2010.09.13 Response to NOIA

SPECTRA

ENVIRONMENTAL GROUP, INC.
ENGINEERING, ARCHITECTURE AND SURVEYING, PC

September 13, 2010

Ms. Karen Gaidasz
Environmental Analyst
NYSDEC, Region 4
1130 North Westcott Road
Schenectady, New York 12306-2014

RECEIVED
SEP 14 2010
By

Subject: Norlite Corporation
Mined Land Permit Modification - Southern Overburden Storage Area
MLF: 401-3-32-0002
DEC ID: 4-0103-00016/00019
Town of Colonie/City of Cohoes, Albany County, New York

Dear Ms. Gaidasz:

Spectra Environmental Group, Inc. (Spectra), on behalf of Norlite Corporation (Norlite), is responding to the New York State Department of Environmental Conservation (NYSDEC) 2nd Notice of Incomplete Application (NOIA), dated August 27, 2010, for the above referenced site. To facilitate your review, NYSDEC comments are included in italics followed by our responses.

Comment 1: Back-Up Alarms

The email correspondence from Mr. DeSilva provided a comparison of the industry standard tonal back-up alarm versus the industry standard broadband alarm. The email included a qualitative statement which summarized the benefit of using broadband alarms (i.e., the sound of the alarm is more confined to the hazard area and that this is achieved by spreading the sound energy over a wide range of frequencies rather than concentrating all of the sound energy over one frequency). The intent of this statement was understood, however, we need a more detailed explanation of how the sound energy is actually spread over a wide range of frequencies and therefore how it would have less of an impact at the receptor sites. Please compare the level of perceptible sound of the broadband alarm versus the tonal back-up alarm at the nearest receptor location. In order to demonstrate the benefits of the broadband alarm, we will need quantitative data in addition to qualitative statements.

The Department has recently endorsed the use of a smart alarm in lieu of a standard tonal backup alarm for certain projects. Smart alarms automatically adjust their sound output to be approximately five dB(A) above ambient noise level. Please also compare the smart alarm technology to the broadband alarm in terms of their potential noise impacts on nearby receptors. Please provide qualitative and quantitative data so that a clear comparison of the pros and cons of each alarm type *are presented. Please indicate if a smart alarm would be more or less appropriate for use at the Southern Overburden Storage Area versus the broadband alarm.*

Response:

In response to this comment and request for additional information, it is important to emphasize that the proposed modification to allow structural berm construction in the drier months is simply a request to change construction timing for one component of the overall construction project. The potential environmental impacts associated with the project as a whole have already undergone a thorough and lengthy State Environmental Quality Review Act (SEQR) process that concluded with the issuance of a Negative Declaration by the NYSDEC in August, 2007. During the SEQR process, the question of back-up alarm noise was thoroughly vetted. The conclusion of all noise analyses demonstrated that construction-related noise will have no impact on surrounding residents. The noise studies that lead to this conclusion were extremely conservative and in all scenarios showed no impact to surrounding residential properties.

The conclusions of the two noise models have been confirmed in the field during the construction of Berm 1. Over the two year construction and operation of the Southern Overburden Storage Area, there have been no complaints from surrounding property owners regarding construction-related noise, including noise from tonal back-up alarms. Data showing why there have been no noise complaints is seen in a comparison of independent sound level monitoring completed by Vibra-Tech Engineers, Inc. in 2004, prior to commencement of operations in the Southern Overburden Storage Area (62.35 dB(A)), and Angevine Acoustical Consultants, Inc. in 2008, during active construction (62.4 dB(A)). Comparison of these data shows that there is essentially no increase in Sound Pressure Level (SPL) at the closest receptor location. The noise monitoring data recorded by Angevine included tonal back-up alarms on equipment operating in the Southern Overburden Storage Area. Even with the tonal alarms sounding during Angevine's monitoring event, the data show no noise-related impacts at the closest receptor (i.e. no increase in ambient sound level). Over and above this analysis, in an effort to be responsive to the comment and request for additional information, a discussion of broadband versus tonal back-up alarms is included herein.

For background information, the NYSDEC Noise Policy "Assessing and Mitigating Noise Impacts" (October 2000, Revised February 2001), states the following regarding back-up alarms:

Pages 11&12 - Section V.B.(4) Sharp and Startling Noise

> "These high frequency and high intensity noises can be extremely annoying... One such noise is the back-up beepers required to be used on machinery. They definitely catch one's attention as they were meant to do. Continual beeping by machinery can be mitigated (see Section V.C. Mitigation – Best Management Practices)."

Page 23 - Section V.C.1.a.

> "Replacing back-up beepers on machinery with strobe lights (subject to other requirements, e.g., OSHA and Mine Safety and Health Administration, as applicable). This eliminates the most annoying impulse beeping."

As discussed during the original SEQR process for the project, and recognized in the NYSDEC's own guidance document (cited above), both OSHA and MSHA require the use of audible back-up alarms on construction vehicles. The strobe light mitigation option discussed in the NYSDEC guidance document is not applicable to the Southern Overburden Storage Area because the hours of operation for construction are limited and no construction takes place at night. As an alternative mitigation effort, Norlite has already agreed to the use of broadband alarms because the benefit of using broadband alarms is well documented in the construction and earthmoving industry. The commitment to broadband backup alarms represents utilization of state-of-the-art technology during construction activities and mitigates noise from back-up alarms to the greatest extent practicable (even though recent noise monitoring data show that noise from tonal alarms is not an issue at the site).

Additionally, the email correspondence referenced in Comment #1 above was provided to NYSDEC in response to a previous request for additional information, which has been reproduced below:

Email correspondence from the NYSDEC to Spectra, dated August, 4 2010:

> "… can you please send me the noise level, in decibels dB(A) for the following equipment: Standard back-up alarm currently used on equipment in the Southern Overburden Storage Area, Broadband back-up alarm, White-noise back up alarm. For comparison purposes when you provide the dB(A) of this equipment, please include the distance it was measured at (i.e., 50 feet)."

Through Spectra, Norlite provided the requested information, demonstrating that broadband back-up alarms operate in a dB(A) range comparable to their tonal alarm counterparts. (Tonal alarm = 87-112 dB(A), Broadband (same as White-noise) = 87-107 dB(A), all at a reference distance of four feet). The qualitative discussion referenced in the comment was included to help explain the benefits of using broadband alarms versus tonal alarms.

In our continuing response to Comment #1, the qualitative comparison previously provided is expanded here to further explain and quantify the differences between tonal alarms and broadband alarms. Appendix A contains two technical papers, one entitled "Broadband Sound – The Safer and Noiseless Back-up Alarm, A Brigade White Paper" (White Paper), and a second entitled, "From Bell to Broadband," both of which compare broadband and tonal alarms. A summary of these documents is included below and serves as the basis for the technical information provided.

As discussed in our email response regarding back-up alarm dB(A) levels, broadband alarms confine more sound energy to the hazard area (the area behind equipment in reverse gear) than do regular tonal alarms, and, therefore, have less noise propagation off-site and less overall noise-related impacts. Three acoustic characteristics of broadband alarms that lead to this behavior are:

1. Lower Sound Pressure Level (SPL) – Figure 4 of the White Paper, included below, illustrates the total sound energy of tonal and broadband alarms, both operating at 100 dB(A). The tonal alarm concentrates all sound energy over a narrow, relatively low frequency band of 1,000 Hertz (Hz) and peaks at 100 dB(A) output. The broadband alarm spreads the total sound energy over multiple frequency bands from 1,000 Hz to 6,000 Hz and this flat curve reaches roughly 90 dB(A), approximately 10 dB lower than the tonal alarm.

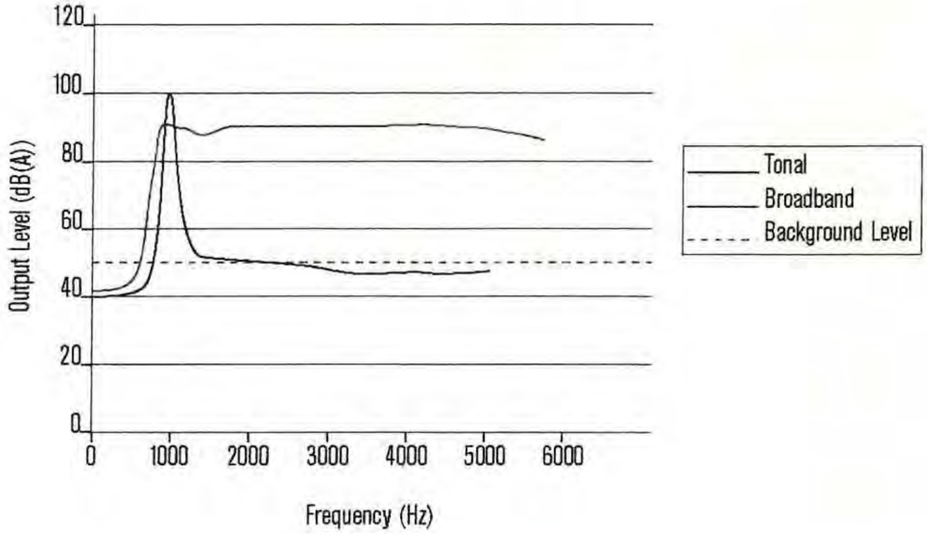
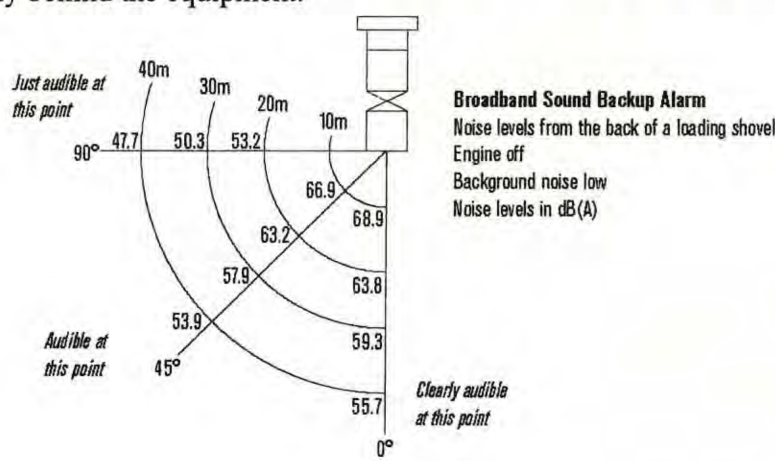


Figure 4

2. Dissipation off-axis – Figure 5 of the White Paper, included below, illustrates the directionality of broadband alarms. The more focused directionality means that there is negligible attenuation of sound in the hazard area, but there is significant attenuation as you move laterally away from the hazard area (that is to say moving away from directly behind the vehicle). Figure 5 illustrates an 8 dB(A) reduction in SPL at a 90° angle and 40 meters from the back-up alarm. Tonal back-up alarms are not directional and send out a symmetrical sound wave, which does not significantly attenuate as one moves laterally away from a piece of equipment. As a result, the perceived loudness of a broadband alarm is significantly less than a tonal alarm when one hears the sound from any vantage point that is not directly behind the equipment.

