ACOUSTIC SIGNATURE OF OPEN CUT COAL MINES

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Abstract

The NSW Department of Planning and Environment (DPE) has a regulatory role in managing the noise from coal mines. Currently there are 56 coal mines in NSW which generally have $L_{eq(15\ minute)}$ noise criteria in the order of 35 to 40 dB(A) at the nearest private residences.

As a consequence of its responsibilities, DPE undertakes a range of high quality audits and noise monitoring studies. This paper presents a brief selection of ancillary data that has been extracted from those studies. The object of this exercise was: to document the noise signature of coal mines; to better understand how to measure mine noise in a noise environment dominated by insect, frog and bat noise; and to identify if there are any shortcomings or areas of potential improvement in the way low frequency noise is identified.

The exercise found that under normal meteorological conditions, differential attenuation over large distances effectively reduces the spectral energy > 630 Hz to very low levels, (if not below the threshold of hearing) with both dB(A) and dB(C) of mine noise usually being controlled by sub 250 Hz energy. The use of low pass filtering as an effective tool to eliminate extraneous high frequency noise such as that from frogs and insects was validated by the exercise. The exercise also found that the characteristic peaks in the 16 and 25 Hz range are unlikely to be audible unless the overall level of mine noise is in excess of at least 45 dB(A). Consequently, it is recommended that these frequencies should not be included in an assessment of low frequency annoyance (with reference to a C – weighted level).

1. Introduction

NSW is home to some of the largest coal mines in the world with the majority of these 56 operations being open cut [1]. To put this resource in perspective, the gross domestic output of mining in England, Scotland and Wales combined is around 12 Mtpa [2] whereas the approved output of Mt Arthur coal mine is 36 Mtpa. Meteorological effects, particularly those of light wind and temperature inversions have long been known to modify the propagation of noise, and the majority of coal mining areas of NSW are prone to both of these effects. The noise signature of a coal mine depends on a number of variables including the spectral sound power level of operational equipment and activities, the quantity of plant and equipment being used, and the distance and topography between the source and receiver, and prevailing meteorological conditions.

The present paper analyses an extensive body of acoustic data that was collected for ancillary purposes at various locations in the Hunter Valley, Western Coal Fields and Gunnedah Basin and examines the spectral signature of this data.

2. The Noise Sources

As discussed in Parnell [3], large coal mines may consist of one or more mining sites operating at any one time. The range of plant and equipment used on site is generally similar for most mines and only varies in the quantity of items. Open cut coal mines will generally remove overburden using a fleet of trucks loaded by shovels or excavators, and at some mines, also by dragline. Excavators and front end loaders are used to load coal into another fleet of trucks for transport to a coal preparation plant, which has associated conveyor systems, stockpiles, and typically, an automated stacking and reclaiming system. There is usually also a train loading facility on a loop, with a rail spur to a main rail line.

Tables 1 and 2 give some general indication of the sound power levels (L_W) of equipment used at open cut mine sites.

Table 1. Typical Fixed Plant Sound Power Levels.

Description	No, length or Area	L_W L_{eq} dB(A)	Controlling Frequency Bands
Coal Washery	1 x 2000m^2	114 - 125	16 - 63
Crushing Plant	1 x 600m^2	104 - 118	16 - 125
Transfer Conveyors	Up to 3 km	102/100m	63 - 500
Total Typical Fixed Plant		**127 - 130**	

Table 2. Typical Mobile Plant and Equipment Sound Power Levels.

Description	No, length or Area	L_W L_{eq} dB(A)	Controlling Frequency Bands
Tracked Dozers	3 - 10	114 - 125	63 - 1000
Front End Loader	2 - 4	110 - 125	63 - 1000
Reject/Product truck uphill	Up to 40	116 - 125	63 - 500
Excavator/Shovel	2 - 6	116 - 125	63 - 500
Total Typical Mobile Plant		**130 - 138**	

Basically, open cut mines are big industrial juggernauts with footprints that can cover 5 km^2 or more and from a distance will appear to be one large noise source with a L_W of around 125 – 140 dB. Whilst topography of the mine area will have significant effect on the transmission of noise, and particular equipment may be more exposed that others (for example a dozer working on the top of a 40 m overburden dump), in general these mines produce a fairly broadband noise spectrum at the source.

