

AMPLITUDE MODULATION CASE STUDY AT THE LEONARDS HILL WIND FARM, VICTORIA, AUSTRALIA

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ABSTRACT

Results of two channel simultaneous audio recordings outdoors in the free field and inside a bedroom are presented from the Leonards Hill wind farm that has two Repower 2MW MM82 wind turbines.

The analysis demonstrates the dynamic effects of amplitude modulation on attenuation of sound between the two measurement locations and shows how outdoor to indoor attenuation is compromised at particular room resonant modes.

Different measurement approaches are discussed with the conclusion that a 10Hz sampling rate of sound level is insufficient to accurately determine peak to trough amplitude modulations.

Infrasound measurements are also presented to show that amplitude modulation is also observable below 20Hz and that low frequency infrasound may also be considered to be amplitude modulation.

INTRODUCTION

Simultaneous outdoor and indoor audio recordings from a dwelling located approximately 700m from two Repower MM82 2MW turbines at Leonards Hill in Victoria, Australia are presented.

Infrasound measurements using a microbarometer indoors are also presented for the Lake Bonnie wind farm in South Australia.

The intricacies of the dynamics are best observed by viewing real-time frequency analysis that will be demonstrated with the presentation of this paper. Only average spectra are shown in this document.

We have a considerable amount of data recorded outside and inside dwellings located near to the two Leonards Hill wind turbines. Accordingly, the detailed analysis presented is only a snapshot of some of the recordings.

The data presented does not rely upon any data from the Leonards Hill wind farm operator. We have pointed out to the wind farm owners that cooperation in this regard may assist in identifying conditions that cause nuisance to neighbours, which could then help in setting appropriate operating conditions for the wind farm. However, after three years of repeated requests for operational data they remain uncooperative. Accordingly, the data presented does not relate to particular operating conditions such as power output, wind speed or direction.

INSTRUMENTATION

Audio recordings were completed simultaneously outdoors and indoors using two Larson Davis 820 Type 1 sound level meters fitted with manufacturer's wind screens. The AC output from the meters were input to Behringer UCA222 16 bit audio interfaces connected to a portable computer that recorded WAV files at a sample rate of 22,050 Hz contiguously in 10-minute periods. Each file was time and date stamped. Calibration files of 94 dB at 1kHz were recorded through each system before and after each measurement period.

Infrasound audio recordings were taken using proprietary microbarometer equipment having a frequency response of 0.075Hz to 20Hz (-1.2dB) sampled at the rate of 3ms (333Hz). Phase change across the frequency range 0.5Hz to 5Hz is less than ± 10 degrees. This instrument can also be configured to record both infrasound and the DC output from a sound level meter, set to any chosen weighting or response, with sample period of 6ms (166Hz). A WAV file generated from this data produces an infrasound signal on the left channel and sound pressure level amplitude in dB on the right channel of a stereo WAV file. When used only for infrasound the resulting WAV file is a mono channel sampled at 3ms (333 Hz).

A DUO sound level meter was also used to collect external sound level data at the maximum rate available from this instrument at 10 Hz. Two-minute audio samples have also been recorded at the beginning of each 10-minute period.

DATA ANALYSIS

Observation of the narrowband spectra whilst playing back outdoor and indoor audio recordings presented in a stereo WAV file (outdoors left channel, indoors right channel) clearly show how the sound pressure spectra raise and fall with audible blade swish.

Figure 1 shows a 90 second average from such a sample.

