AMERICAN NATIONAL STANDARD

Quantities and Procedures for Description and Measurement of Environmental Sound, Part 7: Measurement of Low-frequency Noise and Infrasound Outdoors and in the Presence of Wind and Indoors in Occupied Spaces

ANSI/ASA S12.9-2016/Part 7

Accredited Standards Committee S12, Noise

Standards Secretariat
Acoustical Society of America
1305 Walt Whitman Road, Suite 300
Melville, NY 11747

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Secretariat:

Acoustical Society of America

Approved on April 25, 2016, by:

American National Standards Institute, Inc.

Abstract

Part 7 of the ANSI/ASA S12.9 series describes cautions and unique techniques for measuring low-frequency noise (LFN) outdoors in the presence of wind. It is necessary to measure in wind for wind turbine projects and for countless other industrial power and facilities where environmental wind speed cannot be controlled or levels are specified under downwind conditions. The standard also describes a uniform and repeatable methodology for documenting LFN levels and spectra indoors in occupied spaces where modal considerations are important. The principal concern outdoors is wind-induced noise (WIN) created by wind sources alone. The best estimates for WIN versus wind speed are presented herein based on the literature and special testing conducted by the working group for this standard. The standard is intended to define methods for routinely observed or monitored measurements of infrasound and LFN (ILFN) with standard off-the-shelf instrumentation, commercially available or special windscreens, and microphones appropriate to the task at hand. Following the standard methods should promote uniform, repeatable, and comparable data from site to site.

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Foreword

[*This Foreword is for information only, and is not a part of the American National Standard* ANSI/ASA S12.9-2016/Part 7 American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound, Part 7: Measurement of Low-frequency Noise and Infrasound Outdoors in the Presence of Wind and Indoors in Occupied Spaces. *As such, this Foreword may contain material that has not been subjected to public review or a consensus process. In addition, it does not contain requirements necessary for conformance to the standard.*]

This standard comprises a part of a group of definitions, standards, and specifications for use in noise. It was developed and approved by Accredited Standards Committee S12 Noise, under its approved operating procedures. Those procedures have been accredited by the American National Standards Institute (ANSI). The Scope of Accredited Standards Committee S12 is as follows:

> *Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation, and control, including biological safety, tolerance, and comfort, and physical acoustics as related to environmental and occupational noise.*

This standard is a new part of the ANSI/ASA S12.9 series *American National Standard Quantities and Procedures for Description and Measurement of Environmental Sound*.

This standard is not comparable to any existing ISO Standard.

At the time this Standard was submitted to Accredited Standards Committee S12 - Noise for approval, the membership was as follows:

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Suggestions for improvements to this standard will be welcomed. They should be sent to Accredited Standards Committee S12, Noise, in care of the Standards Secretariat of the Acoustical Society of America, 1305 Walt Whitman Road, Suite 300, Melville, New York 11747-4300. Telephone: 631-390-0215; FAX: 631-923-2875; E-mail: asastds@acousticalsociety.org.

Introduction

Measuring outdoor sound pressure levels and spectra can be difficult in the presence of wind, even at very low wind speeds often defined as "acceptable" in many measurement standards. Wind-induced noise (WIN) is the principal problem and can produce a false indicator of sound pressure at low frequencies mistaken for actual low-frequency noise when in fact no such low-frequency noise is present. WIN is the sound that can be measured in remote quiet environments essentially free of all anthropogenic and natural sources of sound, except for wind-generated noise such as leaf noise and pseudo microphone noise. Experience shows that accurate outdoor measurements down to conventional frequency range limits (i.e., the 16 Hz or 31.5 Hz octave band) can only be made under nearly ideal "calm and still" conditions when using standard relatively small windscreens. Conditions are calm and still when there is no measurable wind speed at microphone height and no observable grass or tree leaf movement or audible sound.

Note that this experience and statement applies to precision type 1 instrumentation while using the windscreen (60 to 90 mm diameter) furnished by the instrument supplier. Measuring the overall A-weighted outdoor level is much less of a problem due to the severe weighting of the A scale filter, but measuring the C- or G-weighted levels usually requires calm and still conditions or improved wind protection. The A-weighting filter may not be appropriate for evaluating low-frequency noise (LFN) or infrasonic-plus-low-frequency noise (ILFN).

The procedures contained herein allow WIN to be estimated yielding the lowest levels for valid measurements in each frequency band in the presence of low to high wind speeds. WIN for seven improved windscreen designs have been measured and are tabulated herein. Using these data, one can separate true acoustic ILFN from wind-induced noise. This information is also informative to instrumentation suppliers in the development of commercial products.

Measurement of indoor sound at low frequencies is addressed, and a standard test measurement methodology is developed that should yield repeatable data from site to site and from one investigator to another.

Acknowledgement

The working group of volunteers for this standard has expended much time and effort in designing, fabricating, and testing improved windscreen devices to lower the valid frequency for which sound can be measured in the presence of wind. The results are contained in the standard and annexes. The chair would like to especially acknowledge the contribution of Dr. Bruce Walker of Channel Islands Acoustics for an extraordinary effort that far surpassed the considerable efforts of other members.

American National Standard

Quantities and Procedures for Description and Measurement of Environmental Sound, Part 7: Measurement of Low-frequency Noise and Infrasound Outdoors In the Presence of Wind and Indoors in Occupied Spaces

1 Scope

This standard provides requirements and methods for measuring low-frequency sound and noise levels outdoors in the presence of wind and indoors in occupied spaces. The most common application anticipated is the measurement of outdoor immission levels either near or far from sound emission sources or emission levels near a source.

A repeatable method for measuring low-frequency levels and spectra indoors is given so that results can be compared from site to site or for repeated measurements at the same site under differing operating scenarios or time periods.

The value of this method to indoor measurements is that wind effects on the microphone are eliminated. However, two new variables are introduced: wind impinging on a structure creates significant low-frequency noise that is difficult to quantify, and measuring indoors with room sizes comparable to or smaller than low-frequency wavelengths requires an accounting of room resonance modes. Nevertheless, following the prescribed measurement technique in low-wind conditions should give a uniform repeatable method of measurement that accounts for differing room modes from space to space.

The standard does not address all factors to be considered when measuring the emissions of sources or background sound levels in the environment that are covered in other standards. Such factors may be measurement metrics, duration of measurements, background corrections, time of day, and countless others. Usually, wind speeds in these specific standards are limited to low values (about 2 m/s or 5 mph) to minimize wind-induced noise effects. Measured data in the annexes show clearly that wind, even at these low wind speeds, significantly affects the measurements at very low frequencies. This standard is limited to measurement techniques, principally microphone wind-mitigation measures that can be used to quantify such wind effects. Hence, the wind-mitigation techniques for microphone protection described herein are supplemental to existing measurement standards.

Advanced signal processing techniques in the time domain that can detect ILFN signals in the presence of wind are discussed briefly and referenced.

2 Normative references

The following referenced documents are indispensable for the application of this standard. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI/ASA S1.1-2013 *American National Standard Acoustical Terminology*

ANSI/ASA S1.4-2014/Part 1 / IEC 61672-1:2013 *American National Standard Electroacoustics – Sound Level Meters – Part 1: Specifications*

ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014 *American National Standard Electroacoustics - Octave-band and Fractional-octave-band Filters – Part 1: Specifications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ANSI/ASA S1.1 and the following apply.

3.1
pseudo-noise
false indication of sound pressure level when in fact it is microphone response to pressure pulsations from airborne turbulence and stagnation pressure occurring in windy environments

NOTE Pseudo-noise is microphone-sensed pressure fluctuations that result from other than acoustic propagation, most commonly convective turbulent pressure fluctuations and vortex shedding by measurement microphones and accessories.

3.2
wind-induced noise
WIN
noise measured by a microphone and associated windscreen that results from the combination of pseudo-noise and the acoustic noise from objects put into motion by the wind (e.g., leaf rustle noise)

NOTE WIN (alone without any significant acoustic signals) can be measured in very quiet and remote environments essentially free of anthropogenic sources. For the purposes of this standard, WIN encompasses the frequency range of near 0.5 to 250 Hz. The overall weighted sound pressure levels, whether A-, C- or G-weighted, are calculated from this measured spectra to minimize contributions of higher frequency sources such as grass and tree-leaf rustle.

3.3
low-frequency noise
LFN
sound pressures in the one-third-octave bands having band center frequencies ranging from 20 to 200 Hz that generally may be audible and detectable

3.4
infrasound
sound at frequencies less than 20 Hz

NOTE For the purposes of this standard, the term “infrasound” may be considered synonymous with infrasonic-plus-low-frequency sound.

3.5
infrasonic-plus-low-frequency noise
ILFN
combination of infrasound and low-frequency noise covering the frequency range from 0.5 to 200 Hz

NOTE Noise is normally defined as unwanted sound at sensitive locations. It is recognized that ILFN measurement techniques addressed in this standard can be made for purposes other than investigating potential or perceived noise issues and the term noise may be inappropriate but it is used herein for convenience.

4 Instrumentation

4.1 Instrumentation sets and measurement grades

Sets of instrumentation are specified in this standard. Each set corresponds to one of the four combinations of source (LFN or ILFN) and grade (survey or precision).

- **Survey-grade measurements** are for general or routine-purpose situations.
- **Precision-grade measurements** are for situations requiring the best available precision.

It is the intent of this standard that these measurements can be made using readily available (from at least three suppliers) off-the-shelf instrumentation, but not to the exclusion of custom-built systems. The microphone/preamplifier used shall be selected based on the measurement grade and maximum low-frequency limit as described below. Windscreen requirements are given in 6.2 and 7.4 for indoors and outdoors, respectively.

4.2 Survey-grade LFN

4.2.1 All instrumentation shall meet the class 1 requirements given in ANSI/ASA S1.4-2014/Part 1 / IEC 61672-1:2013 and filters thereto shall meet the class 1 requirements given in ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014.

4.2.2 The microphone, preamplifier, and associated instruments shall be specially tested to verify that the frequency response is ±1 dB in the frequency range included in the one-third-octave bands from 20 Hz through 200 Hz. Instrumentation with the readily available frequency range of 12.5 Hz through 200 Hz shall be used for the survey grade.

4.2.3 The microphone shall include a windscreen recommended by the manufacturer or better.

4.3 Survey-grade ILFN

4.3.1 All instrumentation shall meet the class 1 requirements given in ANSI/ASA S1.4-2014/Part 1 / IEC 61672-1:2013 and filters thereto shall meet the class 1 requirements given in ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014.

4.3.2 The microphone, preamplifier, and associated instruments shall be specially tested to verify that the frequency response is ±1 dB in the frequency range included in the one-third-octave bands from 3.15 Hz through 200 Hz, and is ± 3 dB in the frequency range included in the one-third-octave bands from 0.5 Hz through 2.5 Hz. Instrumentation with the readily available frequency range of 0.5 Hz through 200 Hz shall be used for the survey grade.

4.3.3 The microphone shall include a windscreen recommended by the manufacturer or better.

4.4 Precision-grade LFN

4.4.1 All instrumentation shall meet the class 1 requirements given in ANSI/ASA S1.4-2014/Part 1 / IEC 61672-1:2013 and filters thereto shall meet the class 1 requirements given in ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014.

4.4.2 The microphone, preamplifier, and associated instruments shall be specially tested to verify that the frequency response is ± 0.5 dB in the frequency range included in the one-third-octave bands from 0.4 Hz through 200 Hz. Instrumentation with the readily available frequency range of 0.4 Hz through 200 Hz shall be used for the precision grade.

4.4.3 The microphone shall include a windscreen recommended by the manufacturer or better.

4.5 Precision-grade ILFN

4.5.1 All instrumentation shall meet the class 1 requirements given in ANSI/ASA S1.4-2014/Part 1 / IEC 61672-1:2013 and filters thereto shall meet the class 1 requirements given in ANSI/ASA S1.11-2014/Part 1 / IEC 61260-1:2014.

4.5.2 The microphone, preamplifier, and associated instruments shall be specially tested to verify that the frequency response is ± 0.5 dB in the frequency range included in the one-third-octave bands from 0.1 Hz through 200 Hz. Instrumentation with the readily available frequency range of 0.1 Hz through 200 Hz shall be used for the precision grade.

