COOLING TECHNOLOGY INSTITUTE

TEST CODE
for
MEASUREMENT OF SOUND FROM WATER-COOLING TOWERS

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FOREWORD

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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board.

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This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2010.

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Test Code for Measurement of Sound From Water-Cooling Towers

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Test Code for Measurement of Sound From Water-Cooling Towers

Section 0. Preamble

There are two fundamental reasons to measure sound emissions from a cooling tower.

(1) To determine compliance with occupational safety regulations. This requires the measurement of maximum sound pressure levels at near-field locations typically accessed by plant personnel

(2) To predict the contribution of cooling tower sound to the overall sound level from a facility at distant locations in the far-field. Such locations are typically plant boundaries, residential area boundaries, dwellings, etc.

Since measurements in the far-field typically pose difficulties in resolving differences between the sound contributions from various sources and determination of background levels, resolution of contractual guarantees may be impossible based on far field measurements. The interest of the end user is best served by specifying sound levels near the tower and testing in that manner, such that outside influences are substantially reduced or avoided.

Typically, the determination of large cooling tower contributions to far field sound pressure levels can be accomplished by carrying out near field sound pressure level measurements followed by the computation of major source (fan outlet, air inlet, etc.) sound power levels.

Section 1. Purpose of the Test Code

The purpose of this code is to provide standard test procedures for measuring the near-field air borne sound from water-cooling towers with reproducible and consistent results. The results obtained may be used to demonstrate compliance with the guarantees offered by the manufacturer, compliance with noise safety ordinances, and as a basis to compare vendor offerings.

Different procedures are provided for both small and large towers:

Procedure 1: Section 8.0 Sound Measurements on Small Towers. This is a methodology to determine free-field sound pressure levels and sound power calculations following a relatively simple protocol.

Procedure 2: Section 9.0 Sound Measurements for Large Towers. There are two protocols, one for the determination of sound pressure levels (worker exposure) and a second for determining partial sound powers for large towers.

The choice of which measurement procedure is to be used shall be made prior to the test by mutual agreement of the parties prior to the test.

Section 2. Scope

This code applies to wet and wet/dry (parallel path), open and closed circuit cooling towers, mechanical or natural draft. The equipment being tested is the cooling tower consisting of the structure (individual cell or tower) with the heat exchange surface, water distribution and collection system, and mechanical equipment in the case of a mechanical draft tower. If other sound producing equipment must be included in or excluded from the equipment being tested, particular reference shall be made to this effect in the test protocol (if one exists) and in the test report.

Section 3. Test Requirement

The test shall be conducted by a CTI Licensed Test Agency or other independent agency mutually acceptable to the parties to the test, in the presence of authorized representatives of the manufacturer and the purchaser if they desire to be present. For compliance testing, these representatives shall be notified prior to the test. The manufacturer shall be given permission to inspect the tower in advance and prepare it for the test. In no case shall any directly involved party be barred from the test site. Compliance test(s) shall be conducted within 12 months after structural completion of the tower, unless otherwise stipulated by contractual agreement of owner and manufacturer.

3.1 Flexibility. It is recognized that the data limitations specified throughout this test procedure represent desired conditions that may not exist at the time the test is performed. In such cases, existing conditions may be used if mutually agreed upon by authorized representatives of the manufacturer, the purchaser, and the test agency, prior to the test.

3.2 Impartial Testing Service It is the intention of the Cooling Technology Institute that independent third-party compliance tests are provided, whether by CTI Licensed or other independent testers. This means that any situation in which the testing agency has a material or any other interest in the outcome of the test must be avoided. The test agency referred to in this Code shall have no connection with the manufacturer, the purchaser or the Cooling Technology Institute, other than a contractual agreement with the latter, unless mutually agreed by the parties to the test.

3.2.1 Certain categories of business interests or activities may compromise the objectivity of an agency and are considered by CTI as inappropriate for an organization providing impartial testing services. When any portion of the revenues of a testing agency or any of its corporate parents or subsidiaries is derived from these interests or activities, this will preclude that organization from consideration. The following is a non-exclusive listing of examples of these categories of business interest or activities:

a) The manufacture, repair, replacement or upgrade of cooling towers or cooling tower components.

b) Operation or ownership of cooling towers related to primary income generating processes.

3.2.2 Further, any specific situation in which the testing agency can be said to have an interest in the outcome of a particular test is considered a conflict of interest and is to be avoided. The following is a non-exclusive listing of examples of such situations:

a) Performing cooling tower design, engineering, construction or related consultation services, such as bid evaluation, for a party to a particular test (for the purpose of this paragraph, operation and maintenance recommendations do not constitute "related consultation services").

b) Engaging in a contractual or business relationship with the cooling tower manufacturer, constructor or supplier of components or equipment on a particular tower to be tested. A conflict of interest shall not exist if the testing agency has conducted independent testing of other cooling towers for cooling tower owners, manufacturers, constructors or suppliers of components and equipment.

4.0 Relevant Standards

4.1 Normative Standards Listed here are the standards, handbooks, and other publications essential to the implementation of this standard. All references listed here are part of this standard.

- ANSI S1.4-1983, (R2001) with Amd.S1.4A-1985 Specification for Sound Level Meters
- ANSI S1.11-2004 Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters.
- ANSI S1.40-1984 (R1997), Specification for Acoustical Calibrators.
- ANSI S1.43 (R2002) Specification for Integrating-Averaging Sound Level Meters
- ANSI S12.34-1988 (R1997), Determination of Sound Power Levels of Noise Sources for Essentially Free-Field Conditions over a Reflecting Plane.
- CTI ATC-105, Acceptance Test Code for Water Cooling Towers, February 2000
- CTI NCL-109 Nomenclature, 1997
- IEC 61672-1 Ed. 1.0 b:2002 Electroacoustics – Sound Level Meters – Part 1: Specifications
- IEC 61672-2 Ed. 1.0 b:2004 Electroacoustics – Sound Level Meters –Part 2: Pattern Evaluation Tests
- IEC 60942 (2003-01), Sound Calibrators.

4.2 Informative Standards Listed here are the standards, handbooks, and other publications which may provide useful information and background but are not considered essential or part of this standard.

General Reference

- ANSI S1.6-1984 (R2001), Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements.
- ANSI S1.13-1995, (R1999) Measurement of Sound Pressure Levels in Air. (Note: for SPL only, not for measuring PWL)
- ANSI S1.26-1995, (R1999) Method for the Calculation of Absorption of Sound by the Atmosphere.
- IEC 61260 (1995-08), Electroacoustics - Octave-band and fractional-octave-band filters.
- ISO 266:1997, Acoustics -- Preferred Frequencies.
- ISO 1683:1983, Acoustics--Preferred Reference Quantities for Acoustic Levels.
- ISO 3740-2000, Determination of Sound Power Level of Noise Sources - Guidelines for the Use of Basic Standards
- ISO 9613-1:1993, Acoustics--Attenuation of Sound During Propagation Outdoors--Part 1: Calculation of the Absorption of Sound by the Atmosphere.

