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Qualification of an anechoic chamber

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ABSTRACT

An anechoic chamber is typically used for acoustical experiments requiring a free-field environment. The free-field properties of the chamber can be determined by using a so-called "divergence loss" (i.e., a draw-away) test to demonstrate that sound pressure decreases with increasing distance in accordance with the inverse square law. For the qualification of free-field environments, the principal governing standard is ISO 26101:2012. This standard prescribes protocols suitable for qualifying both hemi- and fully anechoic chambers including tolerances for deviations from the inverse square law. Either random noise or pure tones can be used for the ISO divergence loss test method, depending on the intended application of the chamber. This paper describes an ISO qualification test for a medium-sized anechoic chamber with an internal volume of 51 cubic meters. The chamber was equipped with a partly-open floor grate and furnished with foam wedges having questionable sound-absorptive performance. The chamber could satisfy the ISO tolerances when using random noise but failed to qualify when using pure tones. The paper discusses the measurements and the likely causes of the discrepancy.

Keywords: Anechoic Chamber, Sound Absorption, Free Field, Divergence Loss, Inverse Square Law, Draw-Away

1. INTRODUCTION

The fully-anechoic chamber was manufactured by Industrial Acoustics Company (IAC). It is equipped with exposed sound-absorptive foam wedges on all six surfaces (see Figure 1). The net volume of the chamber is 51 cubic meters (i.e., in the region between the wedge tips). An expanded-metal mesh walking surface extends across most of its projected floor area (see Figure 1). The walking surface is supported by slender metal posts that bear on pedestals below. Even though the floor grating has many perforations, it is still capable of reflecting high-frequency sound; therefore, the operational assumption is that the user would cover the walking surface with sound-absorptive material during critical measurements. This assumption also applied to the qualification measurements — i.e., whenever the measuring microphones were placed relatively close to the walking surface, its semi-reflective surface was covered by 50-millimeter thick glass-fiber panels (see Figure 4).

The project specifications call for a post-construction acoustical qualification test to be conducted in accordance with Annex A of ISO 3745. The measurements involve using a qualified sound source(s) that emits sound in an omnidirectional pattern. The resulting sound pressures from the source(s) are measured at a number of calibrated distances to check whether the sound pressure amplitudes decrease with distance in accordance with the so-called inverse-square law. If the chamber conforms to the inverse-square characteristic within specified tolerances, ISO 3745 presumes that its acoustical environment constitutes a so-called "free field" (i.e., sound waves propagate freely without reflections).

In an ideal free-field environment, the sound pressure from a small source decreases at a rate of six decibels per doubling of distance (i.e., a halving of sound pressure). The ratio of [decreasing] sound pressure to [increasing] distance is called the "divergence loss" or draw-away characteristic of an anechoic chamber.

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Deviations from the ideal draw-away characteristic represent imperfections of the acoustical environment within the chamber. With respect to a fully-anechoic chamber, Annex A of ISO 3745 specifies limits for deviations from the inverse-square characteristic. For frequencies between 800 and 5000 hertz, the allowable deviations are plus or minus one decibel. Below 800 hertz and above 5000 hertz, the allowable deviations are relaxed to plus or minus 1.5 decibels.

