NOISE and ACOUSTICS

1. Introduction

For practical purposes the term 'sound' is taken to mean vibratory motion perceptible through the hearing organ. Vibratory energy (or sound) travels in waves. It is the frequency of the waves that determines the speed at which the ear-drum and other parts of the hearing organ vibrate while the pressure of the sound affects the magnitude of the oscillation. The brain registers these movements as pitch and loudness respectively.

Loud and other unwanted acoustic stimuli are called noise. The level of annoyance we feel depends not only on the quality of the sound but also on our attitude towards it. Noise is air pollution, and like other forms of pollution it not only affects the quality of life but where the noise source is sufficiently concentrated and the exposure to it sufficiently long, can cause physiological effects leading to deafness.

The recognition of noise as a hazard has been identified within legislation and there is a responsibility on manufacturers and users of certain vehicles and machines to define the sound power level of the product and thereby provide the user with the information he/she needs to assess his/her own local sound protection measures. In addition there is increased attention focusing on acoustic noise as an unwanted by-product of public gatherings, historical events, live music, commercial machinery, etc. Consequently there is a continuing trend towards noise control at public events. In Europe, noise labelling is complementary to legislation, but there is a growing recognition that interplay of such a complementary strategy is essential to successful noise management programmes.

2. Fundamentals

2.1 Nature of sound

If the pressure disturbance as a function of time is sinusoidal, this is a single frequency - a pure tone. However, real sounds are rarely pure sinusoidal tones; they tend to be either a combination of discrete sinusoidal frequencies or a disturbance varying erratically with time but with a frequency band spectrum. Some typical sounds are shown in Fig.1. Complex periodic steady sounds have a pattern which repeats itself at a constant rate. Speech displays a waveform whose character varies with time, is of finite length but possesses a clear form. Traffic noise typically displays complex patterns, a very disordered and random waveform of pressure versus time. Such a wave has no periodic component, but it may be represented by a collection of waves of all frequencies and is known as broadband noise.

(i) Frequency

The number of pressure variations per second is referred to as the frequency of the sound and is measured in cycles per second (Hz). The frequency of sound produces its distinctive tone. The normal range of hearing for a healthy young person extends from approximately 20 Hz up to 20kHz (the range of notes on a piano is from 27.5 Hz to 4.2 kHz). The wavelength of sound (λ) is related to frequency as follows:

\[ \lambda = \frac{c}{f} \]  

where \( c \) = speed of sound (ms\(^{-1}\)) = \( \sqrt{(E/p)} \), \( f \) = frequency (s\(^{-1}\)), \( E \) = Young's modulus for solids and bulk modulus for fluids and \( p \) = density.

In air the speed of sound is a function of absolute temperature \( K \), i.e. \( c = 20.05\sqrt{K}\text{ms}^{-1} = 344\text{ms}^{-1} \) at 21°C. It is worth noting that at 20 Hz, one wavelength is just over 17m while at 20 kHz it is only 1.7cm. In materials, sound travels faster when elasticity is high and density is low. Material acoustical properties are summarized in Table 1 in comparison to air.

(ii) Amplitude

Another quantity used to describe a sound is the size or amplitude of the pressure fluctuations. The minimum sound pressure amplitude that a healthy ear can detect is 20 µPa, some 5 x 10\(^{13}\) less than normal atmospheric pressure, whereas the greatest sound pressure before pain is 60 Pa. Since the acoustic intensity is proportional to (sound pressure)\(^2\), a linear scale would require 10\(^{13}\) unit divisions to cover the range of human experience. However, as a best match to the considerable dynamic range of the ear, a logarithmic scale, rather than linear, equates to subjective response. The logarithmic scale provides a convenient way of comparing the sound pressure of one sound with another, to avoid a scale which is too compressed, a factor of 10 is introduced, giving rise to the decibel (dB).

The decibel is not an absolute unit of measurement, therefore it is a ratio between a measured quantity and an agreed reference level. The reference level is the hearing threshold 20 µPa. This is defined as 0 dB, hence the decibel scale compresses a range of 10\(^6\) into a range of 120 dB. Since the ear reacts to a logarithmic change in level, 1 dB is the same relative change anywhere on the scale.
2.2 Definitions

(i) Sound pressure level

This is the disturbance of the static atmospheric pressure caused by the presence of sound. It is measured with a sound level meter and at any point depends upon the acoustic power output of the noise source, the distance from the source and the environment in which the noise source and receiver are placed. It is common practice to refer to a sound pressure level (SPL or $L_p$) in decibels as the square of the sound pressure with reference to $20 \mu$Pa. The frequency band or weighting must be specified (section 3):

$$L_p (\text{or SPL}) = 10 \log_{10} \left( \frac{P}{P_{\text{ref}}} \right)^2$$

$$= 20 \log_{10} \left( \frac{P}{P_{\text{ref}}} \right)^2$$

where $P$ = r.m.s. value of sound pressure (Pa), $P_{\text{ref}} = 20 \times 10^{-6}$ Pa or $L_p = 20 \log P + 94 \ldots$ dB

Table 1: Properties of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus $E$ (10^9 Nm^-2)</th>
<th>Density $\rho$ (kg m^-3)</th>
<th>Speed of sound $c$ (m s^-1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air (20 °C)</td>
<td>–</td>
<td>1.21</td>
<td>344</td>
</tr>
<tr>
<td>Fresh water</td>
<td>–</td>
<td>998</td>
<td>1481</td>
</tr>
<tr>
<td>Aluminium</td>
<td>71.6</td>
<td>2700</td>
<td>5150</td>
</tr>
<tr>
<td>Steel</td>
<td>210</td>
<td>7800</td>
<td>5200</td>
</tr>
<tr>
<td>Lead</td>
<td>16.5</td>
<td>11300</td>
<td>1210</td>
</tr>
<tr>
<td>Concrete</td>
<td>19.6</td>
<td>1700</td>
<td>3400</td>
</tr>
<tr>
<td>Glass</td>
<td>67.6</td>
<td>2500</td>
<td>5200</td>
</tr>
<tr>
<td>Teak</td>
<td>17.0</td>
<td>900</td>
<td>4350</td>
</tr>
<tr>
<td>Pine</td>
<td>8.0</td>
<td>550</td>
<td>3800</td>
</tr>
<tr>
<td>PVC</td>
<td>2.4</td>
<td>1400</td>
<td>1310</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>1.6</td>
<td>900</td>
<td>1330</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>0.2</td>
<td>930</td>
<td>460</td>
</tr>
<tr>
<td>Nylon 6:6</td>
<td>2.0</td>
<td>1140</td>
<td>1320</td>
</tr>
<tr>
<td>Brass</td>
<td>105</td>
<td>8500</td>
<td>3200</td>
</tr>
</tbody>
</table>

(ii) Sound power level

Sound power is the rate at which acoustic energy is emitted from a sound source, and together with wave intensity, is a true power-related quantity in acoustics. The unit of sound power is the watt and the normal range of interest is $10^{-9}$-$10^{-2}$W. It is common to express sound power as the sound power level (PWL or $L_w$) in decibels with reference to $10^{-12}$ W. Again the adoption of a standard or reference value for the denominator allows the decibel scale to be used as an absolute scale of magnitude. The frequency band or weighting must be specified (section 3):

$$L_w (\text{or PWL}) = 10 \log_{10} \left( \frac{W}{W_{\text{ref}}} \right)$$

$$= 10 \log_{10} \left( \frac{W}{W_{\text{ref}}} \right)$$

$$= 10 \log W + 120 \text{ dB}$$

where $W$ = acoustic power of source (W) and $W_{\text{ref}}$ = reference power ($10^{-12}$ W).

