Guide for Assessment of the Architectural Speech Privacy and Speech Security of Closed Offices and Meeting Rooms

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Summary

This guide describes a framework for interpreting, assessing, and rating the speech privacy and speech security of closed meeting rooms and offices. The document provides a concise technical overview of the underlying concepts and defines categories for rating and setting criteria. This guide also contains a detailed measurement procedure to be followed by technicians or consultants performing field measurements, and guidance for specifying suitable constructions at the design stage. The measurement procedure follows the steps described in a new ASTM measurement standard (ASTM 2638-08).

The approach to assessing speech privacy of closed meeting rooms and offices is based on estimating the likelihood that conversations occurring within the closed room will be audible or intelligible to bystanders outside the room. Whether speech is audible or intelligible depends on the speech signal to noise ratio—how loud the speech is relative to the noise at the listener position. How loud the speech is at a bystander's position depends on how loud the speech is inside the room (which generally cannot be controlled, but can be estimated), as well as the attenuation provided by the sound insulation of the building structure. The background noise at the bystander's position is usually generated by building mechanical systems or other machinery, but could also be generated by occupants or masking sound systems. The current approach uses measurements or design estimates of the sound insulation and background noise, together with statistical estimates of speech levels, to directly estimate the likelihood that speech will be audible or intelligible to bystanders.

The relevant measure of sound insulation is the sound level difference, *LD*, observed between a uniform test sound field (inside the room) and the received level at spot locations (outside the room). This approach has the benefit of being applicable for talkers who could be located anywhere inside the room, for minimizing the acoustical effect of the receiving space, and for assessing specific weak spots in the sound insulation. The relevant measure of background noise is simply the average sound level at the spot receiver (potential bystander) position, L_b. The sum of the frequency-average of these two quantities is called the Speech Privacy Class, $SPC = LD + L_b$, which is a single number rating, in decibels, and is a property of the building. The value of *SPC* determines the protection against a speech privacy lapse, and therefore is used to rate the speech privacy. For design, the level difference *LD* is estimated from the nominal transmission loss *TL* of the specified partitions, using $LD = TL + 1$, and noise must be estimated or assumed.

Ranges of *SPC* corresponding to different categories of speech privacy are defined in this document, along with a description of the likelihood of a speech privacy lapse for each. Users can use this information to define criteria to meet their operational needs.

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1 Introduction

This guide describes methods to assess the architectural speech privacy of closed offices and meeting rooms. Included in the scope is what is frequently termed speech security, which means very high degrees of speech privacy. The aim is to assess the degree to which conversations within an enclosed room would be heard or understood outside the room. The term "architectural" speech privacy is used to indicate the privacy provided by the building structure and background noise. The background noise includes that due to the building systems, and also any intentionally added masking noise. The procedures are applicable to any enclosed room, and any adjoining space that might be the location of a potential eavesdropper. These methods are not suitable for use in evaluating speech privacy in open plan spaces. Potential eavesdroppers outside the room are assumed to not be using overt methods (such as touching the walls) or electronic aids (such as microphones or amplifiers), but rather are listening naturally. The criteria for interpretation of the degree of privacy or security are based on the probability of speech being audible or intelligible to attentive bystanders.

2 Background

Speech privacy and speech security are descriptions of how audible or intelligible speech sounds are likely to be outside of a closed room. This is a 'signal-to-noise' problem where at the listener's position, the signal is the transmitted speech sound, and the noise is the ambient noise. The intelligibility or audibility of the speech depends on how loud it is, relative to the noise.

Research has identified an objective measure, calculated from speech signal and noise spectra at the listener position, which accurately predicts the degree to which the speech signal is intelligible or audible [1, 2]. This measure is a uniformly-weighted frequency-averaged signal-to-noise ratio, given by

$$SNR_{UNI32} = \frac{1}{16}\sum_{f=160}^{5000}[L_{ts}(f) - L_b(f)]_{-32} \ , \qquad (1)$$

where in each of the 16 1/3-octave bands centered at frequency f from 160 to 5000 Hz, $L_{ts}(f)$ is the level of the transmitted speech, $L_b(f)$ is the level of the background noise, and the subscript "–32" indicates that the quantity in square brackets—the signal to noise ratio in each band—is to be limited to a minimum of –32 dB. The result is in decibels, and is larger for less private conditions of high signal to noise, and lower for more private conditions.