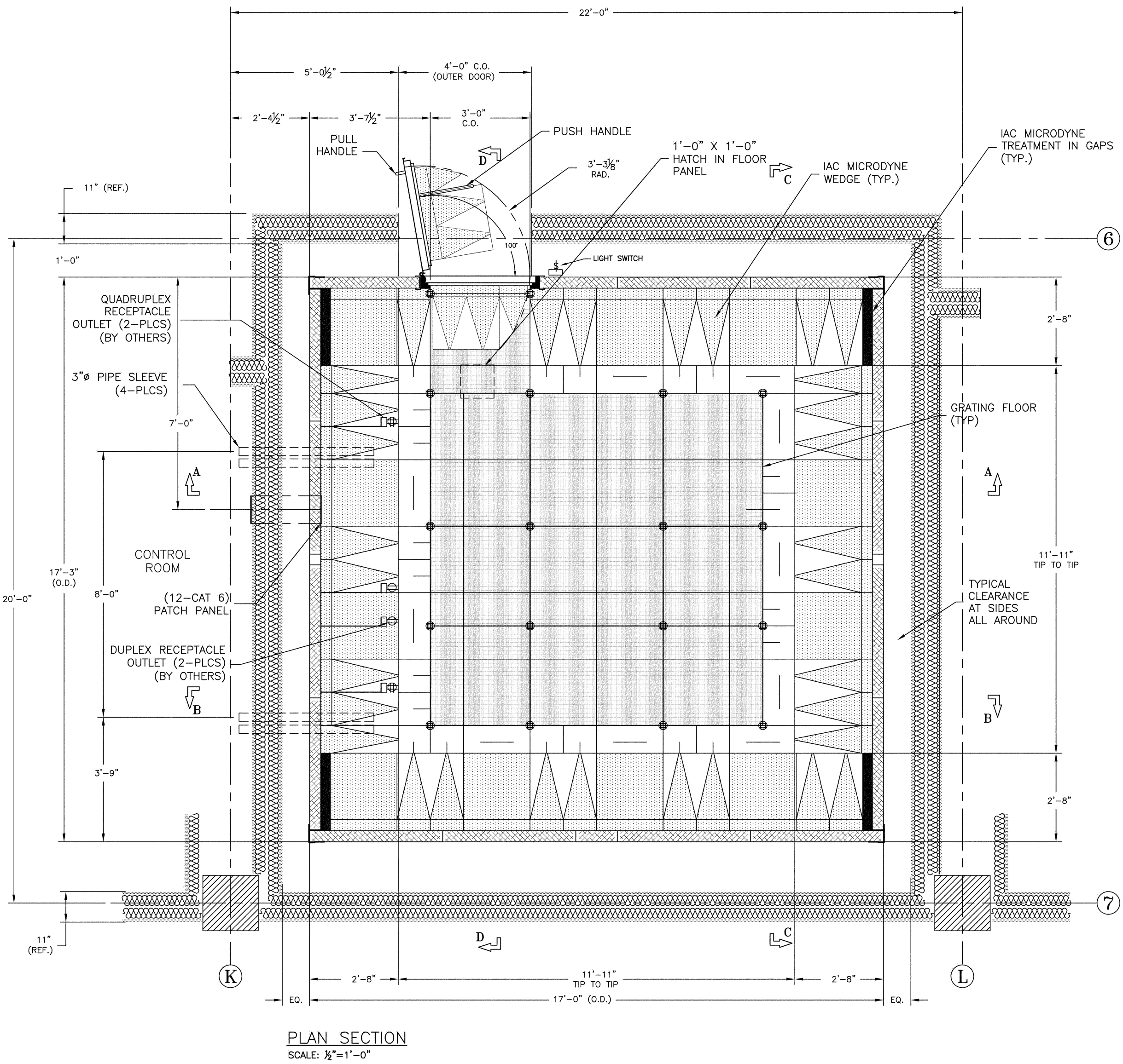

Figure 1 – Plan section of 51-m^3 anechoic chamber. The tips of the foam wedges are spaced apart by 3.63 meters (11 ft., 11 in.)

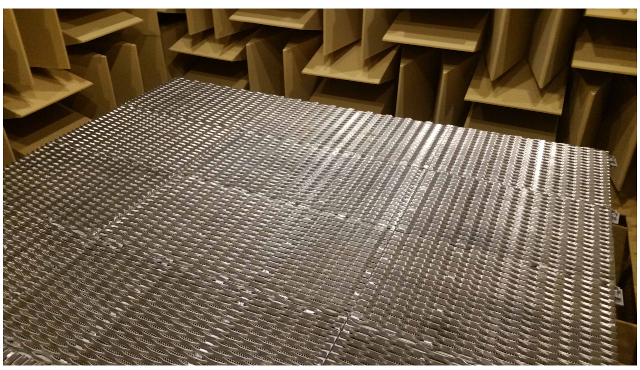

Figure 2 – Expanded metal mesh floor grating used as a walking surface. The floor grating is removable for critical experiments at high frequencies.

