacy between open offices is determined by the degree to which intruding speech sounds from adjacent offices exceed the ambient sound pressure levels at the listener's ear; a classic signal-to-noise ratio situation.

5.2 The sound pressure levels at the listener's ear from speech in adjacent offices depend upon:

5.2.1 The individual vocal effort and orientation of the talker,

5.2.2 The attenuation of speech signals due to distance or intervening barriers, and

5.2.3 The reinforcement of speech signals due to reflections from office surfaces such as the ceiling, furniture panels, light fixtures, walls, or windows.

5.3 The ambient sound pressure levels will usually be controlled to mask intruding speech. This is accomplished by means of a masking sound system. However, in certain positions and frequency ranges, heating, ventilating, or air conditioning equipment (HVAC) may contribute significantly to ambient sound pressure levels. Guide E 1041 may be used to measure masking sound.

5.4 The primary purpose of this test method is to measure the speech privacy for an average speech spectrum using the standard Articulation Index method. This requires measurement of the relevant acoustical characteristics discussed in 5.2 and 5.3 for a pair of offices and calculation of the Articulation Index using an average speech spectrum. The average speech spectrum is for male talkers speaking with normal voice effort.

5.5 The Articulation Index ranges from 0.00, where speech is unintelligible, to 1.00, where all individual spoken words can be understood. Caution should be exercised in interpreting the numerical results of this test method. There is a need for further research to establish the relationship of Articulation Index to speech privacy. One purpose of this test method is to encourage the measurement of data and further research on this topic perhaps leading to development of well-documented speech privacy categories and criteria.

5.6 This test method can be used to:

5.6.1 Compare the relative privacy afforded between different pairs of open offices.

5.6.2 Evaluate how changes in open office components (barriers, furniture, ceilings, masking sound, or wall panels) affect speech privacy.

5.6.3 Measure speech privacy objectively for correlation with subjective responses.

5.7 This test method could be one element of a performance or acceptance test procedure. However, many additional items would need to be specified to use this test method for performance testing of an open office environment, such as, the number of office pairs to be tested and method of selecting those offices, and the method of averaging the results. Specifying a numerical criterion in terms of the Articulation Index is also necessary for acceptance testing; however, the selection of

such a criterion and permissible deviations should be undertaken with care in view of the present state-of-the-art as discussed in 5.5.

5.8 Recent data on speech levels as discussed in Ref (4) are normalized to 1 m (3.3 ft). However, recently developed test methods for evaluating open office components and systems, including this test method, have been developed using distances standardized in U.S. customary units (feet). This test method assumes that speech levels at 0.9 m (3 ft) and 1 m are equivalent. This is a reasonable and conservative assumption considering that the standard deviation of normal voice speech levels is several decibels or more as discussed in Ref (4). Using a point source model of spherical spreading, the difference in sound pressure levels between 0.9 and 1 m (3 and 3.3 ft) would be at most 1 dB.

6. Test Space

6.1 The test space shall be an actual or a mock-up open office environment.

6.2 The ceiling of the test space shall be complete, including ceiling board, light fixtures, and air diffusers.

6.3 The floor covering and wall finishes shall be completely installed prior to testing.

6.4 Office furnishings shall be in place.

6.5 Any masking sound system shall be set as intended for use in the occupied space.

NOTE 1—If the masking system is adjusted to produce significantly higher sound pressure levels, greater speech privacy is obtained; however, the higher levels may be found unacceptably annoying.

6.6 The open office space should be unoccupied during the tests.

NOTE 2—If the purpose of testing is to evaluate the change in speech privacy which results from component changes (for example, installing wall finishes or adjusting the masking system) the different conditions for each test result shall be carefully documented.

7. Apparatus

7.1 The minimum instrumentation required for this test method is as follows:

7.1.1 *Microphone and Amplifier*, that meet or exceed the requirements of ANSI S1.4 for Type 1 sound level meters. A random incidence microphone shall be used, that is, one that has its flattest frequency response for sounds arriving at random angles.

