Reno, Nevada
NOISE-CON 2007
2007 October 22-24

Methods to Eliminate Continuous and Variable Background Noise Sources

David Parzych[a]
Power Acoustics, Inc.
12472 Lake Underhill Rd #302
Orlando, Florida 32828

ABSTRACT
Developers of large industrial facilities, such as power plants, are becoming increasingly sensitive to the impact noise has on community acceptance, project approval from local and state government agencies and the owner's ability to obtain project financing. Their willingness to shoulder a significant financial burden for noise abatement is a commendable trend. However, industrial projects designed to minimize community impact result in facility noise requirements and corresponding guarantees that are often comparable to the existing ambient sound. After a developer has committed a large financial obligation to meet sound level requirements, facility owners and the banks that financed the project want assurance that noise goals have been achieved. Needless to say, accurately measuring and documenting the project's sound level at the facility's financial completion is critical. For the large engineering/construction companies that build the plants, failure to achieve noise guarantees can result in substantial penalties. These low project noise goals create new problems for acoustical engineers and consultants required to document the facility's operational sound level. How does one confidently extract the sound level generated by an industrial plant that is comparable to the existing background or ambient sound? This paper addresses various methods that can be used to extract project sound levels from non-project related sound in situations of both continuous and variable background noise conditions.

1. INTRODUCTION
Often National and International Standards are referenced by acoustical consultants or engineers when measuring sound levels of stationary noise sources. The standards[1, 2, 3] provide simple procedures for removing background noise from operational sound source measurements:

1.) Measure the background sound at a given field point with the sound source of interest turned off.
2.) Repeat the measurement at that same position with the sound source of interest turned on to obtain a representative source sound level PLUS the background/ambient sound.
3.) Analytically subtract the background/ambient sound pressure (item 1) from the TOTAL sound pressure (item 2) to obtain the sound pressure level of the subject sound source.

Simple? It would appear the job of an acoustical consultant is trivial based on these instructions. However, in real world applications, the procedure needed to extract a facility's sound level is rarely this easy – particularly when the facility is very close in level to the existing ambient sound. High continuous ambient noise from industry and road traffic conditions that change throughout the day, combined with intermittent or short duration background sounds often leave

---

[a] Email address: dparzych@poweracoustics.com

the acoustical engineer with the task of developing unique and specialized methods for convincing clients, plant owners, banks and government officials that the sound levels of the facility have been achieved. While the technique and procedures found in the standards are technically and mathematically correct for removing background sound, they are often more applicable to a controlled laboratory environment than for correcting test results in a community environment.

Another issue is large industrial facility sound sources are not easily “turned on” or “turned off”. Many industrial facilities, such as combined cycle or cogeneration power plants, require several hours of warm up time or cool down time to obtain a full load condition or to be completely shut down. There are also cases where industrial facilities, such as base loaded coal fired power plants or refineries are rarely (if ever) shut down after becoming operational - resulting in non-existent background ambient sound data or data that may have been taken long periods of time prior to the facility coming online. In some cases, the ambient data used for background sound correction may have been taken years prior to a facility’s construction and operation. Over these long time periods, the ambient sound in an area can drastically change and make simple subtraction of background sources impractical and highly inaccurate.

This paper offers several ways to eliminate background sound from facility sound level measurements. Most methods discussed are non-standardize and must be used with caution and sound judgment.

2. QUANTIFYING TYPES OF BACKGROUND/AMBIENT SOUND

There are basically two types of background sound we consider and contend with when trying to extract an industrial facility’s community sound level:

1.) Short term and intermittent background sounds
2.) Long term ambient and steady state sounds

Short term and intermittent background sounds are generally related to transient noise, such as airplane flyovers, nearby or local traffic where individual cars and trucks can be clearly identified, construction related activity, transient industrial sounds, wind gust related sound and/or dynamic pressure, and various human and wildlife generated sounds.

Long term ambient sound is a continuous sound source that is generally related to *distant* road traffic noise or the constant continuous sound of industry. In a steady ambient sound environment, no individual vehicle can be identified from road traffic and sounds related to industrial sources are continuous and steady.

In many instances the criteria we are evaluating is the A-weighted sound pressure level since it electronically simulates the perceived response of the human ear. The discussion within this paper mainly concentrates on assessing A-weighted sound for brevity.

The average or “equivalent sound pressure level”, L_{eq}, is often used as the basis of quantifying and regulating noise. L_{eq} is the time-averaged fluctuating mean square sound pressure that has the same sound level as a non-varying or steady state sound observed over that same time period. When evaluating ambient noise or sound that is influenced by transient or moving sources, statistical sound data are also valuable. Statistical sound data allows extraneous sounds to be deemphasized or shorter term transient sounds to be extracted. Sound statistics often used in evaluating environmental noise are L_{10}, L_{50}, and L_{90}. These statistics correspond to the sound level exceeded 10% of the time, the sound exceeded 50% of the time and the sound exceeded 90% of the time respectively.

