AEAT-II-2004-017 Issue 1

Audibility of Warning Horns

Broadband Horn Evaluation

A report produced for Rail Safety and Standards Board

RRK Jones

November 2004

AEAT-II-2004-017 Issue 1

Audibility of Warning Horns

Broadband Horn Evaluation

A report produced for Rail Safety and Standards Board

RRK Jones

November 2004

Title	Audibility of Warning Horns Broadband Horn Evaluation
Customer	Rail Safety and Standards Board
Customer reference	GM/RT2180i4
File reference	PRJ-DF-LD 79531-002
Report number	AEAT-II-2004-017
Report status	Issue 1

AEA Technology Rail
Jubilee House
4 St Christopher's Way
Pride Park
Derby
DE24 8LY
United Kingdom
Telephone +44 (0)870 190 1244
Facsimile +44 (0)870 190 1548

AEA Technology Rail is a trading name of AEA Technology plc
AEA Technology Rail is certificated to BS EN ISO9001:(2000)

	Name	Signature	Date
Author	RRK Jones		
Reviewed by	J Block		
Approved by	J Wood		

Executive Summary

The warning horns fitted to trains are designed to ensure clear audibility as trains approach locations where people at risk of being struck may otherwise be unaware of the train's approach. Conventional pneumatic horns have been in use for many decades, and have proved reliable and adequately audible under a range of conditions. However, in recent years complaints from trackside residents about such horns have increased significantly. One possible method of reducing such complaints would be to use a warning device that ensures adequate audibility ahead of the train whilst minimising the radiation of sound to the trackside. Electronic "Broadband" horns are being considered by the Rail Safety and Standards Board (RSSB) as a means of achieving this aim as they are reported to have a number of advantages over conventional warnings. These include an improved ability to identify the direction of the warning and a lower environmental impact.

AEA Technology Rail have been asked by RSSB to assist in the objective measurement and assessment of the audibility of such devices via field tests and subsequent analysis to account for "worst cases". To achieve this, a Broadband horn was fitted to an electric multiple unit at Selhurst Depot and measurements were taken, at a range of positions, of the sound produced by both the conventional horns of the train and the Broadband horn. The results thus obtained were then used as a basis for an assessment of audibility of both forms of horn under adverse conditions of sound propagation due to terrain and meteorological factors, for a listener with poor hearing in a typical noisy trackside environment.

It has been concluded that:

The Broadband horn tested at Selhurst Depot produced a sound characterstic that was not sufficiently audible under adverse conditions. Conventional pneumatic horns are able to maintain audibility under the same conditions.

There was no strong evidence that the Broadband horn is more directional than conventional horns when mounted on a train, but this would need confirming by testing the horn's directivity in isolation.

An increase in acoustic output of the Broadband horn of 3 dB would raise its audibility to a more acceptable level.

If the acoustic output of the Broadband horn could be raised sufficiently, rigorous listening tests would be advisable to confirm audibility under adverse conditions.

Distribution List

Customer

1. Rail Safety and Standards Board, Floor 7, Evergreen House, 160 Euston Road, London, NW1 2DX.
2. Rail Safety and Standards Board, Floor 7, Evergreen House, 160 Euston Road, London, NW1 2DX.
3. Rail Safety and Standards Board, Floor 7, Evergreen House, 160 Euston Road, London, NW1 2DX.

Internal recipients AEA Technology Rail, Jubilee House, 4 St Christopher's Way, Pride Park, Derby, DE24 8LY.

4. Project File, reference PRJ-DF-LD 79531-002 (unbound).
5. Acoustics Team Library (unbound).
6. Information services (electronically via V. Rayson)
7. R. Smith, Senior Vice President, Railway Infrastructure and Systems (bound).
8. R. Mole, Deputy Chief Executive (title page, executive summary and distribution list only)
9. C. Perry, Deputy Chairman (title page, executive summary and distribution list only).
10. E. Morland, Chief Executive (title page, executive summary and distribution list only)
11. Master copy: Infrastructure Integrity (unbound and electronic copies).

