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# Determination of sound power level and directionality of reference sound sources in a hemi-anechoic chamber using ANSI S12.5/ISO 6926

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## ABSTRACT

Engineering-grade product noise emission testing programs using a hemi-anechoic chamber are qualified, and correction factors are applied to test results, based upon "known" sound power levels of a reference sound source; i.e., a sound source that has been tested and qualified in accordance with ANSI S12.5/ISO 6926. The accuracy and uncertainty of ANSI S12.5/ISO 6926 test results are then transferred to the engineering-grade testing program, and are thus of crucial importance. ETS-Lindgren recently manufactured and installed a precision-grade hemi-anechoic chamber at headquarters in Cedar Park, Texas, and is developing an ANSI S12.5/ISO 6926 reference sound source testing program using the chamber. This work included evaluation of factors contributing to accuracy and uncertainty. The effect of using different microphone configurations on determination of the maximum directivity index (required by standard for reference sound sources to be used in hemi-anechoic chambers) is discussed. The effect of the acoustic field in the chamber on test results is discussed and data presented. Comparison of preliminary results for a small number of reference sound sources to results from an outside laboratory is also presented.

## 1. INTRODUCTION

A reference sound source (*RSS*) is a portable sound source (usually a centrifugal fan wheel on the shaft of an electric motor with vibration-isolating base) which has constant and known noise emission characteristics. Use of a RSS enables an acoustician in the laboratory or field to isolate and solve for unknowns such as contribution of test environment on measured sound pressure levels, or to verify experimental sub-system functionality. One common use of a RSS in product

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noise emission testing programs is to normalize measured sound pressure from a device-under-test (*DUT*) using both the known sound power of RSS and in-situ pressure measurements of RSS, in order to determine the sound power of the DUT. Such "Comparison methods" for determination of sound power levels are specified in ANSI S12.51/ISO 3741 [1] and ANSI S12.54/ISO 3744 [2] for reverberation chambers and hemi-anechoic chambers respectively. Both specify that "known" sound power levels of RSS be determined per ANSI S12.5/ISO 6926 [3] that specifies separate test methods for hemi-anechoic chambers (Section 7) and reverberation chambers (Section 8).

Discussion and presentation of data herein is limited to RSS measurements in hemi-anechoic chambers.

## 2. DISCUSSION

### A. Directionality

Perhaps the most common use of ANSI S12.5/ISO 6926 test results is by test engineers to determine "environmental correction factors" ($K_2$ *values*) to apply to measured pressures from a given measurement surface in an engineering-grade hemi-anechoic chamber for sound power determinations in accordance with ANSI S12.54/ISO 3744. In addition to using known sound power of the RSS to normalize measurements, ISO 3744 relies upon the assumption that the RSS is sufficiently omnidirectional so that the reduced spatial sampling of the engineering-grade measurement does not introduce unacceptable inaccuracy into test results. Thus, ANSI S12.5/ISO 6926 also provides methodology for determining (and imposes limitations to) the directionality characteristics of an RSS when used for hemi-anechoic chamber measurements.

Of interest here are the various microphone arrangements allowed by ANSI S12.5/ISO 6926, and whether or not they yield comparable results with respect to directionality. Here we focus on a comparison of the "fixed point array" arrangement specified in ANSI S12.5/ISO 6926 Section 7.3.4 (using 20 microphone positions at equally spaced heights and 60-degree-incremental azimuths) with the "coaxial circular paths" arrangement specified in Section 7.3.5 (using 20 equal-area surface integrations). However, the observations here also apply generally when considering various arrangements allowable in the standard.

