Uncertainties in Acoustics

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ABSTRACT

In acoustics, we are often required to demonstrate compliance with a given criterion. The criteria may be specified in a Regulation or a specification. When acoustic measurements are conducted to demonstrate compliance, there needs to be a consideration of the uncertainties of measurement and there needs to be an understanding of what the criterion is requiring as well as an understanding of what you are measuring. For example, when measuring environmental noise to check compliance with an EPA criterion, is the case that the actual criterion level must never be exceeded or can it be exceeded by some amount for say 50% of the time. If you measure a noise level of 50.1 dBA when the criterion is nominally 50 dBA, is this really a fail or is it still a pass? In this paper, some of these complexities are explored primarily using the VIC EPA SEPP N-1 Regulation as an example.

1. INTRODUCTION

The ISO Guide to the Expression of Uncertainty in Measurement defines uncertainty of measurement as the parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

- The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.
- Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.
- It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

The uncertainty has a probabilistic basis and reflects incomplete knowledge of the quantity. In acoustics, this uncertainty can be due to differences between instrumentation and calibration and, if measuring environmental noise, due to season, weather, temperature inversions, locations for the monitoring, reflections, standing waves and interference and the impact of ambient sound.

If a consultant was to repeat a measurement in nominally similar conditions, say 5 times over 5 days, then we would have a measure of repeatability. It is likely that the result would be within a standard deviation of the mean value.

If a number of acoustic consultants were able to measure the same sound under the same circumstances using their own instrumentation, it is very likely that the result would be around a similar but not necessarily identical mean but with more variability. So we also have the concept of reproducibility.

Given the uncertainty in our measurements then, what number do we use to determine compliance with a noise Regulation? Does the Regulation indeed tell us what level is required for compliance?

For example, we all know about various criteria for industrial noise, for traffic noise and for train noise. Invariably, there will be a specific decibel level prescribed for a given time period. In some instances, the criterion level is derived based on a measurement of the existing ambient noise level in some form e.g. the Victorian EPA State Environment Protection Policy No N-1 (N1) requires the measurement of the hourly LA90 values for the day, evening and night periods and this is used to determine the appropriate Noise Limit. However, the process of determining the Limit is somewhat undefined and open to interpretation so that different consultants will get different answers.

Similarly, the NSW Industrial Noise Policy requires the measurement of the L_{A90} in 15 minute samples for each period, then describes the process to derive a **rating background noise level** (RBL) that provides a single figure that represents the background noise level for assessment purposes. Note that the current NSW Draft states "The objective of carrying out long-term background noise monitoring at a location is to determine existing background noise levels that are indicative of levels during the entire year". However, the NSW Draft does not specify how long "long term monitoring" is. Depending on the length of time, the answer might differ by a decibel or two: whilst this is not a lot necessarily in background noise level terms, it may have a big impact in terms of compliance and thus with respect to the cost to achieve compliance. A similar question can be raised with respect to the requirement by the Queensland EHP that the proponent "Describe the results of any baseline monitoring of noise and vibration in the proposed vicinity of the project, including long-term measured background noise levels that take into account seasonal variations" whatever "taking into account" means!

In addition, when a Regulation or Policy prescribes a criterion Limit to be achieved for compliance, does that mean that the criterion Limit level is never to be exceeded or can it be exceeded for say 10% of the time or 20% of the time? And when we measure the noise level at a given location, is it the mean of the measured noise level that is to be compared with the criterion Limit or is the mean plus a number of standard deviations? And how many measurements should a consultant conduct to determine the noise level at the location being investigated? One, three, five? Over how many weeks, seasons?

2. BACKGROUND NOISE LEVEL

In the State of Victoria, Schedule C1 in N1 sets out the requirement for measurement of the background noise level. The hourly background noise level needs to be determined for the day, evening and period periods and in Sub Clause 4, N1 states that "the background level shall be rounded to the nearest decibel". Is this rounding to be up or down? Further, Sub Clause 5, N1 requires that the background level be measured during dry conditions with low to calm winds" but these conditions are nowhere defined. So it is left up to the consultant to decide and there is inherently a level of uncertainty in the result.

