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A new methodology for investigating ILFN complaints

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ABSTRACT

The methodology employed in the Cape Bridgewater study started from resident's diaries of disturbances whilst noise monitoring was occurring. The procedure then took weather data, wind farm operating data and noise data as post-processed data to compare with the diaries to find trends where specific wind farm operations corresponded to the report disturbances. A similar procedure occurred for investigating "noise" complaints from residents concerning a coal-fired power station and a large ventilation fan for an underground coal mine. Limitations in obtaining high-quality full-spectrum wave files were encountered. Typical Class 1 sound level meters have storage limitations of 1 – 2½ days for such high-quality samples. Using multichannel systems such as a Bruel & Kjaer Pulse are expensive and lead to very large storage requirements. Utilising the study procedure resulted in the development of a relatively low cost, two-channel, full-spectrum data recorder for field use, coupled with simultaneous biometric monitoring. The methodology has been successfully employed/developed. The opportunities now available for more detailed processing of this data, together with linking the disturbances to the startle reflex is discussed.

INTRODUCTION

Typically, compliance monitoring in relation to industrial noise sources is assessed in terms of permit conditions that generally are expressed in the A-weighted Leq value. Depending upon the noise source of concern the permit conditions may specify that such noise is to be broadband and free tonal or intermittent components, whilst in relation to wind farms there is no such specification. Some regulations or standards for wind farms may require adjustments due to special audible characteristics.

When dealing with complaints associated with such noise sources, Environmental Authorities or the operator of the noise source in question only look to the criteria in the permit conditions – generally in dB(A). However, investigations in response to complaints require a different methodology if one is serious about identifying, resolving and preventing those problems.

When the noise source is low-frequency music from nightclubs or similar, one can undertake on-off tests for identifying the occurrence and source of the noise in the complainant's premises. Whether the noise is audible or inaudible to the persons conducting measurements is not relevant, because in some situations the complainant may have developed a heightened sensitivity to the low-frequency music that is audible to them, but can be inaudible to testing authorities or the consultant employed. The complaint can be investigated by simple on off testing of the music, without the complainant being aware of what is occurring.

In relation to large industrial complexes that may have thousands of noise sources, a more detailed approach is required in relation to investigating the complaint. It is very important to take account of the operating scenarios at which the time the disturbances are alleged to have occurred. In such situations, the benefit of a diary format from residents that can be compared with the operation of the plant is essential.

Going back 30 years ago one relied upon audibly tracking down low-frequency noise and/or the use of graphic level recorders or similar, to monitor the linear output of the sound level meter and/or vibration as part of the investigation, supplemented (if possible) by narrow band analysis.

Successfully identifying noise sources of infrasound or low-frequency noise ("ILFN") complaints in industrial premises was primarily trial and error, and being aware of the various relatively large noise sources on the site that operate at low operating speeds or involve pressure fluctuations that could be the source of the complaint.

It has been observed that in many cases of ILFN noise complaints the matter of perceived vibration and noise in the infrasound and low-frequency regions are interchangeable. Often there is an incorrect identification by the complainant's (and in some cases by consultants or regulatory authorities) of noise versus vibration.

Such a situation has occurred with the development of wind farms in relatively close proximity to residential premises, and similarly with large power stations or underground mines that have induction fans or ventilation fans respectively, running at low speed and transferring large volumes of air.

THE FIRST STUDY

One such investigation that was specific in relation to the operation of a wind farm was over the Cape Bridgewater wind farm in south-west Victoria, in Australia, where a specific brief was given by the wind farm operator to:

- undertake sound and vibration measurements to ascertain certain wind speeds and certain sound levels that related to disturbances reported by specific local residents.

The situation of the specific local residents was that six people had been identified as complaining as to being adversely affected by the operation of the wind farm for a number of years.

Under a very specific brief [1], unlimited access to the wind farm was provided for the purpose of conducting measurements, in addition to unlimited access to the residential dwellings with the continuous monitoring at the residential locations occurring for two months.

Despite requests to undertake simultaneous medical studies and sleep disturbance studies at the time of monitoring, which would have provided useful objective physiological data in addition to the diary observations of the residents, those requests were denied by the wind farm operator. The investigation was restricted to the matter of noise as a primary function supplemented by vibration measurements, together with the diary observations.

