Memorandum

U.S. Department
Of Transportation

Research and Special Programs Administration

Subject: HAARP Diesel Engine-Generator(s) Noise Study

Date: January 7, 2005

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Reply to Attn. of: DTS-34

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1. Introduction

This document presents the results and corresponding analysis of an outdoor noise measurement program conducted by the John A. Volpe National Transportation Systems Center's Acoustic Facility (Volpe Center) at the United States Air Force's High Frequency Active Auroral Research Program antenna array (HAARP) in Gakona, AK from September 27th through 30th, 2004. Specifically, the noise generated by the on-site diesel power plant driving the HAARP antenna array was investigated in this study. This power plant consists of a single diesel engine driving a generator inside the main HAARP facility building, with the cooling and exhaust mounted on opposite sides of the building. The acoustic team, consisting of Eric Boeker of the Volpe Center and Jim Battis of the U.S. Air Force (USAF), performed noise measurements at eight locations equally-spaced around the power plant installation to characterize the existing noise levels of the HAARP power plant, and at a ninth location on the edge of the USAF facility to evaluate the HAARP-generated noise levels at the closest neighboring piece of private property. Three 10-minute-long samples representing the maximum engine-generator loading (resulting in the maximum expected noise levels from the power plant) were broadcast by the HAARP antenna array on September 29th, 2004; and 1-second, A-weighted equivalent sound pressure levels (1-second L_{Aeq}) were measured with slow response at all measurement locations (as well as 1/3-Octave, Un-weighted spectral data for three microphones near the cooling port, the exhaust port, and at the adjacent private property).

In 1993, the noise levels generated by this diesel power plant were evaluated in the Environmental Impact Statement (EIS) for the HAARP project, and deemed to be acceptable. However, the HAARP project has changed substantially since then, and in order to facilitate the planned expansion of the HAARP antenna array (which is almost complete), the HAARP power plant needs to be expanded to a total of five engine-generator pairs. Therefore, this noise study was not only conducted in order to evaluate the noise output of the existing power plant, but also to utilize that collected information to estimate the noise output for a five-fold expansion of the power plant, and to assess the compliance of the HAARP power plant (both one and five engine-generator configurations) against applicable noise regulations and standards. The findings and recommendations of this noise study will then be incorporated into the environmental reevaluation of the HAARP EIS.

This memorandum is broken up into six sections. First, the overall purpose of the noise study is presented. Second, the applicable standards and regulations are discussed, and a resulting set of compliance criteria are distilled for this study. Next, section four covers the measurement methodology used to collect the HAARP noise data. It covers HAARP engine-generator operational characteristics, descriptions of the measurement site and microphone locations, a short description of the measurement equipment, and a short overview of the data collection procedure utilized during the measurement program. In section five, the data processing effort is presented, consisting of acoustic data processing procedures, verification of data quality, the calculation of the noise metrics, and the extrapolation of the noise data to account for the operation of five engine-generators. The noise data are then analyzed for compliance with the applicable standards and regulations, and the results are presented in section six. The final two sections of this memorandum consists of a presentation of conclusions, followed by recommendations for future work.

2. Purpose

This study is part of an environmental reevaluation of the 1993 EIS for the HAARP project. There are plans to expand the power plant to include five such diesel engine-generator configurations all within the existing building. The purpose of this study is to characterize the power plant noise levels, estimate the sound levels emitted from the power plant when all five engines are operating, and compare those estimated sound levels against applicable regulations. This study will quantify the noise output from the HAARP diesel engine-generator(s), and based on existing impact criteria determine if the resulting noise levels are negatively impacting areas outside of and neighboring the HAARP facility.

3. Standards and Regulations

3.1. Standards Governing Measurement and Data Analysis Procedures

Although there are no common standards or regulations that directly govern the noise levels generated by the HAARP power plant (i.e., noise from a diesel engine-generator facility), several regulations and standards do address similar topics, and can be effectively applied to the HAARP noise study. The primary standard utilized in this noise study is the International Organization for Standardization 6190 (1988-12-15) (ISO 6190) Acoustics - Sound Pressure Levels of Gas Turbine Installations for Evaluating Environmental Noise - Survey Method. This standard only addresses gas turbine facilities (not diesel) and does not stipulate noise level compliance criteria, but it does present pertinent recommendations for the noise metric (A-weighted equivalent sound level, L_{Aeq}, and A-weighted maximum sound level with slow response, L_{ASmx}), measurement sites (microphone locations, definition of the installation, acceptable atmospheric and background noise conditions), measurement instrumentation (instrumentation standards and microphone height) and data processing (data correction and averaging). Of particular interest to this project were the ISO 6190 specifications of measurement locations (a minimum of 8 measurement locations approximately equally spaced around the facility at distances around 100 m [based on the size of the installation]), the collection of A-weighted equivalent sound levels, and the energy averaging of the L_{Aeq} values across all microphones to calculate the value used for characterizing the average noise levels produced by the installation. Because of the numerous similarities between gas turbine and diesel power plant facilities, as well as the noises they generate, the procedures and criteria presented in this section were determined to be a solid foundation for the HAARP noise measurement program.

Due to some geographical limitations at the HAARP installation (e.g., dense forest and undulating terrain), the majority of the microphones had to be positioned 50 m from the installation instead of 100 m. Although this differs from the microphone distances presented in ISO 6190, it was considered acceptable because the procedure is utilized to characterize the noise levels generated by the HAARP power plant, and not comply with specific noise level criteria. Other than that, ISO 6190 was the basis of the measurement and analysis procedure developed for this noise measurement program. These procedures will be discussed in more depth in Sections 4, Measurement Methodology; Section 5, Data Processing; and Section 6, Analysis, of this memorandum.

3.2. Standards Governing Noise Impact Criteria

The noise level compliance for the HAARP engine-generator(s) was compiled from several federal noise regulations, including regulations from the U.S. Environmental Protection Agency (EPA); branches of the U.S. Department of Transportation (USDOT), such as the Federal Railroad Administration (FRA), the Federal Aviation Administration (FAA), and the Federal Transit Administration (FTA); and the U.S. Department of Housing and Urban Development (HUD). These regulations are summarized below in Table 1. The two additional metrics presented in this Table are the sound pressure level exceeded 90% of the time during a measurement, L_{90}, and the average sound level over a 24 hour period with an adjustment for the night time sound levels to account for increased noise sensitivity, or the day-night equivalent sound pressure level, L_{dn}.

Agency	Regulation	Metric	Measurement Location	Compliance Level
EPA, FRA	40 CFR Part 201.11, 49 CFR Part 210 Appendix A	L_{90}	Nearest neighboring residence, or receiving property	≤ 65 dB(A) + 2 dB tolerance (which effectively means ≤ 67 dB(A))
FAA	14 CFR Part 150.21	L_{dn}	Receiving property	≤ 65 dB(A)
HUD	24 CFR Part 51.101	L_{dn}	Receiving property	≤ 65 dB(A)
FTA	"Transit Noise and Vibration Impact Assessment" report (DOT-T-95-16)	L_{dn}	Receiving property	≤ Ambient Noise Level (in dB(A)) + 10 dB, if the ambient noise < 43 dB(A)

Table 1. Standards and Regulations applied to the HAARP Noise Measurement Study

The EPA and FRA regulations were utilized in this study, because they are used to measure noise from stationary switcher locomotives operating exclusively in railyards. The noise levels generated by the operation of a stationary switcher locomotive are very similar to the noise levels from the HAARP power plant, especially since the EMD Model 20-645-E4 diesel engine utilized in the power plant is actually a locomotive engine operating at a fixed location inside the boundaries of the HAARP facility. The FAA and the HUD criteria were also used because they characterize maximum noise levels at residents near continually operating, prominent noise sources. The same applies to the FTA noise impact criteria, with the extra caveat to account for noise impacts for residences in areas with noticeably lower background noise levels, where noise levels could potentially impact their quality of life well below the compliance levels laid out in the corresponding regulations. In the noise measurement study associated with the New Jersey Expanded East Coast Plan (1991), similar changes in exposure criteria were used to evaluate noise impacts in New Jersey from aircraft over-flights in quiet, rural areas, where the resulting noise levels were well below the FAA's 65 dB(A) L_{dn} criterion. The FTA criterion is also especially important when considering noise from the HAARP facility, given the constant, low background noise levels in rural Alaska.

Although the HAARP facility is a workplace, the area surrounding the generator building was not evaluated for compliance with the EPA employee personal noise exposure regulation (29 CFR Part 1910.95) because of the limited amount of time the HAARP staff spends outside the building during operations. Furthermore, no inference can be made from the collected data with regards to employee noise exposure inside the HAARP power plant building; an assessment which was not within the scope of the current study.

