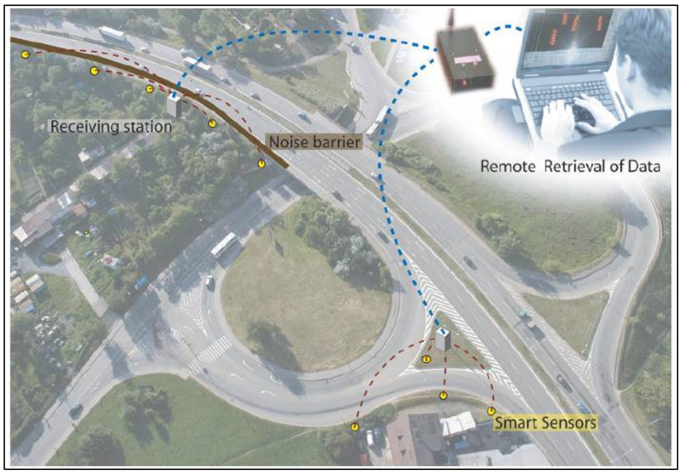
Smart Sensor For Autonomous noise Monitoring (SSAM) Final Report



Douglas Meegan
Paul Waters
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for the

Ohio Department of Transportation
Office of Research and Development

and the

National Cooperative Highway Research Program (NCHRP)
Innovations Deserving Exploratory Analysis (IDEA) Program

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16. Abstract

This project involved the development of a cost-effective sensor for long-range wireless, autonomous traffic noise monitoring. The device is called the Smart Sensor For Autonomous noise Monitoring (SSAM). The SSAM system developed under this project includes ten prototype sensors that measure and report noise levels periodically (e.g., once per minute) to a prototype base station that may be located up to 1.2 miles away. The data reported by SSAM includes flat-weighted and A-weighted sound pressure levels as well as octave band measurements over the frequency range of 22 to 5657 Hz. The system performance is similar to a Type 1 microphone as demonstrated in laboratory calibration tests reported here. The SSAM system developed in this project has been used to measure highway noise barrier insertion loss. The low-cost design of SSAM as well as the ability to perform autonomous measurements provides a new cost-effective approach to noise monitoring.

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Prepared in cooperation with the Ohio Department of Transportation and the
U.S. Department of Transportation, Federal Highway Administration

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

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1. INTRODUCTION

Transportation noise has become a major source of environmental pollution. Homeowners and businesses located near major highway corridors and airports have become intolerant of traffic-related noise, prompting transportation agencies to install noise barriers, develop quite pavement technologies, and closely scrutinize plans for infrastructure construction. To establish existing noise levels and evaluate the true impact of roadway or airport modifications, it is necessary to measure and monitor the associated noise carefully and understand the sources and propagation of noise.

The typical methods of assessing highway traffic noise include wayside measurements and near field measurements (NFM). A significant disadvantage of existing wayside measurement techniques is that they cannot be used to conduct noise measurements at multiple locations or over extended time periods due to cost and logistical considerations. NFM methods such as close proximity (CPX) and onboard sound intensity (OBSI) have been developed to overcome these limitations. While these methods provide cost-effective measurement of the tire-pavement noise source (which is the dominant source at highway speeds), they do not provide the information needed to understand other noise sources or noise propagation into the communities surrounding highways and roads.

On the aviation side, airport noise monitoring also typically relies on a limited set of noise measurement stations spread over large areas. For example, the Denver International Airport uses permanent and portable noise monitors to measure noise levels at about 30 locations. Although the data gathered at these stations is impressive, the actual noise contours are determined through modeling. Thousands of noise measurement stations would be required to accurately determine the true noise contours. Unfortunately, the expense of current noise monitoring technology prohibits measurements at a large number of locations.

There is a need for new technologies that will facilitate cost-effective noise measurement and monitoring in multiple scenarios and at multiple locations over extended periods of time. This will allow transportation and other agencies to gain a deeper understanding of noise sources and noise propagation and will aid their decision making with regard to mitigation or enforcement. A more cost-effective approach to noise measurement would also provide the data needed to refine noise models such as the Federal Highway Administration (FHWA) Traffic

Noise Model (TNM) or the Federal Aviation Administration (FAA) Integrated Noise Model (INM).

2. RESEARCH OBJECTIVE

A new approach to noise measurement and monitoring was developed here. As illustrated in Figure 1, the new approach provides simultaneous noise measurements at tens, hundreds, or thousands of points along extended lengths of highways and/or neighboring communities in a cost-effective manner—in other words, more data at a fraction of the cost. This is accomplished by distributing small, inexpensive wireless smart sensors at positions of interest. Each of these sensors, referred to as Smart Sensor for Autonomous Noise Monitoring (SSAM), incorporates a microphone and related microelectronics that analyzes the data in real-time to provide the desired noise related metrics. During their operation, each sensor is periodically (e.g., once per minute) reports the noise metrics to a central receiving station via a long-range wireless connection. The central receiving station generates data files containing noise time histories and a graphical map display indicating the level of noise at the sensor location in real time. The data generated by the central receiving station can be uploaded to a secure website for increased accessibility and data mobility. The uploaded data can be visualized as a function of time using the user's post-processing technique of choice [e.g., Geographical Information Systems (GIS) maps] providing a wealth of information addressing the intended purpose of the sensor deployment, e.g., identifying noise hot-spots or enforcement needs.

The objective of the work reported here was to design, fabricate and test a set of prototype SSAM devices and successfully demonstrate their use and advantages as compared to existing methods of traffic noise monitoring. While the technology has numerous potential applications, particular attention has been paid to specific traffic noise tests of interest to Ohio Department of Transportation, including traffic noise barrier insertion loss.

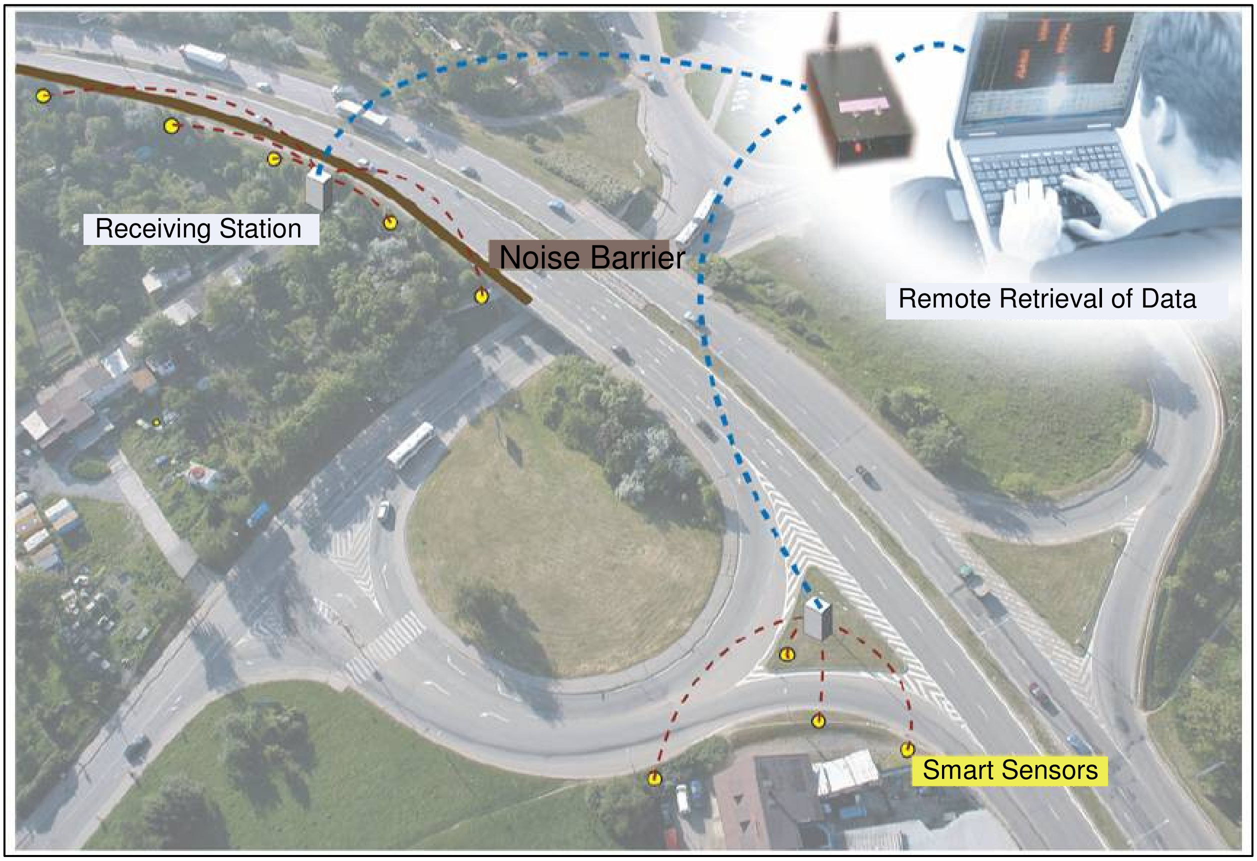

Figure 1: General concept of SSAM for wireless monitoring of traffic noise and evaluation of noise barrier performance.

3. GENERAL DESCRIPTION OF RESEARCH

3.1. BACKGROUND AND SIGNIFICANCE OF WORK

The development of SSAM began by leveraging a related acoustic sensor technology that Applied Research Associates, Inc. (ARA) recently developed for a Department of Defense (DoD) application under a multi-million dollar effort (DAAB07-01-D-G601 and ARA internal research and development funds). The DoD acoustic sensor is water resistant, and includes an integrated wind screen, calibrated microphone, microprocessor, and wireless communication in a small, inexpensive handheld package. The acoustic sensor is designed around commercial off-the-shelf (COTS) hardware in an effort to minimize costs when manufactured in large quantities. Several novel technologies are incorporated in the sensor. For example, the microphone element is a COTS hearing aid element that has frequency-response characteristics similar to research grade microphones, at a fraction of their cost. An on-board microprocessor performs customized real-time analysis of the incoming acoustic data stream. The device was designed to be inexpensive in large quantities, provide customized acoustic data according to the application, operate for an extended period of time with little maintenance, and communicate information wirelessly using a simple and intuitive software interface.

Using this prior technology as inspiration for the development of SSAM has allowed the team at ARA to efficiently develop a technology to fit the needs of the transportation agencies, specifically with regards to traffic noise monitoring. Like the prior technology, SSAM is based on low-cost components, on board microprocessing, and wireless data transfer. Unlike the prior technology SSAM was developed here to accommodate precision calibration and use for ANSI standard noise measurements such as traffic noise barrier insertion loss.

Prior to the development of SSAM, a literature review was performed to characterize the current technology used to study transportation noise and identify needs for advancement in the field. The results of a literature review on this subject revealed numerous studies related to the noise generated at the pavement/tire interface for various pavement types, surface textures, and their impact on surrounding communities and businesses. The literature also revealed several studies on engine noise emissions generated by aircraft (noise contours) in the vicinity of the airports and noise produced by trains and railroad tracks. Generally speaking, none of the technologies revealed in the literature review resembled the unique state-of-the-art device capabilities of SSAM. In particular, none of the technologies allows for a low cost, high fidelity, long term evaluation of noise levels over as large a geographical area.

3.2. DESIGN AND FABRICATION OF SSAM

The development of SSAM involved [1] packaging design (the enclosure), [2] hardware design (microelectronics, wireless connectivity, microphone selection and housing), and [3] software design (embedded microprocessor in the sensor and graphical interface and data processing on the base station). The specific designs and features are described in the following subsections.

3.2.1. PACKAGING

Three packaging designs were considered for SSAM. The first package design closely resembled common sound level meters including a long microphone boom. A second package design accommodated a large battery pack for testing over extended periods of time (several months). A third package design was intended to be small and inconspicuous. After review by several transportation agency personnel, the vast majority choose the small and inconspicuous design because of concerns of theft, vandalism and undesired attention that the other design may attract.

The resulting SSAM package design is shown in Figure 2. The design permits mounting on a tripod as may be required for various ANSI noise tests. The design also accommodates strapping to a telephone pole of sign post for more general noise monitoring. When mounted to a telephone pole, the SSAM's shape and color resemble a common electrical junction box—therefore, SSAM can be deployed in an inconspicuous manner for unattended testing over longer periods of time.

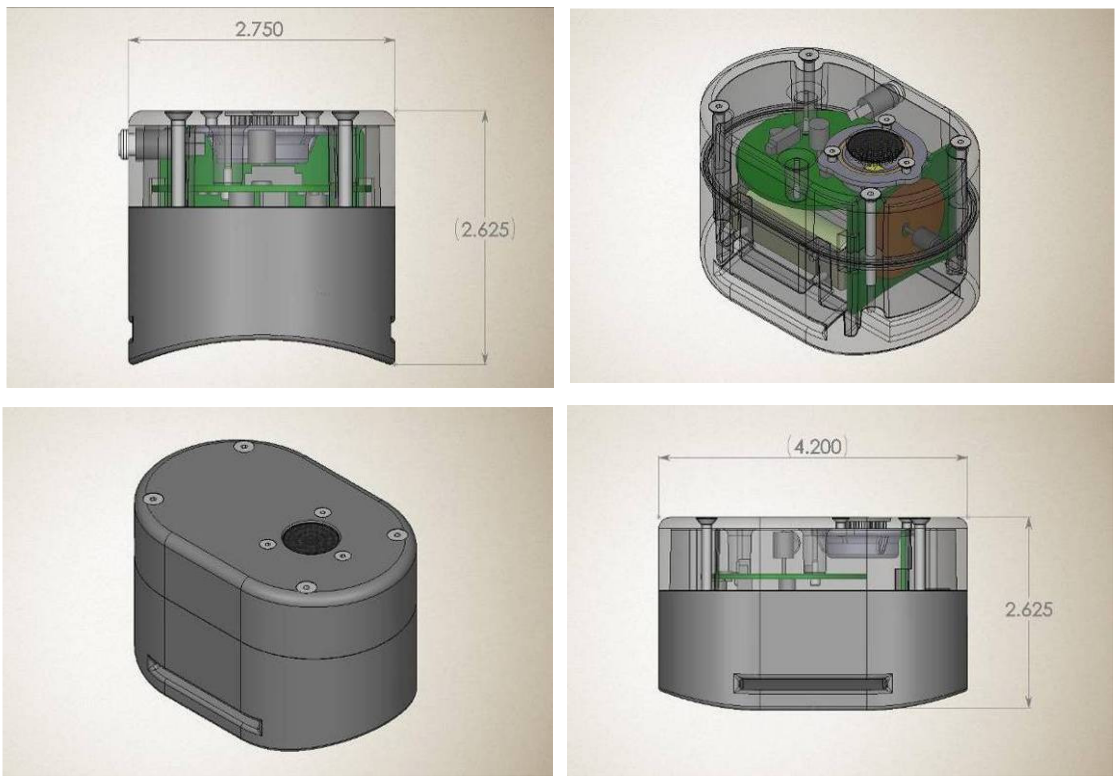

Figure 2: Design of the SSAM packaging for a small and inconspicuous appearance.