General Reference

- ANSI S1.6-1984 (R1997) Preferred frequencies, Frequency levels, and Band Numbers for Acoustical Measurements
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- IEC 1260 (1995-08), Electroacoustics – Octave-band and fractional-octave-band filters
- ISO 266:1997 Acoustics – Preferred frequencies
- ISO 1683:1983 Acoustics – Preferred reference quantities for acoustic levels
- ISO 3740:2000 Acoustics – Detemination of sound power levels of noise sources – Guidelines for the use of basic standards
- ISO 9613-1:1993 Acoustics – Attenuation of sound during propagation outdoors – Part 1: Calculation of the absorption of sound by the atmosphere
- ISO 9613-2:1996 Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation

Propagation Standards

- ANSI S1.26-1995 (R2004) Method for Calculation of Absorption of Sound by the Atmosphere
- ANSI S12.8-1988 (R2003) Methods for Determining the Insertion Loss of Outdoor Noise Barriers
- CONCAWE Report 4/81 – The propagation of Noise from Petroleum and Petrochemical Complexes to Neighboring Communities
- EEMUA Publication No. 140 – Noise Procedure Specification
- VDI 2714 – Outdoor Sound Propagation
- ARI 275-97 – Application of Sound Rated Outdoor Unitary Equipment
- ISO 9613-1:1993 Acoustics – Attenuation of sound during propagation outdoors – Part 1: Calculation of the absorption of sound by the atmosphere
- ISO 9613-2:1996 Acoustics – Attenuation of sound during propagation outdoors – Part 2: General Method of Calculation

Section 5.0 Definitions

5.1 Terms in this document follow the standard industry definitions in the current edition of *CTI NCL-109, Nomenclature* unless otherwise provided in this section.

Air Inlet Surface is a plane, located at the outermost edge of the tower, through which air enters the tower. For example, the outer edge of the air inlet face is at the perimeter columns when louvers are not present, or the outer tip of the louvers when they are present, or the outer edge of attenuators, if so equipped.

Base Level is the underside of towers located at or above grade, and is the bottom of the air inlet for towers with cold water basin floor below grade.

Background Noise is any noise not generated by the tower under test or that is directly radiated by attached components that do not be long to the object under test.

Characteristic Dimension, D_o, is the square root of the sum of the squares of half the tower short axis dimension, w_T, half the tower long axis dimension, l_T and the tower height, h_T:

$$D_o = [(w_T/2)^2 + (l_T/2)^2 + h_T^2]^{0.5} \qquad (1)$$

Decibel is defined as 10 times the base 10 logarithm of a ratio of two quantities, one of which is usually a reference quantity. Decibel is noted as **dB** and sound in decibels is often referred to as a **level**. A sound level in dB is calculated as follows:

level = 10 $\log_{10}$ (quantity / reference quantity) (2)

Directivity is a quality of the noise source relating to the amount to which it does not radiate noise uniformly in all directions. A perfect source that radiates the same noise in all directions would have no directivity. Most real sources have some degree of directivity.

Far Field is where the sound pressure levels start to attenuate in accordance with the inverse square law. The far field begins approximately at a distance of one to two times the characteristic dimension, $\mathbf{D_o}$ from the source.

Free Field is a sound field in a homogeneous, isotropic medium free from boundaries other than the ground. In practice, it is a field in which the reflection effects of the boundaries other than the ground are negligible over the region of interest.

Inverse Square Law is an idealized method of extrapolating sound levels from one distance to another. It is based on the theory that a homogeneous sound source (a source which produces spherical waves of constant sound power with no directivity) will show a decrease in outward-directed sound intensity that is proportional to the square of the distance from the source. For that sound source the sound pressure level will drop off 6 dB for each doubling of distance or:

$$L_{p2} = L_{p1} - 20 \log_{10} (\text{distance}_2/\text{distance}_1) \qquad (3)$$

Large Tower has a characteristic dimension D_o greater than 7.5m (25 ft).

Leq is the equivalent sound level recorded by an integrating-averaging sound level meter over the prescribed measurement time interval.

Near Field is the region within one to two characteristic dimensions of a sound source. In the near field, the sound pressure decreases by less than the "inverse square" rule.

Partial Sound Power is the portion of the total sound power that can be measured for a separately identifiable part of the tower.

Reflecting Plane is, for the purpose of this code, a hard, flat ground surface, such as asphalt or concrete, that extends a distance of $\lambda/2$ (for the lowest frequency of interest, where λ is the wavelength of a sound frequency in air) beyond the projection of the measurement surface on the reflecting plane. Note that for 63 Hz, the distance $\lambda/2$ is about 2.75 meters (9 ft.); for 31.5 Hz it is about 5.5 meters (18 ft.).

Small Tower has a characteristic dimension D_o less than or equal to 7.5m (25 ft).

Sound Power Level (L_W or PWL) is the sound quantity in decibels of the radiated sound power, W, of the source. The reference sound quantity for power used in this standard is the picowatt equal to $1\text{x}10^{-12}$ Watt, denoted as W_o. A sound power level is calculated as follows:

$$L_W \text{ (dB)} = 10 \log_{10} (W/W_o) \qquad (4)$$

Sound Pressure Level (L_P or SPL) is the sound quantity in decibels of the square of the root mean squared sound pressure time variation of the atmospheric pressure, ΔP^2. The reference sound quantity for pressure used in this standard is the square of a pressure equal to 2 x 10^{-5} Pascal, denoted as P_o. A sound pressure level is calculated as follows:

$$L_P \text{ (dB)} = 10 \log_{10} (\Delta P^2/P_o^2) \qquad (5)$$

or

$$L_P \text{ (dB)} = 20 \log_{10} (\Delta P/P_o) \qquad (6)$$

Section 6.0 Instrumentation

As proper usage of all test instrumentation is essential to obtain valid measurements, all instrumentation shall be operated in accordance with the procedures and precautions set forth in the operation manuals furnished by the instrument manufacturer.

6.1 Sound Level Meter and Microphone System The sound level meter and microphone system shall meet the requirements of ANSI S1.4/S1.4a Type 1 (Precision) or IEC 61672 Type 1. Instrument manufacturer's specifications for orienting the microphone with respect to the source of sound and the location of the observer relative to the meter shall be followed. Frequency response shall be within the tolerances given in ANSI S1.4 or IEC 61672 for a Type I instrument system. A real-time analyzer with separate microphone(s) meeting the above specifications may be substituted for the sound level meter.

6.2 Windscreen. In all tests, a porous ball shall be used on the microphone as a wind screen. The effect of the windscreen on the microphone response shall be no more than ± 1 dB for frequencies of 20 to 4000 Hz or ± 1.5 dB for frequencies of 4000 to 10000 Hz.

6.3 Filter (Frequency) Band Analyzer The analyzer shall meet requirements of ANSI S1.11 (Class II) or IEC 61260.

6.4 System Calibration The instrumentation system, including the microphone and cable, shall be field calibrated immediately before and after testing, and during prolonged tests, every four hours during testing. The calibration shall be performed with an acoustical calibrator meeting the requirements of ANSI S1.40 and IEC 60942 Class 1.

