Proceedings of the Institute of Acoustics

THE EFFECTS OF VARYING BANDWIDTH ON SPEECH INTELLIGIBILITY IN REVERBERANT SPACES

R. Dolling Symonds Group Ltd, Holborn London, EC1N 2LX, United Kingdom

1. INTRODUCTION

This paper investigates the importance of maintaining the full bandwidth of speech reproduction through a sound system in a reverberant space, for example an exhibition hall. There are several methods of determining speech intelligibility, some of which include subjective listening tests such as using phonetically balanced word scores, others use objective methods such as the speech transmission index.

This paper uses two methods of assessing speech intelligibility in a reverberant space under noisy conditions. The objective method being the speech transmission index (STI), whilst the subjective assessment uses a simple passage of speech; both demonstrating the effects of varying the bandwidth.

2 THE CONTRIBUTION OF SPEECH BANDWIDTH ON INTELLIGIBILITY

2.1 System Intelligibility

The most common reasons for poor speech intelligibility associated with a sound system are:

(i) Inadequate output level,

(ii) Lack of headroom,

(iii) Low direct to reverberant ratio,

(iv) Lack of coverage,

(v) Poor system frequency response

This paper is limited to a study of the latter factor.

2.2 The Effects of Limited Speech Bandwidth

Speech bandwidth of a telephonic system is limited to the range of 300Hz to 3.4KHz. Because the listener is able to hold the telephone receiver as close as possible to the ear, this provides a high direct to reverberant ratio and a reasonable signal to noise ratio.

Unfortunately, many sound systems are designed with the belief that all systems can produce intelligible speech by using such a limited bandwidth. This may well be true for many systems in, for example a restaurant, office or bar, where speech is often 'tinny' yet remains intelligible. This is possible in such an environment because the acoustic conditions are generally non-hostile.

As acoustic consultants, we come across many acoustically hostile environments. These include spaces such as exhibition halls, large atriums, stadia, railway stations and even shopping malls. In many cases, we hear comments such as *"we don't mind if it's a bit tinny, so long as we can hear it"*.......or *"speech only covers 300Hz to 3.4KHz"*.....

This paper looks at the effects of adopting the telephone bandwidth and the implications this may have on speech intelligibility in a typical reverberant space.

Before studying the restrictions that bandwidth limiting has on speech intelligibility, consider the bandwidth of male and female speech [1] as shown in figure 1 below.

