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System Programme for Acoustical Metrology

A Good Practice Guide on the
**Sources and Magnitude of
Uncertainty Arising in the
Practical Measurement of
Environmental Noise**

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1 INTRODUCTION

Advances in technology have helped reduce instrumentation measurement errors and uncertainties, especially in the functioning and calibration of sound level meters. However, the way in which sound level meters are used and the conditions under which they are operated, especially when out of doors, can give rise to additional uncertainties that can considerably influence the interpretation of any results obtained. Indeed the whole “measurement” chain must be considered as a source of uncertainty in a final measured value. Changes in the way in which the source of noise is operated or controlled, changes in parameters such as weather conditions or ground surface conditions over the propagation path, or changes in the conditions at the “receiver” where the sound level meter is placed, are typical examples of potential sources of uncertainties. Identifying all the sources and magnitudes of such uncertainties provides a means, not only of quantifying the total uncertainty in any environmental noise measurement, but also a route to minimising or at least reducing some of them, with a resultant beneficial improvement in the accuracy of the final result.

All measurement results have an associated element of doubt about their true value. In general terms, this is known as measurement uncertainty, and is attributed in part to unknown factors influencing the measurement, or an inability to determine the influence of a known quantity with a better accuracy. In the case of environmental noise measurements, it is usually factors influencing the source and propagation path rather than instrumentation shortfalls that influence measurement uncertainty. A knowledge of the source and magnitude of these factors will assist with interpretation of the results, indicating differences which may not be significant and identifying areas where greater attention to detail can improve assessments.

The aim of this guide is to present “uncertainties” in as simple a manner as possible, so that users will take up the ideas and use the information to either define the magnitudes of the final measurement uncertainty, or identify the probable sources of uncertainty. Some practitioners find the determination of uncertainties daunting. In this guide, a simple and straight-forward approach has been adopted which will allow the user to decide what is required and how much can be done, based on the available information.

As a basis for handling uncertainties, the straightforward approach adopted by Stephanie Bell¹ has been adopted. This type of approach has proved successful in situations where there is a reasonable degree of control on the

¹ BELL, STEPHANIE, *A Beginner's Guide to Uncertainty of Measurement, Measurement Good Practice Guide No 11*, 1999, NPL

measurement parameters. However, there is no reason why it cannot be applied to the measurement of environmental noise where there is little control on some extraneous factors.

The content of the “Good Practice Guide” is based on assessments, inter-comparison exercises, and case studies that have been carried out or obtained and analysed in terms of uncertainties arising from relevant environmental effects, measurement practice and instrumentation uncertainties. A key element of the guide has been to provide the necessary procedural material for evaluating uncertainties in an easily digestible form suitable for all practitioners. The approach taken is to break each environmental noise measurement exercise into three stages, which can be described as the source, the transmission path and the receiver, and to consider the processes and associated uncertainties in each stage. An uncertainty budget is then drawn up for each stage, and used to evaluate the final combined uncertainty. In a real environmental noise measurement situation it can be extremely difficult to provide a reliable estimate of uncertainty, because it is unique to the particular circumstances of the application. However, by using information and guidance obtained from relevant sources and references, and from carrying out practical studies, it should be possible to evaluate the source of most uncertainties in a measurement, and make an estimate of the magnitude. A list of useful references is included, so that the user can take the analysis further if deemed necessary.

Standards on environmental noise measurement will, in future, require an assessment of the measurement uncertainty to be made. This guide offers an appropriate means of determining such uncertainties.

The emphasis of the guide is on the adoption of good practice to reduce uncertainties in measurement results. Identifying sources and magnitudes of uncertainty are essential to identify where measurement practice can best be improved. A knowledge of the magnitude of the uncertainty in a measurement is particularly useful when comparing measurements with guidelines or with another measurement result.

Contents Overview

A brief introduction to measurement uncertainty, uncertainty budgets, and inter-comparison exercises (repeated measurements), is provided in Chapter 2. The procedure for formulating an uncertainty budget and evaluating magnitudes is outlined in greater detail in Chapter 3. A flow chart summarising this process, and a checklist for the identification of sources of measurement uncertainty are included at the end of the chapter. Two example measurement exercises with corresponding uncertainty budgets are presented in Chapter 4.

Some of the more commonly encountered sources of measurement uncertainty are outlined in Chapter 5. Where possible, information on magnitudes or pointers to where that information can be found are included. The more important sources of uncertainty are highlighted, and “good practice guidelines” provided to help the practitioner identify means of reducing their effect.

Case studies illustrating some of the points made in Chapter 5, and listing of relevant guidelines and further reading are provided in the Appendices.

2 MEASUREMENT UNCERTAINTIES

Measurement uncertainties tend to be either ignored or, at best, politely alluded to by practical scientists and engineers. That is because they have usually been frightened off by what has, in the past, been portrayed as a somewhat imperfect science made quite complex by sophisticated statistical mathematics. Practical scientists and engineers are inherently aware that their measurements are not perfect, and usually draw upon experience to minimise any uncertainty in the measured values. But what is “measurement uncertainty”, and why is it important especially to environmental noise measurements?

Any measured quantity has a margin of doubt associated with it. In the case of noise levels measured in the environment, this doubt can usually be attributed more to factors influencing the source and propagation path rather than the measuring instrumentation. This is not normally the case with laboratory-based measurements, for which a number of evaluation procedures to determine uncertainties have been established.

Before any uncertainty budget can be drawn up it is necessary to decide how the measurement result is to be used. If it is for short-term comparisons, say between events on a particular day, there is unlikely to be any significant change in long-term variables, such as ground cover or even the weather. The magnitude of the uncertainty associated with a particular effect on the day should be used. If however the measurements are for long-term use, for instance, to be compared with data taken at some time in the future, then the long-term uncertainty magnitudes should be considered. Alternatively it might be more pertinent to ensure that a detailed description of factors likely to change over a long period is kept with the measurement results for future evaluation. It is then only necessary to evaluate uncertainties at the time of the measurement.

With environmental noise measurements, some variables affecting the measured levels can often not be controlled, for instance the influence of the weather, or indeed the noise output from the source. In such instances it will be necessary to take a view as to whether measurements should be repeated and if so, how often, to obtain the desired confidence in the results. In general, an estimate of the uncertainty in a measured value gives an idea of the quality of the measurement, but in reality the quality of a measurement can only be determined in the context of the purpose for which the measurement was made. In the case of an evaluation of a noise complaint, it may be necessary for the measurements to encompass a wide range of variables in order to put the source of the complaint in its true context. Quality of measurement, within reason, may not be an issue. In some cases, the

uncertainty of an environmental noise measurement has to be properly quantified, because it is needed to determine whether criteria or allowed tolerances in criteria have been met. For instance, when monitoring legally binding boundary noise levels, a high-quality measurement may be required to ascertain whether a limit has just been breached or not. In most situations, an appreciation of uncertainties in the results can lead to a better understanding of the measurement and its potential variability.

It is therefore necessary to quantify the uncertainties associated with environmental noise measurements in an acceptable and uniform manner. To achieve this, two quantities may be specified: the “confidence interval”, which is the margin within which the true value being measured can be said to lie, and the “level of confidence”, which is a number expressing the degree of confidence in the result (e.g. the noise level is 65 dBA \pm 5 dBA with a confidence of 95%).

Background literature on measurement uncertainty

The need for an internationally accepted procedure for expressing measurement uncertainty has led to the development and publication of the ISO Guide to the Expression of Uncertainty in Measurement (ISBN 92-67-10188-9, 1993) available as BS PD 6461:1995 Vocabulary of Metrology, Part 3, Guide to the Expression of Uncertainty in Measurement, BSI ISBN 0 580 23482 7). The United Kingdom Accreditation Serviced (UKAS) document M3003, edition 1, December 1997, provides a practical approach to dealing with uncertainty. Its overview covers the need for uncertainty assessments. In brief, it states that measurements are subject to errors that are not perfectly quantifiable, and that there is therefore uncertainty associated with such measurements. The ISO Guide describes accepted methods, but it is only a guide designed to produce a reasonably quantifiable uncertainty statement, mainly based on statistical measurements. It does provide a means by which results from different sources may be combined in a meaningful manner. Experience with UKAS requirements has already shown that the guidance currently available is not easy for the layman to understand. The beginner’s guide to measurement uncertainty by Stephanie Bell and the National Physical Laboratory offers more user-friendly guidance.

2.1 UNCERTAINTY BUDGETS

To obtain these quantities, it is necessary to carry out a procedure that considers each separate contribution to the uncertainty chain, evaluates its contribution, and then combines them according to set statistical procedures. Full details of this can be obtained from ¹ and ² and in particular ³ provides a good basic primer for all uncertainty determination. The usual procedure adopted is to set up an “uncertainty budget”, often found in the form of a spreadsheet, in which the various sources of uncertainty, the pertinent magnitudes, the statistical processes and the final combined results can all be conveniently listed.

In many instances, especially when making environmental noise measurements, the sources and values of uncertainties may not be known or cannot be readily evaluated. (Examples which illustrate this point, are unknown changes to the noise source during a process, and the combined effect of temperature and wind gradients on the propagation.) In such cases reasonable estimates, based on experience, can be made and the importance, or otherwise, of the decision evaluated alongside those on other known variables.

Four uncertainty budgets are provided in Chapter 4, however in reality these are just examples, and measurement teams are encouraged to draw up their own budgets even though they may be measuring under similar circumstances.

2.2 INTER-COMPARISON MEASUREMENTS

An alternative approach to providing an overall statement of uncertainty is to consider declaring values, that are statistical maxima based upon sets of practical measurements, which encompass the likely statistical variations. Such statements are based on the values of standard deviations of reproducibility and of repeatability of measured environmental noise levels for typical measurement situations.

For environmental noise, reproducibility measurements are defined as those measurements which encompass the same noise source, measured using

¹ Vocabulary of Metrology, Part 3, Guide to the Expression of Uncertainty in Measurement, *BSI PD6461*, 1995, British Standards Institution

² The Expression of Uncertainty and Confidence in Measurement, *M3003*, Edition 2, January 2007, United Kingdom Accreditation Service (UKAS)

³ BELL, STEPHANIE, A Beginner's Guide to Uncertainty of Measurement, *Measurement Good Practice Guide No 11*, 1999, NPL

the same measurement procedure, by different operators using different equipment at different times, but not necessarily at different sites.

Repeatability measurements cover the same noise source, measured using the same method, repeated at short intervals by the same operators using the same equipment, and at the same site. Examples of these are given in Chapter 4.

3 FORMULATION OF UNCERTAINTY BUDGETS

3.1 PROCEDURE

The following procedure is based on one outlined in “A Beginner’s Guide to Uncertainty of Measurement”¹. It is accepted that this procedure may be over-complicated for certain situations, especially where one or two uncertainties dominate all others. It is important however that when uncertainty magnitudes are quoted, they are in the same units and refer to the same level of confidence - usually 95%.

It must be stressed also, that this procedure is not prescriptive. The primary purpose of this guide is to assist with the identification and reduction of uncertainties. If the nature of the situation is that there is little relevant information available to make an estimate of a particular uncertainty, then a reasoned guess should be made and evaluated alongside other known quantities. It is also perfectly reasonable to ignore some small or irrelevant uncertainties from the final assessment.

When drawing up the full uncertainty budget, the user can incorporate the following steps into a single spreadsheet, or use individual spreadsheets, or simply notes showing the way the decisions have been arrived at. It is important to retain this information with the measurement record for future reference. If the measurement is repeated at a later date, the individual uncertainties can then be cross-checked.

A flow chart summarising this process is presented in section 3.2.

3.1.1 Sectionalise Process

To manage the process, it is suggested that the total environmental noise measurement regime is divided into three sections covering:

- source
- transmission path
- receiver

¹ BELL, STEPHANIE, *A Beginner’s Guide to Uncertainty of Measurement, Measurement Good Practice Guide No 11*, 1999, NPL

3.1.2 List Sources of Uncertainties and Estimate Magnitudes

For each section, list the possible sources of uncertainty and decide how and from what data the magnitude of the uncertainty can be estimated. Some magnitudes may be calculated from repeated measurements (type A evaluation), whereas others may be taken from manufacturers' data, calibration certificates, other published data, or calculated from an estimate of the upper and lower limits (type B evaluation). The value to be used is the half width (or half range), i.e. 2.0 for ± 2.0 . A checklist for the identification of typical sources of uncertainty is given in section 3.3.

3.1.2.1 Type A evaluation - Calculation of uncertainty

For measurement uncertainty of data, where the distribution of values is spread around the mean (normal distribution), the magnitude of the standard uncertainty can be calculated from repeated measurements.

For a set of n measurement data, the standard uncertainty associated with the mean of that data may be calculated:

$$\text{Standard uncertainty of the mean} \quad u = s/\sqrt{n}$$

Also, the standard uncertainty associated with any single measurement may be calculated

$$\text{Standard uncertainty of any one measurement} \quad u = s$$

(where s = the estimated standard deviation (σ_{n-1}) of a set of n data based on a measure of the spread of results of a limited sample).

3.1.2.2 Type B evaluation - Calculation of uncertainty

For most other data you might only have an estimate of the upper and lower limits ($\pm x$) of uncertainty and you assume that the value can fall anywhere between with equal probability (rectangular distribution).

$$\text{for rectangular distributions, the standard uncertainty} \quad u = x/\sqrt{3}$$

(Other distributions might be appropriate. See Beginner's Guide Section 3.1.)

EXAMPLE

Calculation of uncertainty for normally distributed data

The height of a microphone is measured four times at 1.52 m, 1.50 m, 1.52 m and 1.58 m.

The mean value is calculated as $x = 1.53 \text{ m}$
and the standard deviation as $s = 3.5 \text{ mm}$

The standard uncertainty associated with the mean may be calculated:

$$\text{Standard uncertainty } u = 3.5/\sqrt{4} = 1.7 \text{ mm}$$

Therefore, it may be stated that the height of the microphone is 1.53 m with a standard uncertainty of 1.7 mm.

Using the same method, equipment and operator, a second microphone is measured once at 1.51 m.

The uncertainty associated with a single measurement may be calculated from the measurements of the first microphone.

$$\text{Standard uncertainty } u = s = 3.5 \text{ mm}$$

Therefore, it may be stated that the height of the second microphone is 1.51 m with a standard uncertainty of 3.5 mm.

EXAMPLE

Calculation of uncertainty for rectangularly distributed data

A sound level meter displays the measurement result of 55.4 dB, there is equal probability that the true value lies at any point in the range 55.35 dB and 55.45 dB i.e. the true measurement result is 55.4 ± 0.05 dB.

The standard uncertainty may be calculated as

$$u = 0.05/\sqrt{3} = 0.03 \text{ dB (2 decimal places)}$$

Therefore, it may be stated that the sound level meter has displayed a result of 55.4dB with a standard uncertainty of 0.03 dB.

However, for most practical measurements this would be regarded as negligible.

3.1.3 Standardise to Same Confidence Level

Standardise the estimates to plus or minus one standard deviation (known as a standard uncertainty [**u**]). This is normal practice and allows all uncertainties to have equal weighting in the following calculation process.

EXAMPLE

Standardisation of confidence level

A source of literature states that the total estimated accuracy of a type 1 sound level meter is 1.9 dB at a 95% level of confidence.

Standard uncertainty equates to a 68% level of confidence.

Therefore, standard uncertainty $u = 1.9/2 = 0.95$ dB

3.1.4 Convert to Same Units

It is also necessary to convert all uncertainties to the same units, preferably for environmental noise, dB or dBA (re 20 μ Pa). Conversion can often be achieved using simple data tables, charts, or relationships (e.g. the inverse square law for distances). On occasions this will lead to an asymmetric uncertainty interval, the correct treatment of which is discussed in the UKAS publication M3003.

However, a more practical approach may be to approximate the asymmetric interval with a symmetrical one. This can be done by either adopting a conservative approach and taking the larger value, or by re-scaling the interval to a symmetrical one of equal width.

EXAMPLE

Conversion to the same units (dB)

A source-to-receiver distance has been measured at 15 m with a standard uncertainty of ± 1 m. This may be converted to dB using the inverse square law:

$$\begin{array}{lcl} +1 \text{ m equates to} & 20\log(16/15) & = +0.56 \text{ dB} \\ -1 \text{ m equates to} & 20\log(14/15) & = -0.60 \text{ dB} \end{array}$$

This gives an asymmetric uncertainty interval which may be approximated by either: taking the larger value, hence the uncertainty of ± 1 m may be considered to be the equivalent of ± 0.60 dB; or re-scaling to a symmetrical uncertainty interval of equal width.

$$\begin{array}{lcl} \text{Re-scaled interval} & (0.56 + 0.60)/2 & = \pm 0.58 \text{ dB} \\ \text{half width} & & = 0.58 \text{ dB} \end{array}$$

3.1.5 Calculate Combined Uncertainty

The combined uncertainty $[u_c]$ can then be calculated from the individual uncertainties by calculating the root sum of the squares.

$$\text{Combined standard uncertainty} = \sqrt{(u_1^2 + u_2^2 + u_3^2 \dots)}$$

Note: this is a practical approach. There may be occasions when simple addition or subtraction is not appropriate and more complex analysis is required².)

3.1.6 Re-scale to Expanded Uncertainty

The normal practice is to re-scale the combined standard uncertainty to a level of confidence of 95%, by multiplying the combined standard uncertainty by a coverage factor $[k]$ of 2 to give:

$$\text{Expanded uncertainty } U = k u_c$$

Some authorities may require other levels of confidence e.g. $k = 1.65$ for 90% confidence level, $k = 2.58$ for 99% confidence level.

3.1.7 Express Answer

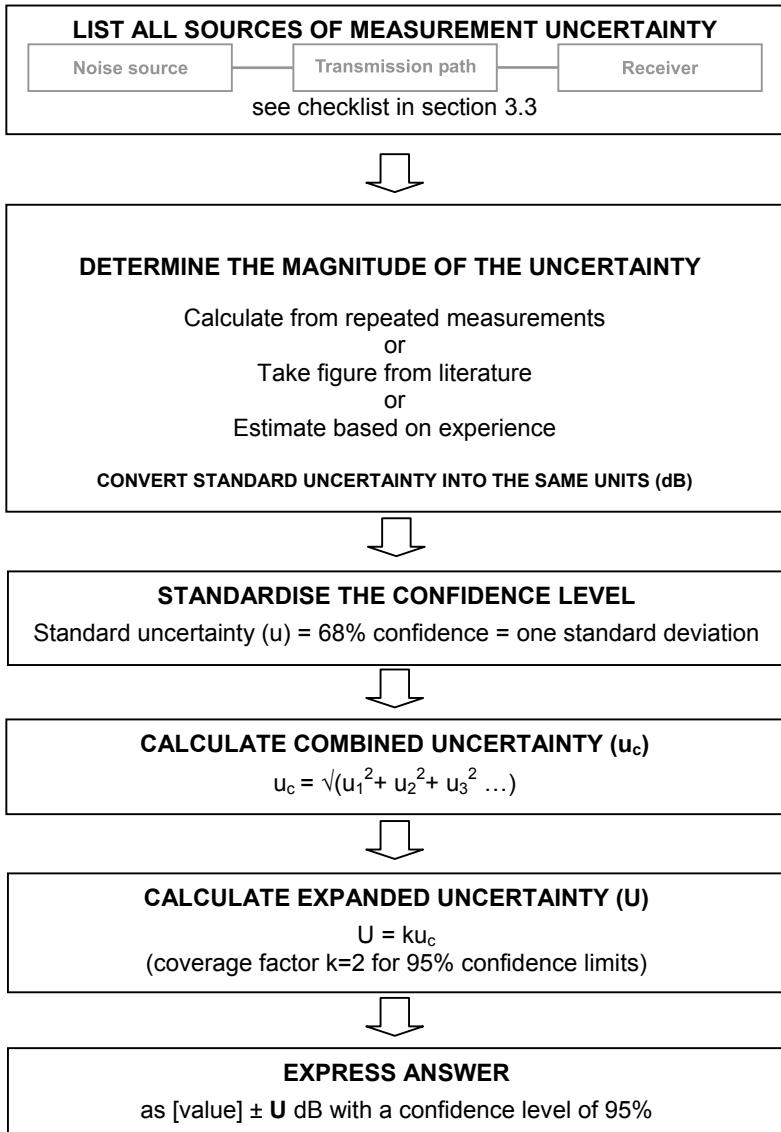
The final answer is then expressed as $[\text{value}] \pm U \text{ dB}$ with a confidence level of 95%

3.1.8 Uncertainty Budget Spreadsheet

A detailed *pro forma* to assist with the above procedure is given in Appendix 3.