Figure 5



3. Lower dB(A) rating – Analysis shows that broadband back-up alarms are equally effective as tonal alarms even when operating at 5 dB(A) lower SPL at the same reference distance. Figure 6 of the White Paper, included below, compares the perceived loudness of a tonal alarm and a broadband alarm and how they relate to the human hearing threshold. Broadband alarms span frequencies to which the human ear is most sensitive, whereas tonal alarms concentrate their energy in frequency bands to which the

human ear is less sensitive. This focus of energy in different frequencies requires a tonal alarm to operate at roughly 5 dB(A) higher SPL to achieve the same perceived loudness as a broadband alarm.

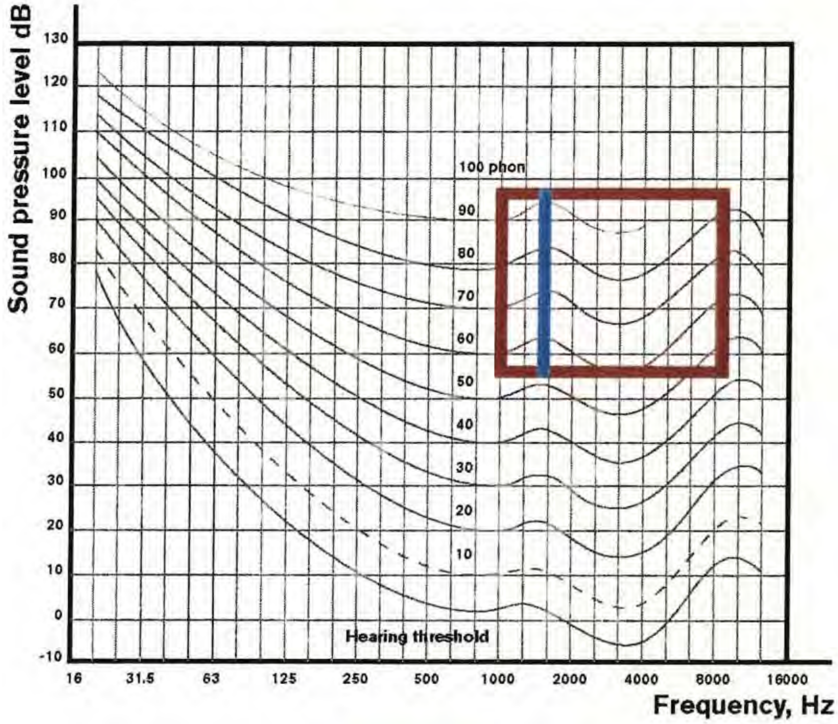


Figure 6

These three characteristics of broadband sound result in enhanced attenuation at distance when compared to tonal alarms, while at the same time being just as effective as tonal alarms for people working in the hazard area. For all of the reasons summarized above, and explained in detail in the attached references, broadband alarms are worthy of recognition by the NYSDEC as a mitigation measure that addresses noise-related impacts from back-up alarms to the greatest extent practicable. For this reason, Norlite has already agreed to install and use broadband alarms on all equipment working in the Southern Overburden Storage Area even though there are no noise impacts at surrounding residential properties and there have been no noise complaints over the past two years of construction activity.

NYSDEC Comment #1 goes on to state that "smart" or self-adjusting tonal alarms are also a potential mitigation technology to replace standard tonal alarms. Given that the average level of construction activity within the Southern Overburden Storage Area includes the operation of two pieces of equipment at any point in time (e.g. haul truck and bulldozer), self-adjusting tonal alarms may not be the best option for alarm noise mitigation, although the Department has endorsed their use in some situations.

As an example, the combined sound emanating from a haul truck [81.4 dB(A) at 50 feet] and a bulldozer [89.2 dB(A) at 50 feet] equals an overall minimum sound level of 90.2 dB(A) in the hazard area between the pieces of equipment. Based on the fact that self-adjusting alarms monitor ambient conditions within the hazard area and automatically emit a warning tone 5-10 dB(A) above the ambient condition, the decibel level of the smart tonal alarm when it sounds may be 95.2-100.2

dB(A). In this example there is no benefit to the "smart" tonal alarm because it sounds at a decibel level similar to a standard tonal alarm and does not have the added acoustical characteristics of the broadband alarms (e.g. lower SPL, enhanced off-axis dissipation, lower dB(A) rating). For this reason, Spectra and Norlite assert that broadband alarms are the preferred back-up alarm for this project and is the reason Norlite agreed to use broadband back-up alarms on July 28, 2010, the date of the first NOIA response.

We trust the data provided above and the technical papers included in Appendix A conclusively address the Department's concerns over the potential noise impacts relative to construction equipment back-up alarms and that there are no further concerns over the use of OSHA and MSHA-mandated alarms during structural berm construction activities.

Comment 2: *Berm Construction Schedule*

Berm 1 was originally estimated to be completed within a 6 month period. However, it is our understanding that the construction of Berm 1 has actually been ongoing since March 2008. It is important to point out that the Negative Declaration prepared on March 15, 2007 for the Southern Overburden Storage Area was predicated on the fact that the construction of Berm 1 would only result in short-term construction related impacts and therefore additional mitigative measures were not necessary. Since the Berm 1 construction has taken longer than the original 6 month estimate, we are concerned that the other berms will also result in a longer construction period which may necessitate the need for additional mitigation measures for noise and dust related impacts. Please provide a response which addresses this concern and provide a detailed schedule for the proposed construction of Berms 2 through 6, including an estimated time frame for completion of each berm.

Response:

The construction of Berm 1 and the placement of fill behind Berm 1 has been consistent will all of the SEQR approved plans for the mine site. The reason Berm 1 has not yet been completed is that the northern end of the berm serves as the construction road entrance where construction and earthmoving equipment gain access to the Southern Overburden Storage Area. This access point has been used to construct all of Berm 1 and to place the fill behind Berm 1. The construction access point was thoroughly described during our site meeting of June 8, 2010. NYSDEC personnel walked the construction access point during that visit, and while in the field, both Norlite and Spectra personnel described the small area of Berm 1 grading needed to close off the active construction road entrance and finish Berm 1 grading in that area. Comment #2 fails to take into consideration the detailed and lengthy discussions NYSDEC, Norlite and Spectra personnel conducted during the June 8^{th} site visit regarding final Berm 1 grading.

The fill and grading needed to close the current construction entrance on Berm 1 will not be completed until work on structural Berm 2 is initiated and access to the construction site is provided at another location. Berm 1 is essentially complete in all practical aspects except for that small section accommodating the access road, and Norlite and Spectra decided that it would be inappropriate to state that Berm 1 is complete until that very small section of the berm is graded and seeded.

As written, Comment #2, can lead one to believe that only structural Berm 1 has been constructed since March, 2008. This is not the case. Comment #2 does not recognize that the entirety of the fill area behind Berm 1 has been filled and graded and that the drainage layers in preparation for structural Berm 2 have been installed. Further, Comment #2 does not acknowledge that according to Norlite's current mining permit, no material could be placed in the Southern Overburden Storage Area after April 30, 2010. Consequently, over the past four and one-half months construction activities have ceased and no material placement has occurred in support of structural Berm 2, final Berm 1 grading, or the placement of fill behind either Berms 1 or 2. The most recent four and one-half month delay in construction activity is a function of the current permit and not a construction issue requiring additional mitigation.

When one recognizes the actual amount of work completed in the Southern Overburden Storage Area over the past two years, and that the lack of recent activity is mandated by current permit conditions, the concern over construction pace and schedule expressed in Comment #2 is unfounded. All construction activities and schedules have been conducted in accordance with the approved plans and there is no need to consider additional mitigation measures relative to future construction activities. As stated in the response to Comment #1 above, there have been no complaints regarding noise or dust from Southern Overburden Storage Area construction activities to date.

Comment #2 goes on to ask for a future berm construction schedule. To respond to this request for additional information, it is assumed that this is the final request for information from the NYSDEC and that no additional response documents are required. It is also assumed that the NYSDEC will issue a modified permit to Norlite by September 30, 2010. With these assumptions as a foundation, it is assumed that structural Berm 2 will be constructed by Summer/Fall 2011, Berm 3 will be constructed during Summer 2012, Berm 4 in Summer 2013, Berm 5 in Summer 2014, and Berm 6 in Summer 2015. Fill material will be placed behind each of the structural berms during the winter months of the construction years cited. This schedule, of course, is entirely dependent on the date of issuance of the modified permit, weather over the next several years being conducive to construction of earthen berms, and overall market demand for saleable clay material.

As stated in the original application documents, a portion of the overburden across the site is fine-grained clay used for clay liners and earthen caps that has historically been sold from the site. When clay material is needed to support local and/or State-approved projects, Norlite will continue its historic practice of making these natural materials available to the local marketplace. For example, in 2009 and early 2010, Norlite shipped approximately 26,000 yards of clay to the NYSDEC-permitted Albany County landfill, and an additional 84,000 yards of clay to the NYSDEC-permitted Colonie landfill.