A condition where 50% of skilled listeners can just understand speech is the threshold of intelligibility. This corresponds to a particular value of SNR_{UNI32}: in laboratory experiments this was –16 dB [1, 2], but in (somewhat reverberant) real rooms was –11 dB, varying about 1 dB with room reverberation [3]. At a lower signal to noise condition, there is a point where 50% of skilled listeners can just hear speech sounds. This is called the threshold of audibility, and corresponds to a higher degree of privacy.

The threshold of audibility corresponds to a SNR_{UNI32} value of –22 dB (in both the laboratory and in real rooms) [1, 2, 3].

To apply SNR_{UNI32} for assessment of closed room speech privacy, it is necessary to determine the transmitted speech levels and the background noise levels at the listener position.

For a given speaking level inside the room, the level of transmitted speech depends on the sound insulation provided by the building structure. More attenuation results in less transmitted speech signal, and therefore more privacy. The relevant measure of sound insulation is the difference in sound level between the average level of a uniform test sound field inside the room and the received level at a spot listener location outside the room [4]. If the average level of the uniform field is $L_s(f)$ and the corresponding received level is $L_r(f)$, then the level difference in each frequency band is $LD(f) = L_s(f) - L_r(f)$. A uniform field is taken inside the room to represent the average of talkers that could be located anywhere, and facing any direction. The spot receiver locations outside are chosen close to the boundaries of the room to minimize the effect of the receiving space, to more realistically represent the locations of potential eavesdroppers, and to allow evaluation of weak points such as doors.

Since the level of speech varies from moment to moment, the speech levels in the room can be assessed statistically. Measurements were made of speech levels $L_{sp}(f)$ in a large number of meetings, and this information has been used to determine the probability of occurrence of certain levels [5, 6]. Logging sound level meters were placed in meeting rooms, and recorded the equivalent sound level (L_{eq}) over 10-second intervals. Analysis of these short-term levels gives information about the statistical fluctuation of speech levels in the meetings. One way to interpret these statistics is to state the percentage of time that a certain level is likely to be exceeded. For example, the median speech level (50th percentile) is exceeded 50% of the time, or one out of every two 10-second intervals (once per 20 seconds). A higher speech level, say the 90th percentile, is exceeded only 10% of the time, or one out of every ten 10-second intervals (once per 100 seconds).

The background noise at the listener position outside of a closed room also varies during the day [5]. The level of the background noise $L_b(f)$ can be measured for a short period of time believed to be representative of the building's normal operation, or it can be logged over a longer period of time, or can be assumed from other knowledge.

Putting it all together, the value of SNR_{UNI32} outside the room is given by

$$SNR_{UNI32} = \frac{1}{16}\sum_{f=160}^{5000}[L_{sp}(f) - LD(f) - L_b(f)]_{-32}\ , \qquad (2)$$

where $L_{sp}(f)$ is the speech level inside the room, $LD(f)$ is the measured level difference between the average inside the room and a listener position, and $L_b(f)$ is the background noise at the listener position. Frequently the –32 dB limitation has minimal effect, so Eq. (2) can be simplified and rewritten as

$$SNR_{UNI32} = L_{sp}(avg) - LD(avg) - L_b(avg)\ , \qquad (3)$$

where *(avg)* indicates the arithmetic average of $L_{sp}(f)$, $LD(f)$, and $L_b(f)$ over the 16 1/3-octave bands from 160 to 5000 Hz.