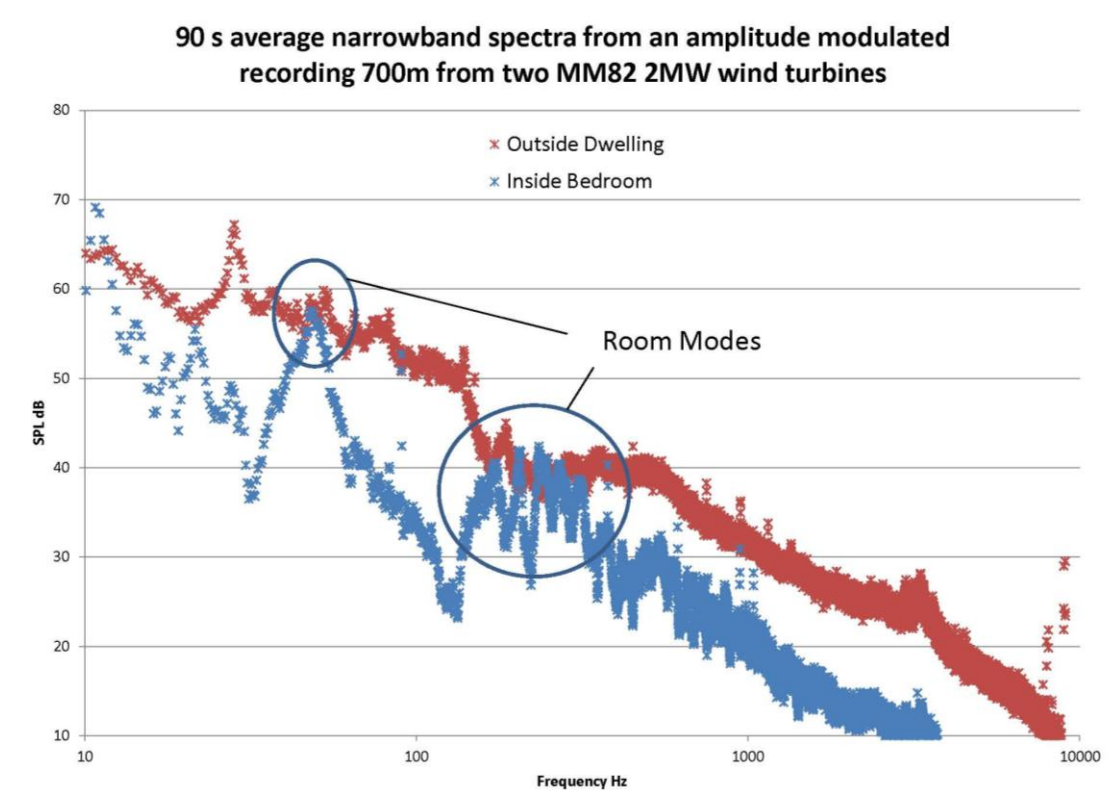


Figure 1

The analysis shows that blade swish measured outdoors is broadband over the frequency range below 1kHz. Corresponding measurements indoors show that the broadband external sound is modified by the dimensions of the room that influences the transmission loss from outside to inside. Room modes at 49 Hz and in the range from 140 Hz to 420 Hz have been calculated for the bedroom.

The depth of amplitude modulation indoors is limited by the reverberation time of the receiving room in 1/3 octave bands, with longer reverberation times corresponding to smaller peak to peak amplitude modulation (AM). However, measurements have shown that smaller A-weighted AM levels outdoors can produce larger A-weighted AM levels indoors. Figure 2 shows an example.