The standard defines *directivity index* $D_{Ii}$ as

$$D_{Ii} = L_{pi} - L_{pf} \,. \qquad (1)^{c}$$

where $L_{pi}$ is the sound pressure level measured on the measurement surface in a given direction, and $L_{pf}$ is the surface-average pressure level. Section 5.5 then imposes a requirement for the performance of RSS that the highest measured directivity index in any one direction in any band not exceed 6 dB. In the case of moving microphones, $L_{pi}$ is not available, so the standard specifies that the maximum of successive "S" time-weighting outputs be used in calculation of maximum $D_I$ for determining acceptability of an RSS as meeting performance requirements of the standard. Taken into consideration with the specified period of circular scan of 60 seconds, the "coaxial circular paths" arrangement has a much greater spatial resolution about the azimuth than the "fixed point array" arrangement (1-degree increments compared to 60-degree increments). This may result in discrepancies between test results from different implementations of the test method.

[c] To avoid confusion here, we note that the standard's definition of $D_I$ as function of measured values, which when applied in hemi-anechoic chambers indexes *measured pressure over reflecting plane*, results in a 3 dB offset from $D_I$ calculated using common theoretical definition of $D_I$ which indexes *free-field pressure of simple point source*.

## B. Influence of acoustic field in chamber on test results

ANSI S12.5/ISO 6926 Section 7 requires that testing of the RSS be conducted in hemi-anechoic chambers meeting the requirements of ANSI S12.55/ISO 3745[4d]. The intent of the requirement of prior qualification of the chamber is to ensure that the test results are indicative of the RSS and sufficiently independent of the test chamber used. In brief, hemi-anechoic chamber qualification is the comparison of measured deviations in pressure level from those estimated from inverse-square law to specified maximum allowable values. These maximum allowable deviations in hemi-anechoic chambers are given in ANSI S12.55/ISO 3745 Table A.2.

If measured deviations are considered a potential source of error, the maximum allowable values are of concern, given stated 95% confidence interval of ANSI S12.5/ISO 6926 (Table 1 below).

**Table 1:** Comparison of allowable deviations in chamber with 95% confidence interval.

| One-third octave band center frequency (Hz) | Maximum allowable deviations from theoretical inverse-square law (+/- dB) | Estimated 95% confidence interval of test method (+/- dB) |
|---|---|---|
| 50 | 2.5 | 3.9 |
| 63 | 2.5 | 3.9 |
| 80 | 2.5 | 3.9 |
| 100 | 2.5 | 1.6 |
| 125 | 2.5 | 1.6 |
| 160 | 2.5 | 1.6 |
| 200 | 2.5 | 1.0 |
| 250 | 2.5 | 1.0 |
| 315 | 2.5 | 1.0 |
| 400 | 2.5 | 1.0 |
| 500 | 2.5 | 1.0 |
| 630 | 2.5 | 1.0 |
| 800 | 2.0 | 1.0 |
| 1000 | 2.0 | 1.0 |
| 1250 | 2.0 | 1.0 |
| 1600 | 2.0 | 1.0 |
| 2000 | 2.0 | 1.0 |
| 2500 | 2.0 | 1.0 |
| 3150 | 2.0 | 1.0 |
| 4000 | 2.0 | 2.0 |
| 5000 | 2.0 | 2.0 |
| 6300 | 3.0 | 2.0 |
| 8000 | 3.0 | 2.0 |
| 10000 | 3.0 | 2.0 |
| 12500 | 3.0 | 2.0 |
| 16000 | 3.0 | 2.0 |
| 20000 | 3.0 | 2.0 |

[d] Dated references to ISO 3745:1977 such as found in ISO 6926:1999 are problematic in that the primary difference in implementation of the chamber qualification testing between the 1977 and 2003 versions of 3745 lies in the requirements of directionality of the qualification sound source. The limitations imposed by the 1977 version are impractical to meet with real-world sources and were expanded for the 2003 version of ISO 3745.

Notably, the maximum allowable deviations shown above are as evaluated at a single microphone position while the 95% confidence interval shown is evaluated for a surface average of pressures. Implied is that surface averaging mitigates errors at individual microphone positions. However, the potential for nontrivial influence of acoustic field on a surface average exists, in spite of chamber having been qualified to ANSI S12.55/ISO 3745.

