Environmental Noise: Better Measures and Reporting Needed

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ABSTRACT

In measuring the environmental noise level for such purposes as compliance monitoring and nuisance noise assessment, the most often used statistic is the A-weighted sound pressure level (SPL), often reported as a percent exceedance level (e.g. L10 or L90) averaged over a time interval such as 10 minutes or 24 hours. This statistic can not be relied upon in situations where noise has 'special audible characteristics,' such as modulation or tonality, since increases in the sound pressure level (SPL) of the loudest n% of sound will be ignored. Furthermore, the use of A-weighting underestimates the lower-frequency sounds, which have recently been shown to be perceived by humans through alternative mechanisms, therefore different measures are required. The analysis of large amounts of data for compliance monitoring can be a time-consuming process. Errors can occur due to inappropriate analysis methods or flawed understanding of the noise under investigation. This paper reports on: (1) some of the current issues with using the A-weighting and exceedance statistics as measures of loudness; (2) the development of several alternative measures to analyse environmental sounds from various sources that exhibit 'special audible characteristics' (including wind farms and impulsive noise); (3) the requirements of automated, standardised methods of data reporting, analysis and assessment for large and complex data sets and (4) the development of a new sound measurement tool that implements the proposed analysis techniques while extending the acoustic spectrum down to less than 1 Hz: the Spectro-Acoustic Meter (SAM).

INTRODUCTION

To the layman the measurement of environmental sound may seem simple both in terms measuring the loudness of the sound and determining its annoyance. Nothing could be further from the truth! Loudness is not a simple physical measure but depends on characteristics of the sound that we do not yet fully understand, let alone know how to measure. Annoyance is even worse since it not only relies upon loudness and objective characteristics of the sound but on the subjective assessment of the hearer.

It is therefore not surprising that the measurement of environmental sound for the purposes of regulating sound sources, such as wind farms, industry, traffic and neighbours, can be controversial. This is not helped when simple and largely inaccurate measures, such as A-weighted sound level and exceedances, are used by those setting policy and used in compliance conditions. When residents then complain of noise, the official response is often that the complaints are unreasonable because the noise is in compliance and should therefore not be annoying.

That there are more sophisticated and accurate statistics, such as the ANSI S3.4-2005 loudness standard for instance, is undeniable. However, these appear to be too complex for local government and other policy-making organisations to understand (possibly), to accept (certainly) and to implement (at reasonable cost). Hence we have a situation in the wind farm industry for instance, where an A-weighted, 10-minute, L90 or 90-percent exceedance is used as the primary measure. (See NZ6808:2010, the New Zealand standard that is also used in all the Australian states bar Queensland.) One must ask if better statistics would be used in these areas if they were designed to be more in-line with the current measures while still improving their accuracy. Are there then intermediate statistics that can capture more of the complexity of human sound perception while still providing policy-makers with confidence to specify and use them? This paper would like to suggest that there are.

This paper seeks to:

- inform on some of the issues with current measurement statistics,
- look at other, better targeted, statistics,
- relate a plea from those who must prove compliance via reports and
- describe a product that incorporates both the new statistics and the answer to the acoustician's plea.

CURRENT MEASUREMENT METHODS

Problems with time or frequency averages

The most vexing controversies relating to objective measures of environmental noise have their roots in the problems of using a single number to represent a complex, underlying system. The two main examples of this relate to averaging in the time domain and weighting in the frequency domain; the L90 and the A-weighting. The L90 is chosen here because it is mandated in the New Zealand NZ6808 wind farm noise measurement standard, which is also used by all the Australian states apart from Queensland. Other measures are also used in Europe and the US (the L_{den} and L_{dn} respectively) but some of the following issues apply to them as well.

Consideration of the L90

The L90 over a time interval is the sound level above which 90% of the sound level measurements lie. In the same way that the median house price (essentially an L_{50} value) tells us nothing about the value of the most expensive houses, the L90 tells us nothing about the sound level of the 89.99% of measurements that are greater.

A simple example is shown in Figure 1 where a quiet, constant sound (upper sound trace) has an arbitrarily-large, semi-periodic signal imposed for 10% of the time (lower sound trace). The L90 values of these two sounds are the same at 52.9 dB despite the L_{eq} values being 48.9 dB and 80.9 dB. Indeed, a neighbour standing outside your bedroom window discharging several gunshots would not affect a 10-minute L90 but would certainly be considered more annoying!

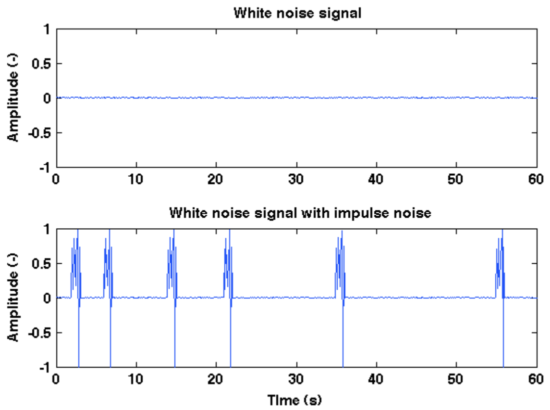

Figure 1. Problems with L90 measurements. The two sounds above have essentially the same L90 even though the SPL of the second figure is much higher and the sound much more annoying. The level of the 'spikes' in the second figure can be arbitrarily large without changing the L90.