7.1.2 *One-Third Octave-Band Filter Set*, meeting the requirements of ANSI S1.11 for Order 3 or higher, Type 1 or better. The nominal center frequencies of the filters shall include all the preferred one-third octave bands from 200 to 5000 Hz conforming to ANSI S1.6. This range may be extended.

7.1.3 *Sound Level Meter, Graphic Level Recorder*, or other device from which the sound pressure level can be read.

7.1.4 *Calibrated Sound Source*, of known sensitivity and directivity, completely described in Specification E 1179 and calibrated in accordance with the Annex of this test method.

7.2 *On-Site Data Acquisition Instruments*, that may consist of a microphone with calibrator, a precision sound level meter capable of measuring average sound pressure level, a one-third octave-band analyzer, and a strip chart recorder (optional). Test data may be read on-site or tape recorded for later analysis. Recording instruments may consist of a microphone with calibrator, precision sound level meter (optional), and an instrument quality tape recorder. Laboratory data reduction instruments may consist of a tape recorder, a one-third octave-band analyzer and a computer.

7.3 The background noise of measuring instruments in each one-third octave band must be at least 10 dB below measured sound pressure levels.

8. Test Signal

8.1 The test signal shall be contiguous, one-third octave bands of pink or white noise, from 200 to 5000 Hz, and may be extended.

9. Speech Spectra

9.1 The *normal* voice effort spectrum (2) of speech peaks given in Table 1 shall be used for the calculations. Additionally, other spectra may be used such as the *raised* voice spectrum of speech peaks in Table 1.

10. Procedure

10.1 *Measurement Location*:

10.1.1 Select a listener (measurement) location at the typical ear-height of a seated listener, that is, the microphone shall be located 1.2 m (4 ft) above the floor.

10.1.2 The measurement location should be at least 1 m (3.3 ft) from any vertical surfaces such as walls, columns, desks, or office furniture. In the event that this cannot be met, the selected location shall be at the usual worker's position.

10.2 *Ambient Measurements*:

10.2.1 With the test signal off, the average sound pressure level shall be measured in each one-third octave band over a time period of at least 4 s at four positions at 90° intervals around a circle of 0.3-m (1-ft) radius centered on the location. The arithmetic mean sound pressure level shall be calculated for each band from the four measured values. The A-weighted sound level shall also be measured and calculated in this manner. All data shall be obtained with the microphone diaphragm parallel to the floor and facing upwards.

10.2.2 Verify that the measured ambient sound pressure levels exceed the background noise of the instruments by at least 10 dB in each band. If not, the data shall not be used.

10.3 *Source Location and Orientation*:

10.3.1 The sound source shall be placed at the talker location and the source point shall be located 1.2 m (4 ft) above the floor.

10.3.2 The loudspeaker axis should be oriented so that its projection in the horizontal plane is along a straight line from the talker to the listener location.

10.3.3 In the vertical plane, the loudspeaker axis should be oriented to be 25° above horizontal.

10.4 *Level Reduction Measurements*:

10.4.1 Turn the test signal on and measure and adjust the electrical signal to be the same as used for the measurement of the reference levels.

10.4.2 Repeat the measurements described in 10.2.1.

10.4.3 Verify that the measured sound pressure levels exceed the *ambient* values measured in 10.2 by at least 10 dB in

each band. If not, the data shall not be used.

10.4.4 Calculate the level reduction due to the environment in each one-third octave band, by subtracting the values measured at the measurement location from the source reference levels (see Annex A1).

11. Calculation

11.1 Select a sound pressure level spectrum of speech peaks from Table 1 or elsewhere. One set of calculations shall use the normal voice spectrum from Table 1, as required by 9.1.

11.2 Calculate the sound pressure levels of peak speech signals in each one-third octave band at the listener location by subtracting the level reductions from the spectrum selected in 11.1.

11.3 Calculate and round to the nearest decibel, the signal-to-noise ratio in each one-third octave band: the amount by which the peak speech levels calculated in 11.2 exceed the ambient values measured in 10.2. Whenever the signal-to-noise ratio is zero or less, use a value of zero; whenever the signal-to-noise ratio is 30 dB or more, use a value of 30.