Contents

Executive Summary iii

Distribution List iv

Contents v

1 Introduction 1

2 Criteria for the audibility of warning sounds 2

3 Site tests 3

4 Measurement results 4

4.1 BACKGROUND NOISE 4

4.2 OVERALL HORN SOUND LEVELS 4

5 Comparison of overall measurements with current and proposed standards 5

6 Objective assessment of audibility 7

6.1 AUDIBILITY AT SELHURST 7

6.2 AUDIBILITY UNDER ADVERSE PROPAGATION AND BACKGROUND CONDITIONS 8

6.3 DIRECTIONALITY OF THE HORNS 9

7 Discussion 10

8 Conclusions 11

9 References 12

1 Introduction

The warning horns fitted to trains are designed to ensure clear audibility as trains approach locations where people at risk of being struck may otherwise be unaware of the train's approach. Conventional pneumatic horns have been in use for many decades, and have proved reliable and adequately audible under a range of conditions. However, in recent years complaints from trackside residents about such horns have increased significantly. One possible method of reducing such complaints would be to use a warning device that ensures adequate audibility ahead of the train whilst minimising the radiation of sound to the trackside. Electronic "Broadband" horns are being considered by the Rail Safety and Standards Board (RSSB) as a means of achieving this aim as they are reported[1] to have a number of advantages over conventional warnings. These include an improved ability to identify the direction of the warning and a lower environmental impact. AEA Technology Rail have been asked by RSSB to assist in the objective measurement and assessment of the audibility of such devices via field tests and subsequent analysis to account for "worst cases".

The conventional pneumatic railway horn produces sound at a "fundamental frequency" and a set of "harmonics", where the fundamental frequency is also known as the "first harmonic", and the "second harmonic" is 2x the fundamental, the "third harmonic" is 3x the fundamental etc. This is known as a deterministic signal. The Broadband horn produces sound at all frequencies, with the potential advantage, therefore, of more frequencies being available to be heard. The amplitude of the sound at each frequency within the Broadband output varies randomly with time and is known as a stochastic phenomenon. Sound pressure waveforms (fluctuation with time) for typical deterministic and stochastic signals are illustrated in Figure 1.1.

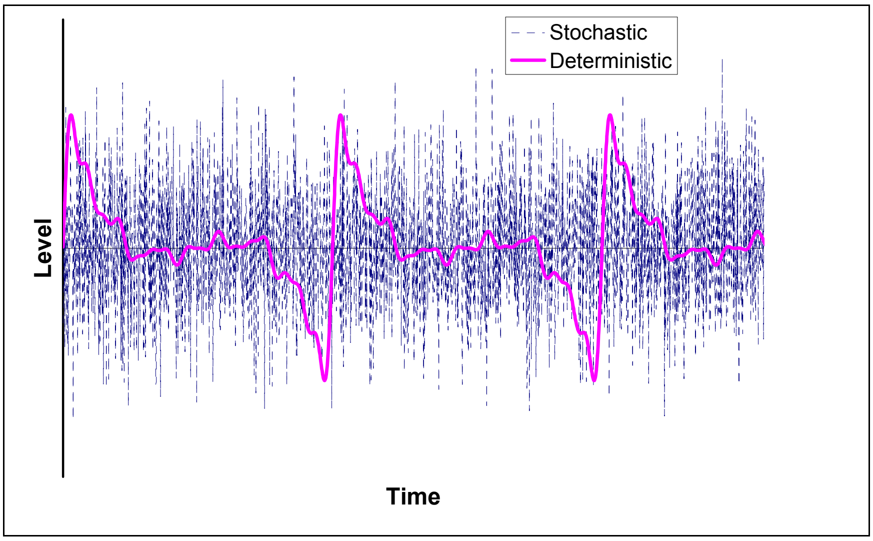

Figure 1-1 Illustrative waveforms for typical Broadband (stochastic) and conventional (deterministic) warning sounds