Based upon a study conducted for the Waterloo wind farm in South Australia [2], the survey questionnaire was modified by the residents in the Cape Bridgewater study to address their perception of "noise" complaints.

As a result of using a modified questionnaire on a five-point rating scale [3], that considered "noise", separately to "vibration", that in turn was separate to "sensation", the investigation then tracked the power output of the wind farm to determine certain wind speeds that related to the disturbance disturbances perceived and recorded by the residents. The residents were unaware of the results of the acoustic measurements, and much of the time inside their homes could not see wind turbines.

To identify the second part of the project brief required recordings of the noise levels during the investigation.

The analysis of wind farm noise in Australia is based upon 10 minute samples and normally utilises the LAeq parameter. An examination of the A-weighted values could not find any relationship to the complaints. However, a change in the power settings of the wind farm identified a pattern with the reported disturbances.

The meters selected for monitoring purposes have the capability of recording wave files for subsequent analysis, that with the inclusion of GRAS 40 AZ microphones permitted full spectrum noise down to 1 Hz.

Contrary to a claim of just looking at infrasound [4] the Cape Bridgewater study looked at full spectrum noise recordings with analysis of the normal acoustic parameters, then followed by 1/3 octave bands and various other parameters identified as having a possible relationship to wind turbines. Having been through a host of acoustic parameters the assessment then considered low-frequency and infrasound components associated with the turbines to identify the typical signature that is associated with wind turbines.

In dealing with the Cape Bridgewater study, limitations in terms of storage capacity for wave files was dependent upon the sample rate and the number of bits being used. In the Cape Bridgewater study using SVAN 979 Sound level meters the meter software in 2014 was limited to 32 Gb of storage either as internal or external storage, thereby giving a capacity of 14 days of continuous monitoring. Use of Bruel & Kjaer Type 2250 sound level meters, with 24-bit sampling and high quality mode with a maximum of 32 Gb card had a limitation of less than two days.

The use of a multichannel system (Bruel & Kjaer Type 3560D Pulse system with 23 channels of recording) resulted in the PTI data source files over some nine weeks of monitoring. When added to the SVAN results, over 9 Tb of data was produced.

Storage capacity of the sound level meters required attendance every two weeks to download data during the course of monitoring. There were capacity issues of the sound level meters saving wave files that involve failures of USB hard drives and USB sticks with a question still unanswered as to whether electromagnetic fields associated with the turbines had caused these unusual equipment problems.

THE SECOND STUDY

A similar procedure in relation to the investigation of a large ventilation fan for an underground coal mine involved continuous acoustic monitoring and analysis in conjunction with residents' diary observations, but was unable to specifically relate specific complaints to the operation of the underground coal mine during that investigation period [5], due to the mine operator declining to undertake on-off testing. Analysis of the diaries and full spectrum acoustic data (as well as power station operational data) resulted in identification of periods of low-frequency noise with pulsations occurring at an infrasound rate which were attributed to a coal-fired power station as the principal source of those disturbances.

Some 12 months after the initial study of the complaints related to the coal-fired power station and ventilation fan, acoustic monitoring was conducted concurrently with a team from Massey University in New Zealand, who were also collecting concurrent physiological data with biometric monitoring. The diary format used in the Cape Bridgewater study was further modified by the New Zealanders [6].

Our monitoring involved the SVAN 979 meters for full-spectrum monitoring and micro-barometers for concentrating on just the infrasound region.