In order to set the Noise Limits, it is necessary to know whether the background noise level is neutral or not (Schedule1 B1 and B3 of N1).

To determine whether the background noise level is neutral for a given period, Schedule C2 requires "at least two measurements of the L_{A90} each of at least 5 minutes' duration and arithmetically averaged to obtain a representative measure of the background level for the period". However, when should these samples be measured and what is meant by a "representative measure" is not defined.

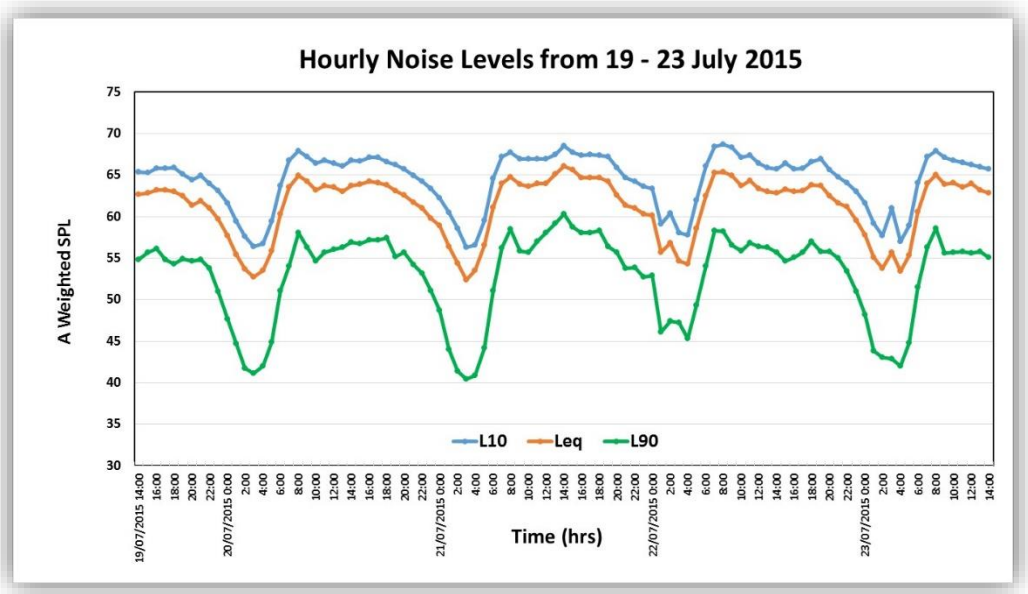

Figure 1 Noise Levels Measured During A Survey in July 2015

Figure 1 below shows the measurement result for a location near a main thoroughfare. Looking at the diurnal level L_{A90} variations, where would you choose your two 5 minute samples so as to be representative? What would you do for the sample shown in Figure 2 below?

