



Designation: E 2249 – 02

Standard Test Method for Laboratory Measurement of Airborne Transmission Loss of Building Partitions and Elements Using Sound Intensity¹

This standard is issued under the fixed designation E 2249; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This standard test method is part of a set for evaluating the sound transmission loss of a partition or partition element under laboratory conditions. It differs from Test Method E 90 in that the sound power radiated by the element under test is measured directly using an intensity probe rather than indirectly from the space averaged receiver room sound pressure and the room reverberation time. This test method is especially useful when the receiver room requirements of Test Method E 90 can not be achieved, or flanking sound involving the receiver room surfaces is present but its influence is to be circumvented (**1**)², as discussed in Annex A3.

Others test methods to evaluate sound insulation of building elements include: Test Method E 90, airborne transmission loss of an isolated partition element in a controlled laboratory environment, Test Method E 492, laboratory measurement of impact sound transmission through floors, Test Method E 336, measurement of sound isolation in buildings, Test Method E 1007, measurement of impact sound transmission in buildings, Guide E 966, measurement of sound transmission through building facades and facade elements.

1. Scope

1.1 This test method covers the measurement of airborne sound transmission loss of building partitions such as walls of all kinds, operable partitions, floor-ceiling assemblies, doors, windows, roofs, panels and other space-dividing building elements. It may also have applications in sectors other than the building industry, although these are beyond the scope.

1.2 The primary quantity reported by this standard is Intensity Transmission Loss (ITL) and shall not be given another name. Similarly, the single-number rating Intensity Sound Transmission Class (ISTC) derived from the measured ITL shall not be given any other name.

1.3 This test method may be used to reveal the sound radiation characteristics of a partition or portion thereof.

1.4 *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.*

NOTE 1—The method for measuring the sound intensity radiated by the

¹ This test method is under the jurisdiction of ASTM Committee E33 on Environmental Acoustics and is the direct responsibility of Subcommittee E33.03 on Sound Transmission.

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² The boldface numbers in parentheses refer to the list of references at the end of this standard.

building element under test defined by this ASTM standard meets or exceeds those of ISO 15186-1. Special consideration will have to be given to requirements for the source room and specimen mounting if compliance with ISO 15186-1 is also desired as they differ from those of this standard.

2. Referenced Documents

2.1 ASTM Standards:

C 634 Terminology Relating to Environmental Acoustics³
E 90 Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements³

E 336 Test Method for Measurement of Airborne Sound Insulation in Buildings³

E 413 Classification for Rating Sound Insulation³

2.2 ANSI Standards:⁴

S1.9 Instruments for the Measurement of Sound Intensity
S1.11 Specification for Octave-Band and Fractional Octave-Band Analogue and Digital Filters

2.3 ISO Standards:⁴

ISO 140-3 Acoustics—Measurement of Sound Insulation in Buildings and of Building Elements—Part 3: Laboratory Measurements of Sound Insulation of Building Elements
ISO 9614-1 Acoustics—Determination of Sound Power

³ Annual Book of ASTM Standards, Vol 04.06.

⁴ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

Levels of Noise Sources Using Sound Intensity—Part 1: Measurement at Discrete Points

ISO 9614-2 Acoustics—Determination of Sound Power Levels of Noise Sources Using Sound Intensity—Part 2: Measurement by Scanning

ISO 15186-1 Acoustics—Measurement of Sound Insulation in Buildings and of Building Elements Using Sound Intensity—Part 1: Laboratory Conditions

ISO 15186-2 Acoustics—Measurement of Sound Insulation in Buildings and of Building Elements Using Sound Intensity—Part 2: In-Situ Conditions

2.4 *IEC Standard*:⁵

IEC 1043 Instruments for the Measurement of Sound Intensity

3. Terminology

3.1 The acoustical terminology used in this method is intended to be consistent with the definitions in Terminology **C 634** and Test Method **E 90**. Unique definitions of relevance to this test method are presented here:

3.1.1 *sound intensity*, I —time averaged rate of flow of sound energy per unit area in the direction of the local particle velocity. This is a vector quantity which is equal to:

$$\vec{I} = \frac{1}{T} \int_0^T p(t) \cdot \vec{u}(t) \cdot dt \frac{W}{m^2} \quad (1)$$

where:

$p(t)$ = instantaneous sound pressure at a point, Pascals,

$\vec{u}(t)$ = instantaneous particle velocity at the same point, m/s, and

T = averaging time, s.