The sound level exceeded 90 percent of the time, or L_{90}, is commonly used to understand community ambient sound levels since it tends to reduce the effect of extraneous sounds. The L_{90} can be thought of as the residual sound level in the community. Basically, it's the sound you hear when all the local traffic passes, no airplanes are overhead and localized human, fauna or mechanical noise are minimal. Another way of thinking about L_{90} is that data taken over a measurement time of 10 minutes would provide sound levels at or below the L_{90} for a total duration of only one (1) minute. Nine (9) minutes of the ten (10) minute data sample time the sound level will exceed the L_{90} level. Similarly, a sound level defined as L_{10} would indicate that 10% of the time, or 1 minute out of ten, the sound level was equal to or higher than the value given. The L_{10} is useful in defining sounds that change in level due to transient sound sources, such as nearby movement of vehicles.

Time history data is also useful in that it clearly documents changes in the ambient sound that can occur in the sound throughout a period of time such as a day, week or year. An example of steady state ambient sound related to roadway traffic is presented in Figure 1. The data was obtained in an area located within 600 meters of two major (interstate and state) highways. Each point is representative of a 10 minute data sample. It can be seen that the statistical and average sound levels are fairly tightly grouped together and deltas between statistical and average levels remain nearly constant. Individual "high points" rarely occur indicating that individual vehicles are not generally observed and the statistical sound levels are generally consistent and repeatable over several hours of time.

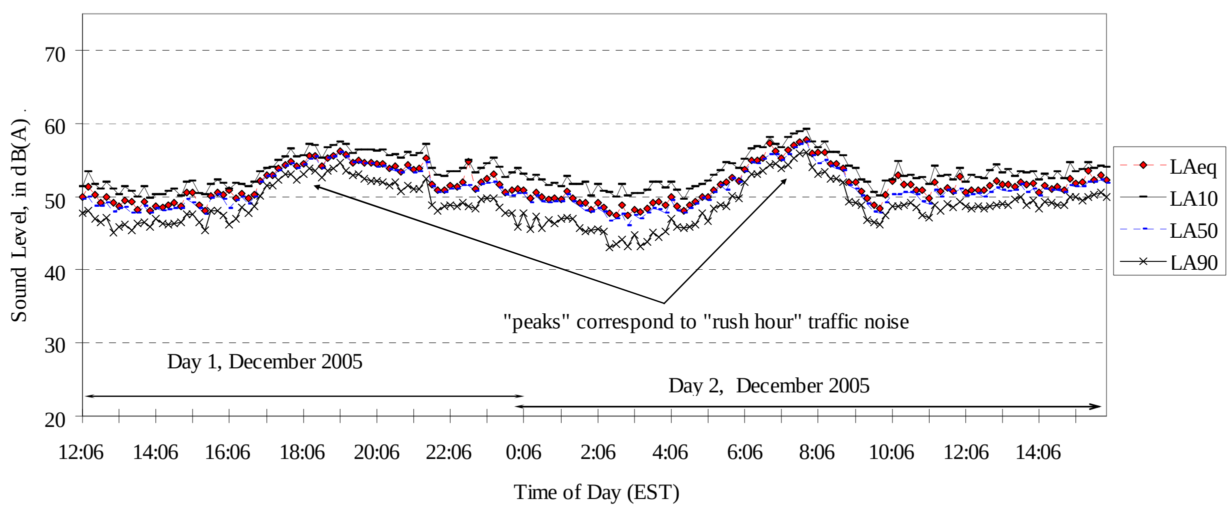

Figure 1: Example of ambient sound dominated by distant highway traffic noise

An example of a case where significant short term sounds prevail, such as near an airport with significant daytime air traffic, can be seen in the time history data presented in Figure 2. Larger differences are typically seen within the statistical data. The sound exceeded 10 percent of the time (L_{10}) and average sound levels are controlled by the individual events (in this case air traffic flyovers) and typically exhibit substantial excursions from the mean (L_{50}) and residual (L_{90}) sound levels.