4.5.3 As a minimum, the microphone and associated windscreen(s) shall be mounted on a ground plane. A ground-plane microphone is shown in the upper and far left in Figure 1. Ground-plane microphone results were the best, i.e., resulted in the lowest level of WIN, of all windscreen combinations tested for this standard and is therefore specified for precision-grade surveys. This arrangement is similar to that described in IEC 61400-11 for wind turbine measurements. In general the arrangement is: place the microphone on a 1 m diameter hard reflective board or surface aimed at the subject source and cover with a 90 mm hemispherical windscreen as commonly supplied with the meter. This in turn is covered with a 450 mm diameter hemispherical turbulence or secondary windscreen commonly constructed of low-porosity foam, cloth or metal screening mounted over a frame. Since this arrangement has not yet been standardized, the survey report shall describe the construction in detail. This standard does not preclude the use of other methods that may have equal or better performance than the ground plane.

5 Measurement metric

5.1 Basic metric

All spectral data shall be reported in one-third-octave band levels in the ranges specified. For complex periodic signals, one-third-octave spectral analysis may be inadequate to predict audibility or annoyance potential and more advanced signal processing may be required.

5.2 Supplemental metric

Narrow-band frequency spectra may be measured and reported as required but if this is done, then the frequency resolution shall be precisely stated, such as: Frequency, Hz (0-200 Hz, 0.25 Hz with 800 line resolution) or Frequency, Hz (0-200 Hz, 2.5 Hz constant bandwidth resolution over 0-20 kHz range).

6 Outdoor measurements

6.1 Measurement types

6.1.1 One of four types of measurements shall be made. The measurement shall be survey grade or precision grade, as defined in 4.1, and the frequency spectra range shall fall within the definition of LFN or ILFN given in 3.3 and 3.5 for these four types of measurements.

6.1.2 For survey-grade LFN or ILFN measurements, the microphone shall be at a height of 1 to 1.5 m above ground.

NOTE The microphone is situated above ground for survey-grade measurements so that the received signal is the combination of the direct and ground-reflected waves and so that the microphone height is at the approximate height of the human receptor's ears.

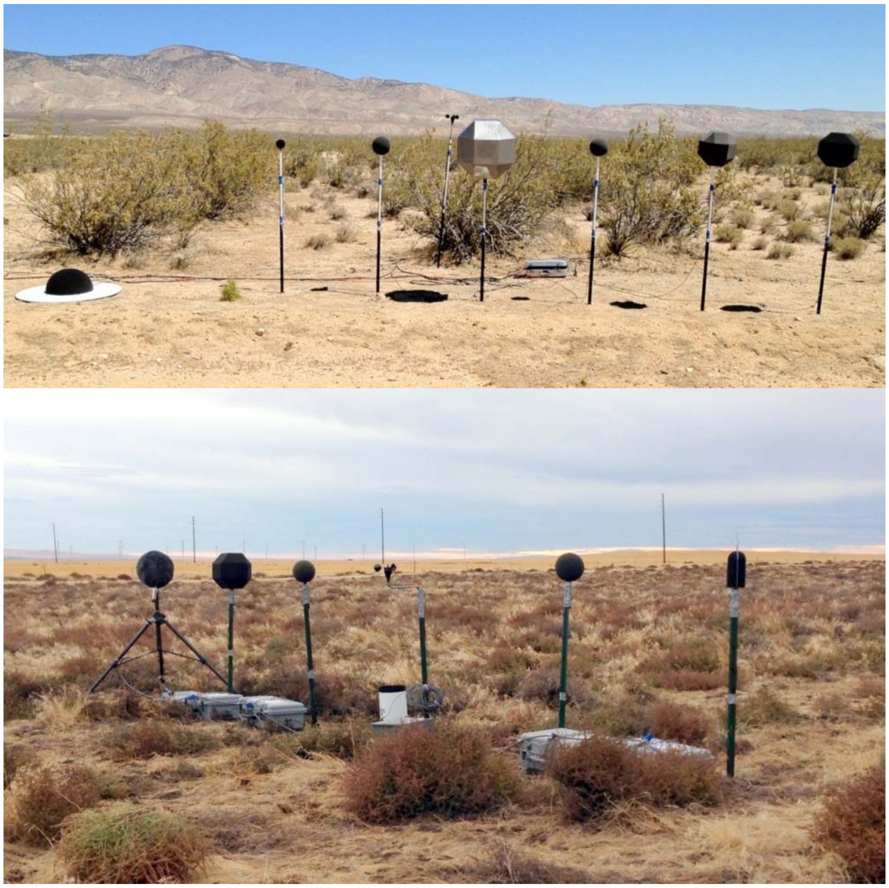


Figure 1 – Wind-induced noise (WIN) measurement setup; in the Mojave Desert (upper image) in California and western Oregon (lower image)

6.1.3 For precision-grade LFN measurements, the microphone shall be at a height of 1.5 m.

6.1.4 For precision-grade ILFN measurements, the microphone shall be positioned in accordance with the requirements for a ground-plane microphone given in 4.5.3 and shown in Figure 1.

6.1.5 For both survey-grade LFN and ILFN simultaneous measurements are recommended at both above grade and on a ground plane for best practice and the most information.

Examples of outdoor measurement setups are shown in Figure 1.

6.2 Windscreen selection

6.2.1 For LFN survey-grade measurements, a 175 mm windscreen (mic 2 or 4 in Annex B) shall be used. (Figure 2 shows WIN for all tested windscreens.)

6.2.2 For LFN precision-grade measurements, the 300 mm solid foam (20 ppi) windscreen (mic 5 in Annex B) shall be used.

6.2.3 For ILFN survey-grade measurements, the 300 mm solid foam (20 ppi) windscreen (mic 5 in Annex B) shall be used.

6.2.4 For ILFN precision-grade measurements, the ground plane (mic 7 in Annex B) shall be used.

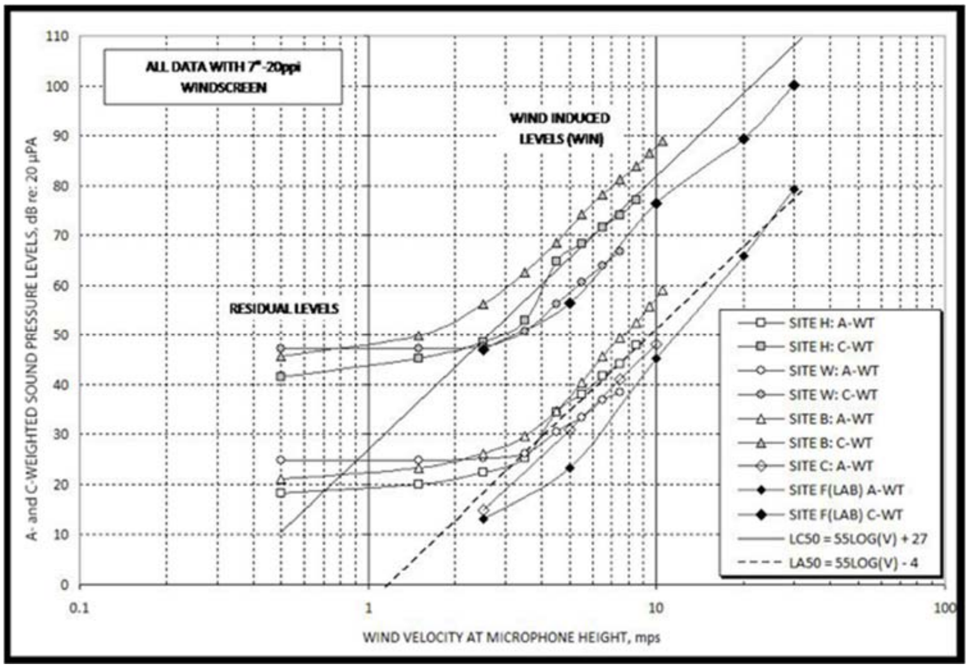


Figure 2a – Measured A- and C- weighted wind-induced noise levels for a 175 mm 20 ppi windscreen

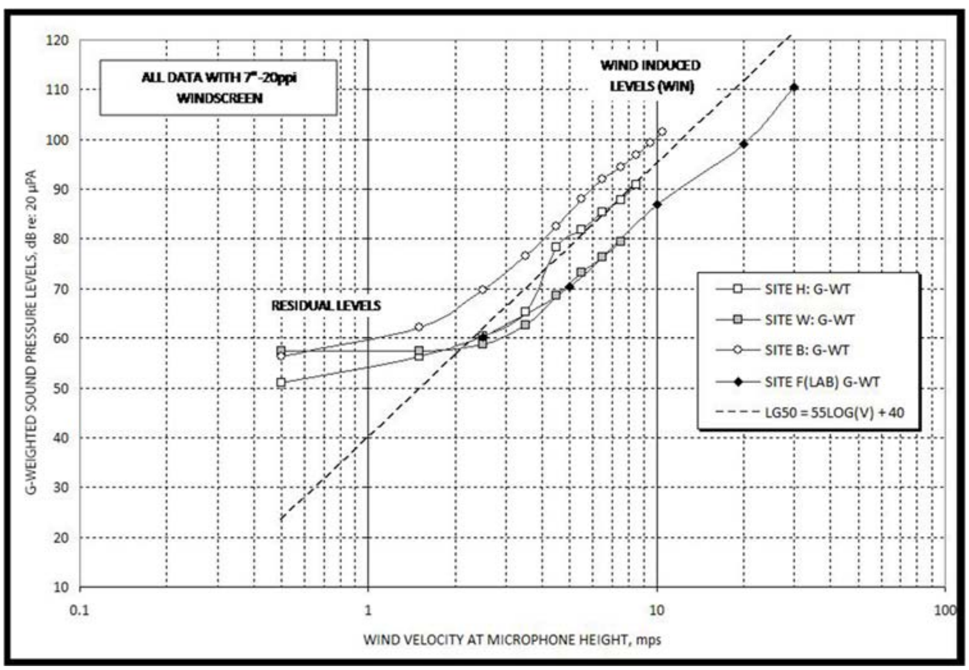


Figure 2b – Measured G-weighted wind-induced noise levels for a 175 mm 20 ppi windscreen

6.2.5 The windscreens in 6.2.1 through 6.2.4 are the minimum windscreens to be used for the specified grade, but better windscreens (lower WIN) may be used.

NOTE 1 The data from Annex B are easily used to rank the seven windscreens starting with the 90 mm diameter screen as a baseline. Figure 3 contains results for C- and G-weighted overall levels. The ground-plane configuration MIC 7 produces the least WIN and improves the capability beyond the standard 90 mm screen by approximately 15 dB of either C- or G-weighted sound pressure level. This configuration should be used for two reasons if infrasound is the main issue: (1) the microphone is lower to the ground so wind velocity is minimized (but not reduced to zero), and (2) the benefit of double screening this configuration provides.

NOTE 2 The results verify that: (1) larger solid foam windscreen configurations reduce more WIN than do smaller configurations, and (2) double screening, i.e., a foam ball surrounded by an outer turbulence reduction screen, is the best practical design. The second most efficient screen configuration is MIC 3, a 175 mm screen surrounded by a perforated sheet metal turbulence screen. This design is impractical when compared to the 300 mm solid foam windscreen configurations (MIC 5 and 6) that deliver almost equal performance. The result of using the 300 mm windscreen provides 5 dB less WIN than does the 175 mm unit.

NOTE 3 There are also windscreen configurations reported in the literature for which the microphone is placed in a pit such that the ground surface is flush. However, this configuration requires calibration (no easy task) and is limited to infrasound or very low frequencies in the LFN range.

NOTE 4 The ground-plane configuration is preferred and recommended because the entire audible spectrum can be measured and is not limited to any maximum frequency in contrast to the pit configuration which is so limited. In addition, the ground-plane configuration is more convenient requiring minimal setup time. One purpose of this standard is to investigate LFN complaints, and a more complicated configuration such as the pit is just not practical.

NOTE 5 The disadvantages for using a ground-plane configuration compared to a more complex configuration (e.g., the pit method) is that the lowest measurable frequency band could be above the frequency of interest (say about 1 Hz for wind turbine blade passing frequencies). Also, the potential source of the ILFN complaint could be masked by WIN. In addition, regulatory requirements essentially always are specified for measurement above grade, including the ground-reflected wave. The presence of a ground-reflected wave necessitates a mathematical correction as presented in Annex C.