Note that the 'blade swish' of a wind turbine represents exactly this type of periodic noise that will be understated by an L90 measure.

A-weighting

While the A-weighting (Figure 2**)** has been used almost exclusively for decades for defining environmental sound limits, there are important issues with this weighting, especially at low frequencies. This weighting has long been used as an approximation to the hearing sensitivity of humans. In this respect, it is a deviation from a direct measure of sound energy to one based upon the perception of a sound level by humans. At high and, especially at, low frequencies the weighting shows a lack of sensitivity leading to a large decrease in weight applied to these frequencies when calculating single-value measures such as the L10, L90 or L_{eq}. (Historically, this weighting was created using analog filters, which had less-than-perfect performance. Thus the weighting does not decline as fast as human hearing sensitivity at the high end of the spectrum.)

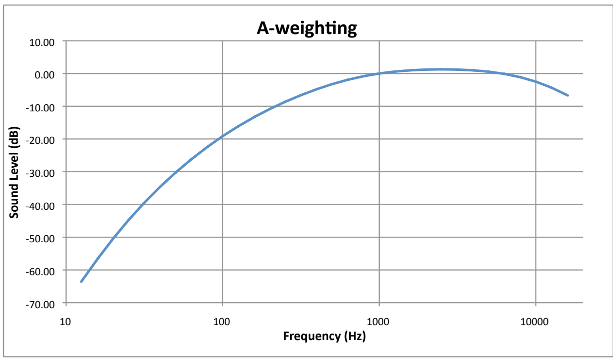

Figure 2. The ubiquitous A-weighting curve used as an approximation to human hearing sensitivity.

That the A-weighting is not appropriate for low frequencies can be seen by a simple experiment summarised in Table 1. Here a white noise signal has had a 40 Hz, amplitude modulated, tone added. The level of the 40 Hz signal was adjusted until it was just audible against the background white noise. The level of the 40 Hz signal was then increased by 10 and 15 dB. (Note that the dynamic range of hearing decreases with decreasing frequency as shown by the bunching up of equal loudness contours at low frequencies. These 10 and 15 dB increases would appear to the listener to be about double what they would be at 1000 Hz, i.e. the equivalent of 20 and 30 dB. (See Figure 3.)) Despite this the A-weighted sound level for this change only increases by 0.1 dB. Clearly this does not represent the perceived change in loudness.

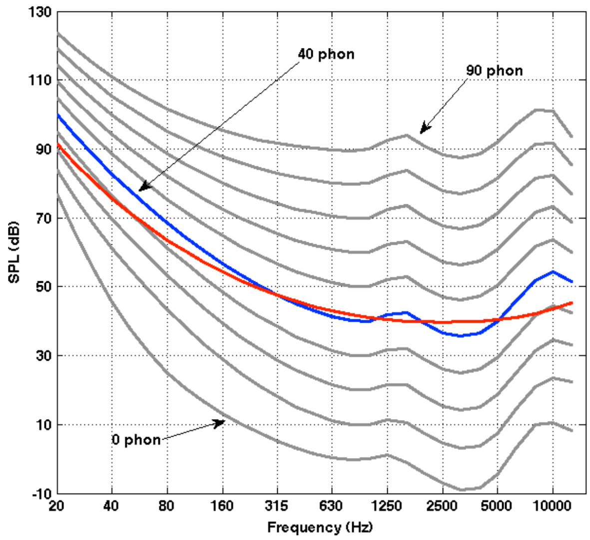

Figure 3. The equal-loudness contours from ISO 226:2003 (grey) with the inverse A-weighting curve (red) superimposed on the 40 phon curve (blue) to show the differences in hearing threshold.

Table 1. A simple experiment

White Noise Plus 40Hz ...	dBLin	dBA	dBC
Just Audible	70.8	67.4	70.0
+10 dB	77.6	67.4	75.9
+15 dB	82.2	67.5	80.3

Different sounds with the same SPL can be perceived as having different loudness, e.g. turboprop aircraft as opposed to jet aircraft.

Another issue with the A-weighting curve is that it approximates human hearing sensitivity to sound detected only through the eardrum/cochlea. As has been shown in a number of studies (Flindell and Stallen, 1999, Griefahn et al., 2008, Leventhall, 2004, Moller and Pedersen, 2004, Todd et al., 2008, Tsunekawa et al., 1987, Vercammen, 1992) that humans can detect sound through alternative mechanisms and respond to low-frequencies and infra-sound with sensitivities much higher than that suggested by the A-weighting curve. Indeed, the outer hair cells of the human cochlea have been seen to respond to very low frequency sounds up to 40 dB below the hearing threshold (Salt and Hullar, 2010). These findings give new credence to the body of complaints regarding low frequency noise from wind farms (Pierpont, 2009, Thorne, 2009, Thorne, 2010).

Complexity of environmental noise

The method by which we perceive sound is a very complex process. Not only are our perceptions of sound non-linear with respect to frequency, to sound level (see Figure 3), and to time, but the characteristics of the sound can change our perception of its loudness. All this is true of pure tones but, in combination, some sounds can mask others, some can make sounds appear where there are none and, on top of everything else, people have different sensitivities to sound, particularly at low frequencies.