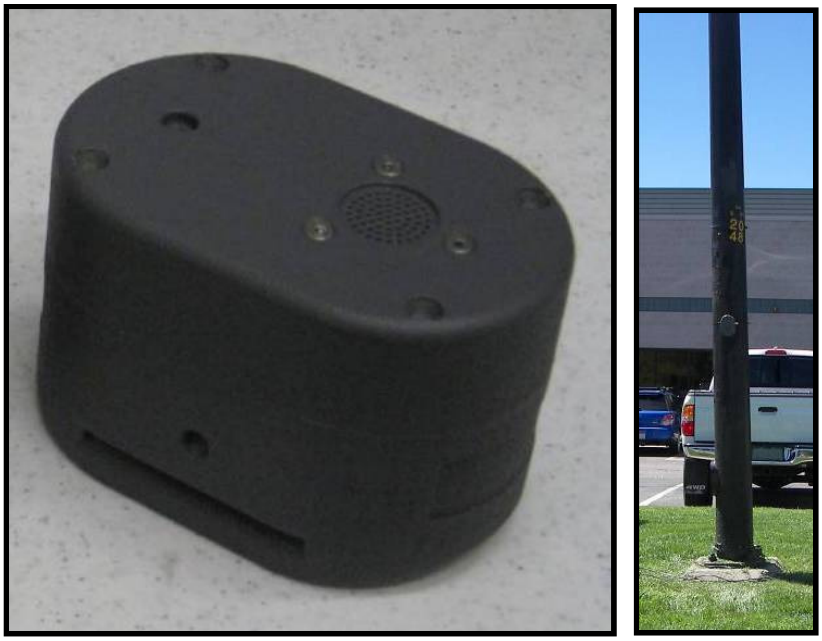

Figure 3: LEFT—water resistant sintered nylon SSAM enclosure. RIGHT—When SSAM is installed on a telephone pole, it is inconspicuous because it resembles a common electrical junction box.

The SSAM packaging was fabricated by a sintered nylon rapid prototyping method. The resulting package is very strong and durable (sintered nylon retains at least 90% the strength of injection molded nylon). A photograph of a SSAM package is shown in Figure 3 on the left. On the right side of Figure 3, the SSAM has been inconspicuously mounted to a street-light pole.

3.2.2. HARDWARE

The key hardware design challenge in developing SSAM was to achieve high-quality noise measurements while keeping the components costs down as low as possible. The design goals for SSAM included:

- Provide on-board, real-time flat-weighted sound pressure levels (to Type 1 frequency-response specifications)
- Provide on-board, real-time A-weighted sound pressure levels (to Type 1 frequency-response specifications)
- Provide on-board, real-time octave band analysis (to Type 1 bandwidth and roll-off specifications)
- Achieve a large measurement dynamic range (e.g., 40 dB to 120 dB)

- Achieve long range wireless transmission while staying below FCC regulated transition powers
- Permit simultaneous operation of ten or more SSAM units transmitting to a single base station with graphical user interface.

The resulting SSAM design was largely successful in achieving these design goals. A photograph of the final hardware installed in a SSAM enclosure is shown in Figure 4 on the left. The back half of the SSAM packaging contains a battery chassis and the front half of the SSAM packaging contains the microphone enclosure, and two circuit boards that accommodate signal conditioning, pre-amplification (gain), octave band filters, analog-to-digital converters, microprocessor, wireless transmitter, and other components. The specific components and board layout are not discussed here. The batteries can be user-replaced if proper care is taken to avoid damage to the circuit board (see "Appendix A: Operator Manual" for battery replacement instructions).

The SSAM base station consists of a dedicated laptop computer with USB interface to the receiver module and antenna. The base station software is described in the following section of this report.

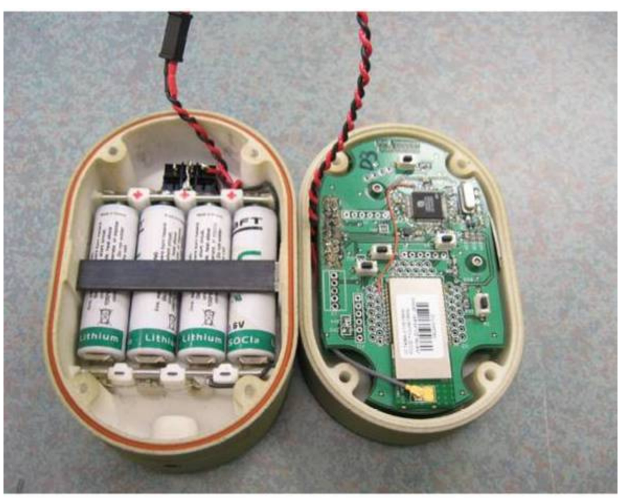

Figure 4: LEFT—Photograph of the hardware installed in the SSAM packaging. The back half of the SSAM packaging contains a battery chassis and the front half of the SSAM packaging contains the microphone enclosure, and two circuit boards. RIGHT—the base station consists of a dedicated laptop computer with USB interface to the receiver module.

3.2.3. SOFTWARE

Software development for the SSAM system consisted of code for the embedded microprocessor in the SSAM sensors plus development of software for the basestation. Features of the software are described in this section. Electronic versions of the software are available to ODOT.[1]

The software that resides on the SSAM sensors is embedded c-code that serves the following functions:

- General system timing controls,
- Establish analog-to-digital conversion rates, programmable amplifier gain settings, frequency of wireless transmissions,
- Digital signal processing including exponential time averages, A-weighting digital filter calculations, and time averages,
- Control of startup calibrations, and wireless transmission of sensor data.

The software that resides on the base station (a Dell Vostra laptop computer) is written in National Instrument's LabVIEW™ software environment. The base station software provides the following functions:

- Provides a graphical user interface to control the SSAM system and data logging,
- Coordinates data logging from up to ten SSAM units via the universal serial bus (USB) interface to the receiver module,
- Provides final signal processing of the data streams to convert data to calibrated units and associated displays,
- Provides graphical display of SSAM data via a map overlay of flat-weighted sound pressure levels,
- Provides graphical display of octave bands at a given sensor location,
- Provides the ability to "play back" a data set to visualize changes in noise characteristic as a function of time.

Figure 5 shows the two main displays from the base station including the map overlay (left) and the octave band analysis (right).

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[1] See limitations as described in the contract.

3.3. LABORATORY TESTING

Following the development of the SSAM system, a series of laboratory tests were performed to verify proper functioning of the hardware and software, to determine the calibrated system parameters required to conform with specifications for sound level meters (ANSI S1.4-1983 and ANSI S1.4a-1985), and to simulate a typical noise barrier test.

3.3.1. FUNCTIONALITY TESTS

A system functionality test of each SSAM sensor was performed to determine:

- noise floor,
- proper functioning of the octave band filters.

Noise Floor:

The noise floor was determined by placing each SSAM unit inside of a sound isolation chamber. The SSAM units are powered on and the receiver station is set up to display raw data transmitted from the SSAM. According to the programmable gain amplifier setting, a relatively consistent noise floor should be observed at the receiver station. The SSAM units were all established as having noise floors less than 40 dB for the typical 100x gain setting.

Microphone and Octave Band Tests:

To verify that each microphone is working and the octave band filters are properly functioning, a tone corresponding to the center frequency of each octave band is generated in the chamber. Proper functionality is demonstrated if the transmitted data shows acoustic energy in the appropriate octave band.

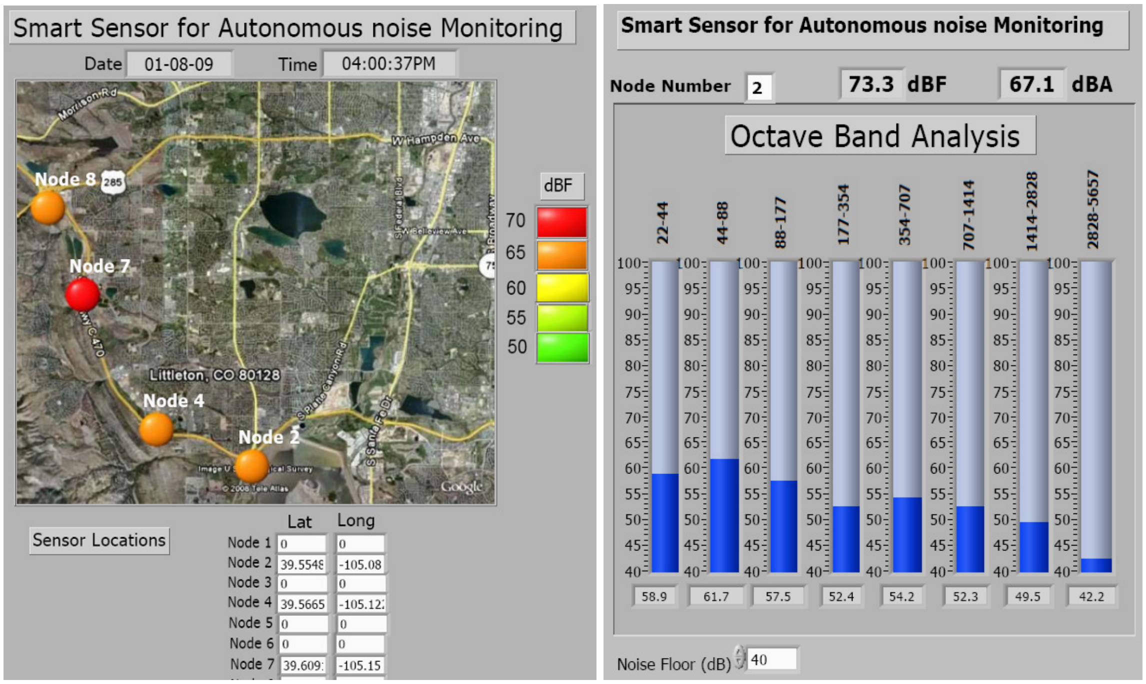

Figure 5: Screenshots from the base station user interface. Left—the main map view showing the location of four deployed SSAM sensors with color coding to indicate flat-weighted sound pressure levels. Right—the data (flat and A-weighted sound pressure levels, octave band levels) from a single SSAM.

3.3.2. CALIBRATION TESTS

Each SSAM unit required an initial test to obtain baseline calibration information and to determine each sensors frequency response. The tests were performed by placing a SSAM unit inside of an anechoic chamber and insonifying the SSAM and a calibrated laboratory microphone over the entire frequency range of operation (22 to 5656 Hz). A photograph if the test arrangement is shown in Figure 6. By normalizing the response of SSAM to the research grade microphone, the SSAM's frequency-response was determined.

The flat-weighted and A-weighted frequency response of a typical SSAM unit is shown in Figure 7. An additional calibration test to determine the performance of each octave band was also completed. The results for these tests are presented in Figure 8.

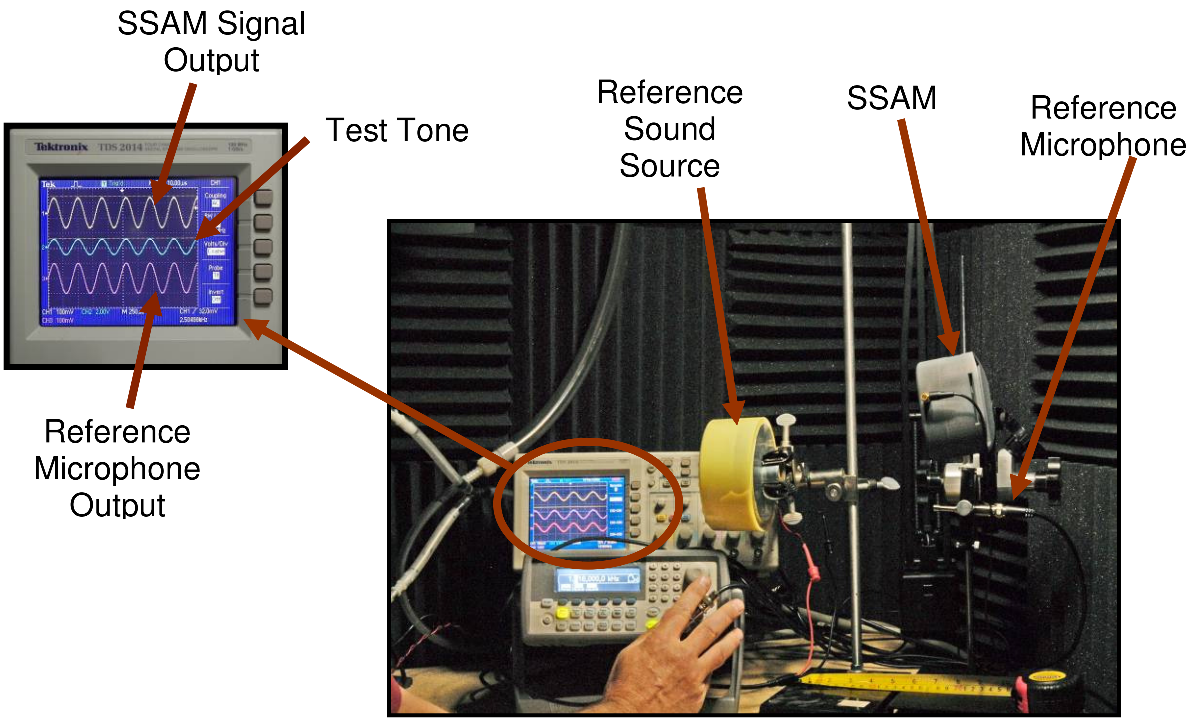

Figure 6: Photograph of laboratory testing and calibration of SSAM.

