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MEASURED PERFORMANCE OF A DIRECTIONAL NOISE MONITORING SYSTEM

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Abstract

The BarnOwl directional noise monitoring system provides direct measurement of the noise level at a monitoring location due to sources in a specific direction or directions. Source directions are separated based on the strength of peaks in the cross-correlation between signals at three microphones. The system is currently deployed at a number of sites throughout Australia. This paper presents results of system performance tests conducted under controlled conditions in an anechoic room. The angular resolution, frequency response and noise rejection characteristics are presented and discussed. The system provides industry and regulatory authorities with a reliable method of monitoring noise levels from specific sources in real time, and can be used both as a management tool and a formal reporting mechanism.

1. INTRODUCTION

In Australia over recent years, a number of large industrial sites have adopted directional noise monitoring techniques to assess and control the noise from their operations. These systems provide real time information on noise arriving at a monitor from any specified direction, and hence allow extraneous noise from sources such as traffic or other industries to be removed from the reported levels. This provides the ability for a site to control its noise level at sensitive receivers in real time, as well as giving improved tools for long-term reporting and compliance monitoring.

The BarnOwl system is described in more detail in Reference [1]. It samples an incoming noise signal at three microphones, nominally 500mm apart in an equilateral triangle, and calculates cross-correlation functions between the three pairs of signals. Local maxima in each of these three functions are identified, and converted to a time delay between the two microphones concerned. A sorting algorithm then identifies sets of three delays which could represent a source in the same physical direction (to within a specified tolerance in angle). All such sets are taken to represent a physical noise source, and the sound level of that source is given by the total measured sound level of the sample multiplied by 10log(C), where C is the mean of the three local cross-correlation maxima. One or a number of sources may be identified in each sample.

This process is repeated for each sound sample. Samples are typically 0.5-1 seconds in duration depending on reporting requirements. Noise from sources within specified angle ranges can be accumulated and reported over logging periods of typically five minutes.

In a more recent development, the above process is repeated after applying various alternative filters to the sound sample. This provides better detection of sources whose frequency content differs significantly from the extraneous noise.

This paper discusses factors that limit the performance of the above system, in terms of angle resolution, frequency response and noise rejection (or ability to detect a source in the presence of extraneous noise). The measured performance of the current BarnOwl system is presented, based on controlled tests conducted in a large anechoic room.

2. FACTORS LIMITING PERFORMANCE

2.1 Physical Limitations

The BarnOwl system uses three Bruel & Kjaer type 4198 external microphone kits, mounted on a flat horizontal plate as shown in Figure 1. The physical size of the microphones and the presence of the plate will clearly have an influence on the level and phase of the received sound, particularly at high frequencies, and hence affect the cross-correlation results. In particular, where a source is located exactly on the line between one microphone and another, there is a potential for diffraction around the closer microphone to interfere with the signal received at the further microphone.

Figure 1 Typical Field Microphone Setup

2.2 Limitations Due to Signal Autocorrelation

If the received signal has maxima in its autocorrelation function (at delays other than zero), then these maxima will also be present in the between-microphones cross-correlations. This gives greater potential for "detection" of spurious sources if some of these maxima happen to correspond to delays that could represent a physical source in some direction. Autocorrelation maxima from a louder source can also act to mask cross-correlation maxima from a lower level source, making the lower level source harder to detect. Autocorrelation maxima occur for two reasons.

- Limited Bandwidth Sources: A pure-tone source at above approximately 700Hz (for 500mm microphone spacing) will introduce additional maxima into the signal's autocorrelation function that are equal in strength to the "true" (zero-delay) maximum, and are at delays that could result in spurious sources being "detected". The probability of this occurring decreases as the source bandwidth increases. At a 3dB bandwidth of approximately ⅓ octave, the highest additional autocorrelation peak is approximately 3.5dB below the main peak, and at 1 octave bandwidth it is approximately 10dB below. Hence the system can be expected to be more reliable for source bandwidths of about ⅓ octave and above.

- Reflections: Significant reflections where the path length difference between direct and reflected sound is between about 8mm and 500mm will also result in additional cross-correlation maxima, and potential "detection" of spurious sources. For ground reflections, the path length difference is generally less than 8mm, and in any case these grazing incidence reflections are usually accompanied by other effects that reduce the resulting autocorrelation peak. Reflections from hard vertical surfaces are minimised by ensuring that the monitor is at least 4m from any large reflecting surface. The effect of reflections is not explicitly quantified in the measurements reported below.