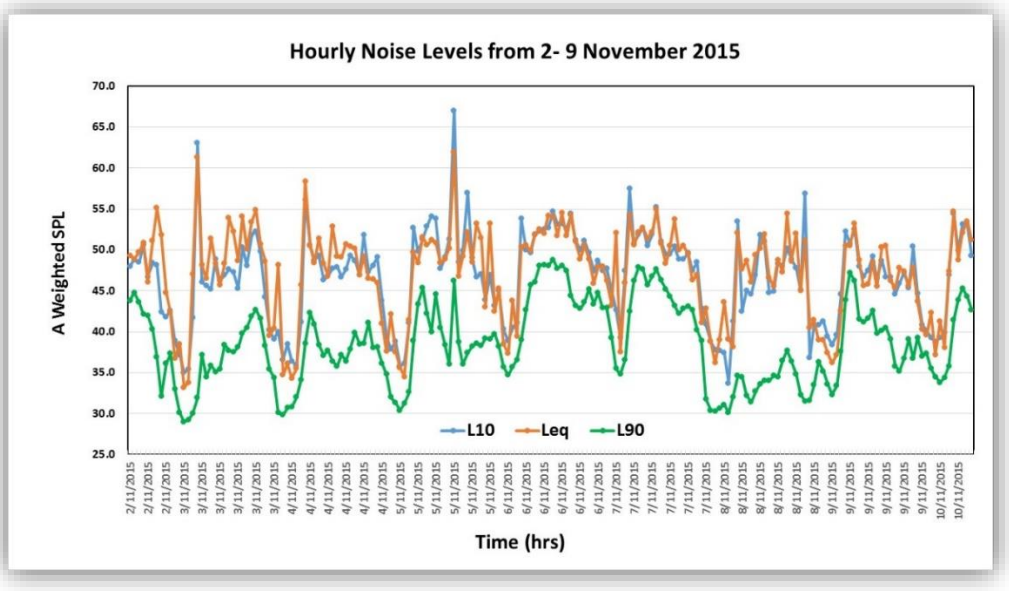

Figure 2 Noise Levels Measured During the Survey in November 2015

So how do you know what is the absolute background noise level and how close to that level do you need to be with your average? This result can have a very important impact on the final derived Noise Limit and thus on the costs to comply with that Noise Limit. The consideration of the level of uncertainty in this result is thus very important.

Table 1 below shows the arithmetic average of the hourly background noise levels for the day, evening and night time periods for a given location over a one-week period. N1 does not state how many measurements need to be made. It can be seen that the values vary considerably across the week of the measurements. The lowest measured value is highlighted for each period and was used as a basis for determining the period Noise Limit. It is quite clear that had only one or two measurements been conducted, that a very different result would have been obtained. But is a week period representative or should the measurement be over 2 or 4 weeks? And is it necessary to repeat this measurement during the Summer season to see if the results are similar? And is choosing the **lowest** period average over a 7-day period an appropriate selection or is this result penalising the industry under investigation?

TABLE 1 Overall background noise levels measured during each time period

Date	**Day** (0700 – 1800 hrs)	**Evening** (1800 – 200 hrs)	**Night** (2200 – 0700 hrs)
7th July 2014	50.6*	**48.6**	40.3
8th July 2014	49.2	48.9	40.9
9th July 2014	52.3	49.6	41.6
10th July 2014	52.7	50	38.8
11th July 2014	52.9	52.6	39
12th July 2014	50.6	50.6	33.4
13th July 2014	**47.5**	51.7	**29.3**
14th July 2014	48.9*		

Incomplete measurement periods

3. THE EFFECTIVE NOISE LEVEL

Part V Clause 15 of the N1 states that where noise emissions "exceed the requirements", then steps shall be taken to reduce the level to, or below, the relevant Policy noise limits. In Schedule A Clause 6 Atmospheric Effects, N1 states that "When the effective noise level may be significantly affected by atmospheric effects (two key words here are not defined – "may" and significant"), a derived point may be used located near to the industry (again "may" and "near" are not defined). "Where it is inappropriate to use a derived point because the of the size of the industry or the unavailability of an alternative measurement point, three measurements shall be taken within a 30-day period at the noise sensitive area. The effective noise level shall be the arithmetic average of the three measurements". In this latter sentence, the "size" that makes the derived point inappropriate is not explained nor is the "unavailability" explored. So that these are open to interpretation and different consultants could get different answers as a result.

Further, in the instance when three measurements are taken within a month, can these three measurements be taken on consecutive days? Or do they need to be spread out at say one a week? The EPA stated to the Author that they consider this requirement to mean that the measurements should be conducted to achieve the 80% level, i.e. not the highest level that might occur but rather one that would occur 80% of the time. In essence, this is a recognition that the highest level might not be representative of the noise emission. But the Regulation does not define clearly what this measurement protocol is so there is an uncertainty in the result that is raised. Again, the impact on an industry could be very important with respect to cost to achieve compliance.