² BELL, STEPHANIE, A Beginner's Guide to Uncertainty of Measurement, *Measurement Good Practice Guide No 11*, 1999, NPL

3.2 UNCERTAINTY BUDGET FLOWCHART



3.3 UNCERTAINTY BUDGET CHECKLIST

This checklist is intended as an aid to assist with the identification of sources of measurement uncertainty. The list is not exhaustive, it is not unusual to encounter situation specific sources of uncertainty.

			SEE SECTION
NOISE SOURCE	Position of source	Height above ground level, etc.	5.1.5
	Operating condition	Duration on/off (typical cycles)	5.1.3
		Load/settings (average/maximum)	
	Character	Steady/Impulsive	5.1.1
		Broadband/tonal(standing waves)	
	Barriers (buildings/enclosures)	Magnitude of screening/shielding	5.1.7
		Variability (open/closed window)	
	Machine condition	New/used/maintenance	5.1.4
		Guards/adapters fitted	
		Operator's personal set-up	
Type of propagation	Spherical/hemispherical	5.1.2	
	Point/line/area source		
	Near/far field		
	Mobile/static source		5.1.6
	Directional/omni-directional		
Environmental effects	Wind/temperature/etc.	5.1.8	
			SEE SECTION
TRANSMISSION PATH	Weather	Propagation distance	5.2.1
		Wind speed and direction	
		Temperature gradient	
		Variability	
	Ground reflection	Magnitude of ground dip	5.2.2
		Variability of surface	
	Barriers	Magnitude of shielding/screening	5.2.3
Variability			

		SEE SECTION	
RECEIVER	Measurement position	Choice of position)	5.3.1
		Height above ground level)	
		Microphone orientation)	
		Tripod mounted/handheld)	
		Small variations between repeated measurements)	
	Façade reflections	Distance to façade)	5.3.1.2
		Size of façade)	
		Type of façade (windows, etc.))	
	Other reflecting surfaces	Distance to surface)	5.3.1.3
		Size of surface)	
		Type of surface)	
	Instrumentation	Calibration (annual, on site))	5.3.2
		Accuracy & precision (type 1/2))	
		Accessories (windshield, extension leads, etc.))	
Environmental influence (wind noise, temperature, humidity))			
Data logging/transfer)			
(digital/manual))			
Background noise level	Timing of measurement)	5.3.4	
	Choice of measurement position)		
Assessor	Competence and experience	5.4.1	
Communication	Complainant)	5.4.2	
	Owner of noise source)		
	3 rd parties, (e.g. local authority))		
Standards/procedures/ guidelines	Interpretation)	Appendix 1	
	Relevance)		

4 MEASUREMENT EXERCISE AND OTHER EXAMPLES AND UNCERTAINTY BUDGETS

As part of an investigation into uncertainties in environmental noise measurements, the University of Salford set up two measurement exercises with the object of gaining a better understanding of the nature and magnitude of uncertainties in environmental noise measurements.

The first measurement exercise was set up to provide both repeatability and reproducibility data on uncertainties to be expected from simple measurements of environmental noise taken under conditions where the source, propagation path and instrumentation uncertainties were reasonably controlled and generally minimised.

The second measurement exercise involved carrying out full-scale measurements to BS 4142:1997 at pre-defined locations around a factory, which provided a large multi-point noise source that operated continuously. With the assistance of three independent, experienced environmental noise measurement teams, four sets of measurements were obtained at each of three different locations at two different times of the day but on different days. This provided the data to calculate reproducibility.

To calculate repeatability, a further set of data is presented. This data was obtained from measurements repeated with several months between each measurement at the same locations around the factory, but the same operator and same equipment were used.

Within the context of these experiments, the conditions for repeatability were defined as measurements conducted by the same operator using the same instrumentation, and those for reproducibility as measurements conducted by different operators using different instrumentation.

Two further practical examples are provided, based upon measurements carried out during routine environmental noise assessments.

4.1 CONTROLLED EXERCISE

The controlled measurement exercise was designed to investigate the lower limit of uncertainty associated with the practical measurement of environmental noise, i.e. that associated with the set-up and operation of a class 1 sound level meter. The uncertainty of noise measurement was calculated in terms of both repeatability and reproducibility for five measurement scenarios:

- (i) Handheld, 1.5 m above ground level, approximate free field
- (ii) Tripod-mounted, 1.5 m above ground level, approximate free field
- (iii) Tripod-mounted, 1.2 m above ground level, approximate free field
- (iv) Tripod-mounted, 1.5 m above ground level, 3.5 in front of a façade*
- (v) Handheld, 1.5 m above ground level, 3.5 in front of a façade*

(* The façade was a three-storey brick-built dwelling.)

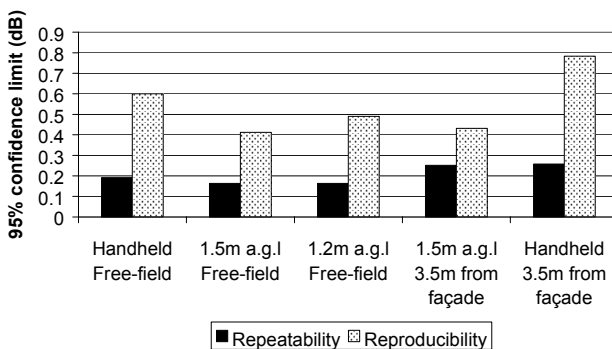
Four measurement teams were selected to represent a cross-section of the user community. One team was chosen to represent a local authority, one an instrument supplier, one an acoustic consultant, and one a University research team.

Wide-band pink noise was played through an omni-directional dodecahedron loudspeaker mounted 2 m above ground level. The noise emission was monitored throughout the experiment at a reference position, 1 m from the source.

Temperature, humidity, wind-speed and -direction were monitored over the duration of the experiment. A gentle rise in temperature and fall in humidity was measured together with a low wind speed. The propagation path was a distance of 25 m, through open space and over flat, grass-covered, ground. This distance was sufficiently large to consider the loudspeaker as a point source, but sufficiently small to ensure that the influence of the weather was minimal.

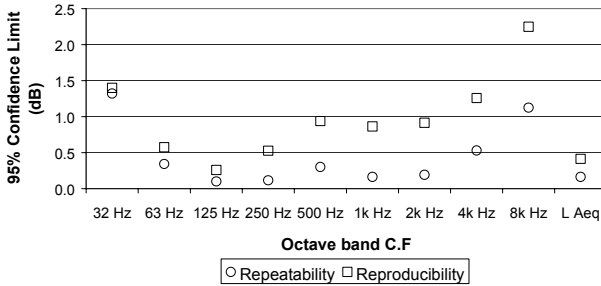
Measurement Results

Repeatability and reproducibility of A-weighted noise measurement



All of the measurements show significantly greater uncertainty in reproducibility than repeatability. There is also a general trend for greater uncertainty to be exhibited by hand-held measurements and those in the presence of a façade reflection.

Repeatability and reproducibility of noise measurement, tripod mounted in an approximate free field



This graph compares the A-weighted and octave band measurement uncertainty for the tripod-mounted measurements taken in an approximate free field. It is clear that the greatest uncertainty exists at the extremes of the frequency range, although some component of the 32 Hz octave band uncertainty is attributable to interference from the background noise level. The effect of measuring broadband and A-weighted levels is to reduce the uncertainty to below that of the majority of individual octave bands. These observations are typical of all the measurements, whether hand-held, tripod-mounted, free-field or in the presence of a façade reflection.

Uncertainty Budget

Example 1 based on detailed repeatability exercise

Scenario

This was an artificial experiment aimed at obtaining a greater understanding of uncertainties in the measurement of environmental noise.

An omni-directional loudspeaker on a stand 2 m above ground level (a.g.l.), was located 25 m from a class 1 sound level meter in the centre of a grass field, well away from any reflecting objects. This was mounted on a stand at either 1.2 m or 1.5 m a.g.l. and was downwind of the source. Wide-band pink noise was reproduced and measured using the sound level meter set to A-weighted L_{eq} . The source was monitored throughout the measurements with a separate class 1 sound level meter. The experiment was repeated using several different class 1 sound level meters. Temperature and wind variations were monitored throughout.

Approach

Using the general uncertainty checklist (section 3.3), the key factors likely to influence the uncertainty in the measurement are identified and considered individually but grouped into source/transmission path/receiver. Where possible, magnitudes of uncertainty are determined either from separate measurements or from data in the literature. Any considered very small can be assumed to be covered in other factors. It is good practice to be slightly pessimistic. Unknown magnitudes should be estimated using experience and their effect on the total budget critically assessed. For future reference, any reasoning should be noted.

Commentary

- (a) The source was very stable and was monitored continuously at 1 metre. The standard deviation of the measurements has been used. (These measurements are themselves subject to some uncertainty, but it will be small and has been ignored here)
- (b) During the experiment the source wasn't moved, so the small variations in radiation pattern would not be significant.
- (c) Any slight change in directivity can be attributed to a small error in angular placement of the sound level meter, and this is assumed to be included in the receiver (mic direction) uncertainty.
- (d) Weather effect was estimated by considering the measured variation in temperature and wind speed and the theoretical data of ISO 9613-2. There was very little change during the period of the measurement and a minimal value of ± 1 dBA has been assumed. On a different day this might be significantly larger.

- (e) If the measurements had been repeated on different days, the ground surface may have been different (moisture content/height of grass) and a value estimated.
- (f) Mic height (sound level meter) – the data taken on site using two different heights was used.
- (g) Inverse Square Law used, applying asymmetric rule discussed in 3.1.4.
- (h) Mic direction – manufacturer’s directivity data for 0-30° was used, although it is unlikely that the positioning would be that bad. However this allows for small variations in source directivity.
- (i) General class 1 overall uncertainty at the reference conditions, excluding directivity. Individual sound level meters will usually be better than this. (Ref IEE 651:1979/BS 5969:1981/BS EN 60651:1994 Specification for sound level meters.)

Uncertainty Budget Example 1

Source of Uncertainty	Notes	Value (half width)	Conversion (dBA)	Distrib (divisor)	Std Uncert (dBA)	Ref
SOURCE						
Sound power variation	From monitor SLM	0.2dBA	n/a	norm(1)	0.2	(a)
Position	No change between meas.	neg				(b)
Directionality	See Receiver below					(c)
TRANSMISSION PATH						
Weather	Estimated	1.0dBA	n/a	rect($\sqrt{3}$)	0.58	(d)
Ground reflex	No change during measurements	neg				(e)
RECEIVER						
Mic height	Est from 1.2m/1.5m measurements	0.25dBA	n/a	rect($\sqrt{3}$)	0.14	(f)
Mic distance	Inverse square law	0.5m	0.18	rect($\sqrt{3}$)	0.1	(g)
Mic direction	Type 1 for say 0-30deg	0.35dBA	n/a	rect($\sqrt{3}$)	0.2	(h)
Instrumentation	Type 1 SLM overall	0.7dBA	n/a	rect($\sqrt{3}$)	0.4	(i)
COMBINED uncertainty (root sum of squares)					0.8 dBA	
EXPANDED uncertainty (95% confidence [k = 2])					1.6 dBA	

* Assumed distribution (and divisor) taking account of type A and type B distribution

Conclusion

The final answer of expanded uncertainty, which is expressed as ± 1.6 dBA with a confidence level of 95%, appears high for this type of controlled experiment. Of the two governing factors, the weather is probably the one that we have least control over. The sound level meter uncertainty would probably be much less for the four specific sound level meters used. The expanded uncertainty of ± 1.6 dBA is larger than the repeatability actually measured on site (see page 20).

4.2 INDUSTRIAL EXERCISE

Scenario

The main reproducibility exercise was carried out on a real factory. The scenario was that complaints had been made about noise, and teams representing different vested interests had been asked to check the levels according to the procedure in BS 4142:1997.

A large factory is located in a valley. Single storey houses are located approximately 400 m across some fields. The factory operates continuously and, provided the product is being manufactured, the external noise sources (mainly extract fans) will remain fairly constant. At the factory, vehicle movements will be a variable source of noise, and there will be shielding of this source by the buildings at times. Vehicle movements are intermittent. One team has carried out measurements close to the factory on a number of occasions over an extended period, and the repeatability of the source is known. Access to the housing was not possible, but access to the adjacent field was. The measurements were therefore made approximately 5 m from the noise-sensitive property. Several teams carried out measurements on different days and at different times using their own class 1 sound level meters. On each occasion the factory was working normally.

Five measurement teams were selected to represent a cross-section of the user-community. One team was chosen to represent a local authority, one an instrument supplier, one a University research team and two acoustic consultants.

Measurement Results

The reproducibility and repeatability uncertainties were calculated at the 95% level of confidence for the measurement of the ambient and background noise levels.

Noise metric	95% confidence limits	
	Repeatability	Reproducibility
Ambient level L_{eq} dB(A)	1.9	7.2
Background level L_{90} dB(A)	2.6	12.6

The reproducibility uncertainty is far greater than the repeatability uncertainty. This is, in part, attributable to the wide range of weather conditions experienced during the reproducibility measurements, compared to the similar conditions experienced during the repeatability measurements.

There is greater uncertainty associated with the measurement of the background level than the ambient level. Due to the continuous operation of

the noise source, it was necessary to select alternative positions at which to measure the background noise level. This variation in measurement position will, in part, account for the small increase in uncertainty between the repeatability ambient and background levels, and the large increase between the reproducibility ambient and background levels.

Uncertainty Budget

Example 2 based on BS 4142 repeatability exercise

Approach

Using the general uncertainty checklist, the key factors likely to influence the uncertainty in the measurement are identified and considered individually, but grouped into source/transmission path/receiver. Where possible, magnitudes of uncertainty are determined either from separate measurements or from data in the literature. Any considered very small can be assumed to be covered in other factors. It is good practice to be slightly pessimistic. Unknown magnitudes should be estimated using experience and their effect on the total budget critically assessed. For future reference any reasoning should be noted.

Commentary

- (a) The source comprises several sources spread over a large area, some are individual sources, such as extract fans, and some come through the buildings and include the effect of the internal acoustics.
- (b) Most of the noise sources are static, machinery inside the buildings, fans at both high and low level but there are vehicle movements in the yard. This was shielded from this chosen measurement position but would have to be included for uncertainty assessments for other measuring positions.
- (c) There is no way in which the individual running condition of each source can be monitored simply. However, in this instance there are many sources: they must be running in a certain way to produce the product, and that fact has been checked by each team by asking the factory management. There will be some changes and ± 3.0 dB is an overall estimate (an educated guess!). To do anything better would require a much larger monitoring effort.
- (d) The management were also consulted to confirm that the machinery was operating normally throughout each measurement period.
- (e) The general nature of the noise is steady broadband with some tones. Whether a tone is present or not is usually the result of a subjective assessment, and would not normally be included in an uncertainty budget but would be noted, including any cause for indecision, in the report. If a tone is included in a measurement then it might require an additional uncertainty assessment if, for instance, it is randomly

intermittent or variable. In this instance it is part of the BS 4142 subjective assessment

- (f) High-level fan flaps (to prevent moisture ingress during driving rain) were observed at a number of positions facing the measurement site. The overall effect of whether open or not would not be large considering the number of other contributing sources. It has been assumed that it can be included in the budget under “Environmental”.
- (g) Again, in this situation one is entirely dependent upon the management. The factory process is complex, there are many inter-dependent processes all linked and running simultaneously on the production line. Cooling fans etc are interlocked to relevant machinery, so it is unlikely that the plant will be allowed to run unless operating under its normal conditions. Small changes can be considered as part of (c).
- (h) The multiple sources and layout suggest omni-directional propagation, and at 400 m can be considered as being a “point” source.
- (i) The multiple sources will, at 400 m, act as an omni-directional source, closer than this would not necessarily be the case. In particular, open doors can make an internal source quite directional depending upon the main frequencies.
- (j) Environmental conditions will affect the production process slightly: for instance, more cooling may be required. Wind on fans, with and without flaps, will affect noise output (e), and some allowance should be made for variability. ± 1 dB is a rough estimate of the likely variation.
- (k) The largest effect on transmission will be the weather, and here it is assumed that all measurements have been carried out downwind. The overall weather conditions were monitored on each occasion, and using guidance from ISO 9613 section 5, a figure for uncertainty of ± 3 dB has been estimated.
- (l) During the period of the measurements (two weeks), there would only be small, negligible, changes in transmission due to the ground surface.
- (m) There were no barriers or changes in barriers during the measurement period.
- (n) Small changes in receiver position chosen by the teams have been accounted for by using inverse square law on an estimated 10m possible change. The half range value is then taken as half the resultant change in decibels.
- (o) Measurements were not made in front of a façade.
- (p) Measurements were made in a field at least 5 m from the nearest property and there were no adjacent reflecting surfaces.
- (q) This practical value has been taken from the Brüel & Kjær guide for a type 1 meter. It assumes a number of uncertainties; some magnitudes may be too large for the sort of changes to be expected over the measurement period. This is perhaps compensated for because five different sound level meters were used by five different teams.

- (r) Background or residual noise measurements will form a separate part of the BS 4142 measurement, and are subject to their own uncertainties. The combined effect will have to be taken into account in the assessment. In this budget we are concerned with the potential “interference” of variable intermittent background noise on the measured result. Two cases are considered: night-time when the background noise was so low as not to affect the measurement, and daytime when the background noise came, at times, to within 5 dBA of the average measured level (estimated from a separate background measurement). This could raise the measured level by approximately 1 dB and such a figure has been included in the budget, but only for daytime assessments.

Uncertainty Budget Example 2

Source of Uncertainty	Notes	Value (half width)	Conversion (dBA)	Distrib (divisor)	Std Uncert (dBA)	Ref
SOURCE						
Position	Multiple/area	inc in run				(a)
Movement	Mainly static					(b)
Run condition	Normal - estimate	3dBA	n/a	Rect($\sqrt{3}$)	1.73	(c)
Operation Character	Continuous					(d)
Enclosure	Fan flaps	inc in env				(e)
Machine cond	inc in run cond	inc in run				(f)
Type of propagation	Point,					(g)
Radiation pattern	hemispherical					(h)
Environmental	Omni-directional					(i)
	Small effect	1dBA	n/a	Rect($\sqrt{3}$)	0.58	(j)
TRANSMISSION PATH						
Weather	400 m downwind	3dBA	n/a	Rect($\sqrt{3}$)	1.73	(k)
Ground reflection	Very small effect	0.1dBA	n/a	Rect($\sqrt{3}$)	0.06	(l)
Barriers	none	nil				(m)
RECEIVER						
Measuring position	Inverse square	10m in 400m	0.22	Rect($\sqrt{3}$)	0.13	(n)
Façade	not applicable					(o)
Reflecting surfaces	Minimal 5 m away	neg				(p)
Instrumentation	Type 1 practical	1.9dBA	n/a	Rect($\sqrt{3}$)	1.1	(q)
Background noise	BS 4142/diff position					(r)
Night-time		neg				
Daytime		1.0dBA	n/a	Rect($\sqrt{3}$)	0.58	
COMBINED uncertainty (root sum of squares)					2.7(2.8 day) dBA	
EXPANDED uncertainty (95% confidence [k = 2])					5.4(5.6 day) dBA	

Conclusion

This result appears quite reasonable given the very practical conditions, and is similar to the reproducibility estimated from the detailed measurements of the five teams.

Tonality is a potential problem especially in marginal cases. If included in the BS 4142 assessment it can make a significant difference and its subjective nature does not help. Fortunately if included, the fact has to be reported.

There is no need to include tonality in the uncertainty budget, but the report should say if it was a marginal judgement. Uncertainties affecting measurements of the background noise at alternative positions should be included in separate budgets for those particular measurements, and any changes to the standard procedure should be reported in detail, but they cannot be included directly in the budget for the ambient noise measurement.

The main contribution to the source uncertainty was the running conditions. This was, at best, a guess to the likely change that could occur. Closer monitoring of the source might produce a more realistic value, but huge effort would be required to monitor multiple sources properly.

As usual, the weather is the largest source of uncertainty. Measuring under downwind conditions does usually produce worst case conditions at distances of several hundred meters, and this is a reasonable approach to take for BS 4142. At much greater distances this does not necessarily hold.