Qualifying the chamber required several draw-away measurements of sound pressure generated by a fixed source having uniform directionality. The specifications called for measuring sound pressure at a discrete points spaced 25 millimeters apart along five independent traverses, each of which would be 500 millimeters long. The measurements were to be obtained at the center frequency of eight contiguous octave bands extending from 125 Hz to 16 kHz.

The project specifications read in part:

> "*....The source signal used during the testing shall be single or multiple discrete frequency sinusoidal pure tones in each octave band over the qualification range. Broadband noise, such as pink noise or white noise, is not allowed...*".

As discovered during the measurements, the requirement for discrete tonal test signals would have significant ramifications when attempting to qualify this particular anechoic chamber.

2. MICROPHONE ARRAY

The large matrix of position and frequency data required by the specifications leads to 800 discrete field measurements of sound pressure. For this reason, it was decided to "mass produce" the field data acquisition by simultaneously recording the acoustical signals from an array of four or seven matched microphones (see Figure 3).

3. SOUND SOURCE SIGNALS

In addition, the tonal source signals were also "mass produced" by creating a pair of complex tone clusters based on the respective centers of each fractional octave band. Each tone cluster represented a low- or high-frequency range, respectively.

The signal frequencies were expressly selected so a) they were aligned precisely with the bin centers of a fast Fourier transform (FFT) analyzer and, b) potential harmonic distortion components from a given tone would not coincide with the fundamental of any other tonal signal. In this way, an FFT spectrum of the recorded complex tonal signal would represent the true received sound pressure at each tonal frequency of interest.

Since the number of discrete tones within each of the frequency clusters did not affect the field measurement time, it was decided to decrease the frequency spacing of the complex tonal signal from octave-band intervals to one-third-octave-band intervals. With this improved spacing of the test signals, the low-frequency tone cluster now contained 12 tones and the high-frequency tone cluster contained 13 tones as shown in Table 1 below.

Table 1 – Tone clusters used with low- and high-frequency sound sources

Frequency, hertz	
Low Range Cluster	**High Range Cluster**
100	824*
125	1000*
160	1248*
206	1600
257	2064
325	2576
388	3248
485	3880
611	4848
824*	6112
1000*	8240
1248*	10000
	12504

*duplicated tonal signals

By intent, three of the tonal signals within each cluster were duplicates of tones in the other cluster; thus, the low- and the high-frequency sound sources each reproduced three duplicate tonal signals.

4. SOUND SOURCES

Given the eight-octave frequency range, it was necessary to use two types of sound sources — one for low frequencies and the other for high frequencies. The low-frequency source was a Bruel & Kjaer OmniSource Type 4295 as shown in Figure 3. The Type 4295 was used to produce signals in the range from 100 Hz through 1250 hertz.