2 Criteria for the audibility of warning sounds

The subject of audibility is a complex one, involving a comparison of the acoustic characteristics of the sound reaching the listener with the “masking threshold”. This threshold arises from a combination of the background noise level and the hearing ability of the listener, which is very variable across the population and is affected by age, noise exposure and disease. A set of expert publications in this field has been studied[2, 3, 4, 5], resulting in the choice of appropriate criteria to assess audibility. These criteria are dependent on the relationship between the spectrum (sound pressure level vs frequency) of the warning sound and the masking threshold. For conventional warnings (deterministic), the spectrum has the appearance of a set of peaks with little sound energy elsewhere, while for the broadband horn (stochastic) the spectrum is more continuous (Figure 2.1).

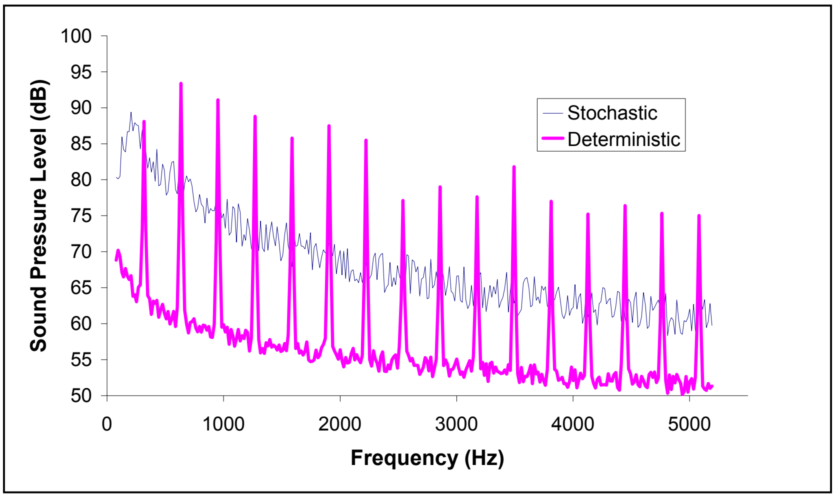

Figure 2.1 The typical frequency content of a Broadband (stochastic) warning and a conventional (deterministic) warning

The chosen audibility criterion is based on the comparison between the warning’s spectrum at the listener and the listener’s masking threshold, similarly presented as a spectrum. Reference to 1/3 octaves in the following text relates to the grouping together of all the sound energy within a continuous band of frequencies, with the centre frequency of each band being 1/3 octave apart, ie at values of 31.5 Hz, 40 Hz, 50 Hz, 63 Hz, 80 Hz, 100 Hz, etc. (note that the frequencies are related by a factor of 2, an octave, at every 3rd value). It was considered that a warning will be “just clearly audible” if the amount by which the warning’s spectrum exceeds the masking threshold (corrected as appropriate to take into account the psycho-acoustic filtering characteristics of human hearing) within a 1/3 octave band is at least 15 dB, with the number of harmonics or 1/3 octave band levels greater than 10 dB above the masking threshold being 3 or more.

3 Site tests

The standard requirement for the performance of a train's warning horn in the UK is that it should be clearly audible 400m from the front of the train, taking into account adverse background noise conditions and a listener with a significant loss of hearing acuity. It is, however, often impractical to attempt to measure horn noise at 400m, and therefore specifications are set in terms of levels close to the horn (typically 5m) that are calculated as indicating an adequate level of audibility at 400m.

In order to assess thoroughly the audibility of Broadband horns compared with conventional horns it was decided, however, that measurements of both types of device would be made both close to, and at distances up to 400m from, the train. These measurements were made at the South Central Trains' Selhurst Depot on 23 October 2003. A parallel set of listening tests using two groups of people drawn from interested parties was also carried out separately from the measurement exercise.