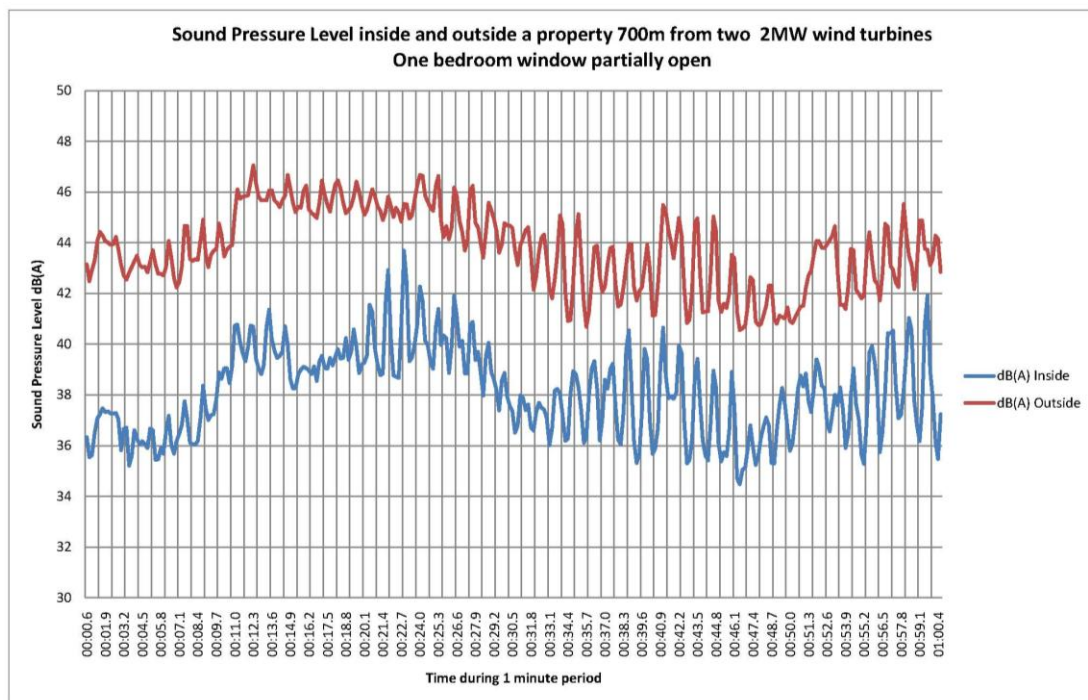


Figure 2

One third octave band levels have been calculated from some of the 10-minute audio recordings at a rate of 100ms. The amplitude modulated results were then analysed to determine the spectral content. This process is quite straightforward and shows the dominant AM frequency. Two examples are shown in Figure 3 and Figure 4 for the 200 Hz and 250 Hz 1/3 octave band data respectively.