A particular speech privacy criterion such as the threshold of intelligibility corresponds to a particular value of SNR_{UNI32}, say $SNR_{UNI32,0}$. Rewriting Eq. (3) as an inequality, when the following is true of the speech level

$$L_{sp}(avg) \leq SNR_{UNI32,0} + LD(avg) + L_b(avg)\,, \qquad (4)$$

then the conditions at the listening point are at least as private as the criterion conditions. The quantities $LD(avg)$ and $L_b(avg)$ are properties of the closed room, so Eq. (4) dictates the maximum speech level $L_{sp}(avg)$ for which the conditions are adequately private. From the statistics of speech levels, this can be interpreted as the length of time in between expected privacy “lapses”, which would correspond to instances for which the speech level is larger than that allowed by Eq. (4).

The privacy criterion is chosen as the threshold of intelligibility, and correspondingly the criterion value of $SNR_{UNI32,0}$ is –11 dB. Then Eq. (4) yields the following relationship

$$LD(avg) + L_b(avg) \geq L_{sp}(avg) + 11\,, \qquad (5)$$

which determines the maximum speech level for which conditions at the listening point remain below the threshold of intelligibility. The likelihood of this speech level being exceeded is the likelihood that the conditions at the listening point will be above the threshold of intelligibility.

As previously stated, the quantities $LD(avg)$ and $L_b(avg)$ are properties of the closed room (i.e., of the building). The sum of these two terms governs the speech privacy rating of a room, and is called the Speech Privacy Class, *SPC*

$$SPC = LD(avg) + L_b(avg)\,. \qquad (6)$$

Speech privacy requirements can be specified in terms of SPC values. Table 1 includes a range of SPC values and descriptions of the speech privacy that each would provide.

Category	SPC	Description
Minimal speech privacy	70	One or two words will be intelligible at most once each 3 minutes, and speech sounds will frequently be audible (at most once each 0.6 minutes).
Standard speech privacy	75	One or two words will be occasionally intelligible (at most once each 18 minutes) and frequently audible (at most once each 2 minutes)
Standard speech security	80	One or two words will very rarely be intelligible (intelligible at most once each 2.3 hours) and occasionally audible (at most once each 12.5 minutes)
High speech security	85	Speech essentially unintelligible (at most once each 16 hours) and very rarely audible (at most once each 1.5 hours)
Very high speech security	90	Speech not intelligible and very rarely audible (at most once each 11 hours)

Table 1. Descriptions of the privacy provided by some SPC values [6].

3 Measurement Procedures

To evaluate the privacy provided by an existing closed room, measurements must be made of the sound insulation to the listening point (*LD*), and of the background noise at the listening point (L_b), so that the *SPC* may be determined.

3.1 Summary

1. A broadband noise sound field is generated at a high level in the closed room. A loudspeaker is placed successively at two or more locations within the room.
2. Receiving points outside the closed room, that are potential weak spots or possible locations for an eavesdropper, are selected for measurement.
3. With the source operating in each successive location in the source room, measurements of sound pressure level are made within the room to obtain source room levels, and at receiving points outside the room to obtain received levels.
4. With the source turned off, measurements of sound pressure level are made at the receiving points to obtain background noise levels, $L_b(f)$ and $L_b(avg)$.
5. The differences in average source room levels inside the room and received levels at each receiving point are determined, and are used to calculate $LD(f)$ and $LD(avg)$ for each receiving point.
6. *SPC* and the corresponding category of speech privacy at each receiving point are determined, using Eq. (6).

3.2 Measurement equipment:

1. Sound Source: the sound source shall be a loudspeaker system driven by a power amplifier. The loudspeaker shall be approximately omnidirectional, such as a dodecahedron with drivers mounted in each face.
2. Test Signal: The input signal to the amplifiers shall be random noise containing an approximately uniform and continuous distribution of energy and frequencies over each test band. White or pink electronic noise sources satisfy this condition.

3. Bandwidth and Filtering: The overall frequency response of the electrical system, including the filter or filters in the source and microphone sections, shall for each test band conform to the specifications in ANSI S1.11 for a one-third octave band filter set, class 1 or better.
4. Frequency Range: The frequency range for measurement shall be the sixteen one-third octave bands from 160 to 5000 Hz.
5. Microphones: Measurement quality microphones that are 13 mm or smaller in diameter and that are close to omnidirectional below 5000 Hz shall be used.
6. Microphones, amplifiers, and electronic circuitry to process microphone signals and perform measurements shall satisfy the requirements of ANSI S1.4 for Type 1 sound level meters, except that weighting networks are not required.