Some of these issues are visible in the sonogram of sound recorded inside a dwelling close to the wind farm at Makara, near Wellington in New Zealand (Figure 4). There is a clear tonal component at about 570 Hz and another, less clear, at about 70 Hz. Pronounced modulation is evident from about 250 Hz down at a frequency of 1 Hz (the blade-passing frequency of the wind turbines). In the infrasound region there is a fundamental at 1 Hz with clear harmonics up to at least 16 Hz clearly visible. Neither the basic A-weighted SPL nor a 10-minute exceedance level can capture any of the basic elements of this environmental sound.

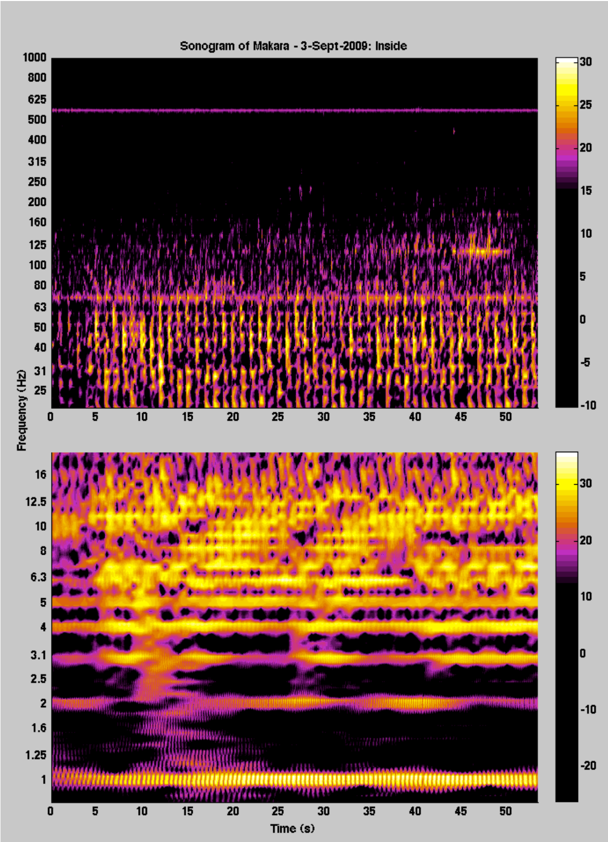

Figure 4. Sonogram of sound from a wind farm as measured inside a residence. Top half is the audible sound showing clear pulsing at the 1 Hz blade-passing frequency. Bottom half is a modulation plot showing strong harmonics in the infrasound region.

A large number of measures have been suggested to try to capture some of the characteristics of sound; tonality, modulation, roughness, loudness, audibility and salience, to name but a few. When measuring environmental noise we can not expect to deal with all these issues; some simplification is required. The alternative measures dealt with in the following section, while being relatively simple to calculate in software, lend themselves to the task of measuring important sound characteristics for the purposes of compliance testing.

ALTERNATIVE MEASUREMENT METHODS

The Case for a Simplified Loudness Measure

As discussed in a previous section, A-weighting is not appropriate for low frequencies mainly because of the reduced dynamic range in human perception, nor does it closely follow the human perception of loudness throughout the frequency range. Given that the intent of most noise measurement is to measure human perception (apart from acoustic trauma, which requires measurement of energy), measurements should be based on *loudness* as embodied in a number of standards from ISO 532 through to the Zwicker and Fastl loudness measure (Zwicker and Fastl, 1999) for time-varying sound, not to mention other such measures like the ITU-R BS.1770 for broadcast loudness.

These are complex measures that deal with, not only loudness due to the sound pressure level, but also masking by neighbouring frequency bands. They are not capable of handling all sounds (only Zwicker and Fastl's measure can handle time-varying sound for instance), are partial estimators of human loudness perception, require skilful programming and much computation time. All of which makes them unsuitable as real-time measures whilest also not being very transparent to industrial professionals and policy makers.

What appears to be required by the industry is a simpler version of these standards that captures some of the characteristics of loudness while still remaining familiar to industrial professionals.

Acousticians or policy-makers almost always use the A-weighting, applied to a sound signal to account for human hearing. Less well-known perhaps is the use of B- or C-weighting curves for different levels of sound. Therefore, the concept of a set of weighting curves that more closely matches human hearing than the A-, B- and C-weighting curves should not be too large a step. This can be achieved quite simply by inverting the equal-loudness curves of the ISO 226:2003 standard and applying the appropriate curve as a weighting curve for any given sound pressure level. Let us call this the L-weighting curve (although this is not loudness as defined by current standards). Let us also assume that the sound level meter is capable of choosing the L-weighting curve from moment-to-moment to match the SPL, even to interpolating the L-weighting curve between those in the ISO 226:2003 standard.

To apply this weighting to SPL in decibels requires that the sound be passed through narrow-band filters to produce a time-series for each band (usually 1/3-octave). This is then converted into sound pressure level in chunks of time, usually 100 or 125 ms. Each SPL can then have the L-weighting applied to give a value in *phons* (the unit of loudness level) as opposed to decibels.

This is usually as far as the conversion goes—a spectrum in phons—because attempting to sum the contributions of the bands to something equivalent to an SPL value is not technically possible. This is because the summation in SPL is done based upon energy in each band. However, when applying a weighting of any form, this step is no longer valid since we are dealing with human sensitivity not measured energy directly. This is as true for A-weighting as it would be for L-weighting, but it is still useful to sum the contributions in the same way to get an integrated figure that can be used in some of the alternative measures that follow. We will call this value audibility, rather than loudness, because it is not a true loudness as defined by current standards.