3.1.2 *normal sound intensity*, I_n —component of the sound intensity in the direction normal to a measurement surface defined by the unit normal vector \vec{n} :

$$I_n = \vec{I} \cdot \vec{n} \frac{W}{m^2} \quad (2)$$

where:

\vec{n} = unit normal vector directed out of the volume enclosed by the measurement surface.

3.1.3 *normal unsigned sound intensity level*, $L_{|n|}$ —ten times the common logarithm of the ratio of the unsigned value of the normal sound intensity to the reference intensity I_o as given by:

$$L_{|n|} = 10 \log \frac{|I_n|}{I_o} \text{ dB} \quad (3)$$

where:

$$I_o = 10^{-12} \frac{W}{m^2} \quad (4)$$

3.1.4 *normal signed sound intensity level*, L_{In} —ten times the common logarithm of the ratio of the signed value of the normal sound intensity to the reference intensity I_o as given by:

$$L_{In} = \text{sgn}(I_n) 10 \log \frac{|I_n|}{I_o} \text{ dB} \quad (5)$$

where:

$\text{sgn}(I_n)$ = takes the value of negative unity if the sound intensity is directed into the measurement volume, otherwise it is unity.

3.1.5 *pressure-residual intensity index*, δ_{pI_o} —the difference between the sound pressure level, L_p , and the unsigned normal sound intensity level when the intensity probe is placed and oriented in a sound field where the sound intensity is zero, expressed in decibels,

$$\delta_{pI_o} = L_p - L_{|n|} \quad (6)$$

Additional details can be found in IEC 61043.

3.1.6 *measurement surface*—surface totally enclosing the building element under test on the receiving side, scanned or sampled by the probe during the measurements. This surface has an area S_m expressed in m^2 .

3.1.7 *measurement distance*, d_m —distance between the measurement surface and the building element under test in a direction normal to the element.

3.1.8 *measurement subarea*—part of the measurement surface being measured with the intensity probe using one continuous scan or a series of discrete positions. The k th measurement subarea has an area S_{mk} expressed in m^2 .

3.1.9 *measurement volume*—the volume that is bounded by the measurement surface(s), the building element under test, and any connecting non-radiating surfaces.

3.1.10 *measurement array*—a series of fixed intensity probe positions where each position represents a small subarea of the sub-divided area of a measurement surface.

3.1.11 *discrete point method*—a method of integrating the sound intensity over the entire measurement surface where a series of stationary microphone positions are chosen to adequately sample the test partition.

3.1.12 *scanning method*—a method of integrating the sound intensity over the entire measurement surface whereby a series of subareas are scanned by moving the intensity probe in a methodical fashion to adequately sample the test partition.

3.1.13 *field indicators*—a series of indicators used to assess the quality of the measurement conditions, and ultimately the accuracy, of the intensity measurement.

3.1.13.1 *dynamic capability index*, L_d —a measure of the usable dynamic range of an intensity measuring system (which is a function of the phase mismatch of the system and the bias error factor, K), expressed in decibels.

3.1.13.2 *surface pressure-intensity indicator*—the difference between the sound pressure level, and the normal sound intensity level on the measurement surface, both being time and surface averaged. F_2 is used for the discrete point method and F_{pI} and for the scanning method.

3.1.13.3 *negative partial power indicator*, F_3 —the difference between the average sound pressure level integrated over a measurement surface and signed (accounting for direction) average normal intensity level.

3.1.13.4 *field non-uniformity indicator*, F_4 —this measure is only applicable to the discrete point method and assess the suitability of the selected measurement array.

⁵ Available from International Electrotechnical Commission (IEC), 3 Rue de Varembe, CH 1211, Geneva 20, Switzerland.

required by ISO 15186-1. Functional definitions are given in Annex A1 and Annex A2.

3.1.14 *flanking transmission*—transmission of sound from a source to a receiving location other than directly through the element under consideration.