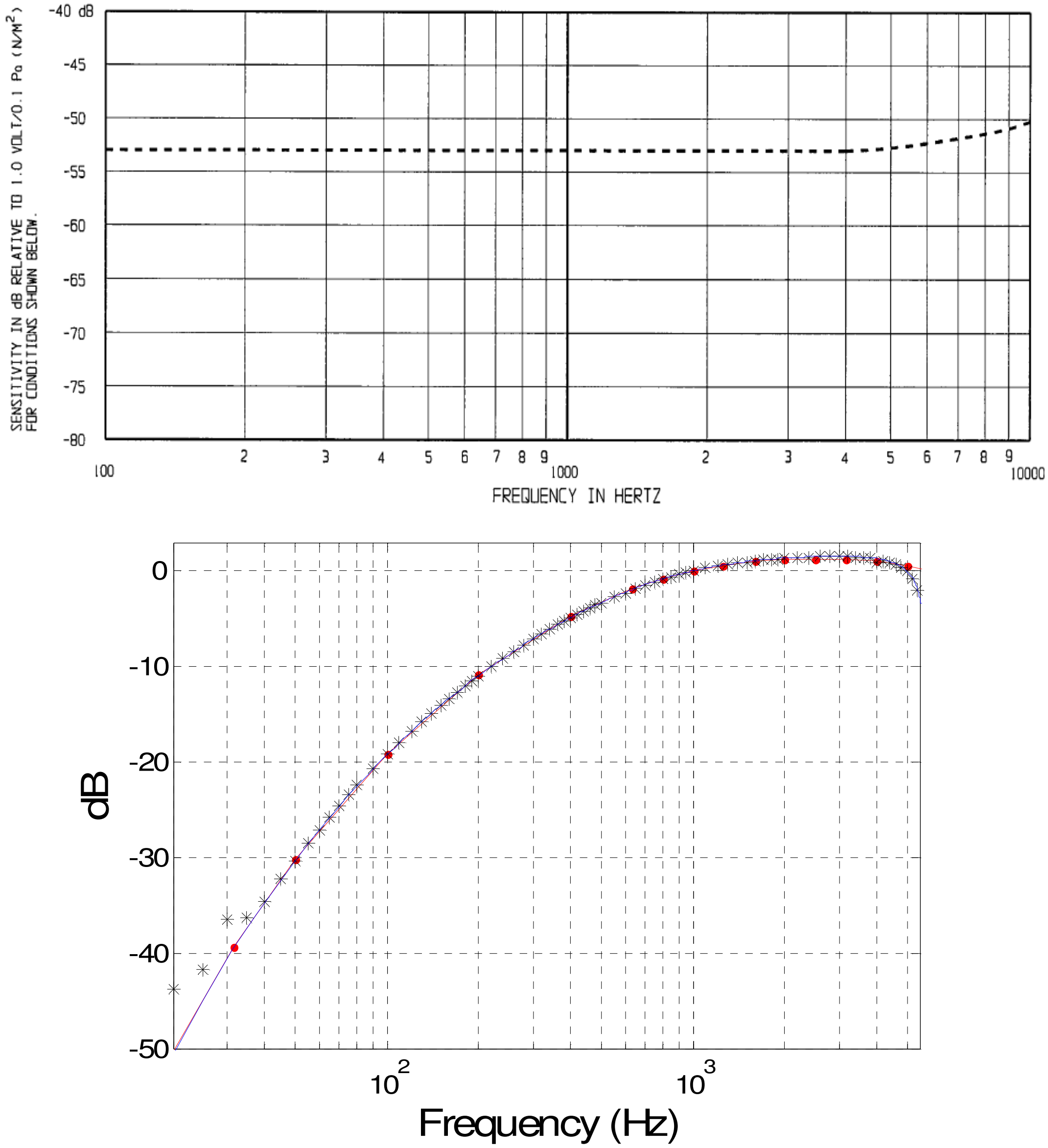

Figure 7: TOP—Flat weighted SSAM frequency response.[2] *BOTTOM—A-weighted SSAM frequency response (blue) compared to the ANSI standard (red circles).*

[2] Manufacturer's measurement (Knowles FG-3629-P16)

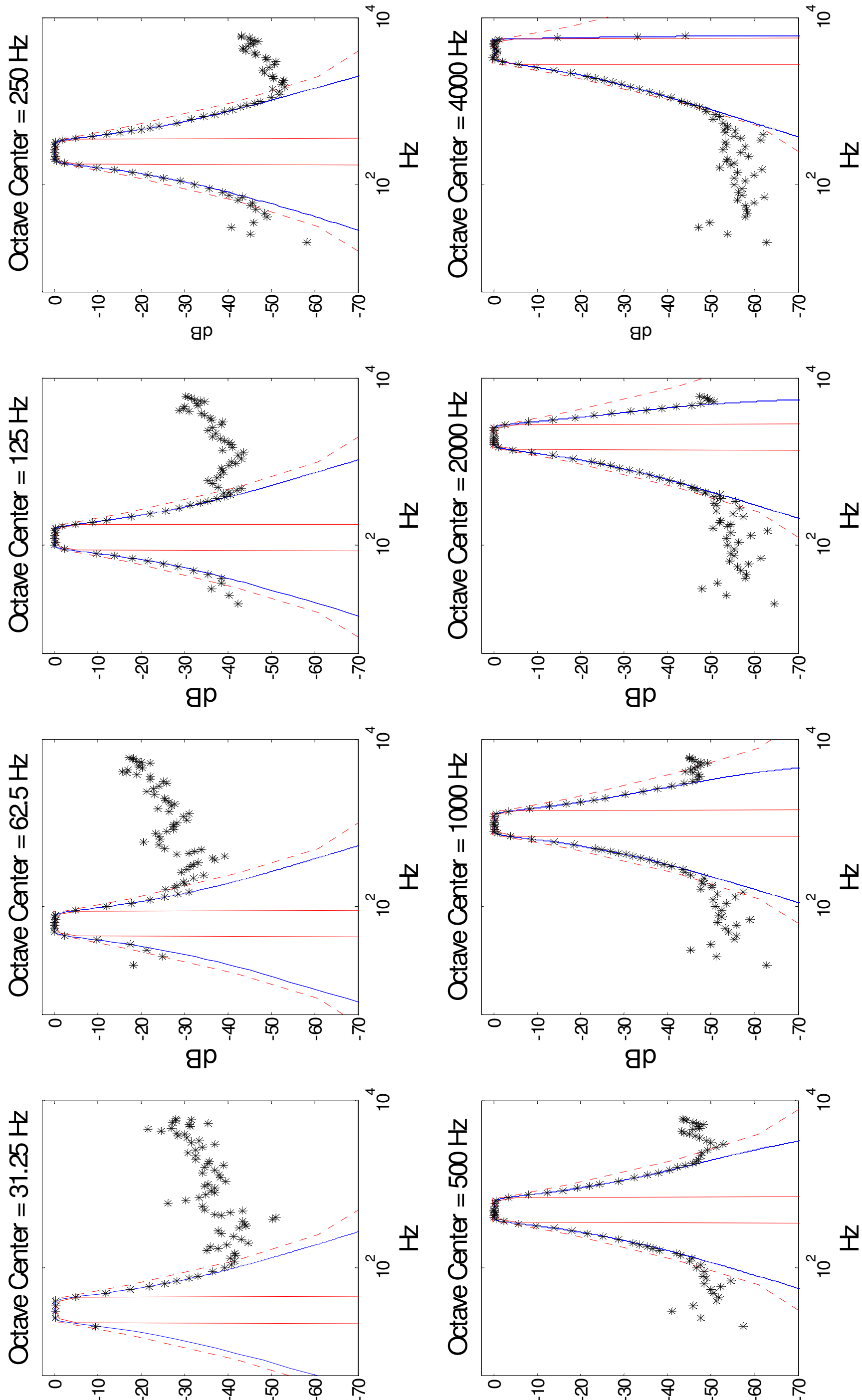

Figure 8: SSAM octave band performance.

4. RESULTS

The prototype SSAM system developed here is ultimately intended for use in traffic and community noise monitoring and testing. This system is to be made available to ODOT at no cost for noise testing. However, the system is the property of ARA and should be returned to ARA when it is not is use in order to facilitate future upgrades and improvements. As a part of this project, the entire system has been packaged into a rugged, waterproof, wheeled case (Pelican™) to facilitate shipping or transport to various test locations. A photograph of the system is shown in Figure 9. The case contains ten SSAM units, the laptop base station, all necessary cables, and replacement batteries. The case does not store the 6' antenna. Details on the operation of the system are described in Appendix A of this report.

In the remainder of this section of the report described various test results that have been performed to validate the performance of the SSAM system and demonstrate its usefulness in various scenarios of interest.

*Figure 9: SSAM system packaged in its storage case. *

4.1. WIRELESS TRANSMISSION RANGE FIELD TESTS

Two range tests were performed to establish the maximum range of wireless transmission. from a SSAM unit to the base station.

The first test was performed along Bradford Rd. in Littleton, Colorado. The test utilized the small receiver antennae that is appropriate for short range wireless noise monitoring when a compact antenna is necessary or desired. The test proved functionality of the SSAM transmitter up to approximately 200 yards.

A second wireless range test was performed at Lookout Mountain in Golden, Colorado utilizing a 6' receiver antennae. The maximum SSAM transmission range was approximately 1.2 miles with a unobstructed line-of-sight between the SSAM and base station antenna. This wireless data link operates with a radiated power that is below the levels required for FCC licensing and regulation. Up to 12 mile transmission ranges are possible through by wirelessly linking the ten SSAM units together, but this requires significant software upgrades that are beyond the scope of this project.

4.2. COLORADO TRAFFIC NOISE FIELD TESTS

An initial field test was performed at a local noise barrier test site along highway C470 in Littleton, CO. The purpose of the test was determine the functionality of the SSAM units in an actual outdoor test environment. Four SSAM units were operated simultaneously at two site locations near the cul de sac at the end of S Newland Ct. Two SSAM units were placed at a site location behind the noise barrier. The remaining two SSAM units were placed at a location 15 m beyond the termination of the barrier.

4.2.1 Acoustical Descriptors

For this test, 9 minute arithmetic averages of 10 fast time weighted acoustical descriptors are used: A-frequency weighting, flat frequency weighting, and eight flat weighted octave bands spanning 22 Hz to 6 kHz.

4.2.2 Site Description

Noise barrier insertion loss measurements were performed along the west bound side of the C470 Highway near the termination of S Newland Ct in Littleton, Colorado. A birds eye image of the location is shown in Figure 1 below.

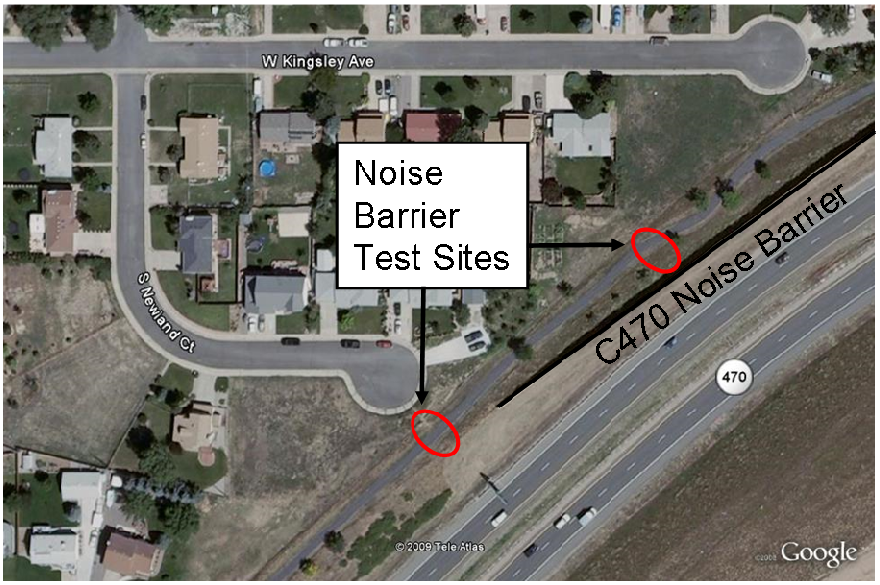

Figure 10: Google Earth® image of the C470 test site locations.

Each SSAM unit is placed on a tripod at a height of 1.5 m from the ground with the exception of the after site location reference SSAM unit which is mounted on an elevated pole 6.3m in the in air. The noise barrier height at the after site location is 4.3 m situated 16.4 m from the edge of C470. Photographs of the SSAM test locations are shown in Figure 2 and Figure 3 below.

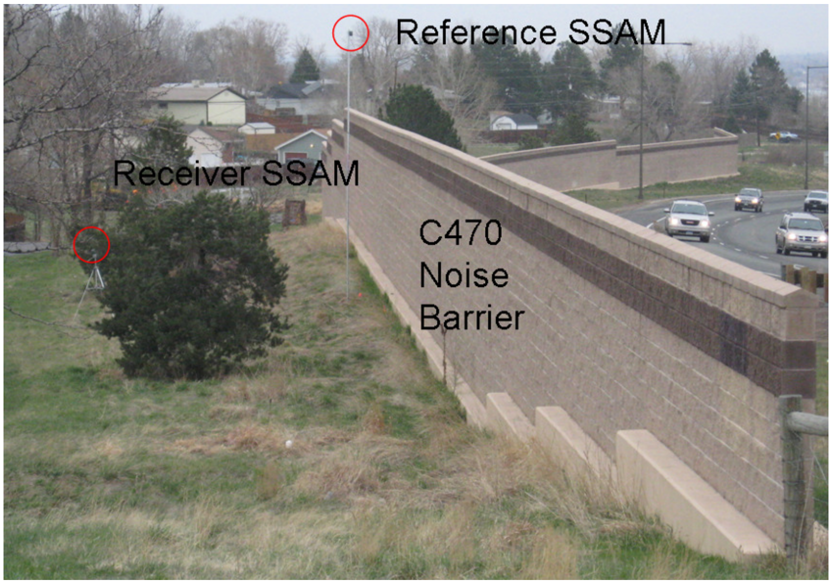

Figure 11: After site SSAM configuration. The reference SSAM unit is 1.7 m above the sound barrier. The receiver SSAM unit is 1.5 m the ground.

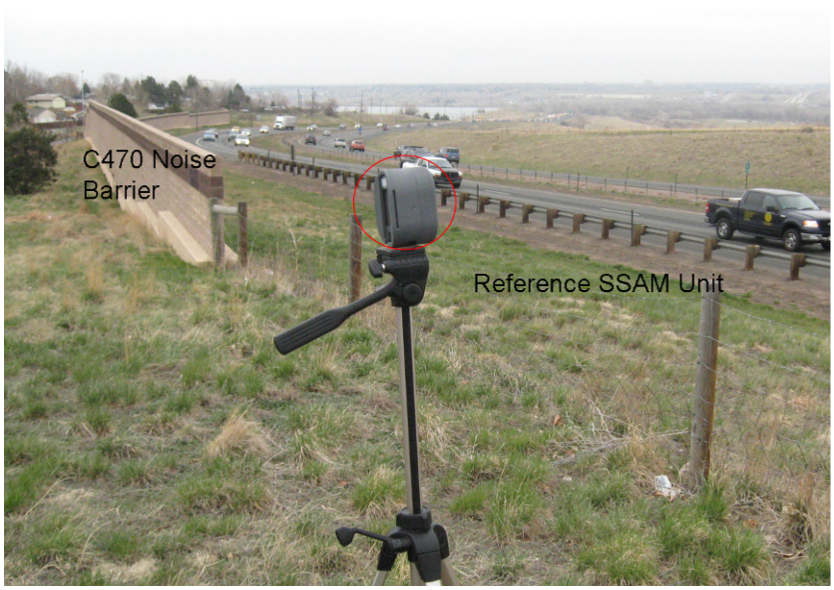

Figure 12: Equivalent before site reference microphone position. The reference SSAM is 1.5 m above the ground and about 4 m above the nominal plane of the sound source.

4.2.3 Results

The SSAM unit performed well under the conditions of the test. The primary advantage of the setup involved in this test is the absolute acoustic equivalence between the before site location and the after site location. The data yields excellent experimental uncertainty with the exception of frequencies between 44 and 177 Hz. In this region, the noise barrier may provide little in the way of noise reduction, causing the values to be skewed based on the frequency content of passing vehicle noise (more trucks could contribute to higher readings in one frequency bin). For this simple test, traffic data was not collected to confirm or refute this hypothesis.