Instrumentation uncertainties dominate the receiver section. Using the data provided by Brüel & Kjær, the instrumentation uncertainty budget can be reviewed and possibly revised in line with values more relevant to the particular use.

4.3 OTHER EXAMPLES

4.3.1 Uncertainty Budget

Example 3 Measurement of Traffic Noise

Scenario

A hotel is to be built on a green field site adjacent to a busy main road. Some bedrooms will be located at ground level 100 m from the carriageway. A simple noise measurement has been carried out in the late evening over one hour to check the expected noise levels. This measurement was made when there was a light wind blowing directly from the road towards the site. Background information from the local authority indicates that there are no plans to alter the road, and that the traffic flows are likely to remain much the

same over the next few years. Small variations in both traffic flow and content are expected on different nights.

Approach

An uncertainty budget has been drawn up and potential sources identified under the headings, source, transmission path and receiver. If we were just concerned with the short-term uncertainties of the measurement itself, there would be no need to consider the uncertainties associated with either the source or the transmission path. An hour's measurement is more than adequate to quantify the source, and over the distances involved the weather or ground will have no short-term effect. In this instance though it is expected that the developer requires some feel for the uncertainty of the result over the longer term and uncertainties associated with both the source and transmission path have been included. The full budget is given in the table.

Comments

- (a) & (b) The most likely change in the source noise (assuming there is no re-surfacing scheduled) will be due to the traffic flow and its make-up (% heavy vehicles and average speed). The number of vehicles passing during the measurement hour, including those classed as heavy (unladen weight > 1525 kg), can be readily counted. An assumption has been made that there could be a change of $\pm 10\%$ in the flow rate (measured on the day at 1000 vehicles per hour with 7% heavy vehicles), and that a range in the percentage of heavy vehicles from 5% at 50km/hr to 10% at 75 km/hr will embrace potential changes. The effect of these changes has been estimated using the DoT Calculation of Traffic Noise Manual which provides a convenient way of converting the uncertainties into decibels. (This manual is primarily aimed at calculation, and the data may not strictly apply to the practical situation, however, data of this type have been derived or verified using extensive sets of measurements, and if applied with care should provide a "feel" for potential changes.)
- (c) Measurements were carried out under conditions which favour propagation to the intended site. Page 14 of ISO 9613-2 provides some insight into the likely uncertainties associated with measurements made in this way. The uncertainties estimated also refer to calculations, and judgement is required in interpretation. Since the distance from source to receiver is short, it has been assumed that there is very little uncertainty due to changes in ground condition, i.e. changes that might occur as a result of the development, e.g. laying a hard surface for a car park need to be taken into account when the measured data is applied, and therefore the report covering the measurements should clearly describe the ground conditions at the time of the measurement.
- (d) There is no expected change and distances are short. New boundary walls could influence the noise level at the hotel façade, but this is

something to be taken into account when the measurement data is used at the design stage, and not included in the uncertainty budget.

- (e) Uncertainty due to repositioning the microphone is included because it may be difficult to define the chosen location with respect to the final position of the building, or indeed repeat it at a future date in the middle of a green field site. Inverse square law has been used to provide an estimate of the potential change in noise level.
- (f) There are no reflecting surfaces on this green field site, but there might be after the hotel is built. If subsequent measurement checks are made, uncertainties for this can be included.
- (g) It is assumed that a type 1 metre has been used. Brüel & Kjær¹ have calculated “accuracies” for various meter types under practical measurement conditions.
- (h) Background noise could not be determined on site, but this was the only road in the immediate vicinity, and there were no other local noise sources. It has been assumed that the “background level” would be too low to influence the measurement.

Uncertainty Budget Example 3

Source of Uncertainty	Value (half width)	Con- version (dBA)	Distrib (divisor)	Std Uncert (dBA)	Ref
SOURCE					
Traffic flow	10% in 1000	0.57	Rect($\sqrt{3}$)	0.33	(a)
% HGV/ Mean speed	5% @ 50 km/h to 10% @ 75 km/h	1.57	Rect($\sqrt{3}$)	0.91	(b)
TRANSMISSION PATH					
Weather	3 dBA	n/a	Rect($\sqrt{3}$)	1.73	(c)
Ground Topography	min inc in weather no change	none			(d)
RECEIVER					
Position	1 m in 100 m	0.87	Rect($\sqrt{3}$)	0.5	(e)
Ref surface	none	none			(f)
Instrument	1.9 dBA	n/a	Rect($\sqrt{3}$)	1.1	(g)
Background	minimal	ignore			(h)
COMBINED uncertainty (root sum of squares)				2.3 dBA	
EXPANDED uncertainty (95% confidence [k = 2])				4.6 dBA	

Conclusion

The main contributor to the uncertainty of the source is associated with the % heavy vehicles/mean speed. This was an estimate and could be reduced by using better information (if available). The main contributor in the transmission path is the weather. This will invariably be the case, and there is little control that can be exercised. The value was, however, taken from ISO 9613, which could be covering too general a situation for this site. It might be

¹ WILLIAMS, MARTIN, Environmental noise and vibration measurement and standards, 1997, Brüel & Kjær

preferable to carry out repeat measurements on different days and use that data. The main uncertainty at the receiver is that due to instrumentation. This is a relatively straightforward measurement procedure, and it is unlikely that this result could be improved.

Note

If this measurement had formed part of a PPG24 assessment, and the measured traffic noise level had been marginally below the noise exposure category boundary, this uncertainty calculation could be used to persuade the authorities that it might be better to err on the safe side and plan for the higher category.

4.3.2 Uncertainty Budget

Example 4 Noise from a Fabrication Plant

Scenario

Complaints have been made by residents living in a row of houses beside a dual carriageway, about noise levels emanating from the premises of a company that fabricates large steel fixtures. The rear façades of the houses are located approximately 100 m from the site boundary at the foot of a grass-covered field, which slopes gently from the factory but then drops about 2 m into the, 10 m-long rear gardens. The plant has several obvious noise sources in a workshop located 20 m within the site, but the main source of complaint appears to be due to the activities of a fork-lift truck. This normally operates in a yard located between the workshop and the site boundary along which there is a 2 m high brick wall. The activities include general manoeuvring, dropping load (steel products weighing 0.5 to 4 tonnes), and banging the forks. Workshop activity includes grinding and hammering. There is an access door from the building to the yard for the fork-lift truck and a smaller personnel door alongside. The company has repaired the yard surface but there are still some irregularities which jolt the fork-lift truck. Complaints are made throughout the day both during winter and summer, but mainly in the summer.

Noise measurements have been made using the BS 4142 procedure on behalf of the Company using a type 1 sound level meter. The main complainant, directly opposite the workshop, would not allow the measurement team access, but a neighbour located two houses to one-side did.

Measurements were carried out from midnight on two occasions during the summer. On the second occasion, a jacking tripod enabled measurements to be made at upstairs window level.

Uncertainty Budget Example 4

Source of Uncertainty	Notes	Value (half width)	Con-version (dBA)	Distrib (divisor)	Std Uncert (dBA)	Ref
SOURCE						
Position	Several, some int'l, some ext'l & moveable	2dBA	n/a	Norm(1)	2	(a)
Character	Mainly impulsive, some tones, intermittent	n/a				(b)
Operation	Variable	Inc in (a)				(c)
Enclosures	Int'l affected by door, ext'l by location of boundary wall	Inc in (a)				(d)
Condition	Minimal compared with operational variability	n/a				(e)
Environmental	Summer running with doors open	Inc in (a)				(f)
Movement	Fork-lift in yard	Inc in (a)				(g)
Type of propagation	Point	n/a				(h)
Radiation pattern	Omni-directional	n/a				(i)
TRANSMISSION PATH						
Barriers	Wind direction and temperature	3dBA	n/a	rect($\sqrt{3}$)	1.73	(j)
Ground reflection	Not a major concern	Inc in (j)				(k)
	Location of fork-lift, gardens, embankment	Inc in (a)				(l)
RECEIVER						
Measurement position	Uncertainty in height location Uncertainty in distance	0.7dBA	n/a	Normal(1)	0.7	(m)*
Façade reflections	(Point source) Need to make assumption	1 m in 100 m	0.09	Rect($\sqrt{3}$)	0.05	(n)
Reflecting surfaces	Check using small changes in position of SLM	(Inc in (m) At 4m)	1.0	Normal(1)	1.0	(o)**
Instrumentation	Type 1 with windshield	1.9 dBA	n/a	Rect($\sqrt{3}$)	1.1	(p)
Background noise	Depends on relative level					(q)
Standards	BS4142 at 3.5m at ground level/1m at 3.5m	See *				
COMBINED uncertainty (root sum of squares)					2.9 dBA* 3.1 dBA**	
EXPANDED uncertainty (95% confidence [k = 2])					5.8 dBA* 6.2 dBA**	

* Applicable only to assessment at 4 m above ground level (a.g.l.)

** Applicable only to assessment at 1.5 m a.g.l. and 3.5 m from façade

Commentary

- (a) The BS 4142 assessment was based on an hourly L_{Aeq} measurement. However, individual contributions were identified and assessed over shorter intervals. Using this data it is possible to determine overall patterns of noise emission from the various sources. In practice, using a short L_{eq} measurement and detailed observations, it should be possible to determine the overall noise for any work pattern. However, it may not be possible to see all the activities or obtain sufficient visual collateral information, and some form of assessment of the possible variation has to be made. This will require carrying out measurements over an extended period, or carrying out repeat measurements on different occasions. If weather is a factor then repeated measurements on different days should be made. Such an approach is always preferable, but financially and operationally is not always possible. At this site, separate measurements were made on two different occasions when weather conditions favoured propagation towards the complainants' houses, and on each occasion the noise was measured over two, one-hour long periods. A difference of 1 dBA was observed between all four sets of data. In addition four 15-minute samples were recorded within each hour, and these showed a standard deviation of ± 2 dBA. Since these shorter observations are likely to demonstrate the magnitude of changes in noise output between different work patterns (supported by visual records of the activity), this value has therefore been used as a measure of the variability of the source. In including this assessment, small variations due to the influence of the transmission path have been ignored, because the distance of the houses from the site boundary is not that great (80 m), and variations due to the weather during the period of each measurement will have been small. The influence of the boundary wall as a barrier to the noise source, especially the fork-lift truck, is also automatically included at this position.
- Note:** If the distance had been greater, or had other potential influences been of concern, it would have been necessary to carry out a set of measurements closer to the source(s) to obtain the variation and associated uncertainty in the noise output. Such measurements would not have been easy to conduct here, because of the considerable influence of the boundary wall on the noise level from the moving fork-lift truck.
- (b) By measuring over an extended period and observing the level and nature of the different sources, some idea of the overall character can be determined, e.g. predominantly impulsive in this instance. An acoustic feature correction of +5 dBA can be included in the final BS 4142 assessment with little hesitation. This type of correction, and any uncertainty as to whether it should be applied, should not be included in any uncertainty budget. It is essentially an assessment feature not a measurement feature. However, if the observations leave some doubt as to whether an acoustic feature correction should be added, it is better to add a note to the report. Any uncertainty associated with an intermittent

- acoustic feature, which is likely to influence the measured level, e.g. brake squeal, should be assessed and included here.
- (c) The variability of operations can be assessed in several ways, for instance, by examining the production records and relating them to work (and therefore noise) patterns, or by simply making observations during extended or repeated noise measurement sessions. In this instance, the latter procedure has been included in the assessment made in (a), and there is no need to include an additional uncertainty. If such an assessment is not possible, it will be necessary to carry out repeated measurements to obtain a reasonable value for the measurement uncertainty.
 - (d) The effect of the boundary wall on the source noise levels is dealt with below. The influence of the door should be included in the assessment described in (a). In some instances, when and whether a door is open or not can have a significant influence upon the measured noise and, as such, the effect must be included together with an assessment of the uncertainty. Again this is best done by observation and associated measurement.
 - (e) Both the state of repair and the actual operating condition can influence the noise source output. In this instance, changes in noise due to operational activities, included in (a), are likely to be very much greater than those due to maintenance. However, such influences as the fork-lift truck running empty with clanking forks should be assessed. If (a) truly reflects the work practice, then the uncertainty will have been taken care of during that assessment.
 - (f) This could be important if, for instance, an assessment has to be made when general climatic conditions have changed (e.g. complaints made in summer but assessed in the autumn), and it is not possible to check the exact conditions, such as the periods of opening, and the reasons for opening doors (to let the fork-lift truck in or to cool the building down). The best that can be done is to carry out measurements with and without the doors open, and calculate the effect on the measured noise of possible different opening times. In this example, the main measurements were made with the doors open for 10% of the time. The difference doors open to doors shut was measured at 3 dBA.
 - (g) Movement of the fork-lift in the yard might appear erratic, but when carrying out a particular work pattern the hourly L_{eq} is likely to be reasonably consistent. A series of short measurements with the fork-lift carrying out different operations can be used to calculate an overall level from a particular set of combinations, and the effect of possible changes in routine calculated. If this is not possible, then measurements will have to be repeated on different occasions, and mean and standard deviation calculated.
 - (h) The main sources of noise can be considered as point sources at this distance, albeit relatively short (80 m – 100 m).

- (i) For the purposes of this exercise, the sources can also be considered as omni-directional. In practice the fork-lift truck is sufficiently far away, and its orientation relatively random in respect to the complainants' houses. The open door will produce some directionality to the internal noise emission, but the door faces the complainants and the directionality will have no noticeable effect.
- (j) Information received before the measurements were made, indicated that complaints were intermittent and somewhat dependent on the weather. The complainants are located reasonably close to the site, so that the wind direction and temperature gradient will have a very small effect. ISO 9613 section 9 gives some guidance as to the magnitude of the effect. At this distance, the mean height source to receiver is less than 5, and the distance 100 m. (A more significant effect due to the weather is that described above, i.e. on warm summer nights, the factory door is likely to be left open longer (see source above). In addition, the bedroom windows are likely to be left open as well, (a receiver effect). The latter will not affect the assessment, but is the most likely reason behind the complaints!)
- (k) Changes in ground condition are also likely to be minimal at these distances. The surface of the yard is concrete and although its condition might affect the noise output from the operations of the fork-lift, its effect on uncertainty cannot be readily established, and in any case will be subsumed in the source assessment above. There may be some changes in ground impedance and sound absorption from season to season with the field, but over a distance of 80 m it is not likely to be of any practical significance.
- (l) The effect of the site boundary wall as a barrier has been dealt with under source. In the transmission path it is a permanent feature, and will not contribute to additional uncertainty. The same is true of the ground where it drops away near the complainants' houses. This feature will not change with time, unless it is physically altered, and will not contribute to uncertainty in the measurements (but see (m)).
- (m) From discussions with the complainants, it was possible to establish that it was noise at first floor level that was the main concern and the reason for the complaints. Checks on site showed that there was an increase in noise level of up to 8 dBA between 1.5 m a.g.l. and 3.5 m a.g.l. over a set of fifteen minute measurement periods. Such a change is significant, and confirms the need to carry out some measurements at first floor bedroom level. It is, however, also indicative that there is a significant noise gradient across the façade, and therefore the positioning of the monitoring microphone will be important. To determine the possible uncertainty in positioning, a set of four measurements were made at slightly different heights and the standard deviation found to be ± 0.7 dB. Another contributing factor to the positioning uncertainty, is the fact that measurements were not possible at first floor height at the house of the

main complainant. It is, of course, perfectly acceptable to present the results of the BS 4142 assessment for the neighbour's house, and argue the case for that particular complainant. An alternative approach is to make an assessment of the possible change from one location to the next, and to accept that this will itself have an associated uncertainty. At this location both houses were a similar distance from the site, and the potential difference was established by carrying out repeat measurements at 1.5 m a.g.l. at the garden boundaries opposite each house. These yielded a small increase of 0.3 dB opposite the main complainant, with a standard deviation of 0.1 dB. The 0.3 dB can be added as a correction to the measured result for an assessment at the main complainant's house. In addition the 0.1 dB uncertainty will have to be included in the accompanying uncertainty budget, but only for that particular location.

- (n) Measurements in front of a façade will yield an uncertainty due to positioning that will vary dependent on frequency content and the nature of the façade. This is a complex situation and is better estimated by repeat measurement. It can be argued that some of the uncertainty determined in (m) also includes an element for the façade.
- (o) In this example, the nearest reflecting surface at 4.0 m a.g.l. is the façade, and the uncertainty is derived as part of (m). For measurements at ground level, reflections from other objects may be significant. However, it will be difficult to provide an estimate of the effect, and it is best dealt with by taking repeated measurements by removing and replacing the measuring system several times, whilst short-term measurements are made. This procedure was carried out, and a standard deviation of 1.0 dB was obtained. This was partly due to the critical positioning relative to the dip in the garden.
- (p) A type 1 instrument was used for all measurements. Data taken from², based on practical measurements.
- (q) The uncertainty due to background noise arises if the latter contributes or interferes in anyway with the measurement of the specific or residual noise. In the case of a BS 4142 assessment, there is also some uncertainty associated with the effect of the residual noise on the specific noise. This can be dealt with by preparing an uncertainty budget for both the specific and the residual noise measurements. In many practical cases there will be little difference between them, and the total standard uncertainty can then be readily calculated as the sum of the squares of both.

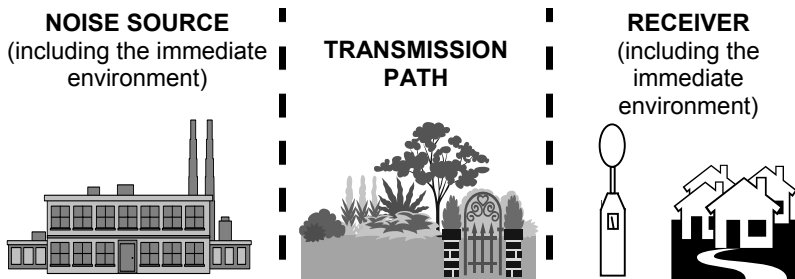
² WILLIAMS, MARTIN, Environmental noise and vibration measurement and standards, 1997, Brüel & Kjær

5 AREAS OF UNCERTAINTY

This chapter discusses and summarises some of the more frequently encountered sources of measurement uncertainty. In order to reflect the real life problems encountered when measuring noise, a deliberately broad view of what constitutes a source of measurement uncertainty has been adopted. Where appropriate 'Good Practice Guidelines' and useful notes are offered to assist the determination and reduction of measurement uncertainty.

The sources of uncertainty are considered in four sections:

- 5.1 the noise source and immediately surrounding environment
- 5.2 the transmission path
- 5.3 the receiver and immediately surrounding environment
- 5.4 key players



5.1 NOISE SOURCE

A major source of uncertainty may be the noise source and its operation.

It is important to consider the following:

- spectral content of the noise emission (see section 5.1.1)
- nature of the noise source: point/line/area (see section 5.1.2)
- running condition, operator preference/machine load (see section 5.1.3)
- state of repair (see section 5.1.4)
- source height (see section 5.1.5)
- whether the sources are stationary or moving (see section 5.1.6)
- enclosures and barriers close to the source (see section 5.1.7)
- environmental conditions (weather) (see section 5.1.8)
- number of sources in operation and their positions relative to the measuring positions
- interaction between each source
- location and state of doors and louvres in any source enclosure

Short-term variations in the noise emission will influence the duration of the measurement required to obtain a satisfactory sample. In general, the duration of the measurement should be representative of a single or several complete cycles of operation.

Longer-term changes can usually be accounted for by suitable sampling strategies, and should be considered in detail when comparing two measurements, or considering a single measurement to be representative of a period longer than that actually measured.

5.1.1 Spectral Content (Broadband and Tonal Noise)

5.1.1.1 Interference Patterns

If the noise emission is dominated by tonal components, care must be taken when placing the microphone in the sound field. Interference patterns may cause large variations (10dB or more) in sound pressure level to occur between points only a small distance apart (10cm or less). This effect is likely to be most severe in the presence of one or two strong reflections.

However, such interference patterns are cancelled out when measuring broadband noise diminished by multiple reflections, and may be undetectable at higher frequencies, (where the wavelength is comparable to the microphone dimensions.)

Subjective assessments of tonality may also be affected by interference patterns.