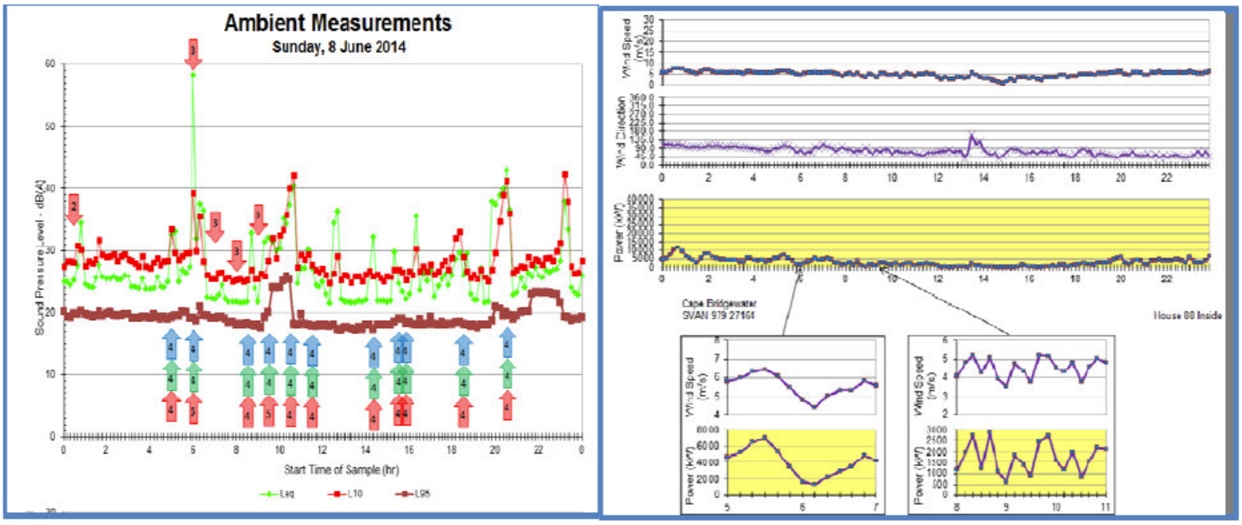
With the assistance of SVANTEK the software for the Wave file weighting in the meter had been modified after the Cape Bridgewater study and permitted a maximum storage of 64 Gb as a microSD card. This permitted longer monitoring periods at a medium sample rate for wave files. However, if the highest quality way file recording was selected for a specific period of testing, such as during a power station shutdown, then the higher performance of monitoring still limited the higher quality of wave files to 5 days.

The limitations in storage capacity of current sound level meters led to the development of the SAM Scribe [7] which is a two-channel full-spectrum data recorder for field used that uses a hard disk to record the data. Data storage capacity can therefore vary according to the size of the hard disk.

Additional investigations of ILFN in rural and urban areas for simultaneous measurements using the SAM Scribe and the Bruel & Kjaer Data Recorder have revealed consistent results.

RESULTS

Using standard 10-minute logger results we plot the A-weighted statistical levels over days and insert the resident's diary comments. If the power output of the source is available that data is included with the above results (Figure 1).

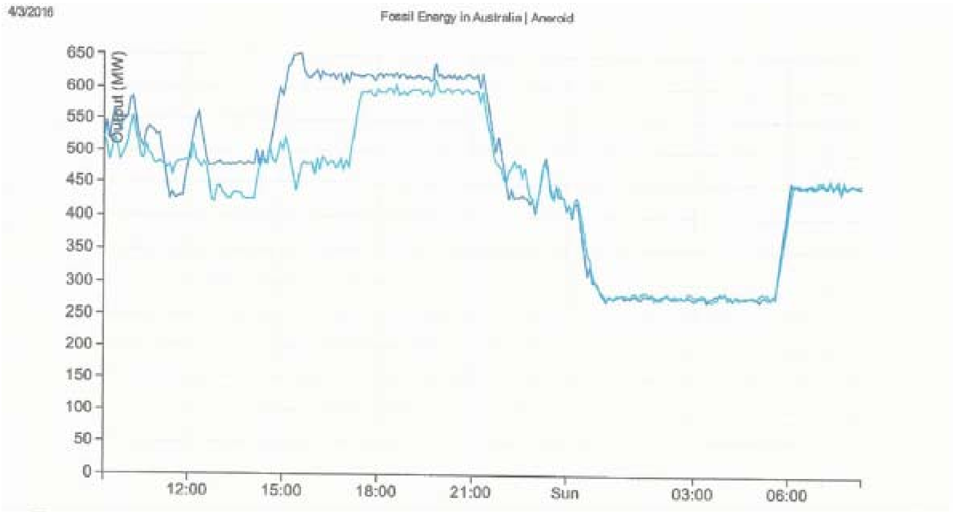


dB(A) results

Wind Farm Power Output with expanded views

Figure 1: Cape Bridgewater Complaint Identifiers

When coupled with the relevant diary response (that is in some cases difficult for residents subject to severe disturbance to continue such reporting) this permits thorough assessment of the noise with a much wider scope of data and additional evaluation processes (Figure 2).