The calibrator shall be checked annually to verify compliance with the requirements of ANSI S1.40 and IEC 60942.

6.5 Recorders If a tape recorder or graphic level recorder is used, its stability and frequency response shall be at least equal to those of the sound level meter and microphone system, over the frequency range of interest.

6.6 Fan Speed Measurement Device A device with minimum accuracy of ±2.0% of fan speed shall be used.

6.7 Electrical Power Measurements Electrical power measurements shall be made with instruments that yield a true rms power, based on measured current, voltage, and power factor. The accuracy of the instrument and associated read-out devices shall be equal to or better than 2% of the actual value.

6.8 Air Velocity Measurement Device A device with minimum accuracy of ±5.0% of air velocity shall be used.

6.9 Recording Precision Survey data reporting and calculation of octave band sound levels, sound power levels and corrections shall be performed in terms of tenths of decibels or rounded whole decibels, but shall be consistent throughout. Final A-weighted sound levels or sound power levels shall be reported to the nearest whole decibel.

Section 7.0 Conditions and Environment of the Test

7.1 Operating Conditions of the Cooling Tower

7.1.1 Mechanical Draft Towers The sound measurements shall be taken with all fans operating at full speed with the motor power at or near design, and with the water flow distributed to all cells as recommended by the manufacturer, unless agreed otherwise. Additionally, Large Towers shall be operating under heat load (Small Towers are exempt from this requirement.)

For mechanical draft towers, the following deviations from design conditions shall not be exceeded:

Circulating water flow...± 15%
Cooling range...................± 40% *
Fan driver power..........± 10%
Fan speed....................± 5%

* Large towers only

7.1.2 Natural Draft Towers For natural draft towers, the following deviations from design conditions shall not be exceeded:

Circulating water flow .. ± 10%
Cooling range .... ± 20%
Wet bulb temperature.. ± 8.5 °C (15 °F)
Dry bulb temperature... ± 14 ° C (25 °F)

7.1.3 Exceptions If the specified operating conditions cannot be obtained, the sound test may be conducted at other conditions or with adjustments to design mutually agreed upon by all the parties concerned, and the actual test conditions shall be clearly described in the test report. The method to determine compliance with the requirements on operating conditions shall be agreed upon in advance by the parties to the test.

7.2 Weather During the test the ambient weather conditions (for example: temperature, humidity, wind or cooling air speed and barometric pressure) shall be noted. Limitations to operation specified by the instrument manufacturer shall be followed.

Tests shall not be conducted during precipitation or snow cover, or climactic conditions for which the instrumentation is not suited.

Sound measurements shall not be made when air velocities over the microphone exceed 4.5 m/s (10 mph). When the wind velocity must be measured the instrumentation shall be in accordance with CTI Code ATC-105.

7.3 Nearby Structures Large structures or other reflective surfaces (excluding the ground) within two characteristic dimensions of the tested cooling tower may adversely affect the accuracy of the sound measurements. Any such surfaces shall be described in the test report (section 10.3). If such structures are only on the side of one face of the tower or cell, measurements from a symmetrically equivalent face may be substituted, if available.

7.4 Measurements to be Taken - Sound Pressure Spectrum The sound pressure level shall be measured at each measurement point for at least each octave band from 31.5 Hz to 8000 Hz. The standard octave band center frequencies in this range are 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz, consistent with the standards referenced in section 4.1. The 31.5 Hz band is optional for Small Towers. The period of observation at each measurement location shall be at least 10 seconds. Use of an integrating-averaging sound level meter is preferred and the reported value at each position shall be Leq.

7.5 Background Noise Every effort shall be made to reduce or eliminate background noise that might affect the measured sound levels of the cooling tower. When extraneous noise sources (such as a circulating water pump) might affect the measured sound levels on only one face of the cooling tower, the measurement(s) from an equivalent face of symmetry may be substituted.

Section 8.0 Sound Measurements on Small Towers

8.1 Sound Measurement. The sound test measurements shall be taken in a free field over a reflecting plane.

8.1.1 Background Sound Pressure Levels. The background sound pressure levels (L_{pb}) in each of the octave bands shall be measured at the same locations as at the operating conditions.

8.1.2 Sound Pressure Level. The sound pressure level (L_P) produced by the operating tower in each of the octave bands shall be measured at the following locations.

8.1.2.1 Side and End Measurement Locations (Air Inlet and Cased Sides) At the midpoint of each of the four sides and/or ends, the sound pressure levels (L_P) shall be recorded at a distance of 1.5 meters (5 ft) and $2D_o$ or 15 meters (50 ft), both at an elevation of 1.5m (5 ft) above the reflecting plane. See Appendix A.

8.1.2.2 Overhead Measurement. At the geometric center of the overhead surface, the sound pressure levels (L_P) shall be recorded at distances of 1.5m (5ft) and $2D_o$ or 15 meters (50 ft) above the top of the tower. On cooling towers with fans on the top surface, the 1.5 m (5 ft) sound pressure level (L_P) measurements shall be measured 1.5m (5 ft) above the fan stack discharge, at an angle of 45 degrees from the stack on the long tower axis. (Note: this is done to keep the microphone out of the air stream.) On cooling towers without fans on the top, the measurements shall be made 1.5m (5 ft) above the geometric center of the top of the unit. See Appendix A.

8.2. Evaluation of Data

8.2.1 Correction for Background Noise Determine the difference between the background sound pressure level and the sound pressure level with the cooling tower operating for each octave band at each measurement point per Appendix F.

8.2.2 Calculation of Sound Power Level for each Octave Band. The cooling tower sound power level (L_W) for each octave band shall be approximated using the following equation:

$$L_W = 10\log_{10}\sum_{n=1}^{n=5}10^{0.1L_{Pn}} + [20\log_{10}(r_H)] + C \quad (7)$$

where:

r_H= Distance at which sound pressure level was measured from the geometric center of the top and sides of the tower. It must be equal to or greater than $2D_o$. (Typically 15m (50 ft))

C= +0.98 if r_H is in SI units (meters)

C= -9.34 if r_H is in IP units (feet)

8.2.3 Presentation of Sound Level Data.

8.2.3.1 The sound pressure data shall be presented by octave band for each of the bands recorded (as a minimum 63, 125, 250, 500, 1k, 2k, 4k, 8k) for all five surfaces of the cooling tower at the 1.5m (5 ft) and $2D_o$ or 15 meters (50 ft) distance. In all cases the measurement distances shall be clearly specified. In addition, a calculated A-Weighted Sound Pressure Level at the 1.5 meter (5 ft.) and 2 D_o or 15 meters (50 ft.) shall be presented for each of the measurement points. (See Appendix B.) Note that most meters can produce A-Weighted output.

8.2.3.2 The Sound Power Levels shall be presented by octave band and as an A-weighted total sound power level. See Appendix E.

