Surface Retexturing to Reduce Tire/Road Noise for Existing Concrete Pavements

Lloyd Herman, Ohio University, 122 Stocker Center, Athens, OH 45701, Ph 740-593-1472, Fax 740-593-0625, Lloyd.Herman@Ohio.edu

Jared Withers, Ohio University, 141 Stocker Center, Athens, OH 45701, Ph 740-593-1461, Fax 740-593-0625, jw100199@Ohio.edu

Elvin Pinckney, Ohio Department of Transportation, Office of Environmental Services, 1980 W. Broad St., Columbus, OH 43223, Ph 614.466.5154, epinckne@dot.state.oh.us

Abstract. A portion of I-76, near Akron, OH, was reconstructed by the Ohio Department of Transportation (ODOT) using concrete pavement to replace the previous surface, which was constructed of asphalt. In the process of reconstruction, the concrete surface was textured with random transverse grooves. Subsequent to construction, residents living in the project area as far as 800 m (2600 ft) from the roadway, perceived an unfavorable difference in their noise environment, which they attributed to the new concrete pavement used on the reconstruction project. Therefore, a project was initiated to re-texture the pavement surface by diamond grinding. The transverse grooves were replaced with longitudinal grooves. Traffic noise measurements were made before and after grinding at five sites in the project area, at distances of 7.5 m (24.6 ft) and 15 m (49.2 ft) from the center of the near travel lane. The average reduction in the A-frequency weighted broadband noise levels at 7.5 m (24.6 ft) was 3.5 dB, and the average reduction at 15m (49.2 ft) was 3.1 dB. Spectrum analysis showed the greatest reduction in noise occurred at frequencies above 1 kHz and that the retexturing had little to no effect on frequencies less than 200 Hz.

INTRODUCTION

A three-mile long portion of I-76, near Akron, OH, was reconstructed by the Ohio Department of Transportation (ODOT) using concrete pavement to replace the previous asphalt surface. During the process of reconstruction, the new concrete surface was textured with random transverse grooves.

Subsequent to construction, residents living in the project area as far as 800 m (2600 ft) from the roadway, perceived an unfavorable difference in their noise environment, which they attributed to the new concrete pavement used on the reconstruction project. ODOT highway engineers, being aware that pavement materials and especially pavement surface textures have a significant effect on tire/road noise, established a plan to change the surface texture from transverse grooves to longitudinal grooves as a means to alleviate the objectionable differences perceived by residents. The change in surface texture was to be accomplished by diamond grinding to remove the transverse grooves and create longitudinal grooves in one operation.

Further, ODOT initiated a research project to quantify noise differences due to the pavement re-texturing in order to have an objective basis for: judging the effectiveness of the re-texturing project, correlating any feedback from residents, and establishing the merits of the strategy for consideration in similar situations in the future. The results of the study are summarized in this paper.

BACKGROUND

There are several parameters that have generally been thought to affect the amount that the road surface contributes to the generation of tire/road noise. These parameters include the texture, age, thickness, and binder material of the pavement.

The overall texture of the pavement has a significant impact on tire/road noise levels. The texture of a pavement surface can be divided into three subcategories, mega-texture, macro-texture, and micro-texture . Most of the tire/pavement noise literature has focused on the last two subcategories. Macro-texture is the roughness or texture that encompasses the tire tread elements and road aggregate up to the size of the tire/road interface area. The function of the macro-texture is to provide a dry pavement surface creating channels where water can escape to create high friction even on wet roads and at high speeds (*1*). Micro-texture can be defined as the small-scale roughness or harshness of a road surface, within the individual aggregate, and extends down to molecular sizes (*2*). The function of the micro-texture is to provide high dry friction on the pavement surface.

The type, method, and direction of texturing Portland cement concrete surfaces has been known to be a significant factor when considering strategies to reduce tire/road noise (*3*). Most of the concrete pavements used on ODOT roadways have been finished with a surface texture composed of transverse grooves. The original groove design included a specification for a constant spacing between adjacent grooves, similar to the design used by most other states. However, ODOT and other states found that the constant spacing tended to produce a tonal quality, or whine, to the noise propagated from tires rolling on the pavement. To combat the “whine” problem associated with constant-spaced transverse grooved concrete pavements, ODOT, like other states, changed the specifications to a random-spaced transverse pattern. This design change was made to spread the peak sound level over a wider range of frequencies.

Sound level data was collected in Ohio in 1998 using ISO 11891-1, The Statistical Pass-By Method, for the major ODOT pavement types. The sound level data was used to develop Statistical Pass-By Index (SPBI) values for each pavement type. Though the “whine” problem had been solved, the SPBI data indicated that random transverse grooved PCC pavement produced the highest sound levels of the pavement types measured, including constant- spaced transverse grooves. These levels averaged 3.9 dB higher than the levels for the average pavement, which was one-year old dense graded asphalt, and 6.7 dB higher than the quietest pavement, which was one-year old open-graded asphalt (*4*).

Sound level data was also collected in a sub-study, using a single test vehicle to compare tire/road noise levels for six different PCC sites. The six sites included three different groove types: longitudinal (1 site), constant-spaced transverse (2 sites), and random transverse (3 sites). The site with the longitudinal grooves produced the lowest sound levels (3.0 dB below the mean of all six sites, for a vehicle speed of 65 mi/hr (105 km/hr)), followed by the constant-spaced transverse grooved sites, then the random transverse grooved sites (as much as 3.2 dB above the mean of all six sites, for a vehicle speed of 65.2 mi/hr (105 km/hr)). However, there was significant variation (almost 2 dB) between the random transverse sites. The sample size for this sub-study was very small, only one test vehicle was used, only two vehicle speeds were measured, and there was only one site with longitudinal grooves (*5*). While these results supported the strategy to remove the random transverse grooves of the SUM-76-15.40 pavement and replace them with longitudinal grooves, the magnitude of these results could not be used as a predictor for the SUM-76-15.40 project results.

The results of other studies have supported the decision to retexture the surface to longitudinal grooves. Longitudinal grinding was shown to reduce noise on both old and new Portland cement concrete surfaces based on measurements performed in Sweden. A noise level reduction in the range of 0.5 - 3.0 dB was achieved after grinding an old Portland cement concrete surface (*6*). Also, an Arizona Department of Transportation study, which compared rubberized asphalt to concrete pavements, found an average improvement of 4.7 dBA over transverse grooved concrete and 1.4 dBA over longitudinally grooved concrete (*7*). It could be inferred then, that this study observed a 3.3 dBA (ie. 4.7 dBA minus 1.4 dBA) difference in noise level between transverse and longitudinally grooved concrete.

OBJECTIVE

The primary objective of the study was to identify traffic noise level and frequency differences due to the re-texturing of the pavement surface.