3.1.15 *sound transmission loss, TL*—In a specified frequency band, ten times the common logarithm of the ratio of the incident sound power, W_i , to the sound power transmitted through the specimen under test, W_t , expressed in decibels.

$$TL = 10 \log_{10} \left[\frac{W_i}{W_t} \right] \quad (7)$$

NOTE 3—For this standard, *TL* is operationally defined by Eq 13 and differs from the definitions given in Test Method E 90 only in the way that the transmitted sound power is estimated.

NOTE 4—Transmission loss is a property of the specimen and to a first approximation, is independent of the specimen area and dimension. Nevertheless, results of specimens that have significantly different dimensions and aspect ratios can vary significantly, especially at low frequencies, as this will hinder comparison. It is for this reason that this standard requires a minimum area for the test specimen.

4. Summary of Test Method

4.1 The building element under test is installed between two spaces creating two spaces as conceptually shown in Fig. 1. The source space is a well-defined room satisfying the criteria of Test Method E 90 while the other, the receiver room, has no specific physical requirements for size or absorption condition. It is assumed that the sound field in the source room is approximately diffuse since the incident sound power is estimated from the space averaged sound pressure level. The sound power transmitted into the receiver space is estimated from direct measurement of the radiated sound intensity over a measurement surface that completely encloses the portion of the building element in the receiver room. The transmission loss of the building element is then estimated using the incident and transmitted sound powers. Because transmission loss is a function of frequency, measurements are made in a series of frequency bands.

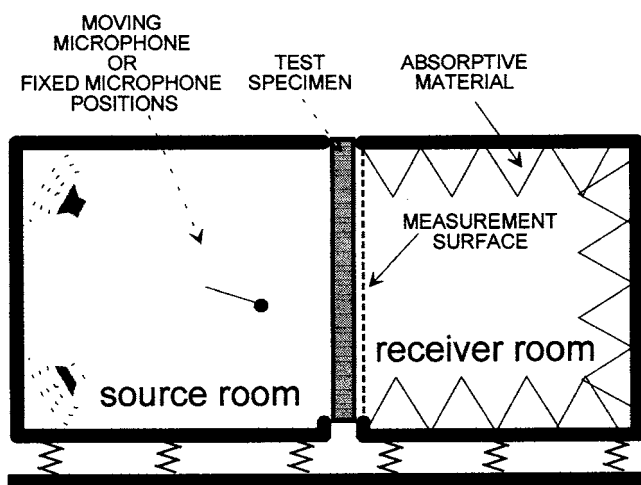


FIG. 1 Conceptualized Testing Arrangement Showing the Source and Receiving Rooms

5. Significance and Use

5.1 This test method can be used to obtain an estimate the transmission loss of building elements in a laboratory setting where the source room and the specimen mounting conditions satisfy the requirements of Test Method E 90. The acceptability of the receiving room will be determined by a set of field indicators that define the quality and accuracy of the intensity estimate.

5.2 By appropriately constructing the surface over which the intensity is measured it is possible to selectively exclude the influence of sound energy paths including the effects from joints, gaps as well as flanking sound paths. This method may be particularly useful when accurate measurements of a partition can not be made in an Test Method E 90 facility because the partition sound insulation is limited by flanking transmission involving facility source and receiver room surfaces, (for example, the path from the source room floor to the receiver room floor via the isolators and the slab supporting the two). Annex A3 discusses this in detail.

5.3 The discrete point method allows the mapping of the radiated sound intensity which can be used to identify defects or unique features (2) of the partition.

5.4 Current research reported in the literature indicate that there exists a bias between measures of transmission loss obtained using the intensity technique and those obtained using the conventional two room reverberation technique (for example, Test Method E 90, (3) and (4)). Appendix E provides estimates of the bias that might be expected. Despite the presence of a bias, no corrections are to be applied to the measured data obtained by this test method.

6. Test Rooms

6.1 *Source Room*—The source room shall possess the following properties:

6.1.1 It shall comply with the relevant sections of Test Method E 90. In particular, it shall possess the appropriate room size, shape, volume, diffusion, absorption characteristics.

6.1.2 Flanking paths involving source room surfaces and the specimen shall be insignificant relative to direct transmission through the specimen under test. The procedure and criterion of Annex A3 shall be followed and satisfied.