Sound power level cannot be measured directly and has to be deduced from SLP measurements corrected for measurement conditions. It is a useful means for quantifying the acoustic power of a source in a way, which for most practical purposes, is independent of the source environment.

(iii) Sound intensity level

The sound intensity level $L_I$ of the intensity $I$ may be defined as follows:
Noise.....The Technical Bit

\[ L_i = 10 \log_{10} (\text{sound intensity}) \]
\[ \text{(reference sound intensity)} \]

hence

\[ L_i = 10 \log_{10}I + 120 \text{ dB} \]

where reference sound intensity = \(10^{-12}\text{Wm}^{-2}\).

Sound intensity at a given point in a sound field in a specified direction is defined as the average sound power passing through a unit area perpendicular to the specified direction at that point, and given by

\[ I = \frac{P^2}{pc} \]

where the quantity \( pc \) is known as the 'characteristic impedance' and

\[ L_i = Lp - 0.2 \text{ (dB)} \]

2.3 Frequency analysis

To diagnose noise, it is convenient to analyse using a series of frequency bands, normally in the audible frequency range 20 Hz to 20 kHz as a constant percentage bandwidth spectrum, i.e. the bandwidth or frequency range over which the sound energy is integrated is a constant percentage of the centre frequency of the band. There are internationally agreed 'preferred' frequency bands for sound measurement and analysis.

The widest band used for frequency analysis is the octave band, i.e. the upper frequency of the band is exactly twice the lower limit, extending from \( \sqrt{2} \) to \( 2\sqrt{2} \) times the centre frequency (Table 2). Occasionally, more detailed information on the noise structure is required, e.g. with one-third octave narrower bands. These are bands approximately one-third the width of an octave band (Table 2), with their centre band frequencies adjusted slightly so that they repeat on a logarithmic scale. For example, the sequence 31.5, 40, 50 and 63 have logarithms 1.5, 1.6, 1.7 and 1.8. The corresponding frequency bands are sometimes referred to as 15th, 16th, 17th, etc. (Table 2).

A typical example of the frequency analysis of a complex sound is given in Fig. 2. The gain of a real filter outside its bandwidth is not zero, but should reduce rapidly as the frequency moves away from the band edges. Filter bandwidth is defined at a point 3 dB below the peak. The simplest analysers produce only octave or one-third octave spectra, which may have limited analytical use. A narrow bandwidth analysis, however, allows consideration of the frequency and repetition rates of the sound (Fig. 3). This information may then be used to link the sounds to the frequencies of the acoustic elements. However, narrow-band frequency analysis usually gives little information about noise processes that are essentially broad band in nature, e.g. flow noise.

\[ \text{Fig 3: Comparison of Octave, one-third Octave and narrow band spectra of the same sound} \]

\[ \text{Fig 2: Frequency Analysis of a Complex Sound plus definition of filter bandwidth.} \]
Table 2: Preferred Centre Frequencies and corresponding Wavelengths

<table>
<thead>
<tr>
<th>Band number</th>
<th>Octave band centre frequency</th>
<th>One-third octave band centre frequency</th>
<th>Band limits</th>
<th>Wavelength in air (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
</tr>
<tr>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
<td>34</td>
</tr>
<tr>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
<td>37</td>
</tr>
<tr>
<td>38</td>
<td>38</td>
<td>38</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
<td>39</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>41</td>
<td>41</td>
<td>41</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>42</td>
<td>42</td>
<td>42</td>
<td>42</td>
<td>42</td>
</tr>
<tr>
<td>43</td>
<td>43</td>
<td>43</td>
<td>43</td>
<td>43</td>
</tr>
</tbody>
</table>

2.4 Decibel arithmetic

Because of their logarithmic nature, noise levels expressed in decibels cannot be added or subtracted directly in the normal arithmetical manner. Instead the values must be converted from decibels to powers or power ratios which can be added or subtracted as illustrated in Fig. 4. Alternatively, a simple chart may be used (Fig. 4). To add, or subtract, a series of levels, group them in pairs from lowest to highest, combine each pair then combine the results of pairs and so on. Note that fractions are of no significance in the final answer as 1 dB is defined as the smallest discernable difference between two sounds of different levels heard under ideal conditions. The procedure described only applies to unrelated sounds. To add or subtract related signals such as two sine waves of the same frequency, it is necessary to take into account the phase difference between the two.

2.5 Loudness levels

Although the healthy ear can detect sound at all frequencies within the 20 Hz to 20 kHz range, it does not allocate the same importance to each frequency. In other words, the ear is frequency sensitive. By using observers to compare two sounds of different frequency content, a 1 kHz reference tone and a pure tone of some other frequency adjusted by the observer to the judged equal in loudness to the reference tone, a mean result map of 'equal loudness curves' is produced (Fig. 5).

The units used to label the equal loudness contours are called phons. The phon is a unit of loudness such that at 1 kHz, the number of phons = sound pressure level. Lines are constructed so that all tones of the same number of phons sound equally loud. For sounds of low amplitude, the ear has a marked frequency sensitivity; a sound at 30 Hz would have to be approximately 50 dB higher than a sound at 1 kHz to be judged equally as loud (Fig. 5). This level of insensitivity or 'deafness' does, however, clearly depend on amplitude. This non-linearity of subjective judgement means that sound does not appear 'twice as loud' by doubling the intensity. In the mid-frequency ranges at sound pressures ≥40 dB, the subjective effects of sound level changes are given in Table 3.