3. Differential Attenuation

Noise from mines is prone to being regularly audible at distances of 5 km or more under certain conditions. This is a result of the relatively high source sound power levels and because mines are often located in quiet areas.

Simple acoustic theory tells us that geometric spreading will significantly reduce the strength of an acoustic signal in all frequency bands over the 3 – 4 km and more that often separates receivers from mine noise sources. However, for a noise source that comprises mostly broadband mid frequencies, differential attenuation of these by atmospheric absorption and ground effects over a long transmission path results in the residual acoustic energy received being mainly in the lower end of the spectrum. This results in a characteristic low frequency rumble that is often associated with industrial noise sources located at large distances.

3.1 Atmospheric absorption

The significant frequency shift in the acoustic signal is mainly due to atmospheric absorption. This is documented in International Standard ISO 9613.1 [4] which establishes the reductions due to atmospheric absorption alone over 4 km under 20 ^{0}C and 50% humidity conditions, as reproduced in Table 3:

Table 3. Atmospheric Attenuation over 4 km

Atmospheric Attenuation	**Frequency Hz**					
	50	**160**	**500**	**1000**	**2000**	**4000**
Rate per km dB	7.84×10^{-2}	6.6×10^{-1}	2.73	4.66	9.86	29.4
Total dB reduction over 4 km	0.3	2.6	10.9	18.6	39	118

As the standard shows, the residual acoustic energy will be mostly below 500 Hz due to the very large attenuation coefficients at higher frequencies. This is not to say that the plant and equipment are generating particularly high levels of low frequency noise, or that their noise signatures are 'unbalanced'. Rather, this confirms that only the lower part of the noise spectrum is identifiable at large distances as a consequence of differential attenuation.

3.2 Cumulative attenuation

In Figure 1, Environmental Noise Model has been used to model pink noise (which has equal energy in octave bands) over a distance of 4 km. Flat terrain with grass has been assumed in the model parameters.