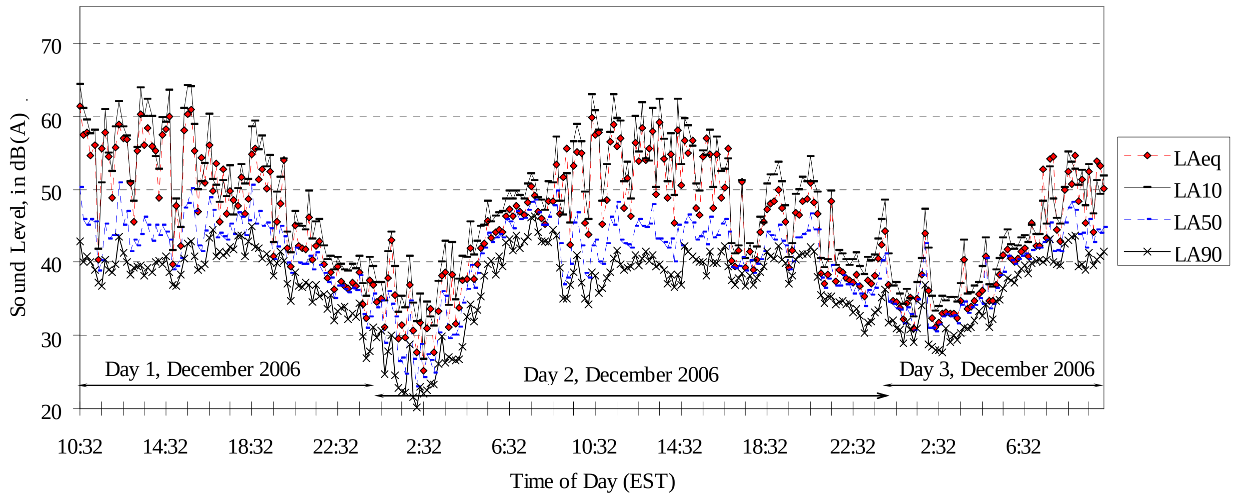

Figure 2: Example of ambient sound taken near regional airport with only daytime use

It should be noted that the sound level measurements shown in Figures 1 and 2 are representative of measurements made in Florida during the early winter. The data was selected since it had little impact from fauna such as crickets, tree frogs and other wildlife which can further obscure the results. Furthermore, differences depending on the time of year such as, prevailing wind direction, changes in traffic patterns and the amount of outdoor human activity often have an impact on outdoor sound levels.

The cases presented in Figures 1 and 2 are examples of two extremes. The commonality of both, however, is that sound level minimums occur around 2:00 A.M. To the dismay of noise control engineers around the world, this is the best time of day to extract an industrial facility's sound levels from background/ambient sound. A key point in Figure 2 is the minimum sound levels observed on back-to-back days can be several dB(A) different. Also, time dependant variations occurring in back-to-back measurements made even 10 minutes apart can cause significantly erroneous background noise corrections if applied to operational sound level data.

The dilemma is clear. When an industrial facility's sound level is close to the ambient sound, can one accurately extract it from the ever changing background and ambient sound found in the community?

3. METHODS TO ELIMINATE SHORT TERM BACKGROUND NOISE

Removal of intermittent or short duration sounds, such as individual cars from local road traffic and airplanes from flyovers can generally be eliminated through simple means such as:

1.) Pausing[3] the sound measurement averaging when a short duration noise event occurs.
2.) Obtaining a series of many short duration L_{eq} measurements[3] and manually eliminating contaminated data.
3.) Using statistical information about the sound, such as L_{50}, or higher statistics to eliminate the short duration intermittent sounds.

Pausing sound measurements is often used when average equivalent sound level, L_{eq}, is needed for comparison to noise ordinances and regulations. Pausing measurements is accomplished by selecting the “pause feature” available on most current technology sound level meters. However, this technique can be extremely tedious and time consuming when many short term disturbances exist. The procedure requires that the measurement be paused at the onset of an event and restarted when the event is no longer audible. Often, near a busy roadway or in an area of high airplane traffic, this method can take several hours to obtain a 20 minute sample of “uncontaminated” data. It also leads to mental fatigue and is prone to human error if the acoustical engineer “forgets” to hit the pause button after dozens of background events. Some sound level meters contain “back-erase” features that eliminate a predetermined length of data, say 5 seconds, prior to pausing measurements to combat this problem. While the back erase feature can reduce human error, it significantly adds to the time necessary to obtain a fixed length of uncontaminated data. It should be noted that the averaging time length of uncontaminated data will be dependant on regulatory requirements and/or the type of sound source one is measuring. A facility that primarily generates steady state sound will require much less averaging time than a facility that generates transient sounds. Extreme care must be given to assure that measurements are not always “paused” for the short term background when trying to capture the transient events of an operating plant.