PROCEDURE

Site Selection

Through coordination with ODOT, a number of potential sites were identified within the project limits. The sites were then inspected with reference to criteria established in the U.S. for the measurement of traffic noise reference levels (*8*) and the international standard for the statistical pass-by method of tire/road noise measurement (*9*). These criteria were developed to enable valid comparisons of noise measurements between different highway sites. They are necessarily more stringent than the requirements for BEFORE and AFTER measurements at the same site, which were the type of measurements planned for this study. However, every effort was made to choose sites that met as many of these criteria as possible, recognizing that the terrain variations and the relatively short project length would limit the number of potential sites and thus preclude meeting all criteria. Further, any criteria in these documents that related to the measurement of individual vehicle pass-bys or test lanes were not considered. Five sites were selected as a result of this process.

Instrumentation

Acoustical Measurements

Random incidence microphones and preamplifiers were positioned at a height of 1.5 m (4.9 ft) above the plane of the roadway at horizontal distances of 7.5 m (24.6 ft) and 15 m (49.2 ft) from the centerline of the near travel lane for all sites. The microphones and preamplifiers were connected by cables to a dual channel spectrum analyzer. The equivalent continuous sound level, A-frequency weighted, was measured in one-third octave bands for the frequency range of 50-10,000 Hz for measurement periods of one hour.

The two microphone positions were selected due to their frequent use in the measurement of vehicle noise sources. The 7.5 m (24.6 ft) position is prescribed in the international standard for the statistical pass-by method of tire/road noise measurement (*9*), and the 15 m (49.2 ft) position is the standard microphone distance for measuring vehicle reference noise levels for use in the Federal Highway Administration's Traffic Noise Model (TNM) (*10*) (*8*). Both of these standard measurement procedures are used to measure vehicle pass-by noise levels for isolated vehicles on the roadway. However, I-76 traffic volumes during daylight hours produced a density that was generally too high to permit the measurement of noise from individual vehicles. Therefore, the measured traffic noise was a composite for all of the vehicle pass-bys for all lanes during each measurement period. Typical hourly volumes were 3000 vehicles, which included approximately 24% heavy trucks and 3% medium trucks.

All sites included, as a minimum, both of these microphone positions with one exception: at Site 3, 1185 Newton St., the merge of an on-ramp with the mainline occurred where the 7.5 m (24.6 ft) microphone was normally placed. While omitting this microphone position was not desirable, there were few acceptable sites in the project area that offered acceptable terrain conditions. Since this site was favorable in all other respects, it was not eliminated.

Supplemental Measurements

A suitable location with pavement unaffected by diamond grinding was not available for a reference microphone to quantify any differences in the traffic noise source levels between before and after measurements. Therefore, the degree to which source equivalence was attained was based on traffic conditions. In order to compare traffic conditions between before and after noise measurements volume, speed, and classification traffic data were collected, by lane, using automatic detection at two locations in the project area. The two locations were required to accurately represent the traffic at all test sites, since there was an interchange located within the project limits.

In order to quantify any departure from atmospheric equivalence between before and after traffic noise measurements, a digital weather station was used to continuously monitor the temperature, wind speed, and wind direction. Temperatures were recorded at an accuracy of +/- 0.5°F and wind speeds at an accuracy of +/- 5%. The relative humidity was measured using a digital hygrometer with an accuracy of +/- 3% full scale. The road surface temperature was measured at the wheel path using a hand held infrared thermometer with an accuracy of +/- 1% of the reading. The instrument was positioned at a height of 3 ft (0.9 m (+/- 0.1 m)) above the roadway surface during temperature measurements. Recorded environmental conditions fell almost entirely within the criteria established in the international standard for the statistical pass-by method of tire/road noise measurement. Overall, the researchers found any differences in meteorological conditions between before and after measurements at each site to be acceptable.

RESULTS

Spectral Data Results

The figures displaying frequency band data from the 7.5 m (24.6 ft) microphone position at both Site 1 and Site 5 are shown below. The data from these two sites was chosen for display in this section in order to provide the reader with the range in results observed for the 7.5 m (24.6 ft) microphone position in this study. The smallest reduction in noise levels due to the diamond grinding was observed at Site 1 and the greatest reduction in noise levels was observed at Site 5. Note, this data has not been corrected for any differences in traffic between before and after measurements. However, the analysis of predicted noise level differences due to observed differences in traffic conditions, as shown in the next subsection, suggests that the actual corrections, if known, would be quite small or negligible for each frequency band.

The one-third octave frequency band data for the before and after measurements at Site 1 is displayed in Figure 1. The greatest differences between the before and after measurements at Site 1 occur in the higher frequencies, especially those at or greater than 1000 Hz. These differences are displayed separately in Figure 2 where the greatest reduction, 4.8 dB, occurred in the one-third octave frequency band centered at 2 kHz. There seems to be a transition in the effectiveness of the diamond grinding in the lower frequencies, as evidenced by the alternating positive and negative differences in the lower frequencies. The presence of this transition suggests that the effect of longitudinal grooves in concrete pavement is similar to transverse grooves at these frequencies.

The one-third octave frequency band data for Site 5 is displayed in Figure 3. As stated above, Site 5 had the greatest traffic noise level reduction due to the diamond grinding. Not only was there a greater difference in levels for the higher frequency bands at Site 5 than those measured for Site 1, but also there were observed differences in noise levels, even as low as 125 Hz. These differences are displayed separately in Figure 4, where the greatest reduction, 5.7 dB, occurred in the one-third octave frequency bands centered at 1.6 kHz and 2 kHz. As observed for Site 1, there seems to be a transition in the effectiveness of the diamond grinding in the lowest frequencies, as evidenced by the alternating positive and negative differences.

While Site 1 represents the smallest, and Site 5 the greatest reduction in traffic noise levels for the 7.5 m (24.6 ft) and 15 m (49.2 ft) measurement locations, it is the mean values of all the measurement sites that provide the best estimate of the expected benefit of diamond grinding if one were to measure at an arbitrary site in the project area. To obtain this estimate the measured values for each one-third octave frequency band were averaged for all sites, for both the 7.5 m (24.6 ft) and the 15 m (49.2 ft) microphone positions. The results are shown in Figure 5 and Figure 6.

Most of the observed noise level reduction due to the diamond grinding appears to occur at frequency bands greater than 160 Hz, on the average, though the higher frequencies display the greatest differences between before and after levels. These average differences are shown in Figure 7 and Figure 8 for the 7.5 m (24.6 ft) and the 15 m (49.2 ft) microphone positions, respectively. When all of the measurements are considered, the greatest reduction in noise levels, attributed to the diamond grinding, occurs at 2 kHz for the 7.5 m (24.6 ft) microphone positions and at 8 kHz for the 15 m (49.2 ft) microphone positions.