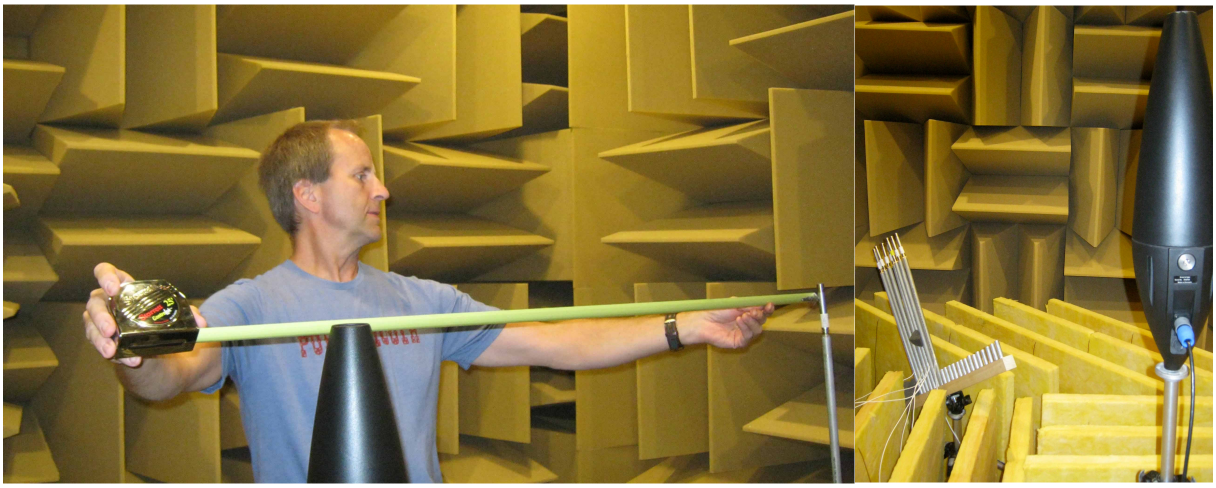

Figure 3 – Left photo: checking the one-meter separation between low-frequency source and closest microphone. Right photo: array of seven microphones installed along a diagonal traverse beginning one meter from the low-frequency source. The 50-millimeter-thick vertical glass-fiber panels help eliminate undesirable reflections from the floor grating.

The high-frequency source was a custom-built design conforming to the arrangement suggested in ISO 3745. It comprised a 1.5-meter length of 1/8-inch, Schedule 80 steel pipe coupled via tapered adapters to a JBL Type 2426J compression driver. The open end of the steel pipe faced upward as shown in Figure 4. This high-frequency source satisfied the ISO 3745 directivity requirements up to 90 degrees off axis. The high-frequency source was used to produce signals between 800 Hz and 12.5 kHz (the upper frequency limit of the compression driver).

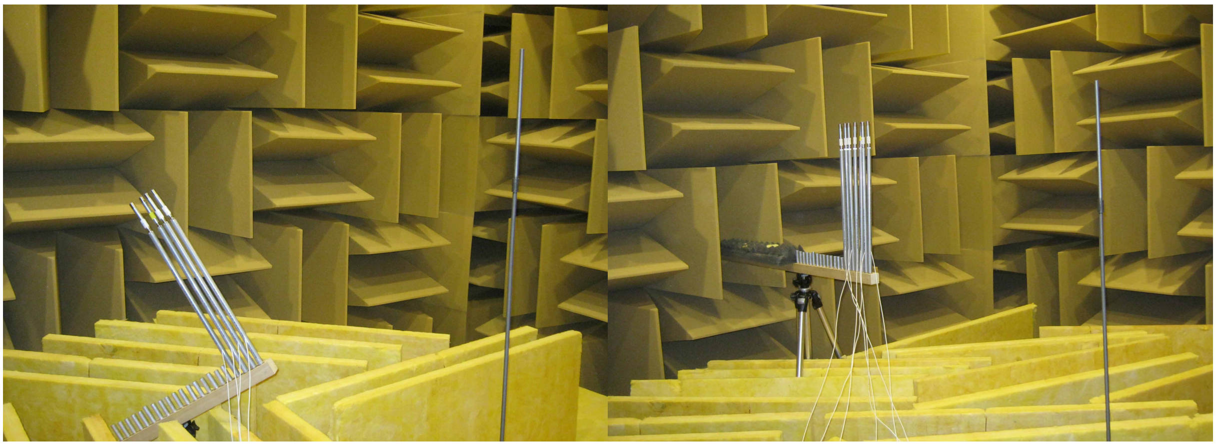

Figure 4 – Left photo: array of four microphones along a diagonal traverse beginning one meter from the high-frequency source. Right photo: array of seven microphones installed along a traverse normal to the high-frequency source

The microphones and their pre-amplifiers were inserted into aluminum tubes fitted over spaced aluminum dowels installed in a square wood member. The wood member, in turn, was supported by an adjustable tripod head. Figure 4 depicts the fixture used for supporting the microphones at 25-millimeter intervals. For each traverse measured using tone clusters, an array of seven microphone tubes was moved three times along the wood member until data were measured at all 20 microphone positions.