3.3 Measurement Procedure

3.3.1 Source positions:

1. At least two source positions shall be selected in the central part of the closed room. These positions shall be at least 1.2 m apart and shall be representative of typical locations of talkers in the room. The source positions shall be 1.5 m above the floor in the closed room
2. The number of source positions used will affect the uncertainty in the final result, which can be calculated according to Appendix 1. More source positions will result in a smaller uncertainty. Users of this method can choose to use the minimum number of source positions (i.e., 2) and obtain a result with unknown, but limited, uncertainty. Users can alternatively decide upon a maximum acceptable uncertainty and repeat measurements with additional source positions until satisfactory results are obtained.

3.3.2 Receiving positions:

1. Select receiving points outside the closed room. Measurements should be made at all locations in the receiving area where possible speech privacy problems are suspected. The regions near doors, windows and other types of weak elements in the boundaries of the room are obvious locations that should be included.
2. To evaluate speech transmission through walls and their components (e.g. doors), microphones should be 0.25 m from the nearest outer surface of the closed room and between 1.2 and 2 m above the floor. (If the microphone is closer than 0.25 m, the measured level is more sensitive to distance from the wall.)
3. Survey for additional locations where sound leaks may occur by performing initial listening tests. Position the sound source near the middle of the closed room and generate a signal so that the average sound pressure level in the room is at least 80 dBA. With all doors closed, listen carefully outside the closed room, near the boundaries, and identify the locations of probable sound leaks where measurements should be made to assess the speech privacy. In some cases, spot measurement locations may not be adjacent to the room boundary. Where there is sound transmission from the room via flanking sound paths such as through ducts,

spot measurements should be made at locations where a potential eavesdropper might be located.

4. In addition to the locations identified as probable weak spots, select other positions around the closed room so as to provide complete and uniform coverage of the periphery. Some receiving points will be close to the bounding surfaces of the closed room. Others may be selected close to suspected weak spots such as ventilation duct openings.

3.3.3 Measurement of levels:

1. With the source operating at each source position in the closed room, the average sound pressure level in the room shall be measured in one of the two following ways:
   a. Measure the sound pressure level using at least five fixed microphone positions. The microphone positions shall be at least 1.2 m apart, at least 1.5 m from the sound source and at least 1 m from the surfaces of the closed room. The sound pressure level $L_{sij}(f)$ in each frequency band, f, shall be measured for each combination of source position i and microphone position j.
   b. Measure the average sound pressure level in each 1/3-octave band by walking around the room with a sound level meter or equivalent analyzer set to measure the time-averaged sound levels L_{eq}. For larger rooms, the operator shall walk slowly moving the microphone in a circular path of at least 0.5 m diameter in front of their body to evenly sample as much as practical of the measurement space. The sound level meter or microphone shall be held well away from the operator's body—at least 0.5 m (a boom serves to increase the distance). The microphone speed shall remain as constant as practical. The operator shall take care to assure that the path does not significantly sample any part of the room volume for more time than other parts. The microphone shall always be more than 1.5 m from the sound source and more than 1 m from the walls of the closed room. The integration time shall be at least 30 seconds. This measurement shall be repeated for each source position i to give $L_{si}(f)$, the average source room level in each band, for source position i.

NOTE—Measurement of the levels in the closed room by walking around with an integrating sound level meter will enable only approximate estimation of the uncertainty in the final result. The optional procedures for estimating the uncertainty are in Appendix 1.

2. The sound pressure level shall be measured at each stationary receiving point outside the room for each source position i in the closed room for at least 15 seconds. Measure the received levels with the source operating, $L_{rbi}(f)$, and the background levels with the source switched off, $L_{bi}(f)$.

3.4 Calculations

All calculations shall be made using unrounded, measured values.