<table>
<thead>
<tr>
<th>Change in sound level (dB)</th>
<th>Change in power</th>
<th>Change in apparent loudness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Decrease</td>
<td>Increase</td>
</tr>
<tr>
<td>3</td>
<td>1/2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>1/3</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>1/10</td>
<td>10</td>
</tr>
<tr>
<td>20</td>
<td>1/100</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 3: Subjective effect of changes in sound pressure level
2.6 Pitch

Pitch is the subjective response to frequency; low frequencies are identified as 'low-pitched' while high frequencies are identified as 'high-pitched'. When presented with a single 'pure' tone or 'clean' timbre, the perceived pitch is related to its frequency and the loudness mainly to its intensity. Presented with two tones simultaneously, the ear can behave as a frequency analyser and split the complex sounds into its component tones if the frequencies are widely spaced. If closely spaced, the perceived sound is a mixture of the two. For tones with separation not exceeding 20 Hz, they sound like a single tone fluctuating in loudness, the fluctuations are also known as 'beats'.

3 Measurement of Sound

3.1 Weighting networks

It has been previously shown that the apparent loudness of a sound varies with frequency as well as sound pressure (Fig. 5). Sound-measuring instruments are designed to make allowances for this behaviour of the ear by the use of electronic 'weighting networks'. The inverse of the equal loudness curve in Fig. 5 gives a fairly good representation of the amount of weighting needed for the various frequency components of sound, but because the curves in Fig. 5 flatten out as the SPL increases, more than one weighting is required to cover the whole range of sound amplitude. The various international standards bodies recommend the use of three weighting networks, A, B and C, as well as a linear (unweighted) network for use in sound-level meters. The weighting curves are illustrated in Fig. 6, the ‘A’ weighting for SPLs up to 55 dB, ‘B’ for levels between 55 and 85 dB and ‘C’ for levels above 85 dB respectively.

The ‘A’ weighting was originally designed to approximate the response of the human ear at low sound levels, but the general trend today would appear to be towards its exclusive use. Table 4 shows the correction which must be added to a linear reading to obtain the weighted reading for a particular frequency. A noise measurement of machinery given as dB(A) without further qualifications is normally taken to be referencing a continuous steady noise.

---

**Fig 4:** Examples of Decibel manipulation; 1) general procedure; 2) chart for adding or subtracting noise levels.

**Fig 5:** Equal loudness contours

**Fig 6:** International Standard ‘A’, ‘B’ and ‘C’ weighting curves for sound level meters.
However, measuring noise in terms of a single number tells us virtually nothing about the frequency content, however representative the weighting shape may be. As long as the weighted overall level is acceptable this perhaps does not matter, but as soon as the noise is found to be over a given limit, noise control techniques will require a frequency distribution spectrum of levels. The manipulation of frequency levels is an extension of the principles outlined in section 2.4 and as illustrated by Table 5.

Table 4: A-Weighting network corrections (dB)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>10</th>
<th>12.5</th>
<th>16</th>
<th>20</th>
<th>25</th>
<th>31.5</th>
<th>40</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-weighting correction</td>
<td>–70.4</td>
<td>–63.4</td>
<td>–56.7</td>
<td>–50.5</td>
<td>–44.7</td>
<td>–39.4</td>
<td>–34.6</td>
<td>–30.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>63</th>
<th>80</th>
<th>100</th>
<th>125</th>
<th>160</th>
<th>200</th>
<th>250</th>
<th>315</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>800</th>
<th>1000</th>
<th>1250</th>
<th>1600</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-weighting correction</td>
<td>–4.2</td>
<td>–3.2</td>
<td>–1.9</td>
<td>–0.8</td>
<td>0.0</td>
<td>0.6</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>2000</th>
<th>3150</th>
<th>4000</th>
<th>5000</th>
<th>6300</th>
<th>8000</th>
<th>10000</th>
<th>12500</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-weighting correction</td>
<td>1.3</td>
<td>1.2</td>
<td>1.0</td>
<td>0.5</td>
<td>–0.1</td>
<td>–1.1</td>
<td>–2.5</td>
<td>–4.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>16000</th>
<th>20000</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-weighting correction</td>
<td>–6.6</td>
<td>–9.3</td>
</tr>
</tbody>
</table>

Table 5: Frequency analysis and overall pressure level

<table>
<thead>
<tr>
<th>Frequency band (Hz)</th>
<th>31.5</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1k</th>
<th>2k</th>
<th>4k</th>
<th>8k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sound pressure level (dB) re 20 µPa</td>
<td>95</td>
<td>95</td>
<td>90</td>
<td>85</td>
<td>80</td>
<td>81</td>
<td>75</td>
<td>70</td>
<td>65</td>
</tr>
<tr>
<td>A’ weighting (dB)</td>
<td>–39</td>
<td>–26</td>
<td>–16</td>
<td>–9</td>
<td>–3</td>
<td>0</td>
<td>+1</td>
<td>+1</td>
<td>–1</td>
</tr>
<tr>
<td>A’ weighting sound pressure level in dB(A)</td>
<td>56</td>
<td>69</td>
<td>74</td>
<td>76</td>
<td>77</td>
<td>81</td>
<td>76</td>
<td>71</td>
<td>64</td>
</tr>
</tbody>
</table>

The overall sound pressure level \( L_p \) can be calculated from the individual band levels using the relationship:

\[
L_p = 10 \log_{10} \left( \sum_{i=1}^{n} 10^{L_i/10} \right) \text{ as outlined in Fig. 4}
\]

3.2 Measurement instrumentation

(i) Sound-level meter

This is the basic instrument for experimental noise evaluation. In its simplest form, a sound-level meter may indicate only dB(A) levels, but at its most complex it may include A, B and C weightings, octave band levels, peak levels, instantaneous peaks, impulse values, integrated averages (linear and weighted) and sample times. The various components of a sound-level meter are illustrated by Fig. 7.

The microphone signal is first amplified. An input attenuator at the first stage of amplification is provided to ensure that it is not overloaded. Next the various filter circuits are introduced. The all-pass (linear) mode accepts and weights equally all frequencies within the range of the instrument. Sounds encountered in practice are seldom ever steady in level, fluctuations in level are always encountered, sometimes significantly so. To accommodate this phenomenon, the sound-level meter is usually provided with three responses:

- **Fast.** This has a time constant of 125 ms and provides a fast reacting display designed to approximate the response of the ear. Follows rapid fluctuations, but difficult to read the meter accurately.

- **Slow.** This has a time constant of 1 s. While not simulating the response of the ear, it is useful for determining mean levels when the sound fluctuates continuously during the course of measurement. Normally used for continuous noise. Enables the scale of an analogue meter to be read which would otherwise be impossible using the fast time constant.

- **Impulse.** A time constant of 35 ms used for the measurement of impulsive or impact-type noises.