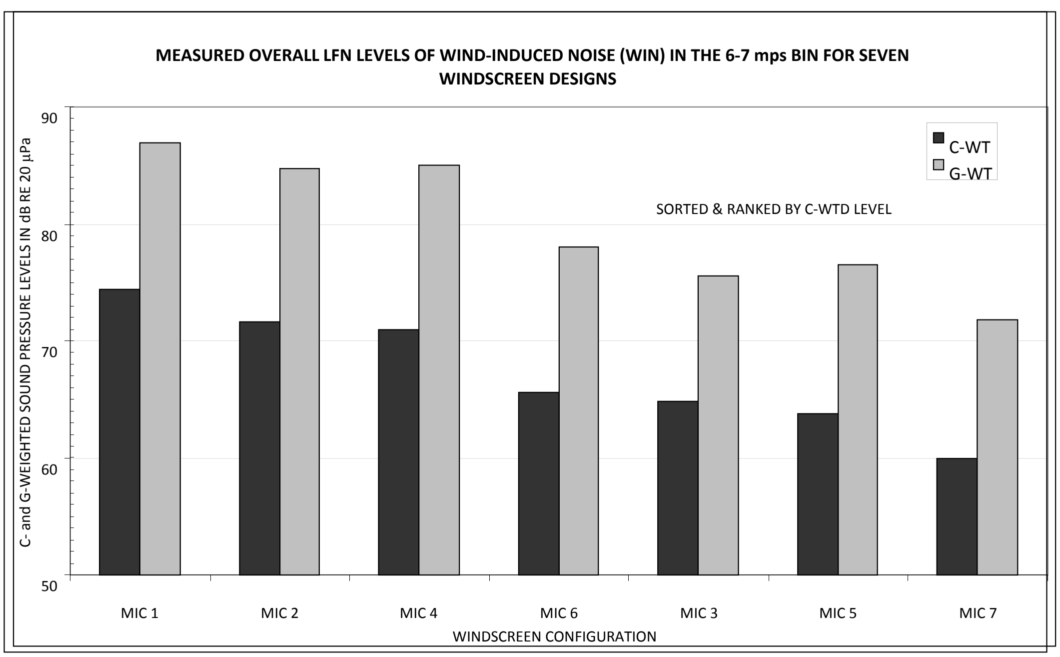


Figure 3 – Measured C- and G-weighted levels in the 6-7 m/s wind speed bin for the seven microphone setups in the Mohave Desert (see Annex B)

6.3 Estimation of lowest measurable frequency band

The estimated spectra for wind-induced noise shall be compared to measured data to judge the validity of the measured data as a function of frequency. For valid data in any one-third-octave band, the combination of estimated WIN plus all other extraneous noise shall be at least 4 dB below the level of the measured data.

For any one-third-octave band, i, the measured data, L_{M_i}, shall be at least 4 dB greater than the combination of WIN_i plus all other extraneous noise, $L_{\mathrm{WIN}*i}$, and measured data that are between 4 and 10 dB above $L_{\mathrm{WIN}*i}$ shall be corrected on an energy basis.

Figure 4 presents a graphical way to find the lowest frequency band. The following equations provide an analytical method.

That is, for the final measured data, L_{FM_i},

$$L_{\mathrm{WIN}*i} = 10\,\mathrm{lg}\left(10^{\frac{\mathrm{WIN}_i}{10}} + 10^{\frac{L_{\mathrm{EXT}\,i}}{10}}\right) \tag{1}$$

and

L_{FM_i} = 0 when $L_{\mathrm{M}_i} \le L_{\mathrm{WIN}_i}$ + 4

$L_{\mathrm{FM}_i} = L_{\mathrm{M}_i}$ when $L_{\mathrm{M}_i} > L_{\mathrm{WIN}_i}$ + 10

and in between,

$$L_{\mathrm{FM}i} = 10\,\mathrm{lg}\left(10^{\frac{L_{\mathrm{M}\,i}}{10}} + 10^{\frac{L_{\mathrm{WIN}\,i}}{10}}\right). \tag{2}$$

NOTE 1 As an example, Figure 4 provides data for a wind turbine site during two time periods, one with low winds and one with high winds. The microphone was 1.25 m above grade with a 175 mm weather-treated windscreen for monitoring. The lowest bands could be shifted lower by one octave had a 300 mm screen been used or lower still with a ground-plane setup except that this setup is not amenable for long-term monitoring with adverse weather.

NOTE 2 The lowest valid frequency band can also be estimated mathematically where the lowest valid frequency band is required to be at least 4 dB above WIN per Annex B, Table B.1 that includes the recommended 5 dB uncertainty value.

NOTE 3 It is sometimes necessary to estimate the levels that would have been measured at a microphone height of 1 to 1.5 m above ground from measurements made using a ground-plane microphone. Annex C gives a suggested procedure to accomplish this task.

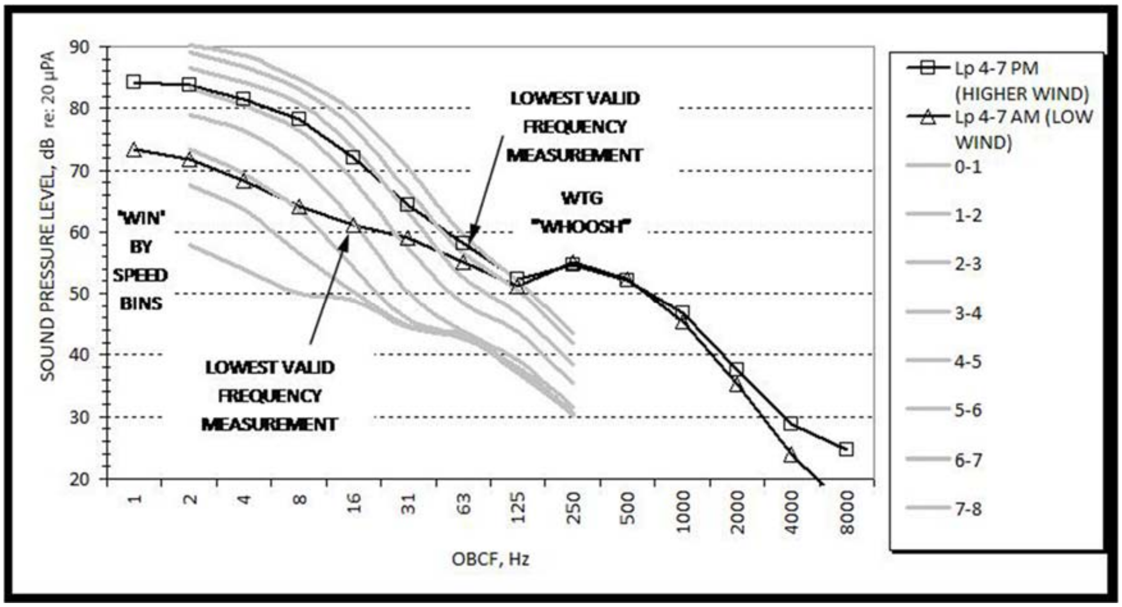


Figure 4 – Example of measured wind turbine generator (WTG) spectra for low and high wind conditions compared to wind-induced noise (WIN)

6.4 Reporting

6.4.1 Compliance with this standard (either survey or precision grade) requires that all measurements and calculations be reported in normal reporting fashion of tables and/or graphics along with site-specific factors and the principal results described herein. The principal results are an estimation of wind-induced noise for comparison to the total measured levels for the survey to establish the lowest valid frequency measurement. In addition, all relevant operating conditions shall be clearly given.

6.4.2 All measurements, calculations, analysis, tables, graphics, and site-specific factors shall be reported in normal engineering report fashion.

6.4.3 The measured frequency response of each microphone/preamplifier combination used in the study shall be included in the report.

6.4.4 The type of windscreen utilized and the height of the microphone above ground shall be stated, and the report shall include a separate photograph for each microphone and windscreen combination that shows the microphone and windscreen and their relation to the ground.

6.4.5 The test report shall be sufficiently thorough such that another competent acoustical test engineer can duplicate the test without ambiguity to assess repeatability or to evaluate changes in source levels from source modification or abatement.

6.4.6 For LFN, if optional narrow-band analysis is used, at least all frequencies in the one-third-octave band range listed in 3.3 shall be measured and reported.

6.4.7 For ILFN, if optional narrow-band analysis is used, at least all frequencies in the one-third-octave band range listed in 3.5 shall be measured and reported.

7 Indoor measurements

7.1 General

A significant advantage for evaluating low-frequency noise inside an occupied space is that microphone wind effects are eliminated. This advantage can be negated by the low-frequency sound created by wind impinging on the structure. For this reason, indoor measurements should be made during low wind-speed conditions. Measurements should not be undertaken whenever wind-induced noise is audible.

Measuring low-frequency noise indoors where room sizes are equal to or smaller than the wavelength of sound of interest is problematic. A methodology is given so that outdoor/indoor levels can be uniformly measured from space to space but under differing operational scenarios.

The purpose of the measurement procedure is to identify and quantify the sound pressure entering the space that is attributable to the LFN or ILFN source of interest at infrasound through the audible frequency range. This requires measurements of both source ON and OFF intervals.

7.2 Winds

7.2.1 The outdoor ground-level wind speed shall be measured periodically during the measurements, and the outdoor average ground-level wind speed shall not exceed 3 m/s (5mph) measured over 10-min sample.

7.2.2 It shall be noted and reported whether or not wind-induced noise was audible inside.

7.3 Measurement locations and descriptions

Measurements shall be made at the three primary locations (Lp1, Lp2, and Lp4) indicated in Figure 5. Additional measurement locations are suggested if need exists.

7.3.1 Location Lp1 (or its alternate location) shall be designated the “free-field” outdoor location.

The purpose of the “free-field” location is to measure sound incident on the indoor structure (being measured) from any (apparent) emission source. The “free-field” location will not be practical or possible in many situations such as multi-unit buildings. In this case, an alternate location on the most affected (loudest) surface of the structure under investigation shall be used. The microphone should be placed flush on a solid portion of the structure surface selected and the surface should have a minimum area of 1 m^2. If these two conditions are met, then 6 dB shall be subtracted from each frequency band to yield the “free field” sound incident on the indoor structure.

7.3.2 Location Lp2 shall be designated the most person-sensitive location. In a non-sleeping space, this location shall be the most often occupied location in the room and shall be at the ear height of an average person that would use this space.

NOTE Lp1 minus Lp2 yields the effective noise reduction (NR_e) of the building façade. NR_e should remain essentially constant for any set of measurements under differing weather or operating scenarios and effectively defines the noise isolation of the structure.

7.3.3 Location Lp3, also designated in Figure 5, is optional. It shall be located near the center of the room; specifically it shall be at the center of the room within a tolerance that is 10% of the smallest room dimension.

NOTE All of the room modes that affect the level at this location may be maxima, minima, or somewhere in between, and some of these modes can vary greatly with small changes to the actual location.

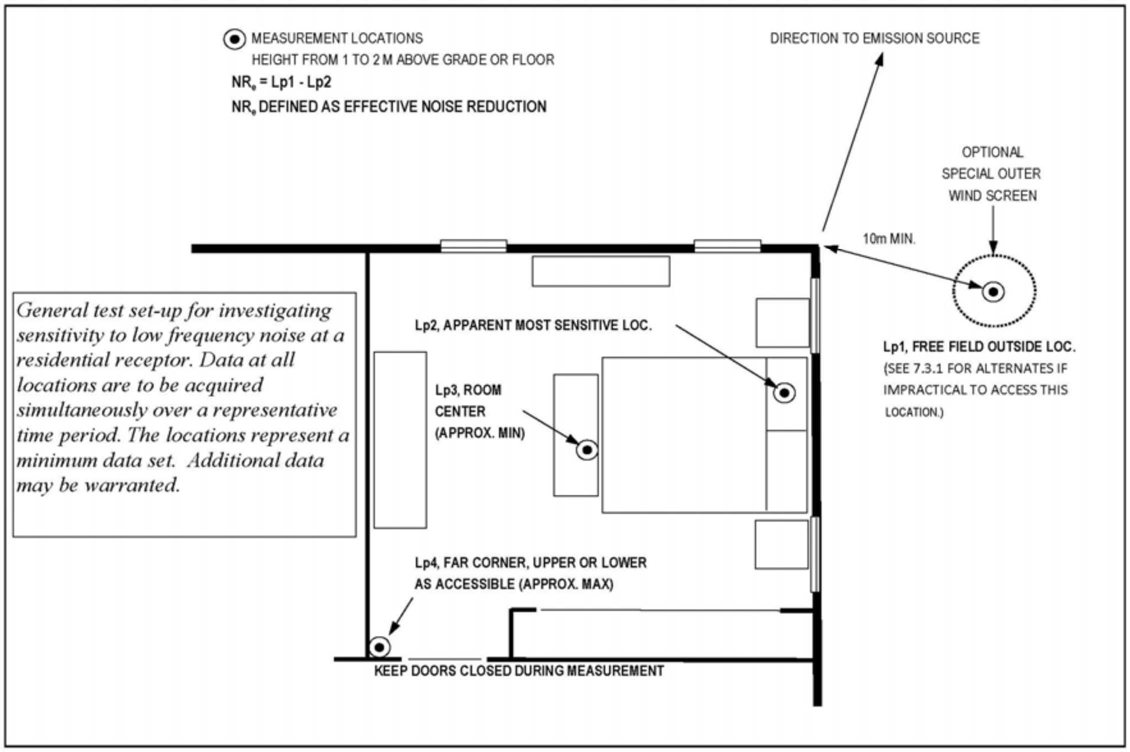


Figure 5 – Indoor test setup

7.3.4 Location Lp4 shall be designated the "corner" position. The corner position shall be the intersection of 3 solid surfaces. Doorways and windows should not be near the corner. Where possible, the most reflecting of 2 opposing surfaces shall be selected. For example, a hard reflecting floor should be chosen rather than a sound-absorbing ceiling.