A Class 377 electric multiple unit was fitted with the Broadband device, whilst retaining its conventional pneumatic horns. The Broadband horn was mounted close to the conventional horns at the front of the train.

Measurement positions for background noise and horn characteristics were:

- 5m in front of the train, 1.5m above the ground
- 5m in front of the train at the same height as the horn
- 30m in front of the train, 1.5m above the ground
- 100m in front of the train, 1.5m above the ground
- 5m from the side of the train in line with a vertical plane through the open ends of the conventional horns
- 400m in front of the train, 2.5m high, where one listening panel was located ("In Depot")
- At the location of the second listening panel, Heaver's Meadow, which was approximately 200 metres to the side of the train

Although propagation to the front of the test train was uninterrupted by intervening structures, stationary trains were positioned between the test train and Heaver's Meadow. This resulted in a screening effect that reduced horn levels in comparison with levels that would be expected over open terrain.

4 Measurement results

4.1 BACKGROUND NOISE

The spectrum of background noise was measured at the two listening panel positions, ie "In Depot" 400m to the front of the train and "Heaver's Meadow" 200m to the side of the train. These are shown in Figure 4.1.

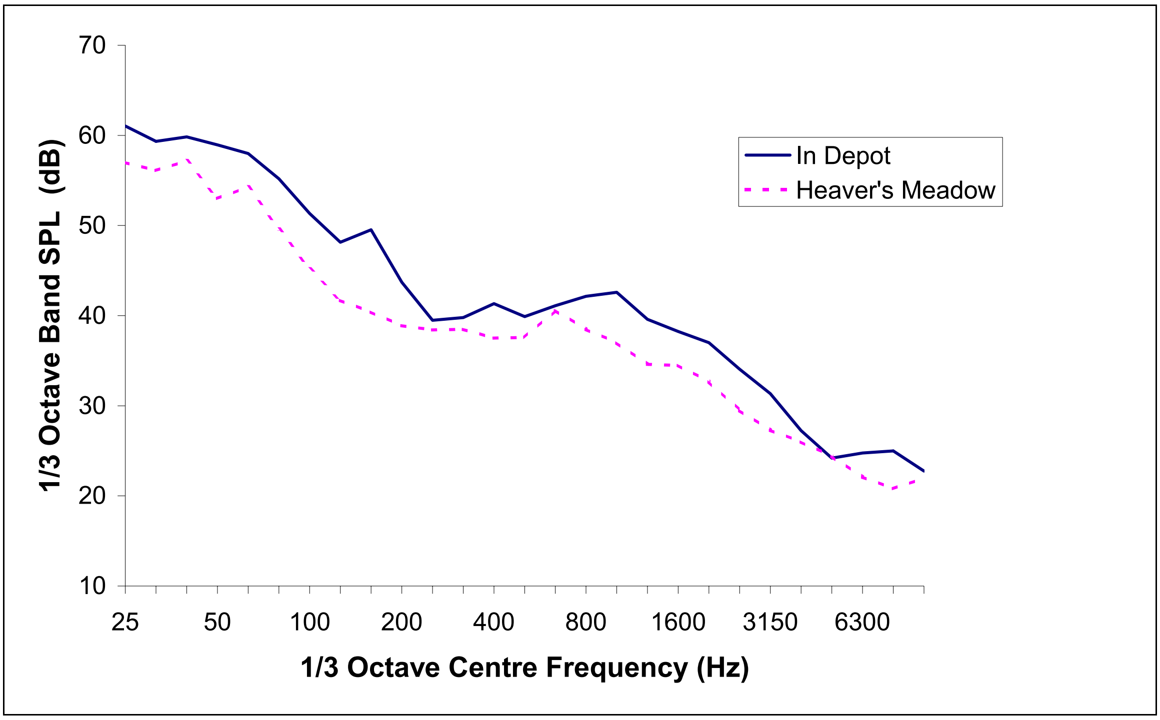

Figure 4.1 Typical background noise levels at the two listening panel positions

4.2 OVERALL HORN SOUND LEVELS

Measurements of the sound from the conventional horns (high note and low note separately) and the Broadband device (with 5 separate loudness settings) were taken 5m, 100m and 400m to the front of the train and at Heaver's Meadow for comparison with the existing and proposed standards and for audibility assessment. The results are shown in Table 4.1. Measurements of the conventional horns at 30m were also used as an intermediate point in the assessment of the sound propagation characteristics over the ground at the site out to 400m. In Table 4.1 the horns are quantified in terms of overall "A-weighted" and "C-weighted" level. These weightings approximate to the response of the human ear to sounds of low level and high level respectively. The background noise spectra shown in Figure 4.1 equate to 50 dB(A) "In Depot" and 46 dB(A) at "Heaver's Meadow".

		5 m, 1.5m h Front	5m, level with horn Front	5m, 1.5m h Side	100m, 1.5m h Front	400m, 2.5m h Front	200m to the side Heaver's Meadow