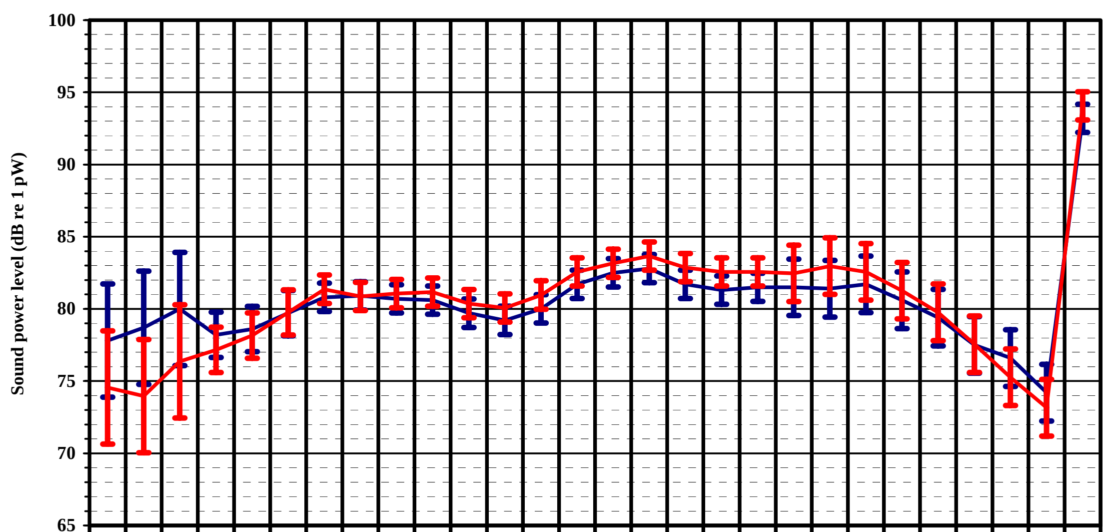
## 3. DATA

Development of an ANSI S12.5/ISO 6926 RSS testing program in a newly-commissioned hemi-anechoic chamber included comparison of results from preliminary testing of four RSS samples with results obtained in accordance with the standard at an outside laboratory[e]. Atmospheric correction $C$ is removed from all data shown here such that sound power level $L_W$ has been calculated as

$$L_W = L_{pf} + 10*\log(S/S_0) \quad \text{dB} \tag{2}$$

where $L_{pf}$ is the surface-average pressure level, S is the surface area (in square meters), and $S_0 = 1\ m^2$.

Sound power level spectra determined by the two laboratories are shown in Figures 1 through 4 below.




| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1 | 1.25 | 1.6 | 2 | 2.5 | 3.15 | 4 | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 20 | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETS-Lindgren | 77.8 | 78.7 | 80.0 | 78.2 | 78.6 | 79.7 | 80.8 | 80.9 | 80.7 | 80.6 | 79.7 | 79.2 | 80.0 | 81.7 | 82.5 | 82.8 | 81.7 | 81.3 | 81.5 | 81.5 | 81.4 | 81.7 | 80.6 | 79.4 | 77.5 | 76.6 | 74.2 | 93.2 |
| Outside Lab | 74.6 | 74.0 | 76.4 | 77.2 | 78.2 | 79.8 | 81.4 | 80.9 | 81.1 | 81.2 | 80.4 | 80.1 | 81.0 | 82.6 | 83.2 | 83.7 | 82.9 | 82.6 | 82.6 | 82.5 | 83.0 | 82.6 | 81.3 | 79.8 | 77.6 | 75.3 | 73.2 | 94.1 |

1/3 octave band (Hz or kHz) or A-weighted

**Figure 1:** ANSI S12.5/ISO 6926 determined sound powers (uncorrected for atmospheric conditions) at ETS-Lindgren and at an outside laboratory. Error bars shown are 95% confidence intervals based on stated standard deviation of reproducibility. **Norsonic Type 261.**