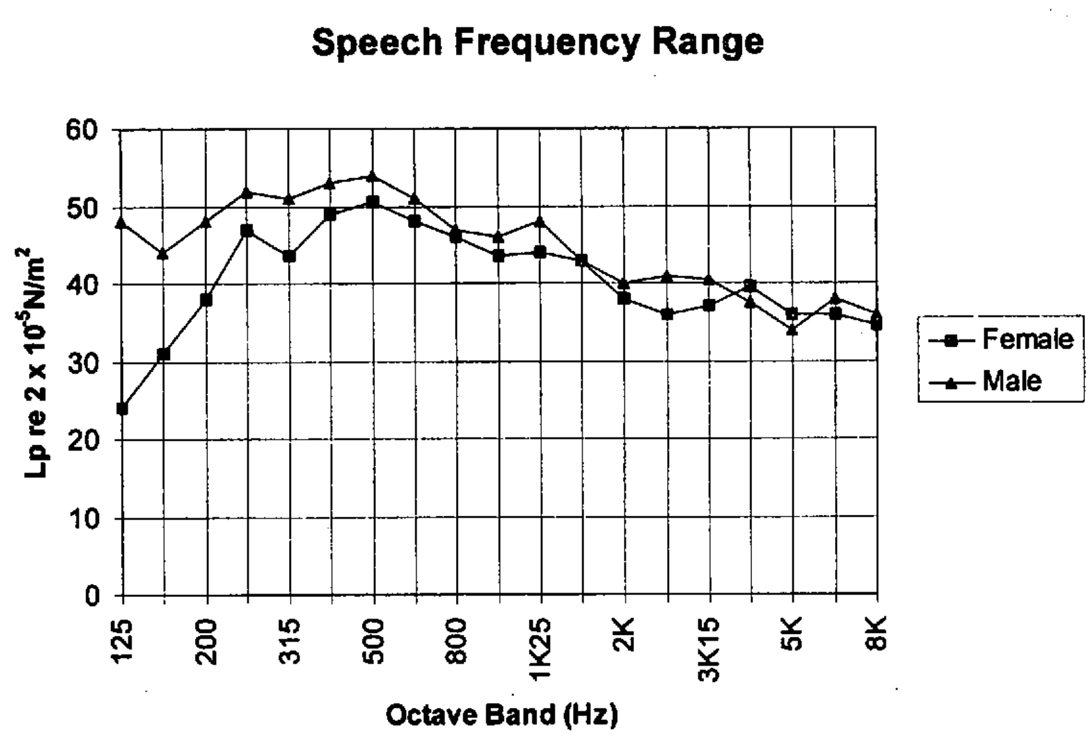

Figure 1 showing male and female speech frequency range

So, it can be seen from figure 1 above, that male speech extends over the range 125Hz to 8KHz (+/-10dB) whilst the female range is 125Hz to 8KHz (+/-13dB), the main difference being in the lower octave bands.

There is a diversity of opinion as to which octave bands contribute to speech intelligibility but the most common are shown graphically in figure 2 below.