When off-site construction projects require natural clay materials and a significant volume of overburden is shipped from the mine site, the rate of construction in the Southern Overburden Storage Area may be slowed due to the shipping of overburden materials off-site. At this time, it is not possible to predict what future outside projects may be approved on either the state or local level, and/or to predict if these projects will impact the construction schedule presented above.

We trust that the information provided herein addresses all remaining concerns of the NYSDEC and look forward to receiving a modified mining permit allowing the construction of structural berms during the months of May through October in any given year. The analyses provided above show that the requested change is consistent with the findings of the 2007 Negative Declaration and that there will be no nuisance-related impacts on surrounding residential property owners from the change in structural berm construction timing. It should also be re-stated that the change in berm construction timing does not constitute a change in any previously approved and currently permitted project elements or components. The request to change construction timing is based solely on the ability to more consistently and effectively achieve requisite construction compactions and ensure the integrity of the structural berms. The change in berm construction timing will have no negative impact on surrounding residential property owners, will be consistent with the findings of the 2007 Negative Declaration, and will be an overall benefit to the project as a whole.

Should you have any questions, please do not hesitate to contact me at (518) 782-0882.

Sincerely,

SPECTRA ENVIRONMENTAL GROUP, INC.

Jason C. Kappel

Jason C. Kappel, P.G.
Director
Mining, Minerals and Environmental Permitting

Enclosures

cc w/ encs: A. Hewitt, NYSDEC Region 4
T. Lachell, Norlite
K. Young, Young Sommer & Moore, LLC

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APPENDIX

APPENDIX A

BRIGADE®

Broadband Sound

The safer and noiseless* back-up alarm

A Brigade white paper
March 2008

**Webster's dictionary definition of 'Noise': "any sound that is undesired or interferes with one's hearing of something". The sound from a correctly selected and installed broadband alarm is heard only in the hazard area - where it is meant to be heard.*

Contents

Introduction

This paper sets out both the safety and the environmental benefits of broadband sound as applied to back-up alarms. The rationale for its adoption as standard fit on trucks, fork-trucks and mobile plant is self-evident.

During Summer 2007 a company suffered fatalities in two separate back-up accidents. In each case the truck and mobile plant involved were equipped with fully functional and compliant tonal back-up alarms. The findings were that each victim had "tuned out" the tonal alarms. The appropriate response to a back-up alarm follows recognition of its being a danger signal. Response failure indicates that the signal was filtered out as irrelevant back-ground noise or a sub-conscious assumption that the sound originated from a truck backing up elsewhere. This effect is emphasized with tones which travel a greater distance than broadband.

Evaluation of backup alarms and scientific research confirm that broadband sound is very effective at indicating the location of a sound source. In 2002 the American Council for the Blind called for the use of locatable sound saying current tonal alarms "serve more to disorientate people who are blind and visually impaired than to assist them"[1].

"Noise seriously harms human health and interferes with people's daily activities at school, at work, at home and during leisure time". "Calling noise a nuisance is like calling smog an inconvenience" and "noise must be considered a hazard to the health of people everywhere" are frequently quoted comments by Dr. William H. Stewart, former Surgeon General of the USA.

In comparison to the conventional tonal (narrowband) back-up alarm, an equally loud (phons) broadband sound back-up alarm is just as effective at alerting a listener to the presence of a reversing vehicle but, by contrast, is little heard outside the danger area. This eliminates noise nuisance complaints and the risk of the alarm being ignored due to "over-familiarity"[2].

Whilst specific circumstances may dictate the retro-fit of broadband back-up alarms this paper presents the general case for their adoption as part of a managed process.

Whilst this paper applies to all types of travel alarm it is directed specifically at back-up alarms.

[1] American Council for the Blind resolution ACB 2002-22.

[2] New York State – Department of Health Case Report 03NY036; "Often people who work regularly near back-up beepers become accustomed to their sound and become desensitized to them as warning signals." http://www.health.state.ny.us/environmental/investigations/face/03ny036.htm

Safety – Fitness for Function

A comparative chart of the relative effectiveness in normal working environments between tonal alarms and broadband alarms:

	Factors	Tonal	bbs®
Safety	**Recognition:**		
	Loudness / Audibility	*An alarm with appropriate loudness should be installed*	
	Is sound an effective danger warning	*Depends*	Yes
	Is the danger relevant	*Depends*	Yes
	Response	*Unreliable*	Good
	Hard of hearing - audibility	*Risky*	Good
	Cause confusion	*Likely*	Unlikely
Environmental	**Strident**	*Yes*	No
	Noise complaints	*Yes*	No
Health	**Risk of hearing damage & stress**	*Greater*	Lower

Figure 1

Every measure of a back-up alarm's fitness-for-function (see Figure 1 above) shows that a broadband signal provides a superior warning than a tonal signal in terms of safety, of health and of the environment.

Safety – Fault Tree Analysis

A "fault tree analysis" is a useful tool for reviewing possible causes of an accident, see copy below. In the UK, for example, a coroner may reach one of three decisions: Death by natural causes; Accidental Death (where neither the deceased nor a third party were a cause of the fatality) or Unlawful Killing. In the fault tree below, the "causes" in red relate to the back-up alarm and in each case the risk is greater when the alarm is tonal. A full "fault tree analysis" is at Annex A.

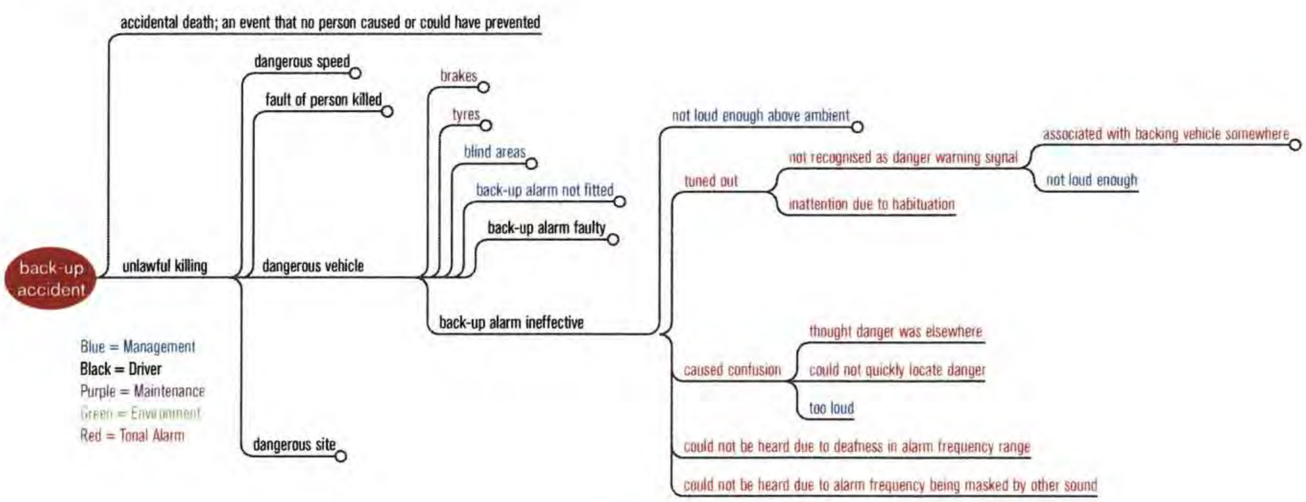


Figure 2

Safety – Key Factors

Back-up alarms are fitted to improve safety. Their function is to alert anyone who may be in the hazard zone that the vehicle is backing-up so that the hazard is recognized and appropriate action is taken to move out of harm's way. The warning signal needs to be heard in all parts of the hazard area. The hazard area is the area where a person is either in, or could move into, the travel path of the backing vehicle. The alarm sound is unnecessary outside this zone and sideways sound "spillage" is unwanted.

Back-up alarm model selection should be to maximize safety within the hazard zone. To this end it should fulfil two criteria:

1. **Recognition.**
    a. **Audibility.** The alarm must be audible enough to alert someone pre-occupied by a task. ISO-7731 defines the audibility[3] required for danger signals. ISO-7731, written for tonal alarms, recommends more than one tone for an alarm to be effective[4].
    b. **Is the sound a danger warning?** The primary requirement for a back-up alarm's warning signal is a sound pattern which makes the signal unambiguous[5]. SAE J994's definition is for the pattern to be 0.8KHz to 1.8KHz, with the length of the on and off periods being within 20% of each other[6].
    c. **Is the danger relevant?** If the sound has a high false alarm rate it will not be associated with danger. Low false alarm rates improve safety and worker/public acceptance. "False alarms negatively impact safety"[7]. False alarms become associated with a vehicle backing-up elsewhere.
2. **Response.** The alarm should demand immediate response by those in the hazard area. Faster response occurs when the sound source direction (and identification thereby of the backing vehicle) is instantly locatable.

Cross References:

Factors	Relevant Section	Page
Recognition	General	6
	Recognition - General	6
	Hard of Hearing – Better Recognition	12
Audibility	Audibility	6
	Audibility Through Ear Defenders (Ear Protection)	12
	Reduced Risk of Alarm Sound Being Masked	12
Is the sound an effective warning Signal?		**All**
Is the danger relevant?	Sound Confined to Hazard Area	7
	Rapid Sound Dissipation	12
	Resonance	10
Response	False Alarms	10
	Locatable Sound	6
	Tonal Alarms Cause Confusion	11

Continued.....

[3] ISO 7731, 4.2.2 Audibility
[4] ISO 7731, 6.3 Special Characteristics
[5] ISO 11429, 4.2
[6] SAE J994, Section 6.2; "Cyclic Pulsation Rate and Duty Cycle
[7] www.grc.nasa.gov/WWW/RT/2005/RI/RIS-hunter.html

Other Factors:

General

The hazard warning signal should be such that people in the reception area hear and react to the signal as intended. Hearing impaired persons and wearers of safety helmets, ear defenders etc require special care to be taken. The characteristics of the signal should be relevant to the situation[8].