5.1.1.2 High and Low Frequencies

Low frequencies (< 100Hz) are notoriously difficult to measure; levels often fluctuate dramatically and may be affected by:

- standing waves
- high background levels
- wind noise
- structure/ground borne vibration
- beating between similar sources

High frequency noise sources (>4kHz) may also be difficult to measure; problems include the following:

- Propagation patterns have a tendency to be highly directional, thus increasing the variability in measured level, due to small changes in microphone position.
- Changes in relative humidity will affect the measured level.
- Even small objects may provide screening/reflections.

Sources of Uncertainty

- Sound level influenced by standing waves/interference patterns/beats
 - Subjective assessment of tonality affected by standing waves/interference patterns
-
-

Good Practice Guidelines

- Determine the probability of standing waves/interference patterns by considering the nature of the source and the influence of any nearby reflecting surfaces.
- Check for the presence of standing waves, either subjectively by listening in several places around the measurement position, or by observing any change in level as a sound level meter, switched to a fast time constant, is traversed around the measurement position.
- If standing waves are present and cannot be avoided, take a spatial average, either by measuring at several fixed positions, or by slowly moving the microphone around the measurement position, whilst continually logging sound energy.
- Anticipate significant levels of uncertainty when measuring noise at the extremes of the audio frequency range, i.e. below 125Hz or above 4kHz.

Useful Notes



- When assessing low frequency noise, it may be possible to monitor the actual change in sound pressure level to determine the effect of standing waves.
- If the subjective assessment is felt to be marginal, a second opinion may be useful. (If subjectively investigating standing waves or interference patterns, place the ear at the proposed level of the microphone: small changes in height (10cm or less) can be significant).
- Long-term beating of the noise signal between two sources almost running in phase can be confused with standing waves or a variable noise emission.
- If long-term beating is suspected, ensure the measurement period covers several cycles of the beats.

5.1.2 Point, Line and Area Sources / the Near and Far Fields

To determine how representative a point measurement is of a larger area, one must appreciate the probable change in sound pressure level over that area.

Point sources

Point sources are defined as having their largest dimension many times smaller than the source-to-receiver distance. The measurement position will normally be in the far field, and the sound pressure level due to the source emission will reduce by 6dB per doubling of distance (except when measuring low frequencies close to the source). Small changes in measurement position may be significant, but the effect diminishes with increasing source-to-receiver distance.

Line sources

Line sources are defined as having one dimension comparable to the source-to-receiver distance. The measurement position will therefore be in the near field and the sound pressure level due to the source emission will reduce by 3dB per doubling of distance. Barriers obscuring a small section of the line are unlikely to have a significant effect on the received sound pressure level. Small changes in measurement position will have little effect, especially where the source-to-receiver distance is large.

Area sources

Area sources are defined as having two dimensions comparable to the source-to-receiver distance. The measurement position will be in the near field, and the sound pressure level will only reduce by small amount with increasing source-to-receiver distance. Barriers obscuring a small portion of the source are unlikely to have a significant effect on the received sound pressure level. Small changes in measurement position will have negligible effect on the measured sound pressure level.

Source of Uncertainty

The degree to which a single measurement is representative of a larger area.

Good Practice Guideline

Investigate all noise sources and determine their type, and the likely pattern of propagation and the effect at the measurement position.

Useful Note

Sources may only be considered as true line/area sources if the noise emission is uniform over their surfaces. When considering the noise break-out from a building, the walls, windows and doors should be considered as separate sources.

5.1.3 Running Condition

When measuring noise from machinery, it is important to consider the running condition. Many variables, such as operator preferences or changes to the machine load, can affect the noise emission.

Sources of Uncertainty

Variability in the running condition of the noise source for example:

- operator preference
 - load
-
-

Good Practice Guidelines

- Determine which variables may affect the noise emission.
- Record the running condition at the time of measurement and consider how it fits in with all possible conditions. If necessary measure under different sets of conditions, the type and number of which depend upon the nature of the task/reason for measurement. Those conditions giving rise to average/maximum noise levels may be considered a minimum

5.1.4 State of Repair and Maintenance

Wear and tear affect both noise sources and enclosures. Long-term drifts or short, intermittent changes may occur in the noise level/frequency content. Where a number of similar sources are operating in the same area, changes on one source may have little effect on the combined noise emission.

Source of Uncertainty

Variation in the noise emission due to wear, tear and subsequent maintenance

Good Practice Guidelines

- Determine and record the state of repair of the noise source(s) and enclosure(s).
- Carry out additional checks to determine the likely variation in level before and after maintenance.

**Useful
Notes**



- This is a very difficult area to pin down: if no reliance can be placed on the word of the operator, repeated measurements must be considered in critical situations.
- It is common for distinct tones to develop as machines fall into a state of poor repair, and subsequently disappear once the appropriate maintenance has been completed, (e.g. squeaking bearings, blown exhaust, slipping fan belt, worn gears), this may significantly affect overall noise levels.

5.1.5 Source Height

The influence of weather on outdoor noise propagation (see section 5.2.1) can increase with the height of the source above ground level. Ground reflections may also be greatly affected by the source height (see section 5.2.2).

Source of Uncertainty

Greater variability in the measured sound pressure level due to the increasing influence of weather with source height or change in ground surface condition

Good Practice Guideline

Anticipate greater uncertainty when measuring noise from elevated sources, repeat measurements under different propagation conditions if necessary.

5.1.6 Movement of the Noise Source

Source rotation, if there is a strong directivity pattern, or significant displacement can influence measured levels.

If the source moves within a complex of buildings, reflections and/or shielding will also influence the levels at the receiver.

Road traffic may be approximated as a line source provided that the number of traffic movements is sufficiently high. If the number of traffic movements is low, the traffic should be treated as a series of moving point sources and a greater level of uncertainty anticipated.

Sources of Uncertainty

- Unknown random pattern of a movable source
 - Number of moving sources unknown
-
-

Good Practice Guideline

Determine and log the movement and number of source(s) during the measurement. If the movement follows a routine, measure representative levels for one or more complete cycles.

Useful Note

When measuring noise from moving sources, it may prove useful to break the movement into a number of well-defined shorter sections. By measuring a large number of short L_{eqS} , each section may be considered in isolation, or used to calculate composite values of SEL or L_{eq} and possible uncertainties evaluated accordingly.

5.1.7 Enclosures, Buildings and Barriers

Enclosures, buildings and barriers local to the noise source are likely to have a large effect upon the noise emission. In most instances buildings are not erected within the span of a normal measurement, but this may not be true with barriers and temporary obstructions, (e.g. vehicles parked directly in front of the source). Such items could both attenuate the noise directly radiated and/or reflect some of the energy onto other reflecting surfaces. Noise emitted by sources in buildings, or partial enclosures, will be affected by the condition of openings such as windows, doors, extraction grilles, movable louvres.

Source of Uncertainty

Changes to enclosures, buildings, openings in buildings or barriers surrounding the noise source

Good Practice Guideline

Inspect the noise source to determine the probable effect of and possibility of changes occurring during the measurement. List possible changes and periodically check.

5.1.8 Weather

The prevailing weather conditions may not only influence noise propagation (see section 5.2.1) but also the noise emission.

Wind strength and direction, which dominate the propagation of noise, may also influence source levels by providing a varying load on fans, or causing ventilation hoods to turn in alternative directions.

The ambient temperature may affect the noise source for a number of reasons, including:

- change in the sound power of the noise source
- change in the attenuation characteristics (enclosures) due to different ventilation requirements
- operation of additional coolers/fans etc (often automatic)
- weather (see section 5.2.1)

Source of Uncertainty

Changes in source sound power and/or enclosures due to changes in the weather

Good Practice Guidelines

- Determine the likely effect of changes in the prevailing weather conditions on the noise source.
- Ensure that the noise source is operating under conditions relevant to the purpose of the survey.
- Record and report the prevailing conditions at the time of measurement.

Useful Notes



- Many typical background noise sources are affected by the weather, e.g. rustling leaves, wet roads.
- During warm weather the opening of windows and doors may significantly increase the noise breakout from buildings, see section 5.1.7. This can occur in a random manner.
- The mode of operation may be affected, particularly when concerned with outdoor activities, e.g. a football game at a leisure centre may be played either inside or outside, depending upon the weather.
- Refrigeration units - very load-sensitive; low frequency tones increase at high load. Noise level increases as ambient temperature increases.

5.2 TRANSMISSION PATH

For many environmental noise measurements, the prevailing weather conditions constitute a major source of uncertainty, especially where the transmission path spans a medium to large distance. Changes in the weather may occur suddenly, within the duration of a normal measurement.

It is important to consider the following:

- Weather (see section 5.3.1)
- Ground effects (see section 5.2.2)
- Barriers (see section 5.2.3)

Changes to the ground surface or barriers are unlikely to occur suddenly, however, these should always be considered when comparing medium/long term noise levels.

5.2.1 Weather

This section discusses the influence of the weather on outdoor noise propagation. The effect of weather on the noise emission and reception are covered in section 5.1.8.

Unless high frequencies (>2 kHz) are of particular interest, the influence of the weather may be regarded as negligible when considering propagation distances less than 100 m¹. However, over medium or long distances, meteorological changes may exert significant influence. This is demonstrated especially with high level sources where the effects can be observed over long distances. The longer the distance, the greater is the likely influence of the weather.

Difficulties in assessing the influence of weather on a particular measurement arise from:

- understanding how the various meteorological factors influence noise propagation
- measuring the prevailing meteorological conditions over the propagation path for the duration of the measurement.

Outdoor noise propagation is influenced by the weather through three principal mechanisms:

- **Refraction:** Wind and temperature gradients change the propagation path from a straight line to a curve. Sound is either bent upwards, away from the ground causing shadow zones, or downwards, towards the ground causing enhancement or even focussing of the sound.
- **Atmospheric absorption:** Temperature and relative humidity determine the attenuation of high frequency noise due to classic and molecular absorption.
- **Scattering:** Atmospheric turbulence and precipitation scatter sound This allows sound to enter what would otherwise be a shadow zone and reduce the strength of interference patterns, see tonal noise (section 5.1.1) and the ground effect (section 5.2.2).

The combined effect is often complex due to the instability and interdependency of each meteorological variable.

¹ RUDNICK, ISADORE, Propagation of Sound in the Open Air, *Handbook of Noise Control*, CYRIL M HARRIS ed, 1957, McGraw-Hill Inc

5.2.1.1 Refraction (Temperature and Wind Gradients)

Briefly, the noise propagation is controlled by the rate of change of sound speed with altitude, which is mainly a function of the wind vector and temperature. In practice the wind vector has an influence an order of magnitude greater than temperature. When the wind is very light there is often a decrease of temperature (lapse) upward from the ground. This bends sound upward, resulting in a sound shadow at all azimuths. However as the wind speed increases, friction at the surface causes the wind nearer the surface to have a lower velocity than that in the layer above, creating a significant wind gradient up to several hundred metres altitude, resulting in a sound speed increasing with height (positive gradient) downwind. This is easily sufficient to overcome the temperature lapse and produce an enhancement, by bending the sound back to the ground. Upwind, the effects of the temperature gradient are reinforced. In the presence of a low level temperature inversion, experienced on cold, windless, frosty mornings, or at night when there is often a nocturnal temperature inversion of several hundred metres depth above the ground, sound is refracted back towards the ground giving sound enhancement in all directions. If any wind is present, it will result in there being a preferred direction for the enhancement.

Above a few hundred metres altitude, horizontal temperature gradients are the main cause of wind changes especially in the region near a weather front. Ahead of a warm front the winds increase and turn clockwise (veer) with height, and to the rear of a cold front the winds increase and turn anti-clockwise (back) with height resulting in a change in wind direction of up to 180° between the surface and 3000m. This can result in significant changes in the sound speed gradient that cause the sound to return to the ground at several kilometres from the source, often in a different direction to the surface wind. In addition, there is always a possibility that elevated inversions will occur in the area of frontal systems. These can be quite sharp and can considerably influence propagation by refracting sound back to the ground.

Strong winds will reduce temperature gradients by mixing up the layers of air. An indication of the influence of wind and temperature on propagation can sometimes be obtained by observing the plumes of smoke from chimneys. Smoke rising vertically and then turning to the horizontal suggests the presence of an inversion. Billowing of smoke suggests turbulent conditions (see below) and smoke rising vertically indicates no wind or smoke being emitted horizontally indicates high wind velocities.

5.2.1.2 Atmospheric Absorption (Temperature and Relative Humidity)

Atmospheric absorption of sound is far greater at high frequencies and dependent upon both temperature and relative humidity, see table.

ISO 9613-1:1993 Calculation of octave band attenuation due to atmospheric absorption.

Relative Humidity (%)	Temp (°C)	dB/1000 m							
		63 Hz	125 Hz	250 Hz	500 Hz	1k Hz	2k Hz	4k Hz	8k Hz
20	0	0.3	0.6	1.9	6.2	17.7	34.6	47.0	58.1
	10	0.3	0.6	1.2	3.3	11.0	36.2	91.5	154.0
	20	0.3	0.7	1.4	2.6	6.5	21.5	74.1	215.0
50	0	0.2	0.4	0.8	2.1	6.8	23.8	71.0	147.0
	10	0.2	0.5	1.1	1.9	4.3	13.2	46.7	155.0
	20	0.1	0.4	1.3	2.7	4.7	9.9	29.4	104.0
80	0	0.1	0.4	0.8	1.5	4.1	13.8	48.8	147.0
	10	0.1	0.4	1.0	2.0	3.6	8.8	28.7	103.0
	20	0.1	0.3	1.0	2.8	5.2	9.0	21.3	68.6

Although the absorption characteristic is susceptible to sudden change (e.g. directly after a rainfall), detailed consideration is only warranted where high-frequency components dominate the noise emission. Where the transmission path spans a medium or large distance, it is possible that the atmospheric absorption will attenuate high-frequency components to a level below the background, even under the most favourable temperature and humidity conditions.

5.2.1.3 Scattering (Turbulence)

Turbulence does not significantly absorb sound, but will scatter sound into regions which might otherwise be acoustic shadows. Turbulence can be caused by the wind being forced around trees and buildings or by convection air currents generated on sunny days by the warming of the air near the ground surface. Turbulent conditions can be identified visually by the shimmering of distant objects by day or the twinkling of stars at night. On a larger scale, the presence of cumulus clouds and strong cloud plumes indicates regions of turbulent air.

Turbulence may also reduce the effect of interference patterns, see ground effects (section 5.2.2). The coherence between two or more propagation paths is destroyed by the random changes to the path lengths.

5.2.1.4 Ambient Pressure, Fog, Rain and Snow

Ambient pressure has little effect on propagation when compared to the other variables and can generally be ignored. Changes in atmospheric pressure can however influence the operation of the noise source and the measuring instrumentation (see sections 5.1.8 and 5.3.2.5).

High frequencies propagate better in fog because of the high humidity. Fog is usually formed when warm moist air lies over a cold surface. The upper air is often cold and shadow zones can form.

Rain will affect humidity and its onset can herald a change in both temperature and wind velocity. Rainfall and hail can produce wide band noise that can significantly change the general background noise.

Snow can significantly affect ground absorption (see section 5.2.2) and modify the absorption expected from shrubs and trees. Some caution must be exercised when estimating the effect of snow on the ground, because the impedance can be influenced by the presence of more dense frozen layers and sometimes the presence of standing pools of water.

5.2.1.5 Acquisition and Interpretation of Meteorological Data

Without detailed meteorological data and sophisticated interpretation, it is difficult to assess the influence of the weather on any particular situation. There are a growing number of sound propagation prediction programs now available but they all have limitations. The more sophisticated models are however quite capable of providing useful data to assist with the deployment of measuring equipment and subsequent analysis of the data, provided the appropriate meteorological data is available. Currently these models require sound speed profiles up to several hundreds of metres, and these data are generally available only at selected radiosonde stations. The meteorological office can interpret such data and couple it with more detailed ground-based data close to the area of measurements, to provide a good estimate of the weather profile with height in that area.

The application of prediction programs may be enhanced with the development of ground-based meteorological sensing devices, such as SODAR and LIDAR, but the technology is not yet sufficiently developed for everyday use.

A reasonable “rule of thumb” to determine the height to which the meteorological data is required is “one unit up for every ten units out”, i.e. 100 m height for each 1 km along the ground from source. However neither the meteorological data nor its interpretation are generally available, and due to the considerable influence of meteorology on sound propagation, this fact must be realised and acted upon if significant uncertainties are to be reduced.

5.2.1.6 Suitable Weather Conditions

Noise measurements should only be performed when the weather conditions are representative of the particular situation under investigation. If complaints are made about noise occurring under particular weather situations, then the measurements should be made under conditions which replicate those particular situations. Long-term average measurements must be made during periods with different types of weather. Several attempts have been made to “classify” weather situations (e.g. CONCAWE²), and these classifications are quite useful when determining average weather patterns. They are often accompanied by statistical data on the rate of occurrence and season and time of day of occurrence. If the measurement sample is to be truly representative of a particular season or even a whole year, then the weather patterns for the whole of that period must be taken into account. If sample measurements are made under different conditions, then each sample should have its associated uncertainties calculated and appropriately combined.

Attempts which have been made to quantise weather conditions are becoming increasingly popular. One such method is currently being discussed in the draft version of ISO 1996. This document also contains an informative index, giving an indication of the magnitude of uncertainties likely to be experienced at distances up to 400 m from source, and for receiver heights up to 4 m above ground level. It only applies to short-term measurements and to the weather conditions stated, and is based upon a knowledge of the “sound ray curvature”. This guidance must be considered tentative.

In the absence of any information on the operation of the noise source which is specific to particular weather conditions, it is recommended that measurements are carried out under reasonably stable meteorological conditions. This will improve reproducibility.

The most common stable condition for noise measurements occurs under downwind refraction, when the noise levels usually decay uniformly with

² MANNING, C J, The propagation of noise from petroleum and petrochemical complexes to neighbouring communities, 1981, CONCAWE

distance and remain reasonably steady over an extended period (provided the source remains steady). Measuring under downwind conditions is normally the “worst case”. This is usually the situation of most interest, i.e. highest noise level at the reception position. To meet these requirements, the wind direction should remain within approximately $\pm 60^\circ$ of the direction from the source (wind blowing from source to measurement position). The wind speed should be between 2 m/s and 3 m/s at 3 m to 11 m above ground and there should be no strong temperature gradients near the ground.

In general, noise levels tend to remain reasonably steady downwind of the source on days when the atmosphere is relatively stable, and under such conditions a general enhancement of the noise level takes place over a relatively wide arc. Small changes in wind direction are not usually critical. Upwind areas are usually in a sound shadow but the depth of the shadow will be determined mainly by the amount of turbulence that causes scattering of sound.

Sources of Uncertainty

- Meteorological changes during measurements
 - Meteorological conditions different from previous measurement period
 - Meteorological conditions unrepresentative of conditions under which measurements should have been made
-

Good Practice Guidelines

- Use the weather forecast when planning measurement sessions.
- For long-term averages determine statistical spread of weather classes and proportion measurement sessions accordingly.
- Record meteorological conditions for the duration of the measurement and report.
- Avoid measuring during extreme conditions.
- Unless specific conditions are required measure only during favourable propagation conditions.

5.2.2 Ground Effects

For most environmental noise measurements, the ground surface provides the strongest - and therefore most important - reflection. The amount of sound energy reflected is dependent upon the acoustical impedance of the ground surface, which is a function of frequency and angle of incidence.

Reflections from acoustically hard surfaces (e.g. water or concrete) are strong due to the high acoustic ground impedance, whereas reflections from acoustically soft surfaces of complex impedance (e.g. dense vegetation or dry sand) are comparatively weak and subject to a phase shift.

Although it would be unusual for the ground surface to change during the span of a normal measurement, it is not unusual for the ground to change between measurements. A change in ground impedance may be due to:

- Weather, see section 5.2.2.1
- Human activity, see section 5.2.2.2
- Vegetation, see section 5.2.2.3

5.2.2.1 Weather

Weather can change the acoustic impedance of the ground surface:

- Rainfall: surface water increases acoustic impedance (characteristics will change as ground dries out).
- Ground frost: increases acoustic impedance - stronger reflection (potential significant change during early stages of thaw)
- Snow: impedance depends upon the type of snow, its depth and compaction. Surface freezing, ice or water on ice can all increase variability.
- Wind: the surface of a lake may change from smooth, providing a strong specular reflection, to uneven (waves), scattering the reflected sound.