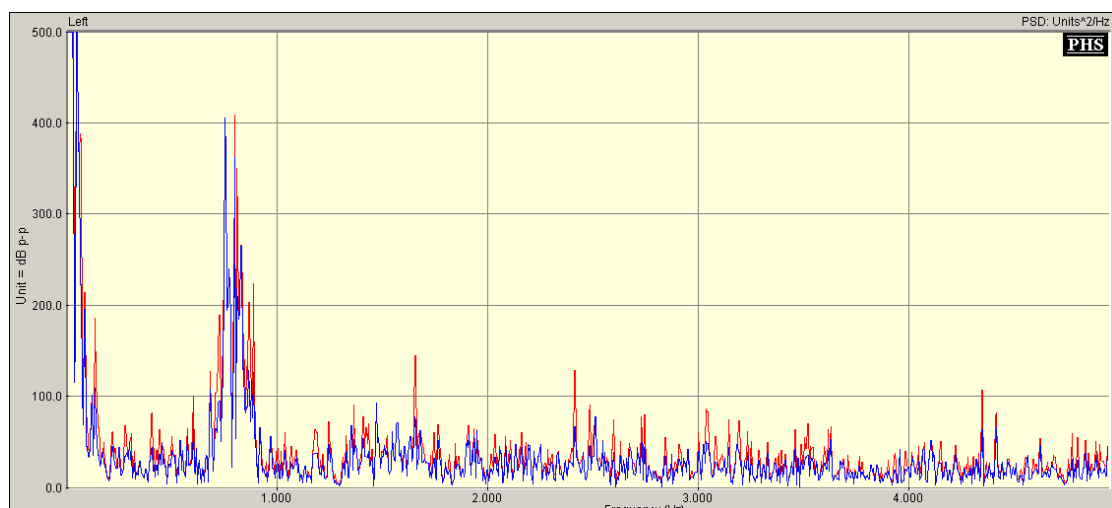


Figure 3 PSD of 200Hz 1/3 Octave 10-minute indoor data sampled at 10Hz

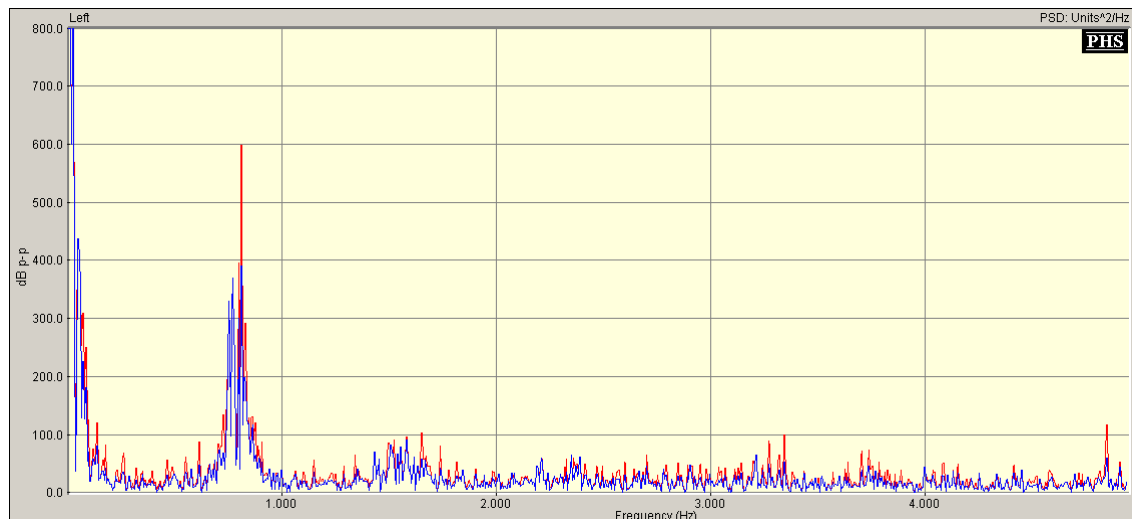


Figure 4 PSD of 250Hz 1/3 Octave 10-minute indoor data sampled at 10Hz

The peaks in the PSD charts clearly show the blade pass frequency of the two turbines around 0.8 Hz. The amplitude of the PSD charts is in units of dB (p-p re 20μPa) squared per Hz.

It is possible to use the amplitude of the PSD spectrum peak to quantify an amplitude modulation value. This is an approach used by RenewableUK in their recently released AM assessment tool 'OAM'. Comparison of the peak PSD result with the average PSD result may also be of quantitative value because it could be the peak AM that cause complaints. The peak spectrum (red) and average spectrum (blue) are shown in Figures 3 and 4.

OTHER AM CHARACTERISTICS

It is unknown if the envelope of the modulated sound is more or less annoying than a constant AM (as seen in the example of figure 2 for the two asynchronous wind turbines at Leonards Hill using Fast response).

Another unknown potential nuisance factor is the change in swish repetition rate. Figure 5 shows 100ms LAeq data from a 73s sample outdoor DUO measurement at Leonards Hill. Over approximately one-minute the observed swish repetition changes from twice blade pass frequency (BPF) to BPF. Closer inspection of the data shows that in the earlier part of the chart, when the blade pass frequencies are out of phase, there is only one data point representing each of the peaks. In this situation a 10Hz data rate can underestimate real peak values, even though the frequency of AM can be determined from spectrum analysis.

TIME CONSTANT CHOICE

Fast response corresponds to a 125 ms time constant, **Slow** corresponds to a 1 second time constant and **Impulse** has a time constant of 35 ms. One must question if the Fast response of 125ms is suitable for accurately tracking AM pressure changes caused by multiple turbines.