Audibility

An acoustic warning signal "shall be clearly audible. The effective masked threshold of audibility shall be distinctly exceeded. If relevant, the possibility of hearing loss in the recipient population may be assessed and taken into account." If ear-defenders are worn, their levels of attenuation shall be known and considered in the assessment.[9] SPL (decibels) and Loudness (phons) are not the same. (See glossary.)

Recognition - General

The primary requirement for a warning signal is that its message is clear and unambiguous and is recognised under the environmental conditions[10].

Locatable Sound

The American Council for the Blind reported at their 2002 annual Conference in Houston, Texas, that conventional alarms serve more to confuse blind people than to assist them and called for the use instead of locatable sound.

Instant location of a sound-source is a part of Nature's survival mechanism. An animal in imminent danger of attack promptly locates the sound of the stalking predator by naturally occurring "broadband" sounds such as the crack of a breaking twig or the rustle of leaves, which accurately reveals the approach direction of the danger, triggering instant flight in the opposite direction.

In locating a sound source, three parts of the frequency spectrum are heard simultaneously, as a single sound:

1. **Low Frequencies**. With low frequencies (about 1.5 KHz and below) the brain can process the time difference between the sounds arrival at one ear then the other. This is known as the Interaural Time Difference (ITD)[11]. These leave a 'cone of confusion' as illustrated in Figure 3 below. (Sources on the surface of the cone have the same time delay between the two ears.)

[8] ISO 7731, 4.1
[9] ISO 7731, 4.2.2.1
[10] ISO 11429, 4.2
[11] Human Localisation, Binaural cues http://www.isvr.soton.ac.uk/FDAG/VAP/html/localisation.html

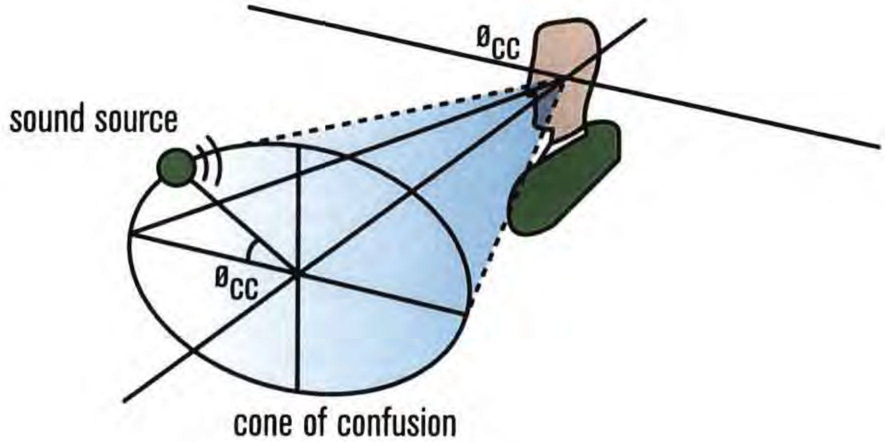


Figure 3

2. **Mid frequencies.** At mid frequencies (3KHz up to 5KHz[12]) the brain senses the intensity difference of the sound at each ear, i.e. the brain determines that the ear receiving greater sound intensity is closest to the source. With this frequency range we can determine if the sound is to the left or right. This is known as the Interaural Level Difference (ILD) or Interaural Intensity Difference (IID)[13].

3. **Higher Frequencies.** Due to our outer ear shape and body shape, higher frequencies (5KHz and above) are modified before entering the ear canal. This is an individual response and is the high frequency end of the Head Related Transfer Function (HRTF). This phenomenon becomes significant when the wavelength of the sound is similar to or shorter than the dimension of the outer ear. It use is a learned skill and assists front/rear sound source location.

With a selection of each of these frequency ranges the brain can locate the direction of the sound source. The more the better, and with broadband sound the accuracy of instant locatability is around 5 degrees.

Tonal alarms often create confusion in the work place. The location of a tonal sound source is unreliable and takes precious time. (See section – Tonal Alarms Cause Confusion on page 7.)

Sound Confined to Hazard Area

Broadband sound is localised within the hazard area. This has two main benefits:

1. It eliminates noise nuisance and complaints from those outside the hazard area who do not need to hear the warnings.
2. Tonal alarms which are heard well away from the hazard zone become "meaningless"[14] which leads to their being disregarded, even in a hazard zone. A broadband alarm is normally heard only in a hazard zone and consequently is respected as a genuine warning.

[12] Various sources give above between 1.5 kHz and 3 kHz.

[13] http://en.wikipedia.org/wiki/Sound_localization

[14] Toyota Industrial Equipment booklet; 00698-20036-04 06TMH35158; with reference to tonal alarms - "Pedestrians become habituated to the alarm and ignore it, as it constantly sounds a meaningless warning."

How is this achieved?

1. **Lower SPL** Figure 4 illustrates a tonal alarm and a broadband alarm each 100dBA. The tonal alarm concentrates all its energy into one narrow frequency band. The broadband alarm spreads its energy over a wide frequency range, typically at levels about 10dB lower than the tonal alarm, though the total sound energy is similar for both.

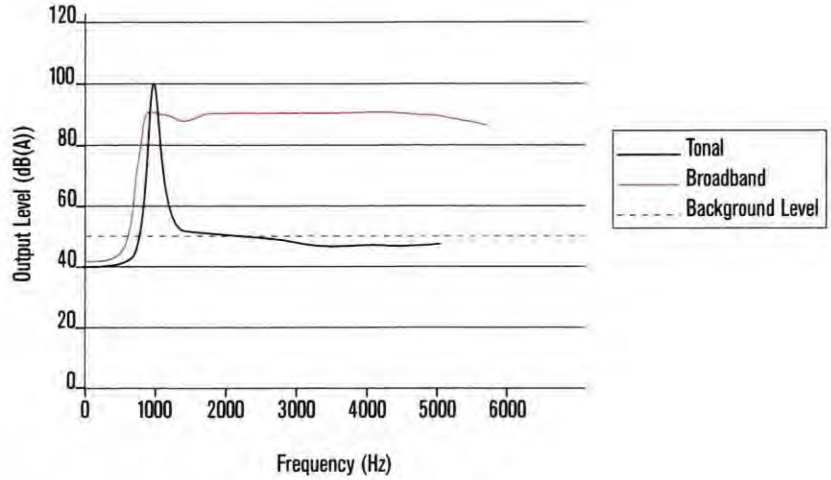
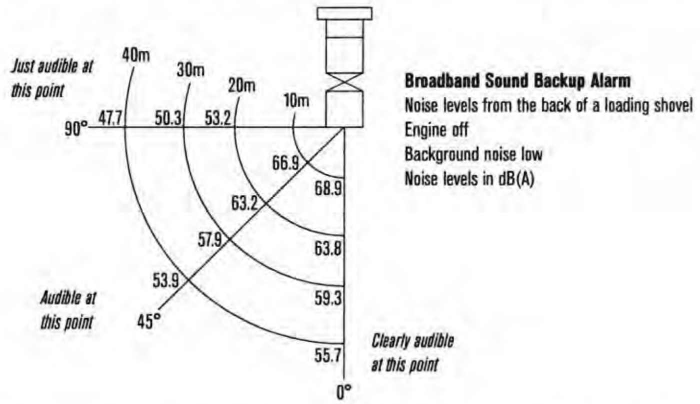


Figure 4

2. **Dissipation off-axis.** Whereas a tonal alarm is largely omni-directional, broadband is focused into the hazard area. The schematic at Figure 5 below, recorded by Hanson Aggregates[15], is typical of several studies reviewing broadband SPL reduction off rear axis. Whilst there is negligible sound dissipation in the hazard area, there is significant reduction (typically around 10 dBA at 90 degrees to the side of the vehicle) outside the hazard area. The inherent directivity of an alarm measured in the absence of any reflecting surfaces will be different from the directivity of an alarm when mounted on a vehicle. E.g. a 102 dBA broadband alarm in an open space shows 8 dBA reduction at 90 degrees but on a vehicle might show 13 dBA or greater reduction.

Figure 5



3. **Lower dBA rating.** Scientific analysis has revealed that a broadband back-up alarm is equally effective at 5dBA lower SPL than a conventional tonal alarm[16 17]. Consider the measurement of loudness as detailed in Figure 6. from ISO-226:2003. A contour dips into a region of more sensitive hearing. The dip around 3,000Hz is due to resonance in the ear canal, which increases the sound input to the ear. Figure 6. shows typical broadband (red box) and tonal (blue line) alarm SPLs. In the range of around 1kHz to 4kHz, tonal alarms operate at the frequency that is least audible to the human ear; whilst broadband alarms include the regions of the ear's enhanced sensitivity and are subjectively louder than a tonal alarm of the same total SPL. A tonal alarm requires about 5 dBA higher SPL for equal loudness to a broadband alarm. Conversely, a broadband alarm provides the same loudness at 5dBA less than a tonal alarm.

[15] Tom Hill, Environmental Manager, Hanson Aggregates, Whatley Quarry; drawing dated 15 July 2002

[16] Martin Lever, HS&E Manager RMC (Cemex); verified results of 150 subjects at South East Quarries Liaison Safety Day 2003.

[17] UK Health & Safety Executive report "Improving the safety of workers" Contract Research Report 358/2001.