As an alternative to “pausing” sound measurements, series of short duration L_{eq} data can be obtained. The short duration L_{eq} can be 10 seconds to 2 minutes in duration and taken continuously over a period of several hours or as necessary to generate the desired amount of uncontaminated data. After completion, all contaminated data are manually removed from the series and the full duration, (for example 1 hour), L_{eq} are computed as:

$$\text{full duration } L_{eq} = 10\log_{10}\frac{1}{N}\sum_{n=1}^{N}10^{0.1*Leq(n)}$$

where:

N is the total number of short duration L_{eq} samples
(N = 60 if 1 minute short duration samples are used in generating a full 1 hour sample),

$L_{eq(n)}$ is the n^{th} short duration uncontaminated L_{eq} sample within the series of data

Statistical data can be used, if allowed by test protocols and governing agencies, by providing information on sounds that are exceeded a percentage of the time. Obtaining statistical levels above the mean or L_{50}, will eliminate the short duration “high points”. Setting statistical levels as high as the 99 percentile can eliminate all but the quietest 1% of the sound. Unfortunately, an L_{99} requires 100 minutes of test data to obtain 1 minute of representative steady state facility data.

4. METHODS TO ELIMINATE LONG TERM BACKGROUND NOISE

While no single method is clearly “the best” when extracting an industrial facility’s community sound level from background noise sources, several methods can be used depending on the facility’s frequency spectrum content, typical operation, and location relative to the background/ambient sound sources. The simplest and most straight forward being direct measurements when background levels are 10 dB or more below the source level. In many cases, however, a facility's sound level requirements are set by fixed regulatory limits or by criteria allowing small incremental increases to the existing ambient sound levels in the area.

Some of the ways long term background/ambient sounds may be removed from measurements of an industrial facility are through one or a combination of the following:

A. Measuring facility noise during the quietest ambient times.
B. Using sound level time histories to show the impact of sources starting up or shutting down.
C. Frequency analysis to separate the facility's spectrum components from continuous ambient sounds
D. Analytical extrapolation of facility sound levels to community locations based on measurements made close to the plant.
E. Using shielding to reduce the background sound sources
F. Using "equivalent" positions to obtain ambient sound simultaneously with facility measurements.

A. Measuring facility noise during quiet ambient times

In many cases the facility's sound level criteria are too low to measure during the daytime hours when ambient sound is high. Unfortunately, it is sometime difficult to convince a plant owner with his own sound level meter that the plant he just purchased to achieve 40 dB(A) is actually achieving the criteria when every time he takes measurements, his meter reads 50 dB(A). Often simply taking data at nighttime can provide the desired results – particularly when used in combination with time history data.

Industrial facilities, such as a combined cycle or cogeneration power plant, make continuous steady state sound with little or no variation while operating at base load conditions. On the other hand, long term ambient sound levels increase or decrease with traffic volume and other human activities. Shown in Figure 3 is an example of a daily time sound level history of a residential location adjacent to a power plant. It appears that the facility is in excess of the requirements during daytime hours (artificially) but below the plant noise limits during the quietest nighttime period. The changes in levels are due to changes in the ambient sound and not the steady state plant sound. No correction was made for background sound in this example since it is implied that the "corrected" levels would lower than the minimum level measured.

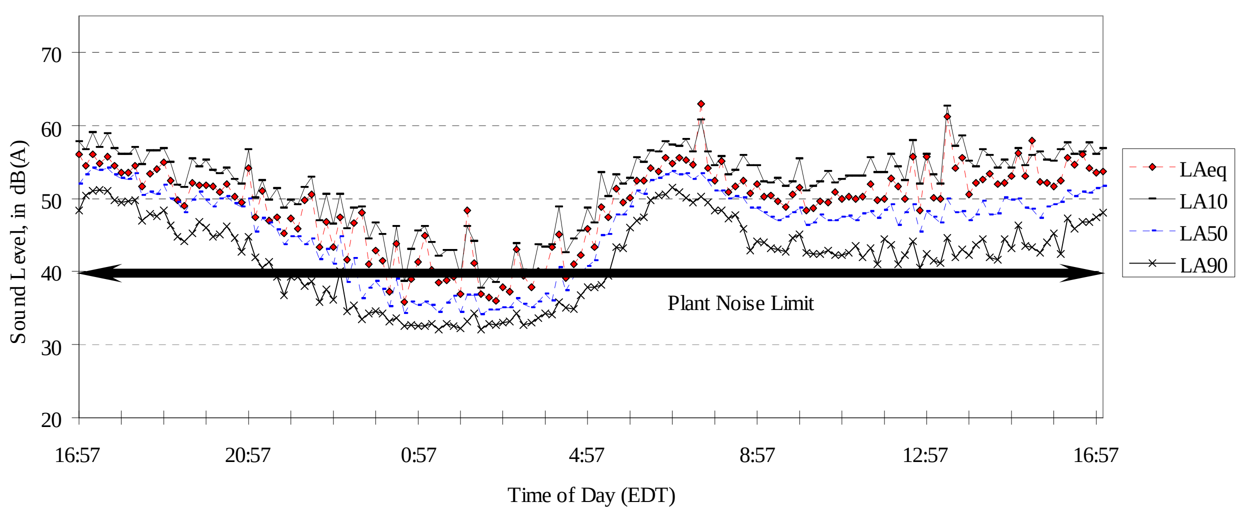

Figure 3: Example of power plant sound measured in a high noise ambient environment.