2.3 Limitations due to Extraneous Noise

As the noise level of the signal to be detected becomes lower compared with the ambient noise, at some point the cross-correlation maxima associated with the source are lost among small random maxima in the cross-correlation function for the remaining noise. If the ambient noise contains a strong signal from another source, particularly a low-frequency source, the resulting large broad maxima in the cross-correlation function have a greater chance of obscuring maxima associated with a weaker second source.

The lowest detectable source level, expressed in terms of decibels below the total ambient level, depends to a significant extent on the nature and directionality of the ambient noise. An important purpose of the measurements reported below was to investigate how this parameter depends on those factors.

2. MEASUREMENT PROCEDURES

Measurements were conducted in the large anechoic room at the National Acoustic Laboratories, Sydney, measuring 11.6m x 9.0m x 7.1m (between wedge tips). The setup is shown in Figure 2.

A loudspeaker source was located in one corner of the room, with the cone approximately 500mm from the inside of the wedges. The measurement microphones were located at approximately 2m from the opposite corner, giving approximately 11.2m between the source and microphones. Unless otherwise noted, microphones were aligned so that the apex of the triangle axis points to the centre of the speaker. This alignment is accurate to an estimated 2°.

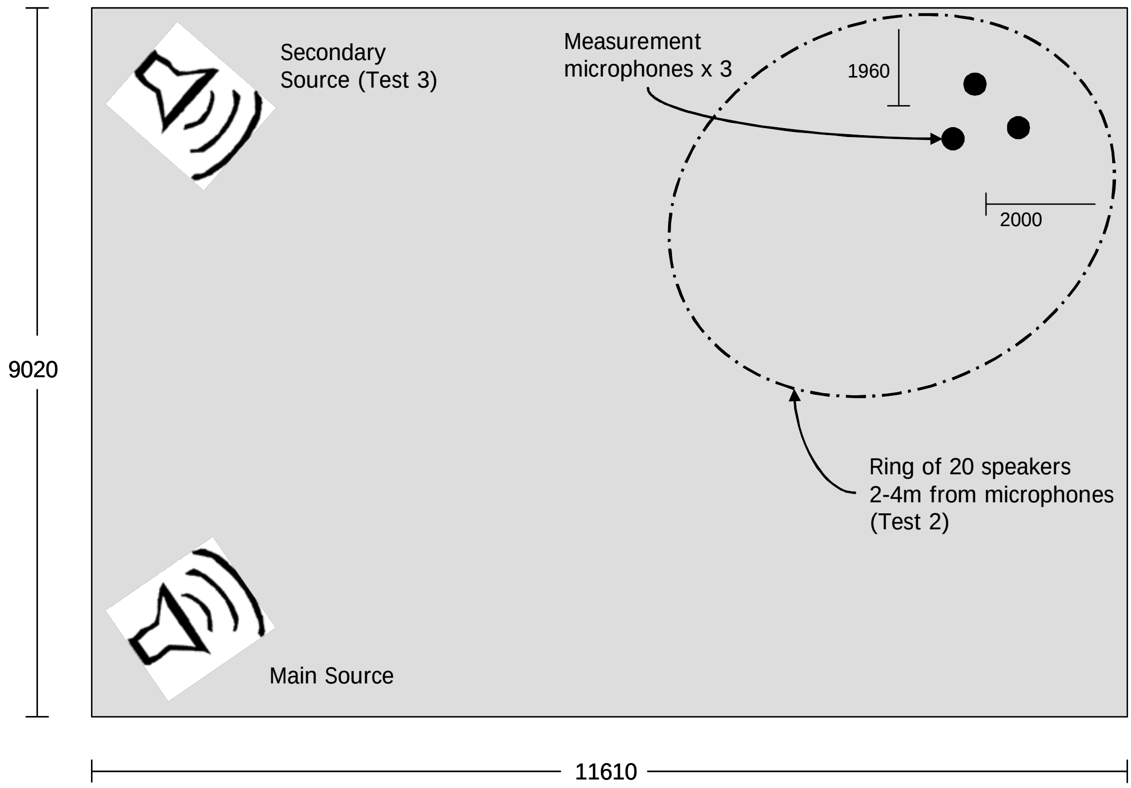

Figure 2 Setup of Measurement Procedure

The test sounds played through the speaker (and other sources described below) were pre-recorded broadband pink noise; octave and third-octave filtered pink noise; traffic noise; and speech. These represent a range of sounds, in terms of both frequency and time variation. Ambient noise in the room was below 10dBA, and well below any measured level from the test sources. Three sets of tests were conducted, as follows.