4. Measurement Methodology

4.1. HAARP Generator Description and Operational Characteristics

The HAARP generator is an EMD Model 20-645-E4 diesel locomotive engine driving a Baylor Model G855VRV-362 generator inside a building, with the cooling and exhaust mounted on opposite sides of the building. A muffler is used on the exhaust, and there is a horizontally mounted fan operating with the cooling system. The building also houses numerous offices, a control room, etc. The engine-generator is mounted in a large room, and there are plans to expand the power plant to include five such diesel engine-generator setups, all within the same room in the existing building. All the exhaust ports will go to one side of the building, and all of the cooling will be located on the other. The cooling fans are said to have a noticeable, high frequency component. The building itself is on a concrete slab, is made of metal, and is surrounded by a relatively flat gravel area or pad. The nearest residence is approximately 3200 m (2 miles) away, and approximately 250 m (820 ft) from the closest edge of the building is the Tok Cutoff Highway and nearest neighboring piece of private property. The HAARP building and the surrounding area are documented below in Figure 1.

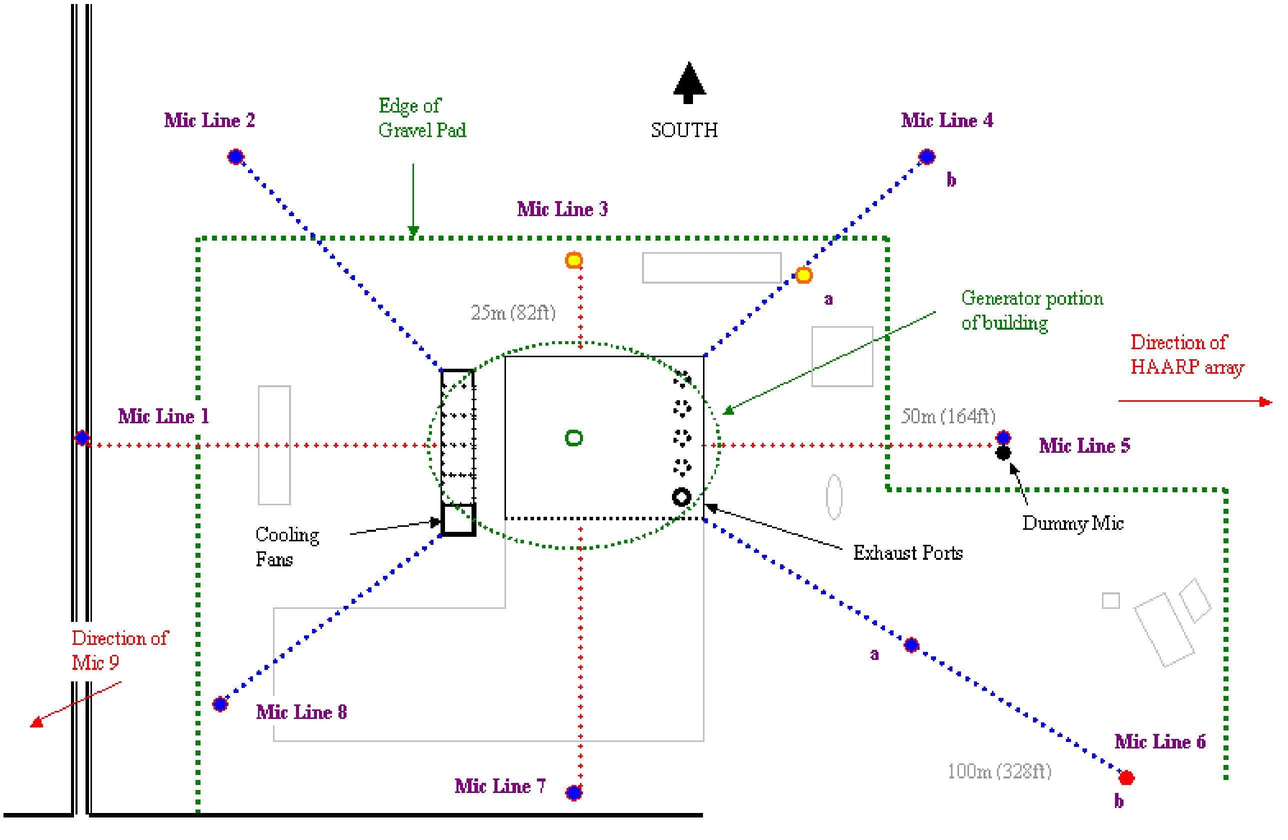


Figure 1. HAARP Building and Noise Measurement Positions 1 through 8

As far as diesel engine operation is concerned, the noise levels produced during it's operation were essentially steady-state. However, this is only after it had warmed up, and it is a fairly long and involved procedure to turn on and off the generators. Although the HAARP array can be operated at various engine-generator loadings (dependant upon the signal being broadcast), the signal used for this study resulted in a continuous, full loading (80% load, or full load) on the HAARP power plant. This signified the maximum loading that the HAARP array is expected to generate during normal operations, and therefore conservatively assumed to be the loudest noise level. Three 10-minute-long full load signals were broadcast on September 29th, 2004 starting at 09:19:30 GMT as part of this noise measurement program.

4.2. Measurement Site and Microphone Locations

The noise measurements took place in 8 locations, that were 50 m (164 ft) from the power plant portion of the HAARP building (with the exception of Mic 3), and equidistant from each other at 45 degree increments (see Figure 1). This included a microphone lined up with the cooling fan (Mic 1) and another lined up with the exhaust port (Mic 5), the later being the expected noisiest position outside of the power plant building according to Vol. II of the EIS. Because of the limited free space around the HAARP building and because the exhaust and cooling fans were ported outside of the engine-generator room/building, only the portion of the HAARP building encompassing the power plant room and the exhaust and cooling ports was considered to be the power plant installation for determining microphone locations according to ISO 6190.

Even though the measurement distances were reduced from 100 m (328 ft) to 50 m from the HAARP building due to topographical constraints, the measurement area on the gravel pad surrounding the building was further limited by the surrounding terrain for one of the microphone lines (Mic Line 3). Unfortunately, most of Mic Line 3 was concealed by dense tree and vegetation cover, and the farthest available microphone position was on the gravel pad 25 m (82 ft) from the nearest side of the HAARP building. This differing distance was accounted for during the data processing through the application of an average drop-off rate (see Section 5). To measure the drop-off rate, both 25 m and 50 m microphones were deployed for the neighboring mic line (Mic Line 4), and a second microphone was also setup on Mic Line 6 at a 100 m location.

A final measurement microphone (Mic 9) was setup at the turnoff from the Tok Cutoff Highway onto the HAARP access road (see Figure 2). This measurement position was located approximately 250 m (820 ft) from the closest edge of the "installation" roughly along Mic Line 8, and represents the nearest potential location for neighboring residential building to the HAARP facility. Currently, the closest residence to the HAARP facility is approximately 3200 m (2 miles) away.

Figure 2. Photograph from the Tok Cutoff Highway of Measurement Position 9

In order to monitor potential HAARP radio interference on the acoustic measurement system, an additional sound level meter was stationed side-by-side with Mic 5. This additional meter was mounted with a "dummy" microphone simulator, and recorded the electronic noise floor of the sound level meter for the duration of the entire measurement period. Electromagnetic interference from the HAARP array (or any other nearby source) during the noise measurements at that location could impact the noise floor of this system. In addition, a microphone simulator test was performed as part of the system checkout and calibration of each measurement system.

All the microphones were setup on tripods at heights of 1.5 m (5 ft) above the ground, were oriented at grazing incidence to the facility, and were not located near any large reflecting objects (see Figure 3). Unfortunately, the HAARP building and surrounding gravel pad are up on a small hill, and as a result microphones 1, 2, 8 and 9 are all below the plane of the base of the HAARP building, and the bases of Mics 4b and 5 were also lower than the base of the HAARP building by approximately 1 m. Still, all the microphones had clear line-of-sight to the HAARP building (see Figure 4). However, microphones 7, 8 and 9 did not have line-of-sight to the power plant portion of the building because they were blocked by other portions of the HAARP building. In addition, there was a temporary structure near the main building (used by the company installing the additional engine-generators) that partially blocked the line-of-sight to the cooling fans and the installation from Mic 1, and another permanent structure near both Mic Lines 4 and 5, that also blocked a small portion of the line-of-site to both Mics 4b and 5. Although ISO 6190 does not restrict terrain elevation changes, it does specify that all terrain variations should be documented and considered during the analysis.

Figure 3. Setup at Measurement Position 4b

Figure 4. Measurement Position 6a in the Snow Facing the HAARP Facility

4.3. Measurement Equipment

For this noise measurement study, Larson-Davis model 820 Environmental Analyzers (LD-820, which are integrating-averaging sound level meters) were employed at microphone positions 2, 3, 4a, 4b, 6a, 6b, 7 and 8. The LD-820s were tripod mounted and used in conjunction with Brüel &Kjær (B&K) model 4189 microphones and B&K model UA 0237 windscreens. An additional LD-820 sound level meter mounted with a "dummy" microphone simulator was stationed side-by-side with Mic 5 (Dummy Mic). Larson-Davis model 824 Integrating Sound Level Meters/Real Time Analyzers (LD-824) were deployed at the remaining measurement positions (Mics 1, 5 and 9), in order to collect 1/3-Octave frequency data along with sound pressure levels. The LD-824s were tripod mounted and used in conjunction with GRAS model 40AE microphones and B&K model UA 0237 windscreens. The LD-824s were utilized at the microphone locations nearest to the cooling and exhaust ports, in order to evaluate any tonal characteristics that might be present at either port. The LD-824 setup at the cooling fan position (Mic 1) was also connected to a Sony model TCD-D100 DAT recorder, in order to record the time history data as a backup. B&K model 4231 Sound Level Calibrators were also used on this measurement program. All the acoustic instrumentation conformed to the corresponding American National Standards Institute (ANSI) and International Electrotechnical Commission (IEC) standards.