These multi-microphone and multi-tone signal configurations enabled the field data matrix to be reduced from [5 traverses x 20 microphone positions x 8 bands =] 800 recordings to [5 traverses x 3 microphone array positions x 2 frequency ranges =] ~30 recordings.

5. RECORDING INSTRUMENTATION

G.R.A.S. Type 40AE pre-polarized, one-half-inch condenser microphones were installed on Brüel & Kjær Type 2671 constant-current line drive (CCLD) microphone pre-amplifiers. Each microphone pre-amplifier was connected to one channel of a Brüel & Kjær Type 5963 eight-channel accelerometer power supply system. The Type 5963 featured a DeltaTron® constant-current supply combined with a custom amplifier having a gain of 40 decibels. The amplified output signals from the Type 5963 were recorded on an eight-channel Sony Type 208Ax digital audio tape (DAT) machine — the eighth channel of the DAT machine recorded the source test signal as a timing reference. The frequency response of the entire acoustical measuring/recording system was qualified to >10 kHz.

6. DATA ANALYSIS

The calibrated recordings were later played back into a fast Fourier transform (FFT) dynamic signal analyzer using a flattop window. This analysis resulted in 210 individual FFT spectra, each containing an array of either 12 or 13 tones, depending on the frequency range of the source signal cluster. Each tonal amplitude was extracted from the FFT spectrum and placed in a spreadsheet so a series of divergence loss (i.e., draw-away) data could be plotted at each respective frequency.

In addition to tonal signals, broad-band ("pink") noise was also used as a supplemental high-frequency source signal for one of the five traverses. In this case, only four microphones were deployed so the noise data could be measured onsite using a four-channel one-third-octave-band analyzer. The microphones were spaced 100 millimeters apart — for this measurement, the length of the four-microphone array was 300 millimeters. The array was successively moved to nine overlapping measurement positions along the fixture, resulting in 36 measurements (including 14 duplicates). The broadband noise test (with its duplicated measurement positions) was intended as a further quality control technique in case of discrepancies found in the tonal measurements.

7. DISCUSSION OF MEASURED DATA

Figure 5 is a scatter plot of one-third-octave-band data from the broadband noise test. The abscissa axis represents the log of the distance ratio in the region between the near and far ends of the 500-millimeter traverse (the closest microphone is one meter from the source). The ordinate axis represents the sound pressure level.

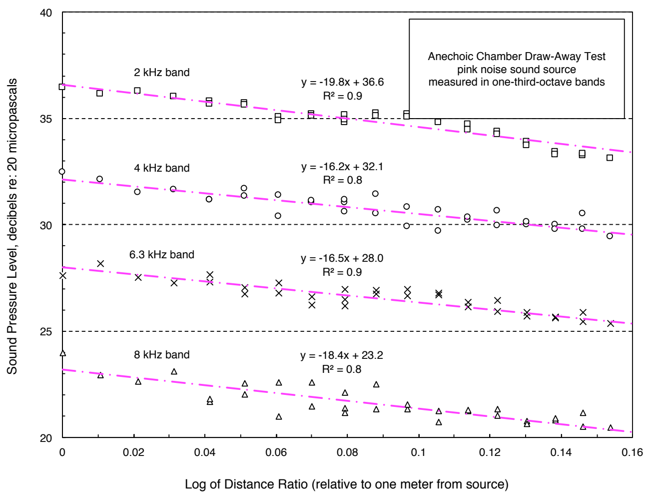

Figure 5 – Draw-away data from a random noise test signal as measured in one-third-octave bands. At first glance, the straight-line fits appear reasonable except that the downward slopes for the 4 kHz and 6.3 kHz bands are too shallow for a free field. Many of the scatter points in this chart have multiple values — these data represent duplicated microphone positions.