Broadband Results

The differences in before and after broadband traffic noise levels, A-weighted, for the measurements at the 7.5 m (24.6 ft) and 15 m (49.2 ft) microphone positions are shown in Table 1. As stated in the procedure, a suitable location was not available to use a reference microphone to quantify any differences in the traffic noise source between before and after measurements. Instead, a before and after traffic noise model of the I-76 roadway was generated using TNM version 2.5 to predict the differences in the noise source. In this TNM model, the traffic volumes, speeds, and classifications, which were collected from the field measurements, were entered for each lane for a straight and level section of the highway with the same lane geometry as the test sites. The predicted difference between the before and after traffic was simulated at 7.5 m (24.6 ft) and 15 m (49.2 ft). in TNM and should represent the difference in the noise source only (independent of environmental, geometric, and equipment variances). These differences were used to correct the broadband measurements. However, TNM does not currently provide predictions in one-third octave bands. Therefore, the spectral results were not corrected. The uncorrected broadband differences, the TNM corrections, and the corrected differences in before and after broadband microphone levels at each site, are shown in the Table 1 and plotted in Figure 9. The mean broadband noise level difference, attributed to diamond grinding, of 3.5 dB for the 7.5 m (24.6 ft) microphone and 3.1 dB for the 15 m (49.2 ft) microphone is also shown in the Figure 9.

Additionally, broadband measurements were made in the area of complaints by distant receivers (approximately 800 m from the roadway). However, after spectral analysis, it was determined that varying environmental conditions (meteorological and excessive nearby community noise) had too great an effect on the measurements, and thus the results were not valid.

CONCLUSIONS

The analysis of the traffic noise measurements made before and after retexturing the Portland cement concrete pavement to change the random transverse grooves to longitudinal grooves resulted in the following findings:

1. The reduction in broadband noise at the 7.5 m (24.6 ft) distance from the centerline of the near travel lane ranged from 3.2 dB to 4.2 dB, while the range for the 15 m (49.2 ft) distance was 2.0 dB to 4.9 dB.

2. The average reduction in broadband noise for 4 test sites at 7.5 m (24.6 ft) from the center of the near travel lane was 3.5 dB, and the average reduction for the 15m location for 5 sites was 3.1 dB.

3. Spectrum analysis showed the greatest reduction in noise occurred at frequencies above 1 kHz and that the retexturing had little to no effect on frequencies less than 200 Hz.

Based on these conclusions, diamond grinding is an alternative that should be considered where there are concerns about traffic noise levels at sites with random transverse tined concrete pavement. It is an effective mitigation strategy providing an expected overall average noise level reduction of 3 dB or more for receivers located adjacent to the roadway.

ACKNOWLEDGMENT

This research was sponsored by the Ohio Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

REFERENCES

1. Sandberg, U. Noise and the Road - Is There a Conflict Between Requirements for Safety and Noise? *Journal of Ingenieurs De L' Automobile*. Society Des Ingenieurs De L' Automobile, Paris. Jan-Feb, 1987.

2. Sandberg, U. Characterization of Road Surfaces with Respect to Tire Noise. *Proceedings of the International Tire Noise Conference*, Stockolm, The National Swedish Board for Technical Development, Stockholm. 1979.

3. Sommer, H. Reduction of Rolling Noise on Concrete Road Surfaces - Final Report. *Proceedings of a PIARC Workshop*. Vienna, Austria. 1992.

4. Herman, Lloyd A., Matt J. Ambroziak, and Elvin Pinckney. Investigation of Tire-Road Noise Levels for Ohio Pavement Types. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1702*, TRB, National Research Council, Washington, D.C., 2000, p.57-62.

5. Herman, L and M. Ambroziak. *Effects of Pavement Type on Traffic Noise Levels*. Publication FHWA-OH-99-012. FHWA, U.S. Department of Transportation, 1999.

6. Sandberg, U. *Study of the Tire/Road Noise Generation and Measurement-State-of-the-Art Supplement.* Publication VTI NOTAT TF 52-09. Swedish Road and Traffic Research Institute. Linkoping, 1992.

7. Henderson, M. and S. Kalevela. *A Comparison of Traffic Noise from Asphalt Rubber Asphalt Concrete Friction Courses (ARACFC) and Portland Cement Concrete Pavements (PCCP).* Publication FHWA-AZ96-433. FHWA, U.S. Department of Transportation, 1996.

8. Lee, C. S., and G. G. Fleming. *Measurement of Highway-Related Noise*. Publication FHWA-PO-96-046. FHWA, U.S. Department of Transportation, 1996.

9. International Organization for Standardization. *Method for Measuring the Influence of Road Surfaces on Traffic Noise: "The Statistical Pass-by Method"*. ISO/01S 11819-1. Delft, Netherlands: ISO/TC43/SC 1/WG 33 N 63. 1997.

10. Menge, Christopher W., et. al. *FHWA Traffic Noise Model – Technical Manual*. Publication DOT-VNTSC-FHA-98-2/FHWA-PD-96-010. FHWA, U.S. Department of Transportation, 1998.

Table Title:

TABLE 1: The Differences in Before and After Broadband Traffic Noise Levels, A-weighted, for the Measurements at the 7.5 m (24.6 ft) and 15 m (49.2 ft) Microphone Locations with TNM Corrections.

Figure Captions:

Figure 1: The equivalent continuous sound level, A-weighted, by 1/3 octave frequency bands, measured before and after diamond grinding for the 7.5 m (24.6 ft) microphone location at Site 1.

Figure 2: The difference in equivalent continuous sound levels due to diamond grinding, A-weighted, by 1/3 octave frequency bands, for the 7.5 m (24.6 ft) microphone location at Site 1.

Figure 3: The equivalent continuous sound level, A-weighted, by 1/3 octave frequency bands, measured before and after diamond grinding for the 7.5 m (24.6 ft) microphone location at Site 5.

Figure 4: The difference in the equivalent continuous sound level due to diamond grinding, A-weighted by 1/3 octave frequency band, for the 7.5 m (24.6 ft) microphone location at Site 5.

Figure 5: Average equivalent continuous sound level of all sites, A-weighted, by 1/3 octave frequency bands, for the 7.5 m (24.6 ft) microphone location.

Figure 6: Average equivalent continuous sound level of all sites, A-weighted, by 1/3 octave frequency bands, for the 15 m (49.2 ft) microphone location.

Figure 7: Average equivalent continuous sound level difference of all sites, A-weighted, by 1/3 octave frequency bands, for the 7.5 m (24.6 ft) microphone location.

Figure 8: Average equivalent continuous sound level difference of all sites, A-weighted by 1/3 octave frequency bands, at the 15 m (49.2 ft) microphone location.