6.2 *Receiving Room or Space*—The receiving room may be any space meeting the requirements for background noise and the field indicators and associated field criteria (Annex A1 for the discrete point method, and Annex A2 for the scanning method).

7. Test Partitions

7.1 *Size, Mounting and Ageing*—Specimens shall be installed in full compliance with all relevant requirements of Test Method E 90.

8. Test Signal Sound Sources

8.1 *Signal Spectrum*—The sound signals used for these tests shall be in full compliance with the requirements of Test Method E 90.

8.2 *Sound Sources*—The number, characteristics, orientation and location of loudspeakers shall be in full compliance with the requirements of Test Method E 90.

8.3 *Standard Test Frequencies*—As a minimum, measurements should be made at all of the one-third-octave bands stated in Test Method E 90.

9. Measurement Surface

9.1 The measurement surface shall define a measurement volume that (1) completely encloses the portion of the specimen under test, (2) contains no extraneous or flanking sources, (3) contains no absorbing materials that are not part of the specimen, and (4) satisfies the field indicator criteria.

9.1.1 An absorptive material is defined as a material having an absorption coefficient greater than 0.1 in any of the frequency bands for which data will be reported.

NOTE 5—The measurement surface must be chosen so that all the radiated sound power of the portion of the building element under test passes through the measurement surface. Failure to do so will cause a significant underestimation in the radiated sound power.

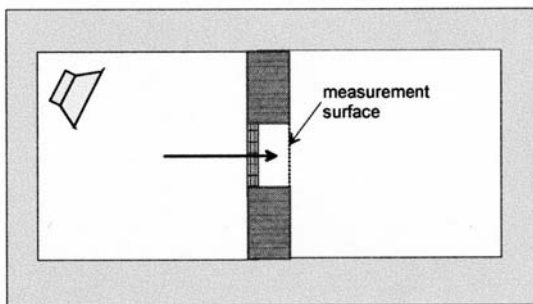
9.2 Define one or more flat hypothetical surfaces that satisfy the conditions of 9.1. Measurement distances shall be no less than 0.1 m. Initially, select a distance between 0.1 and 0.3 m. Longer distances are usually undesirable since the proportion of direct to reverberant field decreases with increasing measurement distance. Measurement positions inside a niche shall be avoided.

NOTE 6—Measurement points closer than 0.1 m are to be avoided because of near field effects. Measurement conditions in a niche are usually unfavorable due to the presence of standing waves.

9.2.1 The number of surfaces needed to construct the measurement surface can be reduced if the building element under test is bounded by a rigid non-absorbing surface as shown in Figs. 2 and 3. A rigid non-radiating surface is defined as one having, in all frequency bands for which data are to be reported, a transmission loss in excess of 20 dB, and a radiated sound power that is at least 10 dB lower than the power radiated by the building element under test.

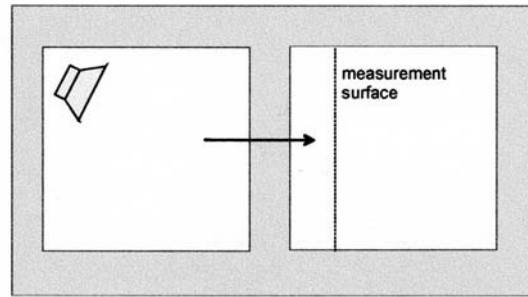
9.2.2 Typically small building elements, such as windows, require the use of a five-sided box as shown in Fig. 4, and the measurement distance shall be no more than 0.3 m.

NOTE 7—As shown in Fig. 4, four of the five faces of the box-shaped measurement surface intersect the perimeter of the element under test. These side surfaces will have a depth equal to 0.1 to 0.3 m; the distance between the frontal face and the specimen. Thus, complete sampling of the side surfaces may include the effect of near-field radiation. This situation



A single measurement surface can be used when the specimen is mounted in a niche as shown above.

FIG. 2



A single measurement surface can be used when the specimen is bounded on all sides as shown above.