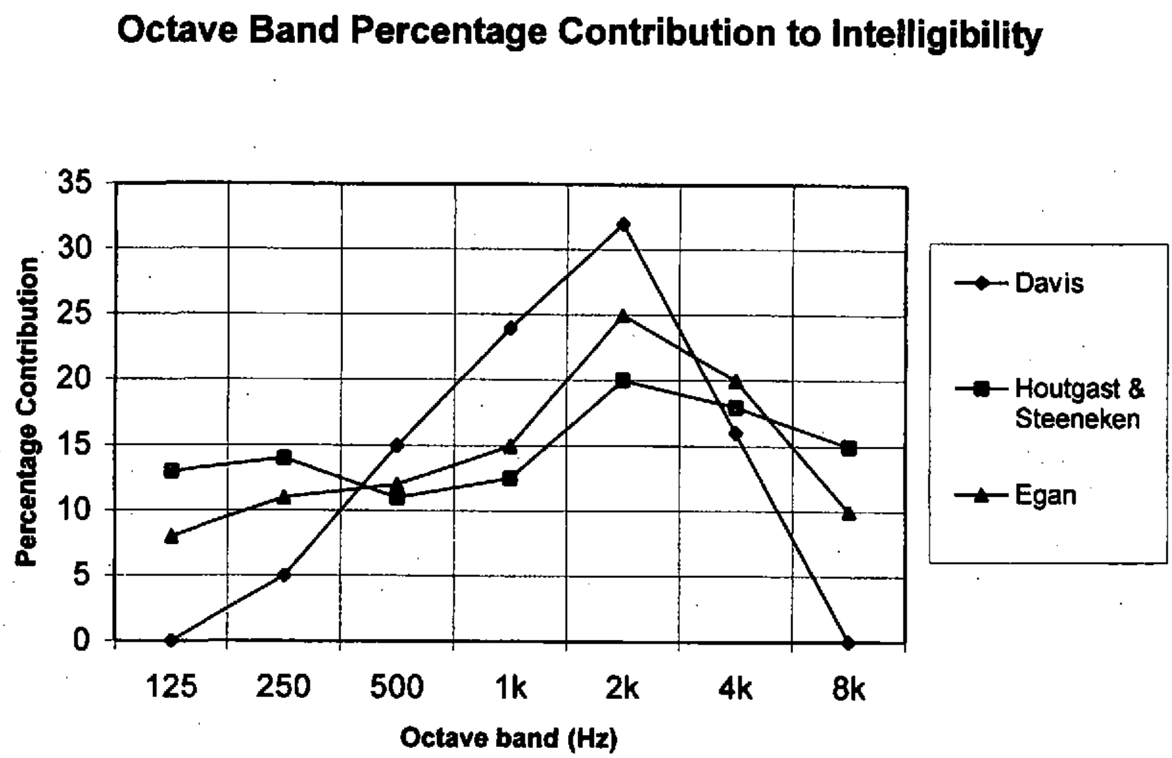

Figure 2 showing the octave band percentage contribution to intelligibility

As far back as 1946, Egan[2] showed the benefit of increasing bandwidth under a varying signal to noise ratio as shown in fig 3 below.

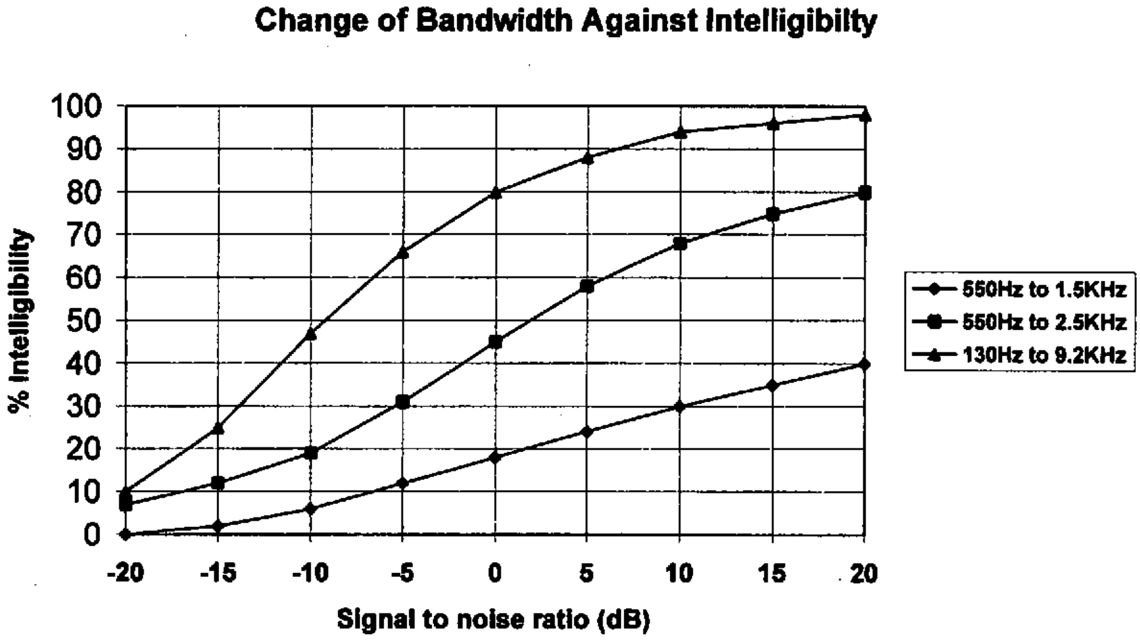

Figure 3 showing the influence of bandwidth on intelligibility under different signal to noise conditions.

So, according to Egan, increasing the bandwidth of speech under conditions where the signal to noise ratio is, say between 6 to 10dB (which is a typical design target for most reasonable sound systems), there is a corresponding increase in speech intelligibility.

Egan provided this evidence as long ago as 1946. Over fifty years hence and still system designers fail to appreciate how intelligibility may be optimised by this fundamental design parameter!

This paper aims to reinforce the work undertaken by Egan et al in the research to demonstrate the necessity to faithfully reproduce the original speech signal content. This provides the fundamental rationale behind choosing microphones, loudspeakers and the appropriate signal processing components, without which our industry retards to 'pre- war' design!

The research presented in this paper comes as a result of being asked to justify the rationale behind using loudspeaker components with 'full bandwidth' in preference to those with restricted bandwidth.