Measurement specifications and standards usually specify the meter response to be used. If the background noise is less than 10 dB below the total level when the source is turned on, a correction must be made to each reading as per Fig. 4. If the difference between the total noise level and the background noise in any octave band is < 3 dB, then meaningful acoustic measurements in that band probably cannot be made. The grades of sound-level meter used for engineering measurements are as follows:

- **Type 1.** Precision sound-level meter, for laboratory or field use where the acoustical environment may be closely controlled.

- **Type 2.** General-purpose sound-level meter for general field use and for recording noise level data for subsequent analysis.

- **Type 3.** Survey sound-level meter, intended for preliminary investigations only.
(ii) **Microphones**

Sound measurement primarily depends on the microphone and its associated pre-amplifier which together generate an electrical signal from a sound pressure. The microphone is a crucial part of any measuring system, a sound-measuring microphone being the most accurate and reliable class of microphone available. The most common type is the condenser microphone and to a lesser extent the piezoelectric microphone. Both have very uniform frequency response and long-term sensitivity stability. However, the piezoelectric microphone tends to be microphonic, i.e. it may respond equally well to vibration and sound, whereas a condenser microphone is relatively insensitive to vibration. The sensitivity of a microphone is expressed in decibels relative to a reference level:

\[
\text{Sensitivity } s = 20 \log_{10} \left( \frac{\text{sensitivity (mV Pa}^{-1})}{1000 \text{ mV Pa}^{-1}} \right)
\]

or, in terms of SPL,

\[
s = 20 \log_{10} E_0 - L_p + 94 \text{ dB}
\]

where \(E_0\) = output voltage for input \(L_p\).

Typical values of sensitivity would be in the range 10-50 mV Pa\(^{-1}\) at 250 Hz. Since the output voltage of a microphone is proportional to the area of the diaphragm, the smaller the microphone of a given type, the smaller will be its sensitivity. Thus a microphone with large diaphragm diameter will produce a large output voltage, but the requirement for high-frequency response is against a large diameter. The problem is that at high frequencies, sound wavelengths are small so for any microphone there is a frequency at which the wavelength of sound and diaphragm diameter are equivalent. This is termed a diffraction effect. In terms of general-purpose characteristics though, 12.5 mm microphones tend to be a popular choice. However, since for practical reasons of sensitivity the problem of diffraction cannot be avoided, it is necessary to consider the orientation of the diaphragm with respect to the sound field being measured and calibrate the microphone response accordingly. Three types of microphone response are recognized:

1. Free-field-response microphones are used for measuring sound mainly coming from one direction, i.e. flat response for normal incidence.
2. Random-response microphones have a flat frequency response in diffuse sound fields where sound arrives from all angles, i.e. a reverberant sound field characterized by sound intensity incident from all directions.
3. Pressure-response microphones measure the actual sound pressure level at the diaphragm; uses include measuring surface sound pressure levels where the microphone is flush mounted. They can be used as free-field microphones if orientated 90° to the sound direction, but frequency response may then be reduced.

### 4 Noise Metrics – Environmental Noise

The metric applied to quantify noise depends on the noise source and purpose for the noise measurement. Table 6 lists noise metrics that are used commonly in vehicular noise engineering. Some of these metrics require additional calculations beyond sound level measurements, but noise-prediction software usually calculates the desired metric for the user. With each of these metrics, different frequency weightings, as mentioned previously, also can be applied.

**Table 6. Some common noise metrics**

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-weighted equivalent sound level</td>
<td>(L_{AeqT})</td>
<td>LAEQ</td>
<td>Sound level associated with the sound energy averaged over a specified time period</td>
</tr>
<tr>
<td>Day-Night average sound level</td>
<td>(L_{dn})</td>
<td>DNL</td>
<td>(L_{AeqDNL}) with a 10dB(A) penalty between the hours of 10pm and 7am</td>
</tr>
<tr>
<td>Community noise equivalent level</td>
<td>(L_{den})</td>
<td>CNEL</td>
<td>(L_{AeqCNEL}) with a 10dB(A) penalty between the hours of 10pm and 7am and a 5dB(A) penalty between the hours of 7pm and 10pm</td>
</tr>
<tr>
<td>A-weighted maximum sound level</td>
<td>(L_{Amax})</td>
<td>LAMAX</td>
<td>A-weighted maximum sound level during a noise event or specified time period</td>
</tr>
</tbody>
</table>
Noise is not necessarily steady and continuous but tends to fluctuate in level over a period of time. Historically several single number measures for time-varying sound levels have been developed, the more relevant ones as follows:

1. Level exceeded 90, 50 or 10 per cent of the time \( L_{90}, L_{50}, L_{10} \ldots \ldots \ldots L_x \)
2. Equivalent sound level \( L_{eq} \)
3. Sound Exposure level SEL
4. Impulse sound
5. Community equivalent noise level CENL, (sometimes \( L_{den} \))

### 4.1 Level exceeded x% of time

In the case of the \( L_x \) value, \( L_{10} \) the level exceeded 10 per cent of the time is a measure of the higher-level (more intrusive) components of a noise, whereas \( L_{90} \) is a measure of the background, residual or ambient level. With a sound meter set to fast response, \( L_{40} \equiv \text{average of the maximum deflections} \) and \( L_{90} \equiv \text{average of the minima} \). However, to foster uniformity and simplicity of measurement and monitoring, the equivalent sound level concept, \( L_{eq} \), has generally been adopted in preference. Both \( L_{eq} \) and \( L_x \) are expressed in dB(A) units.

### 4.2 Equivalent sound level \( L_{eq} \)

\( L_{eq} \) is defined as the continuous equivalent sound level. It is the sound-pressure level, if it was constant, that would contain the same energy as the fluctuating sound (such as traffic levels) that is being monitored over the evaluation time period. If the A-weighted sound level \( L \) varies with time as in Fig. 10, the equivalent sound level for the time \( T \) is defined as:

\[
L_{eq} = 10 \log_{10} \left( \frac{1}{T} \int_{t_1}^{t_2} 10^{L_{10}/10} \, dt \right)
\]

Where \( T = t_2 - t_1 \) The value in brackets gives the mean value of \( P_A^2/P_{ref}^2 \) over the period concerned where \( P_A \) = the 'A'-weighted r.m.s. sound pressure and \( P_{ref} \) = reference sound pressure, 20 μPa.