- 2pm Subject 1 claims head starts pounding
- 2.10pm subject 3 is swaying (unsteady)

Figure 2: Output of power station

When coupled with simultaneous biometric monitoring, the diary format that accompanies the study procedure permits more accurate identification of the wave files of concern (corresponding to the complaint).   When coupled with power output of the noise source, the data revealed that there are certain operating parameters that give rise to a greater level of disturbance. The question that then comes to the fore is what acoustic signatures correspond to the reported disturbance?

The use of high-quality wave files that cover the full-spectrum permits further analysis to identify the relationship of the acoustic signature at the time of disturbance versus normal operations.

The primary analysis tool used in the above various studies is the Bruel & Kjaer Reflex program. With the appropriate calibration signal the Wave files from the SVAN 979 and SAM Scribe can be used (Bruel & Kjaer Pulse/Data Recorder are automatically calibrated with Reflex).

Our analysis standard protocol derived from the above studies evaluates any wave file into dB(A)/dB(C)/dB(Lin) trace over time, 1/3 octave bands as Leq, Sonogram and Waterfall plots, narrow band 0-4K Hz, 0-1K Hz, 0-400 Hz, 0-100 Hz, 0-50 Hz and 0-25 Hz as Leq spectra, Sonogram and Waterfall plots.

A methodology that has been developed during the above investigations has involved production of a movie plot to show the time variation signal. The movie of the frequency and amplitude variation identifies the presence of both frequency modulation and amplitude modulation [8].

The movie format has permitted looking in either 1/3 octave or narrowband spectra for a specific time signal to find amplitude modulation. Amplitude modulation is not restricted just to wind farms but also occurs for large ventilation fans associated with power stations and in this case an underground coal mine.

The analysis methodology employed has identified that on a narrowband basis, one can determine infrasound signals but on a time basis one can establish that the operation of the industrial noise source can produce amplitude modulation of clearly audible frequencies where the modulation occurs at an infrasound rate.

Using multi-channel data recorders in the field has permitted comparison of simultaneous measurements from outside to inside dwellings to identify the room effects on the nature of the signal recorded.

Figure 3 shows the results of biomonitoring during a field expedition where two of the noise sensitized residents experienced severe disturbance when entering a wave guide effect from operational wind turbines located over 3.5 km from the nearest turbine.