Figure 9: The differences in before and after broadband traffic noise levels, A-weighted, for the measurements at the 7.5 m (24.6 ft) and 15 m (49.2 ft) microphone locations with TNM corrections.

TABLE 1

	Sound Level (dB)	
	7.5m	15m
Site 1		
Before…………………	85.5	81.1
After……………………	82.8	78.7
Difference…………….	-2.7	-2.4
TNM Correction……….	0.6	0.6
Corrected Difference….	-3.3	-3.0
Site 2		
Before…………………	85.5	81.1
After……………………	81.7	77.8
Difference…………….	-3.8	-3.3
TNM Correction……….	-0.6	-0.8
Corrected Difference….	-3.2	-2.5
Site 3		
Before…………………	x	82.7
After……………………	x	79.8
Difference…………….	x	-2.9
TNM Correction……….	x	0.0
Corrected Difference….	x	-2.9
Site 4		
Before…………………	86.9	81.8
After……………………	82.8	78.9
Difference…………….	-4.1	-2.8
TNM Correction……….	-0.7	-0.8
Corrected Difference….	-3.4	-2.0
Site 5		
Before…………………	86.5	82.9
After……………………	81.9	78.4
Difference…………….	-4.6	-4.5
TNM Correction……….	-0.4	-0.4
Corrected Difference….	-4.2	-4.9

Figure 1

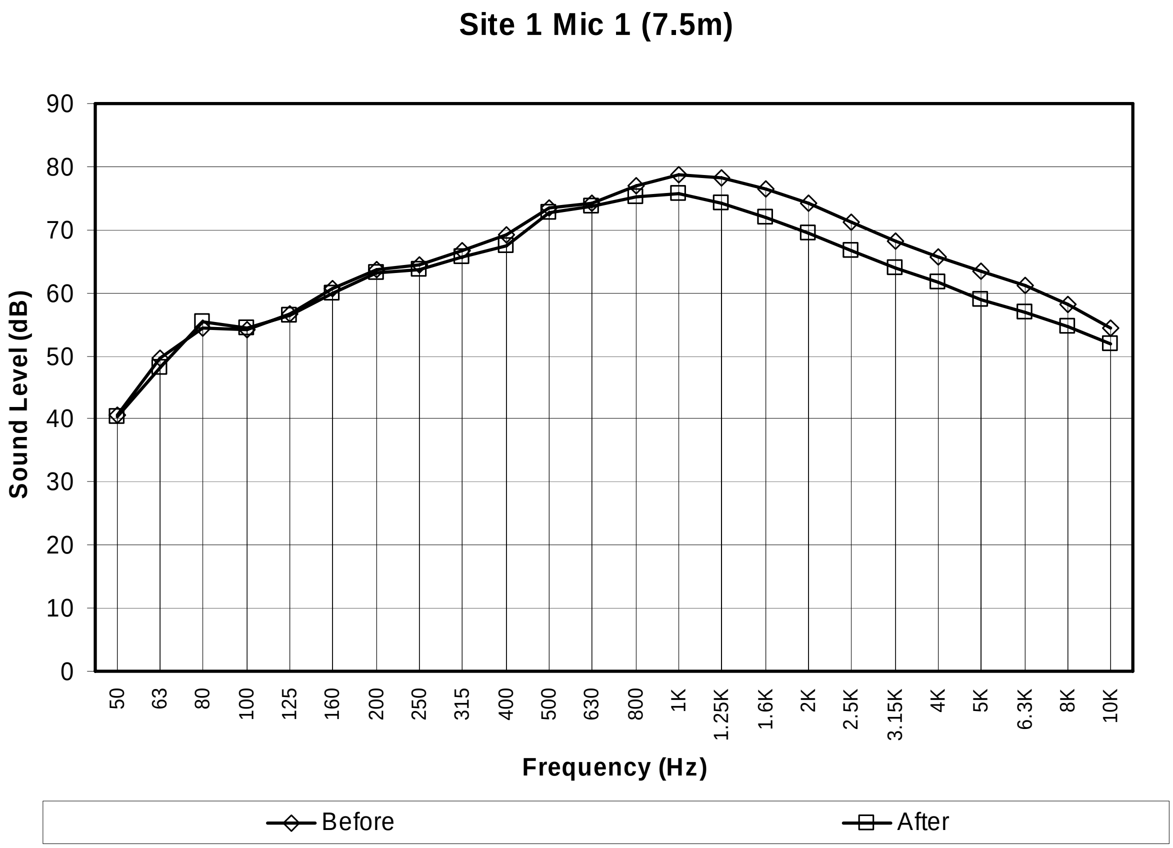

Site 1 Mic 1 (7.5m)
Sound Level (dB)
0
10
20
30
40
50
60
70
80
90
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
Frequency (Hz)
Before
After