4. UNCERTAINTY IN NOISE LEVEL

The Author often sees noise level measurements quoted with more than one digit past the decimal point e.g. 73.36 dBA. This example has 4 significant digits but is it legitimate to claim such accuracy as implied by having two digits after the decimal point? This implies that the real number is in the range 73.356 to 73.364. In practice, you would be lucky to be able to claim accuracy to the tenth place (ie one digit after the decimal point). For the example above, this would be 73.4 dBA. More likely is that you can only claim accuracy to the units place. For the example above, this would be 73 dBA.

In determining the uncertainty of a measured noise level, you need to consider the uncertainty associated with the measurement equipment. This is likely to small, of the order of say 0.1 dB. Then you need to consider the uncertainty related to the measurement conditions. If you repeated the measurement a number of times, you would get an indication of the mean and standard deviation and you could determine the confidence level of the result. Figure 3 below shows a normal distribution and the range for two confidence limits. For a normal distribution, the 95% confidence interval is within +/- 1.96 standard deviations of the Mean and the 99.73% limits are within 3 times the standard deviation.

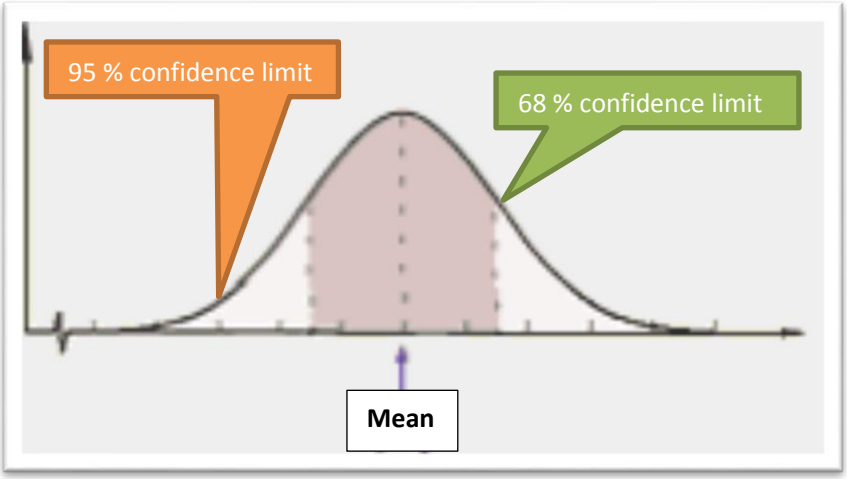

Figure 3 Normal distribution showing the mean and the shaded areas representing +/- one standard deviation about the mean. For a normal distribution, ± u encompasses about 68 % of the distribution

For most cases of environmental noise level measurement, an expanded uncertainty of +/- 3 dBA representing a coverage factor of 2 is reasonable. This represents a confidence interval of 95% ie one can have 95% confidence

that the result is within 3 dBA of the measured value.

5. COMPLIANCE

So if the measure value has an uncertainty attached, how is compliance demonstrated? For example, if the Noise Limit was 73 dBA and the measured value was 73 +/- 3 dBA, would this be considered a pass? If uncertainty is not considered, then clearly this measured level could be considered a pass. But if the uncertainty is considered, then does that require that the measured value be say 70 dBA for a pass or maybe 71.5 dBA would be required for compliance. Most Regulations/Guidelines do not explain what the requirement on the measurand needs to be and what uncertainty is required in making an assessment.

It is necessary for the Regulation or Guideline to define what is required for compliance. Should it be that the mean measured noise level not exceed the Noise Limit ever or should it be that the mean plus either 2 or 3 standard deviations not exceed the Limit? In order for an assessment of compliance to be made, clearly some statement about uncertainty is required.

6. PREDICTING COMPLIANCE

Table 2 below shows a calculation of the predicted internal noise level in a room in a hospital due to a helicopter landing on a helipad nearby. The calculation shows the incident noise level, the noise reduction of the tested façade, and area and room corrections to arrive at an overall internal noise level of 69 dB L_{AFmax}, which is claimed to be well below the 75 dB L_{AFmax} criterion.