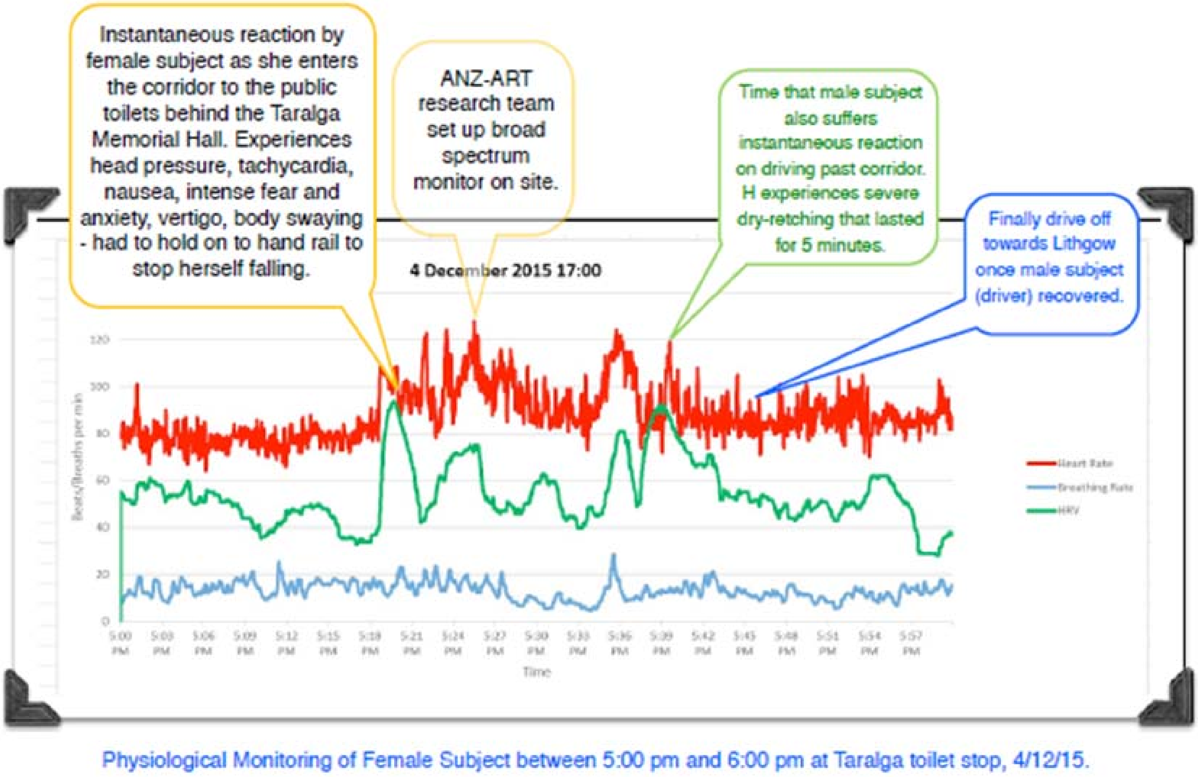


Figure 3: Resident's response to Taralga Wind Farm (Courtesy of Atkinson & Rapley Consulting P/L (New Zealand)

Figures 4 and 5 show a period of disturbance at night with a change in the output of a coal fired power station. The disturbance was documented by the residents, and this type of disturbance associated with change in power station output is not an isolated occurrence for these residents. Biometric monitoring (undertaken by others) reveals changes in the heart rate of the individuals coinciding with the reported disturbance.

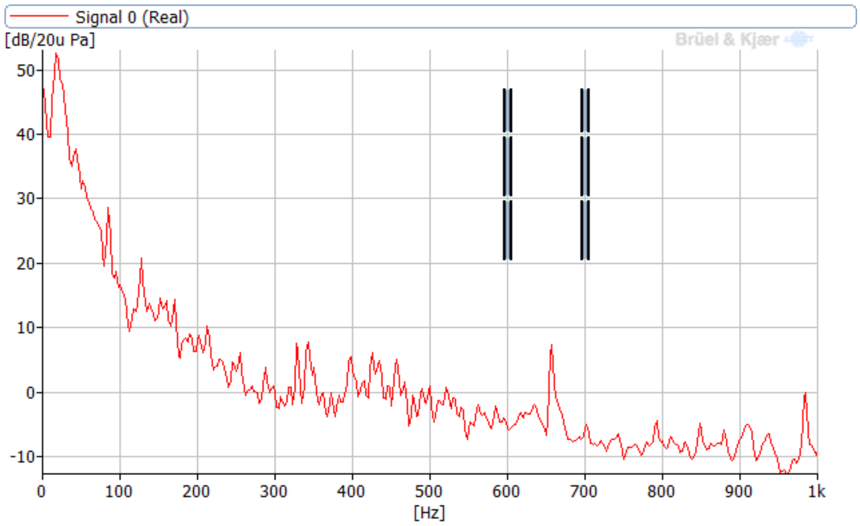


Figure 4: FFT relative to reported sleep disturbance (24 Oct 2016)