Section 9.0 Sound Measurements For Large Towers

Sound is radiated from cooling towers mainly through the air outlet, the air inlets, and, in mechanical draft towers, from the fan motors. Additionally, many materials used to enclose casings and endwalls are transparent to sound and may also radiate significant noise.

This standard provides two procedures for the measurement of sound emanating from the tower. The first quantifies the sound pressure levels at typical worker exposure locations for use in assessing compliance with safety ordinances (near field). The second provides a basis for determining the contribution of the cooling tower sound levels to far-field points.

9.1 PROCEDURE 1: Determination of Near Field Sound Pressure Levels (worker exposure). This section specifies near field measurement points for typical cooling tower designs. As an alternative to the 1 m (3 ft) measurement distance specified in the following sub-sections, a 1.5 m (5 ft) distance may be used.

In multiple cell towers, two cells (one middle cell and one end cell for towers with 3 cells or more) shall be selected for measurements.

9.1.1 Air Inlet -- Mechanical Draft, Rectangular Measurements shall be taken at grade level in at least two locations along each air inlet face. Each measurement point shall be at a distance of 1 m (3 ft.) outward from the air inlet surface and at a height above grade of 1.5 m (5 ft). If the 1 m (3 ft) horizontal distance does not locate the measurement plane outside the plane of the cold water basin curb wall, the air inlet measurement plane shall be located immediately outside the plane of the basin curb wall.

9.1.2 Air Inlet -- Round or Polygonal Mechanical and Natural Draft Measurements shall be taken at four locations spaced at 90° increments around the periphery of the tower,each measurement point shall be at a horizontal distance of 1 m (3 ft.) from the basin rim , at a height of 1.5 m (5 ft) above grade.

9.1.3 Fan Deck / Air Outlet Plane Measurements of sound at the air outlet (fan deck) are required only if the tower has a walking surface on the fan deck, or at air outlet plane.

9.1.3.1 Induced Draft Measurements shall be taken in four locations around the periphery of the fan, spaced 90° apart, starting at 45° from the motor main axis. Each measurement point shall be at a horizontal distance from the fan exhaust rim of 1 m (3 ft) and 1.5 m (5 ft) above the walking surface of the fan deck.

9.1.3.2 Forced Draft Measurements shall be taken in two locations along each walkway,; each measurement point shall be at the center of the walkway and 1.5 m (5 ft) above the walking surface.

9.1.4 Air Outlet -- Natural Draft Measurement at the shell exit plane is not required.

9.1.5 Fan Motors Sound measurements of motor noise are required only if the motor is located outside the fan stack and it's outer surface is not within 2 m (6.5 ft) of the measurement locations specified in sections 9.1.3.1 (for induced draft fan towers) or 9.1.3.2 (for forced draft towers). See Appendix C.

Two measurements shall be taken, one on each side of the motor in a vertical plane flush with the outboard end of the motor. Each measurement point shall be at a horizontal distance of 1 m (3 ft) from the side of the motor and an elevation of 1.5 m (5 ft) above the walkway.

9.1.6 Pump and Motor for Closed Circuit Cooler Spray System Measurements shall be taken in two locations for each pump/motor at a horizontal distance of 1 m (3 ft) and an elevation of 1.5 m (5 ft) on both sides of the motor at the outboard end of the pump/motor.

9.1.7 Casing For this simplified procedure, measurement of sound radiated through the casing is not required unless the casing extends to grade level. If such a measurement is required, follow the directions for the air inlet measurement surface in determining the measurement positions.

9.1.8 Evaluation of Data For each of the major sound sources (air inlet, fan deck, motor, etc.) adjust the sound pressure data for background noise as described in Appendix F.

An overall A-weighted sound pressure level can be calculated for each location using the procedure described in Appendix E.

9.2 PROCEDURE 2: Determining Partial Sound Powers For Large Towers This procedure employs an enveloping surface methodology to quantify partial sound power levels for each of the major cooling tower sound sources that can be used to estimate cooling tower sound contribution at some far-field point.

9.2.1 Test Site Because cooling towers are normally of large dimensions, these measurements should be made outdoors in the free field over a reflecting plane. There should be no reflecting objects within a distance from the measurement surface equal to twice the largest dimension of the measurement surface.

9.2.2 Air Velocities The air velocities generated by the tower at the measuring points shall not exceed 4.5 m/s (10 mph). At higher air velocities, new measurement surfaces shall be selected at a greater distance from the tower, such that the air velocity is reduced to the above limits, if possible. If a more distant measurement surface is used, the area S used in the sound power calculation shall be increased to compensate for the reduction in sound pressure with the distance increase. The ambient wind velocity shall not exceed 4.5 m/s (10 mph)

9.2.3 Preliminary Survey Sound is radiated from cooling towers primarily through the air outlet, the air inlets, the tower casing and end wall surfaces and, in mechanical draft towers, from the fan motors.

A preliminary survey of the cooling tower shall be made, measuring sound pressure levels at the midpoint of all cased areas, end walls, and adjoining faces of the tower . If the level of sound radiated from the casing or shell is 10 dB or more below the sound emitted through adjacent surfaces, their contribution to the overall noise level of the tower is negligable and measurement points for the casing or shell need not be defined. To determine the partial sound power levels for each of the remaining partial sound sources, measurement surfaces shall be defined and the measuring points be arranged as shown in Appendix D.

In multiple fan towers, at least two fans (one middle cell and one end cell for towers with 3 cells or more) shall be selected for air outlet and motor measurements.

9.2.4 Rectangular Mechanical Draft Counterflow/Crossflow Wet and Wet/Dry Towers Each tower face or air inlet face shall be treated as an individual sound source and each individual fan outlet and motor shall be treated as an individual cell sound source.

9.2.4.1 Air Inlets and Cased Faces- Wet and Wet/Dry Measurements shall be taken at one or more stations along each tower face (cased, wet and/or dry) at the points shown in Appendix D, Figure D-1. The number of vertical stations and their elevation shall be consistant around all sides of the tower.

a. Measurement Surface. The measurement surfaces shall be vertical planes parallel to the side and end faces of the cooling tower, at a distance 1 m (3 ft), distance *"d"*, outward from the tower face. If the 1 m (3 ft) distance does not locate the measurement plane outside the plane of the cold water basin curb wall, the measurement plane shall be located immediately outside the plane of the basin curb wall. The size of the measurement surface depends upon the construction of the tower. When the tower is cased with light materials virtually transparent to sound, such as FRP, the measurement surface shall be the projection of the full tower face on the measurement plane. When the tower is cased with a dense material, virtually opaque to sound, such as concrete, the cased portions can be disregarded (see Section 9.2.3) and the projections of the air inlet height and length define the measurement surface(s) (see Appendix D, Figure D-1). The area used to calculate the partial sound power level for each tower or air inlet face is.

$$S_{AI} = h_{AI} * l_{AI} \qquad (8)$$

Where:

S_{AI} = the surface area used to calculate the partial sound power level of a tower or air inlet face (m^2)

h_{AI} = the height of the tower or air inlet face (m).

l_{AI} = the length of the tower or air inlet face (m).

b. Measurement Locations. The *minimum* number of horizontal measurement stations, $N_{H_{min}}$, along a tower or air inlet face is approximated as a function of the length of the face in meters (l_1), rounded up:

$$N_{H_{min}} \geq (l_1)^{0.3} \qquad (9)$$

$$N_H = N_{Hmin}\text{, rounded up} \qquad (10)$$

where, l_1 is the total length of the tower or air inlet face in meters.