- Test 1 – Sound from the source was detected in the absence of other sound. The angle at which a source is detected gives confirmation of the accuracy of direction measurement. The measured sound level from the source was compared with the level measured by a reference microphone (Bruel & Kjaer type 4133), after removing the BarnOwl microphones, mounting plate and tripod. This indicates the level accuracy of the BarnOwl system, as a function of frequency. A-weighted levels were measured, so this test includes the accuracy of BarnOwl's A-weighting filter. By turning the microphones, the effect of interference by the microphones themselves was investigated.

- Test 2 – 20 small speakers were arranged roughly in a ring around the microphones, and configured to play either uncorrelated pink noise or traffic noise, with each speaker producing the same L_{eq} noise level (to within 1dB) at the microphones. (In the case of traffic noise, all speakers played the same 30 sec section of noise in a loop, but starting at different times, ensuring that the total L_{eq} noise level over any 30 sec period is reproducible.) This represents a typical ambient noise environment with no pronounced single noise source. The sound level from the main source was varied from well above the level from the small speakers to well below it, and the sound level detected from the source direction was recorded.

- Test 3 – A second main speaker was added, at a different direction, as shown in Figure 2. The detectability of the initial source was studied, as a function of the sound level from the secondary source and the "ambient" sources.

3. RESULTS

3.1 Test 1

3.1.1 Direction measurement

The BarnOwl algorithm accumulates source noise levels into angular "bins" of width 5°. In the standard test configuration, the main sound source was aligned at an angle corresponding to the junction between two "bins". In this case, whenever the source was detected, it was in one or both of these two "bins". Hence the angular accuracy of the system can be conservatively stated as ± 5°. In the following, the sound level "from the source direction" refers to the total sound level recorded as arriving in these two "bins".

3.1.2 Level measurement

Figure 3 shows the accuracy of measured levels of third-octave band filtered pink noise, in the absence of other noise.

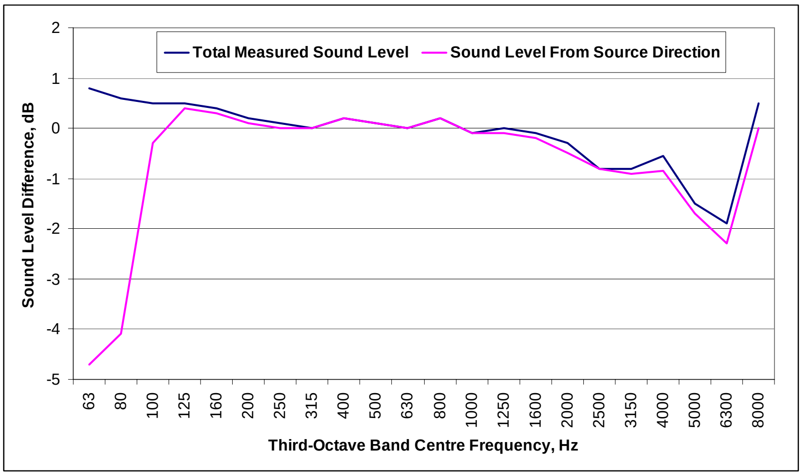

Figure 3 Difference between sound level measured by BarnOwl and by a reference microphone – Third-octave band filtered pink noise

At frequencies below 100Hz, BarnOwl's total measured noise level agrees with the reference microphone to within 1dB, but allocation of this noise to a source direction is impaired. This is because at these frequencies the cross-correlation maximum is very broad, and statistical fluctuations can affect the position of a local maximum, to the extent that in some samples the source direction cannot be detected. Above 2KHz a correction is necessary due to the directional characteristics of BarnOwl's Type 4198 microphone kit when used at 90° incidence, and this published correction is incorporated in Figure 3. The measured response is still more than 1dB low at 5KHz and 6.3KHz, presumably due to reflection effects from the microphone assembly.