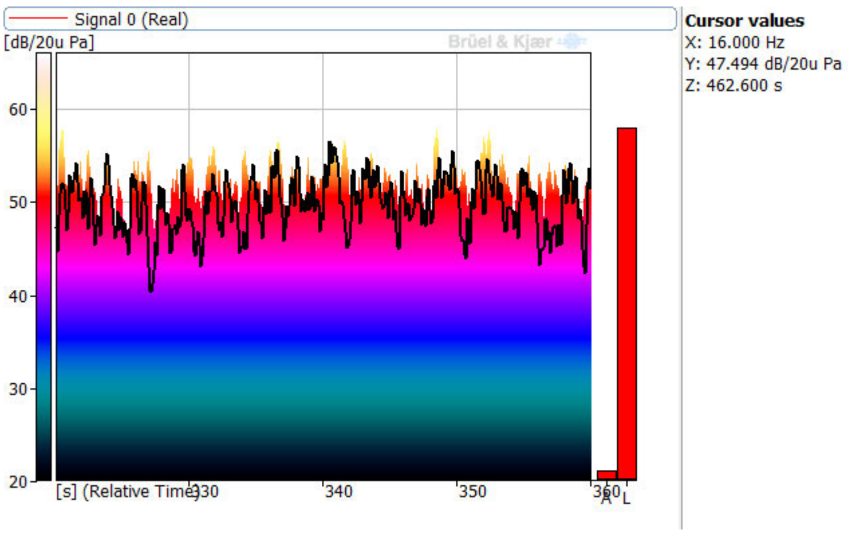


Figure 5: 16 Hz 1/3 octave band time signal relative to reported sleep disturbance for Figure 4

Griefhan and Basner [9] identified the increase in sleep disturbance from industrial sources (including wind farms) to be scarcely studied (when compared to aircraft/railway/road noise). Griefhan, Brode, Marks and Basner [10] analysed heart rate response to traffic noise occurring during sleep disturbance in sleep laboratory studies.

In order to investigate and precisely identify the specific acoustic triggers for the physiological stress response frequently reported by residents living near a range of industrial facilities, including wind farms, the above methodology using full spectrum wave file recordings, large data storage capacity, and concurrent portable biological monitoring in addition to diaries has merit in accurately identifying the acoustic triggers.

Disturbances, including those involving physiological stress episodes caused by acoustic triggers, can be identified by discrete episodes of acceleration of the heart rate when such biological monitoring is conducted concurrently, as detected in the Taralga data obtained by the New Zealand researchers (Figure 3 above). Biological monitoring which includes sleep and body movement data in addition to heart rate will provide useful additional data about the role specific acoustic triggers are playing, especially with respect to sleep disturbance.

In one instance transport of the portable acoustic monitoring equipment to various monitoring locations in close proximity to the noise sources has been undertaken by the residents themselves so as to have self-reporting of the disturbance, acoustic data, and also biometric monitoring at the same time. Specific acoustic triggers in the field were reliably identified using this methodology.

In one situation with respect to large ventilation fan for the coal mine whilst there is a strong infrasound component at 12 Hz, which has some variation in terms of airflow, the predominant audible noise that the residents are able to detect is a tone at 127 Hz, which is modulated approximately at a 2 Hz rate. In order to clarify whether or not this frequency was responsible for the reported symptoms of those particular residents, 127 Hz was reproduced in a controlled laboratory setting.

Reproducing a steady tone at 127 Hz in a laboratory situation did not cause residents of concern but modulation of that tone at an infrasound rate of 2 Hz did cause disturbance to the residents.

THE THIRD STUDY

Further examination of the full spectrum acoustic signature of operating wind turbines reveals amplitude modulation of the spectrum for levels at or near the threshold of hearing. In some instances, the depth of the modulation increases in the low frequency region when the "normal" audible "swish" component of the turbine becomes inaudible.

We have found from a limited study of a small number of residents who have become sensitized to ILFN sources [11], that they have a lower threshold of hearing in the low frequency region. When exposed to other industrial ILFN sources with the same characteristics (e.g. amplitude modulation) they also react to other sound sources, as happened at Taralga. This warrants further investigation, particularly because animal research has demonstrated sensitization to sound with impulsive characteristics, via repeated elicitation of the acoustic startle reflex [12].

Neurophysiological research has separately demonstrated that when acoustic, vestibular and tactile startle reflexes are stimulated simultaneously, that the physiological response is synergistic. It is therefore possible that an enhanced biological response is occurring in noise sensitized people exposed to amplitude modulated sound, if their acoustic, vestibular and tactile reflexes are simultaneously triggered [13].

As a result of the above attendance to the Capital wind farm in NSW (Australia) has been undertaken to obtain wave file samples for examination of the amplitude modulation [14].

Figure 6 is a short A-weighted graph that involved clearly audible amplitude modulation, barely audible amplitude modulation and no audible amplitude modulation.