B. Sound level time histories of sources starting up or shutting down

A and C-weighted sound level time histories can be very valuable when combined with the startup and shutdown of a facility. Shown in Figure 4 is the time history of sound from a simple cycle combustion turbine power plant measured at the home of a nearby resident. C-weighted sound time history showed clear trends of increasing with plant startup and decreasing with plant shutdown. The high C-weighted sound is related to infrasound generated by the gas turbine's exhaust. Infrasound is not generally heard as noise but often felt as vibration. It provides a clear and certain marker of startup and shutdown when A-weighted sound levels sometimes do not. Unfortunately, once a simple cycle gas turbine power plant is commercial, it is dispatched on as needed basis - only during times of peak power demand. Many times, this means starting up in the morning and shutting down at night – just as the ambient sound is also decreasing in level. Much of the day the measured A-weighted sound was well above 45 dB(A). Ambient measurements taken on days where the units weren't operating showed similar sound levels near 50 dB(A) much of the time. The informative data is a combination of the C-weighted and A-weighted sound between 8:00 P.M. and 10:30 PM (20:00-22:30) – just prior to shutting down for the day. While the C-weighted sound is stable during this time, the A-weighted sound shows a clear trend of decreasing in mean (L_{50}) and residual (L_{90}) sound level as the ambient also decreases. Supporting time history data measured at the plant property line showed no changes in sound levels from the plant during this time. The community time history trend, when coupled with supporting time history data measured at the plant property line, provide substantial evidence that the facility is at or below an A-weighted L_{eq} of 45 dB(A).

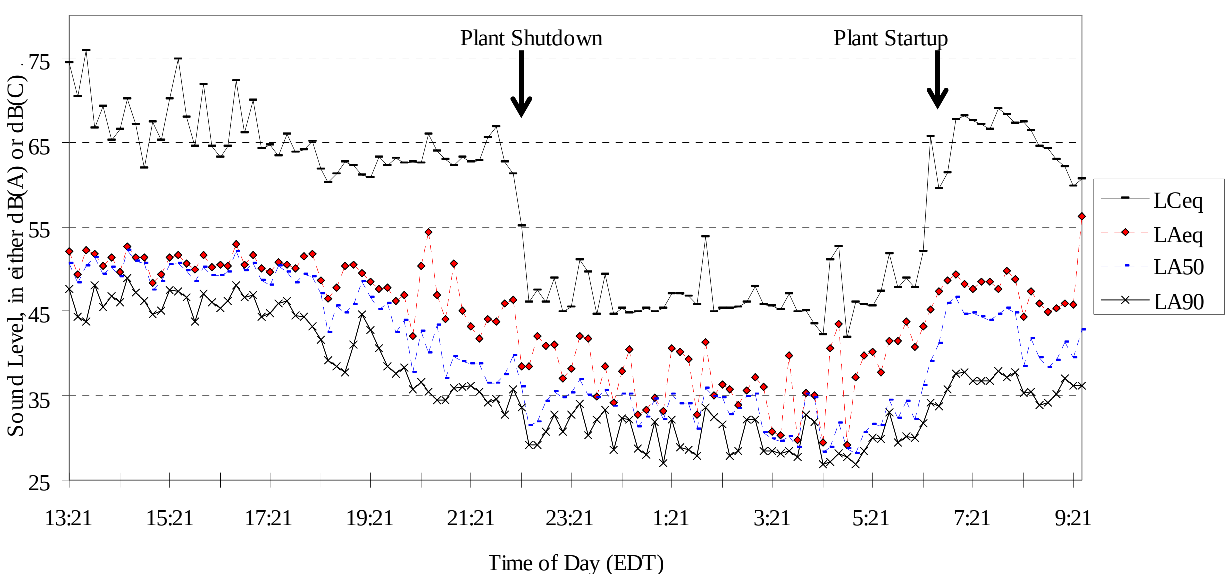

Figure 4: Example of simple cycle gas turbine power plant during operation at startup and shutdown. .

C. Frequency analysis to minimize continuous ambient sounds

A simple approach that can be used to remove ambient sound from plant sound data is through relatively narrow frequency band analysis. Often, 1/3 octave band data is sufficient but narrower bands can be used if necessary. Shown in Figure 5 is a comparison of operational sound level data taken near a home with an industrial facility operating and shut down. Measurements were also made close to the facility. A similar spectrum shape measured near and far from the equipment below 125 Hz indicated that the sound being measured at the residence is related to the operating facility. The spectra can be inspected and components not related to the facility can be analytically removed such as insect noise. The resulting A-weighted sound can then be obtained by computing it from spectrum components that are only related to the facility.