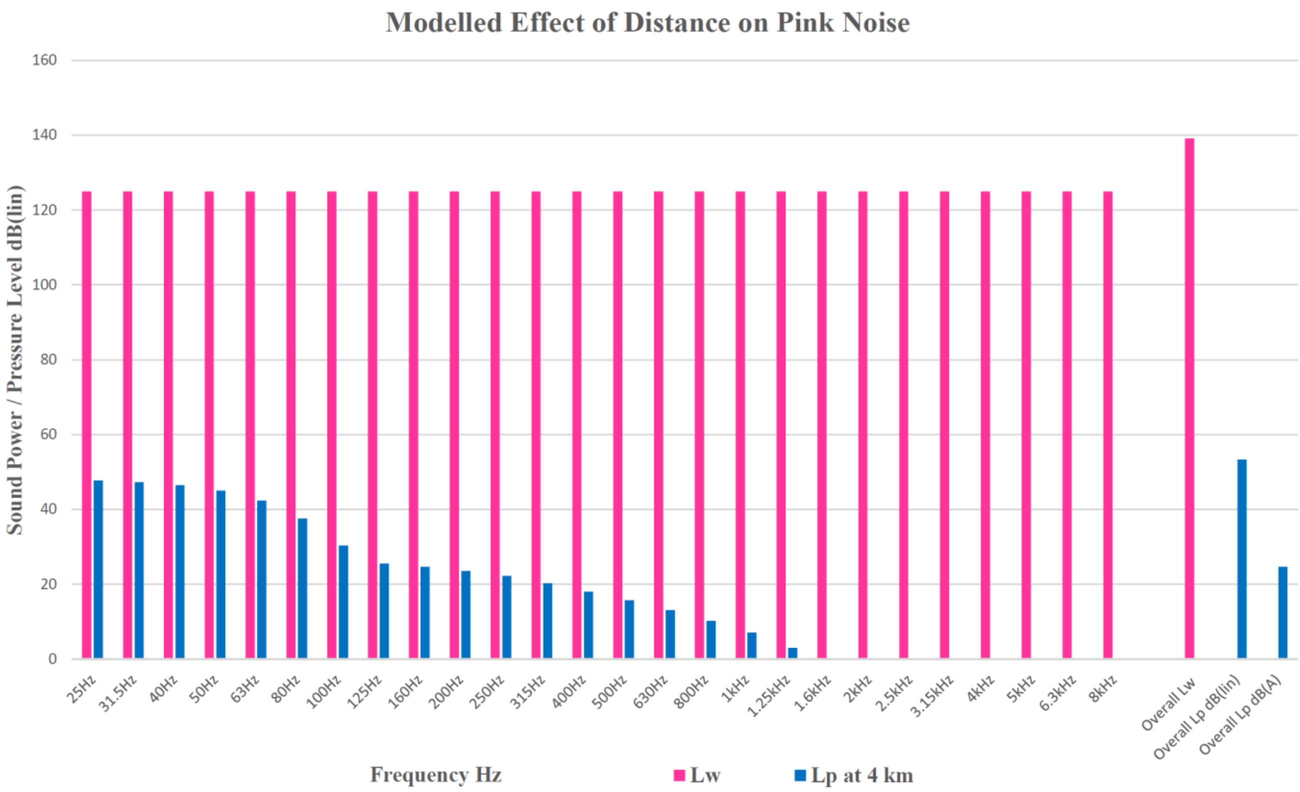

Figure 1. Differential attenuation of Pink Noise over distance

As can be seen in Figure 1, despite starting with a completely broadband acoustic signal at x = 0, by the time x = 4 km, differential attenuation will result in a dB(lin) – dB(A) value of around 28 dB.

4 Noise Spectrum

Noise at several km from a mine is typically a mix of acoustic signals. Some of the spectra generated at the mine site will have been altered significantly over the distance propagated, while other, closer sources will have been altered less. This is because mines are large and typically sources are spread out over some kilometres, resulting in a significant difference in propagation path lengths. Close proximity extraneous noise sources may not have had their acoustic signals altered very much at all.

Mine noise measured in close proximity contains mostly broadband mid frequencies, although the spectrum from some surface facilities like washeries and preparation plants tend to include emissions in 1/3rd octave bands around 16 – 25 Hz. However, differential attenuation of high frequencies due to atmospheric absorption and ground effects results in a very different noise spectrum shape being experienced at distances of more than around 3 - 4 km. At these distances, the sound pressure levels of frequencies >250 Hz are such that they generally do not contribute significantly to the A or C weighting of the audible noise signal.

Whilst Tables 1 and 2 identify the broadband range of greatest acoustic energy, there are several characteristics of mine generated noise that can be observed within the spectrum and attributed to specific sources or activities. With the assistance of Global Acoustics [5], these have been identified as follows:

4.1 Coal washery plant

Washeries can be the source of significant noise, particularly in the lower end of the frequency spectrum. Both the screens and the large centrifuges can generate identifiable energy in the 16 and 25 Hz bands as shown in Figure 2. Note however that the threshold of hearing curve should only be compared against the linear graph [6].