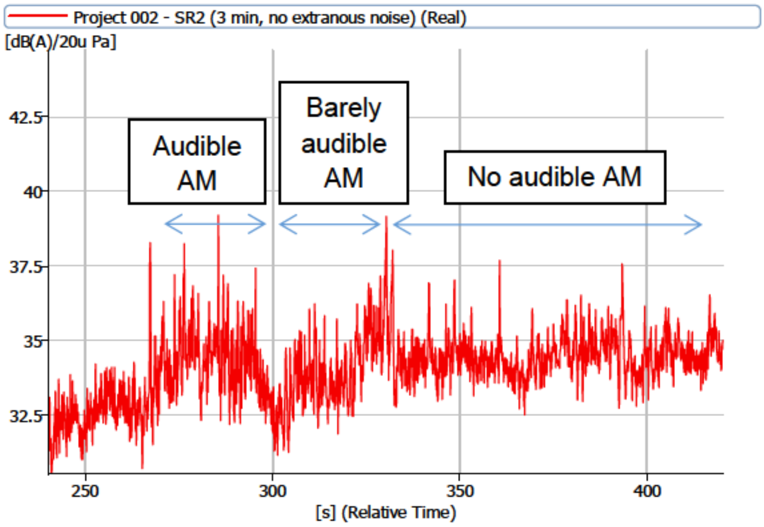


Figure 6: A-weighted time trace – Capital Windfarm

Figure 7 provides Linear weighting 1/3 octave band results for the three periods with identification of peak at 25 Hz.

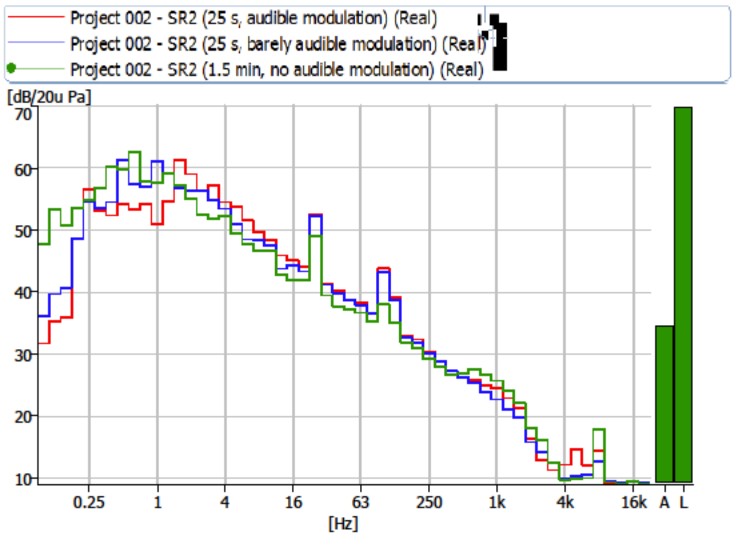


Figure 7:

Figures 8 – 10 show the corresponding time signal for the 25 Hz 1/3 octave band and the depth of modulation that was present.

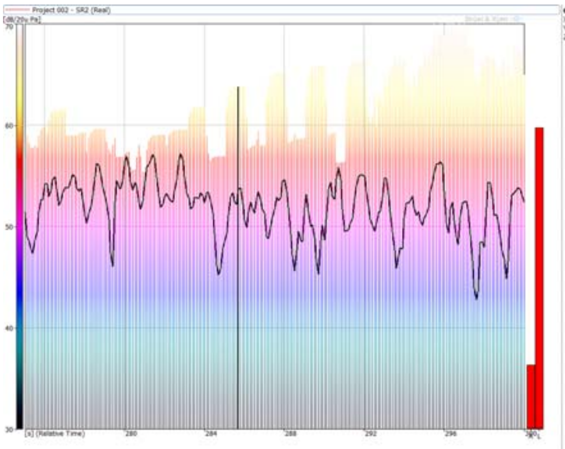


Figure 8:

