PROPAGATION OF SOUND BEHIND VEHICLES EQUIPPED WITH DIFFERENT BACKUP ALARMS

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1. INTRODUCTION

In the last few years, a new type of acoustic signal has been introduced for vehicle backup-alarms and has drawn increasingly more interest from many industrial sectors. This signal, based on the use of broadband noise, sounds rather different from the typical tonal ("beep") signal and is deemed to reduce annoyance for residents living in close proximity to industrial settings and construction sites. From a safety perspective, the broadband signal is believed to be more efficient in terms of spatial localization and uniform sound propagation behind vehicles, thus reducing the risk for workers. While conceptually appealing, few published and peer-reviewed scientific studies have demonstrated the advantages and disadvantages of such an alarm signal to ensure worker safety, particularly in comparison to existing technologies (Burgess and McCarty 2009; Homer 2008; Withington 2004). This study focused on sound propagation behind vehicles by examining the distribution of sound pressure levels for three types of backup alarms: the standard tonal "beep" signal, a multi-tone signal and the broadband noise technology. Sound pressure levels were measured at various fixed locations behind heavy vehicles by using a test method inspired from the ISO 9533 standard (1989). Sound propagation contour maps were also obtained for various vehicles and terrain configurations.

2. METHODS

Three backup alarms were tested in this study: i) a standard tonal alarm; ii) a broadband alarm and; iii) a custom-made multi-tone alarm. The multi-tone was proposed by Laroche (1995) as an improvement over the conventional tonal alarm and was included in this study for comparison with the two other signals. The frequency content of the alarms is illustrated in Figure 1. The multi-tone alarm consists of three major tones between 1000 and 1300 Hz, in contrast to the standard tonal alarm with its acoustic energy concentrated around 1250 Hz. For the broadband alarm, energy is distributed over a larger frequency span, most of the energy being found in the 700-4000 Hz range.

Field tests were performed at three different locations: a sawmill site, a limestone, and a quicklime plant, all with various terrain configurations (hard soil or gravel & dirt) and vehicles. The tested vehicle was stationary and two mounting scenarios of the alarm were considered: i) a "realistic" one, which consisted of using the alarm as installed on the vehicle (the alarm was off-centered in all three cases tested) and; ii) an "ideal" one where the alarm was centered, unobstructed and facing outward.

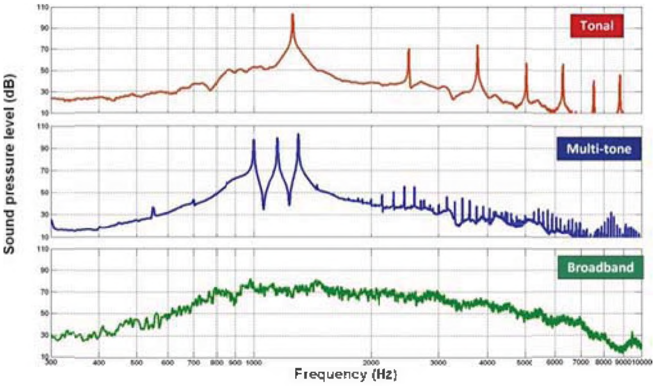

Figure 1: Frequency content of the three alarms tested

Two sets of measurements were performed for each alarm. In the first set, alarm level adjustments were performed by measuring sound pressure levels at the seven fixed microphone positions specified in the ISO 9533 standard (see Figure 2(a)). The alarm level was manually adjusted so that a difference equal to or greater than 0 dB (signal-to-noise ratio $S/N \geq 0dB$) was obtained at all measurement points between the noise levels generated when the vehicle was operating at high idle without the alarm and those prevailing when the reverse alarm was activated and the vehicle operated at low idle. The procedure was repeated for each alarm to determine if one alarm type would require higher levels than the others to maintain the desired $S/N \geq 0$ dB at all microphone positions. In a second set of measurements, a microphone was mounted to a pole and digital audio time recordings were performed while the alarm was activated by moving the microphone slowly along 9 axes and 2 curvilinear arches behind the vehicle (see Figure 2(b)). The alarm levels were set at the values found during the first set of measurements and the vehicle engine was stopped. A post-processing scheme was developed to extract the alarms' sound pressure levels along the various lines. Afterwards, an interpolation algorithm was used to produce sound pressure level contour maps behind the vehicle when the alarm is activated. Such procedures were used to investigate the uniformity of the sound field generated by each alarm.