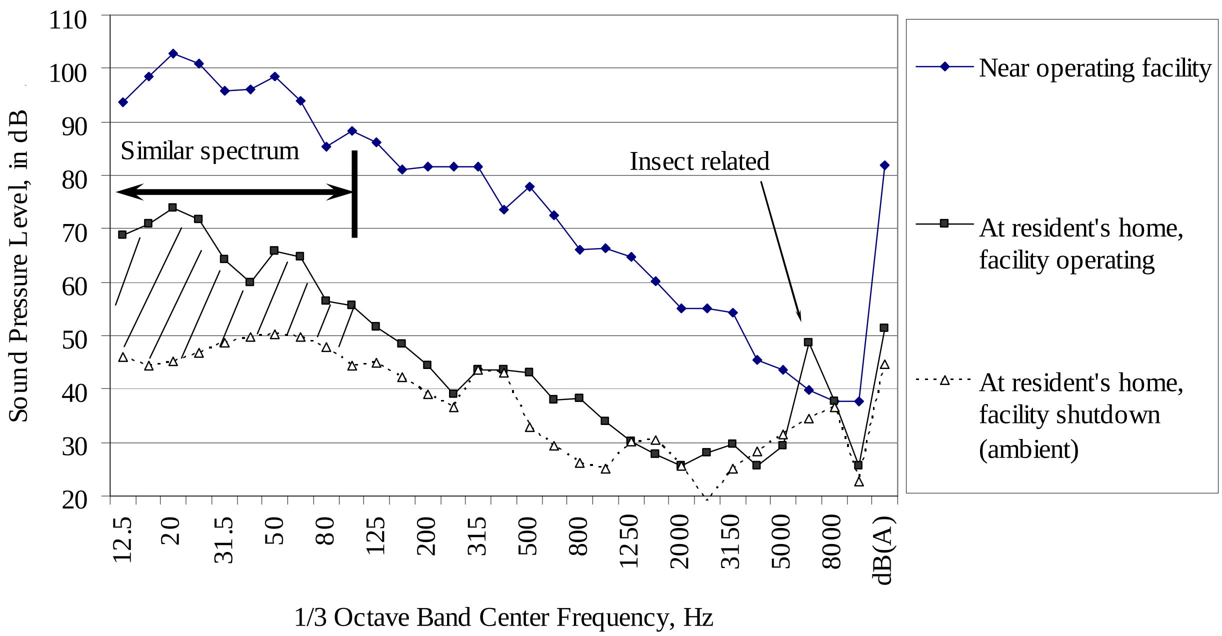

Figure 5: Example of using sound spectra to identify and eliminate ambient sources.

D. Analytical extrapolation of facility sound levels to community locations based on measurements made close to the plant

Another method for evaluating community sound generated by an industrial facility is through a combination of measurements and analytical extrapolation. Hale[4] has demonstrated community noise limits have been met through modeling techniques and Greene and Limberg[5] provide extrapolation techniques. A combined modeling/extrapolation technique is described in the example provided in Figure 6. The facility sound levels are based on sound pressure level measurements made close to the plant ($Lp_{1measured}$) in the direction of the community noise receptor location. The location is selected where the facility is clearly the dominant noise source. An analytical model, based on ISO 9613 part 2[6], such as SPM9613, CadnaA or SoundPlan, is then used to model the sound level at the community location ($Lp_{2calculated}$) and the “close in” position ($Lp_{1calculated}$).