FIG. 3

can be avoided by providing an offset of 0.1 m for the four sides of the box-shaped measurement surface when the sound power radiated by the building element under test is considerably greater than that radiated by non-specimen surfaces contained in the measurement volume. Radiation from the non-specimen surfaces can be viewed as being unwanted flanking and this alternate configuration can only be deemed acceptable if the sound power is 10 dB lower than that radiated by the partition.

9.3 Once an appropriate measurement surface has been defined, each face of the surface may be subdivided into smaller subareas arranged in rows and columns, which establish the measurement array.

NOTE 8—For convenience it is recommended to make each subarea of equal area although the subareas may be smaller on the side faces of a box surface than the frontal face.

9.4 When the discrete point method of measurement is used, the probe shall be placed in the geometric centre of each subarea with the probe axis normal to the subarea, and transported either by mechanical means or by a human operator.

9.5 When the scanning method of measurement is used, the probe will be passed over the entire surface of each subarea, and transported either by mechanical means or by a human operator.

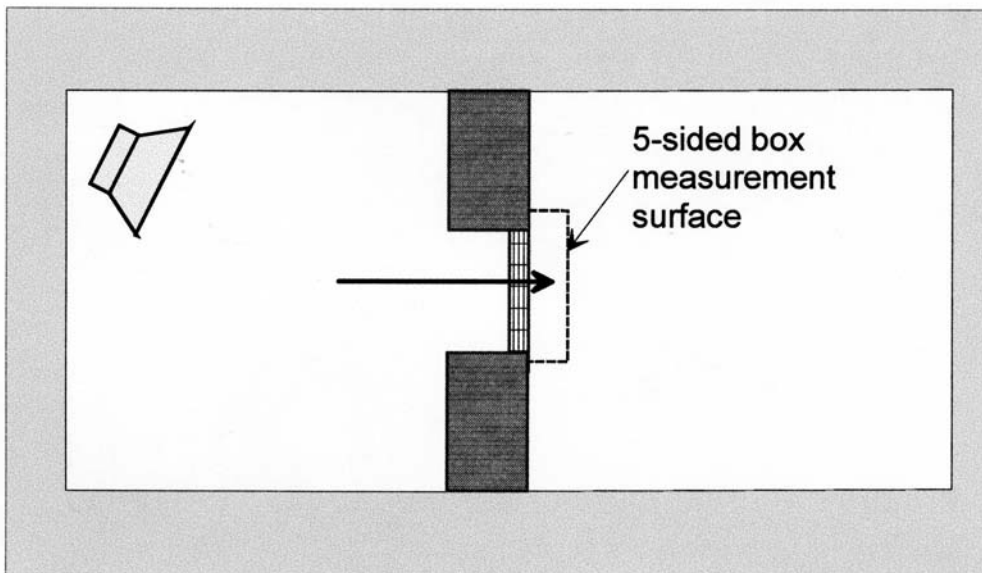
10. Microphone and Intensity Probe Requirements

10.1 *Bandwidth*—For each test band, the overall frequency response of the electrical system, including the filter or filters in the microphone sections, shall satisfy the specifications given in ANSI S1.11 for a one-third octave band filter set, Order 3 or higher, Type 1 or better.

10.2 *Source Room Microphones*—Microphones are used to measure average sound pressure levels in the source room. The electrical characteristics and calibration procedures shall comply with the relevant sections of Test Method E 90.

10.3 *Source Room Microphone Positions*—Stationary microphone positions or a moving microphone may be employed to determine the space-average sound pressure level in the source room. The system adopted shall comply with the relevant sections of Test Method E 90.

10.4 *Intensity Probe*—The intensity probe shall comply with the requirements of ANSI S1.9 and shall allow determination of the sound intensity in a known direction. The probe shall consist of two pressure-sensing microphones spaced a known distance apart.



A five-sided measurement surface forming a box may be used to completely enclose a small specimen that is mounted in a larger partition.

FIG. 4

10.5 *Probe Calibration*—Using a sound intensity probe calibrator and following the manufacturers instructions, conduct the following before each test:

10.5.1 Calibrate both microphones for sound pressure.

10.5.2 Calibrate the probe for sound intensity.

10.5.3 Measure the pressure-intensity residual index, δ_{PI_0} .

NOTE 9— δ_{PI_0} is measured by exposing the microphone pair to a sound field where the sound intensity is zero. Increasing values indicate increased phase matching between the measurement channels.