Figure 2

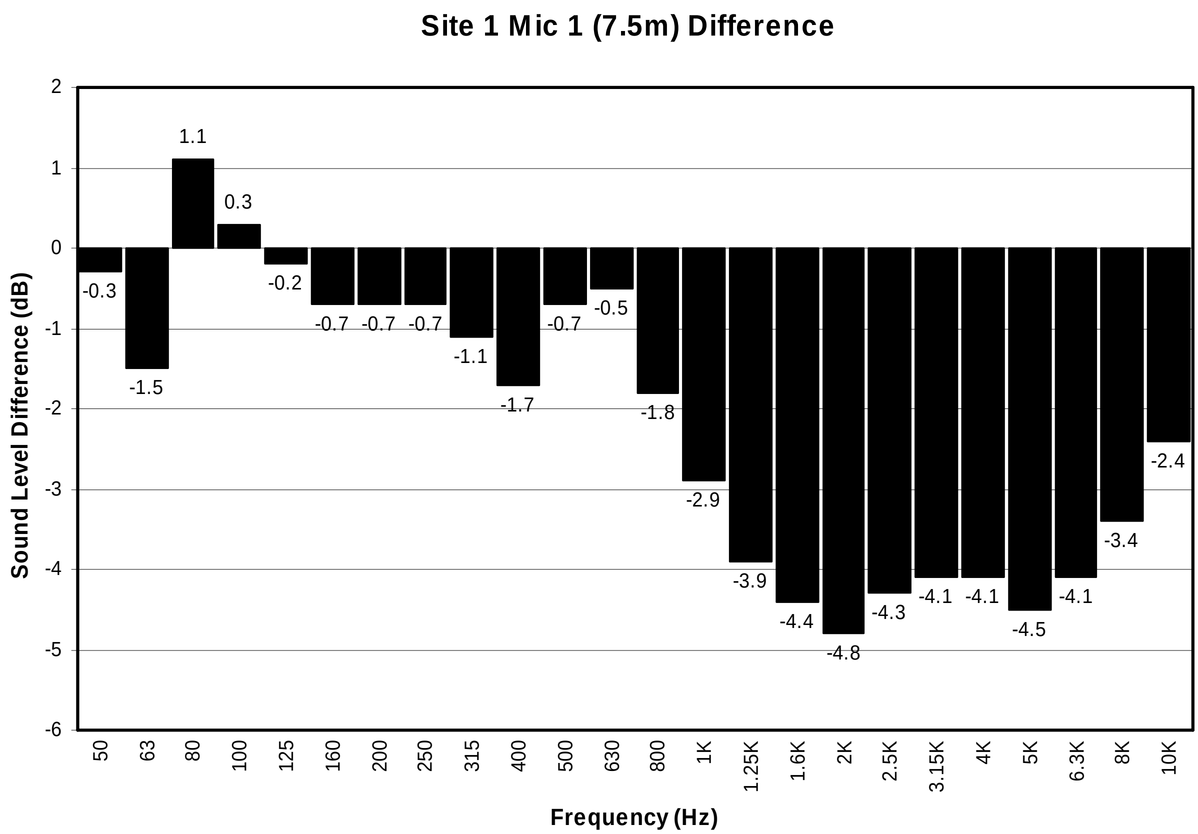

Site 1 Mic 1 (7.5m) Difference
Sound Level Difference (dB)
Frequency (Hz)
2
1
0
-1
-2
-3
-4
-5
-6
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
-0.3
-1.5
1.1
0.3
-0.2
-0.7
-0.7
-0.7
-1.1
-1.7
-0.7
-0.5
-1.8
-2.9
-3.9
-4.4
-4.8
-4.3
-4.1
-4.1
-4.5
-4.1
-3.4
-2.4

Figure 3

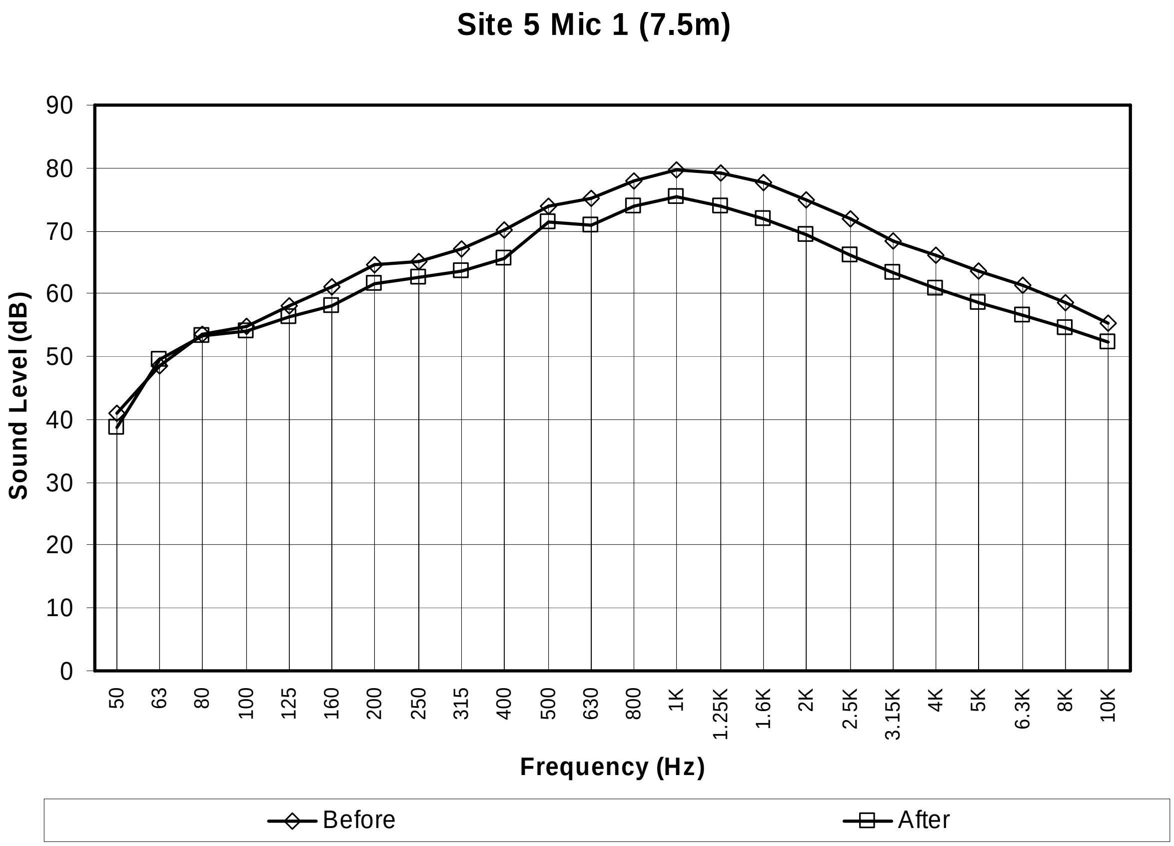

Site 5 Mic 1 (7.5m)
Sound Level (dB)
0
10
20
30
40
50
60
70
80
90
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
Frequency (Hz)
Before
After