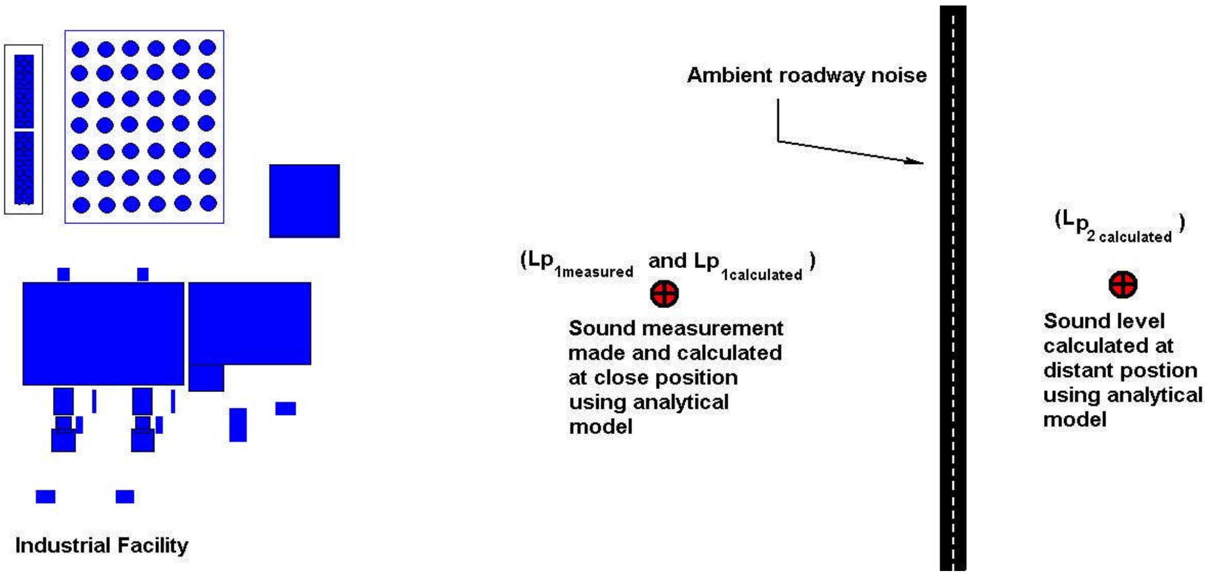

Figure 6: Extrapolating facility sound levels to distant positions using test data and analytical predictions.

The facility sound level is then computed by:

$$\mathbf{Lp}_{\mathbf{Facility}} \text{ at community location} = Lp_{1measured} + (Lp_{2calculated} - Lp_{1calculated})$$

The simple approach basically "calibrates" the analytical method by removing errors associated with sound source definition. The software then accounts for the facility's size and geometry, atmospheric absorption, ground attenuation effects and sound barriers as shown by Parzych[7]. The resulting extrapolation is considerably more accurate and reliable than a simple correction of $20\log_{10}$(distance ratio). Also, modeling accuracy can be significantly improved by measuring the sound power level emissions of the equipment using methods such as ISO 10494[8] and ISO 3746[9] and incorporating these levels into the analytical model.

E. Using shielding to reduce the background sound sources

When the opportunity presents itself, a building or structure situated as a noise barrier to the ambient sound can be used to help evaluate sound generated by an industrial facility. Shown in Figure 7 is an example where this strategy can work. Under these conditions, the ambient noise source can be reduced by several decibels relative to a position with a clear line of sight to the highway. The likelihood of successful extraction of the facility's sound level, ($Lp_{measured}$), is then significantly better particularly if combined with taking sound level data during low noise nighttime periods. A danger of this method is the possibility of specular reflections of plant sound interacting with the building being used as the shield. If the possibility of a specular reflection exists, corrections are needed to assure the facility's sound levels are not overstated. Brittain and Hall[10] presented a shielding method using an anechoic baffle that effectively eliminates most of the specular reflections.