Since sound intensity is approximately proportional to the square of the sound pressure, the equivalent continuous sound level is the constant sound level which would expose the ear to the same amount of A-weighted sound energy or noise dose as does the actual time-varying sound over the same period. Thus \( L_{eq} \) is also called the energy equivalent sound level. Here, \( L_{eqT} \), can be measured directly using an integrating sound-level meter, sometimes called a noise average meter, over a preset period of time \( T \). This would normally be between 60 s and 2.8 hours for a single instrumentation read-out. Over longer periods of time, or where integrating meters are not available, the variation of sound level as a function of
Noise.....The Technical Bit

time is given as a histogram (Fig. 11). Discrete levels $L_1, L_2, L_3 \ldots L_n$, are plotted for the given time $x$, that they occur. Hence in this case:

$$L_{eq} = 10 \log \sum_{i=1}^{n} x_i \times 10^{L_i/10}$$

In the case of a single constant sound level $L_i$, which occurs for a fraction $x_i$ of the total time and for which the background sound level is negligible then

$$L_{eq} = L_i + 10 \log_{10} x_i$$

If the background level $\neq 0$, then the $L_{eq}$ is a sum of the two partial $L_{eq}$ (section 2.4). In its usual context $L_{eq}$ equates the measured fluctuating noise level to a steady noise level considered to be received over an 8-hour period, written $L_{eq,8h}$. An integrated noise level measured for a period less than 8 hours is not necessarily the same value.

4.3 Sound exposure level (SEL)

A feature often found on the more elaborate integrating sound-level meters is referred to as SEL. Measured in dB(A) it is defined as that level which, lasting for 1s, has the same acoustic energy as a given transient noise event lasting for a time $T$ (e.g. Fig. 12). It is a measure of acoustic energy and thus can be used to compare unrelated noise events because the time element in its definition is always normalized to 1s. It is a useful parameter for comparing single events of different levels and duration, e.g. vehicle pass-by, workshop processes, etc. It is defined by:

$$L_{EA,T} = 10 \log \frac{1}{P_{ref}} \int \left( \frac{P(t)}{P_{ref}} \right)^2 dt$$

where $T_{ref} = 1s$ and $T = $ time interval. Sound exposure levels of unrelated transient noise events can be combined on an energy basis and be converted to an $L_{eq}$ acting over a specified time-scale by subtracting, say, $(10 \log_{10} 60)$dB to give $L_{eq,60s}$

Fig 12: Sound exposure for both a single event and continuous sound

Fig 13: The Impulsive noise characteristic
4.4 Impulse sound

Impulse noise is defined as a short-duration sound characterized by a shock front pressure waveform (Fig. 13). The major characteristics of impulse noise are (a) the extremely fast rise time and (b) the high peak levels attained for brief moments (<0.5s). Typical impulse sounds are metal stamping operations, mechanical impacts, etc. The duration of impulsive noises may vary from microseconds to 50 ms. If the peak levels of 140-170 dB were maintained for a full 1s, it is certain that ear damage would occur. Most damage risk criteria for impulse noise are based on exposure to repetition.

The difficulty with impulse sound is measuring it. The normal fast response available on sound-level meters cannot follow short-duration impulse noises. Some meters are fitted with impulse or impulse-hold settings which are intended to display a reading corresponding to the subjective impression of an impulsive sound, referred to as the ‘I’ characteristic. Although this is short enough to enable some detection and display of transient noise, the true maximum sound pressure level is not measured because a 35 ms response time is relatively long (Fig. 13). Meters with a peak hold facility can measure true instantaneous sound levels but cannot measure the total sound received during the measurement period, i.e. the peak hold figure is unrelated to the length of time the signal is produced. A fast impulsive setting gives a reading which is the approximate average of the peak hold and slow readings and although it will not record sharp pulses, nor is it a good measure of steady noise, it does record all the fluctuations. The measurement of sound energy, $L_{eq}$, compensates for all the shortcomings of the above methods.

Figure 14 is a schematic representation of measured sound-level formats as determined for a free-field single impulsive noise. The implications of these varying methods of measurement are important. All are correct but their relevance to the situation being evaluated has to be decided.

For continuous noise sources, if the difference between the A-weighted impulse sound pressure level and the A-weighted level, $[Lp(A)I - Lp(A)]$ is > 3 dB, then the noise is considered to be impulsive, and the greater the correction the larger the impulse content.

Fig 14: Schematic representation of impulsive noise evaluations

4.5 Cumulative exposure over time; DNL and CENL

CNE is a single number result that is calculated for a complete 24-hour period normally applied to airports and usually made up of results taken at shorter intervals such as 5 minutes or 1 hour and then averaged over the whole 24 hours. It is the average sound level over a 24 hour period, with a penalty of 5 dB added between 7 pm and 10 pm, and a penalty of 10 dB added for the night-time hours of 10 pm to 7 am. The logic behind these applied penalties is that since most citizens living in a given area are very sensitive to noise in the early morning hours and somewhat sensitive to noise during evening hours, a weighting factor is applied. CNE depends not only on the noise level of individual aircraft approaches, but also on the number of aircraft approaches during the measurement period. Impacts of CNE are both actual and perceived for noise in specific localities around airports. Contour lines are used when depicting existing CNE noise exposure.

Another often used metric is DNL, the day-night average sound level, again normally applied to airports but also applicable to racetracks, especially so in the case of Goodwood where the noise hours often extend into the evening, often with fireworks and music after 10pm, but not in the early hours. This is a way to describe a 24 hour noise dose and correlates well with community annoyance. The equation describing DNL using SEL’s is as follows:

$$L_{dn} = 10 \log \left( \sum_{i=1}^{9} 10^{SELi/10} + \sum_{i=1}^{m} 10^{(SELi+10)/10} \right) - 49$$

Fig.15  Schematic of the DNL exposure level
The Generation of Noise

Machines, vehicles and processes generate noise either as the result of vibration of machine components, structure, motors, tyres, panels, etc. If airborne or structure-borne mechanical noise is generated at low levels, high levels may be apparent through resonance of the engine case (covers) or of resonant surfaces on which the vehicle is travelling. Structure-borne vibrations may be persistent at considerable distances from the source as there is little loss of vibrational energy though structural transmission. Because an engine/vehicle structure consists of a large number of mechanical elements each with their own resonant frequency, the noise spectrum contains numerous peaks and troughs.

Machinery noise can be basically divided into two groups:

**Aerodynamic.** Speeding vehicles interact with the surrounding air by adding energy to it or subtracting energy from it. All aerodynamic processes produce some degree of turbulence by virtue of the work done in moving air around the vehicle obstacles.

**Structural.** Engines contain a vibrating source from which energy is transmitted by structural paths to the outer boundaries of the vehicle. Causes of vibration are unbalanced rotating or reciprocating parts, fluctuating loads and forces, misalignment, ignition cycle, loose mountings or loose fastenings. The exciting force in most cases is a repetitive series of impulses, and resultant vibrations generated at frequencies within the audio range are heard as noise.

In old vintage vehicles there are many transmission paths and many sections of the structure that radiate noise, every vibrating surface being coupled directly or indirectly to a source of mechanical vibration.