For measurement surfaces equal to or less than 2.5 m (8 ft) in height, there shall be one measurement level (N_V = 1) at each measurement station, located at the midpoint of the height of the measurement surface. For measurement surfaces over 2.5 m (8 ft), there shall be two levels of measurement stations (N_V = 2) located at ¼ and ¾'s of the height of the measurement surface. See Appendix D, Figure D-2. The total number of measurement locations per tower face, N_{AI}, is:

$$N_{AI} = N_H * N_V. \qquad (11)$$

9.2.4.2 Air Outlet – Circular For multi-cell induced draft, cooling towers, fans adjacent to the tested fan outlet shall be off for the test period. Background levels shall be taken at several of the measurement stations.

a. Measurement Surface.

Measurements shall be taken in four locations around the periphery of the fan stack discharge, spaced 90 degrees apart, starting at 45 degrees from the motor main axis. Each measurement point shall be at a horizontal distance (d_r) of 1m (3 ft) from the rim of the fan stack and 1m (3 ft) above the discharge level of the fan stack (d_H). See Appendix D, Figure D-3.

The surface area of the hemisphere used to calculate the partial sound power of the air outlet is:

$$S_{AO} = 2\pi\left[(r_S + d_r)^2 + d_v^{\,2}\right]^{0.5} \qquad (12)$$

Where,

S_{AO} = the surface area (m^2) of the hemisphere over the fan stack discharge used to calculate the partial sound power of the circular air outlet.

d_r = the horizontal distance between the rim of the fan stack opening and the measurement point (m)

d_v = the vertical distance between the rim of the fan stack opening and the measurement point (m)

r_S = the radius of the circular fan stack opening (m)

9.2.4.3 Air Outlet - Rectangular For multi-cell cooling towers with rectangular air outlets, fans adjacent to the tested fan outlet shall be off for the test period. Background levels shall be taken at several of the measurement stations.

a. Measurement Surface. The measurement surface shall be a rectangular parallelepiped centered over the rectangular air outlet. The vertical sides of the measurement surface shall be situated one meter (3 ft), distance *"d"*, outward from the perimeter of the air outlet. The top surface shall be 1 m (3 ft), distance *"d"*, above the plane of the air outlet (See Appendix D, Figure D-2). For a cooling tower with rectangular air outlet length l_o and width w_o, the surface area, S_{AO}, used to calculate the partial sound power level of the rectangular air outlet is:

$$S_{AO} = l_O \; w_O + 4d \; (l_O + w_O + 3d) \quad (13)$$

Where,

S_{AO} = the surface area of the measurement parallelepiped used to calculate the partial sound power of the rectangular air outlet, (m^2)

l_O = the length of the outlet, (m)

w_O = the width of the outlet, (m)

d = the horizontal and vertical distance of the measurement points from the perimeter of the outlet, (m)

b. Measurement Locations are at the center of each of the four upper edges of the rectangular measurement parallelapiped. See Appendix D, Figure D-2.

9.2.4.4 Fan Motor Measurements of motor noise are required only if the motor is located outside the fan stack. The background sound level (i.e. the sound transmitted through the fan stack) shall be measured at a point 1 m outward from the wall of the stack at a point 180° opposite the motor. Alternatively, acoustic shielding may be temporarily placed between the fan stack and the motor to reduce sound transmission from the fan stack to the motor.

a. Measurement Surface. A rectangular parallelepiped measurement surface centered over the motor or motor enclosure shall be used. The sides of the measurement surface shall be 1 m (3 ft), distance *"d"*, beyond the dimensions of the motor housing. For a motor measurement surface with width, w, length, l, and height, h, the surface area, S_M, for use in the partial sound power calculation of the motor is:

$$S_M = l_{MP} w_{MP} + 2 \; h_{MP} \; (l_{MP} + w_{MP}) \quad (14)$$

Where,

S_M = the surface area of the parallelepiped around the motor used to calculate the partial sound power of the motor (m^2)

l_{MP} = the length of the parallelepiped (m)

w_{MP} = the width of the parallelepipd (m)

h_{MP} = the height of the parallelepiped (m)

b. Measurement Locations shall be at the geometric center of the three exposed sides and top of the measurement surface (see Appendix D, Figure D-5) unless this places them closer than 1 m (3 ft) to a reflective surface, such as the fan deck or fan housing. In this case, the measurement stations shall be adjusted to be at 1 m (3 ft) from all reflective surfaces.

9.2.4.5 Fan Stack On towers with fan stacks greater than 2 m (6.5 ft) in height, the sound transmitted through the stack wall shall be measured.. For multi-cell induced draft cooling towers, fans adjacent to the tested fan shall be off for the test period. Background levels shall be taken at several of the measurement stations.

a. Measurement Surface. The measurement surface shall be a vertical cylinder centered about the fan stack. The radius of this measurement surface shall be 1 m (3 ft), distance *"d"*, greater than that of the fan stack radius, r_s, at its largest point. The surface area used to calculate the partial sound power level of the fan stack of height is:

$$S_{FH} = 2\,\pi\,(r_s + d)\,h_{FH} \qquad (15)$$

Where,

S_{FH} = the surface area used to calculate the partial sound power of the fan stack (m^2)

r_s = the radius of the fan stack or housing at its greatest point (m).

h_{FH} = the height of the fan stack or housing (m).

b. Measurement Locations. No measurements shall be taken within 1 m (3 ft) of the fan deck. Four measurement stations shall be located on the cylindrical surface, 90° apart, starting at 45° from the fan motor axis. For fan stacks greater than 2 m (6.5 ft) and equal to or less than 3 m (10 ft) in height, one level of measurement stations shall be used, situated at mid-height of the fan stack. For fan stacks greater than 3 m (10 ft), two levels of measurement stations shall be used, one at 1/4 height and one at 3/4 height of the fan stack.

9.2.4.6 Tower Casing Measurements of sound radiated from the casing surface shall follow the guidelines given in section 9.1.1.1 for air inlets.

9.2.5 Circular Type Mechanical Draft Towers

9.2.5.1. Air Inlets and Cased Faces. A preliminary survey shall be made at the centroid of all cased and adjoining faces of the cooling tower. If the level of sound radiated from the casing or shell is low enough to be ignored (10 dB or more below the sound emitted through adjacent surfaces), appropriate measurement surfaces and locations of the measurement points at the siding or shell need not be defined.

a. Measurement Surface. The surface of measurement shall be on a vertical cylinder located outward from the face surface at a distance of 1 m (3 ft). If the 1 m (3 ft) horizontal distance does not locate the measurement plane outside the plane of the cold water basin curb wall, the face measurement plane shall be located immediately outside the plane of the basin curb wall.