Figures 5 and 6 show a comparison of audibility and sound pressure level. The three plots shown in Figure 6 are for the Makara wind farm sound file processed as linear SPL, A-weighted SPL and as audibility (with the component band audibilities combined as discussed above). The wind farm sound has much of its energy in the lower frequencies, which can be seen in the linear-weighting (red) spectrum Figure 5. The spectra show, however that there are clear differences between the audibility and the SPL spectra, particularly at these lower frequencies. Which should be used? Well, the linear-weighted spectrum is a direct measure of the energy in the sound, the audibility spectrum is a measure of the perceived loudness, but the A-weighed spectrum is surely an overly-simplified and out-of-date approximation.

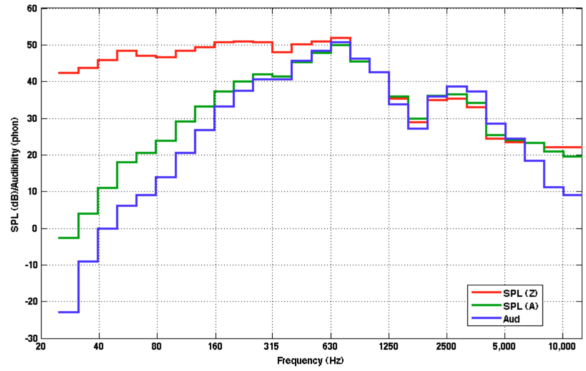

Figure 5. Averaged spectra for the wind farm noise recording comparing traditional A-weighing, linear weighting and audibility.

The spectra show that the differences between audibility and sound pressure level are quite complex and so it is hard to identify what has caused the changes in the plots in Figure 6. Both the A-weighting and audibility measures apply less weight to the lower frequencies (to different degrees), reducing the amplitude of the low-frequency oscillations and lowering the entire SPL curve in Figure 6.

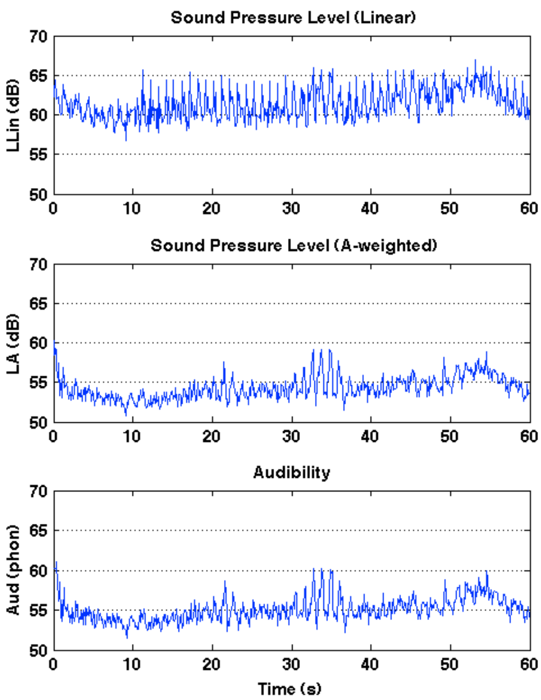

Figure 6. Loudness of wind farm noise from Makara, near Wellington, New Zealand as measured by linear SPL, A-weighted SPL and audibility.

However, audibility takes account of the reduced dynamic range of human hearing at these frequencies and stretches out the loudness of those that are above the hearing threshold. The result can be seen in the peak-to-peak amplitudes, which are 7.7 dB through 30–40 s for the A-weighted curve but 8.1 phon for the audibility curve. There is also a slight increase in the equivalent continuous average of the audibility curve over the A-weighted curve, 55.4 phon over 54.6 dB. This supports the idea behind this audibility measure; that it is a closer match to the perceived level of noise from wind farm reported by residents. As seen in Figure 5, there is a large, low -frequency component to this noise.

It should be noted that, while audibility has improved the measurement of perceived sound - by providing a better approximation to the hearing levels and the sensitivity at lower frequencies - there are still significant issues with this that remain unaccounted for. Some of these were noted in the previous section on A-weighting, relating to alternative mechanisms for perceiving sound, but also include the different sensitivities of individuals. These may raise or lower the hearing threshold by 12 dB in 5% of the population at 50 Hz (Kurakata et al., 2005).

Having made a case for audibility as a better measure than A-weighted SPL, we now proceed to discuss the several measures that look promising as statistical measures of environmental noise.

125ms Amplitude Modulation Method

This method has recently been specified as a compliance condition for the Den Brook wind farm in Britain (Hulme v Secretary of State, 2011, Pease (Ed), 2011). The method is explained in condition 20 of the compliance document as:

> … Amplitude modulation is the modulation of the level of broadband noise emitted by a turbine at blade passing frequency. These will be deemed greater than expected if the following characteristics apply:
> a) A change in the measured $L_{Aeq\ 125\ millisecs}$ turbine noise level of more than 3 dB (represented as a rise and fall in sound energy levels each of more than 3 dB) occurring within a 2 second period and
> b) the change identified in (a) above shall not occur less than five times in any one minute period provided the $L_{Aeq\ 1\ min}$ turbine sound energy level for that minute is not below 28 dB and
> c) the changes identified in (a) and (b) above shall not occur for fewer than six minutes in any hour.
>
> Noise immissions at the complainant's dwelling shall be measured not further than 35 m from the relevant building, and not closer than 3.5 m of any reflective building or surface, or within 1.2 m of the ground. (Hulme v Secretary of State, 2011)

There are a number of interesting features of this method.