Meteorological data were collected by the HAARP facility's in-house weather station. All of the measurement positions were identified using a measuring tape and compass, and a hand-held GPS receiver was used for documentation purposes only.

4.4. Data Collection

Prior to the noise measurements, all of the measurement positions were scoped out, documented and marked with a flagged piece of rebar. Since the measurement positions were so spread out around the building and since the weather conditions were generally unfavorable, all of the measurement systems were assembled and calibrated at a central location back at the HAARP building and later deployed to their designated positions. An electronic noise floor test was also performed for each measurement system at this central location. After the weather conditions had cleared up, the noise measurement systems were deployed at their measurement locations, secured to rebar, and prepared for the noise measurements. Once secured, an additional calibration tone was recorded at each microphone immediately before the commencement of the noise measurements. Time and weather constraints did not allow for additional microphone simulator measurements at each deployed location.

The acoustic instrumentation collected noise data over the three consecutive 10-minute long full-load signals. The Dummy Mic also collected electronic noise floor data over this entire measurement interval. Once completed, a final calibration tone was recorded at each measurement system.

After the HAARP diesel engine-generator had been powered-down and all of the associated noises from the HAARP facility had subsided, background noise measurements were conducted. Because it took so long for the HAARP power plant to warm up and shut down, and because the HAARP staff could not substantially deviate from their operational schedule (which resulted in approximately 7 hours of broadcasting with the full-load signals near the very end), background noise was only collected immediately following the noise measurements. It was collected at microphones 1, 5, 6a, 6b and 9. Due to time and meteorological constraints, background noise could not be collected at each measurement position. All of the background noise measurements were followed up by the measurement of another calibration signal. Complications during the measurement program are discussed in Appendix A.

5. Data Processing

5.1. Acoustic Data Processing Procedures and Verification of Data Quality

For each measurement system, the initial and final calibration, the electronic noise floor, and the background noise measurements (if collected) were investigated. The initial and final calibration measurements were compared to see if any calibration drift had occurred, and needed to be accounted for. In all cases, the calibration drift was less than 0.3 dB(A) over the course of the measurements, so no calibration adjustments needed to be implemented[1]. This is a good indicator that the noise instrumentation performed properly over the course of the noise measurements, even under the severe temperature and meteorological conditions.

The electronic noise floor data measured by each sound level meter was also investigated along with the noise floor data collected by the "dummy" microphone during the measurements. All electronic noise floor measurements were below 20 dB(A) and steady in level over time, including the measurements corresponding to the HAARP full load broadcasts, so the effects of electromagnetic interference (especially from the HAARP array) on the noise instrumentation during the course of the noise measurements were considered to be negligible.

Once the calibration and electronic noise floor data had been checked and verified, the noise data could be processed. The noise data for each microphone corresponding to the HAARP full-load broadcasts (three 10-minute broadcasts) were separated out from the rest of the data, and organized into 5-minute-long data blocks for processing purposes. From this data, the metrics were calculated (see Appendix B).

To further verify data quality, the background noise was collected at several measurement positions surrounding the HAARP building (Mics 1, 5 and 6a) and averaged to produce an average background noise level of 37.9 dB(A). The background noise was also collected near the Tok Cutoff Highway at Mic 9 and determined to be 40.1 dB(A), where the slightly higher noise levels may be explained by the closer proximity to roadway noise sources and less absorptive tree cover. The background noise data is presented in Appendix C. The average background noise level of 37.9 dB(A) was considered representative for microphones 1 through 8, while microphone 9 was compared only to the background noise collected at that site. Background noise collected at Mic 9 was also used as an estimate for the average background noise levels further away from the HAARP facility. It is important to note that these background noise levels were collected over a short period of time at night in the winter. Longer background noise measurements (as well as multiple background noise measurements) could have better characterized the ambient noise levels surrounding the HAARP facility. Furthermore, the background noise could have substantial variation from day to night and from season to season. However, one might speculate that late night ambient noise measurements during the winter in rural Alaska would be lower than average for the background noise levels at the facility. Regardless, time and weather conditions did not allow for extensive background noise measurements (see Appendix A), so the background noise levels used in this study were based on the best available data.

[1] The manufacturer' specified accuracy for the model 4231 calibrator is 0.3 dB.

As mentioned in Section 3 of this memorandum, ISO 6190 specifies background noise criteria that need to be considered during data processing. If the background noise was more than 10 dB below the measured noise levels at a specific microphone (evaluating each $L_{Aeq\ 5min}$ data block), then the background noise was considered to have no effect on the HAARP noise measurements and could be ignored[2].

This was the case with all the noise measurements except for the data collected at microphones 8 and 9. The average background noise was between 3.2 and 8.6 dB(A) below the $L_{Aeq\ 5min}$ calculated for each data block at Mic 8. Therefore, the noise from the power plant was acoustically discernable from the background noise, but was still affected by the background noise. To properly account for background noise within 10 dB but greater than 3 dB of the collected noise data, ISO 6190 also specifies a background noise adjustment factor to be applied to the collected noise data. These adjustment factors were applied to each noise data block for Mic 8, and the metrics were recalculated. Unfortunately, the noise levels measured at Mic 9 were much closer to the background noise, falling within 1.6 to 3.9 dB(A). Since the difference between the background noise levels and the L_{Aeq} values of a couple of these data blocks were less than 3 dB(A), those data blocks were not considered to be discernable from the background noise, and had to be discarded. The Mic 9 data blocks that did meet the ISO 6190 background noise criteria were analyzed in this study. Furthermore, the fact that in several cases the HAARP engine-generator noise was not distinguishable from the background noise at Mic 9 will be discussed further in Section 6 of this memorandum.

5.2. Calculation of Metrics and Presentation of Data

After the noise data were processed, the desired noise metrics were calculated. For data reduction purposes, the A-weighted equivalent sound pressure level for each 5-minute-long data block at each measurement system, $L_{Aeq\ 5min}$, and the corresponding, un-weighted 1/3-Octave spectrum (if collected) were calculated (see Appendix B). The $L_{Aeq\ 5min}$ metrics are presented in Appendix C, along with the maximum and minimum sound pressure levels and standard deviation across each data block. The associated spectral data are discussed in Section 6. The 30-minute-long, A-weight equivalent sound pressure levels, $L_{Aeq\ 30min}$, were then calculated for each 50 m microphone from the corresponding six $L_{Aeq\ 5min}$ values. The resultant $L_{Aeq,\ 30min}$ values are presented below in Table 2.

Microphone	$L_{Aeq\ 30min}$ Levels [dB(A)]
Mic 1	61.9
Mic 2	63.3
Mic 3	56.5
Mic 4b	59.8
Mic 5	55.3
Mic 6a	65.1
Mic 7	49.3
Mic 8	41.2

Table 2. The $L_{Aeq\ 30min}$ Values at Each 50 m Measurement Location

As discussed in Section 4.2, there was not enough room to setup a microphone at 50 m from the HAARP installation along Mic Line 3, because of the dense tree coverage in the area. Therefore, the sound levels at 50m in Mic Line 3 had to be estimated. This was done by calculating an average drop-off rate per double of distance for the HAARP site, 4.7 dB, and applying it to the measured $L_{Aeq\ 5min}$ values for Mic 3 at 25 m (see Appendices B and C). The estimated $L_{Aeq\ 30min}$ at 50 m for Mic Line 3 was then calculated, and is also presented in Table 2.

The average $L_{Aeq\ 30min}$ across all of the 50 m microphones was then calculated, using energy-averaging as specified by ISO 6190. L_{dn} values were also calculated based on the average $L_{Aeq\ 30min}$, as well as the $L_{Aeq\ 30min}$ for Mic 9, making the assumption that those levels would be constant over a 24 hour period. Therefore, both L_{dn} values would be representative of the noise levels produced by the HAARP facility at different locations , if the power plant operated at full-load for a 24-hour-long period. Although, the HAARP facility will probably never broadcast a full

[2] Similar background noise criteria is also presented in ANSI 12.8-1998, Methods for Determining the Insertion Loss of Outdoor Noise Barriers.

load signal for 24 hours straight, these estimated L_{dn} values represent the loudest expected day-night sound levels that could be generated by the HAARP power plant. The average $L_{Aeq\ 30min}$ and L_{dn} values were presented in Table 3.