NOTE Since all room modes are a maximum in the corners, Lp4 spectra represents the maximum spectrum that can occur anywhere in the room due to room mode resonances.

7.4 Windscreen selection

7.4.1 For indoor measurements, there are at least two (2) indoor-located microphones and at least one (1) outdoor-located microphone for determining outdoor-to-indoor noise reduction.

7.4.2 For indoor-located microphones, no windscreen, or the manufacturer's recommended windscreen, or better, may be used.

7.4.3 For outdoor-located microphones, the windscreen requirements of clause 6.2 shall apply.

7.5 Analysis results

7.5.1 Compliance with this standard requires that all results supported by measurements and calculations be reported in normal reporting fashion of tables and/or graphics along with site-specific factors and the principal results described herein. The principal results are the data measured at locations Lp1, Lp2, and Lp4 with the source(s) both ON and OFF. The other principal quantity is NR_e, which is the difference between simultaneous measurements at locations Lp1 and Lp2.

7.5.2 In situations where the source cannot possibly be turned OFF, it is suggested that outdoor measurements be made close to (within 1 m of) the rear wall of the structure so that the structure itself shields and minimizes the impinging source of ILFN or LFN. Likewise, indoor measurements are suggested in rooms remote from the room under investigation. These data can be used to evaluate and estimate the maximum background level indoors and outdoors that could exist if the source were turned off.

7.5.3 All relevant operating conditions, building façade construction, window position/construction, etc. shall be clearly given. The outdoor wind speed shall be measured periodically during sound level logging and reported with a statement if outdoor wind was audible inside or not. Outdoor average wind speed shall not exceed 3 m/s (5mph).

7.5.4 The source of interest may vary with time or be constant such as a loudspeaker source. For both cases, measurements shall be logged in synchronized intervals covering the source OFF-ON-OFF or ON-OFF-ON over the test duration. The logging interval should be chosen to capture the temporal character of the source and for an adequate time to define the background sound with reasonable certainty. A logging time of 1 min is suggested as a starting point and may be increased or decreased as required by the source character. If it is not feasible to acquire the three intervals, simple ON-OFF or OFF-ON data may be used.

7.5.5 The metrics of Leq, L10, L50, and L90 shall be acquired in one-third-octave band frequency bands for each logging interval. The frequency range commencing at 0.5 Hz through 10 kHz is the *preferred* frequency span. Instrumentation starting at 12.5 Hz is the minimal acceptable frequency range if it can be shown that the source of interest has no significant energy below 12.5 Hz. Leq is the metric to be reported unless it is shown that another metric is more appropriate due to test conditions or source character.

7.5.6 The source ON and OFF Lp1 through Lp4 shall be reported. Both the ON and OFF logging results shall be examined to ensure the data do not contain any extraneous or spurious extraneous noise not associated with the source or residual background. Such interval data may be excluded from the averaging process. The number of OFF interval samples shall be at least equal to the number of ON samples. For a controlled loudspeaker test, three repeating Leq(1min) samples may be sufficient, whereas an unsteady source may require substantially more.

NOTE 1 Annex A contains a summary of results for an unsteady source for information and guidance.

NOTE 2 Judgment requiring deviations from the above may be required in the field. The examples in Annex A expand on this and show some detailed adjustments for information.

7.6 Reporting

7.6.1 All results described above plus all measurements, calculations, analysis, tables, graphics, and site-specific factors shall be reported in normal engineering report fashion.

7.6.2 As stated in 7.2.2, the report shall state whether or not wind-induced noise was audible inside.

7.6.3 The measured frequency response of each microphone/preamplifier combination used in the study shall be included in the report.

7.6.4 For indoor microphones, the position of the microphone shall be identified, and the report shall include a separate photograph for each microphone and its position.

7.6.5 For the free-field microphone, Lp1, the type of windscreen utilized and the height of the microphone above ground shall be stated, and the report shall include a photograph that shows the microphone and windscreen and their relation to the ground, or mounted flush on a building.

7.6.6 The test report shall be sufficiently thorough such that another competent acoustical test engineer can duplicate the test without ambiguity to assess repeatability or to evaluate changes in source levels from source modification or abatement.

7.6.7 For LFN, if optional narrow-band analysis is used, at least all frequencies in the one-third-octave band range listed in 3.3 shall be measured and reported.

7.6.8 For ILFN, if optional narrow-band analysis is used, at least all frequencies in the one-third-octave band range listed in 3.5 shall be measured and reported.

7.6.9 The test report shall be thorough enough so that another competent acoustical test engineer can duplicate the test to assess repeatability or to evaluate changes in source levels from source modification or abatement.

8 Signal processing techniques

Advanced signal processing techniques using time domain measurements with multi-channels controlled by the same clock can produce significant information about the measurement source. While beyond the scope of this standard, Annex D is included for information purposes.

Annex A

(informative)

Examples of outdoor/indoor measurement testing – unsteady source

A.1 Introduction

A test was set up using an unsteady source to demonstrate use of this standard. The source was a grass mowing operation using two 48-inch mowers and various gasoline powered trimmers and blowers, hence the source was very unsteady. The room was a bedroom and the façade was a typical insulated 3.5-inch wood stud wall with plywood exterior covered with vinyl siding and 0.5-inch gypsum board interior. The window used most of the wall area and was a modern (Year 2000) double-insulated glass. The photo in Figure A.1 shows three of the four measurement locations.

Figure A.1 – Depiction of measurement locations from inside interior space

A.2 Possible deviations

The first question posed was where to place the Lp1 microphone as the only solid surface was the window. The vinyl siding and shutters were very thin and could be pushed easily with a finger. Another test was done to see what results would be measured with four choices of location. The photo in Figure A.2 illustrates the choices.

The meter location “MIC 4” was 1.5 m from the surface while the others were flush mounted. The free-field level in this setup would be the flush microphone result minus 6 dB and the 1.5 m microphone minus approximately 3 dB. When these factors are applied to normalize the four locations to the free-field incident level, we arrive at the plot presented in Figure A.3.

Figure A.2 – Depiction of measurement locations on exterior of interior space

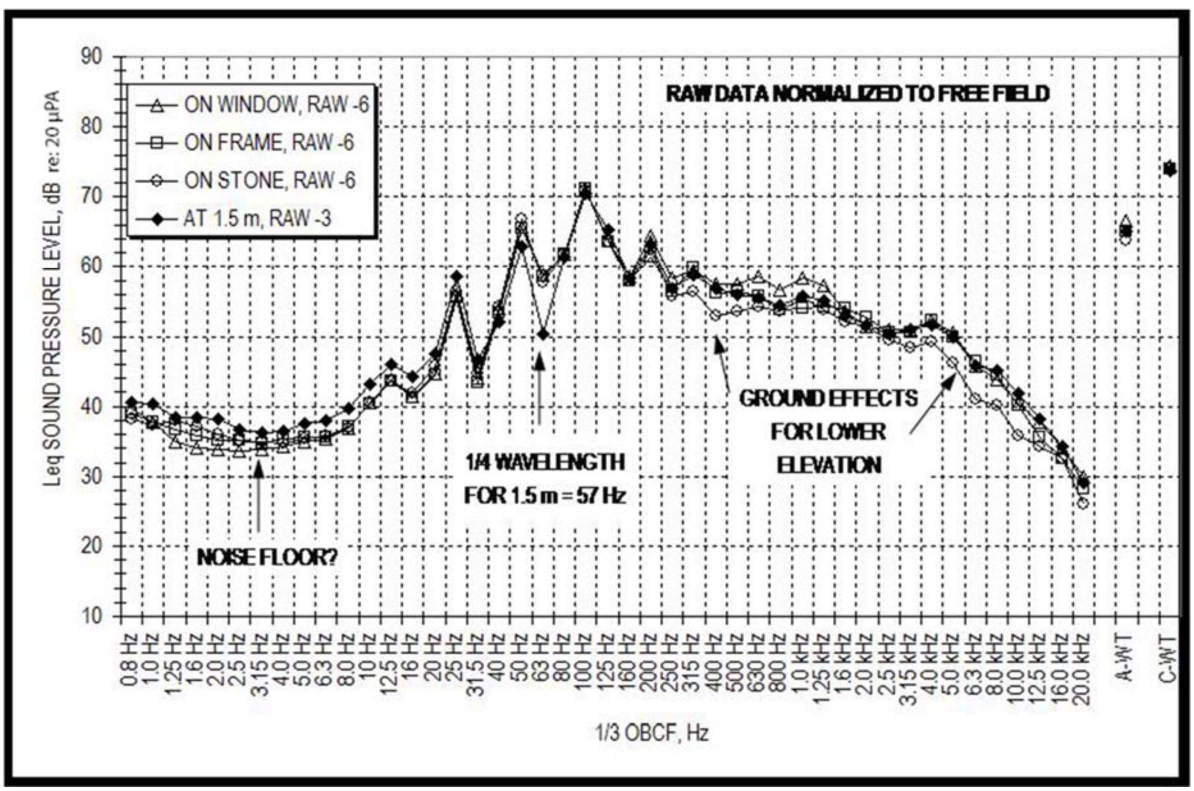


Figure A.3 – Raw measurement data normalized to free field

The plot in Figure A.3 shows good agreement between the flush microphone and the one at 1.5 m from the wall. The exception in the 63 Hz band is attributed to minimum pressure from the reflected wave at one-quarter wavelength (57 Hz). The lower level for microphone 3, the stone surface, is attributed to the lower elevation where ground effects above 200 Hz could be expected.

Based on this result, we conclude that a modern tight window glass surface or window frame is a satisfactory surface for mounting the microphone when no other surface is available.

The second question was the indoor corner location. Crown molding prevented the ceiling/walls location, and the floor was carpeted. The floor location was used with a hard plastic sheet placed over the carpet.

A.3 Test results

Two tests were completed two weeks apart with the same mowing operation as the source to determine repeatability. The chosen interval was changed from 1 to 5 minutes. The plots of noise reduction values appearing in Figure A.4 indicate good repeatability considering field conditions.