2.3 New Research

Before discussing the outcome of this research, refer to figures 4 and 5 below which show the frequency response of two distinctly different products used in equally diverse environments.

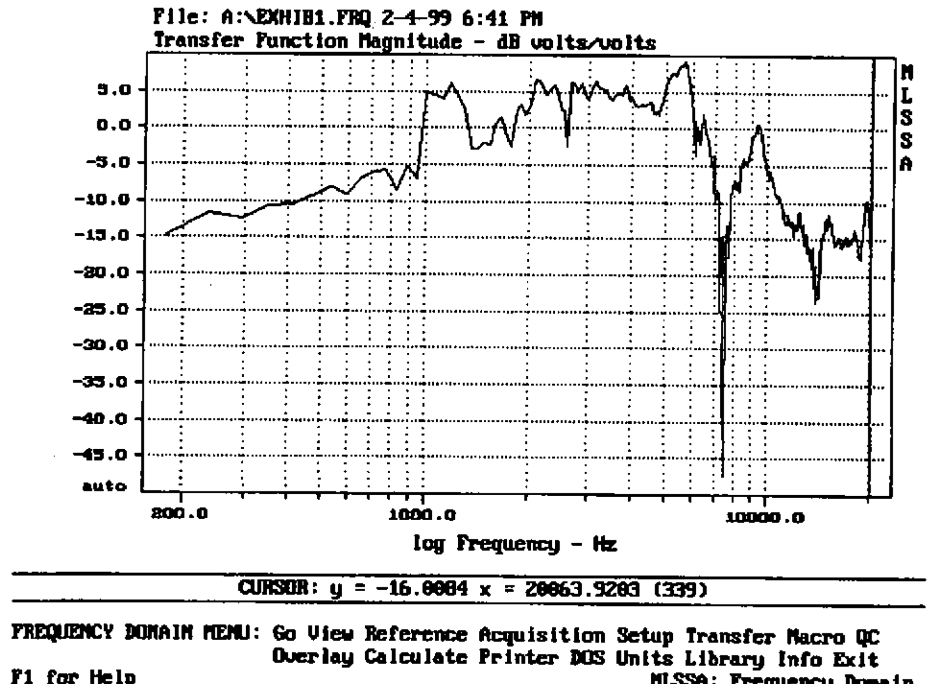

Figure 4 showing the frequency response of a 'sound projector' loudspeaker measured in an entertainment centre. (900Hz to 7KHz)