Conventional High note	**L_A (dB)**	118		118	92	80	68
	L_C (dB)	118	120	119	92	79	70
Conventional Low note	**L_A (dB)**	125		120	100	77	69
	L_C (dB)	126	125	121	100	78	71
Broadband Loudest	**L_A (dB)**	113		108	82	70	58
	L_C (dB)	113	112	103	82	70	58
Broadband Next loudest	**L_A (dB)**					62	49*
Broadband Middle	**L_A (dB)**					56*	43*
Broadband Next Quietest	**L_A (dB)**					53*	41*
Broadband Quietest	**L_A (dB)**					50*	38*

* Values too low to measure accurately in the presence of the background noise, and therefore extrapolated from closer measurements using transfer functions obtained from the loudest Broadband warning

Table 4.1 Overall sound levels measured during the Selhurst test.

5 Comparison of overall measurements with current and proposed standards

Values from Table 4.1 can be compared with the current RSSB Group Standard for warning horns GM/RT2180 Issue 3[6], and also with draft Group Standard GM/RT2484 Issue 1 Draft 1f[7], which is designed to reduce environmental impact whilst maintaining adequate audibility, with a testing approach that guarantees repeatability. Table 5.1 shows this comparison for the "as-measured" values.

	C-weighted Sound Pressure Level (dB re 20 µPa)				
	Conventional		Broadband Loudest	Standard	
5m, 1.5m high	High	118	113	120-125	'2180'
	Low	126			
5m, level with horn	High	120	112	112+	'2484' up to 160km/h
	Low	125			
100m, 1.5m high	High	92	82	94	'2180'
	Low	100			

+Note that this value is based on the audibility and propagation characteristics of conventional horns with strong tonal content, as required by the current and proposed Group Standards. The Broadband characteristics would require this value to be increased to 116 dB for equivalent audibility at the limiting distance of 400m.

Table 5.1 Comparison between values measured at Selhurst and levels specified in current standard GM/RT2180 Issue 3, and in proposed standard GM/RT2484 Issue 1 Draft 1f.

However, to ensure consistent results the draft standard GM/RT2484 requires measurements against the specification to be taken over a ground covering of new, clean ballast. At the test site this was not the case, with the ground being old ballast partially filled with fine dirt. The sound propagation characteristics measured on site were therefore used to correct the measured values to those that would have arisen if the site had been covered with new, clean ballast. The result of this is shown in Table 5.2.