However, in the most important frequency range 100Hz-4KHz, the measured noise level from the source direction is within 1dB of the true level in all third-octave bands, and is within the required tolerance for a Type 1 SLM. Results are within the required tolerance for a Type 2 SLM at all frequencies between 100Hz and 8KHz.

This test also confirms that autocorrelation effects do not limit source detection if the source bandwidth is at least ⅓ octave.

3.1.3 Microphone shielding

When two microphones were aligned exactly with the source, and at the same height, the source was generally not detectable due to interference effects. The range of angles over which this occurs depends on the source frequency, and was somewhat inconsistent between trials. However, a high-frequency (pink noise) source may be undetectable over a range of 5-7° either side of the alignment angle, while for a low-frequency (traffic noise) source the undetectable range was about ± 2.5°. If the microphone plate is tilted slightly (2.5°) toward the source, traffic noise is detectable at all times. Pink noise may still be undetectable within ± 5° of the alignment angle.

3.2 Test 2

Figure 4 shows typical results for source detection in the presence of non-localised background noise. It shows the measured noise level from the source direction where the source is producing pink noise, traffic noise and speech at various levels relative to the (pink noise) background. The measured source level is accurate to 1dB for source levels down to about 10dB below the background, and to within 2dB down to about 15dB below the background. Below this, the source becomes undetectable. Similar results were obtained where the background noise was traffic.

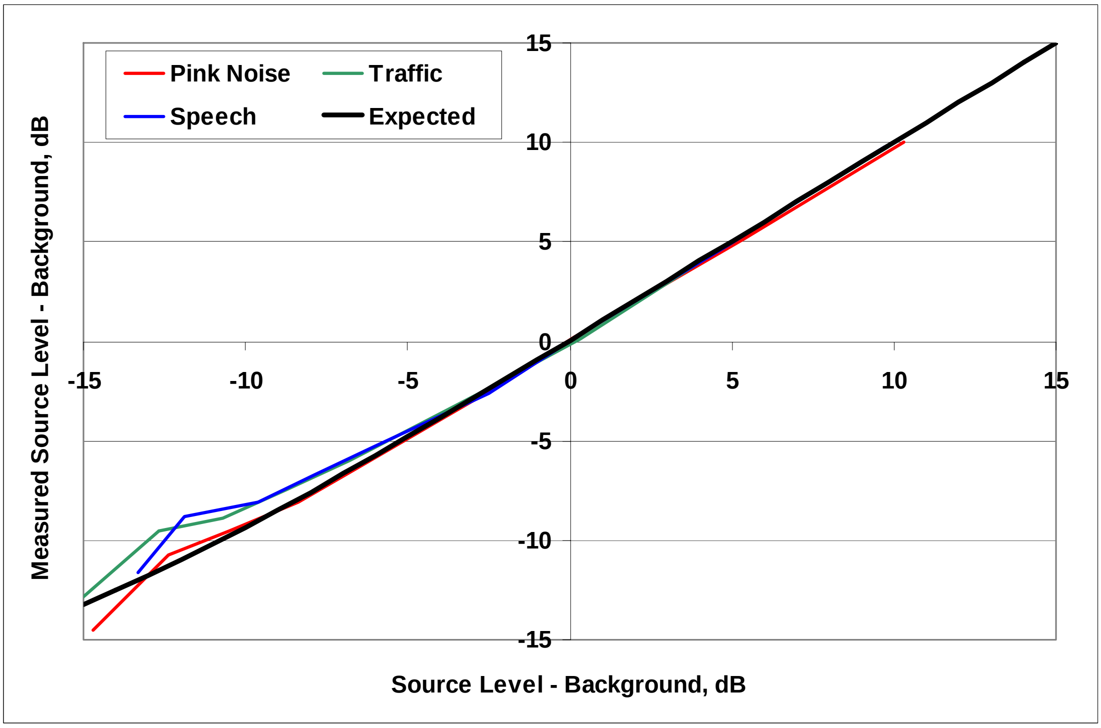

Figure 4 Accuracy of source detection in background (pink noise)

3.3 Test 3

Where the background noise contains another localised noise source apart from the one to be measured, source detection is not as good as shown in Figure 4. Figure 5 shows results for the case where the non-localised background, a single point source in the background, and the source to be detected are all represented by recorded traffic noise.