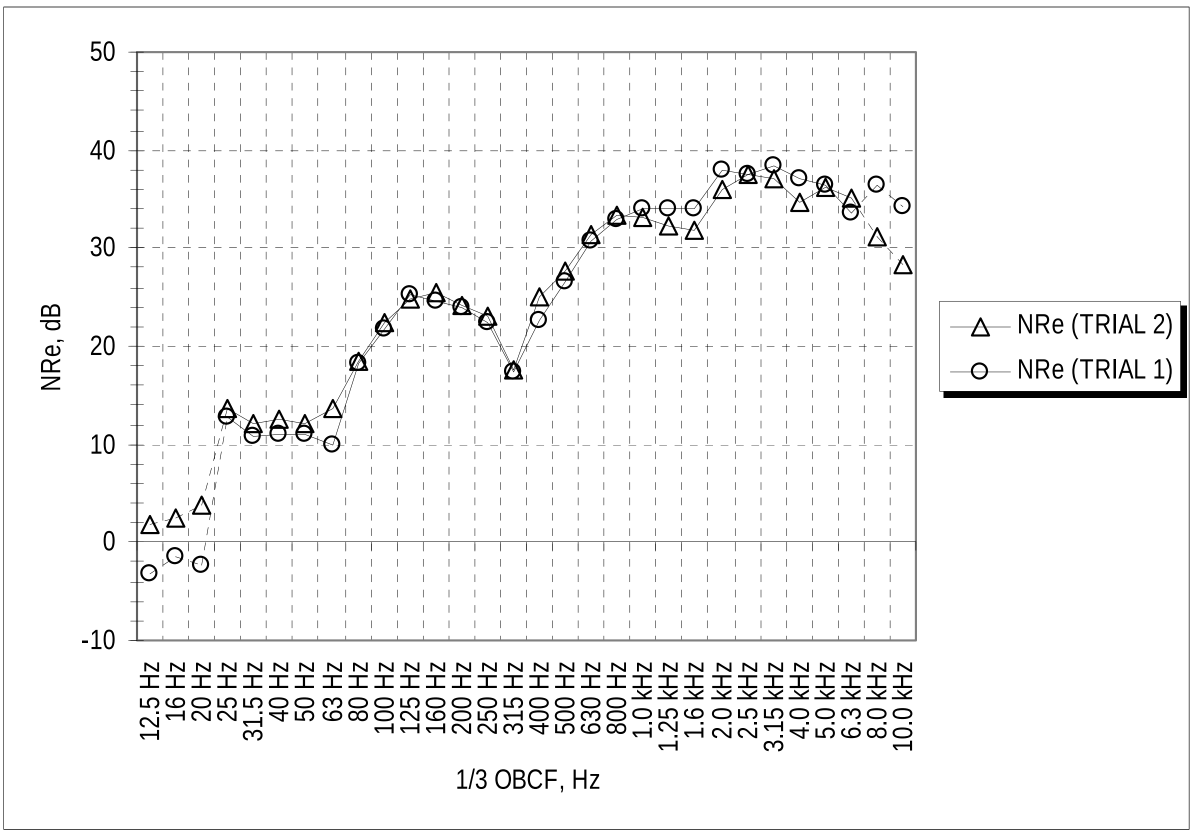
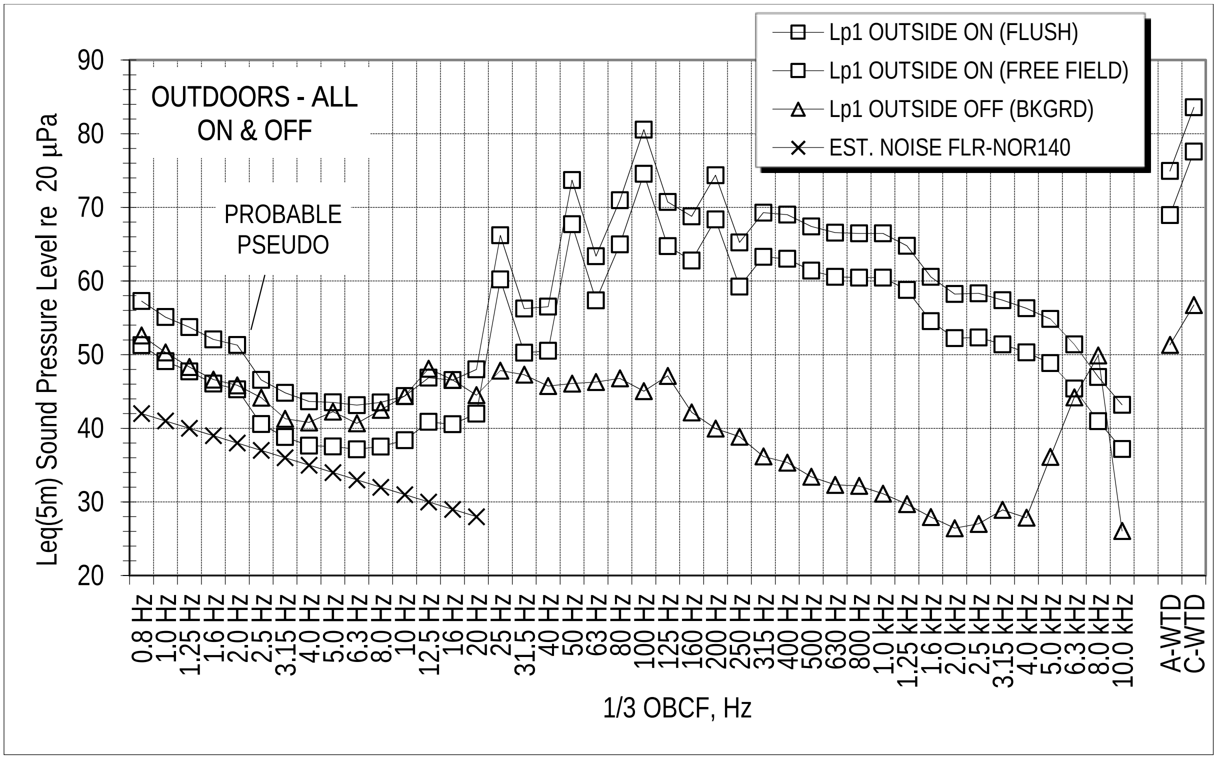


Figure A.4 – Noise reduction (NR_e) for each of two trials

The following plots in Figure A.5 show the outdoor and indoor raw data. It is clear that there is no significant source noise below 25 Hz and the plots show the prominent firing tones from the source.



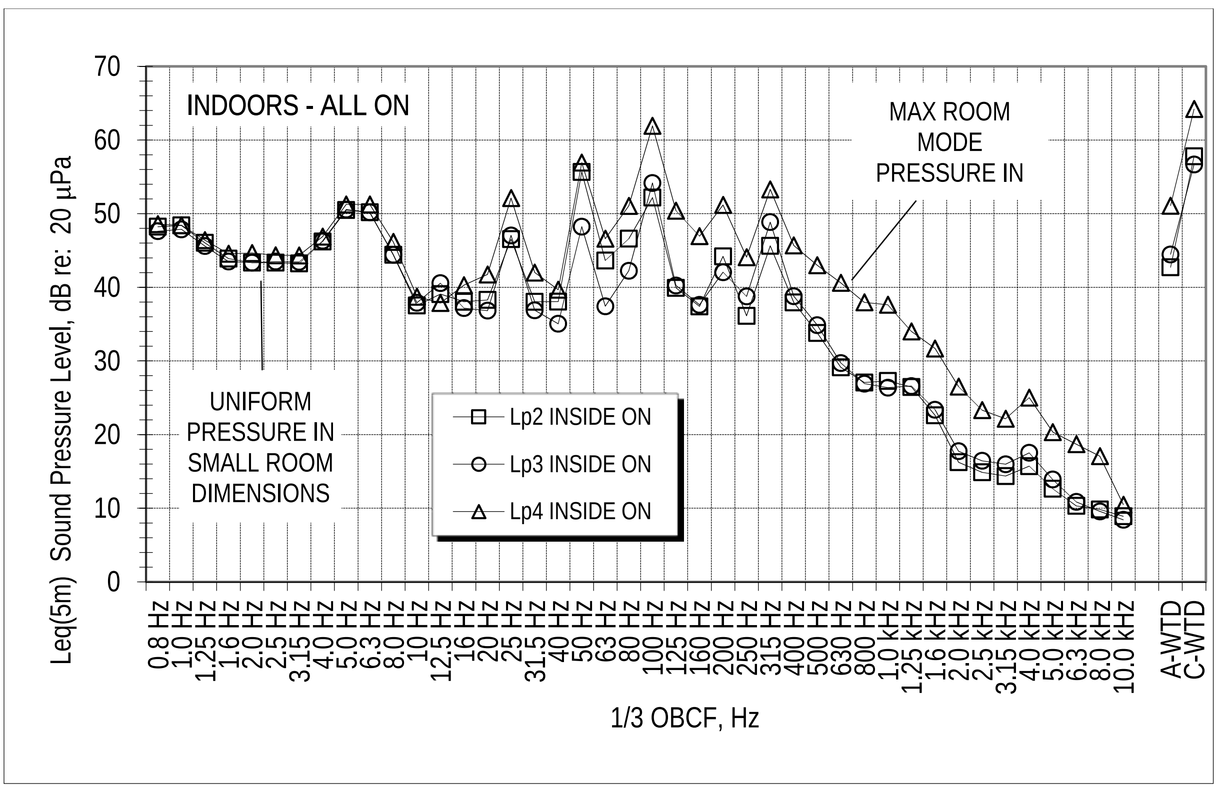


Figure A.5 – 5-min duration Leq for outdoor and indoor measurement locations

The indoor data shows the relationship between locations. The maximum spectrum will always be in a corner at about 9 dB above the spatial average for small wavelength-to-room ratios. At large ratios the pressure will converge to a constant pressure everywhere.

The following plot in Figure A.6 summarizes the test results. The source has multiple engine firing tones at 25, 50, and 100 Hz that makes source noise particularly evident indoors and outdoors. It can be seen that infrasound levels inside are higher than outside; i.e., there is no infrasound source outdoors and levels are barely above the noise floor of the instrumentation. It can also be seen that measurable intrusive noise begins at 25 Hz and ends at 4 kHz for this site. Thus, Lp1 – Lp2 equals NR_e in this frequency range. The range for NR_e will be smaller for narrower band sources.

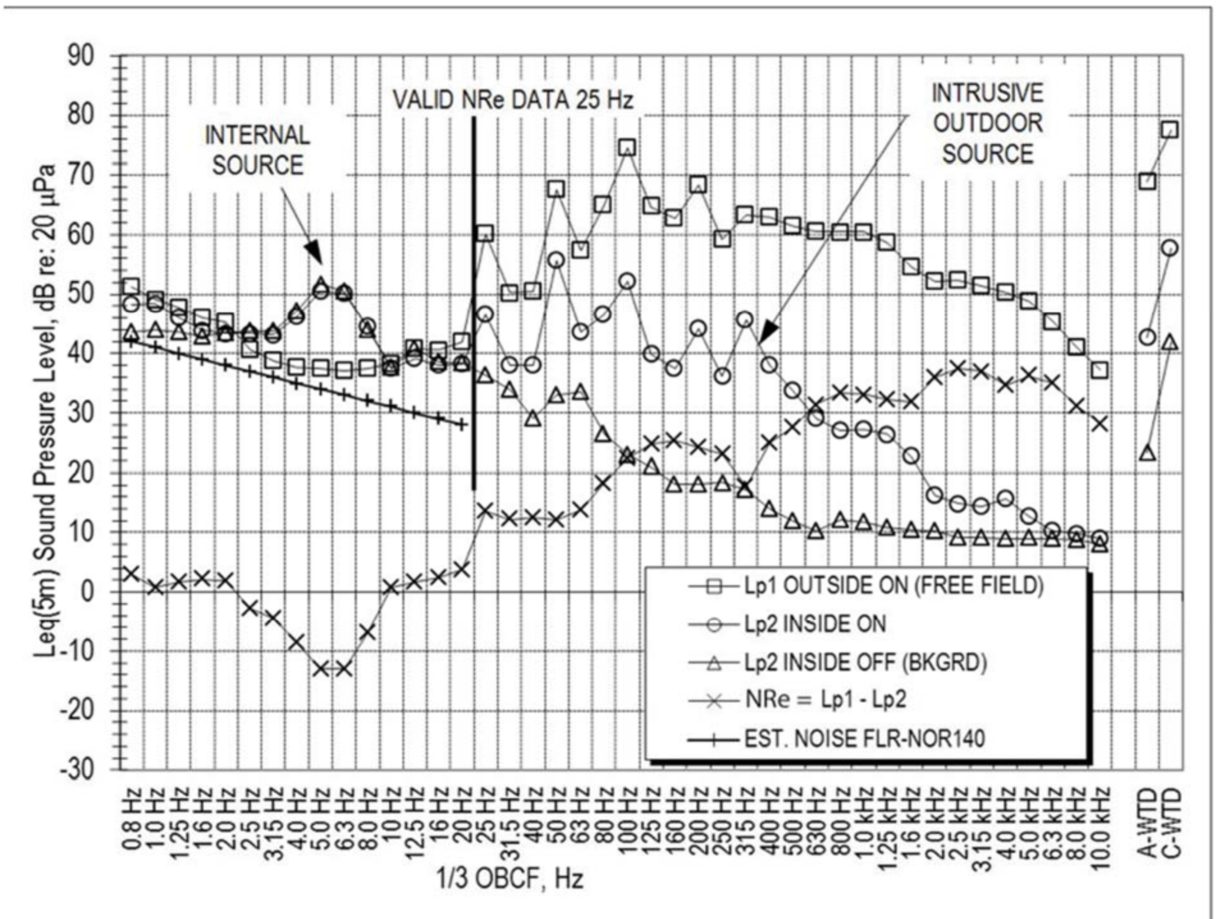


Figure A.6 – 5-min duration Leq summary

Thus, the objective of the standard is met; i.e., identifying and quantifying the outdoor-to-indoor transmission of source noise to indoors.

Annex B

(informative)

Development of wind-induced noise (WIN) estimates

Wind-induced noise (WIN) can be measured in quiet remote areas devoid of manmade sources of sound/noise but where there is significant wind. Spectral WIN and measured insertion loss (IL) are tabulated on Tables B.1 and B.2 respectively. These data may be copied and pasted into an analysis program.