	C-weighted Sound Pressure Level (dB re 20 µPa)				
	Conventional		Broadband	Standard	
5m, 1.5m high	High	120	113	120-125	'2180'
	Low	127			
5m, level with horn	High	121	113	112+	'2482' up to 160km/h
	Low	126			
100m, 1.5m high	High	94	86	94	'2180'
	Low	99			

Table 5.2 Comparison between values measured at Selhurst corrected for propagation over new, clean ballast and levels specified in current standard GM/RT2180 Issue 3, and in proposed standard GM/RT2484 Issue 1 Draft 1f

6 Objective assessment of audibility

6.1 AUDIBILITY AT SELHURST

As outlined in Section 2, a warning is considered just clearly audible if the amount by which the warning's spectrum exceeds the masking threshold (corrected as appropriate to take into account the psycho-acoustic filtering characteristics of human hearing) within a 1/3 octave band is at least 15 dB, with the number of harmonics or 1/3 octave band levels greater than 10 dB above the masking threshold being 3 or more. The masking thresholds used for this assessment are based on a combination of the measured background spectra either at the position 400m in front of the train or at Heaver's Meadow, with hearing thresholds based on population distributions as presented in ISO 7029[8]. From this standard, it was considered that a suitable classification of hearing threshold to combine with background noise would be that which applied to a 60 year old male at the worst 5% point in the distribution, as a standardised representation of an individual with poor hearing. Figure 6.1 shows the importance of the hearing threshold to this analysis, where the effect of combining the "worst 5%, 60 year old" criterion with the background curves in Figure 4.1, as used in the following analysis, is compared with the same background situations for a 20 year old male with average hearing, where hearing threshold has minimal influence.

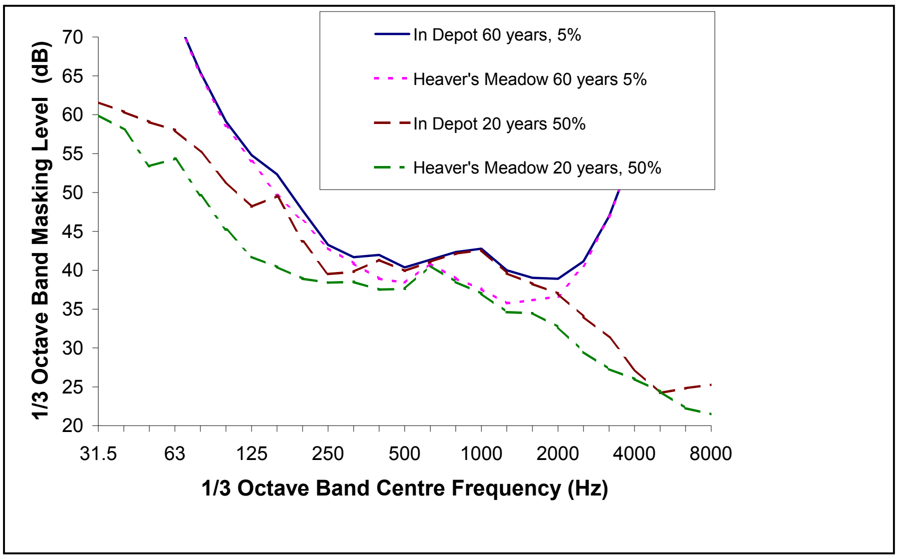

Figure 6.1 Masking thresholds at Selhurst for a person with poor hearing ("60 years, 5%") and for a person with good hearing ("20 years, 50%")

The results of this analysis are presented in Table 6.1.

	400m in front of train		200m to side of train, Heaver's Meadow	
	Amount above masking threshold (dB)	Number of Harmonics or 1/3 Octave Bands 10 dB or more above masking threshold	Amount above masking threshold (dB)	Number of Harmonics or 1/3 Octave Bands 10 dB or more above masking threshold
Conventional High note	36	8	27	6
Conventional Low note	45	10	32	7
Broadband Loudest	28	10	16	6
Broadband Next Loudest	19	8	8	0
Broadband Middle	13	4	2	0
Broadband Next Quietest	11	1	0	0
Broadband Quietest	8	0	-3	0

Table 6.1 The audibility of the warnings in the prevailing background noise at Selhurst Depot for a 60 year old male with hearing at the worst 5% level.