Although now out of favour in IEC 61672, the Impulse response will produce a better peak to trough estimation for repetitive swish sounds, such as those shown at the start of the trace in Figure 5 (2 Hz repetition). However, even the Impulse response can underestimate real AM levels since the design goal from IEC 61672 for the relative response of A-frequency-weighted, I-time-weighted sound level to a sequence of 5 ms, 4 kHz tonebursts is -8.8 dB for a 2 Hz repetition rate.

HAAS EFFECT

A situation will arise with multiple turbine blade swish AM where the time between successive swish observations is such that the time reduces to less than about 40ms. In this circumstance an increased perception of loudness will occur even though the AM levels remain relatively constant. Furthermore, an observer can be totally confused about the direction from which the sounds originate.

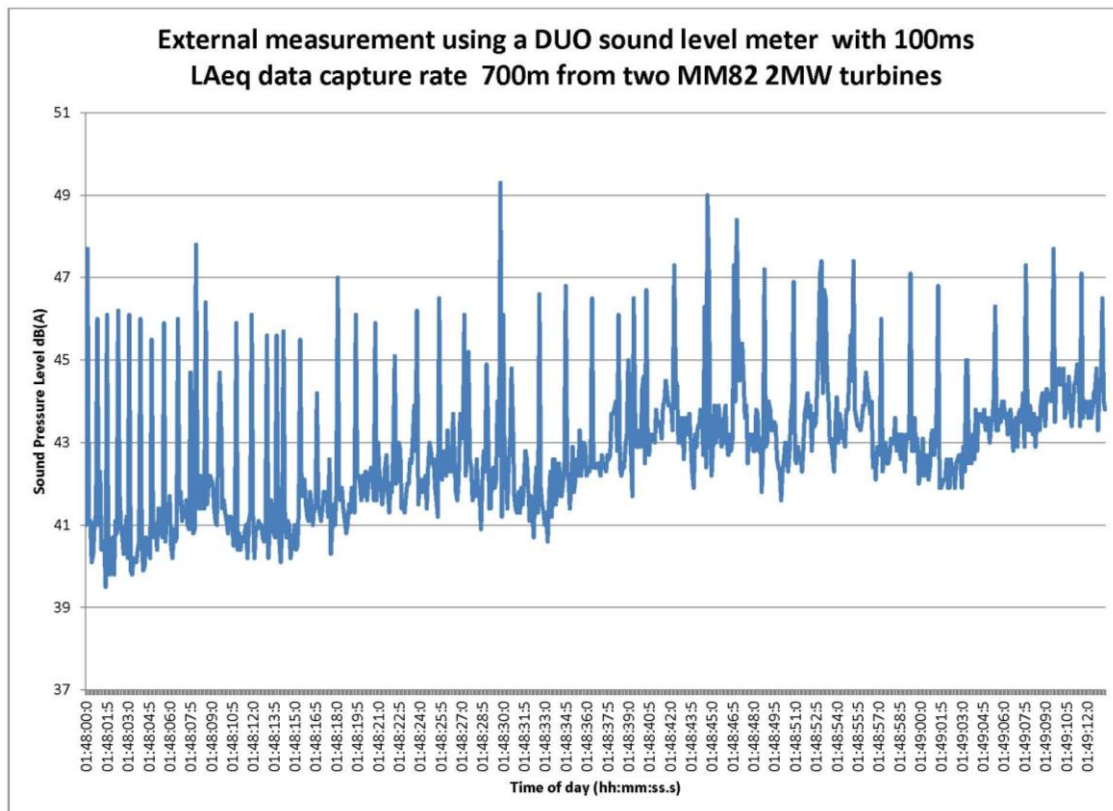


Figure 5

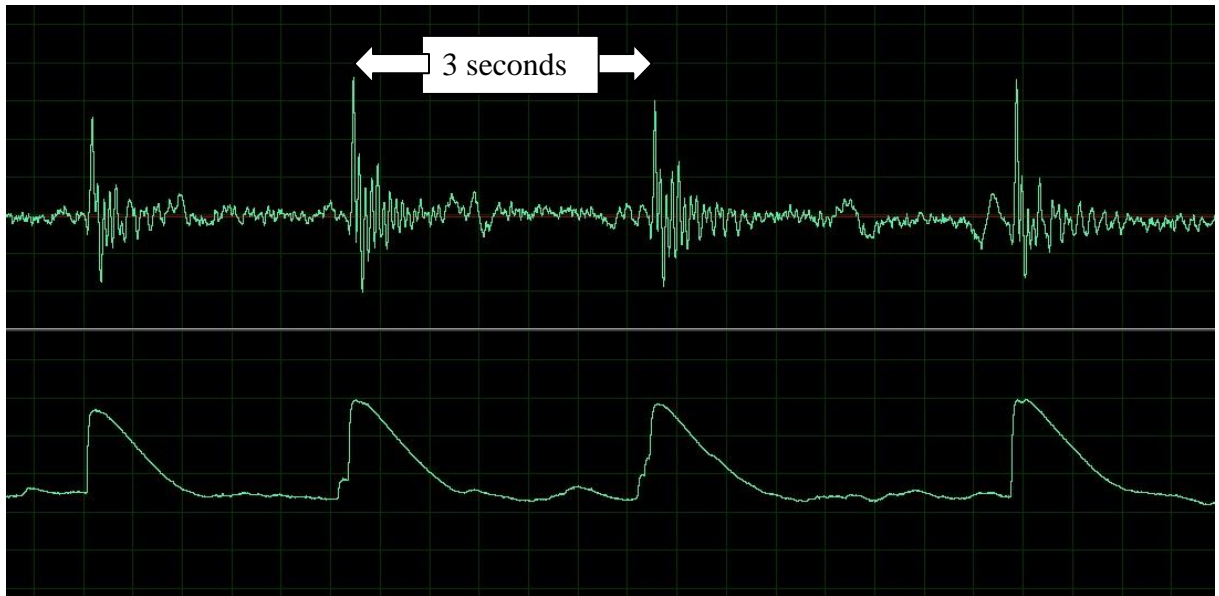
INFRASOUND

The microbarometer instrument was designed to record pressure values at the rate of 3ms between each sample. The data is saved to a microSDCARD in 20-minute blocks and data can be recorded for over 100 days continuously. The unit has a battery backup that can operate for up to 40 hours.

The infrasound recorder has been modified to accept one or more DC channels from other equipment such as a sound level meter and provides a simple way to take long term unattended synchronised sound level and infrasound measurements to compare against resident's diary notes, for example. Data sample rates vary with the number of channels, for example, three channels sample at the rate of 9ms (111 Hz).

Figure 6 shows a test time trace for two channel recording.

Infrasound pressure in Pa from a microbarometer is shown on the upper trace of Figure 6 and dB(Z) from a sound level meter is the lower trace using Fast response. The lower trace decay is a combination of the room RT and the reduction in level of the 16 Hz sound source. The RT was determined separately using the balloon pop method.



**Figure 6 A 16 Hz reducing amplitude test tone in a room with RT of 0.4s
(Not a wind turbine sound)**

An example spectrum produced from a 20-minute infrasound recording inside a dwelling 700m from the Leonards Hill turbines is shown in Figure 7.