1 Source room levels

1.1 If source room measurements were made using fixed microphone positions, determine $L_{si}(f)$, the average sound pressure level in each band, for source position i, as follows:

$$L_{si}(f) = 10\log\left[\frac{1}{m}\sum_{j=1}^{m} 10^{L_{sij}(f)/10}\right] \qquad (7)$$

where m is the number of microphone positions.

1.2 Calculate $L_s(f)$, the mean source sound pressure level in the closed room in each frequency band, using

$$L_s(f) = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{L_{si}(f)/10}\right] \qquad (8)$$

where n is the number of source positions.

1.3 Calculate $L_s(avg)$, the arithmetic average of source room level over the 16 1/3-octave frequency bands from 160 to 5000 Hz from

$$L_s(avg) = \sum_{f=160}^{5000} L_s(f)/16 \qquad (9)$$

2 Received levels at each receiving point

2.1 For each source position i, the received level in each frequency band f at each receiving point shall be corrected for background noise as follows:

2.1.1 If the difference $L_{rbi}(f) - L_{bi}(f)$ is more than 10 dB then no corrections for background noise are necessary and $L_{ri}(f) = L_{rbi}(f)$.

2.1.2 If the difference $L_{rbi}(f) - L_{bi}(f)$ is between 5 and 10 dB, the adjusted value of the received level, $L_{ri}(f)$, shall be calculated as follows:

$$L_{ri}(f) = 10\log(10^{L_{rbi}(f)/10} - 10^{L_{bi}(f)/10}) \qquad (10)$$

2.1.3 If the difference $L_{rbi}(f) - L_{bi}(f)$ is less than 5 dB, then set $L_{ri}(f) = L_{rbi}(f) - 2$. In this case, the measurements provide only an estimate of the upper limit of the received level. Identify such measurements in the test report.

2.2 Calculate $L_r(f)$, the average received sound pressure level in each band for each receiving point using

$$L_r(f) = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{L_{ri}(f)/10}\right] \qquad (11)$$

where n is the number of source positions.

2.2.1 If any of the $L_{ri}(f)$ values are limited by background noise, then the corresponding $L_r(f)$ provides only an estimate of the upper limit of the average received level. Identify such measurements in the test report.

2.3 For each receiving point, calculate $L_r(avg)$, the arithmetic average of received level over the 16 1/3-octave frequency bands from 160 to 5000 Hz from

$$L_r(avg) = \sum_{f=160}^{5000} L_r(f)/16 \qquad (12)$$

3 Background noise levels at each receiving point

3.1 Calculate $L_b(f)$, the average background noise level in each band for each receiving point using

$$L_b(f) = 10\log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{L_{bi}(f)/10}\right] \quad (13)$$

where n is the number of source positions.

3.2 For each receiving point, calculate $L_b(avg)$, the arithmetic average of background noise level over the 16 1/3-octave frequency bands from 160 to 5000 Hz from

$$L_b(avg) = \sum_{f=160}^{5000} L_b(f)/16 \quad (14)$$

4 Level Differences

4.1 For each receiving point, calculate the difference in average source room level and average received level in each band,

$$LD(f) = L_s(f) - L_r(f). \quad (15)$$

4.2 For each receiving point, calculate $LD(avg)$, the average level difference over the 16 1/3-octave frequency bands from 160 to 5000 Hz from

$$LD(avg) = \sum_{f=160}^{5000} LD(f)/16 \quad (16)$$

5 Speech Privacy Class

5.1 For each receiving point, calculate *SPC* from the arithmetic sum of $LD(avg)$ and $L_b(avg)$

$$SPC = LD(avg) + L_b(avg). \quad (17)$$

5.2 The background noise outside the closed room may vary from time to time, so the measured value L_b is representative of that during the measurement period only. For the purposes of estimating *SPC* for different noise conditions, the background noise may additionally be measured at different times, or assumed from other knowledge.

6 **Precision**

6.1 The uncertainty in the final measured value *SPC* depends on the precision of the measurements of: source room average levels, received levels, and background noise levels. Precision of the measurements of the average source and received levels varies with frequency and room properties, the number of source positions, type of loudspeakers used, and the number of microphone positions.