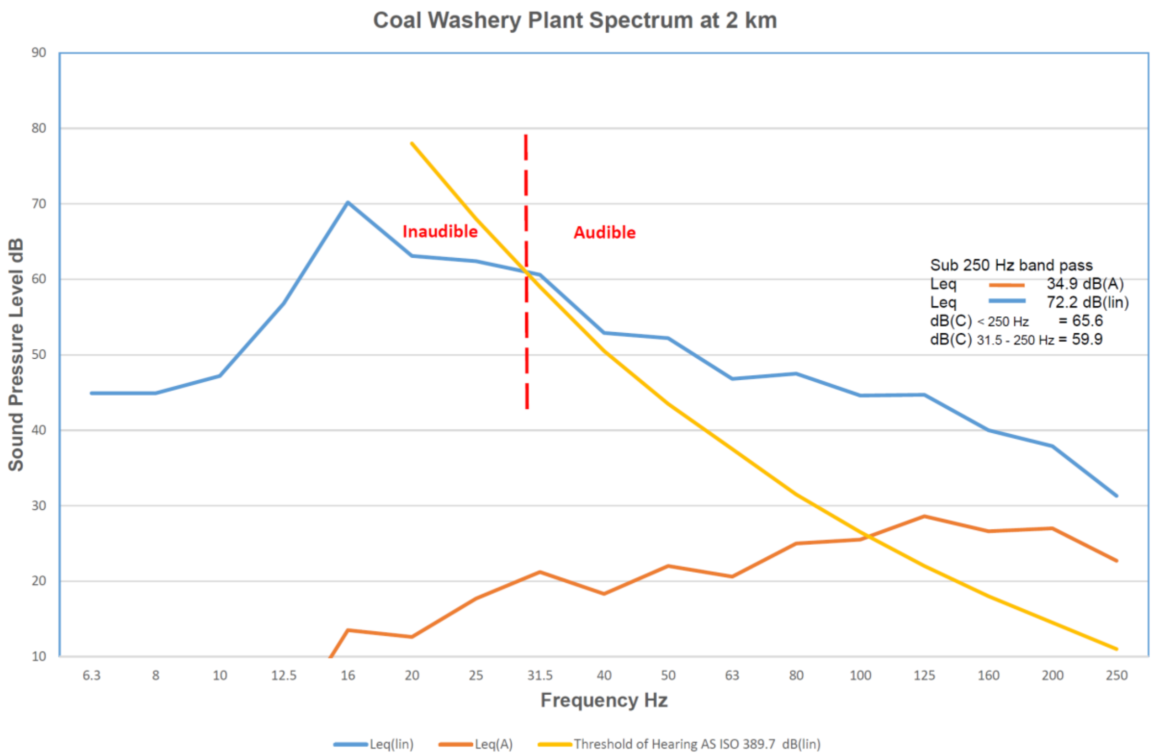

Figure 2. Linear and A-weighted spectrum of a coal washery plant at distance.

4.2 Engine exhausts

Most mobile fleet on a mine site is diesel powered and will generally emit energy in the 125 Hz range. Poorly maintained or standard exhausts may result in more energy being emitted an octave lower in the 63 Hz range as shown in Figure 3. Note however that the threshold of hearing curve should only be compared against the linear graph [6].