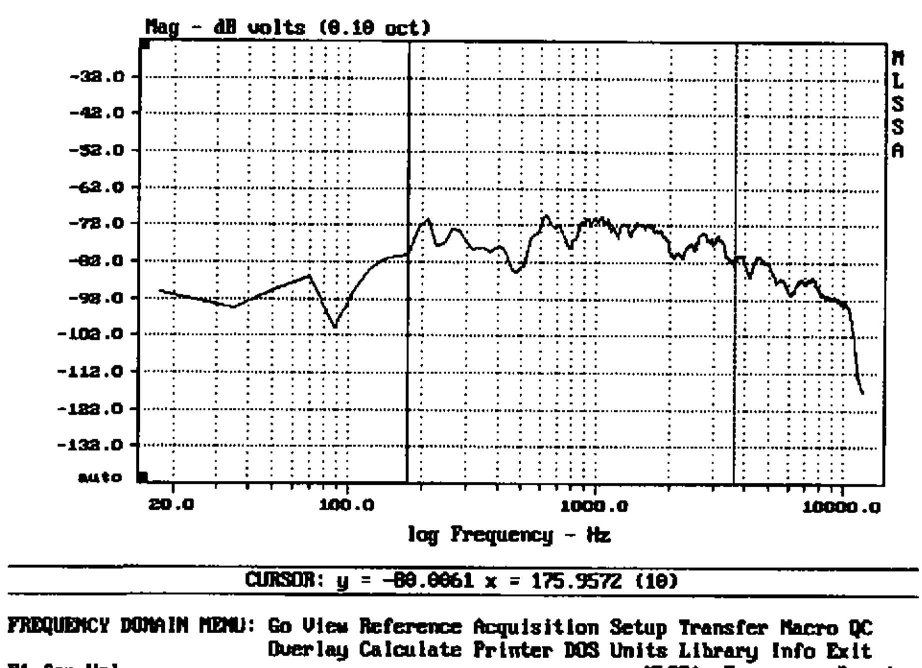

Figure 5 showing the frequency response of a large format compression driven, constant directivity horn, measured in a sports stadium (180Hz to 5KHz).

In both cases, each of the frequency response measurements were made in acoustic environments with an (unoccupied) reverberation time of circa 5 seconds. In each case, the systems were deemed as giving 'disappointing' speech intelligibility. There may of course be several reasons for this, ie. poor direct to reverberant ratio but, clearly, the frequency response of each system does not extend to the full bandwidth of speech. Given the foregoing information pertaining to speech bandwidth and it's contribution to intelligibility as discussed above, the following research was undertaken.

3 VARIATION OF BANDWIDTH IN A REVERBERANT SPACE

3.1 The Acoustic Environment

The space used to make the measurements and assessments for this research is considered to have acoustic characteristics typical of many large public areas such as exhibition halls and arenas. The reverberation time of the space is shown in figure 6 below.

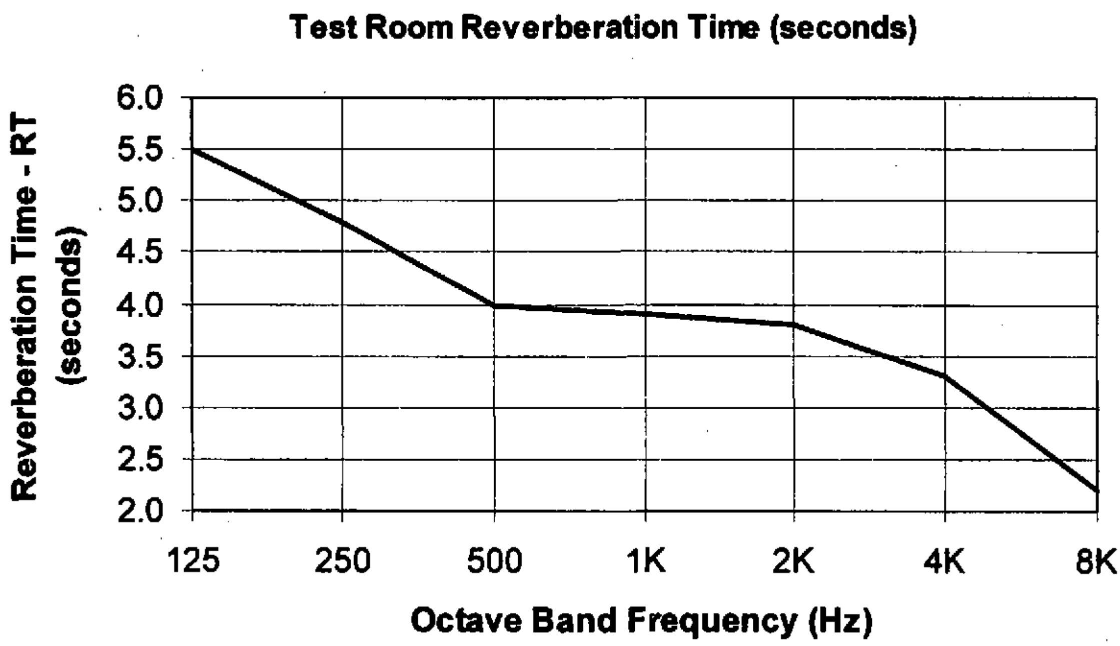

Figure 6 showing the reverberation time of the room used for the research measurements.