Microphone	Metrics	Ave. Level [dB(A)]
Average	Ave. $L_{Aeq\ 30min}$	60.4
Average	Ave. L_{dn}	66.8

Table 3. HAARP Average Metrics at 50 m

The $L_{Aeq\ 20min}$ and L_{dn} values were also calculated for Mic 9 separately. The $L_{Aeq\ 20min}$ metric was used for Mic 9 instead of the $L_{Aeq\ 30min}$ metric, because only 20 minutes of noise data was measured in this study, during which there was no background noise interference. The $L_{Aeq\ 5min}$ values making up the $L_{Aeq\ 20min}$ level were also corrected for background noise according to ISO 6190. The L_{90} metric was also calculated for Mic 9. These values are all presented in Table 4.

Microphone	Metrics	Ave. Level [dB(A)]
Mic 9	$L_{Aeq\ 20min}$	41.0
Mic 9	L_{dn}	47.4
Mic 9	L_{90}	39.7

Table 4. HAARP Metrics at Mic 9

In much the same manner as the Mic 3 results were estimated at 50m, the average drop-off rate was applied to the average $L_{Aeq\ 30min}$ per doubling of distance, in order to estimate noise levels at locations further away from the HAARP facility, than where the measurements were performed. This was a rough estimate based on the average drop-off rates observed on two Mic Lines at the HAARP facility, and long distance propagation effects, such as meteorological effects and attenuation from the dense tree cover in the area, were not considered. However, given the aforementioned caveats, this does present a conservative prediction of noise levels that might be observed at various distances from the HAARP power plant, and may even be a little high, due to the lack of long distance propagation effects. These noise levels were estimated out to a distance of 3200 m (2 miles) from the HAARP facility, in order to account for the current nearest private residence to the facility. These results were then used to estimate average L_{dn} values out to 3200 m, which are used to determine compliance with the applicable regulations and are discussed further in Section 6. They are presented in Table 5 (and later in Figure 8).

Distance (m)	Ave. L_{dn} for 1 Engine (estimate) [dB(A)]
50	66.8
100	62.1
200	57.4
400	52.7
800	48.0
1600	43.3
3200	38.6

Table 5. Current HAARP Noise Levels Estimated out to 3200 m from the Facility

5.3. Extrapolation of Noise Data for 5 Engine-Generators and Presentation of Data

The average $L_{Aeq\ 30min}$ was now be used to estimate the average noise output from an expanded HAARP power plant consisting of five identical diesel engine-generators operating at full power simultaneously inside the same installation. It is important to note that not all of the diesel generators will produce the same noise levels, and it is highly unlikely that all five will be operating at full load simultaneously. Furthermore, potential interaction effects between the engine-generators, such as constructive and destructive interference at specific frequencies, were neglected in this extrapolation. Therefore, this extrapolation is expected to be a conservative estimate of the loudest average noise levels produced by the power plant. Since ISO 6190 allows for the entire installation to be considered as a single noise source, the physical location of the engine-generators inside that location may be ignored as long as the cooling and exhaust ports are in the same general areas (which they are). The extrapolated $L_{Aeq\ 30min}$ value was used to calculate the corresponding, extrapolated L_{dn} value for the five-fold expanded HAARP power plant. Then, the extrapolated L_{dn} were estimated out to a distance of 3200 m from the facility, and these results were presented in Table 6 (and later in Figure 8).

Distance (m)	Extrapolated Ave. L_{dn} for 5 Engines (estimate) [dB(A)]
50	73.8
100	69.1
200	64.4
400	59.7
800	55.0
1600	50.3
3200	45.6

Table 6. HAARP Noise Levels Extrapolated to Account for 5 Engine-Generators Estimated out to 3200 m from the Facility

The extrapolated metrics describing the noise output of the five-fold expanded HAARP power plant at Mic 9 were also calculated. The extrapolated $L_{Aeq\ 20min}$ at Mic 9 was determined to be 58.0 dB(A), and the corresponding, extrapolated L_{dn} was calculated to be 54.4 dB(A).

6. Analysis

The analysis of the noise levels produced by the HAARP diesel engine-generator(s) is split into two categories: measured noise levels from the current HAARP power plant installation and extrapolated noise levels for the expanded HAARP power plant installation.

6.1 Analysis of Measured Noise Levels from the Current HAARP Power Plant Installation

The average $L_{Aeq\ 30min}$ level for the HAARP facility at 50 m was 60.4 dB(A), and the corresponding, average L_{dn} was 66.8 dB(A). However, when the $L_{Aeq\ 30min}$ values of the eight microphones used to calculate the average $L_{Aeq\ 30min}$ for the HAARP facility were assessed individually (see Table 2), the noise output of the HAARP power plant is observed to be highly directional. The highest observed sound levels were at Mic 6a near the exhaust ports for the HAARP power plant (65.1 dB(A)), and the lowest sound levels were observed at Mic 8 (41.2 dB(A)), which is in the same general direction of the nearest adjacent private property to the HAARP facility. The energy averaging used to calculate the average $L_{Aeq\ 30min}$ value biased the metric towards the highest measured sound levels. Therefore, it is important to keep in mind that the average $L_{Aeq\ 30min}$ value is a conservative average for the noise output of the HAARP power plant, because of the influence of the highest sound levels observed at the HAARP facility.

The average noise levels and 1/3-Octave noise spectra at microphone positions 1 and 5 (near the cooling and exhaust ports, respectively) were individually analyzed, since it was reported prior to the measurements that the loudest noise levels near the HAARP facility were observed at these general positions. Tonal components were observed in the spectral data measured at these positions. The Mic 1 average spectra showed peaks at 50 and 630 Hz rising as much as 10 dB higher than their neighboring 1/3-Octave bands, as well as a broader peak spanning from 1.6 kHz to 4 kHz (see Figure 5). Smaller peaks around 5 to 7 dB were observed at 125 and 400 Hz in Mic 5's average spectra (see Figure 6). These peaks should correspond to engine, generator and cooling fan operational parameters (blade speed, etc.), but this operational information was not collected on-site. In both cases, these spectra showed very little variation over all six data blocks, and that repeatability from one data block to the next indicated that the HAARP engine-generator was very stable under full-load operation.