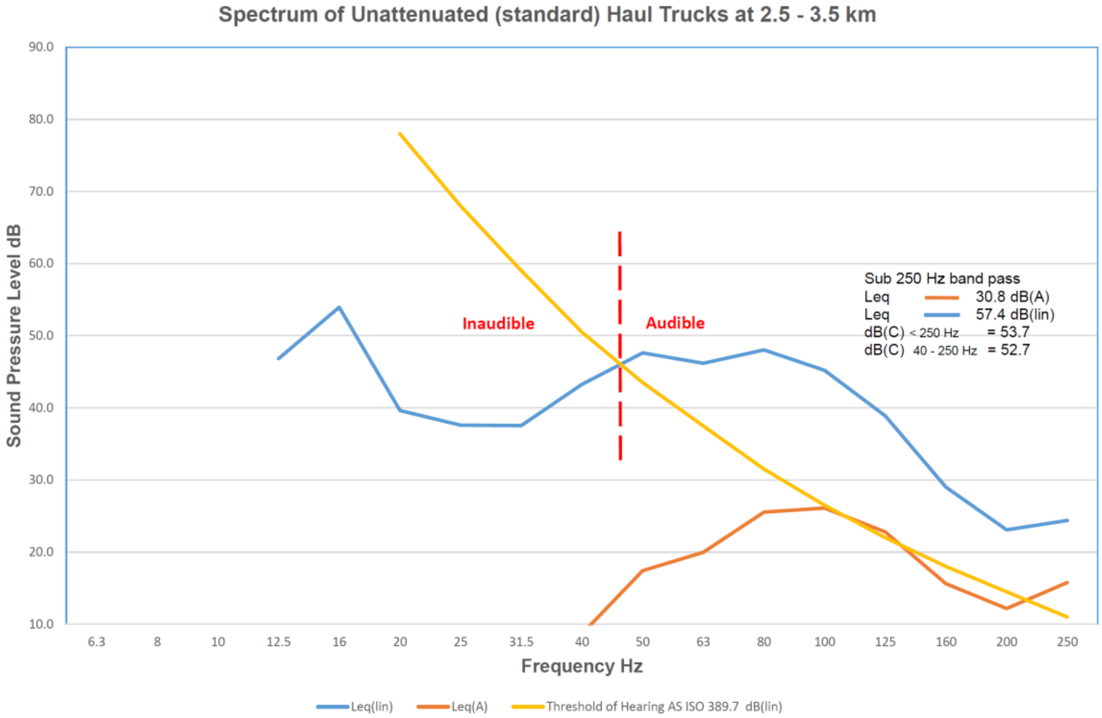

Figure 3. Linear and A-weighted spectrum of haul trucks (standard exhaust) at distance.

4.3 Engine and fans

For haul trucks this is generally broadband across the 125 – 500 Hz range. For excavators and drill fans this may vary, particularly with relation to the number of fan blades and rpm and will be more in the range of 500 Hz. The engine of a haul truck is usually a V configuration of 16 – 20 cylinders with a capacity of 60 – 90 litres.

4.4 Tracked equipment

Dozers are often identifiable by track noise in the 630 Hz range. The sound power of this varies and is usually much higher when they are reversing.

4.5 Gearboxes and differentials

Mechanical noise including that generated by rear dump truck planetary reduction gearing, at the wheels (known as wheel motors) on all types (mechanical and electric drive) and a large gearbox on mechanical drive trucks, is generally in the 630 – 800 Hz range.

4.6 Electric drives

These differ from conventional dump trucks in that they use an electric drive system instead of a mechanical transmission/differential drive. The diesel engine is connected to a traction alternator then high voltage cables transfer electricity to the two wheel motors at the rear of the truck. Electric trucks do have a grid box with 100HP cooling fan which can make a distinctive high frequency ‘air raid siren’ type noise, however, differential attenuation means this is usually inaudible off site.

4.7 Ambient sounds

Most extraneous noise from insects and birds is in the high frequencies with frogs ~ 2 kHz, crickets and cicadas ~ 4 kHz and bats ~ 10 to 16 kHz. Thunder ranges from the infrasonic into the low frequency range, whereas wind (while not a true noise) will usually register on an analyser in the 80 – 160 Hz range.

5 Consequences of Equipment Spectra

In Figure 2, the sub 250 Hz noise spectrum of a coal washery measured at a distance of 2 km has a dominant concentration of energy in the 16 Hz range. While intuitively, it would seem that reducing the 16 Hz peak would reduce overall noise impact, it can also be seen that while this frequency influences the dB(C) reading, at 70 dB(lin) it is below the threshold of hearing and has no influence on the dB(A) level.

Consistent with the comments in Section 4.2, the spectrum of some haul trucks with standard exhausts shown in Figure 3 appears to be showing a shift in acoustic energy to an octave lower than would normally be expected from trucks fitted with high performance exhausts.

The translation of acoustic energy to a lower octave band may not in itself be critical in terms of dB(A) levels. This could actually reduce dB(A) levels, if it were not for the fact that standard mufflers do not reduce the output of acoustic energy as well as higher performance variants. In addition, once lower frequency noise is above the threshold of hearing, it is accepted [7] that it elicits a more rapid increase in annoyance, than does the same increases at higher frequencies.

Figure 4 below shows a compilation of typical measurement spectra at around 4 km from a major open cut mine mining complex.