5.2.2.2 Human Activity

Human activity can change the acoustic impedance of the ground surface:

- Ploughed field
- Harvested crops
- Re-surfacing
- Storage of goods and materials

5.2.2.3 Vegetation

Natural cycles in the growth of vegetation can change the acoustic impedance of the ground surface:

- Fallen leaves covering the ground
- Height of growing crops, or natural surface vegetation

The ground dip

The 'ground dip' is a term used to describe attenuation of noise propagating close to the ground, due to interference between the direct, reflected, ground and surface waves.

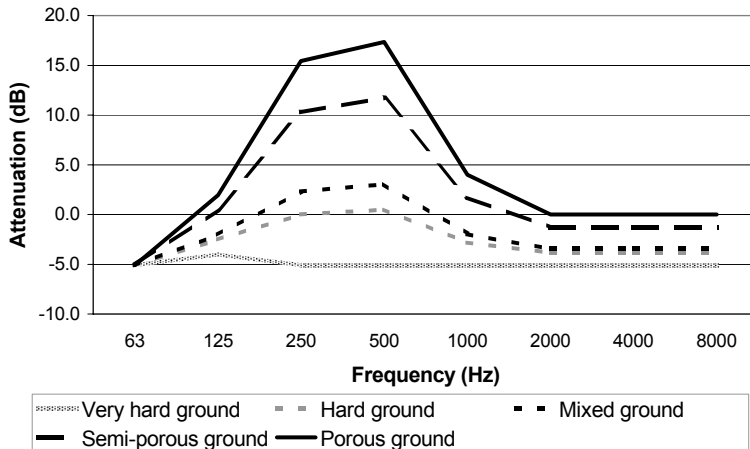
Acoustically hard ground will normally produce regions of constructive and destructive interference close to each other in the frequency domain, often approximated as a 3 dB increase in level when considering bands equal to or wider than one octave. However, the phase shift found in reflections from

acoustically soft ground can produce wide bands of destructive interference, known as the ground dip.

Typically, this excess attenuation occurs in the region 200 Hz to 1 kHz, centred around 500 Hz, see diagram. The exact frequency range is determined by the source/receiver height distance as well as the ground impedance and has been known to extend beyond the 200 Hz to 1 kHz range.

**Calculation of excess attenuation due to the ground dip
ISO 9613-2:1996**

Downwind propagation over 200m for source and receiver heights of 1m



The dip is most severe when the reflected sound hits the ground surface at grazing incidence (0°), diminishing as the ratio of source-height to source-receiver distance approaches 3:100. In practice, significant attenuation is only experienced where the propagation distance is large (greater than a few hundred metres) and the source and receiver heights are low, i.e. the propagation path is close to the ground.

Turbulence in the propagation path destroys coherence between the direct and reflected waves, imposing a practical limit on the magnitude of the ‘dip: attenuations of up to 40dB have been measured³.

³ PIERCY J E, EMBLETON, T and DONTATO, Prediction of the Ground Effect Side Line Noise from Aircraft, *R J.A.S.A* 61, S68, 1977

Under atmospheric conditions favourable for propagation (downwind/temperature inversion), sound energy penetrates the shadow zone, partially or completely nullifying the 'ground dip'. However, under conditions adverse to propagation (upwind/temperature lapse), the dip may be enhanced.

The ability of the prevailing meteorological conditions to exaggerate or hide the 'ground dip' may lead to large and possibly sudden changes in sound pressure level, compounding the measurement uncertainty.

Sources of Uncertainty

Variability in the measured sound pressure level due to:

- changes to the ground surface during or between measurement periods
 - excess attenuation due to the ground dip
-
-

Good Practice Guidelines

- Avoid noise measurement during or immediately after precipitation. (When carrying out long-term measurements it may not be possible or even desirable to avoid such periods. In such cases an accurate log of the weather will assist with the analysis.)
- Accompany measurement results with a description of the ground surface between the noise source and measurement position, noting features which may influence the acoustic impedance. A photographic record may prove useful.
- Consider taking a spatial average when measuring tonal noise close to an acoustically hard surface.
- Estimate source and receiver heights/distance and report with measurement results.

**Useful
Notes**



- By measuring under conditions favourable for propagation (downwind/temperature inversion), attenuation due to the ground dip will be minimised. Not only will the measurements represent the worst case, usually the cause of complaint, but a higher degree of repeatability will be achieved.
- For most environmental noise measurements, the ground surface provides the strongest - and, therefore, most important - reflection. The amount of sound energy reflected is dependent upon the acoustical impedance of the ground surface, which is a function of frequency and angle of incidence.
- Reflections from acoustically hard surfaces (e.g. water or concrete) are strong - due to the high acoustic ground impedance - whereas reflections from acoustically soft surfaces of complex impedance (e.g. dense vegetation or dry sand) are comparatively weak and subject to a phase shift.
- Although it would be unusual for the ground surface to change during the span of a normal measurement, it is not unusual for the ground to change between measurements. A change in ground impedance may be due to:
 - Weather, see section 5.2.2.1
 - Human activity, see section 5.2.2.2
 - Vegetation, see section 5.2.2.3

5.2.3 Barriers

Barriers located on the transmission path will afford screening to the reception position, depending upon their dimensions, location and composition. However, the depth of the acoustic shadow may be extended or reduced by changes to the prevailing weather conditions (see section 5.2.1). Experience, together with an understanding of the principal mechanisms (diffraction/refraction/reflection) affecting noise propagation, is important when determining the likely variation in noise level and associated uncertainty.

5.2.3.1 Temporary Barriers

Where temporary barriers (e.g. a parked lorry) obstruct the propagation path, the measurement result should be accompanied by a description of the barrier including a diagram if appropriate. Where it is likely that a barrier may move during, or shortly after the measurement, the probable affect on the received sound pressure level should be noted.

5.2.3.2 Urban Environments

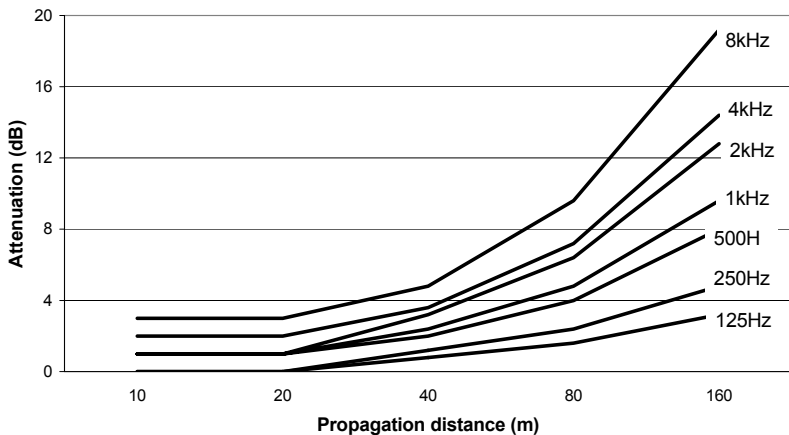
Noise propagation through urban environments is often subject to multiple reflections. Associated phenomena, such as the canyon effect caused by multiple reflections off high-rise buildings in town streets, may negate the effects of a barrier leading to higher than expected sound pressure levels.

Rapid urban development can dramatically change the acoustic environment in a relatively short period of time. The removal or construction of barriers between measurements should be reported with the measurement results. This may warrant detailed consideration when monitoring construction site noise.

5.2.3.3 Foliage

Some screening may be provided by trees and shrubs but only where they are tightly packed, sufficient to block line of sight and extending above this line by at least a few metres. This attenuation, predominantly of high frequencies, is dependent upon the type of vegetation and season.

ISO 9613-2:1996 Calculation of excess attenuation of octave band noise due to propagation through dense foliage



The psycho-acoustic effect of screening by foliage is often far greater than any measurable attenuation of sound pressure level, for example:

- scattering of the sound may reduce the reported 'harshness' without any reduction in L_{eq} ;
- increases in background level may mask other sources (dependent upon season and weather).

5.2.3.4 Topography

Topographical features, whether natural or man-made, may provide additional screening and are unlikely to change during or between measurements.

Any significant feature in the landscape will modify the local climate and exaggerate the effect of the weather on noise propagation, e.g. wind and temperature gradients may increase at the crest of a hill/ridge.

Sources of Uncertainty

- Variation in the depth of the acoustic shadow cast by a barrier due to changes in the weather
 - Changes to a barrier due to man's activity or the season
-

Good Practice Guidelines

- Note potential effect of changes in weather on barrier shadow.
- Have due regard for effect of seasonal changes on foliage.

5.3 RECEIVER

All measuring processes have an associated degree of uncertainty, determined by the accuracy of the instrumentation and the competency of the operator.

It is important to consider the following:

Microphone position (See section 5.3.1)

Instrumentation (See section 5.3.2)

Choice of measurement position (See section 5.3.3)

Background noise level (See section 5.3.4)

The environment immediately surrounding the receiver will affect the measurement result. The proximity of reflecting surfaces to the microphone and the influence of the weather on the instrumentation should be considered.

The selection of an appropriate measurement position is important. This will determine what the measurement actually represents and how relevant the result is to the purpose of the survey. Positions should always be well defined to ensure that repeated measurements are truly comparable.

5.3.1 Microphone Position

The microphone position must be chosen to ensure measurements are meaningful, representative and repeatable. To ensure that later measurements are truly comparable, they should be taken at the same position and microphone orientation. Care should be taken to ensure that at the position chosen small, possibly unavoidable, changes will not alter the measured sound levels.

The following guidance should be followed:

- Microphone height above ground level, see section 5.3.1.1
- Proximity to any surrounding building façades, see section 5.3.1.2
- Proximity to any other reflecting surfaces, see section 5.3.1.3
- Microphone orientation, see section 5.3.1.4

Sources of Uncertainty

- Not reporting the exact microphone orientation and position with respect to all other significant reflecting surfaces
 - Not checking that small changes in location have minimal effect on measurements
-

Good Practice Guidelines

- Criteria for selection of background noise measurement position:
 - Compliance with relevant standards
 - Representative, as justified by the purpose of the measurement (e.g. representative of the noise exposure causing complaint)
- Exact microphone position should be reported in the measurement record. To enable correct interpretation and repetition of the measurement, the record should include:
 - Justification of selection of measurement position
 - Diagrams showing distances to significant reflecting surfaces (including height above ground level) (*consider including an example*)
 - Orientation of microphone

Useful Note



It may not be sufficient to simply state compliance with the relevant standard; the precise position and orientation should be reported. For example, BS 4142 allows the height above ground level to be in the range 1.2-1.5m.

5.3.1.1 Height above Ground Level

Sound pressure levels may vary by several decibels over the first few metres above ground level. This may be due to the ground reflection, local meteorological factors or screening afforded by barriers and the local topography.

A measuring height may be specified in the relevant standard. If it is not, then it must be chosen for the purpose e.g. façade insulation measurements should be carried out at the height of the relevant window(s).

At ground floor level the preferred height is 1.5m above ground level (a.g.l.), (see Notes) representative of the head height of a standing adult, although many standards require 1.2m a.g.l., the head height of a sitting adult. Some aircraft noise standards require a height of 6m a.g.l. and mapping standards in future might require a measurement height of 4m a.g.l.

Sources of Uncertainty

- Inappropriate measuring height chosen
 - Measuring height not noted or incorrectly noted (of concern is the microphone height above a fixed reference)
-
-

Good Practice Guidelines

- Check standards for guidance.
- The microphone height and reason for choosing that height should be recorded.

Useful Note



The height above ground level should be measured from the ground surface to the acoustic centre (i.e. diaphragm) of the microphone. This will be fairly obvious with standard microphones but not always when weather protection systems are used.

5.3.1.2 Measuring Close to Façades (Buildings)

If the measurement position is close to a building, the influence of the façade reflection must be considered. Some standards recommend that measurements should be made at a particular distance from the façade, e.g. BS 4142 : 1997 advises that in order to minimise the influence of reflections, measurements should be made at least 3.5m from any reflecting surface other than the ground, although a distance of 4-5m may allow greater confidence.

At the surface itself, there will be a pressure doubling and the measurements will yield answers 6 dB above those obtained in the same location without the façade present (i.e. when only the incident wave is measured)⁴. A short distance in front of the façade (e.g. 2m), interference between the incident and reflected sound is often approximated as a 3dB rise in level (energy doubling) when considering bands of mid-high frequency noise (i.e. one-third octave bands in the range 200Hz-2kHz)⁵.

However, this rule of thumb should be applied with caution if:

- the façade provides significant absorption or scattering (due to windows, doors etc.)
- the microphone is exposed to additional reflections of a comparable magnitude (e.g. microphone positioned close to the ground)
- the measurement is concerned with narrow bands ($< \frac{1}{3}$ octave) or the noise is tonal.

Sources of Uncertainty

- Not defining measurement position
 - Distance from façade not noted or incorrectly noted
 - Assuming a fixed correction in subsequent calculations
 - inappropriate correction
-

Good Practice Guidelines

- Check standards for guidance.
- Note down distance from façade and features of façade.
- State clearly any assumed correction applied before stating final result.

5.3.1.3 Measuring Close to other Reflecting Surfaces

It is often not possible to select a measurement position away from all significant reflecting surfaces (other than the ground). If an object is large, it is probable that the associated reflection will have some influence on the measurement result (See section 5.3.1.2). However, determining the significance of small- or medium-sized objects (e.g. gate post/fence/tree) may be difficult.

Sound energy is only reflected where the wavelength is small compared to the dimensions of the surface. Low frequency noise with a large wavelength

⁴ QUIRT, J D, Sound fields near the exterior of building surfaces, *J Acoustical Soc Am*, **77**, 1985, pp557-566

⁵ HALL, F L, PAPAKYRIAKOU, M J, and QUIRT J D, Comparison of Outdoor Microphone Locations for Measuring Sound Insulation of Building Façades, *J Sound and Vibration* **92**(4), 1984, pp 559-567

will diffract around all but the largest of surfaces, whereas high frequency noise with a small wavelength may be reflected by both large and small surfaces (e.g. a sound level meter case). However, reflections of low frequency may be weak, even from large surfaces, if the structure is lightweight (i.e. profile cladding).

If the noise is tonal or predominantly mid- to high frequency, the extent to which nearby reflective surfaces affect the measurement result may warrant detailed investigation. However, if the noise is low frequency or broad band it may be possible to ignore the presence of small- or medium-sized surfaces.

Sources of Uncertainty

- Measuring position sufficiently close to a reflecting object that reflected energy affects measurements
 - Location/nature of reflecting object not noted (some objects, e.g. vehicles, could move before next measurement)
-
-

Good Practice Guidelines

- Do not measure near any reflecting object that is less than several wavelengths away.
- Note location, type and characteristics of any unavoidable objects.

Useful Note



The effect of a reflection on the measurement result will be dependent upon the wavelength of the sound.

5.3.1.4 Microphone Orientation

The orientation of the microphone relative to the direction of the incoming sound wave can affect the measurement result. There are several microphone types in use for precision acoustic measurements, and their responses can differ at mid- to high frequencies. The three principal types are the free field (0° incidence) response, the pressure response and the random incidence response (see section 5.3.2.4). In general when making outdoor measurements, a free field microphone should be used and these usually have the most uniform frequency response when they are pointed towards the sound source (i.e. sound normal to the diaphragm). However, standards usually specify the type of microphone to be used. In the case of IEC (used in Europe), a sound level meter with a free field response is specified (i.e. the microphone is pointed to the source). In the case of ANSI (USA), a random incidence response is required. The most uniform response is obtained when the microphone is orientated at 70° to 80° to the source (IEC).

Sources of Uncertainty

- Direction of dominant sound source
 - Unknown type of microphone/instrument in use
-

Good Practice Guidelines

- Where possible, orient the microphone relative to the dominant sound source according to the instrument manufacturer's advice.
- Check standard in use for appropriate microphone response and check microphone in use is appropriate to comply with standard.
- Be aware of the type of microphone in use or the effect of any mechanical or electrical devices that can modify the effective response.
- Ensure that the microphone and sound level meter responses are compatible.

Useful Notes



- Microphones are generally omni-directional at low frequency: orientation is only significant when high frequencies are dominant, e.g. for a typical 1/2" free field microphone the largest attenuation due to a variation in orientation would be less than 2dB at 6 kHz (Brüel & Kjær data).
- The response of a free field microphone can be changed by fitting an acoustic resonator (e.g. a purpose-made random incidence corrector or a nose cone). Some sound level meters can be switched to simulate different responses by internal circuitry, although this may reduce the useable dynamic range of the instrument. It is essential when using such meters that the correct microphone is in use and the meter is switched to the appropriate setting.
- Small changes to the microphone orientation will have a greater effect on the measurement result when measuring noise from point sources, as compared to line or area sources.

5.3.2 Instrumentation

The purpose of a measurement will determine what equipment is required and associated degree of precision.

5.3.2.1 Type Certification

International standards specify four degrees of precision, covering the performance and associated tolerance for each component of the sound level meter (these four degrees of precision, currently known as types 0-3, will be replaced by classes 1 and 2 in the new standards, due for release by the end of 2001). For each degree of precision, the standards prescribe absolute accuracies which must be achieved under specified reference conditions.

Brüel & Kjær have provided the following table⁶, which displays what they consider to be achievable accuracies for practical measurements.

Component of uncertainty	Type 0 (dB)	Type 1 (dB)	Type 2 (dB)	Type 3 (dB)
Application	Laboratory	Laboratory & field use	General field applications	Field noise surveys
Absolute accuracy at reference conditions*	± 0.4	± 0.7	± 1.0	± 1.5
Warm up period (1 hour)	± 0.2	± 0.3	± 0.5	± 0.5
Directional effects 30° from 0° incidence	± 0.5	± 1.0	± 2.0	± 4.0
Frequency weighting (100Hz-1KHz)	± 0.7	± 1.0	± 1.5	± 2.0
Level range control	± 0.3	± 0.5	± 0.7	± 1.0
Slow/fast time weighting (detector-indicator)	± 0.5	± 0.5	± 1.0	± 1.5
Atmospheric pressure (+/- 10%)	± 0.3	± 0.3	± 0.5	± 0.5
Temperature (-10° to +50° C)	± 0.5	± 0.5	± 0.5	± 0.5
Humidity (30-90%)	± 0.5	± 0.5	± 0.5	± 1.0
Calibrator *	± 0.2	± 0.2	± 0.2	± 0.2
Total estimated uncertainty (root of the sum of the squares)	± 1.4	± 1.9	± 3.1	± 5.2

Reference conditions, 20° C, 65% relative humidity, 1013 mbars atmospheric pressure, with plane progressive waves arriving at the microphone from one direction (typically 0° incidence) at 94 dB.

* This applies to a Brüel & Kjær type 4231 calibrated to the manufacturer's data.

Many environmental noise standards specify that sound level meter of type 2 or better is required (e.g. BS 4142 : 1997), however under certain circumstances the use of cheaper, less accurate sound level meters may be acceptable. When measuring in the field, it is not unusual for the overall measurement uncertainty to be sufficiently large as to render the difference between using a type 1 or type 2 meter insignificant. Users should be aware that the tolerances generally widen towards the extremes of measurement ranges (low- or high frequency and/or level).

⁶ WILLIAMS, MARTIN, Environmental noise and vibration measurement and standards, 1997, Brüel and Kjær

Sources of Uncertainty

- Use of instrumentation with an unknown degree of precision in all or part of the measurement chain
 - Uncertainty associated with the precision of the measurement.
-

Good Practice Guidelines

- Ensure that the whole measurement chain (including field calibrator, see section 5.3.2.3) meets the required degree of precision.
- Report the type of meter used with the measurement results together with details of all other instrumentation used.
- Follow the manufacturers' instructions.

Further reading (check for latest editions)

IEC 651:1979 / BS 5969:1981 / BS EN 60651:1994 / BS EN 61672: 2003
Specification for sound level meters
IEC 804:1985 / BS 6698:1986 / BS EN 60804: 1994 Integrating/averaging
sound level meters
IEC 942:1998 / BS 7189:1989 Sound calibrators
Environmental noise and vibration measurement and standards, Brüel &
Kjær, 1997

5.3.2.2 Calibration to National Standards

Instruments that have been pattern evaluated (normally the case for all sound level meters sold by the major manufacturer) will have demonstrated lower uncertainties than those which have not, and should therefore be preferred.