10.6 *Probe Microphone Spacing*—The spacing between the two microphones of an intensity probe affects the usable lower and upper frequency range limits. Errors due to phase mismatch between measurement channels increase as the spacing is decreased. The spacing shall be as large as possible, consistent with acceptable inherent finite difference errors that appear at high frequencies (5). Refer to manufacturer’s specifications for the usable frequency range for a particular spacing. It may be necessary to perform complete measurements using more than one microphone spacing (usually two) to cover the frequency range of interest.

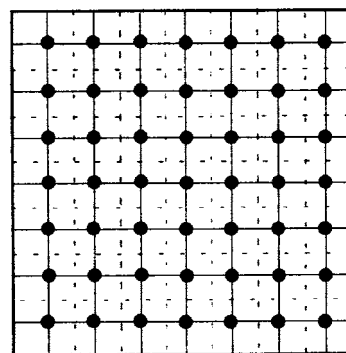
10.7 *Probe Field Check*—Before beginning measurements, verify proper operation of the probe. Place the probe in the receiving room near the center of building element under test at distance of 0.1 to 0.3 m from the surface. Fix the probe position by securing it with a stand and align the longitudinal probe axis normal to the specimen surface. With the sound sources turned on, measure and record the intensity level over the frequency range of interest. Rotate the probe 180° about the acoustic centre of the microphone pair and re-measure the intensity level. For the probe and measurement instrumentation to be deemed acceptable the following shall be satisfied: (1) the direction of the intensity level shall reverse sign, and (2) the magnitude of the difference in the undirected intensity measured for the two probe orientations shall not be greater than 1.5 dB in any one-third-octave band.

NOTE 10—If this can not be attained then it is likely the field criteria will not be satisfied using the surface average values. Check probe calibration. If this fails to rectify the problem, check that Criterion 1 is satisfied. (Use Annex A1 for the discrete point method, and Annex A2 for the scanning method). Add absorption if this condition is not met.

11. Intensity Measurement Methods

11.1 There are two acceptable sampling methods for measuring the average sound intensity radiated by the building element under test: the discrete point method and the scanning method (5). The scanning method is often very much faster than the discrete point method and is also the most suitable method when measurement surface is large. The disadvantage to the scanning method is that it is less reproducible than the discrete point method.

11.2 *Discrete Point Method*—This method uses a set of fixed points to sample the intensity field normal to one or more measurement surfaces. (See Fig. 5). The probe may be supported by a device or held by an operator. Sampling uncertainty



Typical construction of the measurement grid for discrete point measurements. The dots indicate the sampling locations while the dashed lines define the area sampled by each point.

FIG. 5

is a function of the spatial variation of the normal intensity over the measurement surface, the distribution of sample points and the level of background noise in the receiving space. For the initial measurement, the spacing between measurement points should be equal to the probe distance. The side faces of a five-sided box surface, as shown in Fig. 4, will often require a higher density of measurement points than the frontal surface.

11.3 *Scanning Method*—This method is based on sweeping the probe over the surface at a uniform speed so that the integration time is proportional to the area of the surface. A typical scan pattern is a line segment that has been folded several times to cover the subarea as shown in Fig. 6. The straight portions of the scan pattern are referred to as the scan lines. The average distance between adjacent scan lines shall be equal for all intensity measurements made on the same surface. The probe shall be moved continuously and at uniform speed of 0.1 to 0.3 m/s along the selected scan pattern while maintaining the probe axis perpendicular to the measurement surface. It is acceptable to move the probe by mechanical means as long as extraneous noise or intensity does not interfere with the measurement.

NOTE 11—Repeated scans are also required to ensure adequate measurement reproducibility which may also be a function of the operator’s ability to maintain a constant scan speed, especially when the surface has a non-uniform radiation pattern.