Table 1: C470 test results.

C470 Noise Barrier Insertion Loss & Error										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	11.4 +/- 3.2	5.5 +/- 2.6	7.4 +/- 2.8	11.7 +/- 3.7	15.2 +/- 4.1	14.2 +/- 5.7	13.0 +/- 3.7	8.3 +/- 9.0	1.7 +/- 6.7	-1.9 +/- 3.1

4.3. TROY, OHIO I-75 NOISE BARRIER FIELD TESTS

This section details the measurement and calculation of acoustic insertion loss for a noise barrier located along the I-75 corridor in Troy, Ohio. The methods used to determine the insertion loss have been obtained from ANSI S12.8-1998. This section discusses the purpose of the measurement in Troy, Ohio, the chosen acoustical descriptors, measurement methods, equipment settings, and deviations from S12.8-1998.

The purpose of the measurement is to determine the insertion loss of a noise barrier located in Troy, Ohio. The sound source is free flowing traffic in a 65 mph zone along the I-75 corridor. The acoustical descriptors (see Section 8.1 of S12.8-1998) are time averaged A-weighted sound pressure levels (dBA), time averaged non-weighted sound pressure levels (dBF), and 8 time-averaged octave band levels (spanning 22 Hz to 6 kHz). Continuous fast time weighted exponential averages are arithmetically averaged over approximately 15 minute time intervals (see exceptions below). Since the sound source could not be removed, background noise is determined by the fast time weighted measurement obtained for each acoustical descriptor at the minimum measured A-weighted sound level. An indirect measured method, described in Section 4.2 of S12.8-1998, is used to determine the insertion loss.

Despite efforts to adhere strictly to the ANSI standard for measurement of insertion loss of outdoor noise barriers, some exceptions occurred during testing and are summarized as follows:

1. A reference microphone at Site E was omitted. The action is justified by the short distance separating the intended reference location and the first receiver location. The acoustic deviations between these points was too small to be of importance to the insertion loss measurement. This choice provides a slightly more conservative measurement of the insertion loss by eliminating a small spatial decrease in the noise level at the 5 m receiver location in the equivalent before site measurement. The 5 m receiver location is treated as the reference microphone for the 25 m and 50 m receiver locations.
2. Some of the data points average shorter intervals than 15 minutes. For each of these data points, significant background noise would have affected the complete measurement (lawn mowers, weed eaters, etc.). The interval was shortened to prevent data skewing from increased background noise.
3. The elevation of the ground was negligible for most of the measurements, therefore, no survey equipment was used to determine the slope of the ground at each measurement site.

4.3.1 Site Descriptions

Sound level measurements in Troy, Ohio were taken at five independent locations spanning two days of measurement: Tuesday May 5th and Wednesday May 6th of 2009. Four sites are located along portions of the noise barrier and the fifth location is south of the barrier termination. At each location, three receiver microphones were used. Microphone 1 is located 5 m from the noise barrier (or nominal noise barrier location at the equivalent before site E). Microphone 2 is 25 m from the noise barrier. Microphone 3 is 50 m from the noise barrier. Each of the receiver microphones was placed on a tripod approximately 1.5 m in height. For sites A-D, a reference microphone was placed on a fiberglass boom and raised at least 3.5 m above the noise barrier.

4.3.1.1 Site A

Site A is located at the cul-de-sac at the north end of Dorchester Rd. All measurements were taken behind house number 1088. A detailed plan view and several site photographs are shown in Figures 2-4 below. All meteorological data was recorded near microphone 3.

Figure 13: Google Earth® image of site location A.

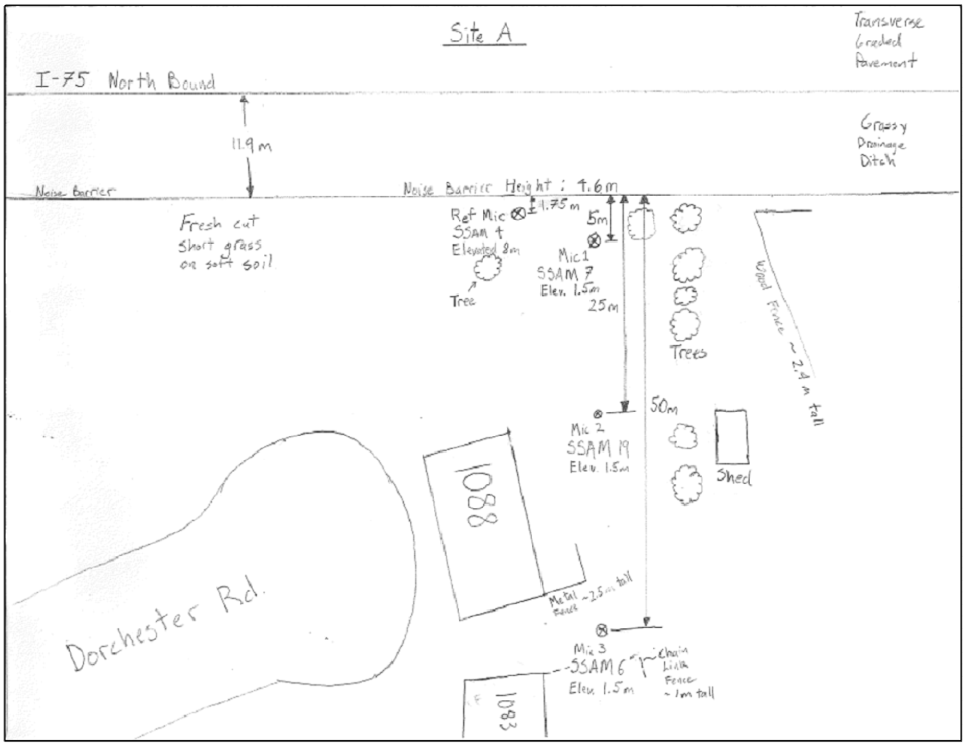

Figure 14: Site A plan view drawing.

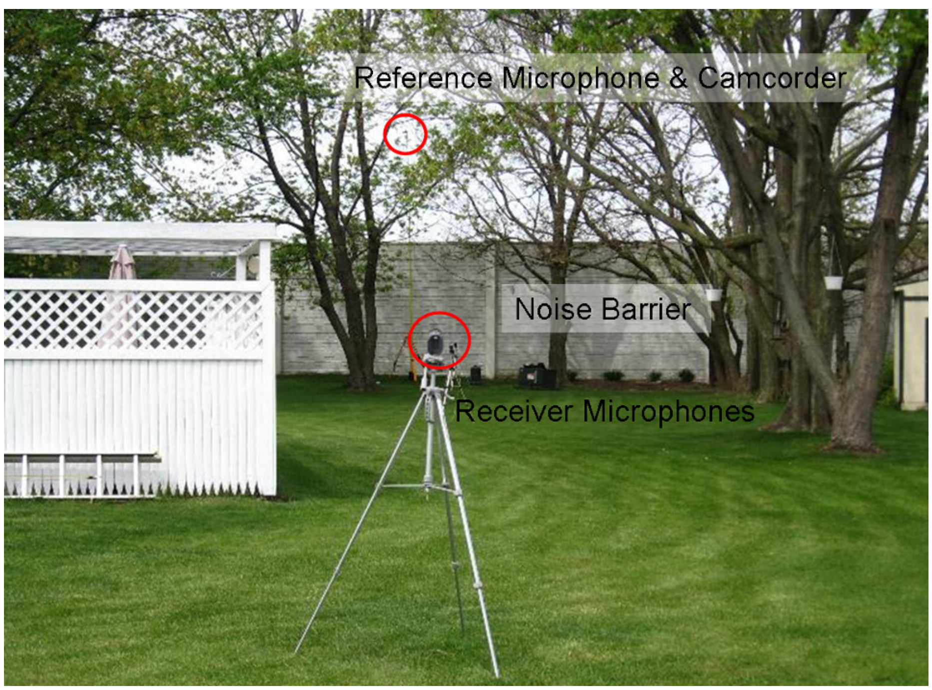

Figure 15: Site A photograph taken from behind microphone 3 looking toward the noise barrier

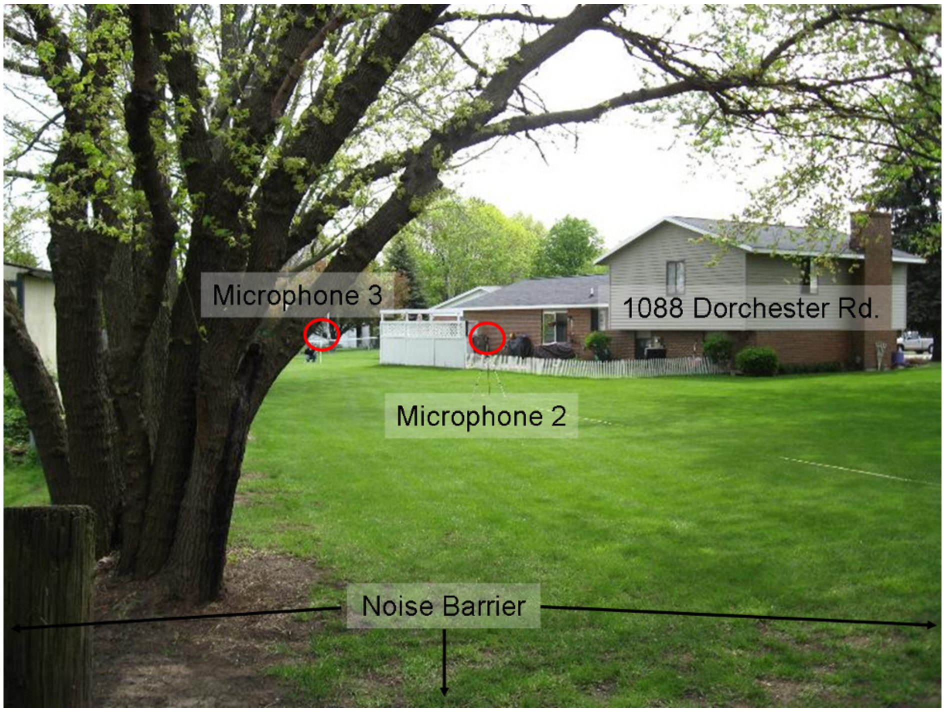

Figure 16: Photograph taken from the north side of the measurement site near the noise barrier, facing toward house number 1088.

4.3.1.2 Site B

Site B is located near the intersection of Branford Rd. and Amesbury Rd. The measurements were taken in the backyard between house number 818 and 826 out to the sidewalk at the corner of Amesbury. A detailed plan view drawing and several photographs of the site are shown in Figures 6, 7, and 8 below. All meteorological data was recorded near microphone 3.

Figure 17: Google Earth® image of site location B.

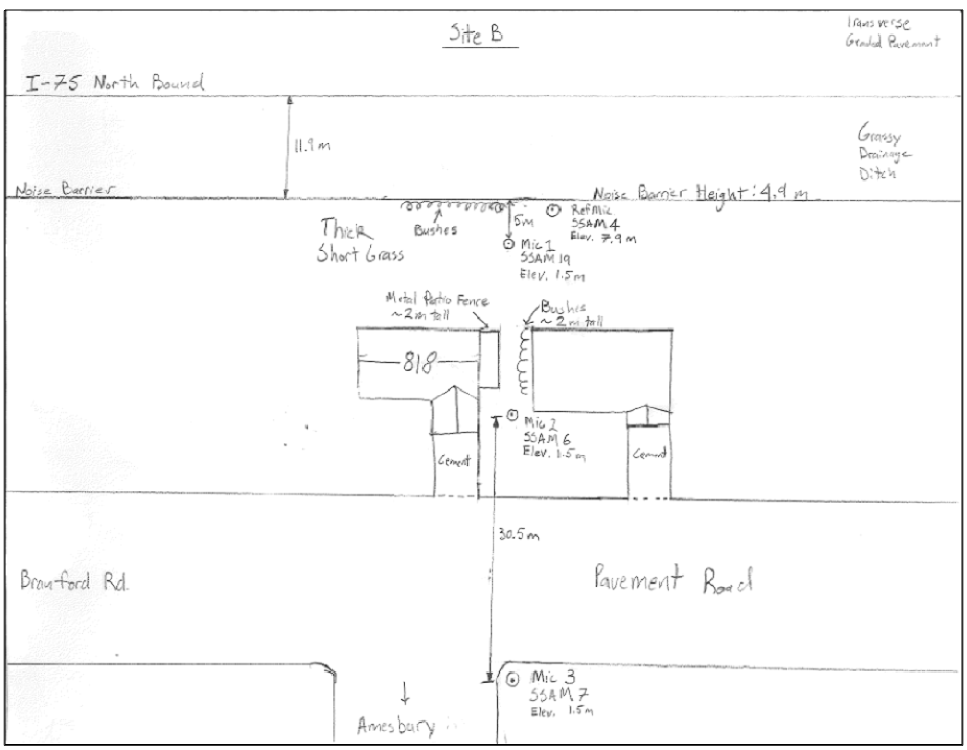

Figure 18: Site B plan view drawing.

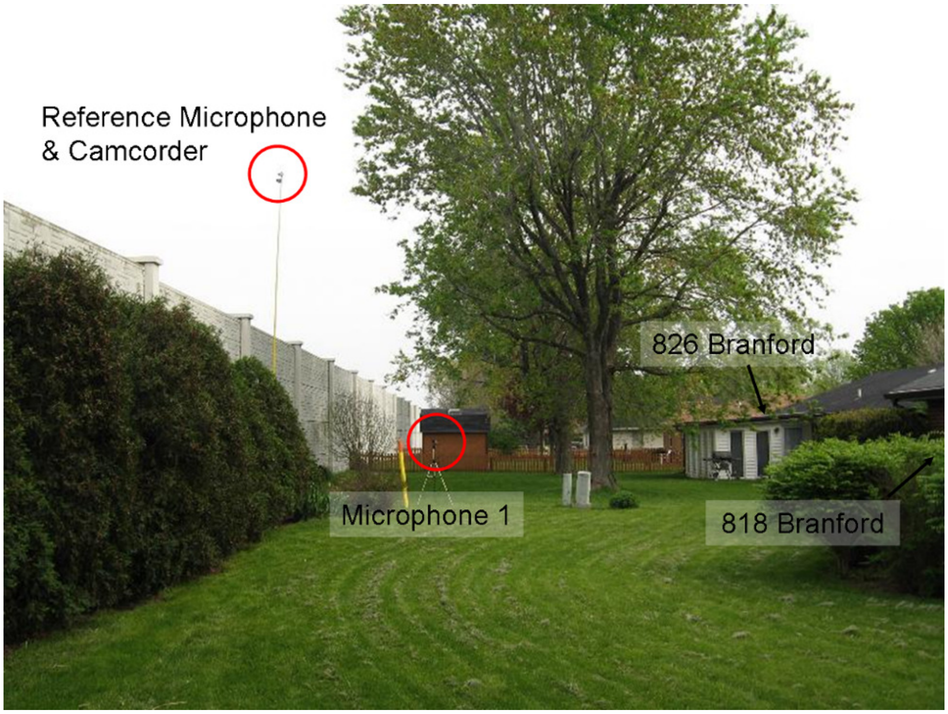

Figure 19: Photograph taken from the south side of the measurement site in the backyard of 818 Branford.