3.2 Methodology

In order to conduct the simple experiment, two, loudspeakers were used, each comprising of a 375mm diameter low frequency direct radiating unit, plus a 90 degree by 40 degree small format, compression driven horn. One loudspeaker was used to generate pink noise to simulate background noise at a level typical of an exhibition centre. The second 'signal' loudspeaker was used to generate two signals:

(i) maximum length sequence (MLS) for objective measurements,

(ii) a 30 second uncompressed anechoic recording of male speech to provide a simple subjective assessment [3].

The noise contaminated signal and speech were then analysed and assessed at a distance of 6 metres on axis to the signal generating loudspeaker. The signal to noise levels were set at 6dB [1].

The bandwidth of both the MLS and speech passage was adjusted by a band-pass filter using a digital signal processor inserted between each respective signal and power amplifier. In each case, the signal to noise ratio was maintained throughout the measurement process.

1 Note that for the MLS signal, a signal to noise level of 6dB was set using a type 1 sound level meter. For the subjective analysis a noise level of 6dB below the L_{Aeq} of the speech passage was used – which relates to approximately a 9dB signal to noise ratio [4]

4 RESULTS

The results of the objective measurements are shown for a varying bandwidth in figure 7 below.

The objective results were found to correlate closely with the subjective analysis of the uncompressed speech message.

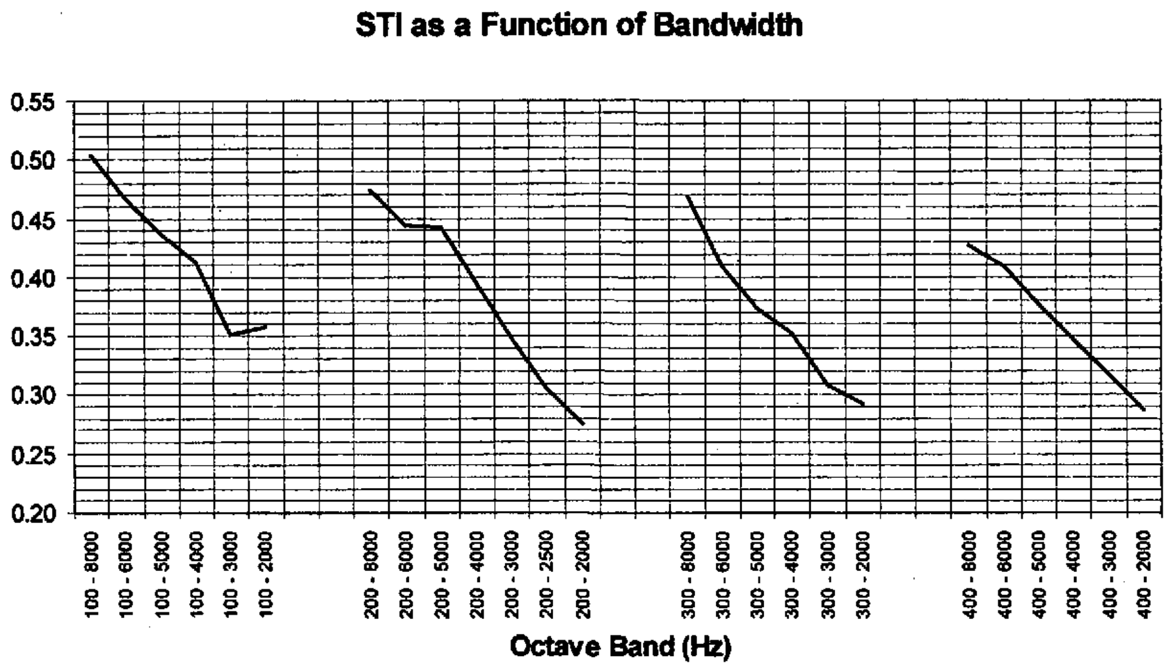

Figure 7 showing the sound transmission index measurements made in the reverberant test space, with a signal to noise ratio of 6dB

Figure 8 below gives a comparison of the objective rating versus subjective assessment of speech intelligibility