11.3.1 Make two separate scans on each subarea of the measurement surface. The two individual scan paths shall be orthogonal (scan pattern rotated by 90°). See Fig. 6. Record the intensity levels $L_{Ink}(1)$ and $L_{Ink}(2)$. Use Criterion 3 in Annex A2 to determine the adequacy of the scan line density for frequency band. If the criterion is satisfied the intensity of the subarea is given by the arithmetic mean of the two scans:

$$L_{Ink} = \frac{L_{Ink}(1) + L_{Ink}(2)}{2} \text{ dB} \quad (8)$$

11.3.2 If Criterion 3 of Annex A2 is not satisfied, repeat the two scans again and check if the repeat measurements satisfy the criterion. If it is impossible to comply with these requirements then no results shall be given for these frequency bands. This may prevent the single number ratings from being calculated and reported.

NOTE 12—A2.5 provides guidance on how to change the scan line

density to satisfy Criterion 3.

11.3.3 Scan each subarea according to Fig. 6. If a box shaped measurement surface is chosen, ensure that the sides of the box are carefully scanned by moving the probe no closer than 0.1 m to the junction between the box and the building element under test.

11.3.4 During manual scanning, the operator shall not stand in front of the subarea being scanned but shall stand to one side so the person’s body does not impede, reflect or diffract sound towards the probe. Similarly, automated scanning mechanisms shall present a minimum of interference to the sound field.

12. Measurement Procedure

12.1 *General*—Measure the average sound pressure level in the source room. Ensure the probe is operating correctly by calibrating it and performing the field check (see 10.7). Once satisfactory, obtain an initial estimate of the receiving room conditions (see 12.2) and add treatments to the receiving room as required. (See Annex A1-Annex A3 for a discussion of possible treatments). Check that the flanking transmission is not adversely affecting the measurement (see 12.3). If satisfactory, measure the average sound intensity level and sound pressure level for each subarea and compute the field indicators for the measurement method (discrete point A1.3 and scanning A2.3). If each subarea meets the background noise criterion (see 12.5) and also meets the field criteria then compute the average sound intensity and sound pressure levels for the complete measurement surface (see 12.6). Compute the field indicators for the complete measurement surface and evaluate the field criteria. Compute the intensity transmission loss for all frequency bands satisfying the criteria (see 12.12).

12.2 *Initial Test for Receiving Room Suitability*—To test the suitability of the receiving room for intensity measurements, switch on the sound sources and scan with the intensity probe diagonally across the building element under test at a distance of 0.1 to 0.3 m.

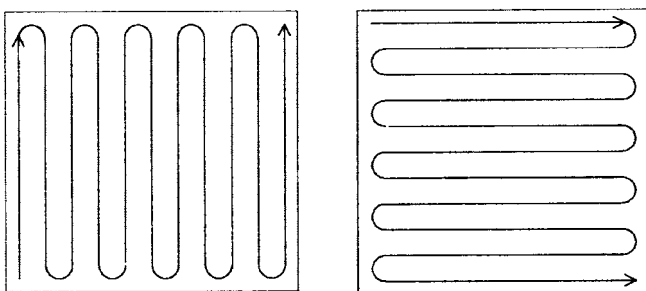
12.2.1 Check that there is sufficient signal by using the background noise criterion of 12.5.

12.2.2 If there is sufficient signal, check that all frequency bands Criterion 1 is satisfied. Use Annex A1 for the discrete point method and Annex A2 for the scanning method.

NOTE 13—If this condition is not satisfied then it is highly likely that the field criteria will not be satisfied for surface averaged values so remedial actions should be taken before beginning the detailed measurements. Annex A2 and Annex A3 provide methods to improve the measurement conditions.

12.3 *Flanking Transmission Check*—The flanking criterion of Annex A3 shall be satisfied since acoustic radiation from building elements adjacent to the measurement surface can adversely effect the accuracy of the measurements. Failure to satisfy the flanking criterion can cause a significant underestimation of the sound insulation (6).

12.4 *Measurement of the Average Sound Intensity Level on the Receiving Side*—Measure the average sound intensity and sound pressure levels for each subarea of the measurement surface. For each subarea, if the background noise criterion is satisfied, calculate the field indicators and evaluate the field criteria according to the type of measurement (Annex A1 for



Scan patterns for the first and second scans differ in orientation by 90°. The measured intensities are $L_{Ink}(1)$ and $L_{Ink}(2)$, respectively. The difference in the measured intensity levels is used to determine the adequacy of the scan line density and the measurement reproducibility.

FIG. 6