Figure 4

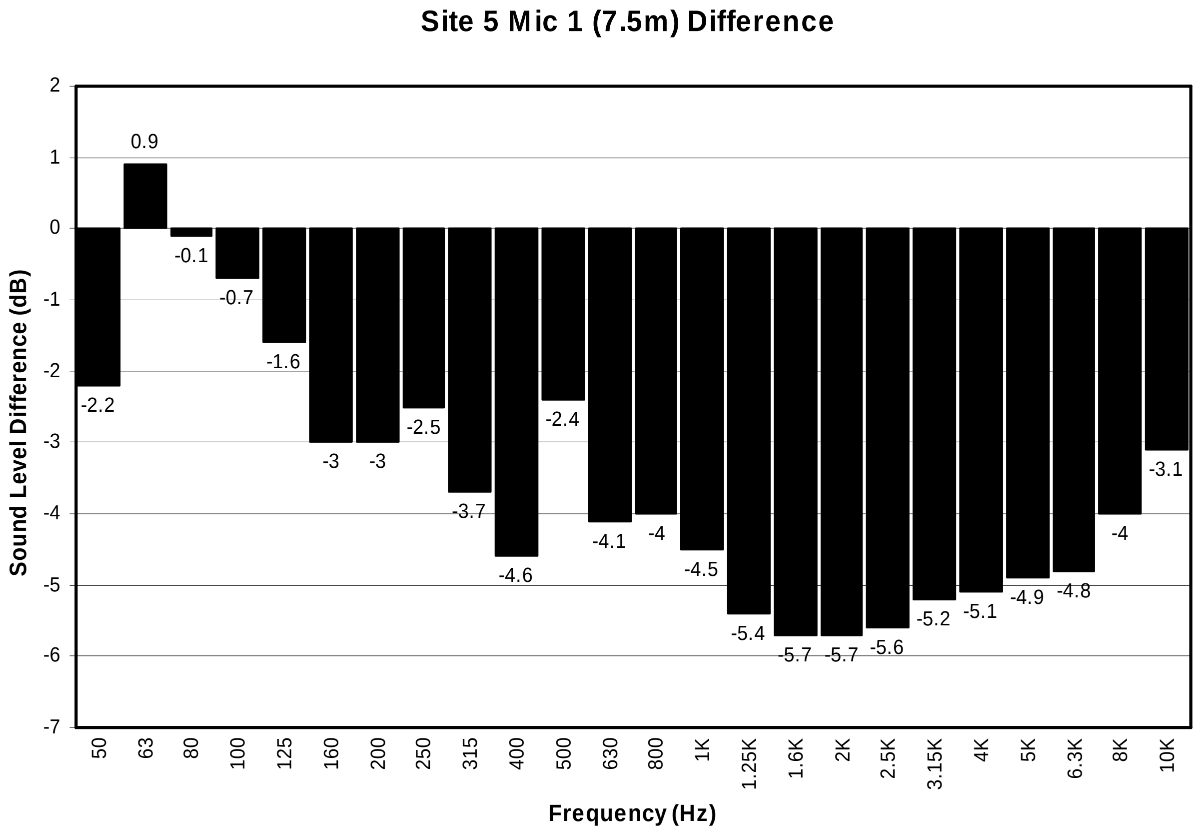

Site 5 Mic 1 (7.5m) Difference
Sound Level Difference (dB)
Frequency (Hz)
2
1
0
-1
-2
-3
-4
-5
-6
-7
0.9
-0.1
-0.7
-1.6
-2.2
-3
-3
-2.5
-3.7
-4.6
-2.4
-4.1
-4
-4.5
-5.4
-5.7
-5.7
-5.6
-5.2
-5.1
-4.9
-4.8
-4
-3.1
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K

Figure 5

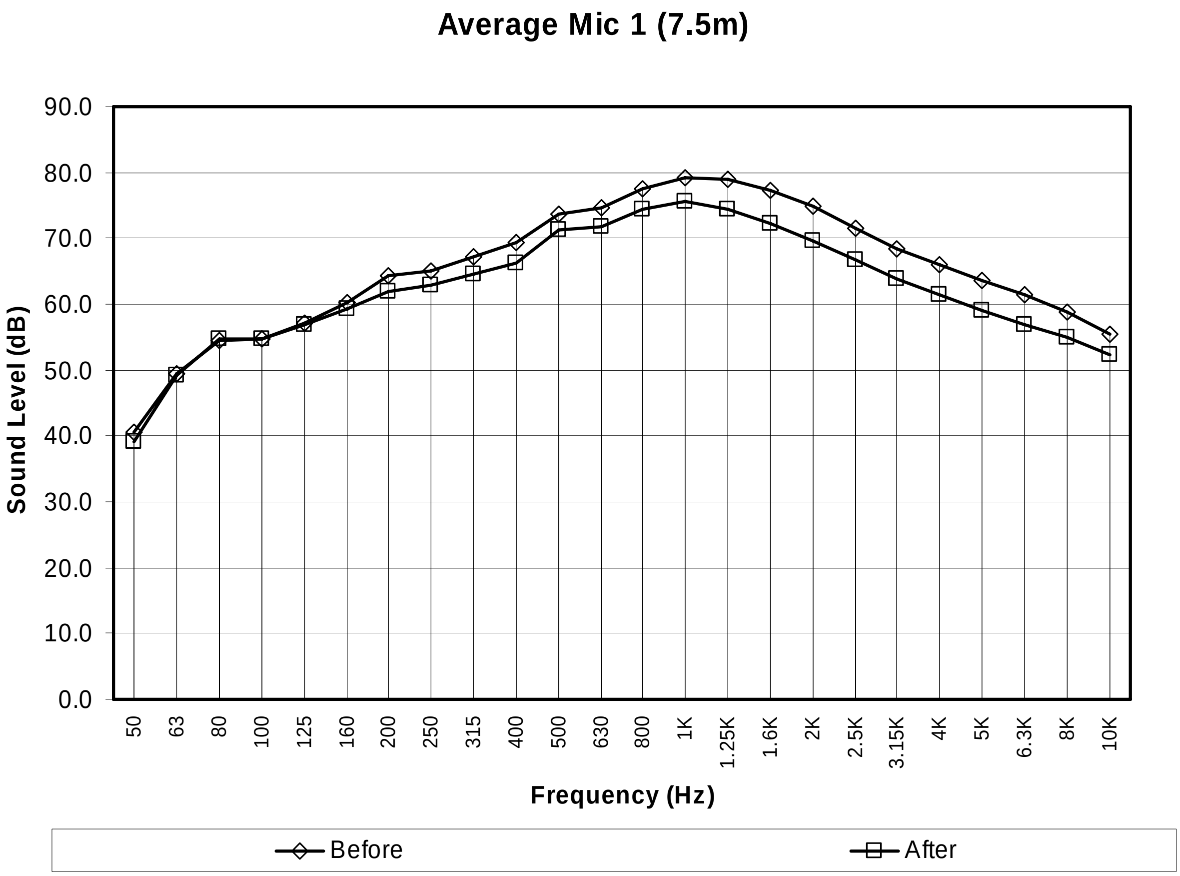

Average Mic 1 (7.5m)
Sound Level (dB)
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
Frequency (Hz)
Before
After