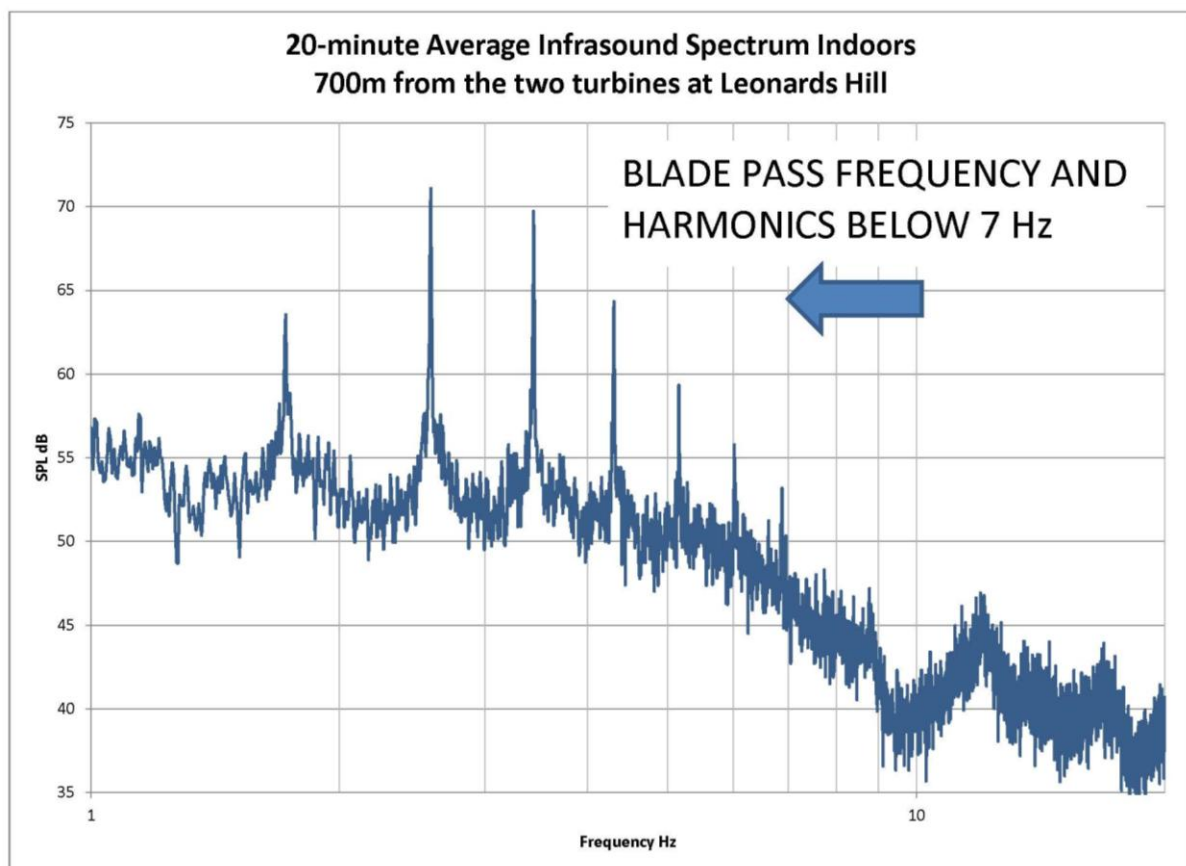


Figure 7 Infrasound spectrum indoors near two MM82 2MW Repower Wind Turbines

AM (rms level) is also a feature of the tones shown in Figure 7. Whilst not ‘audible’ in common terms, perhaps pressure AM from the tones below 7 Hz could be the cause for reported illness near wind turbines.

Figure 8 shows a linear frequency chart to 10 Hz obtained inside a dwelling located 2,300m from the nearest wind turbine at Lake Bonnie in South Australia. The resident noted in his

diary that there was “drumming all night”. Further enquiry indicates that the perception of the level of drumming sound changes and is not constant. This is a candidate for amplitude modulation that is also observed in the recorded data.