STI Objective Rating	Subjective Assessment	STI Objective Rating	Subjective Assessment
0.00		0.54	
0.10		0.56	
0.12		0.58	
0.14		0.60	
0.16		0.62	
0.18		0.64	GOOD
0.20		0.66	
0.22		0.68	
0.24	BAD	0.70	
0.25		0.72	
0.26		0.74	
0.28		0.76	
0.30		0.78	
0.32		0.80	
0.34	POOR	0.82	
0.36		0.84	
0.38		0.86	EXCELLENT
0.40		0.88	
0.42		0.90	
0.44		0.92	
0.46		0.94	
0.48		0.96	
0.50	FAIR	0.98	
0.52		1.00	

Figure 8 Sound transmission index versus subjective assessment of speech intelligibility

5 DISCUSSION OF FINDINGS

From the results of the measurements, it is clear that as the bandwidth was increased, the objective speech intelligibility rating as assessed by the speech transmission index improved.

The subjective assessment of the speech passage also showed improvements in intelligibility as the frequency range was increased. However, syllable masking was detected from the lower frequency sounds as the speech rate increased. This was considered to be due to the excessively long-low frequency reverberation time of the space. To overcome this problem, whilst being able to maintain full bandwidth, it is therefore considered that a low frequency band-pass compressor could possibly reduce this effect on speech intelligibility.

6 CONCLUSIONS

The findings from the research undertaken during the tests, whilst not robust, clearly, show that in this particular reverberant space, increasing the system bandwidth improves the objective rating of speech intelligibility.

The results were found to correlate closely with the subjective assessment made using the simple passage of speech, under the same reverberant conditions.

The reduction in bandwidth of either low frequency (below 500Hz) or high frequency (4KHz and above) would appear to have a similar detrimental effect on speech intelligibility, supporting the earlier research undertaken by Egan.

Extension of the lower frequencies generally gave an improvement in intelligibility. However, because of the long, low frequency reverberation time, the speech sounds containing lower frequencies tended to cause syllable masking as the speech delivery rate increased. It is therefore concluded that, with an extension in the low frequency range, it is important to limit the rate of speech delivery and possibly to compress the lower frequency sounds, rather than restrict them by way of a limited system bandwidth.

It is highly probable from the research undertaken, that in each case presented in figures 4 and 5, (the entertainment centre and stadium system), that increasing the bandwidth would have improved intelligibility.

7 FURTHER RESEARCH

This paper has discussed the benefits of increasing system bandwidth per se. Within the limits of the experiment, it has also been demonstrated that increasing the bandwidth of the system in the reverberant space generally improved intelligibility whether by way of measurement or by simple listening tests. Further research is being undertaken using the same components and conditions in other reverberant spaces and a less reverberant spaces to determine whether the same benefits can be realised.

As a final note, whilst the extension in bandwidth may appear to yield only a small improvement in intelligibility, this is considered to be significant where, under such difficult conditions, any improvement in speech intelligibility can make an otherwise *'poor'* system become one that gives *'fair'* results. This is therefore considered to be wholly important in the interests of public safety in the case of voice alarm system design.

There may be several reasons why a system has a poor or limited frequency response and these include poor loudspeaker and/or microphone response, a lack of signal equalisation or an incorrectly adjusted equaliser. Each of these factors should therefore be given careful consideration at the outset of design through to the commissioning of the system.

References:

[1] Handbook for Sound Engineers
The New Audio Cyclopedia
Figure 7.4 page 160, Male and Female Speech
Ballou, G, Editor

[2] Intelligibility of bands of speech in noise
Egan, J.P., Wiener, F.M. Journal of Acoustic Society of America 1946

[3] Sound Check Compact Disc
Spoken Word

[4] Proceedings of Institute of Acoustics Volume 21, part 8 (1999)
A Proposed Method For The Measurement of Speech with Special Reference to Voice Alarm Systems in Buildings
Barnett, P.W.B, Bokor, S