Figure 6

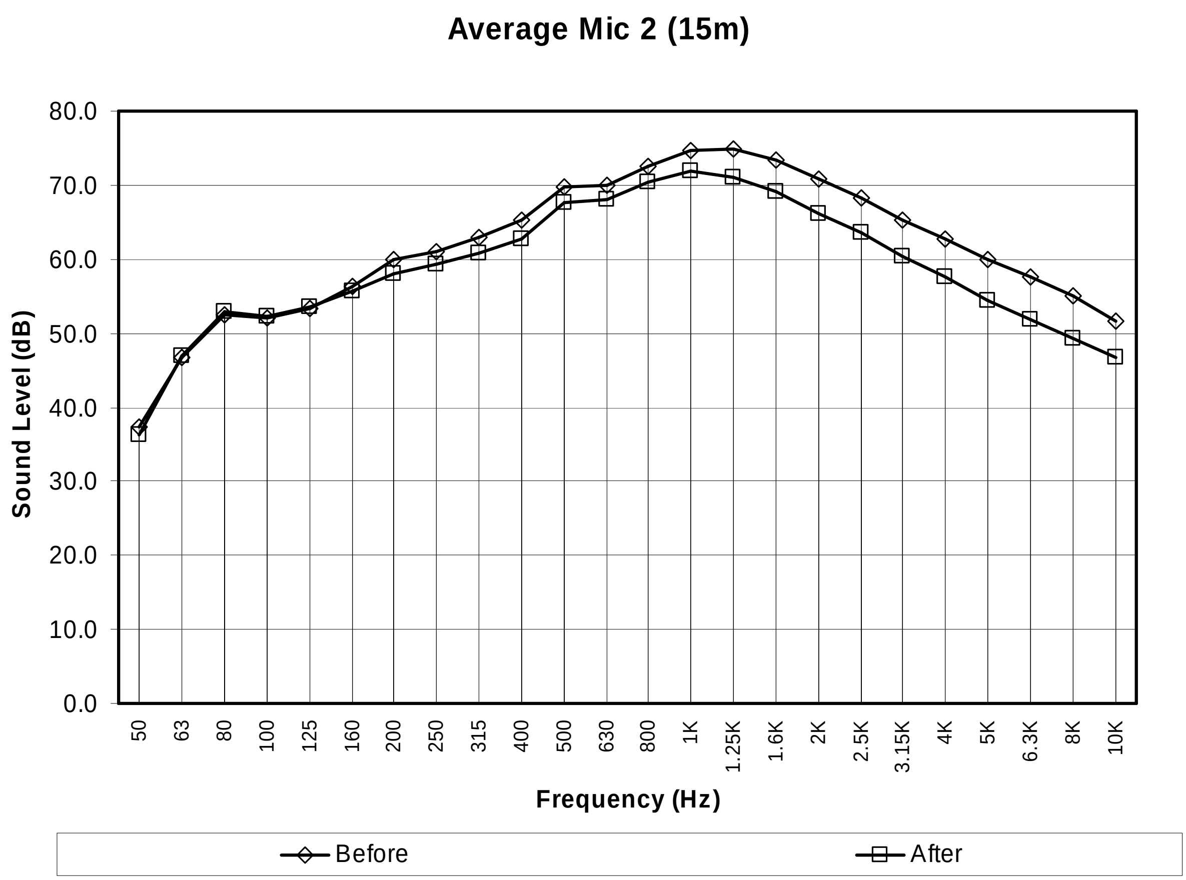

Average Mic 2 (15m)
Sound Level (dB)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
Frequency (Hz)
Before
After

Figure 7

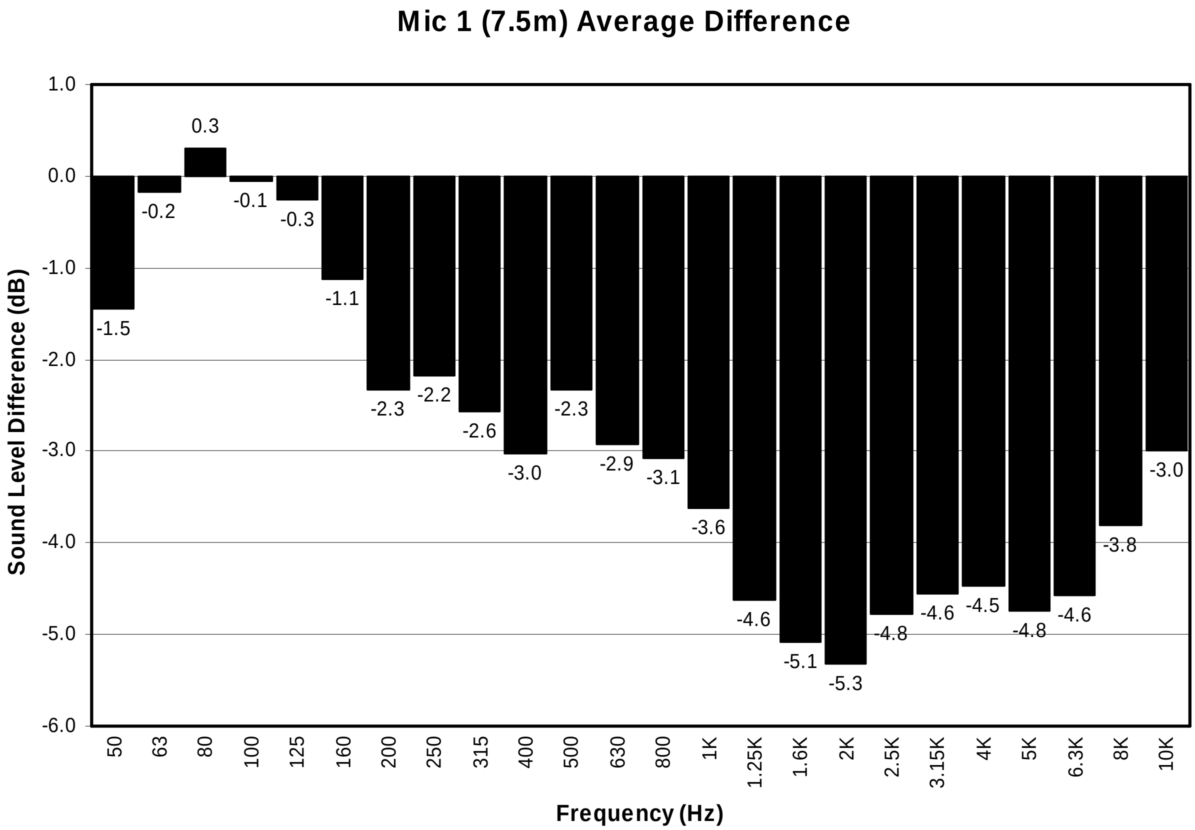

Mic 1 (7.5m) Average Difference
Sound Level Difference (dB)
Frequency (Hz)
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
-1.5
-0.2
0.3
-0.1
-0.3
-1.1
-2.3
-2.2
-2.6
-3.0
-2.3
-2.9
-3.1
-3.6
-4.6
-5.1
-5.3
-4.8
-4.6
-4.5
-4.8
-4.6
-3.8
-3.0