It is the user's responsibility to ensure that instruments are regularly re-tested in accordance with BS 7580, BS 61672 Part 3, or equivalent, by a recognised national laboratory to ensure continuing compliance and traceability. A maximum interval between re-tests, usually 1 or 2 years, is specified by some measurement standards.

An up-to-date calibration certificate refers only to the condition of the instrumentation at the time of test and should not be seen as a 2-year guarantee. Anomalous measurement results should be investigated immediately as faults may develop at any time, e.g. in transit between the calibration laboratory and the owner.

Sources of Uncertainty

- Erroneous measurement results due to inaccurate or malfunctioning instrumentation
 - Non-traceable calibration
-

Good Practice Guidelines

- Conduct all noise measurement using sound level meters and field calibrators whose conformance and calibration have been checked periodically against national standards (guidance can be obtained from UKAS publication, LAB 25, or the relevant measurement standard in use).
- Calibrators should be checked preferably at least once per year and sound level meters every two years, or at more frequent intervals depending upon usage and conditions (harsh environments etc). All instrumentation should be re-calibrated if damaged and after repair.
- Sound level meters, particularly the microphone, and field calibrators should be treated with care and stored in a moderate environment (follow manufacturers' instructions).

5.3.2.3 Calibration in the Field

Environmental variables, e.g. ambient pressure, influence the performance of sound level meters, see section 5.2.1.4. Further changes in sensitivity and performance may be due to the measurement chain, e.g. use of an extension cable, see section 5.3.2.6. To allow such changes to be taken into account, sound level meters should be calibrated on site before, during and after use depending upon circumstances.

Pistonphones and field calibrators couple to the microphone to form a stable pressure field, normally a 1kHz or 250Hz tone, $\pm 0.2\text{dB}$ uncertainty, see section 5.3.2.1. The sound pressure level quoted with the calibrator refers to a linear level; when using a 250Hz tone the linear frequency weighting should be selected.

The effect of temperature and humidity on pistonphones is negligible, however they should be compensated for ambient pressure, and are normally supplied with a barometer and correction chart. (A 2km change in altitude generally results in a correction of less than 2dB.)

Modern sound calibrators use an internal microphone and feedback loop to produce a consistent sound pressure level. The internal microphone is designed for high stability (i.e. its response is unaffected by ambient pressure, temperature or humidity) around the 1kHz region, at the expense of high and low frequency performance.

When calibrating free field microphones (see section 5.3.2.4), using a pressure field (i.e. a piston-phone or field calibrator), a small correction provided by the manufacturer (typically less than 0.5dB) should be applied to the calibration value.

The meter should only be calibrated when the calibration tone exceeds the background level by more than 20dB, e.g. for a 94dB 1kHz calibration tone, the background noise level must be less than 74dB.

Changing the dynamic range (e.g. from 50-120dB to 30-100dB) between calibration and measurement will introduce some error (typically <0.5dB) depending upon the actual instrument, and should be avoided where possible. Operators should also be aware that tolerances can change within the dynamic range window, usually lower tolerances occur towards the higher end of the selected range. The manufacturers' instructions or data should be consulted.

Comparison of the meter reading with a calibration tone confirms operation of the meter but usually only at one frequency and one sound pressure level unless a "multical" type calibrator is used.

Experience, practice and common sense must be used to ultimately determine whether the meter and its associated calibrator are suitable for the particular measurement purpose.

Sound level meters should be calibrated in the field before and after use, although most sound level meters will hold their calibration for several days and often weeks. By repeating the calibration after a measurement, a check can be made to ensure that no serious drift has occurred, due perhaps to a component beginning to fail.

During long-term measurements the system should be regularly calibrated. This may be several times each day and it is good practice to record any small changes (and their direction) in observed calibration level as a check on drift. (It is not unusual in the field to observe changes of ± 0.2 dB, even over a short measurement period. Provided these are random and oscillate about a mean there is unlikely to be an instrument fault.)

If a significant difference in calibration level is recorded over the duration of a measurement period, i.e. > 0.5 dB, the measurement results should be discarded, unless a satisfactory explanation can be found and the change is within the overall acceptable tolerances of the measurement.

Sources of Uncertainty

- Failure to follow the correct calibration procedure
 - Erroneous measurement results due to faulty instrumentation
 - Long-term drift
-

Good Practice Guidelines

- Investigate anomalous measurement results to ensure early detection of faults.
- Sound level meters should be calibrated:
 - before and after noise measurement (and during, if long-term or there are changes in external environment, e.g. change of batteries, change in atmospheric pressure)
 - on-site i.e. under the same environmental conditions as the measurement will be taken
 - in the same configuration as that used for the measurement (e.g. with an extension cable in place)
 - whilst isolated from vibrations, i.e. resting on a resilient (rubber) mat and in a suitable low background noise environment
 - to compensate for local variation in environmental conditions
 - to confirm correct operation of the sound level meter.
- The results of calibration should be recorded and reported with the measurement results.
- When measuring noise using long-term installations, the measurement system should be calibrated regularly. Logging the results will provide data from which calibration intervals can be properly assessed.

Useful Notes



- A pistonphone operating at 250Hz can be used to check the A-weighting network by switching between the A network and the linear or C network. The A-weighted network should attenuate the 250Hz tone by 8.6dB relative to the Linear or C network.
- To minimise fitting errors and errors induced by small movements of the calibrator and/or sound level meter, the two instruments should be laid on a resilient surface (e.g. rubber mat) during calibration.
- Pinhole air leaks in capacitor microphone diaphragms might not cause significant changes at 1kHz but might at other frequencies. If repeated daily checks with a 1kHz calibrator show small changes of a few tenths of a decibel, checks should be made at other frequencies.⁷
- Measurement microphones are extremely fragile and a small knock might cause damage to the microphone diaphragm. Despite the obvious dangers, the protection grid should be removed periodically and a physical inspection made. This check is best carried out in the laboratory before field measurements take place. The condition of the diaphragm surface can also be inspected. If there is a build up of dust this can be removed by means of an artist's fine paintbrush lightly dipped in isopropyl alcohol. (This operation requires some skill.)
- Field calibrators must be fitted correctly over the microphone as small variations in positioning can lead to significant differences in measured sound pressure level (some manufacturers' calibrators are easier to fit than others!). Sealing of the coupler is usually achieved by "o" ring. These should be inspected periodically for damage and only replaced by a manufacturer's approved spare.
- If a quiet environment can not be found when calibrating the meter, the octave or one-third octave filters may help to reduce the background noise level but may introduce additional uncertainty.
- The manufacturer's recommended coupler should be used to connect the calibrator to the microphone. The coupler is constructed so as to provide the correct cavity volume and other manufacturer's couplers are not necessarily the same size, even though they may fit both the calibrator and microphone.

⁷ KRUG, R W, Sound level meters, *Handbook of Acoustics*, MALCOLM J CROCKER ed, 1998, J Wiley, Chapter 105, pp

5.3.2.4 Microphones

Measurement microphones are fragile and should always be handled with great care. Over the life span of a single sound level meter, it may be necessary to replace the microphone a number of times. The influence of the environment on the microphone is usually far greater than on any other component of the meter, see section 5.3.2.5.

Many type 2 meters can be upgraded to type 1, simply by fitting a better microphone and preamplifier (check manufacturer's data).

A range of measurement microphones are available, varying in sensitivity, frequency response, quality and price. Consideration should be given to the sound field before determining which type of microphone is the most appropriate.

Sound field and microphone type

Microphones are classified in terms of their sensitivity relative to the frequency and angle of incidence. Many sound level meters allow a single microphone to be switched between responses using an electronic filter.

Free fields are composed of plane waves propagating in one direction from a point source. In practice, a measurement may be considered to be in the free field, when taken in an open area with only one significant source and the source to receiver distance is many times the largest source dimension.

Free field microphones compensate for the disturbance to the sound field caused by their presence, i.e. they measure the sound field as though the microphone was not there. Designed for use under free field conditions, they are commonly used in the measurement of environmental noise and should be pointed at the dominant noise source. The frequency response is almost flat for sound waves arriving at 0° incidence, but falls off with increasing angle of incidence and frequency.

Pressure fields are found in enclosed spaces or cavities where the dimensions of the space are small compared to the wavelength. Characterised by a sound pressure of equal magnitude and phase throughout the space, these are exploited in calibrator design to induce a stable and repeatable sound pressure level at the microphone diaphragm.

Pressure microphones measure the sound pressure level actually present at the diaphragm; no correction is made for the disturbance caused by the presence of the microphone. When used to measure under approximate free field conditions (i.e. outdoors), the microphone should be mounted at 90° to the direction of sound propagation.

Diffuse fields are composed of sound waves of equal level arriving at a specified point from all directions with equal probability. In practice, diffuse sound fields may exist where a space is enclosed by hard reflecting surfaces (e.g. a church) or where there are many sources (e.g. a factory).

Random incidence microphones are designed to respond equally to noise arriving from all angles i.e. reverberant spaces (diffuse fields). They should be used in diffuse fields, or where a number of sources are present. Some ANSI standards specify that random incidence microphones should be orientated at 70° (in both horizontal and vertical planes) to the source, to achieve for optimal linearity. High frequencies arriving at angles less than 70° will cause the meter to read on the high side, and for angles over 70°, the meter will read less than the true value.⁸

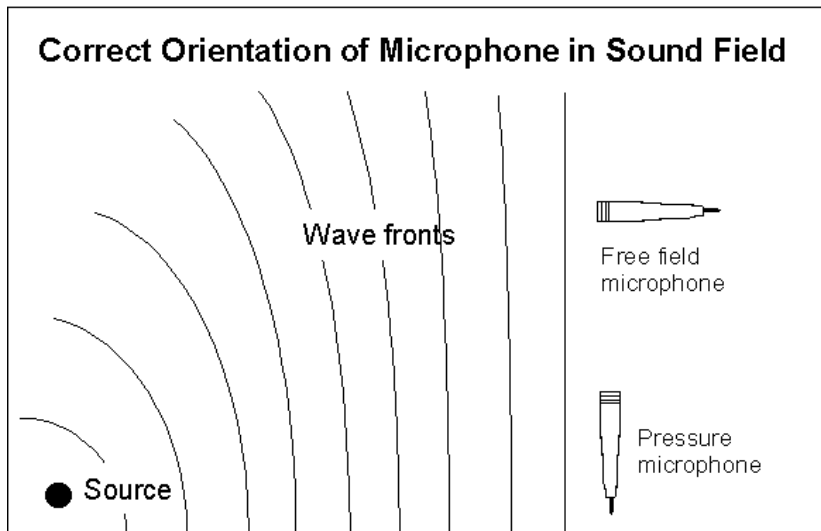
Sources of Uncertainty

- Inappropriate choice of microphone
 - Inappropriate angle of orientation
-

Good Practice Guidelines

- Chose the most appropriate microphone for each situation.
- Place the microphone at the correct orientation to the major noise sources.

⁸ KRUG, R W, Sound level meters, *Handbook of Acoustics*, MALCOLM J CROCKER ed, 1998, J Wiley, Chapter 105, pp



Useful Note



If it is necessary to mount the microphone vertically (e.g. when a rain cap is used), it will usually be appropriate to use a pressure microphone. The measurement of over flying aircraft may be an exception, when a free field microphone would be more suitable.

Further reading: Brüel & Kjær microphone handbook

5.3.2.5 Environmental Effects

The performance of a sound level meter will be influenced by the environment. Some of the variables which should be considered include; temperature, humidity, ambient pressure, wind, magnetic fields, electromagnetic fields, and vibration.

Temperature

The effect of temperature on type 1 microphones is slight, and may be ignored unless the sound level meter is exposed to extreme levels (below -10°C or above +50°C).

The effect of temperature on type 2 microphones may be significant. Those that use an active compensation circuit should have the temperature sensor close to the microphone, this may be difficult if used with an extension lead.

Equipment should not be left inside cars during hot weather, or exposed to extreme temperatures for prolonged periods of time. Battery life may be dramatically shortened at very high or low temperatures.

Humidity

Humidity has a negligible affect on the sensitivity of microphones. However, some microphones have a layer of quartz on the diaphragm (distinguished by the appearance of rainbow colours on the diaphragm), which may absorb moisture leading to increased sensitivity. The magnitude of this effect will be in the region of 0.4 dB/100% relative humidity⁹, the manufacturer should be consulted for further information.

Fast changes from warm and humid to cool and dry environments (e.g. air-conditioned) should be avoided to prevent condensation forming inside the instrument. Condensation may cause electrical leakage affecting the pre-amp and microphone, resulting in instrument malfunction.

When moving from a dry to humid environment, condensation will form on the outside of the instrument. This will not normally affect performance, however, if there is also a large change in temperature the instrument should be allowed to acclimatise.

The use of windshields, rain caps and dehumidifiers to protect the microphone from humidity and precipitation should be considered when conducting long-term measurements. Prolonged exposure of the sound level meter to extreme levels of humidity, either high or low, should be avoided.

Ambient (static) pressure

The ambient air pressure affects air stiffness density, which partially determines the compliance of the cavity behind the diaphragm and therefore the microphone sensitivity. However, this effect is small: a $\pm 10\%$ change in atmospheric pressure will normally affect a measurement result by less than ± 0.3 dB. When measuring at very high altitudes this may be exaggerated; the manufacturers' instructions should be consulted.

Sound level meters should be calibrated at the altitude at which the measurement will be made; corrections may be necessary when using a pistonphone.

Differences in ambient pressure on either side of the diaphragm are normally equalised via a static vent, the dimensions of which control the microphone's low frequency response. Microphones which are designed for the

⁹ Transducers and Conditioning, *Interactive CD-ROM*, 1999, Brüel and Kjær

measurement of low frequency noise have this static vent partially blocked. These low frequency microphones must be allowed extra time to acclimatise (equalise the pressure across the diaphragm) after any change in ambient pressure; the manufacturers' instructions should be consulted. If used with a closed coupler calibrator, ample time should be allowed for the pressure pulse caused by the insertion of the microphone into the calibrator to die away, this may take a few minutes.

Wind

Wind noise is caused by turbulent flow of air around the microphone and pre-amplifier. The magnitude of the turbulence increases with wind speed, but is also affected by wind direction relative to the microphone. Small amounts of turbulence induce a little noise at low frequencies, whereas greater turbulence will induce higher levels of noise stretching further up the frequency range.

Windshields may be used to suppress wind noise, see section 5.3.2.6.

Magnetic fields

The effect of magnetic fields on the performance of high-quality sound level meters may be regarded as negligible, unless the meter is very close to a strong magnetic source.

Electromagnetic compatibility

Electromagnetic compatibility is the extent to which a piece of hardware can perform its intended function without being adversely affected by, or without adversely affecting other hardware through electrical interference.

The range and number of sources of electromagnetic radiation has ballooned over recent years with the rapid development of new technologies, such as the mobile phone industry, adding to traditional sources, such as sub-stations.

The whole measurement chain must be protected; microphones are normally well-shielded, active components such as pre-amplifiers should be CE labelled to confirm electromagnetic compatibility, extension cables may need screening to prevent them acting as RF antenna. Modern, high-quality, sound level meters are designed with immunity to electromagnetic interference as a priority, however, this may not be true of older equipment.

Electromagnetic interference may appear on the audio output of the meter as distinct humming or sharp tonal noise. The presence of a 50Hz spike in the frequency domain should always arouse the suspicion that the mains electricity supply may be the source of electromagnetic interference.

Such fields typically induce pure tones, which may be detected by listening to the audio output of the meter using a set of headphones (see section 5.3.2.6). Attenuating checks may be made with a dummy microphone.

Vibration

Although sound level meters are relatively insensitive to vibration, small shocks may damage the microphone. A foam rubber pad may be used to isolate the meter whilst calibrating, or where strong vibrations are present.

Microphones are most sensitive to vibrations normal to the diaphragm, typically $1/\text{ms}^{-2}$ in this plane is the equivalent to 65dB (SPL).

5.3.2.6 Accessories

Windshields

Sound level meters are seldom used without a windshield, not only because they reduce wind noise but also to cushion the microphone from sharp impacts when measuring in the field. Even when measuring in gentle winds, it is not uncommon for strong gusts of wind to introduce wind noise despite the use of a windshield.

The windshield will act as an acoustic filter and alter the apparent frequency response of the microphone. Some sound level meters include corrective filters that partially equalise this effect. The total change to the frequency response of the system will be dependent upon the design and age of the windshield but is usually greater the higher the frequency. For standard windshields, provided by the manufacturer, it will normally be small (typically less than 1dB at any one frequency over the range 10Hz–10kHz), and so rarely merits detailed consideration in the context of a field measurement.

A windshield of 10cm diameter should suppress wind noise by 12dB or more, although this is dependent on exact size and construction.

The size of foam windshield is a trade-off between a reduction in wind noise and the insertion loss through the foam. Larger windshields will attenuate more wind noise but also more of the acoustic signal.

Water loading of foam windshields can further change the sound level meter frequency response, depending on the type of windshield and amount of water. It has been observed that wet windshields can attenuate sound over the range 1.5–12kHz and amplify frequencies above 12kHz. This effect may distort the acoustic signal by up to 2.5dB for wet windshields and up to 4dB for water-saturated windshields. (See Product data - Accessories for Falcon range microphones, Brüel & Kjær.)

It has been proposed that the following correction factors may be used to compensate for the use of a wet windshield¹⁰.

Corrections for wet windshields' effects at 0° incidence, for discrete frequencies

Frequency (Hz)	1.5k	2k	3k	4k	5k	6k	7k	8k	9k	10k	12k
Correction (dB)	0.0	1.5	2.5	2.0	2.2	2.2	1.5	1.2	1.0	0.5	0.0

Dry windshields

Deterioration of windshields by ultraviolet degradation or by contamination with dust can alter the porosity affecting both wind reduction performance and frequency response. Degradation of the surface can induce eddying in wind and cause an increase in noise level.

Sources of Uncertainty

- Wind induced noise affecting measurement results
- Filtering of the acoustic signal by the windshield
- Unknown effect of wet or degraded windshield

Good Practice Guidelines

- Use a windshield when measuring in the field.
- Avoid the use of wet windshields.
- Carry a spare windshield and alternate use when it is raining, (wet windshields may be dried out in the heater tray of most cars).

For a more detailed discussion of wind noise see section 5.2.1.1.

Weather protection

When using permanent or semi-permanent installations to measure noise, it is normal to use rain covers and bird spikes to protect the microphone. The manufacturers' instructions should always be followed, however, when using a rain cover it is usually necessary to mount the microphone with the diaphragm facing vertically upwards. Vertical mounting may mean that it is more appropriate to use a pressure microphone instead of the usual free field microphone. See section 5.3.2.4.

Use of tripod and microphone clip

The use of a microphone clip and tripod to support the microphone will affect the measured sound field. Only high frequencies, where the wavelength is comparable to the dimensions of the clip and tripod, will be affected, i.e. at high-frequencies, ±1dB is typical effect.

¹⁰ RAY, ELDEN F, Jr, Measurement uncertainty in conducting environmental sound level measurements, *Noise Control Eng J* **48** (1), 2000, 1999,

The interference can be minimised by using an extension rod to mount the microphone away from the tripod.

Further reading:

Brüel & Kjær Technical Review No.4 1985 Influence of tripods and microphone clips

Reflections from the body of the user

If a person (e.g. the operator) stands close to the microphone during a measurement, reflections and shielding effects from that person’s body will have an impact upon the measured sound field. This will be unavoidable if the measurement is made when the meter is hand-held.

The following interference patterns have been observed¹¹ for hand-held measurements made by a ‘typically-sized and dressed’ operator facing the noise source. Results will differ from meter to meter and operator to operator.

Distance between microphone and the operator’s body	Interference pattern
30cm	±2dB over 200Hz-5kHz
40cm	-2dB at 25 Hz, ±1dB over 300Hz-3kHz
50cm	-1 dB dip at 250 Hz, ± ½ dB over 200Hz-10kHz

Source of Uncertainty

Reflections from the body of the operator interfering with the measured sound field

Good Practice Guideline

When taking hand-held measurements, hold the meter away from the operator’s body or to use a gooseneck type extension for the microphone. Modern sound level meters are sufficiently light to be held at arms length, heavier meters may be fitted with a goose neck extension. In this case, the operator can stand sideways to the source to minimise reflections. It is, however, better to mount the sound level meter or microphone on a tripod.