By applying the chosen audibility criteria, the Broadband horn provides adequate audibility at the 400m position with the "loudest" and "next loudest" settings, but is only clearly audible at Heaver's Meadow at the loudest setting. The conventional horns are clearly audible at both locations.

6.2 AUDIBILITY UNDER ADVERSE PROPAGATION AND BACKGROUND CONDITIONS

Although the results are a useful initial indication of the comparative performance of Broadband horns and conventional horns, more adverse propagation and background noise conditions can occur on the operating railway. To represent this, a ground characteristic of "compacted cinders" which leads to maximum attenuation with distance, and a background noise taken as the 95th percentile spectrum of sound near to a railway (typical of sites near busy roads) was taken. Ground with a "compacted cinders" acoustic characteristic is common adjacent to many railway lines, and it is ground of this nature that the horn sound would propagate over on a curved section of track. By taking these background characteristics into account, but maintaining the hearing threshold of the listener at the "worst 5%, 60 year old" level, a revised audibility assessment was possible, as shown in Table 6.2. However, even these conditions are not representative of a true adverse situation, as train movement and meteorological conditions can all be detrimental to sound propagation. Therefore the situation for an air temperature of -5^{o} C, a wind speed of 30 km/h from listener to train and a relative humidity of 30%, with propagation over a ground with a "compacted cinders" acoustic character, was also modelled from the measured results. This situation is also presented in Table 6.2.

	400m in front of train Stationary High noise background Meteorological conditions as at Selhurst		**400m in front of train 160 km/h High noise background Adverse meteorological conditions**	
	Amount above masking threshold (dB)	**Number of Harmonics or 1/3 Octave Bands 10 dB or more above masking threshold**	**Amount above masking threshold (dB)**	**Number of Harmonics or 1/3 Octave Bands 10 dB or more above masking threshold**
Conventional High note	31	7	25	5
Conventional Low note	40	8	34	6
Broadband Loudest	23	9	12	4
Broadband Next Loudest	15	5	4	0
Broadband Middle	9	0	-2	0
Broadband Next Quietest	7	0	-4	0
Broadband Quietest	3	0	-8	0

Table 6.2 The audibility of the warnings in adverse background and propagation conditions for a 60 year old male with hearing at the worst 5% level.

Under the adverse meteorological conditions combined with the high noise background, with the train in motion, it can be seen that the conventional horns remain audible, but the Broadband horns are no longer in the "clearly audible" category. An increase in level of 3 dB would be necessary to ensure audibility of the Broadband horn under these conditions.

6.3 DIRECTIONALITY OF THE HORNS

Ideally a warning horn will focus its sound on the position where the warning is required, with little spurious sound energy propagating to locations to either side of the track. Unfortunately this is not easy to achieve. The pneumatic horn in isolation will tend to radiate sound equally in all directions, although once installed on a train and close to the ground the effects of train and ground will modify its directional characteristics. The difference between the sound level at the front of the train, and that at an equal distance to one side, tends to be very variable from train to train fitted with conventional horns. The measurements taken 5m from the front and side of the train at Selhurst enabled some indication of the directionality of the conventional and Broadband horns to be established. Table 6.3 shows these results and also shows results obtained subsequently for a Class 458 Multiple Unit, in terms of the measured value at 5m from the side of the train subtracted from the measured value 5m in front of the train.

	Weighting	**Difference (dB)**	
		High Note	**Low Note**
Class 458 Measured at same height as the horns	A	4	10
	C	4	8
Class 458 Measured at 1.5 m above the ground	A	12	11
	C	10	10
Selhurst Conventional (Class 377) 1.5m above ground	A	1	5
	C	-1	5
Selhurst Broadband (Class 377) 1.5m above ground	A	5	
	C	10	

Table 6.3 The reduction in sound level 5m from the front to 5m from the side of the train

It can be seen that the Broadband horn shows a 5-10 dB reduction from front to side, which is in the range also exhibited by the Class 458 (and similar stock), but significantly better than the directionality of the conventional horns at Selhurst. It was observed, however, that the conventional horns on the Class 375/377 used at Selhurst are mounted very close to a fibreglass fairing which will tend to lead to its acoustic excitation and radiation of sound to the side.