For an ideal anechoic chamber, the draw-away characteristic should appear as a straight line defined by the expression,

$$y = -20x + \text{intercept}$$

where: y is the sound pressure level in decibels
x is the common logarithm of the distance ratio
intercept is the sound pressure level at the point where the line intersects the y-axis

For a distance ratio of 1.5, an ideal free field should exhibit a reduction in sound pressure of precisely 3.522 decibels (equivalent to 6.0206 decibels per doubling of distance). In Figure 5, the fitting equation for the 2 kHz band nearly attains this ideal draw-away slope. For this same band, the coefficient of determination (the squared correlation coefficient, R^2) is 0.9, indicating that the data exhibit relatively minor fluctuations about the straight-line approximation.

For the higher frequency noise bands, the slopes of the fitting lines do not conform to the model. In the 4 kHz and 8 kHz bands, the slopes vary from -16.2 to -18.4 and the squared correlation coefficients have fallen to 0.8.

Figure 6 is a scatter plot for the same traverse using high-frequency tones. Compared to bands of noise, the use of discrete tones is more revealing of residual acoustical reflections arising from the walls, floor, and ceiling surfaces. It is now quite obvious that the acoustical environment in the chamber is not behaving like a free field.

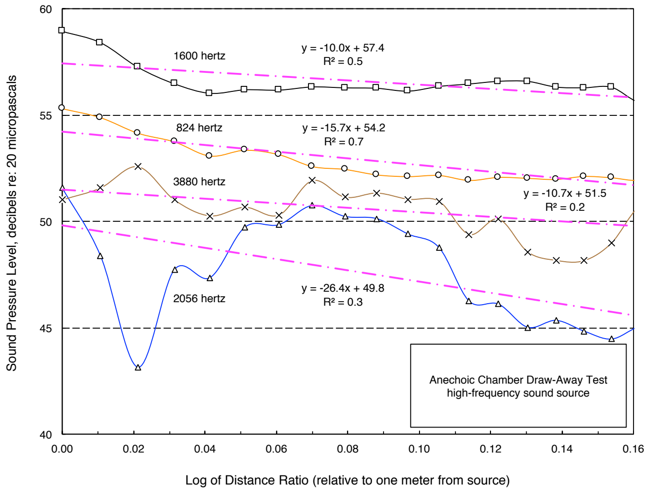

Figure 6 – Draw-away data from the high-frequency tone cluster. The unusual behavior of the 2056-Hz trace indicates that the chamber is not anechoic.

The draw-away for the 2056-Hz tone bears no resemblance to the 2 kHz one-third-octave band of random noise shown in Figure 5, above. In Figure 6, the slope of the straight-line fit for the 2056-Hz tone is minus 26.4 (eight decibels per doubling) — a value that is physically impossible. The severe notch in the draw-away for the 2056-Hz tone suggests an acoustical cancellation occurring between the arriving wave front and a strong reflection from a nearby surface.

Figure 7 shows draw-away data measured with the low-frequency sound source and its associated tone cluster. Here, the slope for 125 hertz is much too shallow and the slope for 824 hertz is much too steep. The squared correlation coefficients appear to be acceptable; however, this appearance is deceiving since the 25-millimeter spatial sampling interval is only a small fraction of a wavelength.

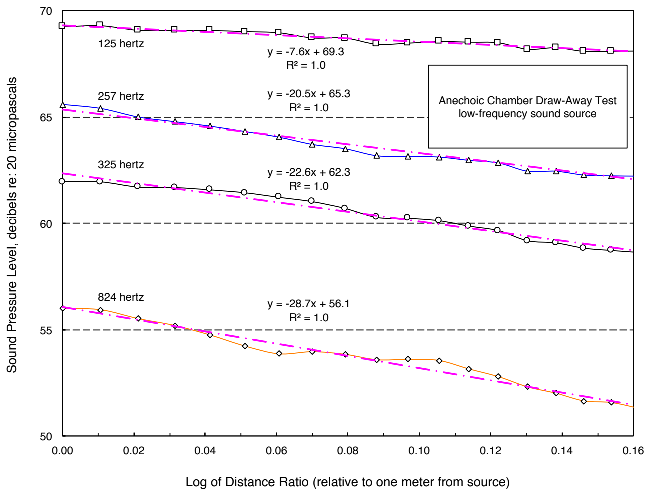

Figure 7 – Draw-away data measured with a low-frequency tone cluster. The downward slopes of the 325-Hz and 824-Hz test signals are too steep for a free-field environment.