6.2 The 95% confidence interval for *SPC* can be calculated according to Appendix 1. This is not mandatory. Users of this method can decide what is an acceptable 95% confidence interval, and if the initial number of source positions does not give an acceptable value, then more source positions must be used.

6.3 Using the minimum specified number of source and fixed microphone positions (i.e., 2 source positions, 5 microphone positions) in a wide range of rooms, the average 95% confidence interval for $L_s(avg)$ has been found to be ±1.1 dB using omnidirectional sources, and ±1.6 dB using directional sources [4]. Uncertainty in the final value of *SPC* will be no smaller than this. Rooms that are smaller than 60 m^3 or larger than 200 m^3 with a reverberation time less than 0.6 s will likely have larger uncertainties.

3.5 Report

Report the following information:

1. Statement of Conformance to Method—If it is true in every respect, state that the tests were conducted in accordance with the provisions of this Guide.
2. Description of Test Environment— Give a general description of the closed room and furnishings. Give a sketch showing the relationship of the receiving points to the closed room. State the volume of the closed room.
3. Description of Measurement Method—Identify the type of loudspeaker used and the microphone method used to measure the levels in the closed room. Indicate the source positions used on the room sketch.
4. Statement of Precision—If the confidence interval for *SPC* was calculated, report it; otherwise state that the uncertainty of the result was not determined.
5. Provide a table giving the values of $L_s(f)$, and for each receiving point of $L_r(f)$, $LD(f)$ and $L_b(f)$ at the specified frequencies, rounded to the nearest 1 dB. Identify those values of $L_r(f)$ and $LD(f)$ that were contaminated by background noise.
6. Provide a table giving the values of $L_s(avg)$, and for each receiving point $L_r(avg)$, $LD(avg)$, $L_b(avg)$, and *SPC*. Identify those values of $L_r(avg)$, $LD(avg)$, and *SPC* that were contaminated by background noise.

4 Design Procedures

At the design stage, it is necessary to specify an assembly that will, after construction, provide the desired degree of speech privacy. Usually the only information available at this stage is transmission loss (*TL*) data of individual specimens, measured in the laboratory according to ASTM Test Method E 90.

Research has shown that the transmission loss data can be used to estimate the level difference between a uniform sound field on one side of a partition, and the received level at 0.25 m from the other side of the partition [3]. Therefore, *SPC* can be estimated at the design stage. Designers must be aware that the performance of partitions in buildings is almost always degraded by flanking transmission (i.e., sound transmission via paths other than directly through the nominally separating partition), and that laboratory performance is usually not realized in the field.

Measurements for a range of walls and with a wide range of acoustical absorption in the rooms on either side of the walls have demonstrated that for a uniform field incident on one side of a wall, the received level at 0.25 m on the other side can be estimated from

$$L_{0.25}(avg) \approx L_s(avg) - TL(avg) - 1, \qquad (18)$$

where, $L_{0.25}(avg)$ is the received level at 0.25 m from the wall, $L_s(avg)$ is the level of the uniform field on the source side of the wall, $TL(avg)$ is the transmission loss of the wall, and *(avg)* means the arithmetic average over all 16 bands from 160 to 5000 Hz. Eq. (18) is correct within ± 0.5 dB for most rooms with reverberation times less than about 1.2 s, and can be rewritten to predict the required level difference as follows

$$LD(avg) \approx TL(avg) + 1 \qquad (19)$$

where $LD(avg) = L_s(avg) - L_{0.25}(avg)$.

Equation (19) can be used to predict the Speech Privacy Class from transmission loss data follows,

$$SPC = TL(avg) + L_b(avg) + 1\,, \qquad (20)$$

which allows designers to estimate the degree of speech privacy from published laboratory *TL* data, and an assumption or knowledge of the background noise $L_b(avg)$ in the listening space. The descriptions in Table 1 can be used to set criteria for *SPC*.