TABLE 2 Prediction of Internal Noise Level Due to a Helicopter

	Frequency								
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**Overall dB(A)**
Source Noise Level at the Façade	103.0	105.0	102.0	101.0	96.0	92.0	85.0	82.0	102
Vision Façade Performance (Laboratory Tested)	-28.1	-25.9	-35.7	-41.2	-42.9	-47.4	-57.2	-59.0	
Area Correction	10.3	10.3	10.3	10.3	10.3	10.3	10.3	10.3	
Room Absorption Correction	-5.5	-6.4	-7.3	-8.2	-9.1	-10.0	-10.9	-11.8	
Resulting Noise Level	**79.7**	**83.0**	**69.3**	**61.9**	**54.3**	**44.9**	**27.2**	**21.5**	**69**

Based on the resulting of calculations for the vision and non-vision areas of the façade compliance with the 75 dB(A) $_{LAmax}$ noise level criteria will be achieved.

As can be seen, the noise source level is shown with one significant figure after the decimal point. For example, the 250 Hz octave band level is shown as 102.0 dB. This implies that this octave band source level is between 101.05 and 102.04 dB. But we know that the uncertainty in the incident noise level can be at least +/- 3 – 10 dB depending on which octave band you are dealing with. Similarly, there are uncertainties associated with each line in the

calculation. When taking into account the different uncertainties which are additive, compliance is seen to be not as straight forward and not necessarily achieved. What was previously a predicted noise level well below the criterion is now only just within the criterion! Table 3 shows the revised calculation and the statement of compliance (U95 in the table represents the 95% confidence level).

TABLE 3 Prediction of Internal Noise Level Due to a Helicopter and Uncertainty

	Frequency								
	63	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**Overall dB(A)**
Source Noise Level at the Façade	103	105	102	101	96	92	85	82	102
Vision Façade Performance (Laboratory Tested)	-28	-26	-36	-41	-43	-47	-57	-59	
Area Correction	10	10	10	10	10	10	10	10	
Room Absorption Correction	-6	-6	-7	-8	-9	-10	-11	-12	
Resulting Noise Level	**80**	**83**	**69**	**62**	**54**	**45**	**27**	**22**	**69**
Uncertainty U_{95}, dB (2sf) {Information only}	5	4	3	3	3	3	3	3	
Rounded Uncertainty U_{95}, dB (1sf)	6	5	4	4	4	4	4	4	
Sample Noise Level + U_{95}, dB	86	88	73	66	58	49	31	26	73
Criterion, dB									75
Design complies									Yes

The above table shows that in accounting for design uncertainty, there is a 95% probability the true value under the scenario assessed will be within 5dB of the result, i.e. 97.5% probability it will be less than 73dB and 99.2% probability it will be less than 75dB.

7. CONCLUSION

The issue of uncertainty in acoustics has generally not been considered but is becoming more recognised as a consideration in measurement and assessment of compliance. The Regulations/Specifications need to be clear about what exactly they require in this regard so that compliance can be clearly demonstrated. Whilst Regulators want a noise level below a fixed limit, the level of confidence of a measurement needs to be indicated and considered when assessing compliance. In addition, the criteria need to explicitly state what is required in terms of uncertainty.

REFERENCES

ISO Guide 98-3 Uncertainty of Measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)

State Environment Protection Policy No N-1 "Control of Noise From Commerce, Industry and Trade"

NSW Draft Industrial Noise Guideline http://www.epa.nsw.gov.au/resources/epa/150185-draft-industrial-noise-guide.pdf

Queensland EIS Information Guideline http://www.ehp.qld.gov.au/management/impact-assessment/eis-processes/documents/generic-tor-supporting-guidelines/tor-guideline-noise-vibration.docx

Uncertainty of Measurement Results http://physics.nist.gov/cuu/Uncertainty/glossary.html

Rounding and Significant Digits http://www.purplemath.com/modules/rounding2.htm