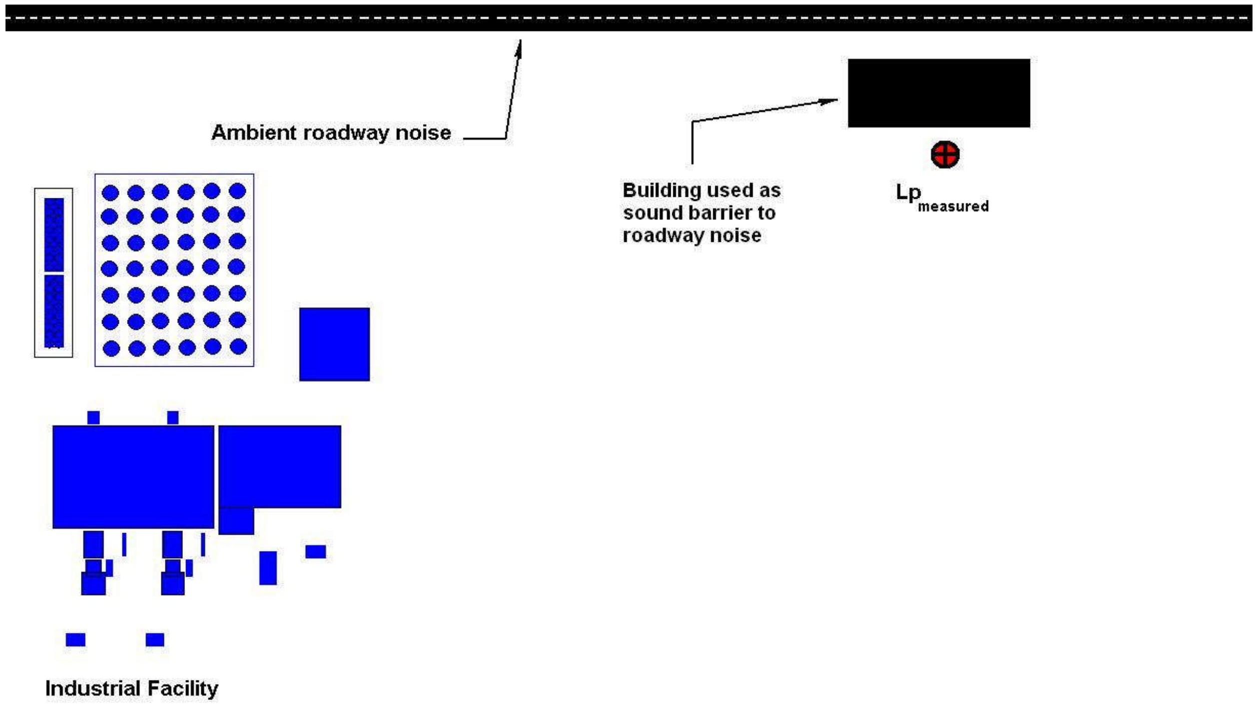

Figure 7: Using a building as a sound barrier to ambient noise source.

F. Using "equivalent" positions to obtain ambient sound simultaneously with facility measurements

In situations when it is impossible to measure the ambient with an industrial facility shut off, simultaneous "equivalent positions" may be considered for measuring and documenting the ambient noise. Under these conditions, an ambient measurement position is selected that presumably has the same ambient sound as the compliance measurement location. Both the equivalent ambient and facility operational sound data are measured simultaneously. The assumption is that an area's residual ambient level is nearly constant over a large geographical area if the environmental sources are far away. The key is finding "equivalent" locations that are similar in distance from the environmental ambient noise sources - but at remote locations far removed from the operating plant noise so the operating plant does not effect the "ambient". Extreme care is needed to select locations that are truly "equivalent". Wind direction, terrain, buildings and localized sources make this technique impossible to use in many instances. Hessler[11] experimentally verified this technique through preliminary testing prior to an industrial facility's operation. He found that with careful selection of "equivalent" test positions, he was able to find locations that met the criteria. To further minimize the effects of the ambient sound, Hessler set the sound test window for plant operational measurements during the early morning hours – when ambient noise is lowest. The equivalent ambient data is then analytically subtracted from the facility sound data. This method appears to be viable under some conditions but clearly requires preliminary testing to assure the ambient positions selected are truly "equivalent".

SUMMARY

We have offered several methods to help reduce or eliminate short term background and long term ambient sound from facility sound level measurements. Some have been developed by necessity through discussions and negotiations with clients and facility owners. Each method may work for a unique situation. Using one or a combination of the methods can be explored to get the desired results. As with all non-standardize methods, they must be used with caution and sound judgment.

REFERENCES

[1]American National Standard - Gas Turbine Installation Sound Emissions, American National Standards Institute ANSI B133.8 – 1977, (The American Society of Mechanical Engineers, New York, 1977)

[2]Acoustics – Measurement of sound pressure levels of gas turbine installations for evaluating environmental noise – Survey method, International Organization for Standardization, ISO 6190:1988 (E) Geneva, Switzerland, 1988. (International Organization for Standardization, Switzerland, 1996)

[3]American National Standard – Quantities and Procedures for Description and Measurement of Environmental Sound. Part 3: Short Term measurements with and observer present. ANSI S12.9-1993/Part 3, (Acoustical Society of America, New York, NY, 1993)

[4]Marlund E. Hale, "Demonstrating that community noise limits have been met using modeling", Proceedings of Noise-Con 2007, Reno, Nevada, October 22-24 2007.

[5]Rob Greene and Grant Limberg, "Verifying community noise limits have been satisfied using extrapolation of measured data", Proceedings of Noise-Con 2007, Reno, Nevada, October 22-24 2007.

[6]Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation, International Standard ISO 9613-2: 1996 (International Organization for Standardization, Switzerland, 1996)

[7]David Parzych, "Predicting Far Field Sound Levels of Large Industrial Noise Sources Using Point Source Radiation Models", Proceedings of Internoise 1999, vol 3, 1113-1118

[8]Gas turbines and gas turbine sets – Measurement of emitted airborne noise – Engineering/survey Method" ISO Standard 10494; 1993(E) (International Organization for Standardization, Switzerland, 1993)

[9]Determination of sound power levels of noise sources using sound pressure - Survey method using an enveloping measurement surface over a reflecting plane. ISO 3746:1995, (International Organization for Standardization, Switzerland, 1995)

[10]Frank H. Brittain and Henry R. Hall, "An anechoic baffle for measuring refinery noise in the presence of near-by noise sources", Proceedings of Noise-Con 98, Ypsilanti, Michigan, April 5-8 1998.

[11] Private Communication with George Hessler of Hessler Associates, Inc. regarding a verification testing of a simulated ambient technique for the far field compliance sound measurements of an industrial facility located in New York, June 2007.