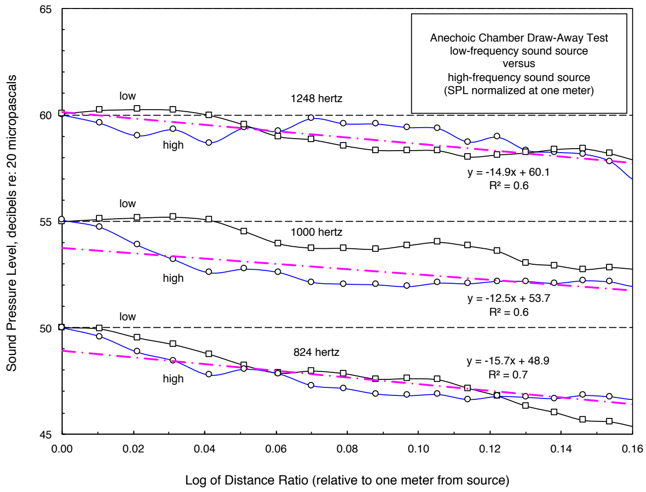

Figure 8 – Comparison between the low- and high-frequency sources radiating the three duplicated signals from the pair of tone clusters. The slopes are much too shallow for a free field.

As shown in Figures 8, both sources exhibit significant problems with respect to the slopes of the straight-line fits being far from the ideal value of -20; nevetheless, one would still expect the draw-away performance of the two sources to match one another more closely.

8. CLOSING REMARKS

For this particular anechoic chamber, it is likely that the sound-absorption properties of the foam wedges were deficient. There was no evidence that the wedges were ever qualified by testing them in an impedance tube.

The slopes of the straight-line fits are affected by reflections from the walls, floor, and ceiling of the chamber. These phase-dependent reflections lead to narrow-band acoustical cancellations at high frequencies and non-ideal slopes at low frequencies.

In short, the chamber is absorptive but not anechoic.

ACKNOWLEDGEMENTS

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REFERENCES

Duda J. Basic design considerations for anechoic chambers. J Noise Control Engineering; September-October 1977, p. 61-67.

Koidan W, Hruska GR. Acoustical properties of the national bureau of standards anechoic chamber. J Acoust Soc Am. 1978; 64(2): 508-516.

Maling G, Wise RE, Nobile MA. Draw away testing for qualification of hemi-anechoic rooms. Proc Noise-Con 90; Austin, TX, October 1990, p. 363-68.

Duda J. Inverse square law measurements in anechoic rooms. Sound and Vibration; December 1998, p. 20-25.

Impeduglia J. Acoustic test facility raises plant capability. Sound and Vibration; July 1999, p. 12.

Babineau F, Tinianov B. Research into quality assessment methods for anechoic chambers. Proc Noise-Con 2000; Newport Beach, CA, December 2000.

Winker D. Designing and building a low-noise hemi-anechoic chamber. Acoustics Today; Oct 2009, p. 16-21.

ISO 3745:2012 Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for anechoic rooms and hemi-anechoic rooms, International Organization for Standardization; Geneva, Switzerland, 2012

ISO 26101:2012 Acoustics - Test methods for the qualification of free-field environments, International Organization for Standardization; Geneva, Switzerland, 2012

Winker D, Stahnke B. The influence of changes in international standards on performance qualification and design of anechoic and hemi-anechoic chambers. Proc Inter-noise 2016; Hamburg, Germany, 2016