The instrumentation for Mojave work consisted of Bruel & Kjaer and Larson-Davis 0.5-inch microphones and preamps, a Larson-Davis 2210 signal conditioning amplifier, Data Translation DT9836 USB data acquisition interface, and an Acer Laptop PC running Matlab Data Acquisition Toolbox. The 2210 was set to 1 Hz to 10 kHz response and, following calibration with a B&K 4231, data was recorded in 10-min blocks at 24 kHz sampling rate. Simultaneously, wind speed signals from an NRG cup anemometer and resolver were recorded on the last channel of the DAQ system. In post-processing, the signals were filtered into one-third-octave bands and divided into 10-second time blocks. The LZFeq10sec were tabulated with 10-second average wind speeds for subsequent binning of Leq, L50, and L90.

Details for the seven windscreens as referenced in Table B.1 are:

MIC 1. B&K Standard low porosity 90mm diameter windscreen [BASELINE]

MIC 2. ACO 175mm diameter 20ppi untreated for weather

MIC 3. ACO 175mm diameter 20ppi covered with a 525mm perforated sheet metal turbulence screen

MIC 4. ACO 175mm diameter 80ppi treated for weather

MIC 5. Fabricated 300mm rhombi cuboctahedron foam 20ppi untreated for weather

MIC 6. Fabricated 300mm rhombi cuboctahedron foam 80ppi treated for weather

MIC 7. Mini ground plane per Figure 1 and 4.5.3 with outer turbulence screen (foam hemispheric dome)

Table B.1 Measured spectral wind-induced noise (WIN) at site W (Mojave Desert) for seven windscreen designs (continued on next page)

	MIC 1-90mm STD WS							
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	56	62	67	71	75	78	80	81
0.6	59	67	71	75	79	82	84	85
0.8	60	67	73	77	81	84	85	87
1.0	60	67	72	78	81	83	85	88
1.3	59	67	72	77	80	83	86	89
1.6	59	67	72	77	81	84	86	90
2.0	58	65	70	75	80	83	85	88
2.5	55	63	69	74	78	82	84	88
3.2	54	62	68	73	77	81	83	86
4.0	52	60	66	72	76	80	82	85
5.0	50	58	65	71	75	79	81	84
6.3	49	56	63	69	73	78	80	83
8.0	48	55	61	67	72	76	78	81
10.0	47	52	59	65	70	74	77	80
12.5	46	51	57	63	69	73	75	78
16.0	46	49	55	61	67	71	74	76
20.0	45	47	53	59	65	69	72	75
25.0	42	44	50	57	63	68	70	73
31.5	39	41	46	54	61	65	68	71
40.0	39	41	44	50	57	63	66	69
50.0	38	39	42	48	54	60	63	67
62.5	39	38	41	45	51	56	60	63
80.0	39	39	40	43	48	53	56	60
100.0	34	35	36	40	46	50	54	57
125.0	32	33	34	37	43	47	50	53
160.0	30	30	32	34	39	43	47	49
200.0	28	28	29	31	36	40	43	45
250.0	26	26	27	29	33	37	40	42
A-WT	25	25	26	29	35	40	43	46
C-WT	48	50	55	61	67	71	74	77
G-WT	59	62	68	75	80	84	87	90

	MIC 2-175mm 20ppi UNTREATED							
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	53	62	66	71	74	77	79	82
0.6	58	65	70	74	78	81	83	85
0.8	57	67	71	76	80	83	85	88
1.0	56	66	71	77	81	84	86	88
1.3	56	64	69	75	79	83	85	88
1.6	56	64	70	76	80	84	86	87
2.0	53	61	67	73	78	81	84	87
2.5	52	59	65	71	76	80	82	86
3.2	50	58	64	69	74	78	80	84
4.0	51	60	65	70	75	78	80	82
5.0	48	54	61	67	71	75	78	81
6.3	46	52	59	65	71	76	78	80
8.0	46	52	59	65	71	76	78	81
10.0	44	47	53	60	66	70	73	76
12.5	44	47	52	58	66	71	73	76
16.0	45	47	50	55	63	68	71	74
20.0	44	46	53	58	63	68	71	74
25.0	41	42	47	55	59	63	66	69
31.5	39	40	42	50	57	61	63	65
40.0	39	39	40	46	56	63	65	67
50.0	38	38	39	43	51	57	60	63
62.5	39	37	39	41	47	52	56	60
80.0	39	38	38	40	45	50	52	55
100.0	34	34	35	36	41	43	47	49
125.0	32	33	33	34	39	42	47	47
160.0	30	30	31	33	38	42	45	46
200.0	28	28	29	31	36	39	42	44
250.0	26	26	27	29	33	37	39	40
A-WT	25	25	25	27	33	37	40	42
C-WT	47	48	52	58	64	69	72	74
G-WT	58	60	65	71	77	82	85	88

	MIC 3-175mm W/ TURBULENCE SCREEN							
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	49	57	62	67	72	76	77	78
0.6	53	60	66	71	75	80	81	84
0.8	53	61	66	72	77	81	83	87
1.0	51	61	66	71	76	79	81	85
1.3	49	58	64	70	75	78	80	83
1.6	49	59	64	71	75	79	81	82
2.0	48	55	62	68	73	76	79	81
2.5	46	52	59	66	71	75	77	79
3.2	46	50	56	64	70	74	76	79
4.0	45	48	54	61	68	72	75	78
5.0	45	47	51	58	65	70	73	76
6.3	44	45	49	55	63	68	71	74
8.0	43	44	46	52	60	65	68	72
10.0	43	43	44	50	57	62	65	68
12.5	43	43	44	48	54	59	63	67
16.0	45	45	46	49	55	60	63	66
20.0	44	44	44	46	51	56	59	62
25.0	41	41	43	48	55	58	60	62
31.5	39	40	41	48	56	59	61	63
40.0	39	39	38	41	49	55	58	60
50.0	38	38	38	40	46	53	57	59
62.5	39	37	38	38	41	44	48	51
80.0	39	38	38	38	42	44	45	48
100.0	34	34	34	35	40	42	45	47
125.0	32	33	33	34	39	42	46	45
160.0	30	30	31	32	37	41	44	46
200.0	28	28	29	30	34	38	41	45
250.0	26	26	27	28	32	36	38	41
A-WT	25	25	25	26	31	34	37	40
C-WT	47	47	48	51	58	62	65	67
G-WT	57	57	58	62	68	72	76	79

	MIC 4-175mm 80ppi TREATED							
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	45	51	55	59	63	66	68	70
0.6	49	57	62	67	69	72	75	77
0.8	52	61	65	70	74	76	78	81
1.0	54	61	67	73	76	79	81	83
1.3	53	63	68	73	77	80	82	85
1.6	54	64	70	75	79	82	85	86
2.0	53	63	68	74	78	82	84	85
2.5	51	62	67	74	78	81	84	85
3.2	50	61	66	73	77	80	83	85
4.0	49	59	65	72	76	80	82	83
5.0	48	56	63	70	75	79	81	83
6.3	46	54	61	68	73	77	80	81
8.0	45	51	58	66	72	76	78	79
10.0	44	48	55	63	69	74	77	79
12.5	43	46	51	59	66	71	74	76
16.0	45	46	49	56	63	68	72	75
20.0	44	44	47	52	59	65	68	72
25.0	41	41	43	48	56	62	65	69
31.5	39	39	40	45	51	56	61	64
40.0	39	39	39	42	48	53	57	61
50.0	38	38	38	40	45	50	55	58
62.5	39	37	38	39	43	46	50	53
80.0	39	38	38	38	42	45	47	50
100.0	34	34	35	36	41	44	47	50
125.0	32	33	33	34	39	42	46	47
160.0	30	30	31	32	35	39	43	44
200.0	28	28	28	29	33	36	40	42
250.0	26	26	27	28	31	35	38	39
A-WT	25	25	25	26	30	34	37	39
C-WT	47	48	51	57	63	68	71	74
G-WT	57	59	64	71	77	82	85	88

Table B.1 - Measured spectral wind-induced noise (WIN) at site W (Mojave Desert) for seven windscreen designs (page 2)

MIC 5-300mm 20ppi UNTREATED								
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	46	52	56	61	65	69	70	72
0.6	49	56	60	66	71	74	76	77
0.8	50	58	64	68	73	77	79	81
1.0	49	58	63	70	74	78	80	82
1.3	50	58	63	70	74	78	80	82
1.6	49	59	65	70	75	79	82	84
2.0	49	57	63	68	74	78	80	83
2.5	48	56	62	68	74	77	79	83
3.2	47	53	59	66	71	75	77	81
4.0	46	51	57	64	70	75	77	80
5.0	45	49	55	62	68	72	75	77
6.3	45	47	51	59	66	70	73	76
8.0	44	45	48	56	63	68	71	73
10.0	43	44	46	52	60	65	68	72
12.5	44	44	46	50	56	62	65	69
16.0	45	45	46	49	54	58	62	65
20.0	44	44	44	47	52	56	59	61
25.0	41	41	42	45	51	55	58	61
31.5	39	39	40	42	48	52	55	59
40.0	39	39	38	41	46	51	53	57
50.0	38	38	38	39	45	49	53	55
62.5	39	38	38	39	43	45	48	52
80.0	39	39	38	38	42	45	46	50
100.0	34	34	35	35	41	42	46	49
125.0	32	33	33	34	39	42	46	46
160.0	30	30	31	31	35	38	42	43
200.0	28	28	28	30	34	37	40	41
250.0	26	26	27	28	32	36	39	39
A-WT	25	25	25	26	31	33	37	38
C-WT	47	47	48	51	56	61	64	67
G-WT	57	57	59	63	69	73	76	79

MIC 6-300mm 80ppi TREATED								
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	47	53	57	62	65	68	70	72
0.6	51	58	62	67	71	74	76	79
0.8	53	61	64	70	74	76	78	82
1.0	54	62	66	71	75	78	80	83
1.3	54	62	66	71	75	79	81	84
1.6	54	63	68	72	77	80	83	86
2.0	51	60	66	71	75	78	80	83
2.5	51	59	65	70	75	78	80	83
3.2	49	58	63	68	74	77	80	82
4.0	48	55	61	67	72	76	78	81
5.0	48	53	58	65	70	74	77	79
6.3	47	51	55	62	67	72	75	76
8.0	45	49	53	59	65	69	73	75
10.0	44	47	50	56	61	66	70	73
12.5	44	46	49	53	59	63	67	70
16.0	45	46	48	51	56	60	63	65
20.0	44	44	46	49	54	57	60	63
25.0	41	42	43	48	53	57	60	62
31.5	39	40	41	48	56	58	60	61
40.0	39	39	39	42	47	52	54	58
50.0	38	38	38	41	46	50	53	56
62.5	39	37	38	40	44	46	50	53
80.0	39	38	38	39	43	46	48	51
100.0	34	35	36	39	44	48	50	53
125.0	32	33	34	36	41	45	49	49
160.0	30	30	31	31	36	39	42	44
200.0	28	28	28	29	33	36	39	41
250.0	26	26	26	27	31	34	37	38
A-WT	25	25	25	27	32	35	38	40
C-WT	47	48	49	53	59	63	66	68
G-WT	57	59	61	65	71	75	78	81

MIC 7-IEC 61400 MINI-GROUND PLANE								
1/3	WIND SPEED AT MIC, mps							
OBCF	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
0.5	40	47	52	56	61	64	67	68
0.6	45	52	57	62	67	71	73	76
0.8	47	55	60	66	70	73	76	79
1.0	46	55	60	66	71	74	77	80
1.3	47	54	60	66	71	74	78	80
1.6	47	55	61	67	71	76	79	81
2.0	48	52	58	64	69	73	76	79
2.5	47	51	56	63	68	72	76	77
3.2	47	49	54	61	67	71	74	76
4.0	46	48	52	59	65	69	72	75
5.0	46	47	51	56	62	67	71	73
6.3	46	46	49	54	59	64	68	71
8.0	45	45	47	52	57	61	65	68
10.0	44	44	46	49	55	58	62	65
12.5	44	44	45	47	53	56	59	62
16.0	46	45	46	47	51	55	57	60
20.0	45	44	44	45	49	53	56	57
25.0	41	41	41	42	47	51	56	58
31.5	39	39	39	40	45	48	51	54
40.0	39	39	38	39	42	46	49	52
50.0	39	38	38	39	42	45	49	50
62.5	39	38	39	39	41	43	45	48
80.0	40	39	39	39	42	44	45	47
100.0	35	35	36	36	42	43	46	47
125.0	34	34	34	35	41	43	47	46
160.0	32	32	33	33	37	40	44	44
200.0	30	30	30	31	35	38	42	42
250.0	29	29	30	30	34	38	42	42
A-WT	27	26	27	27	32	35	38	38
C-WT	48	47	48	49	53	57	60	62
G-WT	58	57	58	60	65	68	72	74

Notes:

Values below a wind speed of approximately 3 mps are controlled by residual ambient noise.