Figure 8

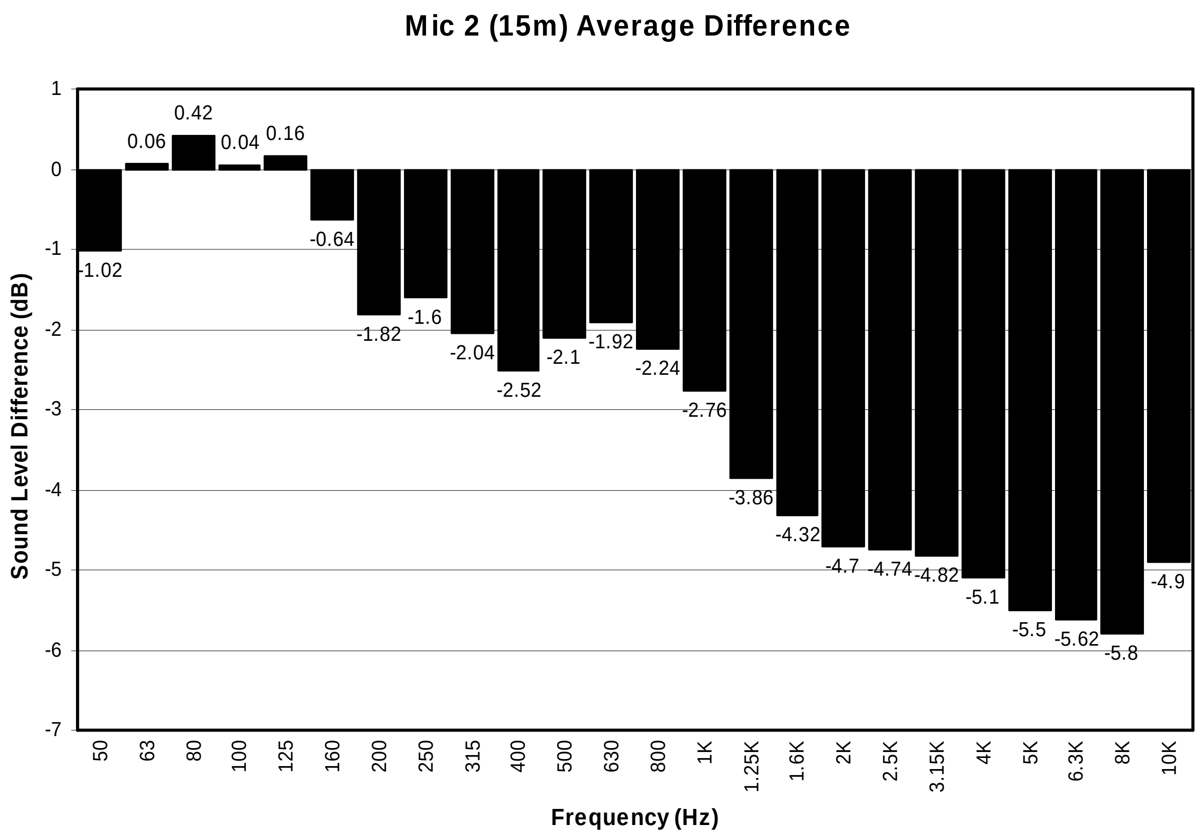
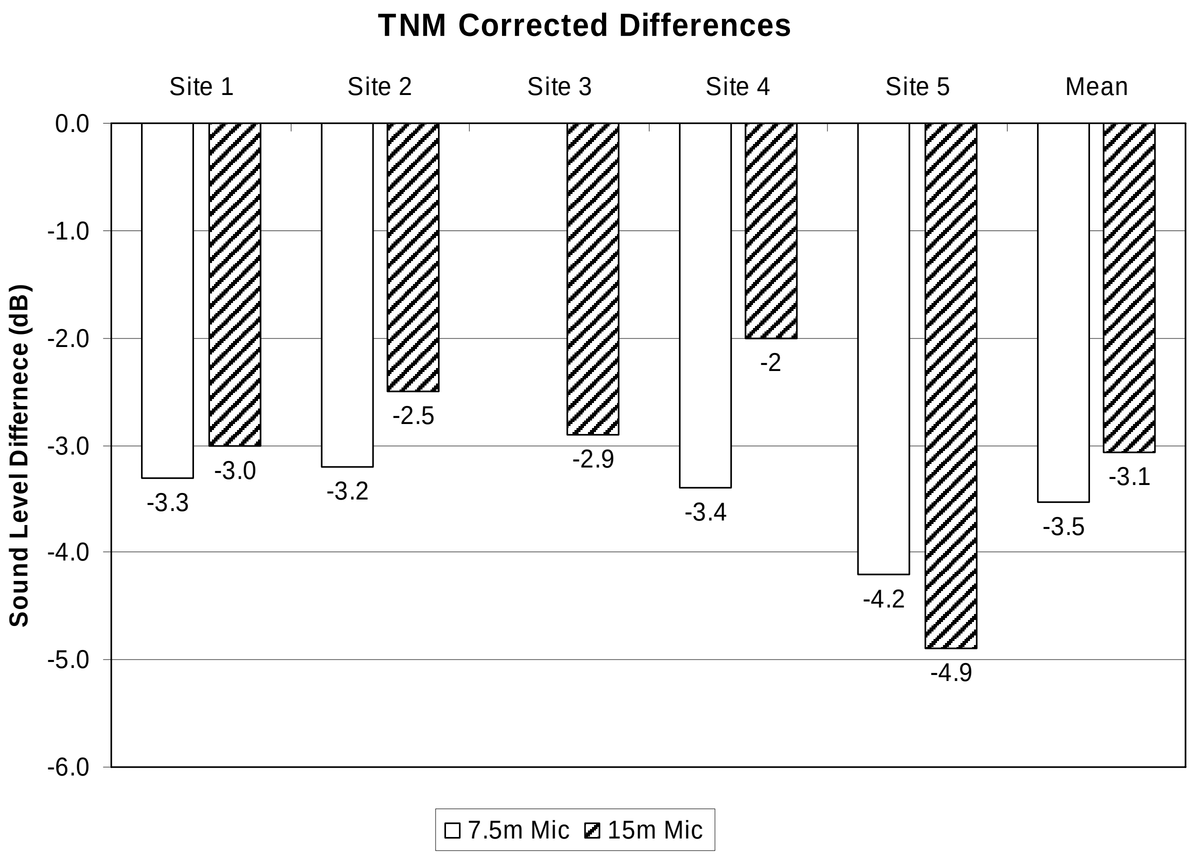

Mic 2 (15m) Average Difference
Sound Level Difference (dB)
Frequency (Hz)
1
0
-1
-2
-3
-4
-5
-6
-7
50
63
80
100
125
160
200
250
315
400
500
630
800
1K
1.25K
1.6K
2K
2.5K
3.15K
4K
5K
6.3K
8K
10K
-1.02
0.06
0.42
0.04
0.16
-0.64
-1.82
-1.6
-2.04
-2.52
-2.1
-1.92
-2.24
-2.76
-3.86
-4.32
-4.7
-4.74
-4.82
-5.1
-5.5
-5.62
-5.8
-4.9

Figure 9


TNM Corrected Differences
Site 1
Site 2
Site 3
Site 4
Site 5
Mean
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
-6.0
Sound Level Differnece (dB)
-3.3
-3.0
-3.2
-2.5
-2.9
-3.4
-2
-4.2
-4.9
-3.5
-3.1
7.5m Mic
15m Mic