Figure 5: Mic 1 - 1/3-Octave, Un-weighted Spectral Data + Background Noise

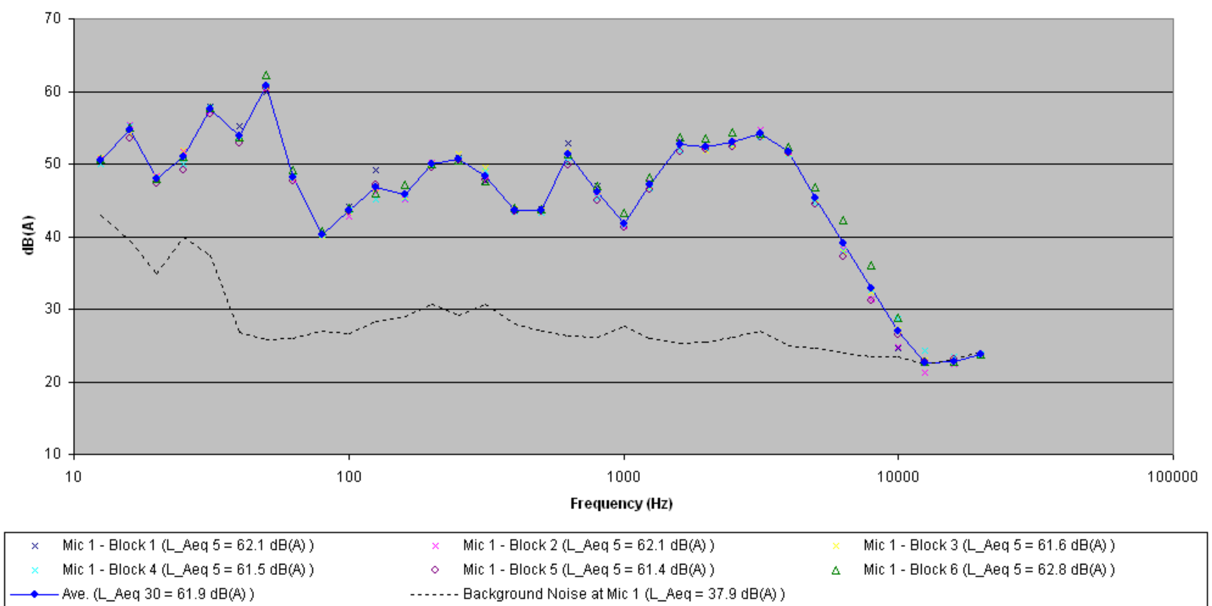
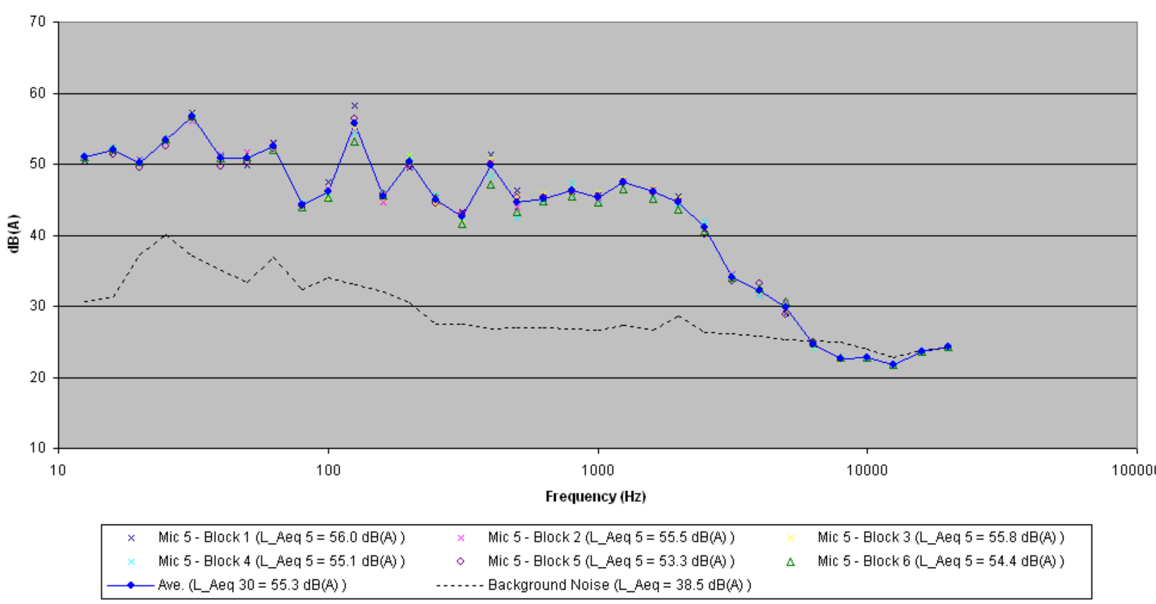
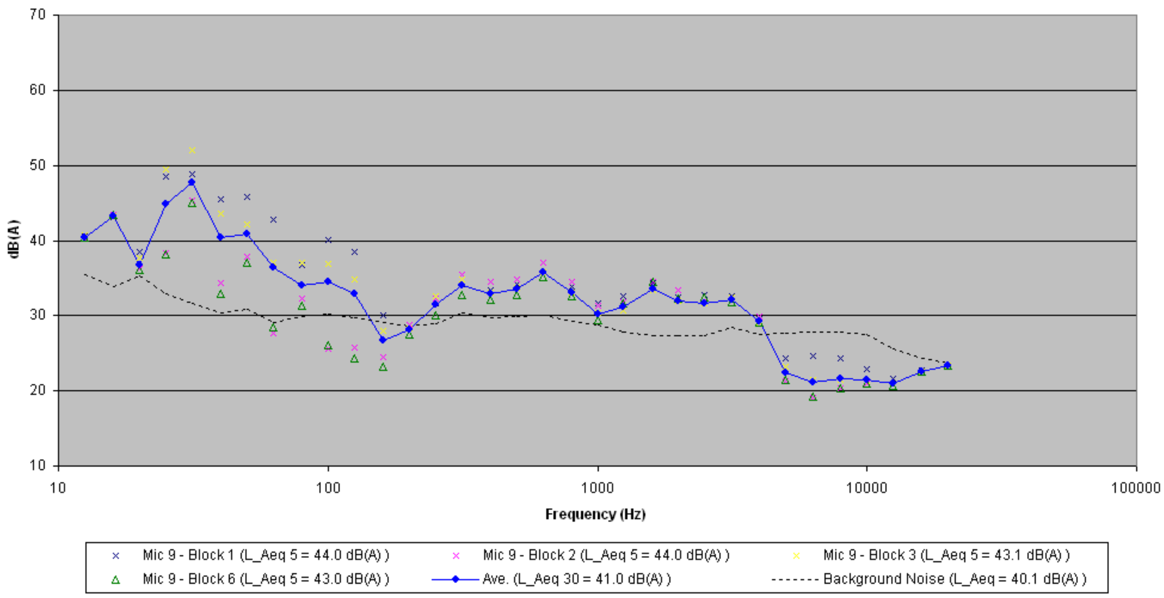


Figure 6: Mic 5 - 1/3-Octave, Un-weighted Spectral Data + Background Noise



1/3-Octave spectral data was also collected at Mic 9 on the property adjacent to the HAARP facility, and they are presented in Figure 7. None of the dominant frequency components observed at Mics 1 and 5 are prominent in the spectra at Mic 9. In fact, the noise levels from the current HAARP power plant were barely audible at Mic 9. Furthermore, two of the $L_{Aeq\ 5min}$ values measured at Mic 9 were considered to not be discernable from the background noise, according to the background noise criteria presented in ISO 6190.

Figure 7: Mic 9 - 1/3-Octave, Un-weighted Spectral Data + Background Noise

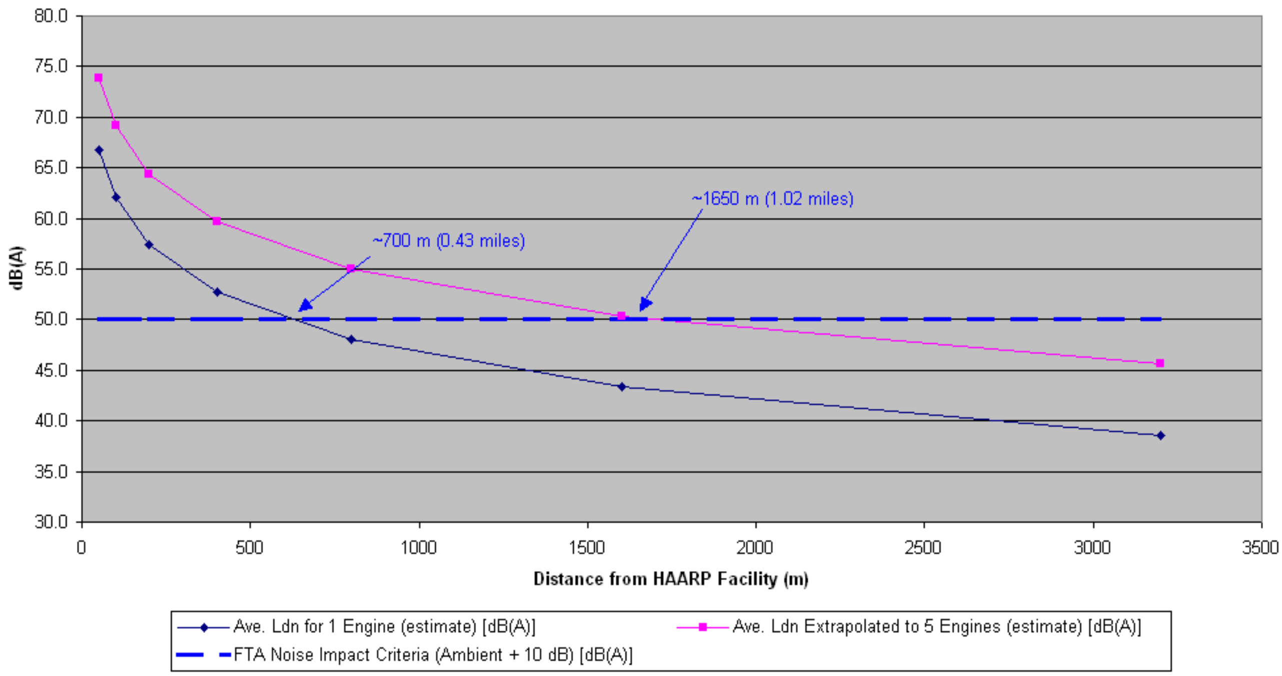


It is important to note that the measured noise spectra for Mic 9 appears to have dropped below the background noise spectrum at several frequencies, as shown in Figure 7. Simply put, overall measured noise levels (which include a noise source and the background noise) cannot drop below the actual background noise level. Therefore, the background noise level must have changed slightly from it's level during the HAARP power plant noise measurements to the level observed during the background noise measurement at Mic 9. The dips below the background noise around 160 Hz and 5000 through 16000 Hz are indicative of the need to collect more extensive background noise data. A longer, more representative sample of background noise would have undoubtedly shown that the background noise dominated all the spectra around 160 Hz and 5000 through 16000 Hz.

L_{90} was also calculated for Mic 9, and was found to be 39.7 dB(A). It is important to note that this value was also lower than the background noise level at Mic 9. Therefore, the L_{90} value was found to be indiscernible from the background noise at the nearest piece of private property adjacent to the HAARP facility.