As an example, for a circular cooling tower with air inlet height and radius to the measurement surface, the surface area used to calculate the partial sound power level for the air inlet is:

$$S_{AI} = (2\,\pi\,r_{cm})\,h_{AI} \qquad (16)$$

Where,

S_{AI} = the surface area used to calculate the partial sound power of the circular inlet (m^2)

r_{cm} = the radius to the measurement points = $r_c + d_r$ in meters.

h_{AI} = the height of the air inlet (m).

r_c = the radius of the air inlet face (m)

d_r = the measurement distance beyond the air inlet face (m).

b. Measurement Locations. There shall be two elevations of measurement locations for each face. At each elevation are three measurement stations at 120° apart for a total of six measurement points. The stations on the two elevations shall be offset by 60°.

9.2.5.2 Air Outlet The procedure of section 9.2.4.2 or 9.2.4.3 shall be followed, depending on whether outlet is rectangular or circular.

9.2.5.3 Fan Motor The procedure of section 9.2.4.4 shall be followed.

9.2.6. Natural Draft

9.2.6.1 Air Inlets The procedure of section 9.2.5.1 shall be followed.

9.2.6.2 Air Outlets For a cooling tower with radius at the exit plane r_{ND}, the three locations shall be spaced 120° apart, at a height of 1 m above the exit plane of the tower.

The measurement surface to be used to calculate the partial sound power level for this surface is

$$S_{ND} = \pi \, (r_{ND})^2 \qquad (17)$$

Where,

S_{ND} = the surface area for use in the partial sound power calculation of the circular outlet

r_{ND} = the radius of the tower outlet

Section 10.0 Calculation of the Total Tower Sound Power

The calculations described in the following sections 10.1 through 10.3 shall be applied for each individual partial measurement surface.

10.1 Corrections for Background Noise Each of the octave band sound pressure levels from each measurement station shall be corrected for background noise, preferably using the background noise (LP(b)) measure at the same position. See Appendix F.

10.2 Calculation of Surface Average Sound Pressure Level For each octave band, calculate the average sound pressure level over the measurement surface ($\overline{L_P}$) using the following equation:

$$\overline{L_P} = 10\log(1/n)(\sum_{i=1}^{n} 10^{0.1 L_{P(i,adj)}}) \qquad (18)$$

where:

$\overline{L_P}$ = the sound pressure level for each one third octave band, averaged over the measurement surface, in decibels re: 20 μPa.

$L_{P(i,adj)th}$ = the sound pressure level at the i^{th} measurement position, adjusted for background noise, in decibels re: 20 μPa.

n = the total number of measurement positions

10.3 Calculation of Partial Sound Power Levels The Partial Sound Power Level ($L_{W(i)}$) characterizing the noise emitted by the source for each octave band shall be calculated as:

$$L_{W(i)} = \overline{L_{Pf(i)}} + 10\log(S/S_o) \qquad (19)$$

Where:

$L_{W(i)}$ = the sound power level in the nth octave band

$\overline{L_{Pf(i)}}$ = the average surface sound pressure level for the nth octave band in decibels, re 20 μPa.

S = the area of the measurement surface over which the measurements were averaged (m^2).

S_o = The reference surface area = 1 m^2

10.4 Calculation of Aggregate Sound Power Level of Tower, L_{WT} For n individual partial sound power levels, the aggregate sound power level, for individual frequencies or overall level, can be found as follows:

$$L_{WT} = 10\log(\sum_{i=1}^{n} 10^{0.1 L_{Wi}}) \qquad (20)$$

Where:

L_{WT} is the aggregate sound power level

L_{Wi} is the i^{th} partial sound power

Section 11.0 Test Report

A test report shall be supplied that shall include the following information.

11.1 Code Compliance Statement that the test was conducted and instruments used were in accordance with this Test Code. Exceptions must be identified.

11.2 Tower Description A description of the tower, including its conditions of installation and operation shall be included. Describe operating conditions as listed in section 7.1 of this Code including, but not limited to, the air relative humidity and dry bulb, barometric pressure, water flow rate, heat load, fan power, fan speed, and wind velocity.

11.3 Site Sketch A dimensional sketch of the test site, showing the location of the tower and significant structures in the immediate vicinity, and all measurement locations shall be included. Indicate North.

11.4 Instruments Used Make, model and serial number of each instrument used, including laboratory calibration date and certificate.

11.5 Personnel All parties to the test, and their personnel present during testing shall be recorded.

11.6 Tabulation of Test Data:

11.6.1 Calibration Record the pre-test and post-test calibration, as specified in section 6.3.

11.6.2 Tower Sound Pressure Levels The measured and corrected sound pressure level, by octave band, at each measuring point (dB) shall be included.

11.6.3 Background Sound Pressure Levels Background sound pressure levels by octave band at one or more points (dB).

11.6.4 Sound Power Levels For tests following the procedure of section 9, the individual source sound power levels, by octave band and overall A-weighting shall be included in the report along with the individual surface areas used in the determination of the values.

11.6.5 Test Data Authentication Statement of findings including signatures of the test team on the data sheet shall be included.

Appendix A.