Figure 20: Photograph taken from Amesbury looking toward the noise barrier measurement location behind 818 Branford.

4.3.1.3 Site C and D

Site C is located near the intersection of Heather Rd. and Cheshire Rd. The portion of noise barrier tested at this location is positioned behind a row of two-story apartment complexes. Site D is located beyond the cul-de-sac at the south end of Heather Rd. between the apartment complex buildings and McKaig Ave. The noise barrier terminates prior to reaching McKaig Ave. Detailed plan view drawings and several photographs of site C are shown in Figures 10, 11, and 12 below. Similar images are shown for site D in Figures 13 and 14. All meteorological data was recorded near microphone 3 at site C.

Figure 21: Google Earth® image of site locations C and D.

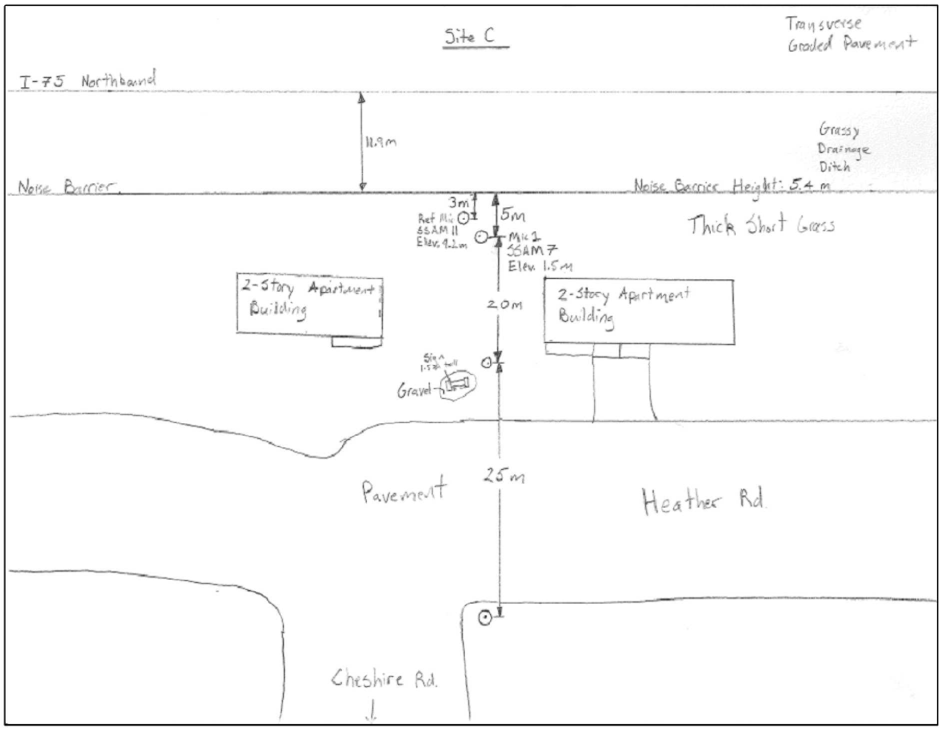

Figure 22: Site C plan view drawing.

Figure 23: Photograph taken from behind microphone 3 looking toward the noise barrier.

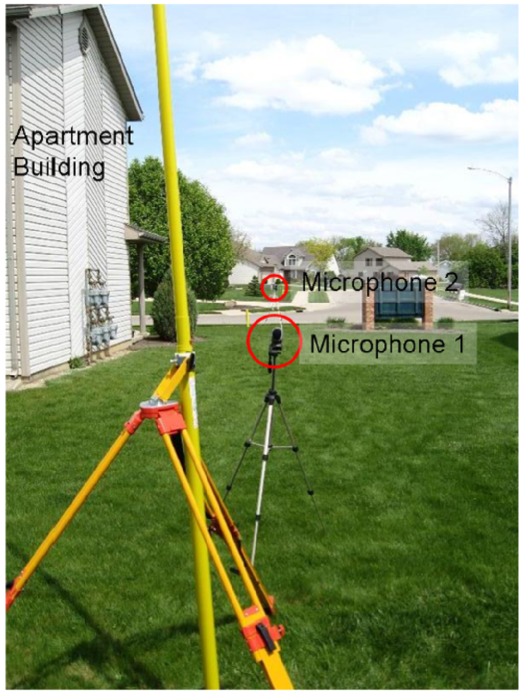

Figure 24: Photograph taken from the noise barrier looking toward the array of measurement microphones.

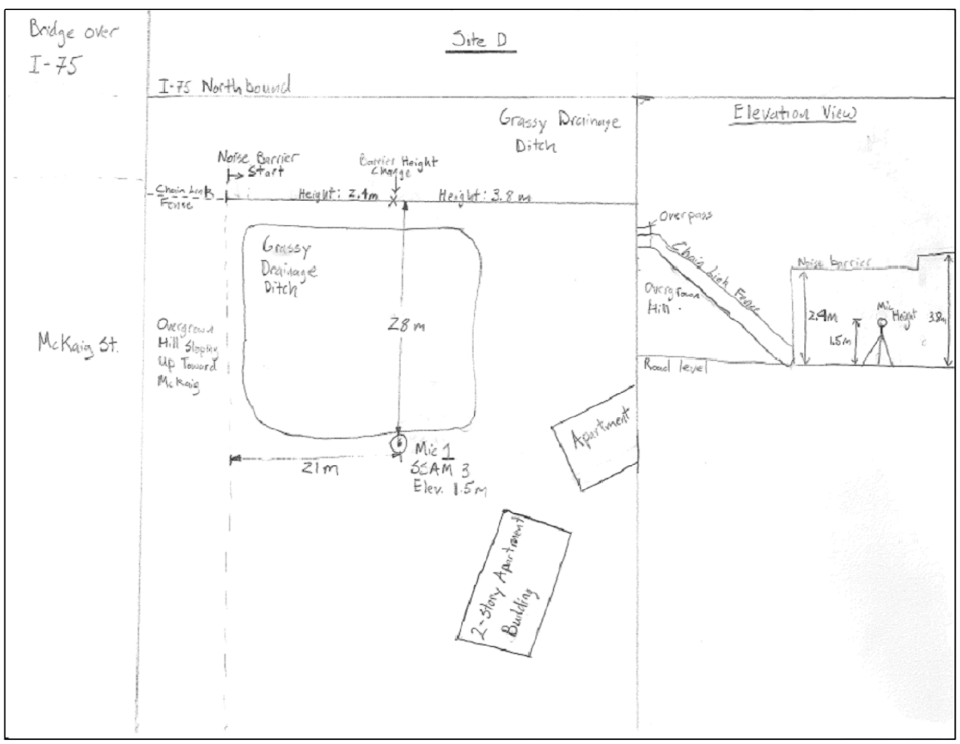

Figure 25: Site D plan view and elevation view drawings.

Figure 26: Photograph taken from the North East side of Site D facing the McKaig Avenue/I-75 overpass.

4.3.1.4 Site E

Site E is located south of 700 S Dorset Rd in an empty lot next to the highway. There is no sound barrier at this location. A detailed plan view and several photographs of site E are shown in Figures 16, 17, and 18 below. All meteorological data was recorded near microphone 3.

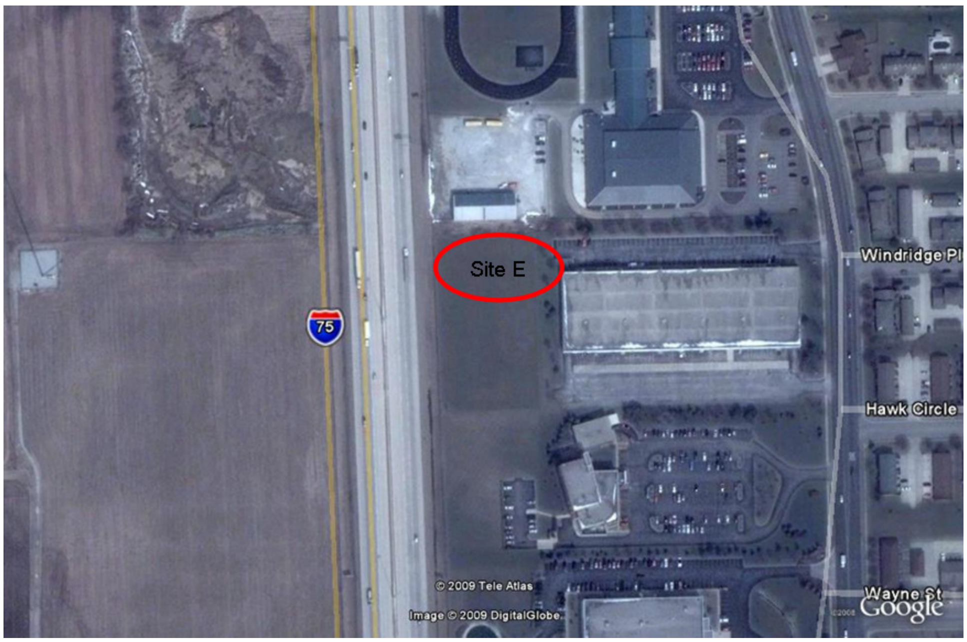

Figure 27: Google Earth® image of site location E.

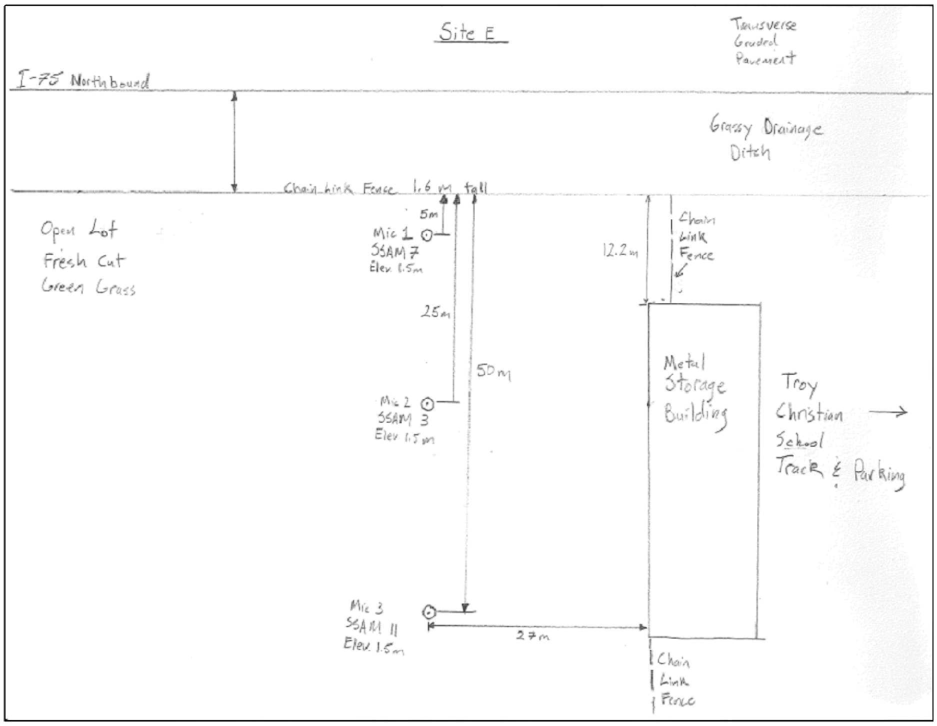

Figure 28: Site E plan view drawing.

Figure 29: Photograph taken from the South East side of microphone 3, facing toward I-75

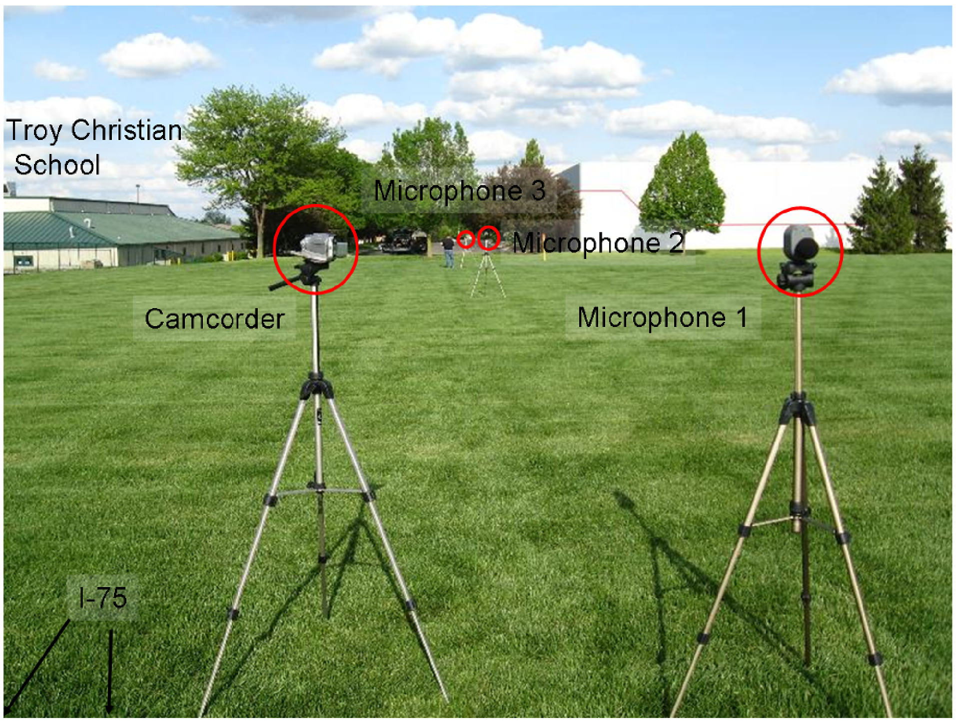

Figure 30: Photograph taken from I-75

facing toward the array of measurement microphones.

4.3.2 Equipment Summary

The equipment required to perform noise insertion loss measurements can be divided into two categories: acoustical and meteorological. The acoustical equipment acts together to provide reliable information about the sound source and background noise at each test location. The meteorological data ensures that each test site falls within comparable environmental conditions to assume acoustical equivalence between measurement locations. In addition to acoustical and meteorological data, a video recording of the noise source was created for each measurement location and duration.

4.3.2.1 Acoustical

- Six Smart Sensors for Autonomous noise Monitoring were used over the course of this two day study. Each sensor is a self contained sound level meter complete with microphone, amplifier, analog/digital filters, microprocessor, and wireless transmission technology. Serial numbers of the SSAM units are: 4,6,7,11,19.
- One smart sensor base station to receive individual SSAM transmissions and export them via USB to a computer.
- An ND9 Acoustic Calibrator (94/114 dB @ 1000 Hz), Serial Number N414220 satisfying IEC942 Class 1 standards for acoustic calibrators. A small rubber seal has been added to the unit to allow for calibration of the SSAM unit.
- Six Parts Express 242-030 wind screens.
- Dell Vostro 1310 Laptop for data recording.
- Proprietary software developed in LabView® for retrieving and processing SSAM data transmissions.