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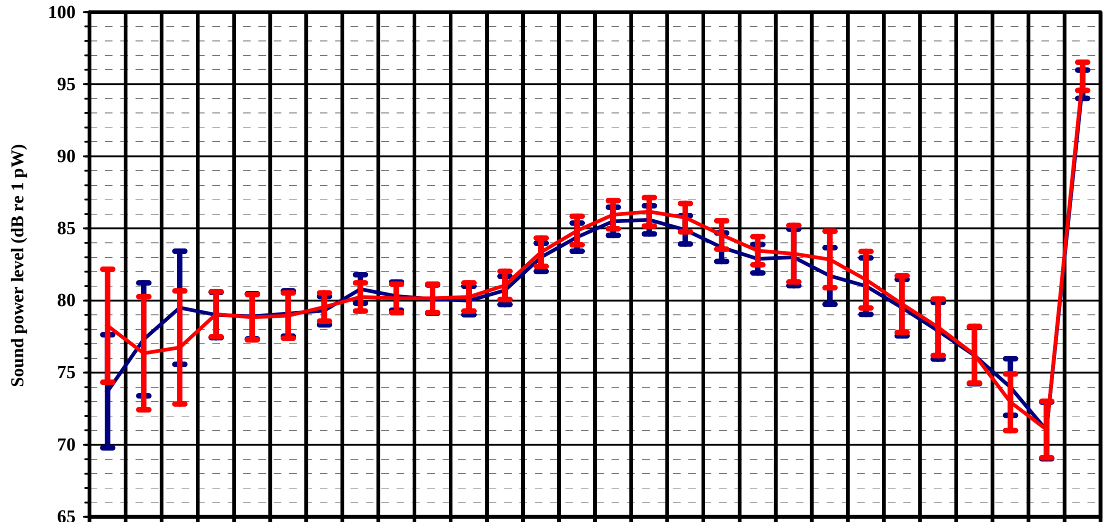
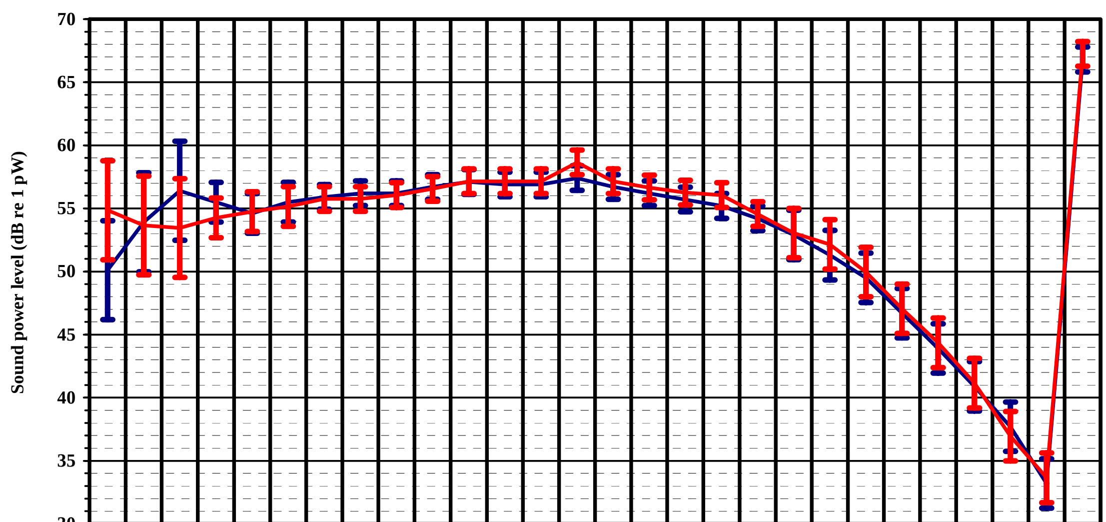
[e] Data in the 100 Hz to 10 kHz one-third octave bands were acquired in accordance with standard. Data outside of this range is not in accordance with the standard, and is likely influenced by chamber and microphone frequency response.




| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1 | 1.25 | 1.6 | 2 | 2.5 | 3.15 | 4 | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 20 | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETS-Lindgren | 73.7 | 77.3 | 79.5 | 79.0 | 78.9 | 79.1 | 79.3 | 80.8 | 80.3 | 80.1 | 80.0 | 80.7 | 83.0 | 84.4 | 85.5 | 85.6 | 84.9 | 83.7 | 82.9 | 83.0 | 81.7 | 81.0 | 79.5 | 77.9 | 76.2 | 74.0 | 71.0 | 95.0 |
| Outside Lab | 78.3 | 76.4 | 76.8 | 79.1 | 78.9 | 79.0 | 79.6 | 80.3 | 80.2 | 80.2 | 80.3 | 81.1 | 83.4 | 84.9 | 86.0 | 86.2 | 85.8 | 84.6 | 83.5 | 83.3 | 82.9 | 81.5 | 79.8 | 78.2 | 76.3 | 73.0 | 71.1 | 95.6 |

1/3 octave band (Hz or kHz) or A-weighted

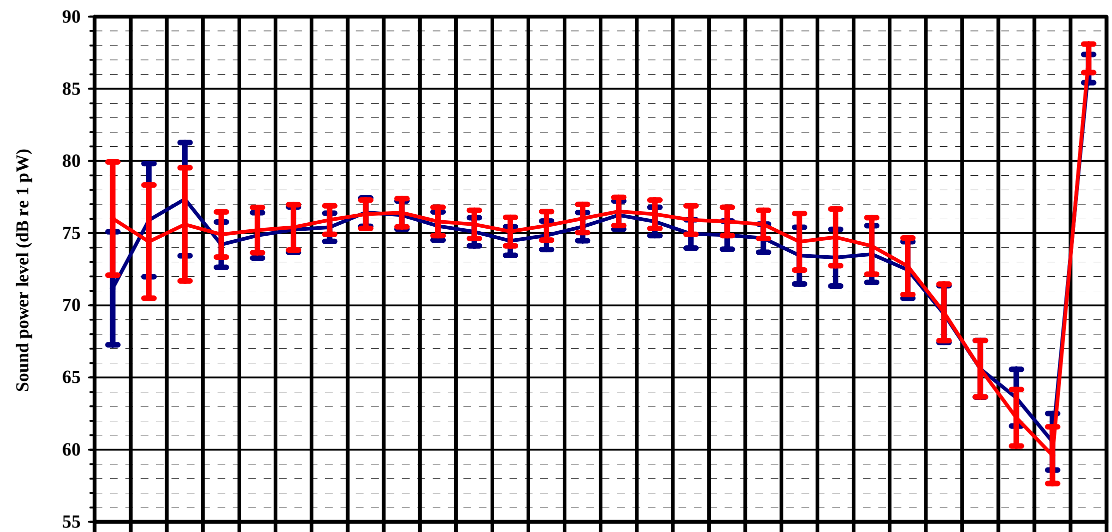
**Figure 2:** ANSI S12.5/ISO 6926 determined sound powers (uncorrected for atmospheric conditions) at ETS-Lindgren and at an outside laboratory. Error bars shown are 95% confidence intervals based on stated standard deviation of reproducibility. **Brüel & Kjær Type 4204.**




| | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1 | 1.25 | 1.6 | 2 | 2.5 | 3.15 | 4 | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 20 | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETS-Lindgren | 50.1 | 53.9 | 56.4 | 55.5 | 54.6 | 55.5 | 55.9 | 56.2 | 56.2 | 56.7 | 57.1 | 56.9 | 56.9 | 57.4 | 56.7 | 56.2 | 55.7 | 55.2 | 54.2 | 52.9 | 51.3 | 49.5 | 46.7 | 43.9 | 40.9 | 37.7 | 33.2 | 66.8 |
| Outside Lab | 54.9 | 53.7 | 53.5 | 54.3 | 54.8 | 55.2 | 55.8 | 55.8 | 56.1 | 56.6 | 57.2 | 57.2 | 57.2 | 58.7 | 57.2 | 56.7 | 56.3 | 56.1 | 54.6 | 53.1 | 52.2 | 50.0 | 47.1 | 44.4 | 41.2 | 37.0 | 33.7 | 67.3 |