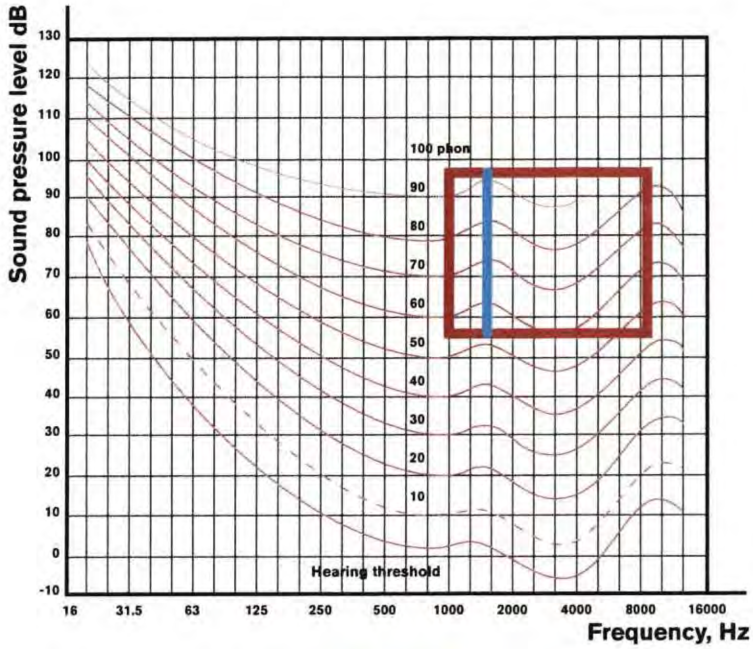


Figure 6

Net Effect

Aggregating these three factors reveals broadband sound's full potential as a noise-abater. A doubling of distance from sound-source gives a 6 dB reduction in SPL. The higher frequencies in broadband sound attenuate more rapidly with distance.

In Figure 7, the components of the broadband alarm are typically 10 dB closer to the background noise than the tonal alarm. As distance from the alarms increases the SPLs reduce until the broadband sound fades into background whilst the tonal sound remains typically 10dB higher. The broadband SPL drops off more rapidly than the tonal SPL because the higher frequencies attenuate faster.

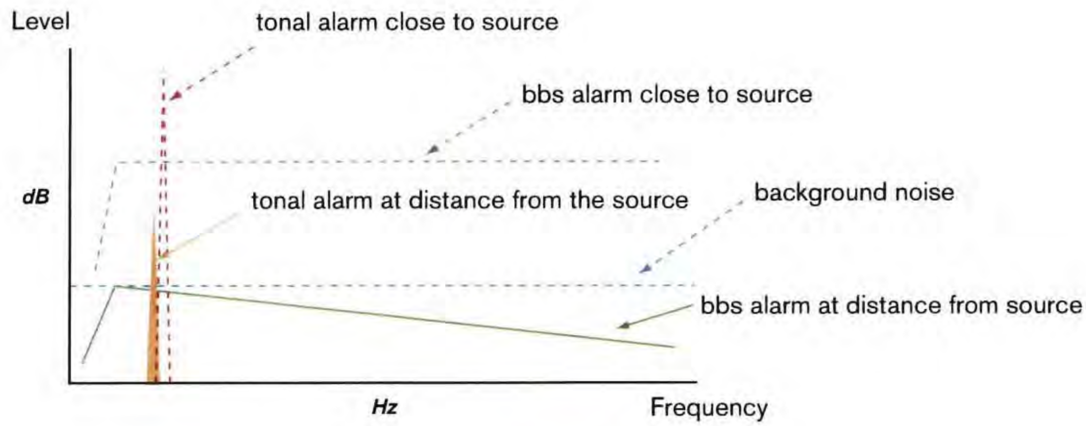


Figure 7

Additionally, as the sound level of the broadband alarm is typically 5 dB lower for equal loudness this could lead to a 15 dBA difference. This is illustrated in Figure 8 below.

Net Effect - Illustration

Illustration of equally SPL rated tonal and broadband alarms range of audibility i.e. ranges at which the broadband alarm sound blends in to background noise (blue circle), whilst the tonal alarm (outer circle) is still above background.

1. Black Outer Circle. Alarm zone of a tonal alarm.
2. Blue disc. Alarm zone of a broadband alarm with the same over-all SPL as a tonal alarm (without directivity characteristic included). Assuming that the tonal alarm is 10dB above background noise, the area covered by the broadband alarm is about 10% of that of the tonal alarm.
3. Mauve disc. Indicating the alarm zone of broadband alarm with directivity characteristic included. This area is less than half that of the blue disc.
4. Red Area. Alarm zone of broadband alarm with 5dBA lower output than tonal alarm. This area is smaller than the mauve area because as distance from the broadband source increases it's SPL drops to background level whilst the tonal alarm sound remains about 15dB above background.

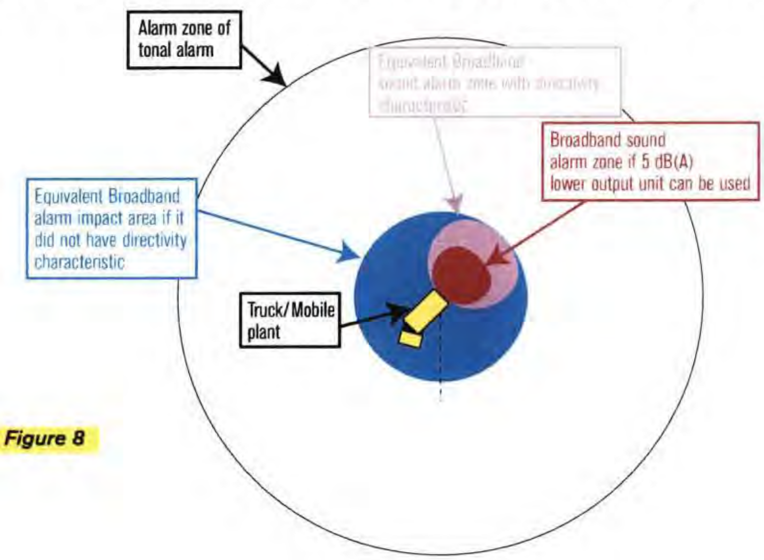


Figure 8

False Alarm

A false alarm is an alarm heard outside the hazard zone. "False alarms are of no use to anyone, serving only to increase noise levels. Over time they become less effective as people sub-consciously match their response level to the false alarm rate."[18] For example, alarms which are genuine for 90% of the time produce response rates close to 100%, whereas alarms which are genuine only 10% of the time will trigger a response rate of only 10%. False alarms are costly both in terms of annoyance and of performance[19].

False alarm rates for tonal alarms are unacceptably high.

Resonance

A tonal alarm can resonate with truck (or other metal) panels. This resonance increases noise levels, sound-source confusion, environmental noise nuisance and loss of respect as an alarm.

The level of increase can be startling, 5 dBA[20] for a garbage truck and over 20 dBA[21] on a fork truck working near metal panels.

[18] Bliss et al, 1995.

[19] Edworthy Judy, Hellier Elizabeth; Auditory warnings in noisy environments

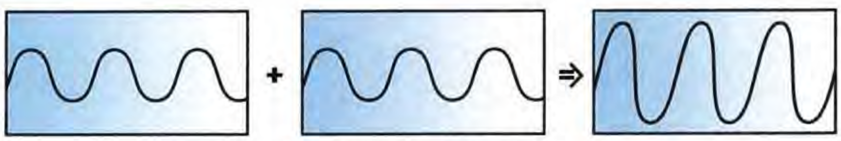
[20] Geoff Leventhall: Noise Measurements on Garbage Truck and Back-Up Alarms

[21] Tony Gardner: Ibstock Bricks Lodge Lane Factory noise exposure study 2004

Tonal Alarms Cause Confusion

Whilst broadband sound-source is locatable, of concern is sound-source confusion caused by tonal alarms.

This problem results from the acoustical phenomenon of standing waves. A typical tonal back-up alarm has a frequency around 1.25 kHz with a wavelength about 11 inches. When radiating a tone, its speaker oscillates at a constant rate (frequency) to produce the sound. It compresses the air in front of the speaker, then it rarefies the air; these compressions and rarefactions similarly affect the ear-drum and so we hear the sound. When a tonal alarm "beeps" these compressions and rarefactions are sensed by the ear either directly or via one or more reflections. When the distance between two paths of the alarm sound travel is a multiple of the alarm wavelength then the compressions combine and intensify and for a good reflection this can increase the sound pressure by up to 3dBA (See Figure 9 below). Similarly, if the path difference is ½ the wavelength, the compression and rarefaction can cancel each other out in the case of a good reflection and no sound is heard! "Reflections of these sound waves on the ground or diffraction by the sides of vehicles have the effect of reducing or even cancelling them before reaching the listener. Within spaces of less than a few inches, Laroche and Lefebvre found variations in sound pressure level (on construction sites) of more than 15 dB[22] behind vehicles."[23]



The superposition of two identical transverse waves in phase produces a wave of increased amplitude

The superposition of two identical longitudinal waves in phase produces a wave of increased intensity

Figure 9

Whilst a tonal back-up alarm's narrow frequency band does not enable sensing of the subtle intensity difference required to locate a sound source[24], there are often much larger intensity differences due to reflections. The listener assumes the greater SPL in one ear is due to its being closer to the sound source but it can be due to standing wave pressure differences.

What's more; as the listener's head turns towards the assumed sound-source the SPL varies in these few centimetres unconnected with sound source direction – compounding the confusion. This is not possible with a broadband alarm because it's wide frequency band has wavelengths varying from under 2 inches to over 17 inches. While a frequency analysis will show intensity variations due to standing waves, the over-all SPL remains constant.

[22] Laroche, C., and L. Lefebvre: Determination of optimal acoustic features for reverse alarms: Field measurements and the design of a sound propagation model. Ergonomics 41:1203–1221 (1998).

[23] Alice H Suter: Construction Noise: Exposure, Effects, and the Potential for Remediation; A Review and Analysis - AIHA Journal (63) November/December 2002. This Suter paper can be accessed on http://www.cdc.gov/elcosh/docs/d0100/d000054/d000054.html

[24] See section "Locatable Sound, 2. Mid Frequencies.

Audibility Through Ear Defenders (Ear Protection)

Low frequencies more readily penetrate solid objects. When loud music is played in a building or in a car with windows and doors shut, it is the low frequency boom-boom noise that is heard. Low frequencies can travel through the body and be heard through ear defenders. Fog horns use low frequencies because they travel long distances, round corners and penetrate solid objects such as windows, walls etc.

Ear-defenders are better at attenuating some frequencies than others. A broadband alarm with its wide range of low frequencies is more likely to be audible through ear-defenders than a tonal alarm.