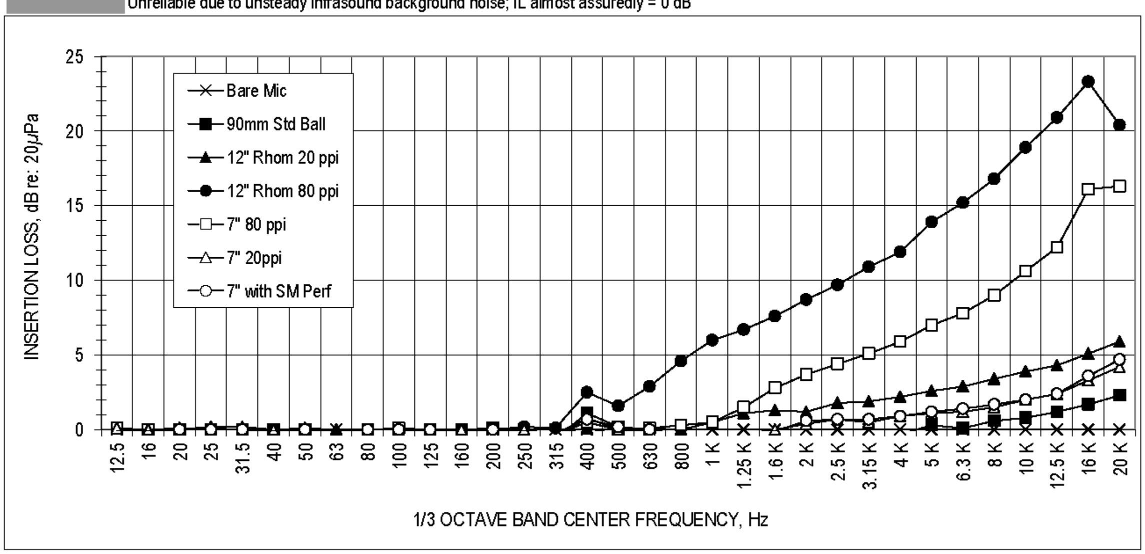
Values below 1 Hz fall off due to microphone and pre-amp limitations for this data.

These data represent the minimum to be expected with reasonably smooth flow over flat topography and coincide with measured levels in a wind tunnel with low turbulent flow. It is recommended that a minimum of 5 dB be added to account for more turbulent flow and site to site variations.

Table B.2 – Windscreen insertion loss

BAND/CASE	1/3 OBCF, Hz	Bare Mic	90mm Std Ball	12" Rhom 20 ppi	12" Rhom 80 ppi	7" 80 ppi	7" 20ppi	7" with SM Perf	Background
0	1.0	0.0	-5.0	2.2	4.2	3.6	2.8	-8.6	-10.0
1	1.3	0.0	-0.5	0.0	6.3	7.2	4.7	-2.6	1.3
2	1.6	0.0	4.1	4.5	9.4	12.7	11.9	1.1	5.9
3	2.0	0.0	5.9	4.9	11.1	12.9	12.4	2.2	6.9
4	2.5	0.0	3.1	4.7	6.9	9.9	9.5	-0.6	4.3
5	3.2	0.0	4.3	5.1	3.8	6.5	7.4	-1.5	3.6
6	4.0	0.0	4.2	4.2	3.6	5.2	6.0	1.6	8.3
7	5.0	0.0	0.2	0.0	0.3	0.6	0.8	-1.3	8.0
8	6.3	0.0	0.4	0.3	0.4	0.2	0.2	-0.7	11.6
9	8.0	0.0	0.2	0.6	0.5	0.5	0.3	0.3	15.4
10	10.0	0.0	0.7	0.8	0.7	0.6	0.6	0.6	15.7
11	12.5	0.0	-0.3	-0.1	0.1	0.1	0.1	-0.1	16.8
12	16.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.1	21.6
13	20.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	28.3
14	25.0	0.0	0.0	0.2	0.0	0.0	0.1	0.0	30.5
15	31.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0	29.7
16	40.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1	36.7
17	50.0	0.0	0.0	0.1	0.0	-0.1	0.0	0.0	36.9
18	63.0	0.0	-0.1	0.0	-0.1	-0.1	-0.1	-0.1	38.7
19	80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.9
20	100.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	36.8
21	125.0	0.0	0.0	-0.1	-0.1	0.0	0.0	0.0	26.8
22	160.0	0.0	0.0	-0.1	-0.1	-0.1	0.0	-0.2	30.4
23	200.0	0.0	0.1	0.1	0.0	-0.1	0.1	0.0	28.2
24	250.0	0.0	-0.1	-0.2	0.2	-0.1	0.0	-0.1	31.5
25	315.0	0.0	-0.6	-0.2	0.1	-0.3	-0.3	-0.3	29.3
26	400.0	0.0	1.1	0.1	2.5	0.5	0.8	0.7	27.2
27	500.0	0.0	0.2	-0.3	1.6	0.0	0.0	0.2	29.5
28	630.0	0.0	-0.2	0.1	2.9	0.1	-0.1	0.0	35.3
29	800.0	0.0	-0.2	0.0	4.6	0.3	-0.4	-0.3	38.6
30	1 K	0.0	-0.2	0.5	6.0	0.5	-0.4	-0.4	39.8
31	1.25 K	0.0	-0.3	1.1	6.7	1.5	-0.3	-0.2	42.2
32	1.6 K	0.0	-0.5	1.3	7.6	2.8	0.0	-0.1	42.8
33	2 K	0.0	-0.6	1.2	8.7	3.7	0.4	0.6	40.3
34	2.5 K	0.0	-0.8	1.8	9.7	4.4	0.7	0.7	38.3
35	3.15 K	0.0	-0.7	1.9	10.9	5.1	0.5	0.7	38.4
36	4 K	0.0	-0.3	2.2	11.9	5.9	0.9	0.9	34.6
37	5 K	0.0	0.3	2.6	13.9	7.0	1.1	1.2	35.2
38	6.3 K	0.0	0.1	2.9	15.2	7.8	1.2	1.4	39.9
39	8 K	0.0	0.6	3.4	16.8	9.0	1.5	1.7	43.1
40	10 K	0.0	0.8	3.9	18.9	10.6	2.0	2.0	42.2
41	12.5 K	0.0	1.2	4.3	20.9	12.2	2.4	2.4	36.4
42	16 K	0.0	1.7	5.1	23.3	16.1	3.3	3.6	28.3
43	20 K	0.0	2.3	5.9	20.4	16.3	4.2	4.7	20.6

Unreliable due to unsteady infrasound background noise; IL almost assuredly = 0 dB



Annex C

(informative)

Estimation of sound level spectra at normal above-grade microphone height from ground-plane results

The direct and ground-reflected waves arriving at a receptor combine depending on the angle of incidence or geometry, particularly as determined by the source and receiver heights and intervening distance. Equation (C.1), below, shows the necessary conversion variables.

$$L_{ag} = L_{gp} + K_r + K_w \tag{C.1}$$

Where L_{ag} is pressure level above grade at 1.5 m; L_{gp} is pressure level at ground-plane elevation; K_r stands for a correction to account for the combination of the direct and ground-reflected waves; and K_w accounts for the reduction of WIN due to reduced wind velocities at grade level.

Figure C.1 shows the theoretical combination (K_r) for a special test setup using both a 175 mm ground-plane windscreen and a 300 mm rhombi cuboctahedron windscreen on an above-grade microphone (mic 5 in Annex B). The measured and theoretical agree very well but it should be pointed out the large cancellation at 100 Hz for the example and the tabulated values do not occur in practice due to non-uniform atmospheric conditions. That is the reason for Note 1 in the tabulated values to the right of the plot limiting the correction to -5 dB in any band. This table is a parametric study produced from a theoretical template by varying the source height and distance. It is clear that infrasound requires no correction and the table values can be used to convert the measurement at higher frequencies.

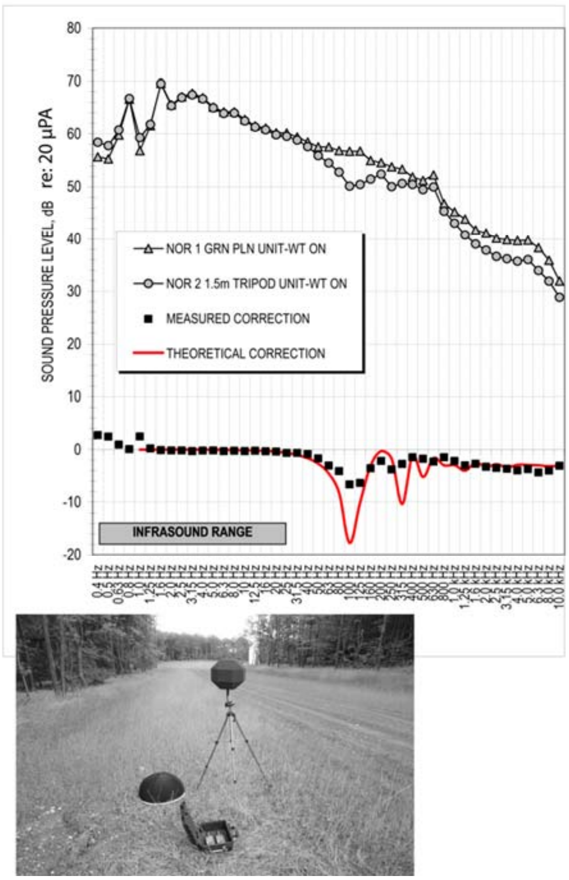
NOTE It should be noted that the test conditions for the test setup in Figure C.1 were ideal with essentially no wind at ground level or above grade at either microphone ($K_w = 0$). This was caused by a tree buffer to either side but sufficient wind speed at higher elevations to create sound from the wind turbines. The point is that in higher winds, the ground-plane method will detect lower infrasound levels than the above-grade unit and hence is the superior method for infrasound measurements.

$L_{1.5m} = Lgp + Kr + Kw$

where:

Kr = addition of ground reflection wave to ground plane measurement without it.

Kw = adjustment for wind-noise difference at ground and 1.5m height



METERS			O.B. CENTER FREQUENCY, Hz													
Hs	Hr	D	1	2	4	8	16	32	63	125	250	500	1K	2K	4K	8K
5	1.5	100	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4
10	1.5	100	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3
20	1.5	100	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3	-3
40	1.5	100	0	0	0	0	0	0	-2	-9	-2	-3	-3	-3	-3	-3
80	1.5	100	0	0	0	0	0	-1	-6	-4	-3	-3	-3	-3	-3	-3
160	1.5	100	0	0	0	0	-1	-3	-10	-2	-4	-3	-3	-3	-3	-3
5	1.5	200	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3
10	1.5	200	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4
20	1.5	200	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3
40	1.5	200	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3	-3
80	1.5	200	0	0	0	0	0	0	-2	-9	-2	-3	-3	-3	-3	-3
160	1.5	200	0	0	0	0	0	-1	-6	-4	-3	-3	-3	-3	-3	-3
5	1.5	400	0	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2
10	1.5	400	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3
20	1.5	400	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4
40	1.5	400	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3
80	1.5	400	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3	-3
160	1.5	400	0	0	0	0	0	0	-2	-9	-2	-3	-3	-3	-3	-3
5	1.5	800	0	0	0	0	0	0	0	0	0	0	0	-1	-2	-10
10	1.5	800	0	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2
20	1.5	800	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3
40	1.5	800	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4
80	1.5	800	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3
160	1.5	800	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3	-3
5	1.5	1600	0	0	0	0	0	0	0	0	0	0	0	0	-1	-2
10	1.5	1600	0	0	0	0	0	0	0	0	0	0	0	-1	-2	-10
20	1.5	1600	0	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2
40	1.5	1600	0	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3
80	1.5	1600	0	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4
160	1.5	1600	0	0	0	0	0	0	0	-1	-2	-10	-2	-3	-4	-3

NOTE 1: RECOMMENDED A MAXIMUM OF -5 dB IN ANY ONE BAND BE USED.