11.4 Calculate the Articulation Index by multiplying the band weighting factors from Table 2 by the signal-to-noise ratios and summing as follows:

$$AI = \sum_{i=1}^{15} W_i \cdot R_i \qquad (1)$$

where:

AI = Articulation Index,
W_i = weighting factor (from Table 2) for band i, and
R_i = signal-to-noise ratio for band i.

NOTE 3—Fig. 1 presents a data sheet that may be helpful in performing these calculations.

12. Report

12.1 Report the following information:

12.1.1 Statement, if true in every respect, that tests were conducted in accordance with the provisions outlined in this test method. Any options or exceptions to this test method shall be noted.

TABLE 2 Articulation Index Weighting Factors for Preferred One-Third Octave Bands in Accordance with ANSI S3.5 (7)

One-Third Octave-Band Center Frequency, Hz	Weighting Factor
200	0.0004
250	0.0010
315	0.0010
400	0.0014
500	0.0014
630	0.0020
800	0.0020
1000	0.0024
1250	0.0030
1600	0.0037
2000	0.0038
2500	0.0034
3150	0.0034
4000	0.0024
5000	0.0020

12.1.2 Description of the test space including the ceiling material, the type of ceiling suspension system, light fixtures, ceiling height, the partial height space dividers, and the floor covering. Optionally, descriptions may be useful for ceiling diffusers, construction details above and below the ceiling, the plenum depth, wall finishes, and interior furnishings.

12.1.3 Description of the sound source location and orientation and the measurement location including distances from office boundaries and furniture. Optionally, sketches may be used to illustrate positions and distances.

12.1.4 Description of any masking system including the means of generating and distributing sound.

12.1.5 Description of the air handling system or other ambient noise sources that contribute to masking sound.

12.1.6 Complete description of the test signal and the sound source.

12.1.7 Description of the instruments used to acquire acoustical data including manufacturer, type, and model.

12.1.8 Statement identifying data that were not acquired at least 1 m (3.3 ft) from the nearest vertical surface.

12.1.9 Statement that "The calculated Articulation Indices given in this report are a function of the specific environment and should not be construed as applying to other environments."

12.1.10 Listing, and optionally a graph, of the following one-third octave-band sound pressure level spectra rounded to the nearest decibel:

12.1.10.1 Reference levels for the sound source,

12.1.10.2 Ambient values measured in accordance with 10.2.1, including the A-weighted sound level,

12.1.10.3 Values measured with the sound source on in accordance with 10.4.1,

12.1.10.4 Level reductions calculated in accordance with 10.4.3,

12.1.10.5 Spectra of speech peaks used (one of which must be the normal voice spectrum),

12.1.10.6 Levels of speech peaks calculated in accordance with 11.2, and

12.1.10.7 Signal-to-noise ratios calculated in accordance with 11.3.

12.1.11 Calculated Articulation Index rounded to two decimal places.

12.2 If testing is undertaken to compare the resulting speech privacy under different conditions such as with different masking spectra, the test report should indicate the Articulation Indices for each condition.

13. Precision and Bias

13.1 The precision and bias of this test method have not been established.

14. Keywords

14.1 architectural acoustics; articulation index; field test; open office; open office system; open-plan space; speech privacy; system test

A	B	C	D	E	F	G	H	I	J
Band	Source Lp 1 meter	Listener office mean Lp	Level reduction (dB) (B-C)	Normal voice peak Lp	Speech Lp listener office (E-D)	Listener office mean ambient Lp	Signal-to-noise ratio (dB) (F-G)	Weighting factor	A I contribution (HxI)
200				60				.0004	
250				64				.0010	
315				63				.0010	
400				65				.0014	
500				66				.0014	
630				64				.0020	
800				58				.0020	
1000				58				.0024	
1250				59				.0030	
1600				56				.0037	
2000				52				.0038	
2500				53				.0034	
3150				53				.0034	
4000				50				.0024	
5000				46				.0020	
A-weighted								AI (Total):	

NOTE 1—L_p denotes sound pressure level, dB re 20 μPa. Example: (B-C) denotes arithmetic subtraction of values in Column C from Column B. Column H: If less than 0 use 0, if more than 30 use 30.