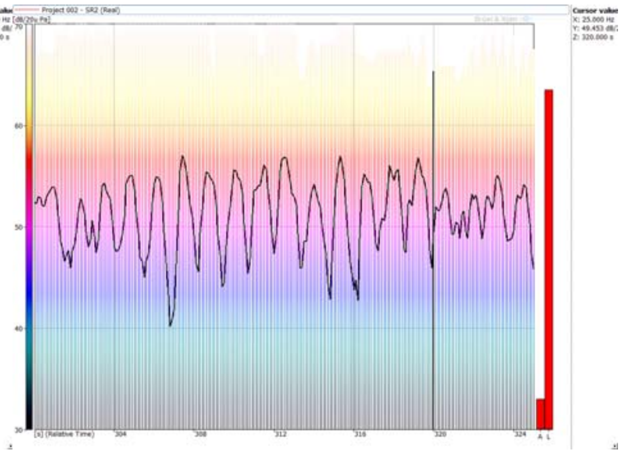


Figure 9:

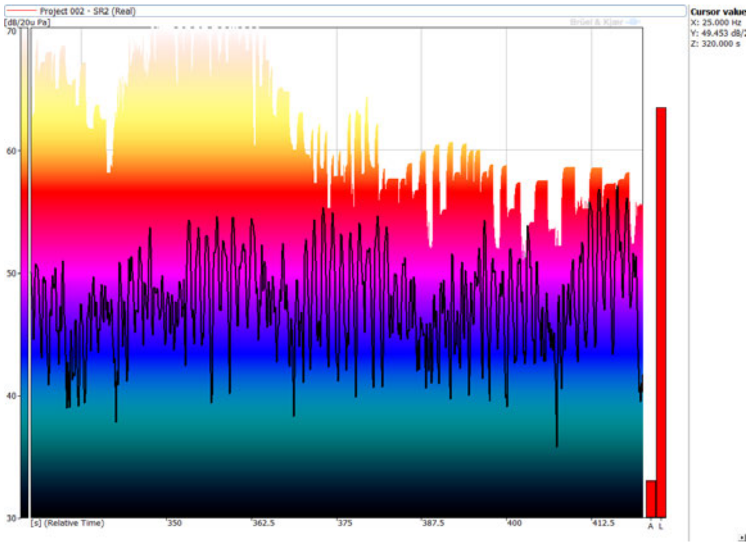


Figure 10:

The results to date have been presented using a single microphone.

Other researchers have suggested that there may be differences in the timing of the received signal in each ear in humans.

Two channel monitoring using a manikin head to obtain full spectrum stereo recordings for the same location have been undertaken. The aim of the stereo measurements was to identify:

- the pressure response at the individual's ear,
- look at timing considerations of the modulation, both in terms of the pressure fluctuations that the people are receiving and incremental differences between the two ears,
- undertake subjective testing of wind turbine amplitude modulation of mono versus stereo images.

The issue of peak level, crest factors, duration of pulses, duty cycles, and Leq levels are an additional area of analysis requiring further investigation [15].

CONCLUSION

Our work to date in using multi-channel extended monitoring (to obtain simultaneous inside/outside measurements) under different operating scenarios of ILFN sources has found that modulation of low-frequency noise at an infrasound rate that occurs at or near the threshold of hearing is able to trigger a response in individuals.

Narrowband analysis has identified the presence of discrete infrasound "components" for repetitive pulsations ("dynamically pulse amplitude modulation") that may simply be the result of the analysis, not necessarily the presence of such a signal.

The presence of amplitude modulation in the low frequency region, that modulates at an infrasound rate, at or near the threshold of hearing has been identified and may support the following proposal:

> "Wind Turbine Syndrome, I propose, is mediated by the vestibular system—by disturbed sensory input to eyes, inner ears, and stretch and pressure receptors in a variety of body locations. These feed back neurologically onto a person's sense of position and motion in space, which is in turn connected in multiple ways to brain functions as disparate as spatial memory and anxiety. Several lines of evidence suggest that the amplitude (power or intensity) of low frequency noise and vibration needed to create these effects may be even lower than the auditory threshold at the same low frequencies. Re-stating this, it appears that even low frequency noise or vibration too weak to hear can still stimulate the human vestibular system, opening the door for the symptoms I call Wind Turbine Syndrome." Pierpont 2009

With the latest development of technology and analysis that is available the provision of multi-channel data recorder for use in the field provides the acoustic starting point (when coupled with the appropriate analysis), that permits the medical investigations necessary for ascertaining the impacts of infrasound and low-frequency noise.

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