Reduced Risk of Alarm Sound Being Masked

Tonal travel alarms are easily masked by similar frequency background noise. A broad frequency band eliminates this risk.

Rapid Sound Dissipation

Broadband sound's wide frequency spectrum enables lower over-all SPL for the same loudness. While it's low frequencies travel further they are more benign. The less tolerable high frequencies are more readily absorbed by air and ground and as a result the over-all SPL reduces more rapidly with distance from source.

Less Irritating

Tonal alarms are strident and irritating. Broadband alarms are environmentally "friendly". (See Technical Stuff; Psychoacoustics & Tonal Aspect sections below).

End to Intentional Disconnects

Increased hazards and repair costs result from sabotage of tonal alarms. Broadband alarms are rarely, if ever, sabotaged.

Hard of Hearing – Better Recognition

The cochlea (inner ear) is a long 'string' of receptors, akin to a ticker tape. Each receptor receives within a narrow frequency band. Hearing impairment is restricted to those receptors which are damaged. Figure 10 below shows a case where the damaged receptor frequencies align with the tonal alarm's frequencies. As a result the tonal alarm is unheard. Conversely, all the other frequencies of the broadband alarm are heard.

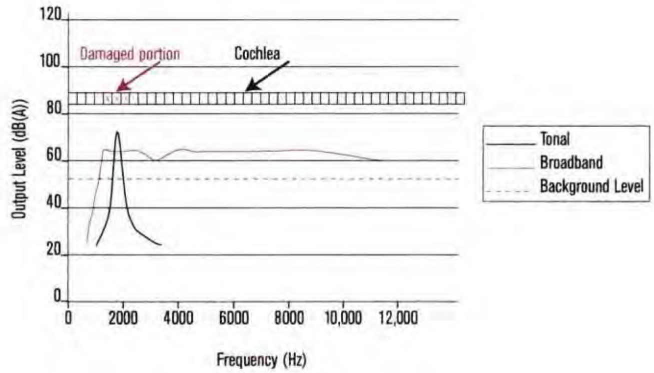


Figure 10

Reduced Risk of Hearing Damage

High lower-frequency content for a similar tonal SPL reduces the risk of hearing damage.

Reduce Heart Risk due to 'Startle'

ISO-7731 states; "Reactions due to fright (e.g. more than 30dB in 0.5 seconds) may be caused by using too high a sound-pressure level." These can delay, or even prevent escape from danger due to 'freezing'".

The risk of shock/startle is unlikely using broadband alarms with their lower SPLs and multi-frequency band width.

Technical Stuff

Equal SPL measurements and Spectral analysis

A reading of sound pressure on an SPL meter (as per ANSI S1.4 or IEC 60651) – specification for sound level meters) will 'average' the sound pressure in each frequency band and present a consolidated single figure output - weighted as per the settings on the meter.

It is the industry norm to measure SPL using the 'A'-weighting dBA which adjusts the measured SPL to the response of the human ear.

The graph at Figure 11 below shows the SPLs which might be expected from a tonal alarm (when centered on 1250Hz) and a broadband alarm. By definition, the frequency content of broadband is vastly larger than for tonal, but is at a lower SPL. These SPLs can be read using a sound meter (and filter set) as per ANSI S1.4 & S1.11 (or IEC 60651 & 61260) set to the one third octave range.

Although the broadband spectrum shows lower SPLs in each one third octave band the added effect of these is equal to the tonal travel alarm - 100dBA at 1m.

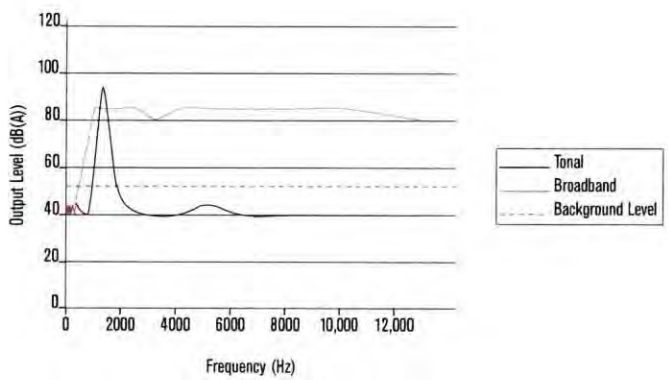


Figure 11

Sound versus Distance

In a free field (open 3D spherical space) sound dissipates from a point source according to the inverse square law. The reduction in dB compared with 1m from sound source is calculated as:-

$$SPL = 20 \log \left[{}^{1}/_{r} \right]$$

where 'r' is the distance of the listener from the source. This results in the well known 6dB drop for each doubling of distance from the source. However, most sound sources are not 'ideal point sources' and hence have less than ideal sound distribution in every direction.

The rate of sound-absorption depends on numerous other features including frequency content. Air absorbs sound faster (i.e. more rapidly per doubling of distance) in the higher frequency ranges. Atmospheric conditions (humidity, temperature, wind direction and speed etc.) all affect the speed of sound. The rate of sound absorption by physical structures between source and listener (buildings, fences, trees etc) is also frequency dependent.

Psychoacoustics

Perception of sound is highly subjective. Music to one person is noise to another. Sensitivity is greater and sounds therefore seem louder in the 1KHz to 4KHz band (this forms the basis for the 'A' weighting system). Tonal alarm noise is intrusive to all ears even in high ambient noise levels.

Tonal Aspect

The 'Tonal' aspect is important enough for the Federal Aviation Administration to have made provision for the presence of "tones" in aircraft noise in the Federal Regulation for Noise Standards on Aircraft. (Title 15 - Aeronautics and Space, Chapter 1, part 36.803 - Noise evaluation and calculation). The FAA "penalizes" tonal content by nearly 7 dBA. In other words aircraft noise containing tones is considered to be equally annoying as a 7dBA louder noise without tones.

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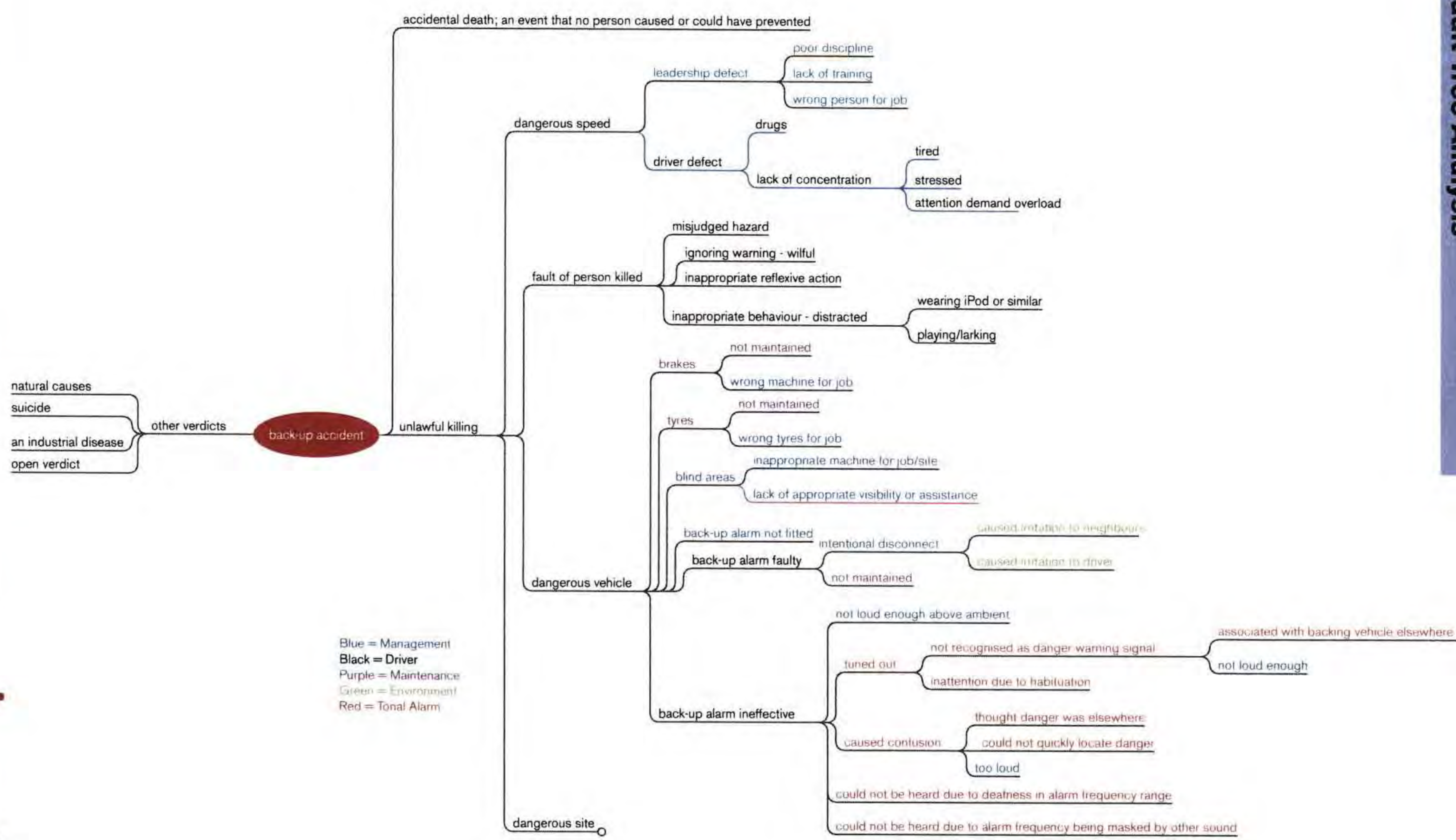
back-up accident
other verdicts
natural causes
suicide
an industrial disease
open verdict
accidental death; an event that no person caused or could have prevented
unlawful killing
dangerous speed
leadership defect
poor discipline
lack of training
wrong person for job
driver defect
drugs
lack of concentration
tired
stressed
attention demand overload
fault of person killed
misjudged hazard
ignoring warning - wilful
inappropriate reflexive action
inappropriate behaviour - distracted
wearing iPod or similar
playing/larking
dangerous vehicle
brakes
not maintained
wrong machine for job
tyres
not maintained
wrong tyres for job
blind areas
inappropriate machine for job/site
lack of appropriate visibility or assistance
back-up alarm not fitted
back-up alarm faulty
intentional disconnect
caused irritation to neighbours
caused irritation to driver
not maintained
back-up alarm ineffective
not loud enough above ambient
tuned out
not recognised as danger warning signal
associated with backing vehicle elsewhere
not loud enough
inattention due to habituation
caused confusion
thought danger was elsewhere
could not quickly locate danger
too loud
could not be heard due to deafness in alarm frequency range
could not be heard due to alarm frequency being masked by other sound
dangerous site
Blue = Management
Black = Driver
Purple = Maintenance
Green = Environment
Red = Tonal Alarm