4.3.2.2 Meteorological

- Extech 45158 Mini Thermo-Anemometer, serial number 20908, for measuring average wind speed and temperature.
- Engineer Lensatic Compass for determining prevailing wind direction and direction between source and receiver.

4.3.3 Results

Below is a summary of the test results indicating the minimum noise insertion loss number for 10 different acoustic descriptors, and 3 standoff distances from the noise barrier. The mean insertion loss, reported here, represents the minimum insertion loss that the noise barrier provides. In order to obtain a true noise insertion loss, the sound source would have to be removed to obtain an appropriate background noise measurement for exact calculation of the insertion loss. The calculations used to obtain these results can be reviewed in ANSI S12.8-1998. The field data worksheets for each microphone location are included in Appendix A for reference purposes.

For each site location there are three tables. The first table describes the measurement conditions including time and duration of measurement, wind conditions, cloud cover conditions, temperature, and traffic data. Traffic data is obtained by counting vehicles passing on both sides of the highway during the measurement. Vehicles are classified in five categories: automobiles (A), medium trucks (MT), heavy trucks (HT), buses (B), and motorcycles (M). The second table gives the mean insertion loss for each source receiver pair. The third table gives the total experimental uncertainty calculated for each measurement in the second table. Values given in the second and third table have units of decibels referenced to 20 μPa.

Table 2: Site A test results.

Measurement Data									
Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A MT HT M B
1	9:31:06	9:46:37	0:15:31	0.1	31°	Calm	70°	2	441 52 153 3 0
2	9:49:08	10:04:39	0:15:31	0.5	31°	Calm	71.1°	2	434 40 138 0 0
3	10:07:10	10:22:41	0:15:31	0.2	31°	Calm	72°	2	507 35 148 1 1

Site A: Mean Insertion Loss										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	13.0	9.6	15.6	17.3	19.2	22.8	16.4	12.8	4.3	-4.1
25	10.9	7.4	11.9	16.0	15.9	18.9	16.0	10.3	3.9	-5.1
50	8.8	7.2	4.2	9.6	11.1	14.7	14.8	11.4	5.0	-4.0

Site A: Mean Insertion Loss Uncertainty										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	4.3	2.1	2.6	5.4	8.4	6.8	4.4	3.7	5.9	3.7
25	4.5	2.3	2.8	5.6	8.9	6.8	4.5	4.6	8.1	3.1
50	4.1	3.3	3.0	5.9	8.2	6.8	4.4	4.8	6.3	4.3

Measurement Notes:

- A dog inside 1088 Dorchester barked intermittently through each of the measurement intervals. The sound was undetectable at microphone 1, detectable only during quieter traffic periods at microphone, and detectable at most levels at microphone 3. The author does not believe the dog affected the integrity of the data.
- Ambient bird chirping was present through most of the measurement period. A significant flock of birds landed near microphone 2 during the second measurement interval for approximately 1 minute. Standing near the microphone caused the birds to retreat.
- A lawnmower more than 100 m away was semi-audible at Microphone 3 during the third measurement interval.

Table 3: Site B test results.

Measurement Data													
Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data				
									A	MT	HT	M	B
1	7:30:32	7:46:06	0:15:34	0.2	N/A	Calm	64	2	455	50	137	1	2
2	7:46:21	8:01:53	0:15:32	0.8	N/A	Calm	66	2	505	45	143	2	2
3	8:04:23	8:13:13	0:08:50	0.6	N/A	Calm	68	2	247	18	70	0	0

Site B: Mean Insertion Loss										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	15.5	10.7	18.2	20.5	21.7	22.9	15.8	12.0	6.0	-3.1
25	15.3	8.4	14.6	21.4	22.4	22.2	16.4	13.1	7.3	-5.0
50	9.2	7.6	6.9	10.0	11.9	15.3	12.4	9.6	6.0	-2.6

Site B: Mean Insertion Loss Uncertainty										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	3.8	2.6	2.4	5.2	6.7	1.9	3.3	8.5	3.9	1.9
25	3.8	2.7	2.5	5.3	6.5	2.3	3.4	3.1	4.3	2.3
50	3.9	2.5	2.9	5.7	6.6	2.2	3.3	4.9	5.3	1.6

Measurement Notes:

- Between five and seven cars passed on the road in front of Microphone 3 during each measurement interval. Each was driving around the speed limit of 30 mph. The noise from this traffic was inaudible at Microphone 1 and only semi-audible at Microphone 2.
- Some residents were playing fetch with a small dog within 10 m of Microphone 2 during the second and third interval, however the sound was no louder than a conversation level and noticeably quieter than the highway noise.
- Each of the measurement intervals were cut short by at least a 2 minute interval to accommodate a lawn contractor that agreed to take a break from mowing near microphone 3 to allow us to take measurements. The contractor began work again 12 minutes into the third measurement interval. All data beyond this point was omitted from analysis.

Table 4: Site C test results.

Measurement Data									
Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A MT HT M B
1	1:03:39	1:19:11	0:15:32	1.5	358	Calm	72	3	773 46 135 8 3
2	1:21:41	1:37:13	0:15:32	1.5	358	Calm	72.5	3	823 45 176 2 2
3	1:39:44	1:50:45	0:11:01	1	358	Calm	73	3	712 32 107 1 1

Site C: Mean Insertion Loss										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	17.0	9.7	21.0	25.4	24.7	21.3	13.0	7.1	2.6	-1.9
25	16.4	10.2	14.6	23.1	22.2	20.6	16.9	10.8	5.5	0.2
50	10.1	8.7	6.9	11.5	13.6	15.5	14.5	9.3	5.5	0.3

Site C: Mean Insertion Loss Uncertainty										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
5	5.0	3.0	3.2	7.1	9.1	2.1	5.0	3.9	4.2	3.8
25	4.4	2.6	2.8	5.5	7.6	1.7	4.0	3.9	5.5	4.4
50	4.6	2.4	3.3	6.2	8.3	1.9	4.1	3.7	5.4	4.0

Measurement Notes:

- Between four and six vehicles passed by Microphone 3 during each measurement interval. During the second interval, a bus and a UPS truck passed.
- The wind picked up some during the second measurement interval. For a 10 s period, the wind gusts approached 2.9 m/s from 350° from due North.

Table 5: Site D test results.

Measurement Data									
Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A MT HT M B
1	1:03:39	1:19:11	0:15:32	1.5	358	Calm	72	3	773 46 135 8 3
2	1:21:41	1:37:13	0:15:32	1.5	358	Calm	72.5	3	823 45 176 2 2
3	1:39:44	1:50:45	0:11:01	1	358	Calm	73	3	712 32 107 1 1

Site D: Insertion Loss										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
28	9.4	5.2	12.8	15.0	14.2	14.0	10.2	4.2	0.3	-3.6

Site D: Insertion Loss Uncertainty										
Standoff Distance (m)	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
28	4.5	2.4	4.3	6.2	7.6	2.8	4.7	4.6	5.6	5.2

Measurement Notes:

- A man was edging his yard with a weed eater within 10 m of microphone 1 during the first measurement interval. The sound lasted approximately 3-4 minutes. No data was omitted since the microphones at site C were not experiencing any noise fluctuations.
- Sounds from McKaig Ave. were inaudible during the measurement period.

4.3.4 Comparison with Standard Sound Level Meter Measurements

Standard sound level meter measurements at the Troy, OH site were collected in the fall of 2008 under SJN 134365 and are described in the report "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement." At the time of this writing, this report is available in draft form, dated January 29, 200, and the data in that draft report is preliminary. Therefore, no comparison is being made in this report. The results of the SSAM data collection ore summarized in Tables 6-11 for future comparison with the data from SJN 134365.

Table 6: Data gathered with SSAM at Site A.

Site A: SSAM vs. Traditional Sound Level Meter							
Microphone Label	Standoff Distance (m)	Average SPL (dBA)	Traffic Data			Start Time	Duration
			L	M	H		
SSAM Microphone A2	25	64.8	1382	127	439	11:30 AM	45 min
*Traditional Mic S2A2	26.8	[redacted]					
SSAM Microphone A3	50	60.8	1382	127	439	11:30 AM	45 min
*Traditional Mic S2A1	57.9	[redacted]					
SSAM Microphone Aref	0	82.5	1382	127	439	11:30 AM	45 min
*Traditional Mic S2A8	0	[redacted]					

*From draft report on "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement"

Table 7: Data gathered with SSAM at Site B.

Site B: SSAM vs. Traditional Sound Level Meter							
Microphone Label	Standoff Distance (m)	Average SPL (dBA)	Traffic Data			Start Time	Duration
			L	M	H		
SSAM Microphone B1	5	67.7	1207	113	350	9:30 AM	40 min
*Traditional Mic S2B5	8.2	[redacted]					
SSAM Microphone Bref	0	83.1	1207	113	350	9:30 AM	40 min
*Traditional Mic S2B8	0	[redacted]					

*From draft report on "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement"

Table 8: Data gathered with SSAM at Site C.

Site C: SSAM vs. Traditional Sound Level Meter							
Microphone Label	**Standoff Distance (m)**	**Average SPL (dBA)**	**Traffic Data**			**Start Time**	**Duration**
			L	**M**	**H**		
SSAM Microphone Cref	0	85.2	2319	123	418	3:00 PM	40 min
*Traditional Mic S2C8	0						

*From draft report on "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement"

Table 9 Data gathered with SSAM at Site D.

Site D: SSAM vs. Traditional Sound Level Meter							
Microphone Label	**Standoff Distance (m)**	**Average SPL (dBA)**	**Traffic Data**			**Start Time**	**Duration**
			L	**M**	**H**		
SSAM Microphone D1	28.7	68.7	2319	123	418	3:00 PM	40 min
*Traditional Mic S2D4	28.7						

*From draft report on "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement"

Table 10: Data gathered with SSAM at Site E.

Site E: SSAM vs. Traditional Sound Level Meter							
Microphone Label	**Standoff Distance (m)**	**Average SPL (dBA)**	**Traffic Data**			**Start Time**	**Duration**
			L	**M**	**H**		
SSAM Microphone E2	25	73.7	2146	93	407	5:50 PM	45 min
*Traditional Mic S2E5	20.4						
SSAM Microphone E3	50	67.2	2146	93	407	5:50 PM	45 min
*Traditional Mic S2E6	47.5						

*From draft report on "Effectiveness of Noise Barriers Installed Adjacent to Transverse Grooved Concrete Pavement"

5. CONCLUSIONS AND RECOMMENDATIONS

The compact size, ease of use, and low cost of the SSAM sensors offer a unique benefit to traffic noise monitoring. For example, tens or even hundreds of SSAMs could be distributed along many miles of roadway for continuous, long-term monitoring. The resulting technology would provide reduced overall noise test costs and a great increase in data gathering and automated analysis. The added information can provide improved understanding of highway noise sources, airport noise sources, and their variation as a function of location, time-of-day, day-of-week, weather conditions, and other parameters that effect traffic noise levels.

The potential payoff of this project is best realized by considering current traffic noise monitoring and evaluation methods. Although the current wayside techniques provide transportation agencies with valid, accurate data, they are time consuming, cumbersome, and costly to operate. The resulting data must be post-processed, sometimes requiring several additional days before the desired noise metrics are available. In addition, agencies are reluctant to leave noise equipment unattended for extended period of time due to risk of vandalism or theft. The prototype SSAM system provides the ability to perform long-term wayside measurements that can supplement standardized methods or provide a lower-cost alternative to standard noise measurement methods in some situations. Further, SSAMs can directly measure noise characteristics along roadways, in front of and behind traffic noise barriers, over/through rows of buildings and vegetation, and other scenarios that the FHWA's Traffic Noise Model cannot currently predict. SSAM may therefore facilitate validation and improvement of the TNM, or direct measurement of the desired noise contours.

This report compares the precision and accuracy of SSAM to that of conventional noise measurement methods through laboratory testing and wayside traffic noise measurements. The data shows that SSAM can provide highly accurate noise measurements, comparable to typical Type 1 data logging sound level meters. The additional provision for long-term installation of SSAM with wireless transmission of data provides a great capability that has not previously existed.

Recommendations:

The SSAM system provides a flexible technology that can be adapted to many other noise monitoring applications of interest to DOTs. For example, the SSAM technology can be modified (through additional research) for use in other areas such as bridge vibration monitoring. Now that the basic technology has been developed, various improvements to SSAM can be implemented through modest investments.

6. IMPLEMENTATION PLAN

This project has transitioned SSAM from concept through demonstration of a working prototype system for multipoint wireless noise monitoring. The prototype SSAM system and training materials are available to ODOT staff for their use in future noise monitoring projects. Use of SSAM in future transportation noise studies is encourage in order to

- gain exposure and acceptance in the transportation community,
- identify needed improvements or desired features,
- establish a substantial data base of SSAM measurements validated against simultaneous standard noise methods.

By advocating the use of SSAM and incorporating the use of SSAM in future noise studies, the technology can transition from prototype, to a mature, accepted system with well established performance characteristics. Once this transition is made, the substantial cost-effectiveness of the technology can be realized as automated noise monitoring and testing becomes the accepted norm. Ultimately, SSAM will be available for sale or lease as a commercial product or service.

APPENDIX A. TECHNICAL MANUAL OF OPERATION

A.1. INTRODUCTION

This section provides instructions on the setup, operation, maintenance, and troubleshooting of the Smart Sensor for Autonomous noise Monitoring (SSAM). The operation manual is organized into the following subsections:

- Theory of Operation—general overview of the system and intended capabilities;
- System Set-up—step-by-step instructions for set up;
- Test Procedures—step-by-step instructions to operate the system;
- Troubleshooting and Maintenance.

A.2. THEORY OF OPERATION

The Smart Sensor for Autonomous Noise Monitoring system is intended for use in numerous applications where noise monitoring in the frequency range of 22 to 5656 Hz and approximate amplitude ranges from 45 dB to 150 dB (~60 dB range for a given amplifier settings). The current configuration of the SSAM device is designed to monitor traffic noise and report amplitude values in eight octave bands according to ANSI standards.

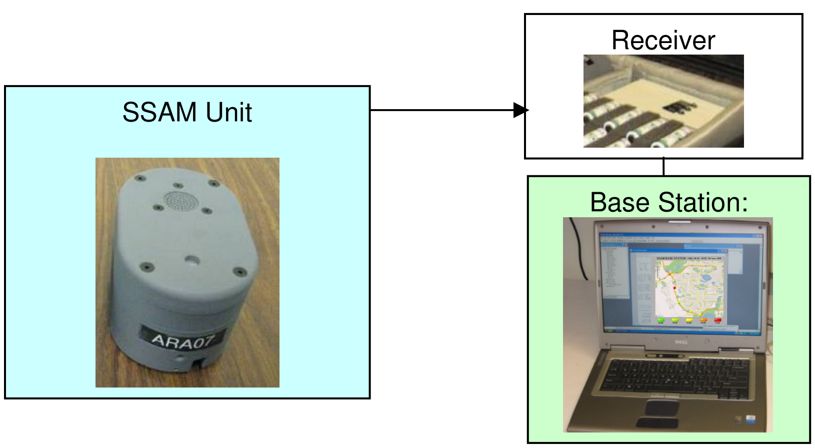

Figure 31: The SSAM system consists of SSAM units equipped with onboard noise filters and transmitter, a receiver and a base station.