7 Discussion

It is clear that a warning system that is reliably audible for the majority of likely conditions to arise on the operational railway but with minimal environmental impact is highly desirable. Devices that are directional and/or with especially audible characteristics will go some way to achieving this. The conventional pneumatic warning horn has suitable characteristics for high audibility, but it is very difficult to arrange for it to be directional, other than by mounting it on the train in such a way that the train's body shields radiation to the side. Indeed it is difficult to arrange for directional characteristics for any single-source sounder device. Normally an array of devices, linked mechanically or electronically so that their output is coherent, is needed to provide a directional characteristic from the system in isolation.

The Selhurst results with subsequent correction to allow for a listener with poor hearing as well as for train movement, adverse meteorological conditions and a high noise background, show that the Broadband horn is not, in its tested form, fully able to provide adequate audibility in all situations. It has been shown, however, that the Broadband horn does provide acceptable audibility under less onerous conditions, and that a 3dB increase in acoustic output from the Broadband horn would rectify the low audibility.

The Broadband horn as mounted on the train at Selhurst does display some useful directionality, but it should be noted that this is very similar to values measured previously for conventional horns, and it is possible that this is a function of diffraction of sound around the train rather than an inherent directional character. Further tests of the horn in isolation would be advisable to establish whether it has true directionality. The horn is, however, potentially more localizable because of its character, which could be considered an advantage over the conventional horn.

If the Broadband horn concept is to be further considered for potential railway application, it is recommended that:

- Its acoustic output be increased by at least 3 dB if possible
- Rigorous controlled listening tests be carried out under a real, rather than modelled, set of background noise conditions
- The railway industry consider whether it can have confidence that the complete change in character of the horn from the current standard will not confuse the public and staff and lead to potential serious incidents.
- Conflicts with the Interoperability Directives be considered.

8 Conclusions

The Broadband horn tested at Selhurst Depot produced a sound characterstic that was not sufficiently audible under adverse conditions of sound propagation due to terrain and meteorological factors, for a listener with poor hearing in a typical noisy trackside environment. Conventional pneumatic horns are able to maintain audibility under the same conditions.

There was no strong evidence that the Broadband horn is more directional than conventional horns when mounted on a train, but this would need confirming by testing the horn's directivity in isolation.

An increase in acoustic output of the Broadband horn of 3 dB would raise its audibility to a more acceptable level.

If the acoustic output of the Broadband horn could be raised sufficiently, rigorous listening tests would be advisable to confirm audibility under adverse conditions.

9 References

1 Withington, DJ ‘A comparison of Conventional and bbs-tek Reversing Alarms’, School of Biomedical Sciences, University of Leeds, obtained via the author
2 Patterson, RD ‘Guidelines for auditory warning systems on civil aircraft’, (CAA Paper 82017), Civil Aviation Authority, London, 1982
3 Scharf, B ‘Foundations of modern auditory theory: Volume 1’, (Editor J.V. Tobias), Academic Press, 1970
4 Green, DM and Swets, JA ‘Signal Detection Theory and Psychophysics’, Peninsula Publishing, 1988
5 Skeiber, SC, Mason, RL and Potter, RC ‘Effectiveness of Audible Warning Devices on Emergency Vehicles’, Sound and Vibration, February 1978
6 ‘Visibility and Audibility Requirements for Trains’ Rail Safety and Standards Board, Railway Group Standard, GM/RT 2180 Issue 3, February 2000
7 ‘Audibility Requirements for Trains’ Rail Safety and Standards Board, Railway Group Standard GM/RT2484 Issue 1, Draft 1f, August 2004
8 ‘Acoustics. Statistical distribution of hearing thresholds as a function of age’, BS EN ISO 7029:2000