- The measure is a relative one in that, so long as the absolute sound level is above 28 dB, it is the relative difference in level between peaks and troughs that are the basis of the method. This acknowledges that it may not be the loudness of the sound that determines the annoyance but the characteristics of the sound itself. It also makes the method less sensitive to the exact location of the sound capture, which has been shown to be of concern in wind farms (Bakker and Rapley, 2010).
- The impulsive nature of the sound is being measured since the peaks must be less than 2 seconds duration. Rather than smearing out this characteristic with an average, the detail of the sound is of importance.
- There is acknowledgement that the disturbance might be short but may be repeated a number of times over a longer time (up to an hour).

The result of applying this method to the sound file whose sonogram is shown in Figure 4, can be seen in the third plot of Figure 8, discussed in more detail in a later section. This sound file is only one minute in length, whereas the method requires between six minutes and one hour of sound (There must be six separate minutes within an hour, each with five peaks.), but it can be seen that there are more than five peaks in this one minute. (The five red triangles indicate the first five peaks that occur within a minute.) If the sound file were six minutes in length then it is highly likely that five further five-peak-minutes would be found and that this wind farm would fail compliance.

Sleep Disturbance Index

One of the most useful measures of the invasiveness of night time noises would be the probability of, or predicted number of, sleep disturbances in a night. One such measure of a sleep disturbance index (SDI) was suggested by Bullen (Bullen et al., 1996); his modified form is discussed here. The index defines events where the sound level exceeds the average by more than 5 dB. It then uses a weighting factor, which is a function of how much the maximum sound level exceeds 45 dB, to calculate the index.

$$SDI = \textit{sum over all events of}\ (W(L_{max})/100) \qquad (1)$$

where W is the weighting factor and L_{max} is the maximum sound level of the event.

The weighting factor is defined, only for sound levels, L, greater than 45 dB, as:

$$W(L) = 0.142(L - 45) + 0.00473(L - 45)^2 \qquad (2)$$

The modification to the index ties the event to the average sound level rather than 45 dB using

$$W_{mod}(L_{max}) = W(L_{max}) \text{ when } L_{max} - L_{eq} \geq 20 \text{ dB} \quad (3a)$$

$$W_{mod}(L_{max}) = W(L_{max})*(L_{max} - L_{eq} - 5)/15 \text{ when } 5 \text{ dB} > L_{max} - L_{eq} > 20 \text{ dB} \quad (3b)$$

$$W_{mod}(L_{max}) = 0 \text{ when } L_{max} - L_{eq} \leq 5 \text{ dB} \quad (3c)$$

The weightings are determined from 11 studies into sleep disturbance. (A survey of more recent such studies could be used to provide better weightings.)

An event is defined as

- "the noise level reaches a maximum,
- the noise level drops by at least 5 dB between this and any other maximum; and
- the maximum is separated from any other maximum by at least 15 seconds." (Ibid.)

The SDI is usually calculated on the A-weighted SPL but, for the reasons already given, this measure was implemented with audibility instead of SPL. Since the SDI is based upon studies of sleep disturbance that are measured in SPL, the fitted curve used by Bullen is not strictly applicable to audibility; however in light of the lack of studies using audibility, there is little choice but to use the same curve.

One of the problems that Bullen faced was that he used L_{eq} as the measure of the base noise level. This meant that he had to subtract the contribution of the event itself from the L_{eq} but this did not make sense in all cases and so Bullen did not apply this in all cases. Clearly the intent was, and should be, that it is the excess loudness of the event(s) above the normal sound that is important. To achieve this it would, in fact, be better to use an exceedance measure, the L_{50} being the obvious choice, to represent this normal level of sound.

In line with these comments, in the implementation here the maximum audibility, A_{max}, and 50% exceedance audibility, A_{50}, are used to directly replace L_{max} and L_{eq} in the equations and are calculated in the same fashion as their SPL equivalents.

Some Examples

In the following figures these measures have been applied to some example sound files. These are:

- Urban background - a recording taken inside a suburban house with steady rainfall being the predominant noise. The sound level is fairly constant with one impulse sound (a bang) Figure 7.
- Wind farm - the recording used to produce the sonogram in Figure 3. The sound file displays strong amplitude modulation—the swish noise common of wind farms—at the blade-passing frequency, Figure 8.
- Firearms - a recording taken of police firearms practice in an otherwise quiet, rural setting. The sound file contains shouts (Fire!) and individual gunshots, Figure 9.
- Dogs - a rural recording of individual dog barks at some distance, Figure 10.

Each of the figures shows; the sound amplitude (full scale is -1 to 1), the audibility overlaid with amplitude modulation events as triangles (blue for normal, red for the first five events in the minute) and the audibility overlaid with SDI events as red triangles.

Acoustic analysis was undertaken at a suburban house in a residential suburb, late in the evening. There was minimal traffic flow and no detectable sound from human activity. The predominant sound was one of rain on the roof. The results, Figure 7, show a fairly constant sound level in the amplitude plot and also in the audibility plots of the AM method and the SDI except for the impulse sounds, which are fairly high frequency. One impulsive event at about 57 seconds triggers an AM method event but not a SDI event.