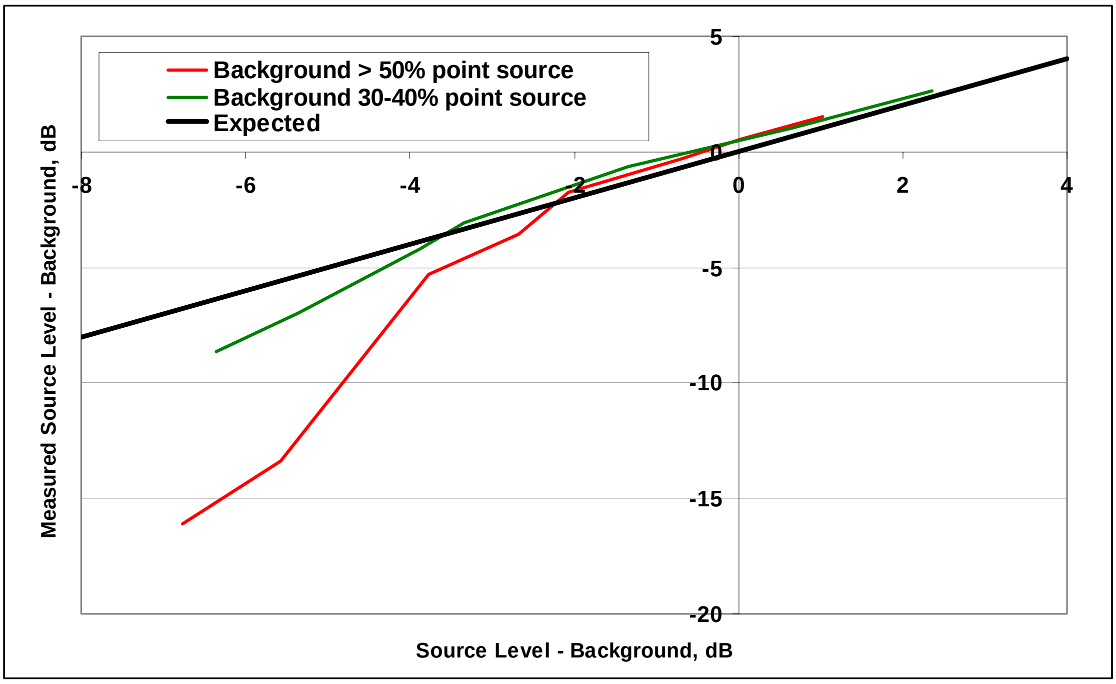

Figure 5 Accuracy of source detection in background containing a point source

Where a point source represents more than 50% of the background noise, a second source can be accurately detected to about 3-4dB below the total background level. Below this, detection is unreliable and the reported level will be lower than the true level.

Where a single point source represents 30-40% of the total background, a second source can be detected to about 6dB below the total background level.

Results consistent with these were also found with other combinations of noise types for the non-localised background and localised sources.

4. CONCLUSIONS

A directional noise monitoring system using BarnOwl's cross-correlation principles can provide a significant improvement over non-directional monitors in identifying the noise level from source that is localised in direction. In particular:

- Where other noise is generally non-localised in nature, the level from a source can be measured within 1dB down to approximately 10dB below the ambient level, or within 2dB down to approximately 15dB below the ambient.

- Where the remaining noise contains other localised sources, detection capability is somewhat more limited, as indicated in Figure 5, but still extends to at least 3dB below the ambient level.

- There are "blind spots" in detectability where the source is exactly aligned with the line between two microphones. The width of these depends on source frequency, and for a low-frequency source (traffic noise) the "blind spot" can be eliminated by tilting the microphones 2.5° toward the source.

- Although detection of pure tone sources above about 700Hz is problematic, sources with a bandwidth of at least ⅓ octave can be detected reliably. Level accuracy for source detection is within the requirements for a Type 1 sound level meter between 100Hz and 4KHz, and a Type 2 sound level meter between 100Hz and 8KHz.

REFERENCES

[1] R. Bullen, "A system for automatically detecting the direction of noise sources", *Proceedings of Australian Acoustical Society Conference, 2001*, B.5.5 1/7–7/7.