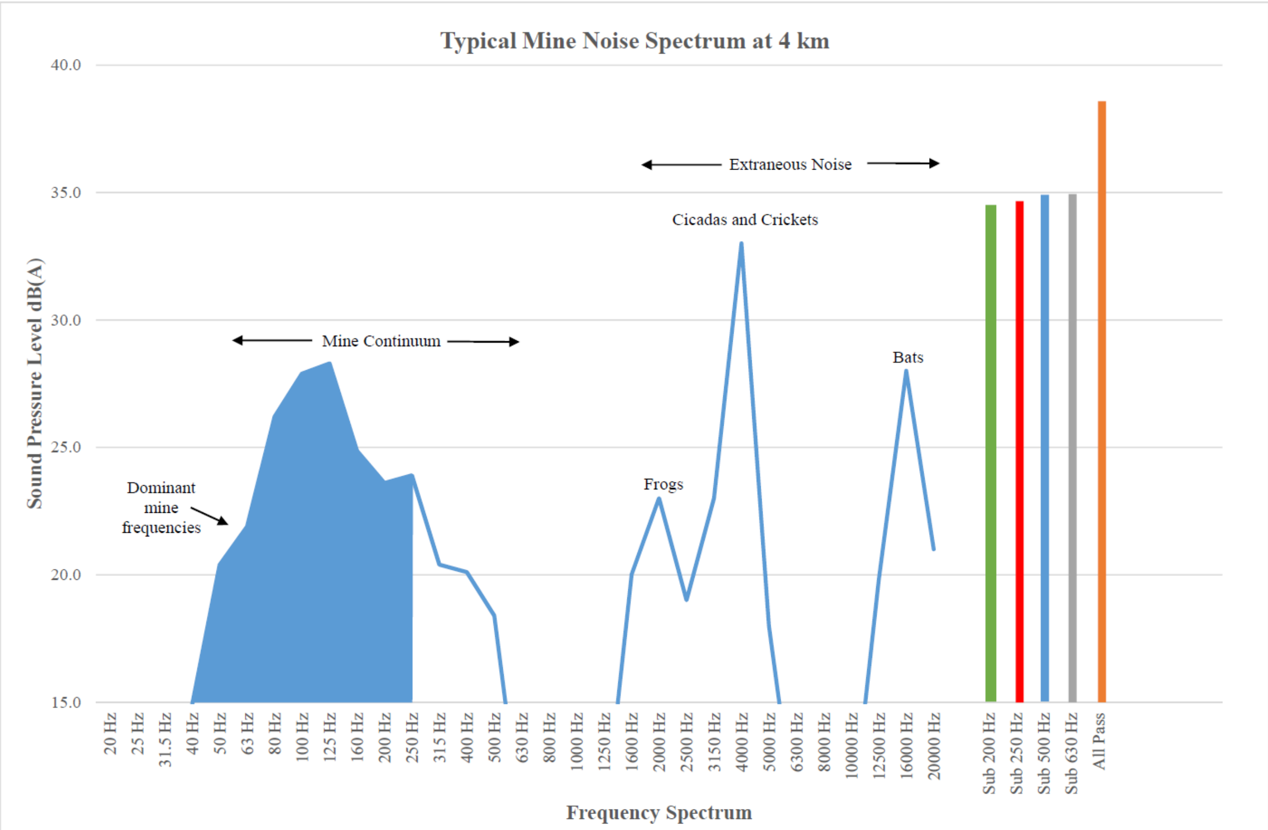

Figure 4. A typical spectral signature of a large open cut mine at around 4km.

The data used to compile Figure 4 has been extracted and averaged from several large data sets which were filtered to only present data collected under neutral meteorological conditions ie. < 1 m/s wind and normal adiabatic lapse rate (up to Pasquill Stability Class E). Meteorological conditions which enhance the propagation of noise tend to raise the overall levels and broaden the mine noise spectrum by introducing more frequencies in the 200 – 500 Hz and upwards into the audible range.