Note that the amplitude modulation method and the sleep disturbance index are incomplete for these short sound files. The AM method requires up to an hour of sound and the SDI requires an all-night recording. Also, the SDI may have events but still be 0 if the sound level does not exceed 5 dB above the L_{eq}.

Given the low sound level and constant sound character of this recording, we can consider this to be a base case of sorts. As such we would expect that none of the measures we are investigating would return positive values, which is the case.

A two year investigation of noise from a wind farm at Makara, near Wellington, New Zealand was the source of data for the results shown in Figure 8. The findings display evidence of the strong amplitude modulation at about one second intervals. This can be seen in the amplitude plot as well as the audibility plots of the AM method and the SDI.

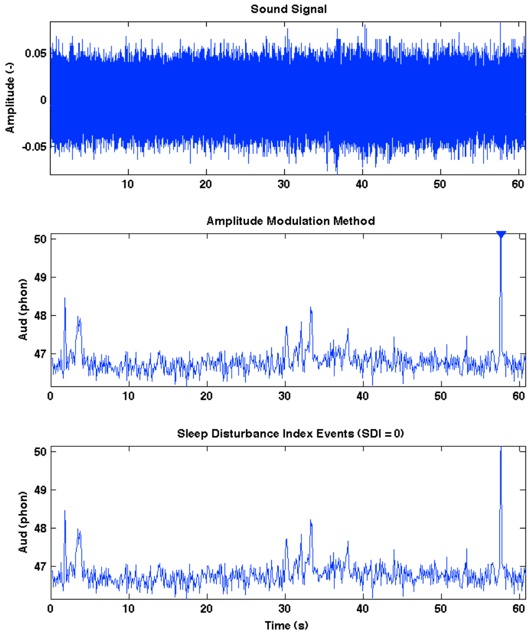

Figure 7. Urban background. Inside a quiet suburban house with some background traffic noise and bird song.

The amplitude modulation method has recorded five events in the first 30 seconds and thus a five-event minute. A continuation of this recording would have signalled a compliance failure (Hulme v Secretary of State, 2011) after only six minutes of the hour.

The SDI is still 0 despite events occurring in two out of the four 15-second intervals of the recording. The SDI will not recognise periodic changes in sound of this level. Indeed, unless the L_{eq} excludes the maximum sound levels that make up the event, it will not recognise most sufficiently-rapid, periodic functions.

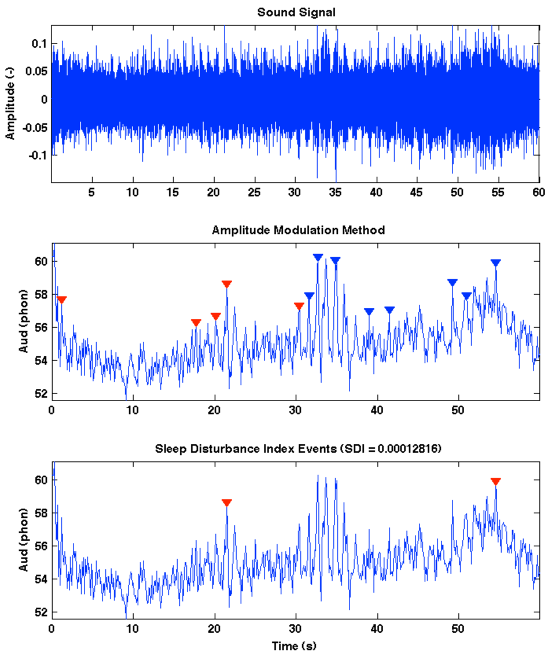

Figure 8. Wind farm noise inside a residence, from Makara, near Wellington, New Zealand. This recording shows very pronounced amplitude modulation from the swish of the blades at the blade-passing frequency.

It is pertinent to note that the recordings used for this analysis were the subject of a complaint from residents at Makara, so there is a case for noise nuisance, regardless of the adequacy of the measurement statistic to reveal that.

Impulse noise is a source of multiple concern. It is known to be disruptive of sleep and well-being, and classified as a modern environmental pollutant (Berglund and Lindvall, 1995). Health effects of impulsive noise have long been understood, (Osada, 1988) and is a common cause for complaint, i.e. as nuisance noise. Firearms are an example of such impulsive noise comparable with loud traffic sounds (Buchta and Vos, 1998). High impulse noise can be the cause of physiological consequences such as cardiovascular events (Belojevic and Saric-Tanaskovic, 2002, Parrot et al., 1992) and hypertension.

The firearm noise results, Figure 9, can be considered as an example of distinct, loud, impulsive noises. The amplitude plot shows the timing of the gunshots with the preceding shout being too small to see at the scale shown.

The AM method picks up, not only the gunshots themselves, but also the inconstant nature of the background noise. However, this would probably not be a minute with 5 events since the one-minute A_{eq} (Equivalent Audibility, cf L_{eq}) is below the 28 dB (phon) limit.

The SDI has naturally picked up the gunshots as an event and the SDI itself is non-zero. Because the gunshots are quite far away in this recording sound level only reaches about 65phon and it would take about 4 of these events to single-handedly lift the SDI beyond a "relatively insignificant level of disturbance." (Bullen et al., 1996) Note that using the A_{eq} instead of the A_{50} would have lowered the SDI from 0.57 to 0.039, due to the multiple peaks above the obvious baseline.