Figure C.1 – Theoretical and measured corrections to convert from a ground-plane measurement to one at 1.5 m above grade to include ground-reflected wave

Annex D

(informative)

Advanced signal processing techniques

D.1 Introduction

The measurement and reporting methods described in this standard are primarily designed so that data can be collected using readily available certified equipment and reported in a consistent and unambiguous form. The primary metric is therefore time-averaged one-third-octave sound pressure level.

However, the standard is also aimed at measuring low-frequency and infrasonic signals. It has been observed (Bray, Swinbanks, Walker, *et al*) that for complex low-frequency signals (those comprising multiple frequencies), the temporal relationship between the components can have a significant influence on their subjective assessment. (Indeed, all one needs do is listen to the difference between a gun-shot and an extended Galois sequence signal to observe that two signals with the exact same spectrum can sound dramatically dissimilar.) Figure D.1 shows a less extreme illustration.

The more detailed assessment of very low-frequency sounds may be done with time-domain analysis or full Fourier spectrum analysis. Mean-square (Leq) analysis of filtered (third-octave or narrow-band) signals discards information required to determine relevant properties of complex signals. Figure D.2 illustrates the particularly obscuring nature of one-third-octave analysis as applied to these types of signals.

D.2 Low-frequency wind turbine noise

A particular target for measurement of very-low-frequency sound is the investigation of blade-passage harmonics of large fans and turbines. Four issues that pose special difficulties for this source are:

- The signal is generally a sequence of short duration (0.03 to 0.10 second) pulses with a fundamental frequency that is typically between 0.5 and 1.0 Hz and a series of harmonics extending to approximately 20 Hz (i.e., effectively 20 to 40 simultaneous sinusoidal signals).
- The rotation speed is often not perfectly steady, so the signal is only quasi-periodic and the actual frequencies of the harmonic sequence are in a state of flux.
- Often, the signal received at a measurement location of interest is the combined result of multiple turbines from similar distances, all running at slightly different rotation rates.
- Indoors or out, the quasi-periodic turbine signal coexists with random atmospheric pressure fluctuations in the similar frequency range and often considerably higher overall amplitude.

Wind turbine infrasound is generally experienced at sound levels that would normally be considered subliminal and is generated by aeroacoustic processes that produce consistent pulsation waves that encompass a frequency range of several octaves. In addition to the fundamental pulse repetition rate and power spectrum, understanding the human response to these waves may require considering properties that conventional analysis discards, which include: pulse width, pulse height, wave slope.

This section describes two methods that are under consideration for preserving this information.

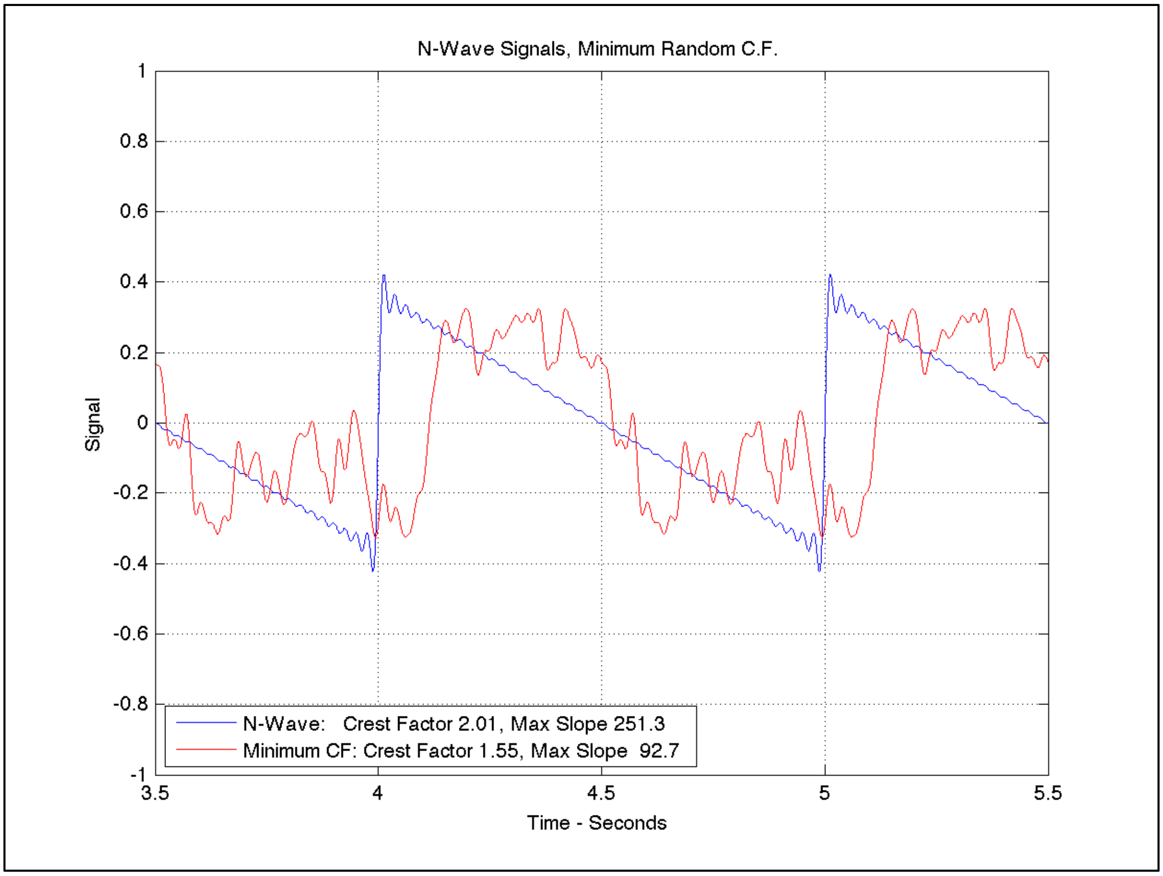
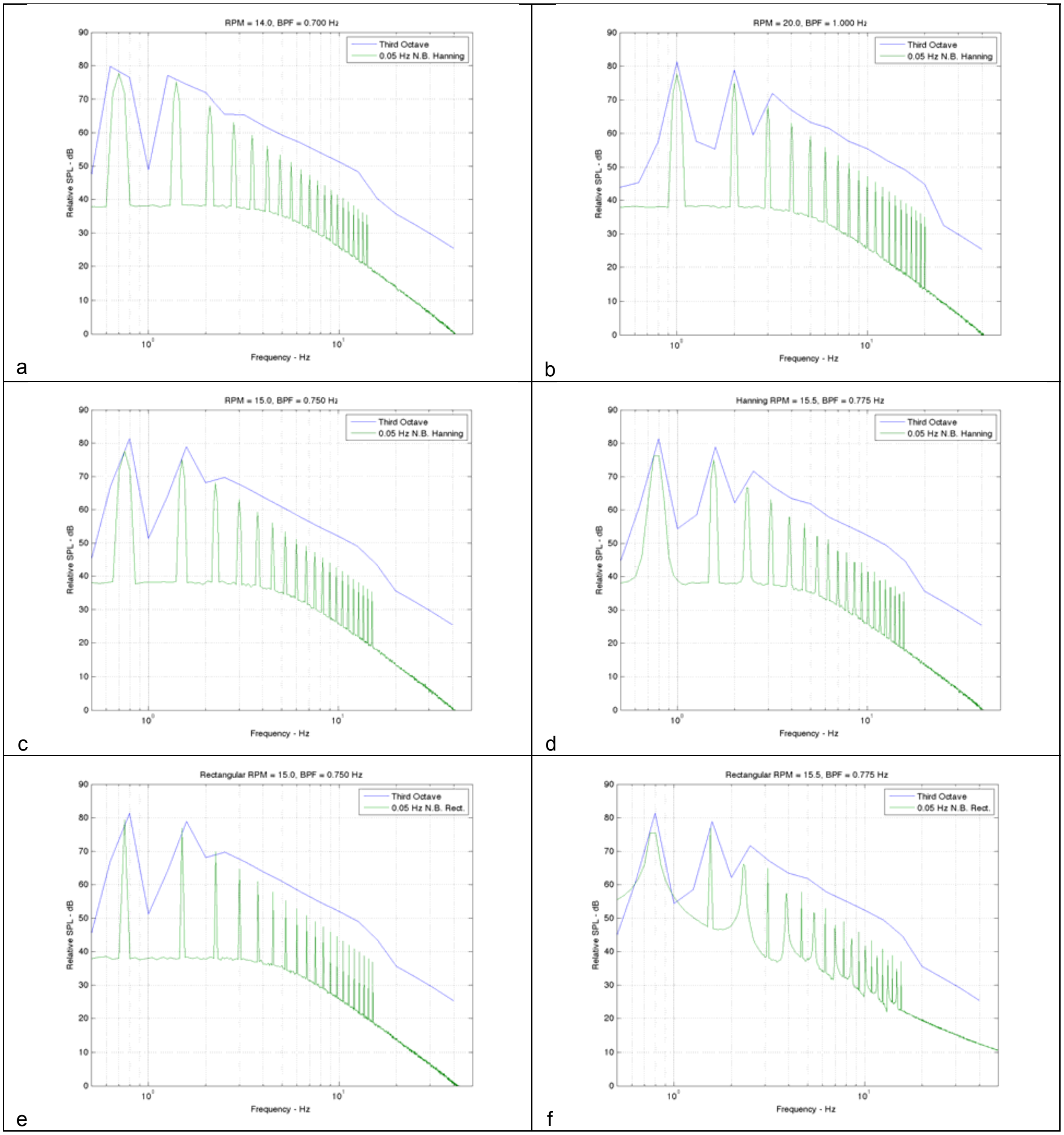


Figure D.1 – Two signals with exact same power spectrum and (therefore) autocorrelation function



Figures D.2a through D.2f – Illustration of the limitation of third-octave analysis for studying low-frequency sound emissions from wind turbines and also show issues associated with Discrete Fourier Transform (DFT) analysis

D.3 Signal acquisition and analysis options

Two methods have been used relatively successfully to preserve or estimate wave details: time domain analysis and time domain synthesis. Both depend on capturing field data with faithful representation of all components of the radiated signals. In the case of time domain analysis, amplitude and phase response of transducers and recording equipment are critical. For the synthesis approach, phase response has to be assumed, and only amplitude response is critical. For practical purposes, a target low-frequency limit of -1 dB at 0.1 Hz or better is preferred.

Time domain analysis outline

Wind turbine data recorded with equipment having adequate amplitude phase response to preserve waves with a fundamental frequency below 1 Hz will almost certainly include atmospheric infrasound below 0.5 Hz that is many decibels higher in amplitude than the wind turbine pulsations and broadband noise from wind/microphone interaction and turbulence that is comparable to the pulsations. The turbine rotation speed is moderately unsteady due to variations in the inflow speed. The following procedure has proved effective for extracting pulsation waveforms from this hostile operating environment (Walker, WTN 2011 and LFN 2012).

1. Apply a sharp cutoff high-pass filter with corner frequency one octave or more below the turbine blade-pass frequency. The filter phase response needs to be linear with frequency or zero. Zero phase is achieved by applying the filter function sequentially in forward and reversed time.

2. Resample the recorded signal from samples per second to samples per rotor revolution using a tachometer signal from the turbine rotor.

3. Ensemble average the signals from a large number of turbine rotations selected, if possible, from relatively steady (±10%) wind/rotation speed data segments. Fifty to 100 rotations has been found to produce useable wave representations.

Wave re-synthesis outline

If only a relatively short signal is available, but with a signal-to-noise ratio that allows a reasonable display of the narrow-band power spectrum, experience has shown that a close approximation of the time-domain waveform can be determined by assuming that all the harmonics have coincident positive zero-crossings. If Hanning-windows power spectra are available, the following procedure can be implemented:

1. For each blade pass harmonic line in the power spectrum, compute the square root of the sum of the squared sound pressures in the spectral peaks and the two adjacent bins. Subtract 3/2 the average of the squared sound pressures in the bins two above and two below the peak. Multiply the square root of the result for each spectral peak by the square root of two. This will be the amplitude of each spectral component in the wave A_n.

2. Form a composite wave at a convenient data rate *FS* by adding

$$P(t) = \sum_n A_n \sin\left(\frac{2\pi n\big(0{:}(FS-1)\big)}{FS}\right) \qquad \text{(D.1)}$$

where (0:X) indicates an integer sequence between the two limits.

Wave parameter estimates

From the ensemble average or re-synthesized waves, one can readily compute the pulse repetition rate, pulse amplitude, root mean square (RMS) wave amplitude, maximum pulse slope, pulse width, and other properties that may be deemed significant for the prediction of human audibility or other physical response.

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