Next, the average L_{dn} level for the current HAARP power plant was extrapolated out to 3200 m (2 miles) and presented in Figure 8. Since the average HAARP noise levels were biased by the higher noise levels directed towards the center of the HAARP property, it was not surprising that the estimated average noise levels at 250 m were noticeably higher than the measured noise levels at Mic 9, which was also 250 m from the HAARP power plant building. In fact, the L_{dn} value for Mic 9 was approximately 9 dB below the corresponding estimated, average L_{dn} level at 250 m (0.16 miles). This difference was due to (a.) the directionality of the HAARP noise output, and (b.) the lack of long distance propagation effects in the estimated levels, like blocked line-of-site. This difference also suggests that a violation of the FTA noise impact criteria would likely occur, if a residence was built 250 m from the HAARP power plant in the direction of the loudest observed noise levels. It is estimated that the FTA noise impact criterion was met around 700 m (0.43 miles) from the HAARP facility, where the estimated, average L_{dn} value drops below 50.1 dB(A).

Figure 8: Estimated Average Day-Night Sound Pressure Levels near the HAARP Facility as a Function of Distance



6.2 Analysis of Extrapolated Noise Levels from the Expanded HAARP Power Plant Installation

The extrapolated average $L_{Aeq\ 30min}$ for the HAARP facility at 50 m to account for 5 diesel engine-generators inside the facility was estimated to be 67.4 dB(A), and the corresponding extrapolated, average L_{dn} was calculated to be 73.8 dB(A). When considering expected noise levels from a five-fold expanded HAARP power plant at the nearest adjacent property, the extrapolated $L_{Aeq\ 20min}$ level for Mic 9 near the Tok Cutoff Highway was 48.0 dB(A), and the corresponding extrapolated L_{dn} is 54.4 dB. These noise levels would definitely be audible at Mic 9, and the L_{dn} of 54.4 dB(A) would not meet the FTA noise impact criteria.

The extrapolated, average L_{dn} was also estimated out to 3200 m from the HAARP facility (see Figure 8). From this information, it was determined that there should not be a noise impact at receivers further than 1650 m (1.02 miles) from HAARP according to the FTA noise impact criteria, once the HAARP power plant is expanded to include five engine-generator pairs. This includes the current nearest residence to the HAARP facility.

7. Conclusions

7.1. Noise Levels from the Existing HAARP Power Plant

7.1.1. Measured Noise Levels at Adjacent Private Property

Noise data were collected at numerous locations on the HAARP facility, but with regard to potential noise impacts the most applicable data set was collected at Mic 9. Mic 9 was located 250 m from the HAARP power plant installation and represents the closest piece of private property adjacent to the HAARP facility, although there is not currently a residential structure on that property. The noise levels for Mic 9 were compared to each of the applicable regulations discussed in this memorandum, in order to determine if the noise levels generated by the current HAARP power plant were in compliance with their criteria should residential development ever be undertaken at this adjacent private property. The results of that comparison are presented below in Table 7.

Agency Regulation and Guidance[3]	Metric	Compliance Level in dB(A)	Measured Level at Mic 9 in dB(A)	In Compliance (Yes/No)?
EPA, FRA	L_{90}	≤ 67 dB(A))	39.7 dB(A)	Yes
FAA	L_{dn}	≤ 65 dB(A)	47.4 dB(A)	Yes
HUD	L_{dn}	≤ 65 dB(A)	47.4 dB(A)	Yes
FTA	L_{dn}	≤ 50.1 dB(A)[4]	47.4 dB(A)	Yes

Table 7. Noise Levels from the Existing HAARP Power Plant Compared to the Appropriate Standards and Regulations

As seen in Table 7, the HAARP power plant is in compliance with the applicable, federal regulations and criteria, should residential development ever be undertaken on this adjacent property. It is especially interesting to note that the L_{90} level was below the background noise level at Mic 9, indicating that the noise from the HAARP power plant was barely discernable from the ambient during the majority of the measurements at the nearest piece of private property adjacent to the HAARP facility.

7.1.2. Estimated Noise Levels at Nearest Residential Structure

Of particular interest were noise levels at the current, nearest residential structures, approximately 3200 m (2 miles) away from the HAARP Facility. Resources did not allow for direct measurements at this location, but estimates were made based on the measurements that were conducted, along with conservative propagation and plant operational characteristics, as discussed in Section 5.2. The sound level estimated at 3200 m is compared with the applicable noise criteria in Table 8.

Agency Regulation and Guidance	Metric	Compliance Level in dB(A)	Estimated Level at 3200 m in dB(A)	In Compliance (Yes/No)?
FAA	L_{dn}	≤ 65 dB(A)	~38.6 dB(A)	Yes
HUD	L_{dn}	≤ 65 dB(A)	~38.6 dB(A)	Yes
FTA	L_{dn}	≤ 50.1 dB(A)	~38.6 dB(A)	Yes

Table 8. Estimated Noise Levels from the Existing HAARP Power Plant at a Distance of 3200 m Compared to the Appropriate Standards and Regulations

As seen above, the HAARP power plant was estimated to be in compliance with the applicable, federal regulations and criteria concerning noise levels at the current nearest residential structure. In fact, based on the limited amount of ambient measurements made and the estimates shown in Table 7, the noise level generated by the HAARP facility at 3200 m was below the ambient sound level in the general area. It was further estimated that any residential structures more than 700 m (0.43 miles) from the HAARP facility would not be impacted by the current power plant noise levels.

7.2. Extrapolated Noise Levels from the Expanded HAARP Power Plant

The noise levels measured at the nearest piece of private property neighboring the HAARP facility (Mic 9) were extrapolated to account for a total of 5 diesel engine-generator pairs powering the antenna array. These extrapolated noise levels were considered conservative estimates, because they assumed that all five engine-generators will be operating at full-load simultaneously 24 hours a day, and because interaction effects were neglected. The estimated noise levels for the HAARP power plant extrapolated to include 5 engine-generator pairs were also compared to each of the applicable noise regulations and standards. The results of that comparison are presented below in Table 9.

[3] Specific Regulations and Policies are presented in Table 1.
[4] The L_{Aeq} of the background noise at Mic 9 was equal to 40.1 dB(A), and the criteria does specify a L_{dn} of less than or equal to the ambient noise level + 10dB.

Agency Regulation and Guidance	Metric	Compliance Level in dB(A)	Extrapolated Level at Mic 9 in dB(A) [5 Engines]	In Compliance (Yes/No)?
FAA	L_{dn}	≤ 65 dB(A)	54.4 dB(A)	Yes
HUD	L_{dn}	≤ 65 dB(A)	54.4 dB(A)	Yes
FTA	L_{dn}	≤ 50.1 dB(A)	54.4 dB(A)	**No**

Table 9. Extrapolated HAARP Noise Levels for 5 Engine-Generators Compared to the Appropriate Standards and Regulations

As can be seen, the noise levels from the expanded HAARP power plant are expected to be in compliance with both the FAA and HUD regulations, but not with the FTA noise impact criteria, if a residential structure were to be placed as close as 250 m from the facility. Following the same method for estimating noise levels at various distances discussed in Section 7.1.2, it was then estimated that residential structures more than 1650 m (1.02 miles) away from HAARP should not be impacted by the noise from the expanded power plant. This leads to the conclusion that to prevent a noise impact due to the expanded power plant, a buffer zone of at least 1650 m around the HAARP power plant building must be maintained, and no residential development should be undertaken within that zone. Since the current, nearest residential structure to the HAARP facility is approximately 3200 m away, no noise impact is expected from the expanded facility at that location. However, carefully planned land-use must be employed to avoid future noise impacts.

8. Recommendations for Future Work

To more accurately assess the noise levels generated by the expanded HAARP power plant, another noise measurement study should be conducted once all of the engine-generators are installed, the on-site construction has stopped and all of the temporary structures and machinery has been removed from the site. Such a study would allow for additional noise data to be collected with any combination of one to five generators operating at multiple different load settings over several days. A second study would also provide the opportunity to collect more background noise data (before and after the noise measurements at all microphone locations), to collect more spectral data, to collect continuous 24 hour noise data, and to measure at additional measurement sites (more sites neighboring the HAARP property [possibly at the closest residence], and even inside the HAARP control room). This study would be used to definitively verify the compliance of the expanded HAARP power plant with all of the applicable regulations, as well as better characterize the noise levels produced by typical HAARP power plant operations. Furthermore, any additional changes to the HAARP engine-generator, exhaust system (including mufflers) or cooling system designs would warrant another noise study, in order to verify that these changes to the HAARP power plant did not result in a violation of any applicable noise regulations.

Appendix A. Complications during Measurement Program

Unfortunately, several complications arose during the HAARP noise measurements. Although the measurement program was effectively conducted and good quality noise data were collected, the complications and difficulties warrant explanation, in order to effectively document any resulting measurement and processing variations and to serve as a warning to future HAARP noise measurement programs. These complications are addressed under the following categories: Measurement Site, Weather, and Manpower.