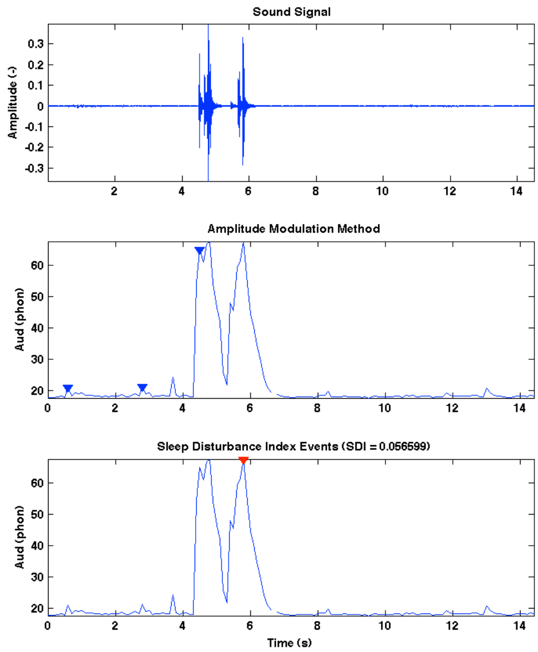

Figure 9. Firearm noise from a police training exercise in a rural area. There are two sets of gunshots and much quieter shouts ("Fire!").

The final example, shown in Figure 10, is of dogs barking. The AM method has generated four events in the 10 second recording and would probably have collected the five events needed in the minute. The SDI is very low reflecting the fairly quiet level of the sound as well as the elevated level of most of the sound, i.e. the A_{eq} is 48phon, about halfway between the extremes.

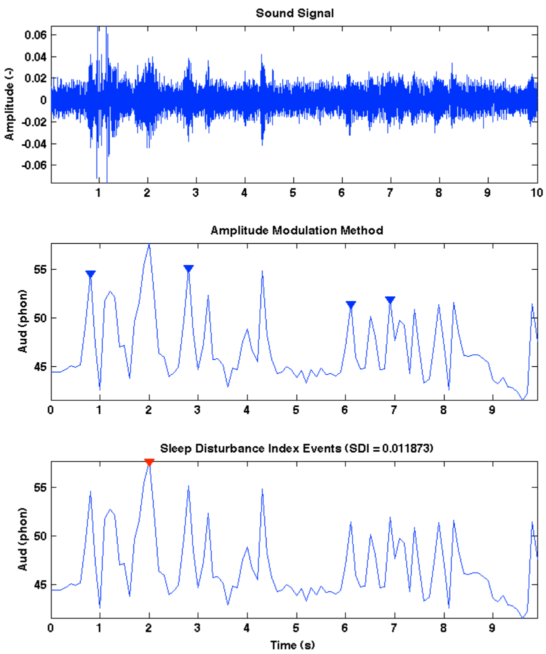

Figure 10. Dogs barking some distance away in a rural setting.

THE COST OF PROVING COMPLIANCE

The burden of proving compliance falls to the approval holder, complainant and regulatory authority with consequential costs for instrumentation and administration. These costs can be considerable. Apart from the cost of the equipment tied up in proving compliance, there are two major aspects that can magnify the cost. The first of these is the time required to retrieve the sound files from the sound level meters in the field. This can be largely eliminated if the sound level meters are capable of uploading sound file data over the Internet.

While it may be possible to record continuously at the full sampling frequency (usually 44.1 kHz), this produces very large data sets that can quickly become unwieldy or impractical to work with or archive, without considering the task of transmitting them via the Internet from a remote location. To reduce the transmission/storage burden it would be better to extract relevant data from the sound data stream and capture full-bandwidth sound information only when there is something of interest, usually by specifying a triggering sound level, sound capture duration and, possibly, a hold-off time after which the trigger is reset. These sound bites should then be integrated into the analysis software and identified in the report at the times when they were captured.

The second, and more difficult aspect of proving compliance, is the creation of reports from the sound and data files. While software exists that is capable of taking sound file data and producing the required statistics, the task of compiling these into a compliance report can take considerable time, far longer than it took to capture the data in the first place (Thorne, 2011). Such reports should capture all the basic parameters of the data capture—date and time, location, frequency weighting, atmospheric parameters, etc—as well as the statistics calculated from the captured data.

The capture of weather data is particularly problematic since it requires integration of data from a separate weather station (two if wind data is required at 10 m and at ground level) and program with the sound data into the final report. Ideally, this integration should be automatic when creating reports.

There is no standard format for reports, which Hayes McKenzie report can result in:

> "...potential problems faced by local planning authorities dealing with noise assessments for wind farm sites, both in terms of the way the documents are structured, and in the variations in the way some factors are taken into account in the assessments." (Hayes McKenzie, 2011)

They go on to state:

> The most striking comparison between sample noise assessments is the variation in the way the reports are structured and the way information has been presented. It is clear that the assumptions used and the details of the way the assessment has been carried out can be difficult to establish, even for those who are familiar with the issues. (Ibid.)

And conclude:

> Although it would be unreasonable to expect all noise assessments to be conducted and presented in an identical fashion due to the different interpretations of developers of presenting information in an Environmental Statement, some level of standardisation would undoubtedly be of assistance such as section headings and information to be included under each one. (Ibid.)

Faced with such an issue, and the fact that reports may have different audiences, the generation of reports should use a template, or templates, that can be created for the different audiences. The data from sound capture and analysis can then be imported to the template to create the report.