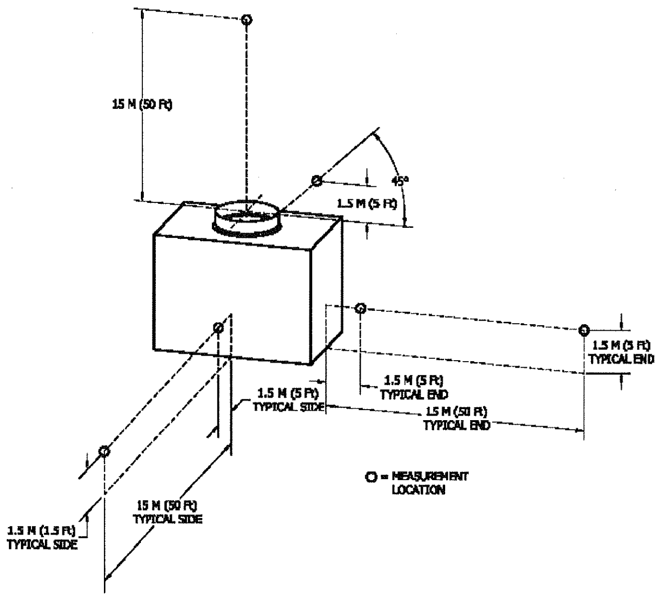


Figure A-1 Induced Draft Small Towers

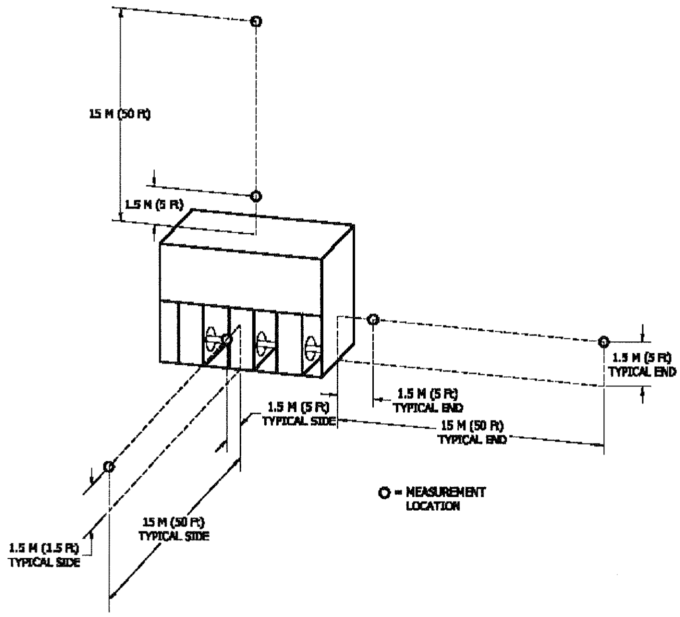


Figure A-2. Forced Draft Small Towers

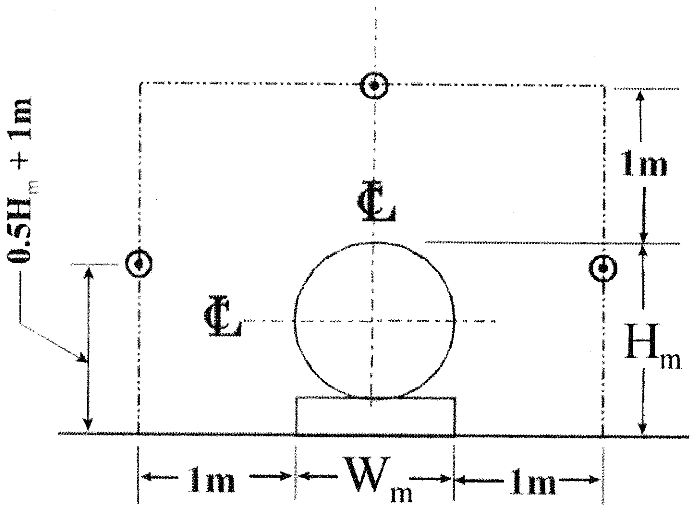
Appendix B. Example unit sound reading table for small towers

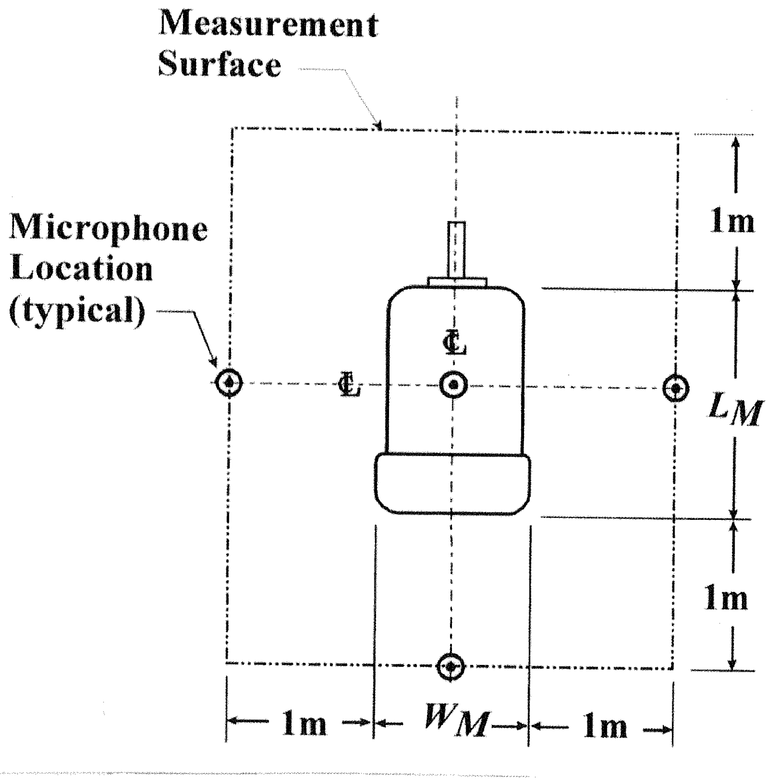
Maunufacturer:	ABC
Model:	XYZ
Number Fans:	1
Fan Motor HP:	30
Number Motors:	1

	SOUND PRESSURE LEVEL										SOUND POWER LEVEL
	END 1		SIDE 1		END 2		SIDE 2		OVER HEAD		
BAND	1.5M	15M	1.5M	15M	1.5M	15M	1.5M	15M	1.5M	15M	
63 HZ	82	75	77	72	82	75	77	72	81	71	106
125 HZ	84	75	82	72	84	75	82	72	88	76	106
250 HZ	83	69	82	69	83	69	82	69	85	76	104
500 HZ	77	62	78	63	77	62	78	63	79	71	98
1K HZ	72	57	70	58	72	57	70	58	75	62	91
2K HZ	69	54	70	55	69	54	70	55	73	59	88
4K HZ	70	52	70	52	70	52	70	52	72	57	85
8K HZ	72	52	72	62	72	52	72	62	67	52	84
dBA	80	66	80	66	80	66	80	66	82	72	100

Data developed in accordance with Cooling Technology Institute ATC-128 for Small Towers

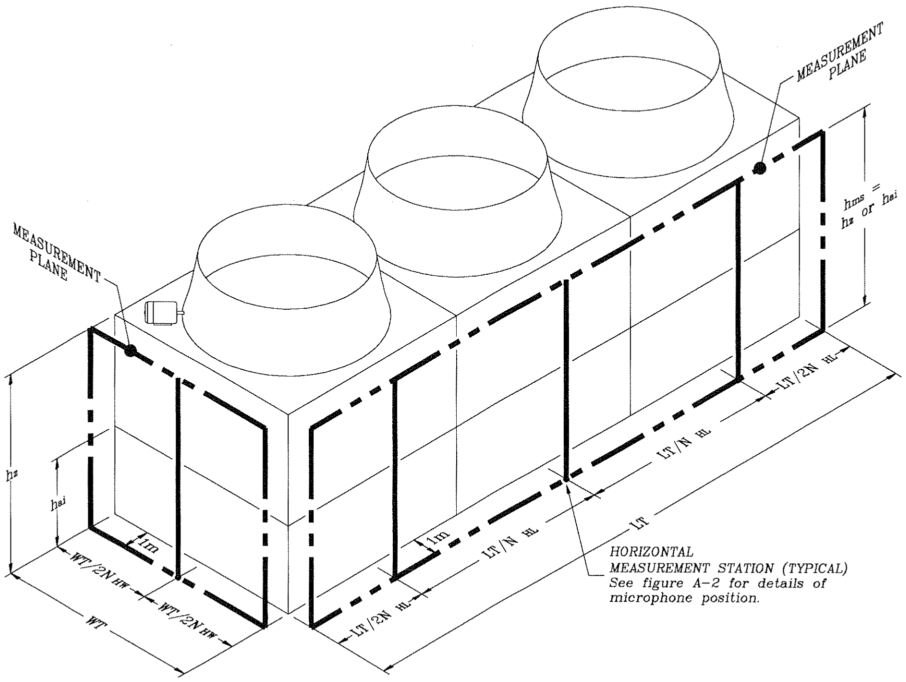
Appendix C. Motor





Appendix D. Induced Draft Rectangular Wet/WD/CF/XF

Figure D-1. Tower Faces Note on figure should say See figure below...