The primary system components (SSAM units, receiver, and base station) are shown in Figure 10. Each SSAM unit is designed to monitor overall noise levels (flat and A-weighted) and octave bands and wirelessly transmit the data to the receiver station. Each unit can be powered in one of two ways: four 3.6 V batteries or a power adaptor cable.

The receiver is designed to accept wireless transmissions from SSAM units and transmit them via a USB connection to the computer base station. The interface between the SSAM units and the receiver station accommodates and coordinates transmissions from multiple SSAM units.

The base Station is a Dell Vostro 1510 laptop computer and software for user interface and data logging. A single executable file controls the SSAM data acquisition, file storage, and map display. The data acquisition and display software was written using National Instrument's LabView Software and compiled into an independent executable program. The same program can be used to collect and store real time data, read data from a file, or access data from the web.

A.3. SYSTEM SETUP

The following subsections provide a listing of all parts, step-by-step setup instructions and photographs and block diagrams.

A.3.1. PARTS LIST

A list of parts contained in the SSAM shipping case are as follows:

Table 11: Parts list.

Part Name	Quantity
SSAM Units	10
Receiver Station	1
Dell Computer Base Station	1
Saft LS14500 3.6V Lithium-Thionyl Chloride Batteries	40
Dell Power Adaptor	1

A photograph of the system packaged in its storage/shipping case is shown in Figure 9.

A.3.2. COMPUTER BASE STATION AND RECEIVER SETUP PROCEDURE

The Base Station setup procedure is as follows:

1. Unpack the laptop, connect and plug in the power adapter, optionally connect an Ethernet cable. Do not power up the laptop yet.

2. Connect the Receiver Station to the laptop via the USB cable. Connect the power adapter to the Receiver station. Do not power up the Receiver yet.

3. Mount the antennae as appropriate and connect the antennae cable to the Receiver station.

4. Power on the Base Station. After Windows startup is complete, power on the Receiver station.

5. Operation of the Base Station is described in Section 4 Test Procedures.

A.3.3. SSAM SENSOR SETUP AND MICROPHONE CALIBRATION PROCEDURE

The SSAM unit setup is described as follows:

1. Setup the base station and receiver (Section A.3.2)

2. Open SSAM_Calibrator.VI. Adjust the COM port setting in the software so that it matches the appropriate COM port associated with the Serial to USB connector. Start the Calibration.VI.

3. Remove a SSAM unit and the piston phone calibrator

4. Hold the open end of the calibrator over the microphone enclosure on the SSAM unit.

5. Activate the calibration tone and power on the SSAM unit either by plugging in the power cable or activating the battery power using the power switch on the back. A yellow light LED will then be flashing on the front of the unit. This light indicates that the SSAM unit is in calibration mode.

6. Hold the activated calibrator to the SSAM unit until the LED stops flashing. The unit is now calibrated.

7. Mount the unit in the desired location with the front face of the SSAM unit facing in the direction of the desired measurement.
8. Data collection, storage, and display is described in Section 4 Test Procedures.

A.4. NOISE BARRIER INSERTION LOSS TEST PROCEDURES

This section describes a test procedure to determine the insertion loss of a noise barrier based on the indirect measured method described in ANSI S12.8-1998. This method assumes the noise barrier of interest is already in place and immovable, but an equivalent site exists to determine the sound level prior to the installation of the noise barrier. Prior to performing the insertion loss measurement, the sound source must be appropriately characterized to choose the necessary time-averaging scheme needed to obtain an accurate measurement.

A.4.1. BASE STATION AND RECEIVER INSTALLATION

1. Setup the computer base station and receiver less than 1 mile from the most distant SSAM test location.

A.4.2. REFERENCE SSAM UNIT AT EQUIVALENT SITE (W/O BARRIER)

1. Activate a SSAM unit according to Section A.3.3.
2. Place the activated and calibrated unit according to the reference microphone position standards listed in Section 5.2.2 of ANSI S12.8-1998. Under this standard, for a noise barrier located between 15 m and 30 m from the sound source region, place the reference SSAM unit at the same distance from the source region at a height 1.5 m taller than the noise barrier at the equivalent site. Make sure the front of the SSAM unit faces the sound source.

A.4.3. REFERENCE SSAM UNIT AT NOISE BARRIER SITE

1. Activate a SSAM unit according to Section A.3.3.
2. Place the activated and calibrated unit according to the reference microphone position standards listed in Section 5.2.2 of ANSI S12.8-1998. Under this standard, for a noise barrier located between 15 m and 30 m from the sound source region, place the reference

SSAM unit exactly 1.5 m above the noise barrier. Make sure the front of the SSAM unit faces the sound source.

A.4.4. ADDITIONAL SSAM UNIT AT NOISE BARRIER SITE

1. Activate each SSAM unit to be used as a receiver according to Section A.3.3. ANSI S12.8-1998 recommends at least 6 receivers for each insertion loss measurement.
2. Place the activated and calibrated units according to the receiver microphone positions described in Section 8.3 of ANSI S12.8-1998. The standard recommends placing two receivers at a distance of 5 m, 20 m, and 50 m from the centerline of the noise barrier, respectively. One of the receivers should be placed 1.5 m above the ground. The second receiver should be placed at the boundary of the noise barrier shadow zone, defined in Section 8.3 of ANSI S12.8-1998.

A.4.5. ADDITIONAL SSAM UNIT AT EQUIVALENT SITE

1. Activate each SSAM unit to be used as a receiver according to Section A.3.3. The same number of receivers set up in Section A.4.4 at the noise barrier site should be used at the equivalent site.
2. Place the activated and calibrated units at the same distance and height at the equivalent site as those set up at the noise barrier location in Section A.4.4.

A.4.6. TEST PROCEDURE

You are now ready to perform an insertion loss measurement on a noise barrier. Open SSAM_Noise_Barrier.VI on the computer base station to begin recording data. The program allows the user to view the data in real time while recording it to disk or on the web for further processing.

A.5. SSAM MAINTENANCE

A.5.1. SSAM BATTERY REPLACEMENT

If the SSAM unit calibration LED does not turn on when the power switch is activated, the batteries are likely discharged. The batteries may be replaced by following a simple procedure:

1. Press the power switch into the of OFF position.

2. Unscrew the four support screws .
3. Remove the four batteries from the battery chassis located in the back piece of the SSAM unit.
4. Place four new Saft LS14500 3.6V batteries with appropriate orientation into the battery chassis.

APPENDIX B. TROY, OH NOISE BARRIER TEST DATASHEETS

Site A: Reference Microphone

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 4	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X		X		88°
Site Description: Cul de Sac along Dorchester Rd. (Mic placed 3.4 m above wall)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat with interspersed trees								
Ground category description: Soft ground, freshly mowed thick grass								
Initial Calibration	93.9	**dBA**	**Sensitivity Shift Factor: (dB)**		0.45			
Final Calibration	93	**dB**						

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	9:31:06	9:46:37	0:15:31	0.1	31°	Calm	70°	2	441	52	153	3	0
2	9:49:08	10:04:39	0:15:31	0.5	31°	Calm	71.1°	2	434	40	138	0	0
3	10:07:10	10:22:41	0:15:31	0.2	31°	Calm	72°	2	507	35	148	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	66.2	67.5	42.9	47.4	53.7	44.0	40.4	44.1	45.5	52.7
2	63.6	67.7	41.0	43.2	45.9	33.5	43.9	48.8	50.2	52.1
3	67.0	67.9	43.9	48.1	55.2	45.9	46.5	44.7	52.8	49.1

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	82.2	83.0	59.2	66.1	71.2	65.5	60.5	62.6	64.3	64.3
2	82.1	82.9	59.0	65.8	71.0	65.9	61.0	62.5	63.6	64.1
3	82.3	83.0	59.1	66.2	71.6	66.5	61.1	61.8	62.8	63.4

Site A: Microphone 1

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 7	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X			X	88°
Site Description: Cul de Sac along Dorchester Rd. (5 m from noise barrier)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat with interspersed trees								
Ground category description: Soft ground, freshly mowed thick grass								
Initial Calibration	94.1	**dBA**	**Sensitivity Shift Factor: (dB)**		0.15			
Final Calibration	93.8	**dB**						

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	9:31:30	9:47:02	0:15:32	0.1	31°	Calm	70°	2	441	52	153	3	0
2	9:47:17	10:02:49	0:15:32	0.5	31°	Calm	71.1°	2	434	40	138	0	0
3	10:05:19	10:20:53	0:15:34	0.2	31°	Calm	72°	2	507	35	148	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	60.9	65.5	36.0	36.0	39.8	36.0	36.0	45.1	45.8	55.4
2	57.9	66.6	34.7	36.0	36.0	36.0	36.0	42.9	52.9	60.2
3	60.9	65.5	37.0	36.4	39.8	36.0	36.0	45.1	45.8	55.4

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	69.2	74.3	43.9	48.2	51.6	43.4	45.1	51.1	60.4	68.6
2	69.5	74.1	44.3	48.8	52.2	44.1	45.3	50.5	59.5	68.3
3	69.7	74.0	44.5	49.5	53.0	44.6	45.2	50.6	58.7	68.1

Site A: Microphone 2

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 19	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X			X	88°
Site Description: Cul de Sac along Dorchester Rd. (25 m from noise barrier)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat ground with interspersed trees								
Ground category description: Soft ground, freshly mowed thick grass								
Initial Calibration	**93.9**	**dBA**	**Sensitivity Shift Factor: (dB)**		0			
Final Calibration	93.9	**dB**						

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	9:32:08	9:47:39	0:15:31	0.1	31°	Calm	70°	2	441	52	153	3	0
2	9:47:54	10:03:26	0:15:32	0.5	31°	Calm	71.1°	2	434	40	138	0	0
3	10:05:57	10:21:28	0:15:31	0.2	31°	Calm	72°	2	507	35	148	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	56.3	62.0	36.0	36.0	36.0	36.0	36.0	36.0	48.0	53.2
2	56.3	61.5	36.0	36.0	36.0	36.0	36.0	39.9	38.5	53.6
3	57.7	63.2	37.3	36.0	37.0	36.0	36.0	36.0	36.0	55.1

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	64.4	71.0	40.1	41.2	44.7	38.8	40.8	48.7	57.3	65.9
2	64.5	70.5	40.9	41.5	45.1	38.5	39.6	47.3	55.3	65.8
3	65.2	70.6	42.1	43.0	46.8	39.8	40.0	47.8	55.4	65.4

Site A: Microphone 3

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 6	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X			X	88°
Site Description: Cul de Sac along Dorchester Rd. (50 m from noise barrier)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat ground with interspersed trees								
Ground category description: Soft ground, freshly mowed thick grass								
Initial Calibration	94	**dBA**	**Sensitivity Shift Factor: (dB)**		0.5			
Final Calibration	93	**dB**						
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.								

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	9:32:31	9:48:03	0:15:32	0.1	31°	Calm	70°	2	441	52	153	3	0
2	9:48:27	10:03:59	0:15:32	0.5	31°	Calm	71.1°	2	434	40	138	0	0
3	10:06:29	10:22:06	0:15:37	0.2	31°	Calm	72°	2	507	35	148	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	54.8	58.6	36.0	36.0	36.0	36.0	36.0	36.0	38.4	54.3
2	54.6	57.3	37.5	36.0	36.0	36.0	36.0	36.0	36.9	48.9
3	55.3	60.4	36.0	36.0	36.0	36.0	36.0	36.0	36.0	51.2

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	60.3	67.4	38.5	36.0	39.3	36.0	36.7	44.8	53.4	62.7
2	60.1	66.8	39.0	36.0	38.9	36.0	36.0	44.0	51.7	62.3
3	60.6	66.7	39.0	36.0	40.8	36.0	36.0	44.3	51.3	62.0

Site B: Reference Microphone

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	4	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
					X		X		86°
Site Description: Noise barrier along I-75 between 818 Branford Rd and 824 Branford Rd. (2.97 m Above Noise Barrier)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat ground with interspersed trees and bushes									
Ground category description: Soft ground, freshly mowed thick grass									
Initial Calibration	93.9	**dBA**	**Sensitivity Shift Factor: (dB)**	0.5					
Final Calibration	92.9	**dB**							
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	7:30:32	7:46:06	0:15:34	0.2	N/A	Calm	64	2	455	50	137	1	2
2	7:46:21	8:01:53	0:15:32	0.8	N/A	Calm	66	2	505	45	143	2	2
3	8:04:23	8:13:13	0:08:50	0.6	N/A	Calm	68	2	247	18	70	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	70.9	72.0	47.2	54.4	58.3	46.9	43.6	45.7	47.6	52.5
2	69.7	70.6	45.7	53.7	56.9	45.8	41.9	47.2	50.4	53.8
3	67.9	69.7	44.0	50.4	55.2	48.4	44.0	44.7	48.9	53.5

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	83.1	83.8	59.9	66.8	72.3	66.4	61.8	62.5	64.9	65.3
2	83.1	83.8	60.1	66.8	72.5	67.1	60.3	61.9	64.9	64.6
3	82.9	84.0	59.6	66.2	71.9	64.8	61.1	66.2	66.4	65.4

Site B: Microphone 1

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	19	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
					X			X	86°
Site Description: Noise barrier along I-75 between 818 Branford Rd and 824 Branford Rd. (5 m from Noise Barrier)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat ground with interspersed trees and bushes									
Ground category description: Soft ground, freshly mowed thick grass									
Initial Calibration	94.5	**dBA**	**Sensitivity Shift Factor: (dB)**	-0.35					
Final Calibration	95.2	**dB**							
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	7:32:39	7:45:56	0:13:17	0.2	N/A	Calm	64	2	455	50	137	1	2
2	7:46:11	8:01:43	0:15:32	0.8	N/A	Calm	66	2	505	45	143	2	2
3	8:04:13	8:13:03	0:08:50	0.6	N/A	Calm	68	2	247	18	70	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	60.9	65.1	36.0	36.0	36.0	36.0	36.0	36.0	48.0	57.8
2	60.3	65.0	36.2	36.0	36.0	36.0	36.0	36.0	47.2	59.4
3	60.7	67.1	36.0	36.0	38.3	36.0	36.3	49.7	42.3	59.8

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	68.5	74.2	42.9	46.3	50.5	44.3	46.4	51.7	59.8	68.7
2	68.7	73.9	43.4	46.8	51.3	44.7	45.2	51.0	59.2	68.4
3	68.6	74.4	42.8	46.3	50.9	43.6	46.2	53.0	60.4	68.7