1/3 octave band (Hz or kHz) or A-weighted

**Figure 3:** ANSI S12.5/ISO 6926 determined sound powers (uncorrected for atmospheric conditions) at ETS-Lindgren and at an outside laboratory. Error bars shown are 95% confidence intervals based on stated standard deviation of reproducibility. **Acculab model RSS-700.**




| 1/3 octave band | 50 | 63 | 80 | 100 | 125 | 160 | 200 | 250 | 315 | 400 | 500 | 630 | 800 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETS-Lindgren | 71.2 | 75.9 | 77.4 | 74.2 | 74.9 | 75.3 | 75.4 | 76.5 | 76.3 | 75.5 | 75.1 | 74.5 | 74.9 | 75.5 |
| Outside Lab | 76.0 | 74.4 | 75.6 | 74.9 | 75.2 | 75.4 | 75.9 | 76.3 | 76.4 | 75.8 | 75.6 | 75.1 | 75.5 | 76.0 |

| 1/3 octave band | 1.25 | 1.6 | 2 | 2.5 | 3.15 | 4 | 5 | 6.3 | 8 | 10 | 12.5 | 16 | 20 | A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ETS-Lindgren | 76.3 | 75.8 | 75.0 | 74.9 | 74.7 | 73.5 | 73.3 | 73.6 | 72.5 | 69.4 | 65.6 | 63.6 | 60.6 | 86.4 |
| Outside Lab | 76.5 | 76.3 | 75.9 | 75.8 | 75.6 | 74.4 | 74.7 | 74.1 | 72.7 | 69.5 | 65.6 | 62.2 | 59.6 | 87.1 |

1/3 octave band (Hz or kHz) or A-weighted

**Figure 4:** ANSI S12.5/ISO 6926 determined sound powers (uncorrected for atmospheric conditions) at ETS-Lindgren and at an outside laboratory. Error bars shown are 95% confidence intervals based on stated standard deviation of reproducibility. **ILG Industries model 8612 (horizontal axis of rotation).**

The figures above indicate close agreement between our laboratory and the outside laboratory – in general, results show the laboratories fall into each other's confidence intervals. Nonetheless, when the deviations between our laboratory and outside laboratory are plotted for the four RSS samples on one graph as in Figure 5 below, a trend is observed.