Noise generation can be visualized in terms of three functional aspects, the noise source, the noise path and the receiver.

1. **Source.** Where the sound originates. The exact definition of the source depends on the scope of the problem.
2. **Path.** The route the sound travels between source and receiver. The path can exist in solid, liquid or gaseous media and often involves multiple paths in one or more.
3. **Receiver.** The person or object who responds to the sound. The response of people is highly variable and subjective, depending on many factors, sheer loudness being the most troublesome. Although noise is a recognized unwanted sound, it is difficult to quantify in a simple manner.

Outdoor Sound Travel

Urban acoustics deals primarily with the outdoor sound environment, except for occasionally ensuring that intrusive sounds do not penetrate building exteriors. Sound travel outdoors, especially over distances greater than 60 to 90 m from a sound source, is highly dependent on weather conditions.

**Temperature and Wind**

The atmospheric conditions that affect sound travel most significantly are temperature variations, wind currents, and humidity. In terms of temperature variations, sound waves generally bend toward cooler temperatures. For example, with all other weather conditions remaining unchanged, on a typical summer’s afternoon temperature decreases with increasing altitude. In this case, sound waves tend to bend upward and generate what is known as a shadow zone, Fig 17. If you are in a shadow zone, you may be able to see a sound source at a distance but not hear it since shadow zones can decrease sound levels by up to 20 dBA at distances greater than 150 m from a sound source. Shadow zones can also be set up when sound is travelling against the wind.

These conditions are reversed when temperatures are cooler close to the ground than at higher elevations, as would be the case early in the morning or over a calm body of water. In these cases, sound waves tend to bend toward the ground, bounce off reflective ground surfaces, and travel farther than
expected. This is why sound is said to “carry” well over water. Sound also tends to travel farther than expected when it is travelling with the wind.

![Sound travel in temperature variations](image)

**Fig.17** Sound travel in temperature variations

**Fig.18** The refraction of sound by wind and by temperature gradients: (a) downwind or in a temperature inversion, (b) upwind or in a temperature lapse.

Sound travels faster in warm air than in cold and faster downwind than upwind. These factors can cause sound rays to be bent, or refracted, when propagating over long distances in vertical gradients of wind or temperature. Fig.18 shows the downward refraction of sound when the propagation is downwind or in a temperature inversion, as occurs at night when the temperature near the ground is cooler than the air higher up. Upward refraction occurs when the propagation is upwind or in a temperature lapse, a typical daytime condition when the air temperature falls with increasing altitude, resulting in the formation of a shadow zone, though in reality some sound will enter this zone due to scattering. Thus, the ability to hear sounds over long distances is a function of local climatic conditions; the noise level from outdoor events can be significantly affected by the time of day and the direction of prevailing winds.

### 6.2 Distance

Space is one aspect of the outdoor environment that is often available, although sometimes at a premium in urban areas. Sound generally dissipates at a rate of 3 to 6 dBA per doubling of distance from a source within 60 to 90 m of that source. Its decay rate beyond that is highly variable depending on the atmospheric (mainly temperature variations, wind currents, and humidity) and terrain conditions between the source and listener. However, sound levels generally decrease with increasing distance from a source. Therefore, the greater distance that can be placed between an objectionable sound source and a listener, the better.

Sound propagating away from a source diminishes in strength at a rate determined by a variety of circumstances. It also encounters situations that can cause changes in amplitude and direction. Simple reflection is the most obvious process for directional change, but with sound there are also some less obvious mechanisms.

At increasing distances from a source of sound the level is expected to decrease. The rate at which it decreases is dictated by the directional properties of the source and the environment into which it radiates. In the case of a source of sound that is small compared with the wavelength of the sound being radiated, a condition that includes many common situations, the sound spreads outward as a sphere of ever-increasing radius. The sound energy from the source (point source) is distributed uniformly over the surface of the sphere, meaning that the intensity is the sound power output divided by the surface area at any radial distance from the source. Because the area of a sphere is $4\pi r^2$, the relationship between the sound intensities at two different distances is:

$$L_2 = L_1 - 20 \log \frac{r_2}{r_1}$$

where $L_1 = $ sound level at distance $r_1$, $L_2 = $ sound level at distance $r_2$

This translates into a change in sound level of 6 dB for each doubling or halving of distance. In practice, however, this relationship must be used with caution because of the constraints of real environments. For example, over long distances outdoors the absorption of sound by the ground and the air can modify the predictions of simple theory. Large sound sources present special problems because the sound waves need a certain distance to form into an orderly wave-front combining the inputs from various parts of the source. In this case measurements in what is called the near field may not be representative of the integrated output from the source, and extrapolations to greater distances will contain errors. In fact the far field of a source is sometimes defined as being distances at which the inverse-square law holds true. In general, the far field is where the distance from the source is at least 2 to 3 times the distance between the most widely separated parts of the sound source that are radiating energy at the same frequency.
If the sound source is not small compared with the wavelength of the radiated sound, the sound will not expand outward with a spherical wavefront and the rate at which the sound level reduces with distance will not obey the inverse-square law. For example, a sound source in the form of a line (line source), such as vehicles on a race track or a long line of traffic on a highway, generates sound waves that expand outward with a cylindrical wavefront. In the idealized case, such sounds attenuate at the rate of 3 dB for each doubling of distance.

Geometric Spreading refers to the spreading of sound energy as a result of the expansion of the wavefronts. It is independent of frequency and has a major effect in almost all sound propagation situations. The two common kinds of geometric spreading are spherical and cylindrical. Sound propagation losses due to spreading are normally expressed in terms of x dB per doubling of distance from the source.

6.3 Ground Effects

If sound is propagating over ground, attenuation will occur due to acoustic energy losses on reflection. These losses will depend on the surface. Smooth, hard surfaces will produce little absorption whereas thick grass may result in sound levels being reduced by up to about 10 dB per 100 meters at 2000 Hz. High frequencies are generally attenuated more than low frequencies. Reflection from the ground can result in another mechanism by which sound levels are reduced. When the source and receiver are both close to the ground, the sound wave reflected from the ground may interfere destructively with the direct wave. This effect (called the ground effect) is normally noticed over distances of several meters and more, and in the frequency range of 200-600 Hz.

6.4 Air Absorption.

There are two mechanisms by which acoustic energy is absorbed by the atmosphere. These are molecular relaxation and viscosity effects. By far the most important of these is molecular relaxation. High frequencies are absorbed more than low. The amount of absorption depends on the temperature and humidity of the atmosphere. Fig 19 shows the variation of the absorption with temperature and relative humidity.