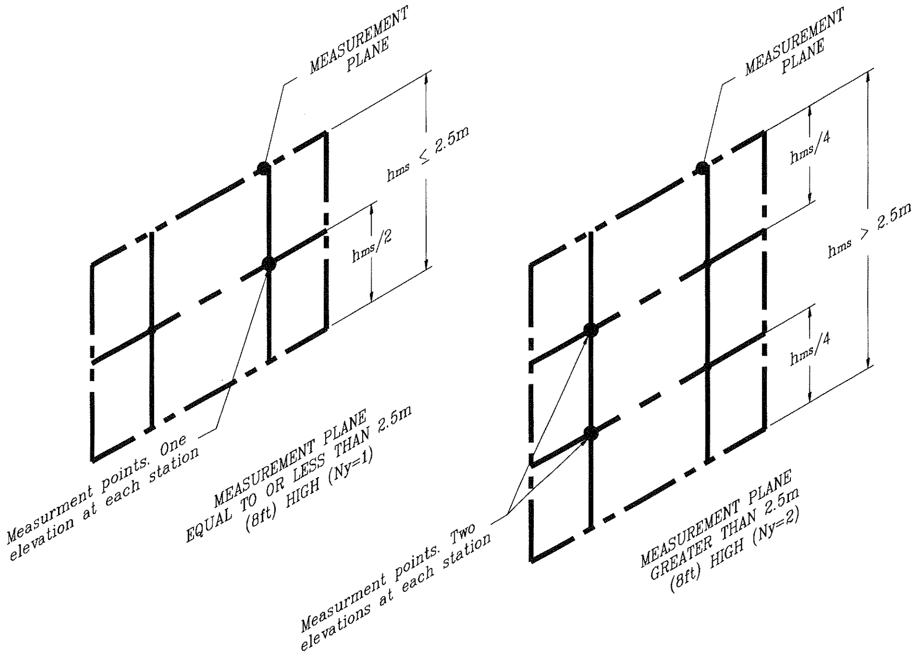


Figure D-2. Rectangular Outlet

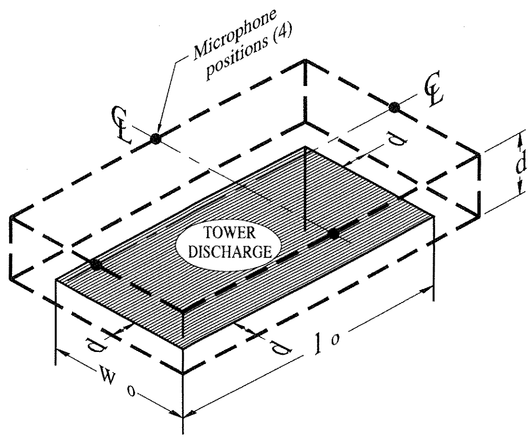
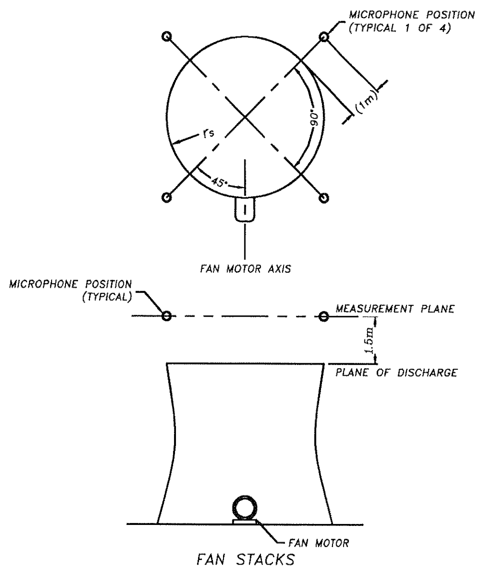


Figure D-3. Circular Outlet Note, rotate figure so microphones show in lower figure below



Appendix E. A-Weighted Calculations

E.1 Calculation of A-Weighted Sound Pressure (or Sound Power) Level. The A-weighted Sound Pressure (or Sound Power) Level for each surface of the unit shall be calculated using the following equation:

$$L_{PA}(\text{or } L_{PW}) = 10 \log_{10}\left[\sum_{f=2}^{f=9} 10^{0.1(Lpf\,(or Lpw)+Cf)}\right] \quad (21)$$

where: L_{PA}= A-weighted Sound Pressure Level
L_{pf}= Sound Pressure Level in band f
C_f = A weighted values from Table E-1
f = the octave band as shown in table E-1

E.2 Calculation of A-Weighted Partial Sound Power Level

$$L_{Wx} = 10\log \sum_{f=2}^{9} 10^{0.1(L_{Wf}+C_f)} \quad (22)$$

Where: L_{Wx} is the A-weighted sound power level of the xth partial source

L_{Wf} is the sound power level in octave band f

f is the octave band as shown in table E-1

The values of C_f, in dB, are given in Table E-1.

Table E-1: A-Weighting Adjustments, values of C_f for octave bands.

f	Octave Band Center Frequency (Hz)	C_f (dB)
1	31.5	-39.4
2	63	-26.2
3	125	-16.1
4	250	-8.6
5	500	-3.2
6	1000	0
7	2000	+1.2
8	4000	+1.0
9	8000	-1.1

Appendix F: Background Noise Adjustment

F.1 Correction for Background Noise. Each of the measured Sound Pressure Levels ($L_{P(m)}$) shall be compared to the measured background noise ($L_{P(b)}$) at the same position and frequency such that:

$$\Delta L = L_{P(m)} - L_{P(b)} \qquad (23)$$

Where: ΔL = The difference in Sound Pressure levels between the measured sound pressure level of the unit and the background noise.

$L_{P(b)}$ = The sound pressure level of the background noise at the measurement point.

$L_{P(m)}$ = The sound pressure level of the noise signal.

Then:

a. If the difference (ΔL) is greater than 10.0, no adjustment is required.

b. If $6.0 \geq \Delta L \geq 10.0$, the adjusted sound pressure level ($L_{P(m, adj)}$) shall be determined as:

$$L_{P(m, adj)} = L_{P(m)} + 10\log(1 - 10^{-0.1\Delta L}) \qquad (24)$$

If the difference (ΔL) is less than 6.0, the actual value for the unit is indeterminate. The measured value may be used in the analysis, however, recognizing it has a significant background noise component.

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