The measurement site and the surrounding terrain presented several difficulties for the noise measurement program. First of all, there was not enough space on the gravel pad surrounding the HAARP installation to set up microphones at 100 m measurement positions, as recommended in ISO 6190. On several sides of the facility, dense forests of tall scrub pine trees butted up against the gravel pads, prohibiting microphone placement outside of the gravel pad on those mic lines. In fact, only two mic lines (6 and 8) were clear up to 100 m away from the building. All the other mic lines were limited to 50 m microphone positions, except for Mic Line 3, which was only clear up to a 25 m measurement position. Because of these site complication, 50 m microphone positions were used for this study instead of the 100 m positions recommended in ISO 6190. An average drop-off rate was calculated, and applied to the Mic 3 noise data, in order to estimate a 50 m microphone on Mic Line 3. Ideally, clear 100 m microphone positions on each mic line would have been preferred.

Second, the HAARP building is located on the top of a small hill, and as a results, there is a drop off in terrain on several sides of the building as soon as the gravel pad ends. Specifically, microphones 1, 2, 8 and 9 are all below the plane of the base of the HAARP building, and the bases of microphones 4b and 5 were also lower than the base of the HAARP building by approximately 1 m. Since all microphones had line-of-sight of the HAARP building and ISO 6190 does not specify terrain elevation criteria, the resulting measurement positions are acceptable. However, the ideal measurement setup would be for all of the microphones to be positioned in the same plane: 1.5 m above the base of the HAARP power plant installation.

Third, even though all of the microphones had line of site to the HAARP facility, some of them were partially blocked by other portions of the HAARP facility. Microphones 7, 8 and 9 did not have line-of-sight to the power plant portion of the building because they were blocked by other portions of the HAARP building, and this could potentially result in lower noise levels at those measurement positions. However, this portion of the building is a permanent fixture, and therefore the resulting reduced noise levels should be accounted for in the noise measurements. There was a temporary structure near the building (used by the company installing the additional engine-generators) that partially blocked the line-of-sight to the cooling fans and the installation for Mic Line 1. This structure was not any of the HAARP site maps, and was therefore a surprise upon arrival at the facility. This partial blocking of the line-of-site to Mic 1 could result in slightly lower noise levels at that microphone, which may not be representative of the true noise levels typically experience at that measurement position, once the temporary structure is removed (after the HAARP power plant expansion). Fortunately, the line-of-site to the HAARP installation was only partially blocked, and any corresponding small reduction in noise levels at Mic 1 could be addressed in the averaging across all measurement positions. There was also a second structure blocking a small portion of the line-of-sight from the HAARP facility to both Mics 4b and 5, that had not been accounted for. Since this is a permanent structure, it is acceptable to incorporated the resulting effect noise levels in this analysis.

Adverse weather conditions also effected the HAARP noise measurement program, causing significant delays and additional work (see Figure 9). It snowed all four days allotted for the measurement program at the HAARP facility: September 27^{th} through 30^{th}, 2004. Over a foot of snow accumulated during that time. The snow made outdoor work, such as the scoping of measurement positions and deploying equipment, very laborious, and caused significant delays in travel (to and from Anchorage, as well as to and from Glennallen, the nearest town to the HAARP facility). Since noise measurement may not be performed during measurable precipitation, the measurements had to be delayed on the evening of September 27^{th}-28^{th} and could only be performed during a 6 hour-long precipitation-free window early in the morning on September 29^{th}. Extra precautions were also taken with the noise measurement instrumentation due to the bad weather conditions. All of the meters had to be setup and calibrated at a central location, and deployed with waterproof protection until the weather cleared up. This also resulted in the need for replacement batteries (which did not last as long due to the low temperatures), and multiple recalibrations before the noise data were collected. Unfortunately, weather conditions are outside of the control of the measurement team, so the best possible work was done as these adverse conditions allowed. However, it should be noted that without the acoustically absorptive layer of snow blanketing the ground, the sound levels from the HAARP facility might be slightly louder due to sound propagation over acoustically hard ground surfaces, such as gravel and hard soil.

Figure 9. The HAARP Array during the Snow Storm

Manpower issues were also present on this noise measurement program. Originally, the HAARP on-site staff had agreed to scope, mark and stake all of the microphone positions around the HAARP building prior to the arrival of the measurement team. Unfortunately, other tasks took precedence, and the noise measurement team had to scope and mark all but three microphone positions once they arrived on the site. Due to the adverse weather conditions, additional manpower would also have helped alleviate any delays caused by extended instrumentation setup, deployment, calibration, operations, observations and documentation. If additional manpower would have sped up the setup and deployment of the instrumentation significantly, more HAARP noise data and background noise data could have been collected as part of this measurement program, including (possibly) noise data at the nearest residence to the facility.

Also, these noise measurements took place coincidentally with several construction projects on the HAARP facility. Although the construction was stopped during the noise measurements, it was difficult to work the noise measurements around their schedule, to make sure the construction was not adversely affecting the noise data.

Appendix B. Noise Metrics

Both the LD-820s and the LD-824s were setup to collect A-weighted sound pressure levels with slow responses once a second (1-seond L_{Aeq}) for the entire duration of the measurement interval. In addition, the LD-824s collected Un-weighted 1/3-Octave spectral data once a second. All of the noise data was divided into 5-minute-long data blocks (6 blocks at each microphone) for processing and further analysis. From this noise data, the following metrics were calculated:

(a.) Equivalent Sound Pressure Level for each data block at each microphone in dB(A),

$$L_{AeqT} = 10 \cdot \log_{10}\left(\frac{1}{T} \cdot \sum_{i=1}^{N} 10^{L_{Ai}/10}\right), \qquad \textbf{Equation A}$$

where L_{Ai} = the i-th 1-second, A-weighted L_{eq} in dB(A),
N = the number of 1-second, A-weighted L_{eq} in the data block (300), and
T = the duration of the entire data block in seconds (300 seconds [5 minutes]).

For the five-minute-long data blocks, this metric is written as $L_{Aeq\ 5min}$.

(b.) Equivalent Sound Pressure Level at each microphone for the entire measurement duration in dB(A) (arithmetic average across all the $L_{Aeq\ 5min}$ values for a single measurement position),

$$L_{Aeq\ 30\min} = \frac{1}{M}\sum_{i=1}^{M} L_{Aeq\ 5\min,\, i}, \qquad \textbf{Equation B}$$

where $L_{Aeq\ 5min,\ i}$ = the $L_{Aeq\ 5min}$ level for the i-th data block in dB(A), and
M = number of data blocks (6).

This metric is written as $L_{Aeq\ 30min}$, because it the equivalent sound pressure level for the HAARP power plant full-load noise levels over a duration of 30 minutes[5]. It is important to note that arithmetic averaging was used in Equation B, as opposed to the energy averaging used in Equation A. ISO 6190 provides some data averaging guidance, recommending that arithmetic averaging should be used for a data set where the range of levels was 5 dB or less. Therefore, arithmetic averaging was used to calculate the $L_{Aeq\ 30min}$ values at each microphone, because the $L_{Aeq\ 5min}$ values for each microphone varied very little from one data block to the next.

(c.) Average Equivalent Sound Pressure Level for the HAARP power plant in dB(A) (energy average across the $L_{Aeq\ 30min}$ values for all measurement positions),

$$average\ L_{Aeq\ 30\min} = 10 \cdot \log_{10}\left(\frac{1}{K} \cdot \sum_{j=1}^{K} 10^{L_{Aeq\ 30\min,\, j}/10}\right),$$

Equation C

where $L_{Aeq\ 30min,\ j}$ = the $L_{Aeq\ 30min}$ value for the j-th measurement position in dB(A), and
K = the number of measurement positions (8).

Energy averaging was employed for Equation C, because there was significant variation between the $L_{Aeq\ 30min}$ values at the eight different measurement positions (up to 23.9 dB).

[5] For Mic 9, this was $L_{Aeq\ 20min}$, because only 20 minutes of noise data were discernable from the background noise.

(d.) Day-Night Equivalent Sound Pressure Level in dB(A),

$$L_{dn} = 10 \cdot \log_{10}\left(\left[\frac{15}{24} \cdot 10^{L_{A,day}/10}\right] + \left[\frac{9}{24} \cdot 10^{\left(L_{A,night}+10\right)/10}\right]\right)$$

Equation D

where $L_{A,\ day}$ = the (average) A-weighted sound pressure level observed during the day (7:00 AM to 10:00 PM) in dB(A), and
$L_{A,\ night}$ = the (average) A-weighted sound pressure level observed during the night (10:00 PM to 7:00 AM) in dB(A), where a 10 dB adjustment is applied to account for the increased sensitivity to noise levels during nighttime hours.

For the purposes of this noise study, it was assumed that the HAARP facility operated 24 hours a day. Therefore, $L_{A,\ day}$ and $L_{A,\ night}$ were the same value. For the average L_{dn}, this value was the average $L_{Aeq\ 30min}$. In addition, L_{dn} was also calculated with the $L_{Aeq\ 20min}$ at Mic 9.