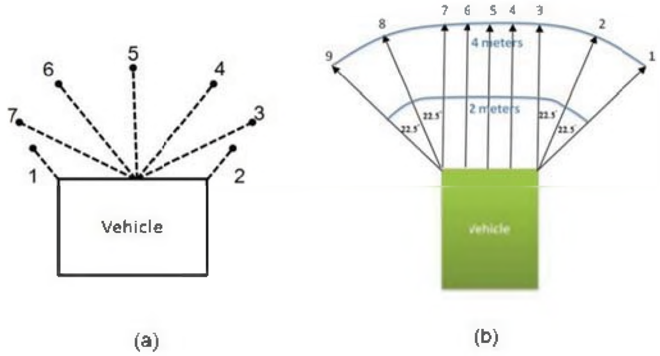

Figure 2: (a) Position of the microphones during alarm level adjustments; (b) Illustration of the scanning lines for sound mapping measurements

3. RESULTS

3.1. Alarm level adjustments as per ISO 9533

Results obtained for the "S/N≥0 dB" procedure are summarized in Table 1. For each alarm and site, the mean and standard deviation of the S/N ratio is presented, as well as the sound pressure levels at a reference microphone located 1 m directly in front of the alarm device. It should be noted that higher levels were required for the tonal alarm compared to the multi-tone and broadband signals. Also, higher mean S/N ratios and standard deviations were obtained for the tonal alarm, suggesting more sound level variations for this signal.

Table 1: Mean (standard deviation) values of the S/N ratio (expressed in dB) & sound pressure levels (in dBA) at the 1m reference microphone (alarm position: "ideal" mounting).

	Site 1		Site 2		Site 3	
	Mean (std)	Level @ 1m	Mean (std)	Level @ 1m	Mean (std)	Level @ 1m
Tonal	6.9 (4,2)	107.2	8.0 (5.9)	112.0	3.2 (2.3)	106.0
Multi-tone	3.9 (2,3)	99.4	5.4 (4.0)	105.2	4.9 (3.1)	102.8
Broadband	1.9 (1.2)	99.3	3.1 (2.9)	104.9	1.0 (0.7)	102.1

3.2. Noise levels behind vehicles

Contour maps of the sound pressure levels behind a vehicle are presented in Figure 3 for one of the sites, with the alarms positioned in the "ideal" mounting condition. Variations in sound pressure levels on the order of 10 dB within a short range of ~1 meter can be observed for the tonal alarm due to acoustic interference effects. Such interference effects appear to be quite prominent for signals characterized by a single tonal component. However, they tend to be smoothed out considerably with the addition of tonal components, as is the case for the multi-tone alarm. Finally, an even more uniform sound field was obtained for the broadband alarm.

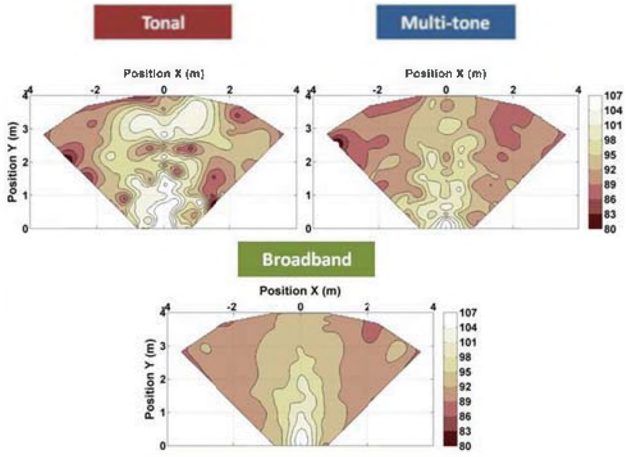

Figure 3: Sound pressure levels behind the vehicle (expressed in dBA) at one site, for the "ideal" alarm mounting position

4. CONCLUSIONS

The uniformity of the sound field behind vehicles produced by backup alarms was investigated by comparing three types of alarm signals: tonal, multi-tone and broadband. The results suggest that alarms with broader frequency content present some advantages over conventional single-tone alarms, including: 1) a more uniform sound propagation pattern behind heavy vehicles; and 2) lower sound pressure levels to meet the requirements set forth in ISO 9533. However, it remains to be seen if such a broadband signal would be recognized as a valid alarm signal from a subjective standpoint (detection, urgency, localization, etc.).

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