The creation of reports can be considered in the following cases;

1. automated, continuous monitoring with regular report generation (e.g. on a web site),
2. one-off sound capture and immediate report generation, and
3. *post facto* analysis and report generation.

Automated, Continuous Monitoring

This case represents the compliance situation most closely with monitoring of environmental noise in the field and production of regular reports at a central site. This is in two separate steps; the capture of sound data with subsequent transmission at the end of a capture period, and the generation of a report when the new data becomes available. The issues of data file size, capture period and required report period must be chosen to satisfy the requirements of the report audience. In the case of compliance monitoring, capture and report periods may well be about an hour.

If the reports are to published on a website, as opposed to a more conventional electronic or paper document, then this will be an added complication.

One-off Sound Capture

This case represents a situation similar to a council response to a noise complaint. An employee will capture a sound at the site of the complaint and may wish to generate a report that can be attached to an abatement notice. Ideally the abatement notice could also be generated automatically. The emphasis here is on the simplicity of the system, as such employees will usually only be semi-skilled in the use of sound capture equipment and report generation. Indeed, often these employees are security guards with very little training in this area.

Post Facto Analysis

This case requires the most flexibility from the system as the analysis may require changing many of the parameters, e.g. the report period might have to span several hours with detailed analysis of much shorter periods as well. In addition, analysis may also have to be performed on the sound bites, not just the processed sound data, and included in the report.

Ideally, this case should only be for one-off analysis at a more detailed level than that required in the automated, continuous monitoring case. If this were to be required at more frequent and regular intervals then it should become part of the automated report generation required in that case. Failing this the time required to generate these, more detailed, reports should be minimised.

NEW TECHNOLOGY INITIATIVE

The effects of community noise have been a focus for the WHO that now acknowledges the potential health effects of increased noise in the human environment. In particular, the rapid expansion of wind turbines has brought with it an unpredicted number of noise complaints world-wide. The continued reliance on the A-weighting and its unsuitability for the task is a major thrust of this paper. Along with the drive to determine better metrics for human-based noise measurement has come the need for an improved sound measuring technology.

In order to address the increasing costs of compliance monitoring and the complex metrics and reporting required for environmental sound monitoring, in particular, for wind turbines, a new instrument has been developed. The system, 13 years in development by the authors and their team, comprises a PC-based implementation of virtual instrumentation to create SAM: the Spectro Acoustic Meter.

An important system requirement is the ability to compare two different, simultaneous measurements, such as would be the case for noise outside versus inside. The PC architecture allows two synchronous audio inputs; accordingly, SAM has twin audio channels that are sampled synchronously at 44 kHz, providing high quality audio for subsequent analysis.

The use of twin, Type I microphones offers both standardisation and flexibility. By careful choice of microphone the standard acoustic range, 20–20,000 Hz can be extended down to levels approaching 1 Hz, providing for low frequency and infrasound monitoring. High pressure microphones could also be used for analysis of impulse sound at high SPLs. As any microphone has its own, unique frequency response, SAM accommodates entry of this frequency response so that tolerances of better than 0.5 dB are achieved throughout the acoustic range.

As stated in the previous section, the requirement to capture simultaneous, integrated weather and sound data for environmental sound monitoring is important but problematic. SAM can take inputs from two weather stations simultaneously with sound data. This allows monitoring of, for example, wind turbines, where wind data may be required at multiple heights. Critical to environmental data gathering is geographic location. The system incorporates a GPS module for verification of spatial position.

Integral to the system is the ability to capture sound bites in real time for subsequent analysis and human interpretation. Sound bite length is user definable as is the trigger level and subsequent hold-off period.

The user has control over the following parameters:

- Time averaging (linear, exponential slow/fast/custom, equal confidence, peak & impulse)
- Bands (1, $^1/_3$, $^1/_6$, $^1/_{12}$ & $^1/_{24}$ octave)
- Low frequency continuous sound file capture (<100 Hz)

For instantaneous determination of a soundscape, a real-time mode is available which displays the two audio inputs (dB/time), spectral histograms and combined SPL for each channel. Alternatively, batch jobs can be scheduled for either one-off sound capture and report generation or regular, daily captures (including continuous capture).

All acoustic input is recorded in linear mode. The choice of weighting, A, C or Z is applied post-capture.

As highlighted by Hayes McKenzie (Hayes McKenzie, 2011), the structure of documents dealing with noise assessments for local authorities is a significant issue where better standardisation could improve documentation and aid understanding. Considerable development of SAM has addressed this issue which now supports the automated production of reports based on templates. The default report template includes:

- Site description and location
- Time and date
- Measurement parameters (relevant standard [e.g. IEC 61260], time averaging, time weighting, time constant, confidence level [dB], bandwidth and range [Hz])
- SPL graph for the time period measured (db/time) and desired weighting
- Sound spectra and weighting
- Individual channel exceedance graphs
- Statistics table (L_{ny}, L_{n05}, L_{n10}, L_{n50}, L_{n90}, L_{n95}, L_{nmax}, L_{nmin} and L_{neq}, where n is any of A, C or Z and y is a post-capture, user-selectable level.)
- Incident histograms (threshold breeches at 5 dB intervals).

Report creation can span multiple sound data files or run over a user-selectable range within, or across, data files.

SAM supports remote logging of data with Internet upload to a server, from which they can be used to create reports. The automated creation of regular reports based on such data, as well as the alternative measures described here, are in development for the next release of SAM, version 4, due for release December 2011.

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