(e.) Sound Pressure Level Exceeded 90% of the Time during a Measurement Interval in dB(A), $L_{90.}$

For example, if 100 noise samples were measured and arranged from highest to lowest level, the 90th sample from the highest value would be the L_{90}. The L_{90} of 30 minutes worth of 1-second L_{Aeq} data would be the 1620th highest value.

L_{90} may be used to assess compliance with 40 CFR Part 201.11 and 49 CFR Part 210 Appendix A, if the noise source is considered to be continuous (or steady-state) by meeting the following criteria:

$$L_{10} - L_{99} \le 4,$$

Equation E

where L_{10} = the sound pressure level exceeded 10% of the time during a measurement interval in dB(A), and
L_{99} = the sound pressure level exceeded 99% of the time during a measurement interval in dB(A).

(f.) Average Drop-Off Rate in dB(A)
(arithmetic average of drop-off rates),

For each mic line with multiple microphones separated by a doubling of distance, determine the drop-off rate:

$$D_{(n-f)} = \frac{1}{M}\sum_{i=1}^{M}\left(L_{Aeq\ 5\min,\ i\_n} - L_{Aeq\ 5\min,\ i\_f}\right),$$

Equation F1

where n = the near measurement position in meters (25 m or 50 m),
f = the far measurement position in meters (50 m or 100 m),
$L_{Aeq\ 5min,\ i\_n}$ = the A-weighted L_{eq} for the i-th data block collected at the near measurement position in dB(A),
$L_{Aeq\ 5min,\ i\_f}$ = the A-weighted L_{eq} for the i-th data block collected at the far measurement position in dB(A),
M = the number of data blocks (6), and
$L_{Aeq\ 5min,\ i\_n}$ - $L_{Aeq\ 5min,\ i\_f}$
= the specific drop-off rate between two microphone positions for a given data block separated by a doubling of distance.

Then determine the average drop-off rate at the facility:

$$D_{ave} = \frac{D_{25-50} + D_{50-100}}{2}, \qquad \textbf{Equation F2}$$

where the average drop-off rate is applied as an adjustment per doubling of distance.

(g.) Extrapolation of Overall Average Equivalent Sound Pressure Level in dB(A) for the HAARP Power Plant to Estimate the Noise Output of 5 Identical Diesel Engine-Generators (logarithmic addition to account for 5 identical noise sources within the same building),

$$extrapolated\ L = 10 \cdot \log_{10}\left(\sum_{j=1}^{5} 10^{L_{A,j}/10} \right), \qquad \textbf{Equation G}$$

where $L_{A,j}$ = is the A-weighted sound pressure level to be extrapolated five-fold, where L_A can be L_{Aeq} or L_{dn}.

It is assumed that all five diesel engine-generators produce the exact same noise levels, and that engine-generator location inside the installation can be ignored. Additional interaction effects between the engine-generators were also neglected. In this noise study, average $L_{Aeq\ 30min}$, average L_{dn}, $L_{Aeq\ 20min}$ at Mic 9 and L_{dn} at Mic 9 were all used to calculated the corresponding extrapolated sound pressure levels.

The L_{Aeq} of the background noise at each measurement position was calculated using Equation A, and then the overall average background noise level near the HAARP building was calculated from the data collected at microphones 1, 5 and 6a using Equation C.

Appendix C. HAARP Noise Data (including Background Noise)

Microphone (Type, Location)	Metrics	5-minute-long Data Blocks [dB(A)]					
		1st	2nd	3rd	4th	5th	6th
Mic 1 (LD-824, 50 m)	$L_{Aeq\ 5min}$	62.1	62.1	61.6	61.5	61.4	62.7
	Max levels	62.6	63.1	62.6	62.0	62.0	65.5
	Min levels	58.2	61.0	60.3	60.6	60.5	60.4
	Standard deviations	0.4	0.4	0.3	0.3	0.3	1.2
Mic 2 (LD-820, 50 m)	$L_{Aeq\ 5min}$	62.8	62.6	63.2	63.1	63.3	64.8
	Max levels	63.9	63.6	64.8	64.8	64.8	67.1
	Min levels	61.1	61.3	62.3	62.1	62.4	62.4
	Standard deviations	0.4	0.5	0.5	0.6	0.5	1.0
Mic 3 (LD-820, 25 m)	$L_{Aeq\ 5min}$	60.8	60.7	61.0	61.1	61.3	62.1
	Max levels	61.7	61.3	61.7	61.7	61.9	64.0
	Min levels	60.1	60.0	60.4	60.7	60.7	61.0
	Standard deviations	0.3	0.3	0.2	0.2	0.3	0.5
Estimated Mic 3 at 50 m	$L_{Aeq\ 5min}$ with Ave. Drop-Off	56.1	56.0	56.3	56.4	56.6	57.4
Mic 4a (LD-820, 25 m)	$L_{Aeq\ 5min}$	65.6	65.6	65.4	65.9	65.3	65.4
	Max levels	67.7	67.1	67.2	67.0	66.8	66.3
	Min levels	64.1	64.6	64.3	64.7	63.1	64.7
	Standard deviations	0.6	0.6	0.6	0.5	0.9	0.4

Mic 4b (LD-820, 50 m)	$L_{Aeq\ 5min}$	60.5	60.0	59.6	59.7	59.5	59.6
	Max levels	63.2	61.3	61.1	61.3	62.3	61.2
	Min levels	59.1	58.8	57.8	58.0	56.1	58.1
	Standard deviations	0.8	0.5	0.5	0.7	1.1	0.5
Mic 5 (LD-824, 50 m)	$L_{Aeq\ 5min}$	55.9	55.4	55.8	55.1	55.3	54.4
	Max levels	58.7	58.6	60.0	57.4	58.9	57.8
	Min levels	52.5	53.0	53.2	53.3	51.7	52.3
	Standard deviations	1.1	1.0	1.1	0.8	1.4	0.9
Mic 6a (LD-820, 50 m)	$L_{Aeq\ 5min}$	65.1	65.0	65.5	65.5	64.9	64.9
	Max levels	66.6	66.1	67.5	66.8	66.9	66.0
	Min levels	64.1	64.1	64.6	64.4	63.1	63.7
	Standard deviations	0.5	0.4	0.5	0.5	0.8	0.5
Mic 6b (LD-820, 100 m)	$L_{Aeq\ 5min}$	60.9	60.7	63.0	61.4	61.1	61.5
	Max levels	62.3	62.3	65.0	63.0	63.2	64.0
	Min levels	59.7	59.6	61.2	59.8	58.0	59.2
	Standard deviations	0.5	0.5	0.6	0.6	1.1	1.2
Mic 7 (LD-820, 50 m)	$L_{Aeq\ 5min}$	48.6	49.6	48.1	50.5	51.7	47.5
	Max levels	53.9	61.8	52.1	53.6	56.6	54.9
	Min levels	47.5	46.7	46.7	47	47	46.1
	Standard deviations	0.8677	2.0255	1.2982	2.1596	2.9935	1.3564
Mic 8 (LD-820, 50 m)	$L_{Aeq\ 5min}$	41.7	41.1	42.0	41.7	45.1	46.4
	Max levels	49.8	54.3	43.4	43.8	53.6	51.8
	Min levels	40.2	39.2	40.9	40.1	40.2	40.0
	Standard deviations	1.4	1.3	0.5	0.8	3.7	3.1
	corrected for background noise [6]	*39.7*	*38.1*	*40.0*	*39.7*	*44.1*	*45.4*
Mic 9 (LD-824, ~250 m)	$L_{Aeq\ 5min}$	44.0	44.0	43.1	41.9	41.7	43.0
	Max levels	55.2	44.8	47.0	43.1	43.3	47.6
	Min levels	42.2	43.1	41.7	40.9	41.0	40.7
	Standard deviations	1.5	0.3	0.7	0.4	0.4	1.3
	corrected for background noise	*42.0*	*42.0*	*40.1*	*N/A*	*N/A*	*40.0*
Mic Dummy (LD-820, 50 m)	$L_{Aeq\ 5min}$	15.1	15.0	15.0	15.0	15.1	15.1
	Max levels	16.5	15.4	15.1	15.1	15.2	15.2
	Min levels	14.9	14.9	14.9	14.9	14.9	14.9
	Standard deviations	0.2	0.1	0.1	0.1	0.1	0.1

Table 10. HAARP Noise Data for Each Individual Microphone and Data Block

[6] The underlined values indicate incidences where the difference between the $L_{Aeq\ 5min}$ and the average background noise levels was between 3 and 5 dB(A). If the difference was less than 3 dB, then the corresponding data block was considered to be invalid, and marked with a N/A.

Microphone	Metrics	Background Noise Level [dB(A)]
Mic 1	Background noise L_{Aeq}	37.9
Mic 5	Background noise L_{Aeq}	38.5
Mic 6a	Background noise L_{Aeq}	37.2
Mic 6b	Background noise L_{Aeq}	38.2
Mic 9	Background noise L_{Aeq}	40.1
Ave.	**Background noise L_{Aeq}** (based on Mics 1, 5 and 6a.)	**37.9**

Table 11. HAARP Background Noise Data

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