Extension cables

When a measurement is made using an extension cable, the system should be calibrated with the extension cable connected between the microphone/pre-amplifier and sound level meter. This will not only ensure

¹¹ Taken from Instructions and Applications for Brüel & Kjær Precision Sound Level Meter Type 2203, 1961

that any extra impedance introduced by the cable is compensated for, but also that the cable is fitted properly and that it works!

When using cables longer than 50m, the calibration should be repeated at regular intervals to ensure that the cables are functioning correctly and all connections are sound.

Capacitance between the parallel cores within the cable effectively short out high-frequency signals. This effect is more pronounced for high-level signals and long cables.

Source of Uncertainty

Attenuation, interruption or corruption of the measured signal

Good Practice Guidelines

- Avoid the use of long cables (>10m) whenever possible
- Carry out field calibrations with all cables in place
- Regularly calibrate the whole measurement system when using long cables
- Use balanced cables

Useful Note



If the cable used is longer than necessary, the spare length should not be coiled: a coiled cable will act as an inductor and low-pass filter any signal it carries. By laying the spare length in a figure of eight configuration, two induction loops are formed which should cancel any induced signal.

Headphones

Most sound level meters have an AC (audio) output, and this enables the operator to listen to the signal as detected by the microphone and amplifier.

High-quality headphones are a useful aid during noise measurement; a tight fit and good cushions are essential to improve the low frequency response and help reduce the leakage of external noise into the earphone, and to avoid any feedback of the signal to the microphone.

Headphones are useful when

- using extension cables, i.e. to monitor what is being measured when not actually in the proximity of the microphone;
- investigating the effect of electro-magnetic fields; (see section 5.3.2.5)
- confirming good operation of the measurement chain.

Tape (digital) recorders and PC-based systems

Tape recorders (and sound cards) are not normally supplied with type certification (see section 5.3.2.1) and require independent calibration. Care

should be taken to ensure that the whole measurement chain meets the required standard and this includes the replay and analysis chain. It is also necessary to ensure correct electrical matching to avoid overloading part of the measurement chain.

Digital sampling rates can affect frequency response and should be compatible with the measurement requirements.

Tape recorders are dependent upon mechanical operation (moving parts) and therefore prone to wear and tear. Hence they should be used with caution and calibrated more regularly than solid state instruments.

It is good practice to record on wide-band linear settings if using a sound level meter as a front end. There is a danger when A-weighting is used during recording to improve signal to noise ratio, that a double A-weighted result might be erroneously produced when conducting subsequent analysis, i.e. know what you have recorded.

Some digital recorders use bit reduction algorithms to economise on data storage, e.g. mini disks. These recordings do not allow faithful reproduction of the acoustic signal and therefore should not be used for anything but simple checks, such as event identification.

Instrumentation practice

Equipment should always be used according to the manufacturers' instructions and a note taken of any guidance provided.

Sound level meters are complex instruments, usually comprised of a microphone, a pre-amplifier and a number of signal processing and interface modules (either hardware or software based), some of which may be interchangeable. However, the manufacture should be consulted before a measurement system is used in any configuration other than specified by the manufacturer, i.e. there is no guarantee that a type 1 meter will continue to meet the requirements if, for instance, the pre-amplifier is changed for one from another manufacturer.

Sources of Uncertainty

Failure to follow manufacturers' instructions:

- incorrect operation of equipment
 - errors introduced to the measurement chain through the use of incompatible equipment
-

Good Practice Guidelines

- Always follow the manufacturers' instructions.
- Use instrumentation in a competent manner.
- Do not mix major components unless you are aware of the consequences.
- Calibrate the whole measurement chain where necessary.

5.3.2.7 Frequency Analysis

Fast Fourier Transform (FFT)

The Fast Fourier Transform (FFT) is relatively simple algorithm allowing frequency analysis of acoustic signals. The transform calculates amplitude values for linearly spaced bins in the frequency domain. Increasing the length of sample in the time domain will improve both resolution in the frequency domain, and the low frequency limit.

The choice of window function is a key decision, representing a trade-off between the accuracy in terms of amplitude and frequency (noise bandwidth), see table below¹².

Window type	Noise bandwidth (relative to line spacing)	Maximum amplitude error (dB)
Rectangular	1	3.9
Hanning	1.5	1.4
Hamming	1.36	1.8
Kaiser-Bessel	1.8	1
Truncated Gaussian	1.9	0.9
Flat top	3.77	<0.01

The Hanning window is recommended for general-purpose frequency analysis.

Constant Percentage Bandwidth Filters (CPB)

Constant percentage bandwidth filters (CPB) of one octave and one-third octave are commonly used in the measurement of environmental noise. The frequency response and associated tolerances are specified for three classes of filter in BS EN 61260:1996 and IEC 1260:1995.

The filter bands are spaced at logarithmic intervals and have equal energy weighting. The use of a logarithmic scale also mirrors human perception of pitch.

¹² RANDALL, R B, Frequency Analysis, 1987, Brüel and Kjær, 3rd edition

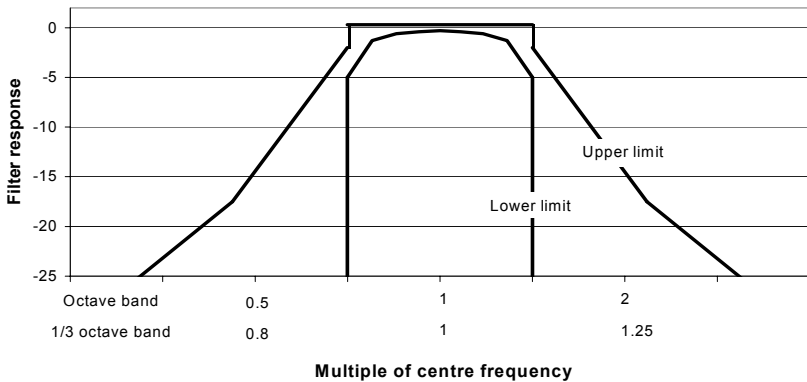
CPB filters require considerably more computational power than the FFT, but offer a high level of accuracy in both the amplitude and frequency domains.

Simultaneous/sequential measurement of frequency bands

Sound level meters incorporating parallel processing (real time analysers) provide a means of measuring a number of frequency bands simultaneously, enabling direct comparisons between the measured levels.

Many sound level meters utilise sequential contiguous filters and it is necessary to step through the frequency bands, measuring each in sequence. This introduces an element of uncertainty if the measurement levels from different frequency band are to be compared. For steady noise the associated uncertainty will be small. However, if the noise level is variable then the associated uncertainty may be significant. This uncertainty may be reduced if the measurement period is extended, allowing further time averaging of the signal. Alternatively, the measurement may be repeated and then a logarithmic average calculated. The magnitude of the uncertainty will be indicated by the dispersion of the measurement results. Greater uncertainty should be anticipated at the extremes of the frequency range.

IEC 1260:1995 type 1 tolerances for octave and 1/3 octave band filters (from 0 to -25 dB)



5.3.2.8 Time and Frequency Weightings, and Noise Metrics

Frequency weightings

The human hearing mechanism is less sensitive to noise at the extremes of the audio spectrum. The A-weighting network is designed to reflect the human perception of moderately loud noise (around 55 dB), and the C-weighting network to reflect the perception of high noise levels (above 85dB).

It is conventional to use the A-weighting network for broadband environmental noise measurements, and the linear (flat frequency response) network when recording audio records or conducting frequency analysis (CPB or FFT) although specific situations may warrant an alternate approach, e.g. the measurement of aircraft noise.

The use of the A-weighting network often reduces the measurement uncertainty. Low and high frequencies are notoriously difficult to measure (see section 5.1.1.2); by weighting the measurement in favour of the mid-range a greater level of repeatability is achieved.

When using either the a.c. or d.c. output of a sound level meter, the operator should determine if this is affected by the selection of frequency network; this may not always be immediately obvious.

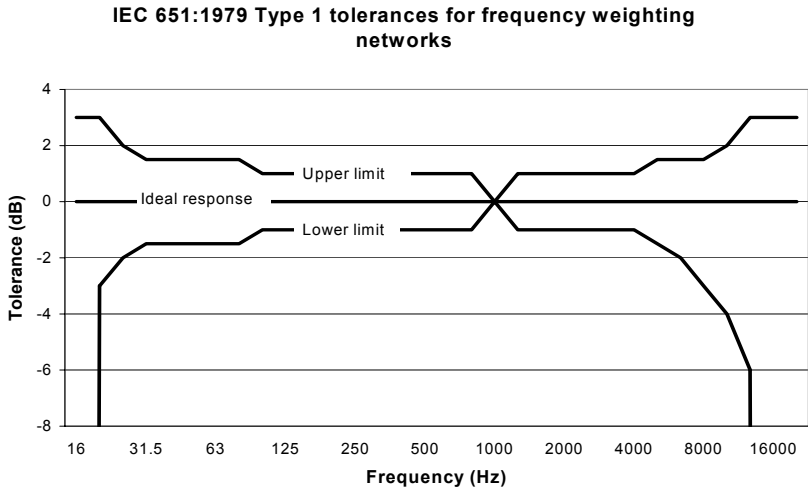
Frequency weighing networks have large tolerances at low and high frequencies which can introduce large uncertainties, especially when measuring tones.

Time weightings

In general, noise levels are likely to be higher when measured using faster time constants. The difference in measured level will be greatest for impulsive noise and metrics such as peak or max.

The fast and slow time weightings were developed for purely practical reasons.

Fast response: 0.125 second time constant - in 1950 this was the fastest moving coil meter available; frequently used for environmental noise measurement in Britain, but non-integrating meters may be difficult to read if the noise is non-steady.



Slow response: 1 second time constant - dampens the response of the meter, to enable 'eyeball-averaging' when measuring fluctuating noise with a non-integrating meter; declining in popularity, but still in use, e.g. PPG 24 Planning and Policy Guidance: Planning and Noise. Department of the Environment 1994.

Impulse response: rarely used in Britain - it was intended as a compromise between the human hearing mechanism (35ms rise time) and enabling the display to be easily read when measuring impulsive noise (1.5 second decay time).

Noise metrics

The noise metrics L_{max} and L_{peak} are prone to interference from background sources and freak events. Measurement results may vary wildly between consecutive periods of apparently equivalent source activity.

The measurement of L_{min} and L_{eq} have a tendency to be more robust. Occasional peaks in the background noise level or freak events will have little influence, provided that the measurement period is sufficiently long. Similarly, the percentiles L_{99} and L_{90} have a tendency to be more stable than L_1 or L_{10} . For periods of equivalent source activity, measurements of L_{90} should be consistent, whereas L_1 and L_{10} levels may vary.

There is no standardised method for the calculation of L_n values - procedures vary between manufacturers and instrument models. In order that the answer is statistically valid, the calculation should be based upon several hundred, or

more, samples. Two different calculation methods are unlikely to yield answers more than 1dB apart, provided both are sensible and the measurement period is not less than 1 minute.

Sources of Uncertainty

- Inappropriate weighting networks used
 - Failure to note or incorrectly noted weighting network
-

Good Practice Guidelines

- All measurements should be made using the time and frequency weighting specified by the relevant standard, guideline or procedure.
- Where no weightings are specified, it is normally preferable to measure using the fast time constant and the A-weighting frequency network, unless significant low- or high frequency energy is present.
- All results should be reported in the context of the time and frequency weighting used during measurement.

5.3.2.9 Dynamic Range

The range of sound pressure levels over which the meter is able to perform accurate measurement (typically 70 dB), is known as the dynamic range. Before each measurement the range of noise levels must be anticipated, and the dynamic range adjusted to suit.

The measurement of L_{eq} will always be affected if the noise level exceeds or drops below the dynamic range. However, the occurrence of slight over-ranging is unlikely to affect the measurement of L_{99} , L_{90} or min noise levels. Equally, the occurrence of slight under-ranging is unlikely to affect the measurement of L_1 , L_{10} or max noise levels.

5.3.2.10 Data Transfer and Processing

Keeping legible records during a noise survey is not always easy, there may be many distractions and adverse weather conditions to contend with. Modern sound level meters allow data to be stored and transferred using digital technology. This guards against human error and ensures that accurate records are kept, not only of the measurement result, but also the instrument set-up. It is often more dangerous to record a measurement result erroneously than to lose it altogether.

A standard worksheet should be used to ensure that all the relevant information is recorded in a clear and ordered manner. Some standards specify what information should be reported (e.g. ISO 1996 and BS 4142). The following list may be regarded as the minimum requirement.

- 1 Types, models, serial numbers, or other identification characteristics for all instrumentation and equipment
- 2 Detailed description of the area in which the measurements are made
- 3 Detailed description of the area over which the sound is propagated
- 4 Detailed description of primary noise source including dimensions, type of mounting, location within space, name plate data, owner's tag number and other important facts such as speed and power rating at the time of measurement
- 5 Description of secondary noise sources including location, type, kinds of operation
- 6 Location of engineers, observers (including names), workers, if any, during the measurements
- 7 Measurement positions including the orientation of the microphone diaphragm relative to the direction of the source
- 8 Barometric pressure, temperature, wind velocity (speed and direction), and humidity, if appropriate
- 9 Results of calibration and operational tests
- 10 Measured frequency band levels at the microphone position
- 11 Measured frequency band background noise levels
- 12 Date and time¹³

Sources of Uncertainty

- Corruption of measurement results due to errors in data transfer and processing
 - “Forgetting” measurement settings
-

Good Practice Guidelines

- Double check when transferring data by hand.
- Use digital transfer methods where possible.

Useful Notes



- Modern sound level meters allow measurement results to be stored and transferred in the digital domain, theoretically reducing the potential for mistakes. Where the options for labelling a measurement within the memory of a meter are limited, it is important to guard against complacency,
- It is often more dangerous to record data erroneously than to lose it

¹³ BRUCE, R D, Field Measurements: Equipment and Techniques, *Noise and Vibration Control*, L L BERANEK ed, 1971, McGraw-Hill Inc

5.3.3 Choice of Measurement Position

Measurements must be made at positions which are relevant to the study and which will allow future repeats.

Points to note when considering community noise surveys:

- The primary complainant may be the most assertive or least tolerant of the local residents but will not necessarily be suffering the highest noise exposure. Communities will often view their most vocal member as a spokesperson and postpone their personal protest.
- Care should be taken when comparing noise measurements taken on behalf of opposing sides in a noise dispute. Access to land, and therefore choice of measurement position, can restrict each side in different ways. The local authority would usually have access to a complainant's property, enabling measurements to be taken outside a first floor window, but may be unable to measure on site at a factory. Whereas the consultant may have ready access to the factory premises, and even some influence on the operating conditions at the time of measurement, but could be requested by the client to maintain a low profile and only measure at discrete locations in the community. Two measurements may have been deemed representative of a particular location but have been taken at quite different locations and as such are not directly comparable.
- When planning remedial noise control, it is important that community measurement positions are chosen to represent the worst case, usually the nearest property to the source in a given direction. It may be necessary to choose a number of measurement positions surrounding the noise source in order to build up a clear picture of the noise landscape. The consequence of changes in the meteorological conditions (e.g. wind direction, see section 5.2.1.1) on the propagation pattern should be considered, and measurements repeated if necessary.

Sources of Uncertainty

- Interpreting measurement results as representative of something other than that which was actually measured
 - Comparing measurement results taken at different positions
-

Good Practice Guidelines

- Measurement positions should be selected to minimise the influence, on the measurement result, of all factors other than the subject of the measurement.
- Report and justify the criteria used to select each measurement position.
- To enable repeatable, and therefore comparable measurements the exact location should be reported in a diagram including distances to all significant reflecting surfaces and other features.
- Measurement results should be viewed in the context of the position where they were taken. Measurements taken at different positions should not be seen as directly comparable.
- When assessing community noise complaints, it is useful to measure at a number of positions around the noise source to build up an understanding of the noise environment.

Useful Notes



- A measurement position chosen during a daytime visit may pose unforeseen problems for night-time measurements. For example:
 - During a daytime visit, it is decided to measure underneath a lamppost as this will provide a convenient landmark and light source for night-time measurement. However when the assessor arrives at night, a buzzing sound emitted by the street light is found to interfere with the measurement. An alternative position is found, however, the night time measurement is possibly no longer directly comparable to that taken during the daytime.
 - A gravel-surfaced driveway at residential property is chosen as a measurement position during a daytime assessment. When the site is revisited at night the background noise level has dropped significantly and it is found that noise from movements by the assessor on the gravel interfere with the measurement.
- Where it is suspected that ground-borne vibration is significant, care should be taken to structurally isolate the microphone (and all other vibration-sensitive components of the measurement chain) from the ground.

5.3.4 Background Noise Level

The “background noise level” (or residual noise level in BS 4142) is the noise level remaining, once the noise from the specific source(s) has been removed or suppressed to a degree such that it no longer contributes to the measured level.

Notes

1. Usually any sources which cannot be considered typical of the background level, e.g. a solitary aircraft fly-by, are also excluded.
2. Where the object of the assessment is to measure the background noise level (e.g. PPG 24) the specific noise source(s) may be defined as all sources which cannot be considered typical of the ambient level.
3. A definition pertinent to the application of BS 4142 is provided in that document
4. Background noise is usually measured in terms of L_{A90} but L_{Aeq} is sometimes used.

Timing of measurement (choice and number of samples)

It is normal for the background noise emission to follow a distinct pattern. Traffic movements are often a dominant factor and follow daily, weekly and annual cycles. Such patterns may be severely affected by random events, e.g. road works may reduce the number and speed of traffic movements, whereas rain will increase tyre noise.

The background noise will usually encompass many sources located at some distance from the measurement position. The combination of large distances and many sources means that small changes in the weather, especially the wind direction, can produce significant variations in the measured sound pressure level. Ensure that the measurement period is sufficiently long to obtain a representative sample.

Sources of Uncertainty

- Variable and complex patterns in the noise emission
 - Large variations in the measured level due to changes in the weather
-

Good Practice Guidelines

- Consider how long-term patterns in the noise emission will affect the measurement result.
- Consider how the weather will affect the measurement result.

Useful Note



To reduce the measurement uncertainty it may be necessary to conduct long-term or repeated measurements representing a range of weather conditions. See below:

Measurement position (BS 4142:1997)

The preferred method for determining the background noise level is to measure at the assessment location, without the specific noise source operating. This should yield the most representative level and avoid the

uncertainty associated with choosing an alternative but presumed equivalent position. It may be convenient to exploit breaks in the source operation, however these might coincide with changes in background level and therefore may be inappropriate, e.g. weekends/lunch hour.

Where the specific noise operates continuously, a position close to the assessment location, but screened from the specific source(s) and yet equally exposed to the major background sources, should be sought.

Considerable judgement is required to ensure that the measurement is representative of the background level. The measurement of L_{A90} should be unaffected by occasional bursts of the specific noise, provided that the measurement period is sufficiently long.

If a suitable position cannot be found locally then a remote position must be chosen. This may require detailed consideration of the topography, distances and bearing between the measurement positions and all of the major background noise sources relative to the prevailing weather. A thorough investigation of the local area may be necessary, for which the judgement and experience of the assessor will be critical factors.

It may be necessary to repeat measurements at a number of positions before making a reasoned decision as to which measurement is the most representative of the background level. A significant degree of uncertainty should be anticipated.

Source of Uncertainty

Changes in the distance, bearing and intervening topography between the background noise sources and the measurement position

Good Practice Guidelines

- Where it is necessary to measure at an alternative position the following should be considered:
 - Distance to each major background noise source
 - Bearing to each major background noise source
 - Topography between the measurement position and each major background noise source.
- There is no recognised method for the choice of alternative measurement positions as problems are often unique to the situation. The best approach is one based upon common sense and reasoned decision-making.
- If the time and resources are available, repeated measurement should be made at a number of measurement positions in order to determine the most representative noise level.
- The choice of background measurement position should be justified in the survey report.

Useful Notes



Typical daily pattern of noise

Time	Build up		Typical week days				Wind-down		Weekend	
	Mon	Tue	Wed	Thu	Fri	Sat	Sun			
00.00										
01.00						Entertainment noise				
02.00	Low background levels									
03.00	Community most sensitive to noise									
04.00										
05.00						Community most sensitive to noise				
06.00	Traffic build up to peak around 09.00*									
07.00										
08.00										
09.00	Normal working hours					Peak level of activity.		Domestic noise i.e. lawn mowers, some traffic movements		
10.00	Community most tolerant of noise					Highest tolerance to noise				
11.00	Lunch time period					Typically low traffic volume				
12.00	Change of traffic pattern									
13.00	Normal working hours									
14.00	Community most tolerant of noise									
15.00										
16.00										
17.00	Peak traffic flow winding down from around 17.00*									
18.00										
19.00										
20.00										
21.00						Entertainment noise				
22.00										
23.00										
24.00										

* Regional variation may be ± 1 hour.