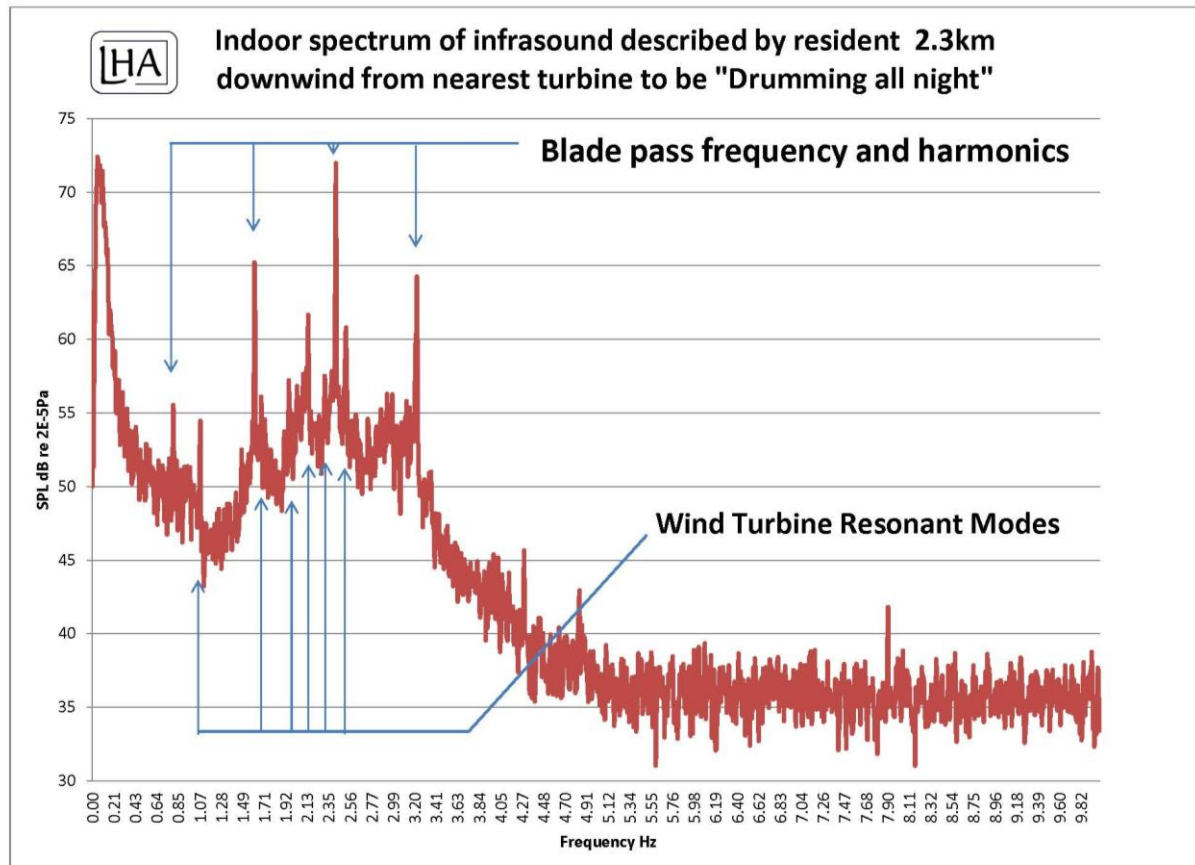


Figure 8 Average 20-minute spectrum causing an observed drumming

CONCLUSIONS

The data recorded and analysed so far suggest that data sample rates greater than 100ms would be advantageous to better quantify AM.

An Impulse response is recommended for sound level recording.

PSD averaging should include peak spectrum values although more work in this area of analysis is required, that should also include the envelope of AM and AM repetition rate change of blade swish from multiple wind turbines.

AM is observed in the infrasound frequency range and should not be discounted.

Some of the questions yet to be answered for planning authorities and regulators are:

- What amplitude modulation should be deemed acceptable?
- Is there a simple compliance method available using spectrum analysis of amplitude modulated levels (perhaps the renewableUK OAM with modifications)?
- How do we address the beating between multiple turbine amplitude modulations?
- Should an extra penalty apply to an envelope of amplitude modulation or rate of change of amplitude modulation frequency caused by multiple turbines?
- Should we consider the full acoustic spectrum below 20Hz and can infrasound pressure variations below 7 Hz themselves be considered to be amplitude modulation?
- Is it appropriate to low pass filter A-weighted measurements below 1kHz for AM?
- Should AM be specified in 1/3 octave bands?