Conversely, conditions such as receiver-to-source wind can progressively reduce the audibility of all frequencies until the mine becomes inaudible. The data presented in Figure 4 excludes avoidable extraneous noise events such as road traffic, trains and aircraft. However, the spectra of relatively continuous (and therefore unavoidable) extraneous noise sources such as insects, frogs and bats have been retained as an example.

5.1 Quantifying mine noise in a complex environment

Table 4 shows the effect of applying different low pass filters to the long distance measurements presented in Figure 4, demonstrating that the extraneous noise from insects, birds etc. can be easily filtered out.

Table 4. Effects of band pass filtering on mine noise spectrum at 4 km

Band Pass Filtering dB(A)					
200 Hz >	250 Hz >	500 Hz >	630 Hz >	1 kHz >	All Pass
34.10	34.50	34.91	34.93	34.96	38.23

In this example, the total (all pass) measured level, including extraneous noise, is more than 3 dB higher than the actual mine noise level of 35 dB(A), the latter determined by exclusion of all non-mine related acoustic energy greater than 1 kHz. It also further demonstrates that under non-enhancing meteorology (this data set), band pass filtering as low as 200 Hz would result in the reporting of a level that would be only slightly less than 1 dB below the estimated mine contribution. Filtering from 250 Hz down would return a result within 0.5 dB of the estimated mine contribution.

The ability to exclude high frequency extraneous noise by low pass filtering is an extremely useful analytical tool in the estimation of mine generated noise contribution to the surrounding noise catchment.

5.2 Additional issues with the use of dB(C) as an indicator of low frequency noise

The scientific validity of a C – A delta as an indicator of low frequency noise has been the subject of debate [8], with arguments generally based on the failure to account for differential attenuation over distance as shown in Figure 1. However, in addition it can been seen in Figures 2 and 3 that although a significant quantity of spectral energy may be below the threshold of audibility, it may still result in the dB(C) levels being increased in the order of 1 to 5 dB beyond the level that would be calculated by using a high pass filter to only include audible acoustic energy. The draft Industrial Noise Guideline [9] recognises the potential for such false-positive identification of low frequency noise, and allows the option for more detailed 1/3rd octave analysis to be undertaken if required.

6 Summary and Conclusion

A series of data sets collected in and around active coal mine sites were examined to improve the understanding of mine generated noise spectra. As expected, the study confirmed that as distance increases, the higher frequencies are rapidly attenuated compared to the lower frequencies (differential attenuation). This is primarily a result of atmospheric absorption, but also is compounded by ground and barrier effects. There are three findings from the data analysis:

i. At distance, measurement of residual acoustic energy will often identify energy peaks associated with particular plant or equipment in the low frequency end of the spectrum between 16 and 25 Hz. However, these frequencies will generally be below the threshold of hearing when total mine noise is below around 45 dB(A).
ii. Analysis supports the contention that use of a dB(C) minus dB(A) or a dB(lin) minus dB(A) delta to identify a low frequency noise impact is not scientifically valid in all situations due to the significant differential attenuation of high frequencies over distance. Moreover, such analysis is deficient because it does not have regard for amplitude, frequency content or audibility threshold. In summary, it was found that a significant amount of the acoustic energy generated on mine sites that underpins the calculation of the C weighting scale may be sub-audible and therefore it is recommended that a high pass filter should be used to remove such data from calculations or impacts may be over-estimated.
iii. The use of low pass filtering is a valid and useful technique for eliminating near-field extraneous insect, frog and bat noise when measuring far-field mine noise. Under neutral

atmospheric conditions and at a distance of 4 km, a low pass filter as low as 250 Hz can be used without any significant change to the true L_{Aeq} value of the mine noise source. Use of a 630 Hz low pass filter will generally cover most enhancing meteorological conditions without loss of fidelity in the calculation of mine generated dB(A) or dB(C) levels (although additional high pass filter of inaudible acoustic energy may be required for dB(C) assessment) when measuring at distances greater than about 2 km.

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