FIG. 1 Sample Data Sheet for Speech Privacy Measurements

ANNEX

(Mandatory Information)

A1. CALIBRATION OF THE SOUND SOURCE

A1.1 Measurement of Reference Levels

A1.1.1 The reference sound pressure level in each one-third octave band is defined as the arithmetic average of the levels measured on the loudspeaker axis at 0.6, 0.9, and 1.2 m from the source point. Obtain these levels in an anechoic room with surfaces that have a minimum normal incidence sound absorption coefficient of 0.990 at all frequencies above 175 Hz as measured in accordance with Test Method C 384.

A1.1.2 Measure and document the electrical signal fed to the source. This can be accomplished by measuring the voltage fed to the loudspeaker using a precision sound level meter set to A-weighting. A precision sound level meter can be used as a wide-band voltmeter by removing the microphone and driving it directly with an electrical signal.

APPENDIXES

(Nonmandatory Information)

X1. RELATIONSHIP OF ARTICULATION INDEX TO SPEECH PRIVACY

X1.1 The Articulation Index ranges from 0.00 to 1.00. Values increase as speech privacy becomes progressively worse. There is a need for further research to establish the relationship of Articulation Index to speech privacy. The following general guidelines are provided to give the user of the test method some means to interpret the numerical results:

X1.1.1 Speech privacy may be described as *confidential* when speech cannot be understood. This degree of speech privacy is indicated at Articulation Index values at or below 0.05 **(5, 6)**.

X1.1.2 At Articulation Index values between 0.05 and 0.20, *normal* speech privacy is indicated. In this range concentrated effort is required to understand intruding speech **(6)**.

X1.1.3 Speech becomes more readily understood at Articulation Index values greater than 0.20. Some describe unacceptable privacy as values above 0.30. At Articulation Index values above 0.40, there is essentially no privacy.

X2. ALTERNATE SINGLE NUMBER RATING

X2.1 Another useful scale for speech privacy is called Privacy Index, (PI). It is expressed in percent and can be calculated from the Articulation Index, (AI) as follows:

$$PI=(1-AI)\times 100\% \qquad (X2.1)$$

X2.2 Consequently, confidential speech privacy is achieved at PI values of 95% or more. Normal speech privacy corresponds to PI values between 80 and 95%.

REFERENCES

(1) Warnock, A. C. C., "Studies of Acoustical Parameters in Open-Plan Offices," *Journal of the Acoustical Society of America*, Vol 63, No. 3, March 1978, pp. 832–840.

(2) Warnock, A. C. C., "Acoustical Privacy in the Landscaped Office," *Journal of the Acoustical Society of America*, Vol 53, No. 6, June 1973, pp. 1535–1543.

(3) Herbert, R. K., "Use of the Articulation Index to Evaluate Privacy in the Open Office," *Noise Control Engineering*, Vol 11, No. 2, September-October 1978, pp. 64–67.

(4) Pearsons, K. S., Bennett, R. L., and Fidel, S., "Speech Levels in Various Noise Environments," *EPA-600/1-77-025*, U. S. Environmental Protection Agency, May 1977, p. 39. Available from National Technical Information Service as *No. PB-270 053*.

(5) Cavanaugh, W. J., Farrell, W. R., Hirtle, P. W., and Watters, B. G., "Speech Privacy in Buildings," *Journal of the Acoustical Society of America*, Vol 34, No. 4, April 1962, pp. 475–492.

(6) Pirn, R., "Acoustical Variables in Open Planning," *Journal of the Acoustical Society of America*, Vol 49, No. 5, May 1971, pp. 1339–1345.

(7) ANSI S3.5–1969, "Method for the Calculation of Articulation Index", American National Standards Insitute, New York, NY 10036.