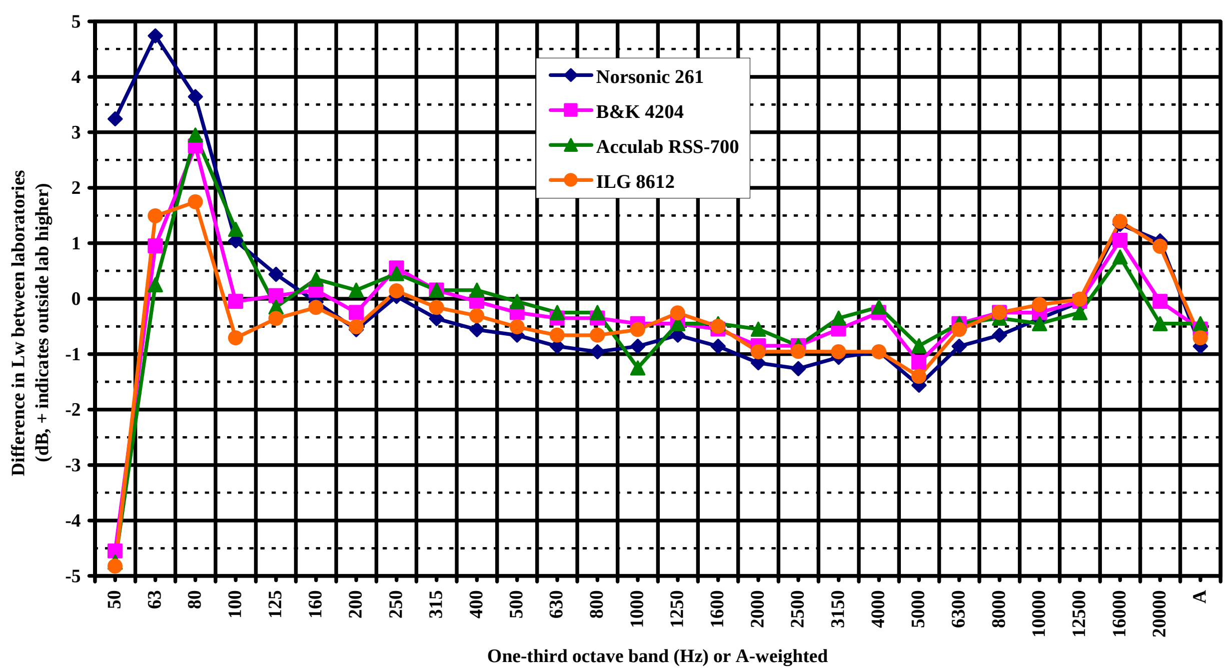



**Figure 5:** Differences between sound power as determined on 20-microphone spiral fixed array at ETS-Lindgren and using 20 coaxial circular paths at outside laboratory.

In addition to the sound power spectra, the test results from the outside laboratory and ETS-Lindgren are compared with respect to maximum directionality indices in Figure 6 below.