Glossary

Loudness	A sound's perceived loudness (phons) is a non-linear varying function of its SPL and frequency (see fig.6).
SPL	Sound pressure level measured in decibels. Not to be confused with Loudness.
Decibel (dB)	The decibel is a logarithmic scale used to denote a change in the relative strength of an acoustic wave. It is a standard unit for expressing the ratio between sound-pressure and a reference pressure. An increase of 10dB is an approximate doubling of perceived loudness. The decibel is not an absolute measure but indicates the relationship or ratio between two sound pressures.
dBA	SPL weighted to the 'A' scale.
Frequency	Measure of the number of times per second a sonic vibration repeats itself, expressed in Hertz (Hz). High frequency sounds attenuate quickly, travelling short distances, low frequency sounds attenuate slowly, and travel far (e.g. fog horns).
Attenuation	Reduction of SPL over distance.
Tonal sound	Sound whose pressure varies sinusoidally with time. Also referred to as a discrete tone such as that produced by a tuning fork when struck lightly. High tone is high frequency, low tone is low frequency.
Broadband sound	Sound whose acoustic energy is distributed over a very wide frequency range. The spectrum is largely smooth and continuous save at the extremes.
Phon	Measure of perceived loudness.
Locatability	Degree of accuracy of a sound-source's directional location by a listener.
Localisation	Confinement a sound-pattern within, or restriction to, a locality.
Directivity	Measure of how a source radiates sound in different directions.

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1773 Mar 08

From bell to broadband

Geoff Leventhall. **Auditory warnings and the environment**

The classic image of train or fire engine, with hand-operated bell clanging its message 'Get out of my way!', is preserved only in old movies and fond memories. Even police cars used bells as warning signals in the earlier part of the twentieth century.

The train bell was replaced first by steam whistles and then by air operated horns, whilst electroacoustics took over for the majority of other applications.This led to a number of alarms, referred to by the nearest descriptive term:

wail a conventional siren sound, cycling over a few seconds
yelp a rapid siren
hi-lo alternating high and low notes
whoop repeated low to high frequency sweep
yeow repeated high to low frequency sweep
horn quasi-continuous steady sound
beep slow intermittent horn, say 60 cycles a minute
stutter rapid intermittent horn, say 140 cycles a minute

The development of this wide range of alarms was partly because electronics made them possible, and partly to gain a commercial advantage with something different, and perhaps more useful. There was a need to improve the effectiveness of alarms, although some problems could be solved only with very high sound levels. Currently, the most widely used of the alarms above are the whoop, for emergency vehicles and the beep, for vehicles to indicate reversing. Outputs of alarms are often specified at 1m distance. A powerful emergency alarm might be around 120dB(A) at 1m. A reversing alarm could be from 60dB(A) to over 100dB(A), chosen in relation to the vehicle noise and local ambient sound levels. As most of the energy in alarms is above 1000Hz, there is little difference between their A and C weightings.

We may dislike, but can forgive, the whoop of the ambulance or police car, but are less tolerant of the incessant beeping which comes from vehicles in reverse gear, whilst either on the road or on off-road work sites. Nobody likes being woken by early morning beeps from the refuse truck reversing down a street, which is too full of overnight cars for the truck to turn. Similarly, a quarry or opencast working may be a source of reversing beeps, disturbing the neighbourhood, as might the reversing beep-beep of fork-lift trucks in a local yard.

For a long time it seemed that in the conflict between on-site safety and environmental disturbance, safety must win and the environment accept the consequences. Then along came broadband sound.

Caterpillar 962G wheeled loading shovel in a sand quarry

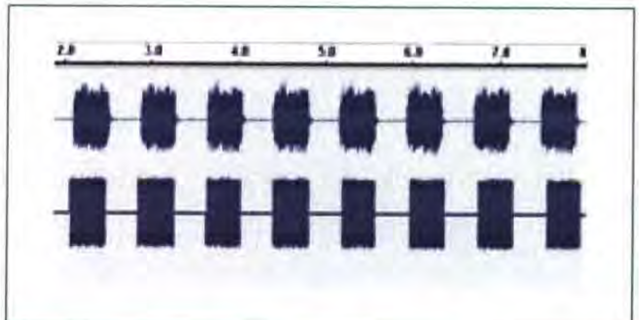

Figure 01

Broadband and tonal alarms

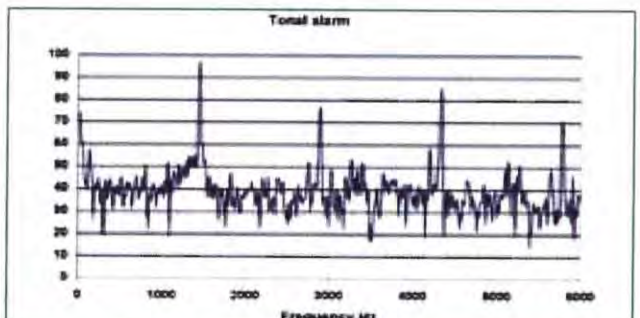

Figure 02

Spectrum of tonal alarm, 1450Hz fundamental

Broadband sound as an alarm signal

The initial development of broadband sound as a component of alarm signals was as an addition to existing tonal alarms, in order to improve the locatability of the alarm, since the broadband sound gives additional information to the listener (see Appendix). The broadband sound is typically from about 1kHz to 4kHz, falling off at each side of this and sounds like a 'sschh... sschh... sschh'. In contrast, a tonal alarm often contains a single frequency plus a few lower level distortion harmonics. Some emergency vehicle alarms alternate whoops with broadband sound. The whoops attract attention whilst the broadband sound helps locate the direction from which the vehicle is coming[1],[2],[3]. Broadband has also been used to guide occupants to an emergency exit when there are problems, for example, in smoke filled buildings and aircraft or from power failures [4]. Another application is as a guide for the blind at road crossings. An important breakthrough came when it was realised that, for many purposes, the tonal component was not required. A broadband sound could serve as both alarm signal and locating signal, bringing welcome environmental benefits with it [5].

Broadband and tonal alarms

Both alarms operate with approximately equal on-off times of about 0.4s. Figure 1 shows typical switching for the two types of alarm. The top scale is in seconds, the upper trace is the broadband alarm and the lower trace is the tonal alarm.

Figure 2 shows the averaged spectrum for a tonal alarm of 1450Hz and Figure 3 is the spectrum for a broadband alarm. Figure 2 represents a rather distorted sound wave, with very little energy in the region between the harmonics. Figure 3 shows continuous energy from below 1000Hz to over 4000Hz.

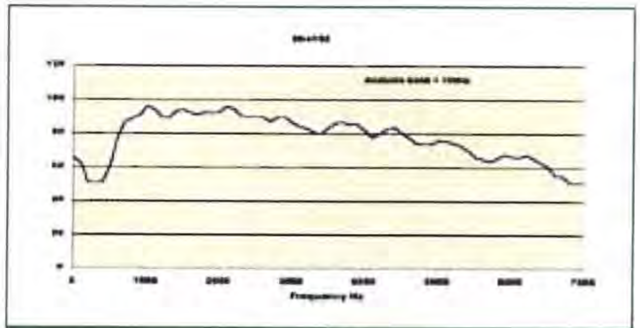

Figure 03

Constant bandwidth analysis (100Hz bandwidth) of broadband alarm

Alarms are designated by their A-weighted levels, measured at 1m. The A-weighted level of a tonal alarm is largely determined by its main component, whilst the level for broadband alarms is given by the summation of all its energy. This is shown in the third-octave analyses of Figure 4, which compares a 97dB(A) tonal alarm with an 87dB(A) broadband alarm. This tonal alarm peaks in the 1250Hz third-octave band. The apparent component in the 1600Hz band at about 88dB breaks through into this band owing to the alarm frequency being towards the upper end of the 1250Hz third-octave band: this spans from 1120Hz to 1410Hz. Each third-octave band for the broadband alarm represents the presence of continuous acoustic energy and the total level is the summation of all the bands.

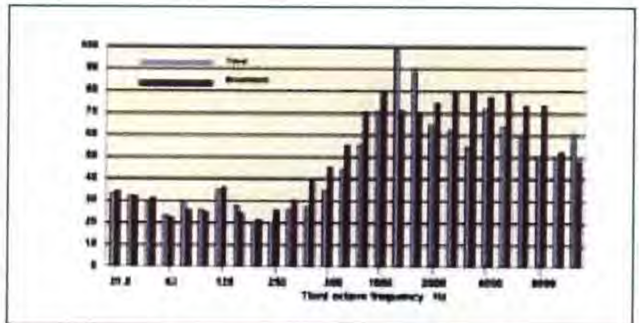

Figure 04

Third-octave spectra of tonal and broadband alarms

A problem with tonal alarms is that interference between the direct and ground-reflected wave may cause local variations in level of around 15dB, occurring over distances of a few centimetres [6]. The ear nearest to a machine in reverse gear could receive a lower level than the further ear, causing confusion to the listener. This does not occur with broadband alarms as, although some frequencies may interfere destructively, others interfere constructively, so that there is very little local change in level.