![Fig 19 Effect of atmosphere on sound attenuation](image)

a) From the diagrams it can be seen that for the middle of the speech frequency range (2 kHz), the absorption is typically .25 dB/100 m for 30% relative humidity and 20°C (68°F). It should be noted, however, it can be as high as 5 dB/100 m at 8 kHz when the temperature is 20°C and the humidity is 10%.

b) (left) Frequency dependence of attenuation as a function of relative humidity at 20°C.

c) (right) Attenuation as a function of temperature for various percentages of relative humidity.

d) Precipitation, rain, snow, or fog, has an insignificant effect on sound levels although the presence of precipitation will obviously affect the humidity and may also affect wind and temperature gradients (see next section).

e) can be neglected except where long distances or very high frequencies are involved. Under 'normal' circumstances, atmospheric absorption

6.5 Scattering

Scattering occurs when sound waves are propagating through the atmosphere and meet a region of inhomogeneity (a local variation in sound speed or air density) and some of their energy is re-directed into many other directions. In environmental noise situations, scattering is caused by air turbulence, rough surfaces, and obstacles such as trees. The scattering of sound by rain, snow or fog at ordinary frequencies is insignificant. Research on propagation through trees has produced greatly conflicting results. It is clear, though, that trees are of more benefit aesthetically than acoustically.

6.6 Barriers

You will often find that earth banks are used adjacent to noisy motorways or racetracks in an effort to absorb and/or deflect sound. The theory is illustrated in Fig.20 but in reality, away from the banks and because of refraction, temperature and wind direction effects, they can be totally useless to a distant observer experiencing the noise. Earth banks are only effective at reducing noise levels within 60m. It is often
thought that trees or other types of vegetation between a source and a listener will provide a barrier effect but studies confirm that vegetation has a minimal effect on reducing noise unless it is in the form of a dense forested area of evergreens more than 30m thick. The only natural design that will serve as an effective noise barrier is a hill. Rows of buildings between a sound source and a listener can provide as much noise as a barrier as long as the buildings cover at least 70% of the street length. Less that a 50% coverage will provide little, if any, noise shielding. When noise barriers are on both sides of a roadway, and parallel to each other, they can create an environment similar to that of an urban canyon.

7. The Noise Survey

Factors such as land value, building cost, and rental cost should be considered when locating a business or event and it is important to compare potential locations on the basis of a noise-level survey. A noise-level survey conducted over a period of time is a simple procedure, but one that can yield valuable information.

In the procedure described here, a noise survey is taken "by hand" with a sound-level meter that measures only sound levels. This might seem elementary and time-wasting, but it would provide a learning experience to those conducting the survey, giving a fundamental understanding of the process. Moreover, although it is laborious, this kind of survey is inexpensive and yields good results. Firstly, a single location should be selected that is on the proposed site, and which appears to sample the known noisemakers of the neighborhood. A 24-hour period of measurements can then scheduled for this location. A sampling interval could be hourly, or every 15 seconds. It is suggested that a measurement be taken every minute on the minute. This yields a set of 1,440 samples, which should give a reasonable picture of the environmental noise. Readings should be taken with the sound-level meter set for A-weighting, resulting in dBA measurements.

A typical data template for recording noise measurements is shown in Fig.21. Sound-level readings would not be written down as numbers, but only as ticks in the appropriate column in which the levels fall, marked in the lower part of the template. Each column contains 3-dBA readings, such as 48—50, 72—74, and so on. Little final accuracy will be lost through this simplified 3-dBA coarseness. Once every minute, a tick would be added to this form in the appropriate column until the 24-hour measurement period is completed.

At the end of the 24-hour period, the measured data can be used to build a statistical distribution curve. In particular, the upper part of the template in Fig.21 can now be completed. The total column would be filled in numerically, with the total number of ticks in each column. When the total column is full, entries can be made in the cumulative column.
Next, the percent (%) column can be completed and the cumulative value expressed as a percentage. This data is used to draw a distribution curve such as the example shown in Fig. 22. This distribution curve gives a statistical picture of the environmental noise at the measured location, for that 24-hour period.

8 Noise Control Directives

This section is included for comparative purposes as it underlines the extent to which legislation applies to the workplace and home, in other words it defines the extent to which workers and householders are protected against ear damage from noise pollution. In its simplest form, noise notification requires that manufacturers and retailers attach to particular categories of machinery and equipment, a label which informs potential customers of the noise emitted during a prescribed test. In this context, it is to be hoped that market power itself can be harnessed to progress towards a quieter environment. 'Less noise' thus becomes positive information alongside machine performance. However, although this subject has been considered within various standards-making bodies for many years, nothing much happened until the emergence of two EEC directives, the Noise Directive effective 1990 and the Machinery Directive effective 1994. These are applicable both to machines and working environments, laying down for the first time a noise control obligation on machine manufacturers, as follows:

1. The Noise Directive, EEC 86/188, states that 'the risks resulting from exposure to noise must be reduced to the lowest level practicable, taking account of technical progress and the availability of measures to control the noise, particularly at source'. Although EEC 86/188 did not provide exposure limit values, the new Directive 2003/10/EC does. The following goals are laid down:
   (a) measurement of noise exposure at the workplace;
   (b) a general obligation to reduce noise;
   (c) adequate information on the noise emission from machinery;
   (d) limit to the noise exposure in the working environment.

2. The Machinery Directive, EEC 89/392, subsequently repealed by 2006/42/EC, puts the noise reduction obligation into a firm requirement, stating 'machinery must be so designed and constructed that risks resulting from the emission of airborne noise are reduced to the lowest level taking account of technical progress and the availability of means of reducing noise, particularly at source'. The directive provides for:
   (a) determination of machine noise emission;
   (b) declaration of noise emission level in the technical documentation;
   (c) a general obligation to reduce noise;
   (d) installation instructions must indicate requirements for reducing noise and vibration.

Directive 2003/10/EC does not require a noise declaration as such, but does require the monitoring of exposure levels to that noise source. Directive 2006/42/EC goes far deeper into the subject and specifies which noise emission quantities have to be declared, expressed in the following terms:

1. An A-weighted continuous sound pressure level at the workstation, L_Aeq.
2. A C-weighted sound peak pressure level at the workstation, L_Pc.
3. The A-weighted sound power level of the machine, L_WA, emitted by the machinery where the equivalent continuous A-weighted sound pressure level at the workstation exceeds 80 dB(A).

This Directive also refers to the Outdoor Equipment Directive 2000/14/EC. For the machinery in its scope, 2000/14/EC applies in addition to 2006/42/EC with respect to noise emissions in the environment. However, for machinery in the scope of 2000/14/EC, value 3 indicated above in the noise emission declaration is the guaranteed sound power level rather than the measured sound power level L_WA.