At the design stage it is difficult to accurately estimate ambient noise levels at each potential listener position. In addition, ambient noise levels typically vary over time and require measurements over long time periods to accurately characterize conditions. As a result it is often necessary to estimate realistic lowest likely ambient noise levels for designs. These values were obtained from measurements[5] of the statistical variations of ambient noise levels near government meeting rooms. During the daytime (8:00 to 17:00) ambient noise levels were only less than 35 dBA about 1% of the time. Therefore, for the daytime period, 35 dBA or L_n(avg) = 24 dB* would be a safe lowest likely ambient noise level to use in a worst case design calculation in the absence of measured ambient noise level values. When rooms are used outside of daytime hours, one can similarly use, 30 dBA or L_n(avg) = 19 dB for a suitable lowest likely ambient level for evenings (17:00 to 24:00) and 25 dBA or L_n(avg) = 14 dB for night time hours (24:00 to 6:00).

(*The conversion from dBA to dB(avg) assumes a typical -5 dB/octave spectrum shape for ambient noise levels).

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Appendix 1 Determination of Confidence Intervals

1 Closed Room Levels

1.1 If the fixed microphone method was used, calculate the 95% confidence interval for the source room average according to the following.

1.1.1 For each measurement of source room levels at microphone position *j* for source position *i*, calculate the average over frequency $L_{sij}(avg)$

$$L_{sij}(avg) = \sum_{f=160}^{5000} L_{sij}(f)/16 \tag{1.1}$$

1.1.2 Calculate the 95% confidence interval for $L_s(avg)$ according to

$$\Delta L_s(avg) = \frac{1.96}{\sqrt{mn}} \sqrt{\frac{1}{mn-1} \sum_{i=1}^{n} \sum_{j=1}^{m} \left(L_{sij}(avg) - L_s(avg) \right)^2} \tag{1. 2}$$

1.2 If the integrating microphone method was used, determine an approximate estimate of the 95% confidence interval for the source room average according to the following.

1.2.1 For each measurement of source room level for source position *i*, calculate the average over frequency $L_{si}(avg)$

$$L_{si}(avg) = \sum_{f=160}^{5000} L_{si}(f)/16 \tag{1. 3}$$

1.2.2 Estimate the 95% confidence interval for $L_s(avg)$ according to

$$\Delta L_s(avg) \approx \frac{1.96}{\sqrt{n}} \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(L_{si}(avg) - L_s(avg) \right)^2} \tag{1. 4}$$

which is equivalent to assuming a large number of receiver positions were used.

2 Received Levels

2.1 For each receiving point, calculate the frequency averaged received level $L_{ri}(avg)$ for source position *i* according to

$$L_{ri}(avg) = \sum_{f=160}^{5000} L_{ri}(f)/16 \tag{1. 5}$$

2.2 Calculate the 95% confidence interval for $L_r(avg)$ according to

$$\Delta L_r(avg) \approx \frac{1.96}{\sqrt{n}} \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(L_{ri}(avg) - L_r(avg)\right)^2} \qquad (1.\ 6)$$

3 Level Differences

3.1 For each receiving point, calculate the 95% confidence interval for *LD(avg)* using

$$\Delta LD(avg) = \sqrt{\left[\Delta L_s(avg)\right]^2 + \left[\Delta L_r(avg)\right]^2} \qquad (1.\ 7)$$

4 Background Noise Levels

4.1 For each receiving point, calculate the frequency averaged background level $L_{bi}(avg)$ for source position *i* according to

$$L_{bi}(avg) = \sum_{f=160}^{5000} L_{bi}(f)/16 \qquad (1.\ 8)$$

4.2 Calculate the 95% confidence interval for $L_b(avg)$ according to

$$\Delta L_b(avg) \approx \frac{1.96}{\sqrt{n}} \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(L_{bi}(avg) - L_b(avg)\right)^2} \qquad (1.\ 9)$$

5 Speech Privacy Class

5.1 For each receiving point, calculate the 95% confidence interval for *SPC* using

$$\Delta SPC = \sqrt{\left[\Delta L_b(avg)\right]^2 + \left[\Delta LD(avg)\right]^2} \qquad (1.\ 10)$$