Loudness of alarms

The main function of a reversing alarm is to warn those in a danger area, which is typically close behind the vehicle, that they must take precautionary measures[7]. Whilst intermittency is one characteristic in alerting, loudness is another important factor, as the alarm must be at a level well above that of its masked threshold in the background noise[8]. For some time there has been anecdotal evidence that, in listening to tonal and broadband alarms of equal A weighted level, the broadband alarms 'sound louder', although the reason for this was not known.A sound level difference of 5dB was suggested for equal loudness[9]. The reason becomes clear if the frequency regions of tonal and broadband alarms are related to the equal loudness contours [10]. Figure 5 shows the contours in which the frequency region for broadband alarms is contained in the rectangle and the vertical line is at a typical frequency region for tonal alarms (1200Hz to 1500Hz). Tonal alarms are situated in the least sensitive local region of the hearing contours, whilst broadband alarms spread across the region of increased local sensitivity between 2000Hz and 4000Hz, which is attributed to resonance of the ear canal. This explains the difference in loudness.

Loudness comparison measurements were made using a CEL 593 sound level meter which was fitted with a loudness module, giving the Zwicker loudness.The microphone was

alarm	L_{Aeq}	loudness
broadband	92.3	103.2
tonal 1250Hz	93.0	95.0
tonal 1450Hz	92.2	95.8
complex 1450Hz	92.1	98.5

Table 01

Loudness comparisons

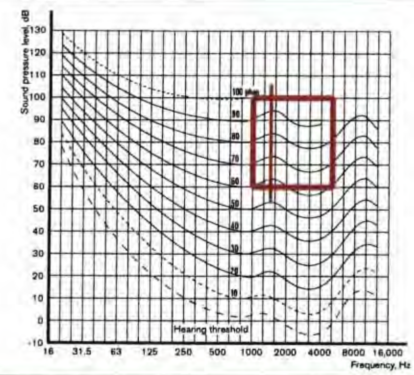

Figure 05

Hearing contours and alarm frequencies

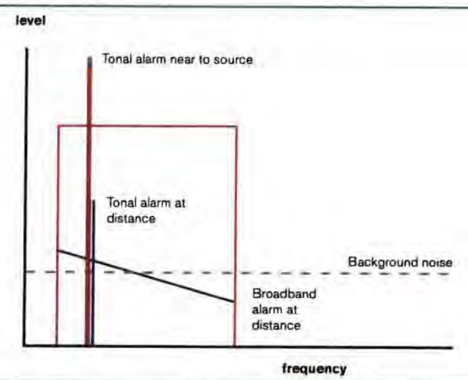

Figure 06

Propogation effects on the sound from tonal and broadband alarms

removed and recordings of alarm sounds fed to the sound level meter as electrical signals, through an adapter. Comparisons are shown in Table 1, from which it is seen that, for given A-weighted levels, the broadband sound is louder than the tonal sounds, the difference reducing for the complex tone at 1450Hz, which has a component at 2900Hz.

The sound level meter calculates loudness from a third-octave band analysis of the equivalent level in the bands, which is lower than the level of the 'on' period, and 3dB lower for equal 'on' and 'off' periods.

The following should be noted.

- It has been known for some time that full loudness sensation is achieved in about 100 milliseconds[11],[12], which is rather less than the duration of an alarm 'on' period
- Different types of alarms with closely similar 'on' and 'off' periods will have similar differences between their L_{eq} and maximum levels.

Consequently, the loudness measurement is a valid comparison of the loudness of the alarms.

Environmental effects

Complaints of beeping alarms have led to local authorities specifying broadband reversing alarms for vehicles as a planning condition (for further information try a Google search for 'broadband alarm planning permission'). This has applied to quarry workings, superstore deliveries etc. The broadband sound is an effective alarm when close to the vehicle, whilst also sounding more pleasant and less intrusive than a beeping alarm does when at a distance. Broadband at a distance has a bland and characterless sound quality.

When tonal and broadband alarms have the same A-weighted level, the component of a single frequency tonal alarm might be 8 or 9 dB greater than the third-octave bands which comprise the spectrum of the broadband alarm, depending on the total bandwidth of the broadband alarm. The relative levels close to the alarm are indicated in Figure 6. At a distance from the alarm, the effects of air and ground absorption are more pronounced for the higher frequencies of the broadband alarm. This leads to a greater reduction of the levels at the higher frequencies of the broadband alarm and a tilted spectrum into higher frequencies as in Figure 6. The A-weighted levels of the alarms, although equal at 1m, are different at a distance. Estimation shows that at 500m, for propagation over grass, the broadband alarm might be at an A-weighted level 4 or 5 dB lower than the tonal alarm. Other beneficial effects of barriers, absorption by foliage, ground type etc also increase with frequency. In addition, the components of the broadband alarm fall below the background noise at a position nearer to the source than the tonal alarm does. This leads to a manufacturer (Brigade Electronics) to refer to broadband alarms as 'noiseless', which effectively is true at distances when they cease to disturb listeners, although the tonal alarm may still remain annoyingly audible.

Penetration into buildings

Disturbance inside buildings may be very pronounced for tonal beeps from an alarm, especially when the occupant is resting. The higher frequency components of a broadband alarm have greater attenuation by the building envelope than the single frequency tonal alarm. The frequency dependent increase of attenuation by the building might be about 5dB per octave. Assuming a 1.5dB per thirdoctave increase in attenuation, it is possible to show that for tonal and broadband alarms which have the same A-weighted level close to the source, the internal level of the broadband alarm is about 4dB lower than that of the tonal alarm. Additionally, the sound has a less disturbing quality.

Directional radiation

It is clearly advantageous if an alarm radiates mainly in the area which it is intended to protect, and does not spill into other directions, where it might cause unwanted disturbance. The directivity of a source depends mainly on the ratio R, which is the source dimension divided by the wavelength of the sound radiated.

A typical reversing alarm may include a small loudspeaker of diameter about 0.06m, with a waterproof cone. Then at 1250Hz the wavelength is 0.27m and R ~ 0.25, whilst at 4000Hz the wavelength is 0.085m and R ~ 0.7.The change of R from 0.25 to 0.7 indicates greatly increased directivity of the higher frequencies of the broadband alarm. Thus the energy of the alarm is concentrated into the areas in which it is required, reducing disturbance to other areas.

Summary

Some advantages of the newer broadband alarms over tonal alarms are:

1 They are about 5 phon louder than tonal alarms of the same Aweighted level, which means that a broadband alarm has a lower level for equal loudness.

2 Improved locatability comes from higher frequencies

3 Radiation is more directional than for tonal alarms

4 Propagation absorption is greater than for tonal alarms

5 Penetration into buildings is less than for tonal alarms.

Much of the interest in broadband alarms has developed for their environmental advantages, in addition to their use as a hazard warning. Tonal alarms still hold their traditional position as a familiar warning signal, but it must be remembered that alarm signals have changed considerably over a period of less than 100 years in their progression form bell to broadband, each phase gaining acceptance as it became familiar. At the present time it is too early to say whether broadband sound will be the alarm of the future, but its current rapid acceptance, for both environmental and safety reasons, is a positive indication.

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Appendix

Locatability of alarms

Locatability refers to the ease of determination of the direction of an unseen source of sound and estimation of its distance. Direction is far easier to determine than distance, which requires different clues including sound spectrum, level, quality etc. There are three main frequency regions which determine the locatability of a sound[13], although these are heard simultaneously.

1. At low frequencies (about 1.5kHz and below) the brain can process the time difference between the sound arriving at one ear and then the other. This is known as the Interaural Time Difference (ITD). However a 'cone of confusion' remains, in which sources on the surface of a cone have the same time delay between the two ears.
2. At mid frequencies (around 3kHz and above) the brain senses the intensity difference of the sound at each ear, ie the brain determines that the ear receiving greater sound intensity is closer to the source.The difference is known as the Interaural Level Difference (ILD) or Interaural Intensity Difference (IID). This frequency range permits us to decide if the sound is to the left or right.
3. Owing to the shape of our outer ear, higher frequencies of about 5kHz are modified before entering the ear canal. This is an individual response and becomes significant when the wavelength of the sound is similar to or shorter than the dimension of the outer ear. Its use is a learned skill and assists front/rear sound source location.

The effects in these three frequency ranges combine to produce the head related transfer function (HRTF) between an external source and the sound into the ear.

A broadband alarm contains frequencies in all the three regions and gives sufficient information for rapid source location. A tonal alarm has components mainly in the first region and is more difficult to locate.

References

1. Sound Alert (2008): Directional Sound Technology. www.soundalert.com.
2. Withington D J (1999): Localisable Alarms. In Human Factors in AuditoryWarnings ed: Stanton and Edworthy.
3. Withington D J (2000): The use of directional sound to improve safety of auditory warnings. 4th Annual Meeting Human Factors and Ergonomics Society.
4. Lower M, Kay A M, Lauren J, and Miur H C (2004): Localisable sound and its application in guiding passengers towards exits during aircraft evacuation. Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference.
5. Brigade Electronics (2008): http://www.reverseinsafety.co.uk/.
6. Laroche C and Lefebvre L (1998): Determination of optimal acoustic features for reverse alarms: field measurements and the design of a sound propagation model. Ergonomics 41, 1203-1221.
7. HSE (2007):Vehicles at work - Reversing. http://www.hse.gov.uk/workplacetransport/information/reversing.htm.
8. ISO-7731 (2003): ISO 7731 Ergonomics: Danger signals for public and work areas - Auditory danger signals.
9. IMC Technical Services (2001): Improving the safety of workers in the vicinity of mobile plant. CONTRACT RESEARCH REPORT 358/2001 for the HSE.
10. ISO:226 (2003): Acoustics - Normal equal-loudness contours.
11. Boullet I, Marozeau J, and Meunier S (2004): Temporal summation of loudness as a function of frequency and temporal pattern Proc Internoise 2004, Prague.
12. Miller G A (1948): The Perception of Short Bursts of Noise. JASA , 20, 160 - 170.
13. Howard D M, and Angus J (2001): Acoustics and Psychoacoustics. Focal press.