The noise emission data declared by the machine manufacturer may be 1 + 2 or 1 + 2 + 3. The applicable noise threshold levels are given in Table 7. A further EEC Directive, 86/594/EEC, that dealt with airborne noise emitted by domestic appliances, but compliance was optional on member states. France and Germany in particular made progress with framing noise emission regulations which influence consumer choice through 'less noise' culminating in the Eco-Design Directive 2005/32/EC. 86/594/EEC introduced the energy label, compulsory for white goods, providing voluntary environmental information on airborne noise emission measured in accordance with EN 60704.

The second sound label is the L_WA, implemented by 2000/14/EC, compulsory for 57 specified types of equipments for use outdoors, Fig 41.

The reasons advanced for noise labelling are many, but the criteria can be summarized into four basic groups as follows:
1. *Economical and marketing.*, (a) To increase the quality of products; (b) to make possible a more loyal dialogue
2. *Prevention during the design process.*, (a) To encourage manufacturers to reduce noise at the source; (b) to predict better the noise impact of a new machine in the workplace.
Noise.....The Technical Bit

3. European, (a) To suppress barriers to trade in EEC and EFTA countries; (b) to contribute to a quieter Europe/world.

Before noise labelling can function effectively, a number of conditions need to be fulfilled: 4

1. There should be a clearly defined and universally acceptable noise descriptor that easily communicates to the buyer the noise emission level of the machine.
2. The noise descriptor should be linked to a clearly defined measuring method.
3. There needs to be a test house methodology for certification and verification of labelled values.
4. The subject of noise labelling will require public education.
5. Consumer rights against false labelling should be accessible in law.

Although EEC directives have been published1-3 outlining the general requirement, European standards are required to supplement these and so create test and performance uniformity. These must be based on international standards and measurement codes wherever possible so that the declarations may be compared at an international level.

9. Government Noise Legislation

The Planning and Compulsory Purchase Act 2004 requires local authorities to draw up local development plans, setting the broad framework for acceptable development in their area and reconciling the conflicts inherent in development. Under the Town and Country Planning Act 1990, and in their development management role, local planning authorities may attach conditions to Planning Consents which may include controls on the emission of noise. Advice on the use of these powers is given to English authorities in the light of the Government's Noise Policy Statement for England in the National Planning Policy Framework (March 2012)

The Environmental Protection Act 1990 provides the principal controls over so-called 'statutory nuisances', including noise emitted from premises so as to be prejudicial to health or a nuisance. By virtue of the Noise and Statutory Nuisance Act 1993, it also applies to nuisances arising from vehicles (e.g. from car alarms but not traffic), machinery and other equipment, in the street. Under the Act, local authorities have a duty to inspect their areas from time-to-time to detect nuisances and, subject to discretion to defer for seven days, when satisfied that a statutory nuisance exists or is likely to occur or recur, to serve an abatement notice on the person responsible and take Court proceedings if necessary to fix the situation. They also have a duty to investigate any complaint made by a person living within their area. Though businesses have a defence of 'best practicable means', failure to comply with a notice is a criminal offence. Local authorities have a power of entry to private premises, power to seize noise-making equipment and powers to carry out works in default of Notices. Section 82 of the Act allows the magistrates Court to act upon a complaint made by any person who is aggrieved by the existence of a noise nuisance

The Noise Act 1996 introduced an offence of emitting excessive noise from a dwelling at night, i.e. between 23:00 and 07:00, following the service of a warning notice. The maximum penalty is £1,000 on summary conviction and any equipment used in the commission of an offence can be forfeit. Alternatively, the local authority can serve a £100 Fixed Penalty Notice. The Act was amended by the Anti-social Behaviour Act 2003 so that it is no longer adoptive and local authorities have discretion in the investigation of night noise complaints.

The Pollution Prevention and Control Act 1999 imposes duties on both local authorities and the Environment Agency to control environmental emissions, including noise, from many industrial processes through a system of prior consents.

The Fireworks Act 2003 provides for the making of "Fireworks Regulations" for the purpose of ensuring that fireworks do not cause death, injury or distress to persons or animals and for prohibiting public displays unless certain conditions are met. The Fireworks Regulations 2004 create a curfew on the use of fireworks, generally between 23.00 and 07.00, with exemptions for certain traditional and special celebrations and limit the noise output of fireworks available to the public.

The Clean Neighbourhoods and Environment Act 2005 provides local authorities in England and Wales with new powers to deal with noise from intruder alarms and extends the powers for dealing with night time noise in the Noise Act 1996 to cover licensed premises. It also contains a new provision allowing local authorities to defer the serving of an abatement notice for up to seven days once satisfied that a statutory nuisance exists.

Noise Policy Statement for England, Department for Environment, Food and Rural affairs, March 2010. This policy statement applies to all forms of noise including environmental noise, neighbour noise and neighbourhood noise but not to noise in the workplace. The Noise Policy aims through effective management and control of noise to avoid and
mitigate significant adverse impacts on health and the quality of life and where possible to contribute to improvements of health and quality of life.

**Byelaws for Good Rule and Government** maintained by many local authorities, also containing controls on particular types of noise in some circumstances. They cannot, however, be used where a specific power is available in primary legislation. See below.

**Chichester District Council Noise Policy**, April 2015. No one should have to put up with unreasonable noise. The Council policy is to:

- Publicise and promote various services including the dedicated noise response service to investigate and resolve justifiable noise complaints.
- Encourage people to report noise issues and make it possible for them to do this
- Promote awareness of noise pollution issues to members of the public, CDC employees and other agencies

**The European Noise Directive 2002/49/EC.** The Environmental Noise Directive requires that the Noise Action Plans contain a number of specific sections including the identification of long term strategies for managing environmental noise. Defra has aligned the Plans with the principles set out in the Noise Policy Statement for England and the government’s localism principles relating to the assessment and management of environmental noise. The Environmental Noise Directive (END) is the main EU instrument to identify noise pollution levels and to trigger the necessary action both at Member State and at EU level. To pursue its stated aims, the Environmental Noise Directive focuses on three action areas:

- the determination of exposure to environmental noise
- ensuring that information on environmental noise and its effects is made available to the public
- preventing and reducing environmental noise where necessary and preserving environmental noise quality where it is good

The Directive applies to noise to which humans are exposed, particularly in built-up areas, in public parks or other quiet areas in an agglomeration, in quiet areas in open country, near schools, hospitals and other noise-sensitive buildings and areas. It does not apply to noise that is caused by the exposed person himself, noise from domestic activities, noise created by neighbours, noise at work places or noise inside means of transport or due to military activities in military areas.

**10 References**

1. European Noise Directive 2003/10/EC
5. BS EN 60651; 1994; IEC 60651; 1979 'Sound level meters'