5.3.5 Attended and Unattended Noise Monitoring

Noise measurements conducted with the operator in attendance provide an opportunity to identify extraneous noise that might interfere with the measurements. During the measurement the operator should keep a log of the:

- activities taking place near the measurement position likely to influence the measured levels
- subjective impression of the noise at the receiver position
- prevailing weather conditions
- operation of each major noise source.

Unattended noise monitoring offers the advantages in terms of convenience, expense and the possibility of long-term monitoring. However, unless real-time recording is used simultaneously, it will not be possible to identify instances where the results might be influenced by extraneous noise.

In order to reduce this uncertainty, the results should be subjected to thorough scrutiny. Any anomalous peaks, drifts, or troughs in the measured level should be viewed with suspicion. Where no adequate explanation can be found, it may be necessary to reject sections of the data, although this practice, in itself, may lead to erroneous results.

Additional information sources may be used to increase confidence in the measurement result.

Audio records: triggered when the noise level exceeds a certain threshold, are often used to discriminate between legitimate noise events and extraneous noise (e.g. a bird landing on the microphone).

Meteorological data: A correlation between low frequency noise and wind speed indicates that the measurement may have been affected by wind noise. A good correlation between increased noise level and a downwind condition may increase confidence in the measurement.

Source operation: A good correlation between the measured noise level and the operation of the noise source (e.g. traffic count, factory production) may also increase confidence in the measurement result.

5.3.6 Permanent Noise Monitoring

Permanent noise monitoring installations require high-quality instrumentation and corrosion resistant weather protection. The risk of system malfunction is potentially high due to long-term exposure to the elements and possible vandalism. A thorough calibration regime is essential to identify problems soon after they develop and maintain confidence in the measurement data. Regular acoustic calibrations conducted in person together with a visual inspection of the instrumentation may be supplemented with remotely conducted electrical calibrations, e.g. charge injection calibrations.

5.4 KEY PLAYERS

5.4.1 The Assessor (the person carrying out the measurements)

The assessor needs to complete the following check list before any measurements are made:

- Is the assessor fully conversant with reason for carrying out the measurements?
- Has the client provided sufficient information for the job to be carried out?
- Has the correct equipment (quantity and type) been allocated?
- Is the assessor fully conversant with the equipment, its uses and misuses?
- Have spares/supplies been made available?
- Does the assessor know the site? (Has a reconnaissance been carried out?)
- Is there any chance that measurements will have to be carried out at a point where the condition of operation of the site cannot be readily verified?
- Have any relationships been established with the source owner/operatives?
- Have the necessary authorities been informed?
- Have the relevant members of the public been informed?
- Does the assessor know how the source is operated?

5.4.2 The Complainant (if applicable)

The following facts need to be established:

- Exactly what is the cause of complaint? (Is the information supplied by the complainant reliable?)
- Are factors other than noise level of importance?
- Check when the complainant is concerned, i.e. relative to process, time of day, etc.

5.4.3 The Client

- Has the client stated exactly what he wants (in writing)?
- If the data is required for comparison with other measurements has all the relevant information been supplied?
- Are the measurements to be carried out covertly?

5.4.4 The Source Owner (or operator)

- Does the source owner know that measurements are being carried out?
- Is he aware that the assessor should be informed of any changes in operation that take place during the measurement period?
- Has the owner/operator/employee been asked to describe the operation of the source?

Source of Uncertainty

Incorrect measurement plan or routine caused by lack or incorrect knowledge of problem/site/source etc

Good Practice Guidelines

- Use the check lists given above or a custom version before setting out the measurement plan or commencing measurements.
- Arrive on site PREPARED.

Appendix 1 — Legislation, Standards, Procedures and Guidelines

Regular checks are necessary to ensure that all noise measurements are conducted in accordance with the latest legislation, standards, procedures and guidelines. At the time of printing, some of the major documents included:

Legislation (Planning)

- Noise Insulation Grant Scheme – MOD
- The Town and Country Planning (Environmental Impact Assessment) (England and Wales) Regulations 1988 and 1999 - Statutory Instruments 1999 No. 293 (as amended)
- The Education (School Premises) Regulations 1999 – SI 1998:2 (as amended)
- The Noise Insulation Regulations 1975/1988/1996: SI 1975:1763 (as amended)
- The Environmental Information Regulations 1992 – SI 1992:3240
- Planning and Compensation Act 1991
- The Town and Country Planning General Development Order 1988 – SI 1988:1813 (as amended)
- The Town and Planning (Use Classes) Order 1987 – SI 1987:764 (as amended)
- The Local Government Miscellaneous Provision Act 1982
- DOE Circular 2/76 (Welsh Office Circular 3/76) “Control of Pollution Act 1974 – Implementation of Part III – Noise”
- The Land Compensation Act 1973
- The Town and Country Planning Act 1947
- EC Directive 96/61 on Integrated Pollution Prevention and Control extends integrated pollution control to include noise, effectively treating noise with the same status of other pollutants
- EC Directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the Environment (as amended by 97/11/EC)

Legislation (Transport)

- Noise Insulation Grant Schemes at Heathrow, Gatwick and Stansted
- The Air Navigation Order, and No 2 Order 1995
- Aeroplane Noise (Limitation On Operation Of Aeroplanes) Regulations 1993 and Amendment 1994
- International Standards and Recommended Practices – Aircraft Noise, Annex 16 to the Convention on International Civil Aviation 3rd Edition, ICAO, 1993
- Air Navigation (Noise Certification) Order 1987 and 1990

- Civil Aviation Act 1982
- EC Directive 92/14/EEC on the limitation of the operation of aeroplanes (as amended by 98/20/EC and 99/28/EC)
- EC Directive 89/629/EEC tightened up the rules limiting noise emissions from certain civil subsonic jet aeroplanes previously covered under the above Directive (as amended by incorporation)
- EC Directive 80/51/EEC established limits on noise emissions from subsonic airplanes based on standards set by the International Civil Aviation Organisation (as amended by 83/206/EEC and by incorporation)
- Road Traffic Acts
- The Motor Cycle Silencer and Exhaust Systems Regulations 1995
- Motor Cycle Noise Act 1987
- The Road Vehicles (Construction and Use) Regulations 1986 (and amendments)
- The Noise Insulation Regulations 1975 (and its amendments)
- EC Directive 78/1015/EEC (and its amendments) set limits on sound levels from motorcycles, laid down requirements for exhaust silencers systems and established a harmonised testing procedure for implementation in Member States
- EC Directive 70/157/EEC The permissible sound level and the exhaust system of motor vehicles, 1970. (as amended by 73/350/EEC, 77/212/EEC, 81/334/EEC, 84/372/EEC, 84/424/EEC, 87/354/EEC, 89/491/EEC, 92/97/EEC, 96/201/EC,99/101/EC and by incorporation)
- Channel Tunnel Rail Link Regulations
- Channel Tunnel Rail Link Act 1996
- The Noise Insulation (Railway and Other Guided Transport System) Regulations 1996 (and its amendments)
- Railways Acts 1993

Legislation (other specific sources)

- The Provision and Use of Work Equipment Regulations
- The Construction Plant and Equipment Regulations
- The Lawnmowers Regulations
- The Energy Information Regulations (Tumble Driers 1996, Washing Machines 1996, Refrigerators and Freezers 1994)
- The Household Appliances (Noise Emission) Regulations 1990 and Amendment 1994

- EC Directive 86/662/EEC sets noise limits and requirements for the issue of an EU type-examination certificate for earthmoving machines used on
- engineering and construction sites (as amended by 89/514/EEC, 95/27/EC and by incorporation)
- EC Directive 86/594/EEC governs the provision of information on the airborne noise levels of household appliances (as amended by 94/101/EC and by incorporation)
- EC Directive 84/553/EEC sets noise limits and requirements for the issue of an EC type-examination certificate for compressors
- EC Directive 84/538/EEC sets noise limits and requirements for the issue of an EU type-examination certificate for lawnmowers (as amended by 87/252/EEC, 88/180/EEC, 88/181/EEC and by incorporation)
- EC Directive 84/537/EEC sets noise limits and requirements for the issue of an EU type-examination certificate for hand-held concrete-breakers and picks (as amended by 85/409/EEC and by incorporation)
- EC Directive 84/536/EEC sets noise limits and requirements for the issue of an EC type-examination certificate for power generators (as amended by 85/408/EEC and by incorporation)
- EC Directive 84/535/EEC sets noise limits and requirements for the issue of an EC type-examination certificate for welding generators (as amended by 84/407/EEC)
- EC Directive 84/534/EEC sets noise limits and requirements for the issue of an EC type-examination certificate for tower cranes (as amended by 87/405/EEC and by incorporation)
- EC Directive 79/113/EEC, a framework Directive, introduced a test procedure to determine the noise emissions of construction plant and equipment to cover compressors, cranes, welding generators, excavators, power generators, concrete-breakers, loaders, dozers and picks (as amended by 81/51/EEC, 85/405/EEC and by incorporation). Lifting appliances were included under EC Directive 81/1051/EEC.

Legislation (General)

- Noise Act 1996
- Health and Safety (Safety Signs and Signals) Regulations 1996
- The Environment Act 1995
- Noise and Statutory Nuisance Act 1993
- Environmental Protection Act 1990
- The Control of Noise at Work Regulations 2005
- Control of Pollution Act 1974
- Health and Safety at Work Act 1974
- Noise Abatement Act 1960

Codes of Practice, Guidelines, Procedures and Standards

- Code of Practice on Environmental Noise Control at Concerts, The Noise Council 1995
- Code of Practice on Noise from Organised Off-road Motor Cycle Sport, The Noise Council 1994
- Code of Practice on Noise Control on Construction and Open Sites Order 1987
- Code of Practice on Noise from Audible Intruder Alarms, HMSO1982
- Code of Practice on Noise from Ice Cream Van Chimes Etc., HMSO 1982
- Code of Practice on Noise from Model Aircraft, HMSO 1982
- Department for Education Design Note 17: Guidelines for Environmental Design in Educational Buildings
- Draft Declaration of Sound Power Level and Tonality Values of Wind Turbines 1999, European Committee For Electrotechnical Standardization (GENELEC BTTF83-2 Working Group 4)
- Guidelines for community noise, World Health Organisation 1999
- Clay Target Shooting – Guidance on the Management and Control of Noise. British Shooting Sports Council 1997
- Water Skiing and Noise. British Water Ski Federation 1996
- Short Oval Circuit Motor Racing. National Society for Clean Air and Environmental Protection 1996
- Calculation of Railway Noise 1995. Department of Transport
- Community Noise – Environmental Health Criteria Document (Draft), WHO 1995
- PPG 24 Planning Policy Guidance: Planning and Noise, Department of the Environment 1994
- Guide to Health, Safety and Welfare at Pop Concerts and Similar Events HSE 1993
- Department of the Environment MPG 11 The Control of Noise at Surface Mineral Workings, HMSO 1993
- Bird Scarers, National Farmers Union 1992
- The UK Civil Aircraft Noise Contour Model, ANCON: Improvements in Version 2, CAA, DORA R&D Report 9842, 1988
- Guidance on Noisy Parties (DOE 1992)
- Calculation of Road Traffic Noise 1988, Department of Transport, Welsh Office
- BS EN 61400-11:1999, 'Wind Turbine Generator Systems – Part 11: Acoustic Noise Measurement Techniques',
- BS 8233: 1999 Sound insulation and reduction for buildings – Code of Practice
- BS 5228: 1997 Part 2 Noise and vibration control legislation for construction and demolition including road construction and maintenance

- BS 4142: 1997 Method for rating industrial noise affecting mixed residential and industrial areas
- BS 6472: 1992 Evaluation of human exposure to vibration in buildings (1Hz to 80Hz)
- BS 7445:1991/ISO 1996, Parts 1, 2, 3 Description and Measurement of Environmental Noise (being revised)
- ISO 9613-2: 1996 Acoustics - Attenuation of Sound During Propagation Outdoors - Part 2 : A General Method of Calculation
- BS 3539: 1986 Sound level meters for the measurement of noise emitted by motor vehicles, Amd 1

Major Noise Reviews and Reports

- Your Council and the Environment – The Model Local Government Charter, DOE
- EC 5th Action Programme Committee [95] 647
- NSCA Pollution Handbook. National Society for Clean Air and Environmental Protection (annual publication)
- DETR 1997 Green Paper on Noise Limits for Aircraft departing from Heathrow, Gatwick and Stansted Airports
- Transport and the Environment - Developments since 1994, Royal Commission on Environmental Pollution 20th Report, 1997
- EC Green Paper on Future Noise Policy Com[96] 540, Final, 1997
- DOE 1995 Green paper on NOISE - Review of the effectiveness of neighbour noise controls
- Transport and the Environment, Royal Commission on Environmental Pollution 18th Report, 1994
- Neighbour Noise Problems – NSCA Local Authority Guidelines, National Society for Clean Air and Environmental Protection 1994
- Report of the Noise Review Working Party 1990, Department of the Environment, Mr. W. J. S. Batho (*Chairman*) 1990
- The 1990 Environment White Paper “This Common Inheritance”
- Neighbourhood Noise, Noise Advisory Council, Sir Hilary Scott (*Chairman*) 1971
- Noise – Final Report, Sir Alan Wilson (*Chairman*) 1963

Appendix 2 – Case Studies

A2.1 Estimation of Daily Indicators

A long-term study of the noise level at the boundary of surface mineral workings has been conducted¹. The results demonstrate how an understanding of the site operation is important when deciding where and when to measure noise.

A2.1.1 Operation of the Site and Timing of the Measurement

The diagrams A-1 and B-1 show the distribution of noise levels measured at positions A and B on the site boundary. This data is inclusive of meal, tea and other breaks.

By excluding these breaks, some of the lower measurement results are removed, and the standard deviation of the distribution is decreased. Diagrams A-2 and B-2 show the distribution when only data relating to the 'hours of normal operation' are considered.

The effect of only measuring for a short period of time is to randomly sample these distributions. The probability that a short measurement will be representative (of the modal average) is greater when sampling a distribution with a small standard deviation. Thus, timing a measurement to exclude breaks in the operation of the site will reduce the measurement uncertainty.

A2.1.2 Choice of the Measurement Position

The noise level at position A is dominated by heavy vehicle movements along a nearby haul road. This is in contrast to position B, situated away from the main activities, where the noise level is composed of a number of roughly equal components.

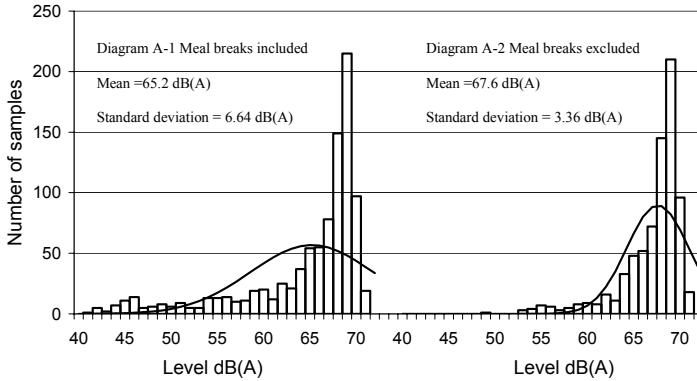
Where the noise level is dominated by a single source, the distribution is negatively skewed, in favour of the higher levels. However, at position B the distribution is statistically better behaved, i.e. the measured distribution is approximately normal.

The effect of only measuring for a short period of time is to randomly sample these distributions. The probability that this short measurement is representative (of the modal average) increases as the distribution tends

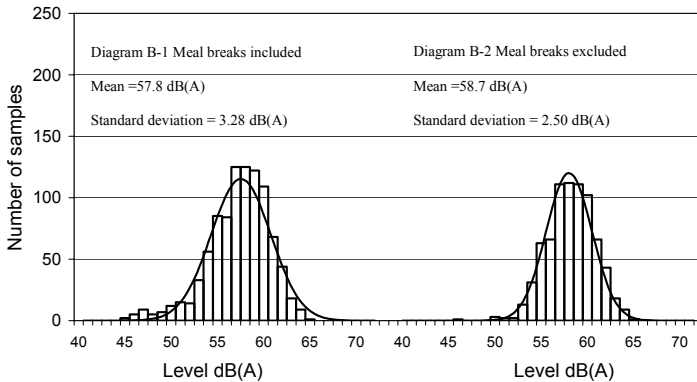
¹ The control of noise from surface mineral workings- Fieldwork supplement Report prepared by W S Atkins Engineering Sciences Ltd on behalf of the Department of the Environment Minerals Division

towards normal. Therefore, if a number of sources contribute to the measured level in roughly equal portions, the measurement is likely to be subject to less uncertainty than if a single source was dominant.

Distribution of noise levels (L_{Aeq},15min)
measured at position A



Distribution of noise levels (L_{Aeq},15min)
measured at position B



A2.2 Estimation of Annual Indicators

Many noise sources follow distinct weekly and annual cycles. The change in weather patterns between seasons will also influence the propagation of noise. Exactly how these cycles affect the noise level at a given reception position will depend upon local metrology, the nature of each major noise source and their respective propagation paths.

Long-term noise monitoring strategies should account for variation in noise level between seasons, e.g. ANSI S12.9-1992/Part2², states that “measurements shall be taken for four distinctly different, entire days of the week. One day shall be chosen from each quarter of the year”.

A2.2.1 Case Study 1

A long-term study³ has been conducted to investigate the levels of environmental noise at two suburban areas of Sweden, Lövstalöt and Marsta. The results demonstrate how annual patterns can affect the generation and propagation of noise.

The dominant noise sources were identified as traffic movements on the surrounding roads and the operation of a nearby military airfield. Over the holiday period in July, activity on the airfield declined and the environmental noise levels decreased. The exact opposite of what might be expected at a civilian airport.

In general, the noise levels were lower through the summer when compared to the winter months. It is thought that this is due to a trend for greater upward refraction of the sound waves and increases atmospheric absorption during the summer months.

A2.2.2 Case Study 2

The measurement of road traffic noise lecture on ‘Designing outdoor sound measurements’ by Ian Flindell.⁴

² Quantities and procedures for description and measurement of environmental noise. Part 2: Measurement of long term. Wide-area sound, *ANSI S12.9-1992/Part2*, 1992, American National Standards Institute, Acoustical Society of America, New York

³ LARSSON C, Weather effects on outdoor Sound propagation, *Int J of Acoustics and Vibration*, 2000, vol 5, No 1,.

⁴ Taken from a lecture on ‘Designing outdoor sound measurements’ by Ian Flindell

The table below compares sampling strategies for the estimation of annual indicators of road traffic noise ($L_{Aeq,24hr}$ 10-year database). The figures clearly demonstrate:

- Increasing the length of the sample improves the quality of the estimate, however the improvement follows the rule of diminishing returns.
- A number of samples chosen at random will provide a more accurate estimate than one continuous sample of equal total length.

Sampling strategy	Probability that sample is within 1 dB of the annual level	90% range
1 day	35%	10dB
7 days continuous	50%	6dB
14 days continuous	54%	5dB
28 days continuous	60%	4dB
7 days random	68%	3.6dB
14 days random	84%	2.2dB
28 days random	94%	<2dB
2 weeks random	64%	3.6dB
3 weeks random	74%	3.2dB
4 weeks random	76%	2.8dB

Appendix 3 – Uncertainty Budget Spreadsheet for Environmental Noise Measurements

Across the following two pages is a spreadsheet illustrating the formulation of uncertainty budgets for environmental noise measurements, as detailed in chapter 3, page 9.

Sources of Uncertainty	Notes	Initial Value	Confidence Level (%)	Convert to Same Units (dB)	Standardise Confidence Level to 68%
Source					
Transmission Path					
Receiver					
Combined uncertainty u_c (root sum of squares)					
Expanded uncertainty $U = k u_c$ (95% confidence $k = 2$)					
Final answer expressed as [value] $\pm U$ dB with a confidence level of 95%					