Site B: Microphone 2

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	6	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
					X			X	86°
Site Description: Noise barrier along I-75 between 818 Branford Rd and 824 Branford Rd. (25 m from Noise Barrier)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat ground with interspersed trees and bushes									
Ground category description: Soft ground, freshly mowed thick grass									
Initial Calibration	93.5	**dBA**	**Sensitivity Shift Factor: (dB)**	-0.5					
Final Calibration	94.5	**dBA**							
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	7:30:45	7:46:17	0:15:32	0.2	N/A	Calm	64	2	455	50	137	1	2
2	7:46:32	8:02:03	0:15:31	0.8	N/A	Calm	66	2	505	45	143	2	2
3	8:04:34	8:13:20	0:08:46	0.6	N/A	Calm	68	2	247	18	70	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	56.0	60.8	36.0	36.0	36.0	36.0	36.0	36.0	36.3	53.5
2	55.4	62.5	36.0	36.0	36.0	36.0	36.0	36.0	36.0	55.8
3	55.4	60.3	36.8	36.0	36.0	36.0	36.0	37.9	42.0	56.3

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	61.8	70.5	37.4	36.0	39.5	36.1	39.0	46.4	54.5	67.0
2	61.8	70.1	37.6	36.1	39.7	36.1	37.9	45.6	53.7	66.7
3	61.8	70.9	37.4	36.0	39.6	36.3	39.9	48.0	55.7	67.0

Site B: Microphone 3

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 7	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X			X	86°

Site Description: Noise barrier along I-75 between 818 Branford Rd and 824 Branford Rd. (50 m from Noise Barrier)

Source Description: I-75 traffic flowing freely

Terrain Description: Flat ground with interspersed trees and bushes

Ground category description: Soft ground, freshly mowed thick grass

Initial Calibration	93.5	**dBA**	**Sensitivity Shift Factor: (dB)**	-0.2
Final Calibration	93.9	**dBA**		

Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	7:30:39	7:46:18	0:15:39	0.2	N/A	Calm	64	2	455	50	137	1	2
2	7:46:33	8:02:08	0:15:35	0.8	N/A	Calm	66	2	505	45	143	2	2
3	8:04:35	8:13:26	0:08:51	0.6	N/A	Calm	68	2	247	18	70	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	55.6	62.3	36.0	36.0	36.0	36.0	36.0	36.0	45.9	56.3
2	54.8	62.0	36.0	36.0	36.0	36.0	36.0	36.0	43.0	57.2
3	55.2	62.6	36.0	36.0	36.0	36.0	36.0	40.6	38.2	56.2

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	61.3	69.2	37.5	36.8	39.9	36.0	42.2	49.5	56.2	63.5
2	60.8	67.7	37.4	37.0	39.6	36.0	38.2	45.8	52.1	63.2
3	60.7	68.2	37.3	36.1	38.9	36.0	40.5	48.0	53.1	63.4

Site C: Reference Microphone

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 11	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X		X		86°
Site Description: Intersection of Cheshire Rd & Heather Rd. in Troy, OH (5 m above noise barrier, 10' behind)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat terrain between two apartment complexes.								
Ground category description: Soft ground, short thick grass								
Initial Calibration	94.5	**dBA**	**Sensitivity Shift Factor: (dB)**		0.5			
Final Calibration	93.5	**dBA**						
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.								

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	1:03:39	1:19:11	0:15:32	1.5	358	Calm	72	3	773	46	135	8	3
2	1:21:41	1:37:13	0:15:32	1.5	358	Calm	72.5	3	823	45	176	2	2
3	1:39:44	1:50:45	0:11:01	1	358	Calm	73	3	712	32	107	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	74.2	75.6	48.5	56.2	62.3	49.7	50.1	51.2	54.2	55.8
2	73.4	75.0	48.2	56.2	61.2	50.4	45.2	47.6	51.1	58.5
3	75.5	76.6	51.8	60.3	63.5	51.8	46.8	51.1	48.2	62.4

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	84.8	85.6	60.7	68.5	74.2	67.2	64.1	65.3	66.4	67.4
2	85.2	86.0	61.0	68.7	74.6	68.1	64.4	64.9	66.1	68.8
3	85.5	86.3	61.5	69.6	75.0	67.4	63.8	66.0	67.6	67.8

Site C: Microphone 1

Project Description : Troy, Ohio I-75 Noise Barrier Test

Node: 7	Site Type:	BEFORE	Equivalent BEFORE	AFTER	Mic Location:	Ref.	Receiver	Direction from Source to Receiver (° from North)
				X			X	86°

Site Description: Intersection of Cheshire Rd & Heather Rd. in Troy, OH (5 m from Noise barrier)

Source Description: I-75 traffic flowing freely

Terrain Description: Flat terrain between two apartment complexes.

Ground category description: Soft ground, short thick grass

Initial Calibration	94.6	**dBA**	**Sensitivity Shift Factor: (dB)**	0.45
Final Calibration	93.7	**dBA**		

Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	1:03:41	1:19:12	0:15:31	1.5	358	Calm	72	3	773	46	135	8	3
2	1:21:43	1:37:14	0:15:31	1.5	358	Calm	72.5	3	823	45	176	2	2
3	1:39:45	1:50:46	0:11:01	1	358	Calm	73	3	712	32	107	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	63.2	69.5	36.3	38.0	42.7	36.0	36.0	43.0	54.5	57.5
2	63.9	69.3	36.5	36.0	36.0	36.0	36.0	36.0	55.8	60.1
3	62.3	68.6	36.1	36.0	40.0	36.0	37.9	36.0	51.9	62.9

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	68.7	76.4	41.0	43.5	49.7	46.0	51.2	58.1	64.3	69.7
2	69.6	76.9	41.8	44.7	50.9	46.6	51.2	57.7	64.8	70.4
3	69.4	76.9	41.7	44.5	50.5	46.3	51.0	59.2	64.4	70.2

Site C: Microphone 2

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	19	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
					X			X	86°
Site Description: Intersection of Cheshire Rd & Heather Rd. in Troy, OH (25 m from Noise barrier)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat terrain between two apartment complexes.									
Ground category description: Soft ground, short thick grass									
Initial Calibration	94.4	**dBA**	**Sensitivity Shift Factor: (dB)**	0.5					
Final Calibration	93.4	**dBA**							
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	1:03:31	1:19:03	0:15:32	1.5	358	Calm	72	3	773	46	135	8	3
2	1:21:33	1:37:05	0:15:32	1.5	358	Calm	72.5	3	823	45	176	2	2
3	1:39:35	1:50:36	0:11:01	1	358	Calm	73	3	712	32	107	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	56.8	61.0	36.8	36.0	36.0	36.0	36.0	36.0	42.8	54.4
2	58.5	63.4	37.3	36.0	36.3	36.0	36.0	38.6	47.6	56.6
3	56.8	62.2	36.4	36.0	36.0	36.0	36.0	36.8	42.2	57.6

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	61.8	69.9	37.6	34.7	41.7	38.3	42.3	50.1	57.5	64.1
2	63.2	70.6	38.4	37.2	44.0	39.4	42.3	49.8	57.4	65.1
3	62.4	70.4	38.0	35.9	42.5	38.5	42.1	50.6	57.4	64.9

Site C: Microphone 3

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	6	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
					X			X	86°

Site Description: Intersection of Cheshire Rd & Heather Rd. in Troy, OH (50 m from Noise barrier)

Source Description: I-75 traffic flowing freely

Terrain Description: Flat terrain between two apartment complexes.

Ground category description: Soft ground, short thick grass

Initial Calibration	94.6	**dBA**	**Sensitivity Shift Factor: (dB)**	0.4
Final Calibration	93.8	**dBA**		

Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	1:05:34	1:21:06	0:15:32	1.5	358	Calm	72	3	773	46	135	8	3
2	1:21:21	1:36:52	0:15:31	1.5	358	Calm	72.5	3	823	45	176	2	2
3	1:39:23	1:50:24	0:11:01	1	358	Calm	73	3	712	32	107	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	57.0	62.5	36.0	36.0	36.0	36.0	36.0	36.0	42.6	57.8
2	58.4	64.0	36.0	36.0	36.0	36.0	36.0	36.0	40.3	56.7
3	57.1	62.9	36.0	36.0	36.0	36.0	36.0	37.3	46.2	55.9

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	60.8	68.2	37.9	36.0	40.4	36.2	40.9	48.7	54.7	62.6
2	63.4	69.7	39.4	39.7	44.8	38.4	41.6	49.0	55.4	64.1
3	61.1	69.0	37.8	36.0	40.3	37.0	42.0	50.2	56.3	63.0

Site D: Microphone 1

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 3	Site Type:	BEFORE	Equivalent BEFORE	AFTER	Mic Location:	Ref.	Receiver	Direction from Source to Receiver (° from North)
				X			X	86°

Site Description: Water retention ditch at the end of Heather Rd. Near intersection with Main st. (28 m from Noise barrier)

Source Description: I-75 traffic flowing freely

Terrain Description: Retention ditch between noise barrier and SSAM unit (~2-3 m deep)

Ground category description: Soft ground, short thick grass

Initial Calibration	94.1	dBA	Sensitivity Shift Factor: (dB)	0.05
Final Calibration	94	dBA		

Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	1:05:05	1:20:39	0:15:34	1.5	358	Calm	72	3	773	46	135	8	3
2	1:23:09	1:38:41	0:15:32	1.5	358	Calm	72.5	3	823	45	176	2	2
3	1:41:12	1:49:57	0:08:45	1	358	Calm	73	3	712	32	107	1	1

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	57.8	65.3	36.0	36.0	36.0	36.0	36.0	37.6	50.5	58.5
2	59.3	66.2	36.0	36.0	36.0	36.0	36.0	40.5	52.4	59.8
3	60.1	67.7	36.3	36.0	37.8	36.0	36.0	40.9	55.4	59.8

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	68.0	75.4	40.5	43.5	49.0	45.4	48.1	58.6	63.1	68.4
2	70.0	76.1	44.0	46.8	51.7	48.6	49.2	57.4	63.3	69.2
3	68.3	75.2	40.7	44.5	49.9	44.6	47.0	55.4	62.9	68.9

Site E: Microphone 1

Project Description : Troy, Ohio I-75 Noise Barrier Test								
Node: 7	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
			X			X		90°
Site Description: Field south of Troy Christian School (5 m from nominal noise barrier location)								
Source Description: I-75 traffic flowing freely								
Terrain Description: Flat ground between road and empty field lot								
Ground category description: Soft ground, freshly mowed thick grass								
Initial Calibration	94	**dBA**	**Sensitivity Shift Factor: (dB)**		-0.2			
Final Calibration	94.4	**dB**						
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.								

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	3:52:22	4:07:56	0:15:34	1.6	90	UW	72.5	3	828	36	126	0	1
2	4:08:11	4:23:43	0:15:32	<1	N/A	Calm	72	3	683	35	121	4	0
3	4:23:58	4:39:32	0:15:34	1.2	350	Calm	68	3	635	22	160	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	62.8	68.9	39.9	39.7	43.7	36.0	41.4	47.9	53.9	58.9
2	69.4	72.6	42.3	44.1	53.4	36.0	42.0	50.7	57.6	56.7
3	67.6	69.4	43.2	49.0	55.5	38.1	36.5	46.1	55.3	58.1

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	80.7	82.4	56.7	64.5	67.2	55.4	57.8	64.5	69.0	68.7
2	81.4	83.3	57.0	64.7	68.1	55.6	58.0	65.3	70.6	69.4
3	80.7	82.3	56.5	64.6	68.2	54.5	56.9	63.3	67.8	69.4

Site E: Microphone 2

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	3	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X				X	90°
Site Description: Field south of Troy Christian School (25 m from nominal noise barrier location)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat ground with interspersed trees									
Ground category description: Soft ground, freshly mowed thick grass									
Initial Calibration		93.4	**dBA**	**Sensitivity Shift Factor: (dB)**			0		
Final Calibration		93.4	**dB**						
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	3:51:56	4:07:27	0:15:31	1.6	90	UW	72.5	3	828	36	126	0	1
2	4:07:42	4:23:14	0:15:32	<1	N/A	Calm	72	3	683	35	121	4	0
3	4:23:29	4:39:01	0:15:32	1.2	350	Calm	68	3	635	22	160	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	58.0	66.1	36.0	36.0	36.0	36.0	36.0	47.3	53.4	57.8
2	62.3	65.4	36.0	36.0	41.4	36.0	36.0	43.9	53.8	54.7
3	60.4	65.8	36.0	37.3	43.1	36.0	36.0	46.5	49.1	56.8

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	72.7	76.4	47.7	53.7	56.2	46.8	51.2	59.6	64.6	65.9
2	73.5	77.0	48.6	55.1	57.4	47.3	51.6	60.6	65.7	65.7
3	73.1	76.3	48.3	55.3	57.3	46.2	50.5	58.8	64.7	65.3

Site E: Microphone 3

Project Description : Troy, Ohio I-75 Noise Barrier Test									
Node:	11	**Site Type:**	**BEFORE**	**Equivalent BEFORE**	**AFTER**	**Mic Location:**	**Ref.**	**Receiver**	**Direction from Source to Receiver (° from North)**
				X				X	90°
Site Description: Field south of Troy Christian School (50 m from nominal noise barrier location)									
Source Description: I-75 traffic flowing freely									
Terrain Description: Flat ground with interspersed trees									
Ground category description: Soft ground, freshly mowed thick grass									
Initial Calibration	93.5	**dBA**	**Sensitivity Shift Factor: (dB)**	-0.1					
Final Calibration	93.7	**dB**							
Method to Determine Background Noise: Minimum F-time weighted dBA measurement recorded.									

Basic Data

Run	Start Time (MST)	End Time (MST)	Duration	Wind Speed (m/s)	Wind Dir. °	Wind Class	Temp (°F)	Cloud Cover Class	Source Operating Data A	MT	HT	M	B
1	3:52:19	4:07:50	0:15:31	1.6	90	UW	72.5	3	828	36	126	0	1
2	4:08:06	4:23:37	0:15:31	<1	N/A	Calm	72	3	683	35	121	4	0
3	4:23:53	4:39:24	0:15:31	1.2	350	Calm	68	3	635	22	160	0	0

Background Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	55.8	65.3	36.0	36.0	36.0	36.0	36.0	40.4	48.6	54.9
2	57.5	63.6	36.0	36.0	36.1	36.0	36.0	42.4	47.7	56.2
3	57.5	61.8	36.0	36.0	36.0	36.0	36.0	36.0	40.5	52.0

Source Level

Run	dBA	dBF	2828-5656 Hz (dB)	1414-2828 Hz (dB)	707-1414 Hz (dB)	354-707 Hz (dB)	177-354 Hz (dB)	88-177 Hz (dB)	44-88 Hz (dB)	22-44 Hz (dB)
1	65.8	73.1	40.7	42.7	45.4	41.5	48.0	57.9	63.1	63.4
2	67.4	73.9	42.6	45.6	47.6	42.3	48.6	58.1	64.4	63.8
3	67.1	72.8	42.9	46.4	47.8	40.8	47.0	56.1	61.8	63.8