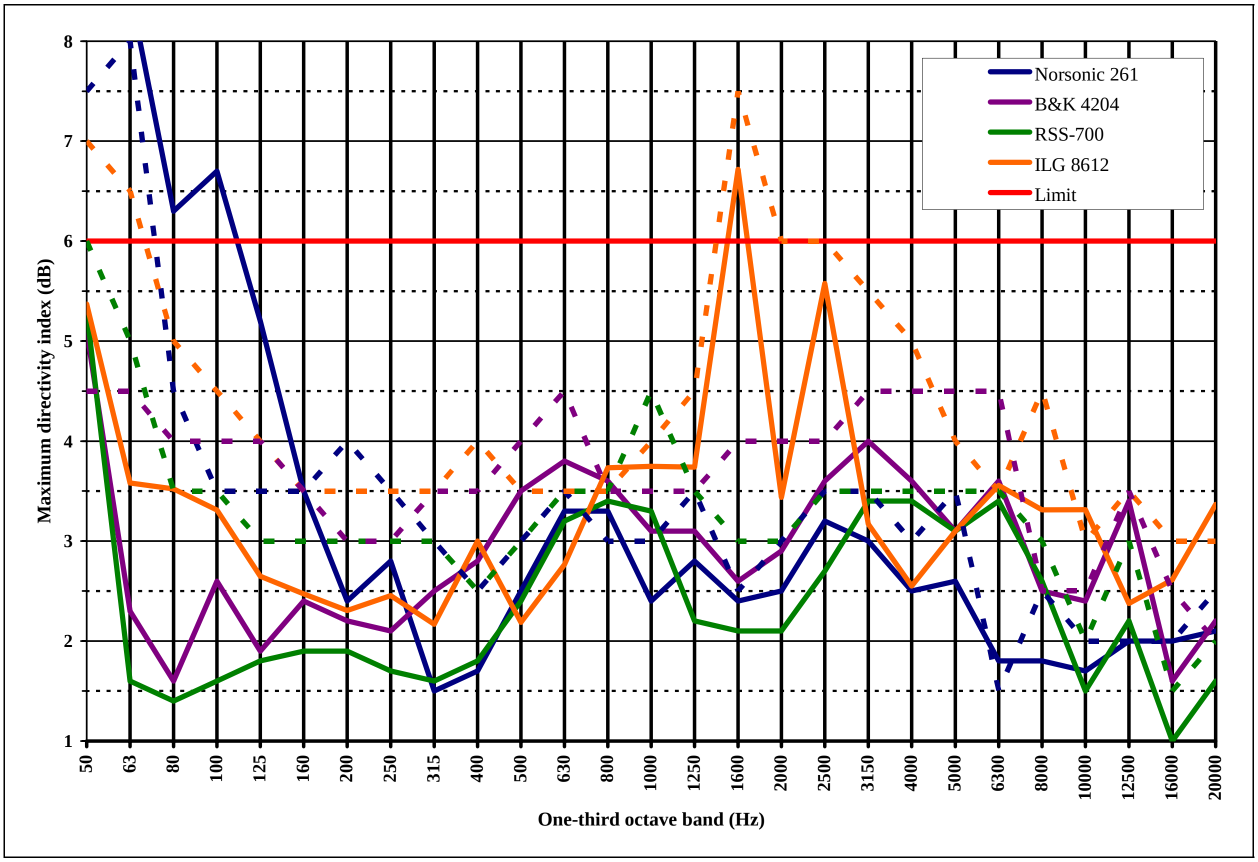



**Figure 6:**.Directivity indices determined by ETS-Lindgren (solid) and ouside lab (dashed).

## 4. CONCLUSIONS

Initial work has shown general agreement between ETS-Lindgren and the outside laboratory in ANSI S12.5/ISO 6926 testing, with respect to sound power levels and directionality indices. The sag in the deltas in sound power spectra approaching around 1 dB below the outside laboratory in the 500 Hz to 5 kHz range (seen in Figure 5) merits more examination. Possible causes for discrepancy in results include acoustic field, use of windscreens, different microphone arrangements, and at high frequencies, frequency response of the microphones. Due to higher spatial resolution implemented by coaxial circular paths arrangement by outside laboratory, slightly higher directionality indices were expectedly determined. However, the fixed microphone arrangement evaluated did indeed identify a known 1.6 kHz directionality issue with the ILG 8612 RSS.

This work also identified issues with the Norsonic 261 and Acculab RSS-700. The Norsonic 261 induced significant wind noise on the lower 2 microphones, as seen in the low frequency data in Figure 5 and the apparent high directivity index in the lower bands in Figure 6. This could be mitigated with use of windscreens, although windscreen correction factors would have to be experimentally determined and applied. The Norsonic 261 also had intermittent rattling of the outer frame cage that occurred unless care was taken to tighten all screws prior to testing. Some question remains as to the physical state of the unit at time of tests compared to as-delivered to outside laboratory. The RSS-700 emits significantly less turbulent wind noise, and thus intermittent rattling of the spring isolation feet becomes significant and can taint results (e.g, the 1 kHz data for the RSS-700 shown in Figures 3 and 5 above).

## REFERENCES

[1] ANSI S12.51-2002 (R 2007) / ISO 3741:1999 “Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision method for reverberation rooms, ” United States Nationally Adopted International Standard (Acoustical Society of America, Melville, NY, 2007).

[2] ANSI S12.54-1999 (R2004) / ISO 3744:1994 “Acoustics - Determination of sound power levels of noise sources using sound pressure - Engineering method in an essentially free field over a reflecting plane,” United States Nationally Adopted International Standard (Acoustical Society of America, Melville, NY, 2004).

[3] ANSI S12.5-2006 / ISO 6926:1999 “Acoustics - Requirements for the Performance and Calibration of Reference Sound Sources Used for the Determination of Sound Power Levels,” United States Nationally Adopted International Standard (Acoustical Society of America, Melville, NY, 2006).

[4] ANSI S12.55-2006/ISO 3745:2003 “Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision methods for anechoic and hemi-anechoic rooms,” United States Nationally Adopted International Standard (Acoustical Society of America, Melville, NY, 2006).