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FEASIBILITY STUDY TO DETERMINE THE EFFECT OF SYSTEM FREQUENCY BANDWIDTH ON SPEECH INTELLIGIBILITY IN THE PRESENCE OF NOISE

P.W. Barnett, R.D. Knight

AMS Acoustics, 52 Chase Side, Southgate, London, N14 5PA.

INTRODUCTION

Frequency bandwidth in the context of public address systems is an emotive issue. The bandwidth is obviously limited by the response of the loudspeaker which in turn may have considerable cost implications.

In general terms the greater the bandwidth the greater the cost and hence some indication of penalties (if any) of restricting the bandwidth would be useful.

This Feasibility Study seeks to examine earlier work prior to carrying out the full investigation. Alternatively any imposed restriction of bandwidth may limit the maximum achievable speech intelligibility.

THE PROPOSED INVESTIGATION

At the time of writing this investigation is underway and hopefully at the presentation of this Paper some initial results will be available.

It is important to understand that the investigation relates to public address systems in the presence of noise.

Hence the receptor will not necessarily see the deliverer and further the receptor will make a judgement based on normal hearing. Secondly we make the point that in this investigation we are only concerned with degradation caused by noise and hence reverberation will be deliberately excluded.

We may therefore understand that the signal shall be monaural and the receptor shall be binaural.

We propose the following method Word Scores shall be recorded to DAT medium (monaural).

Each Word Score may be then passed through an equaliser and subjected to various degrees of filtration.

The filtered Word Scores are then passed through a reference loudspeaker and recorded binaurally in a room with very little reverberation, normally less than 0.5 secs. The recording head was placed some 3m from the loudspeaker.

Broad band pink noise was also recorded binaurally but in this instance many loudspeakers were used and hence the noise was non-directional.

The binaural noise and binaural Word Scores may then be mixed in varying degrees and the results scored by a jury.

The following filtration will be applied:

Set	Octave Band (Hz)						
	125	250	500	1k	2k	4k	8k
1 (full)	✓	✓	✓	✓	✓	✓	✓
2		✓	✓	✓	✓	✓	✓
3			✓	✓	✓	✓	✓
4				✓	✓	✓	✓
5					✓	✓	✓
6						✓	✓
7	✓	✓	✓	✓	✓	✓	
8	✓	✓	✓	✓	✓		
9	✓	✓	✓	✓			
10	✓	✓	✓				
11	✓	✓					
12		✓	✓	✓	✓	✓	
13			✓	✓	✓		
14		✓	✓	✓	✓		
15			✓	✓			
16		✓	✓	✓			

Each filtered Word Score will be mixed with broad band noise in the following ratios:

Proposed S/N Ratio dB				
0	6	12	18	No Noise

To ensure that the results are statistically significant the total number of Word Scores will exceed 1000.

The words were taken from a phonetically-balanced list of which each set is chosen to be equally difficult.

EARLIER WORK

As a precursor to the full investigation, analysis of earlier work has been undertaken and as far as is practically possible the results compared.

Two examinations have been made. Firstly, for the work carried out by Egan *et al* and secondly by simulating the effect on Speech Transmission Index.

THE WORK OF EGAN *et al*

This work was carried out in the 1940's [1] and was mainly concerned with telephone systems. In all other respects it was similar to our investigation.

It is not a simple matter to translate the results into our preferred format.

Our intention is to present the findings of our work in relation to signal-to-noise ratio in ISO octave bands.

Egan's work however related to telephone and related communication systems and in this regard he used orthotelephonic gain and bandwidths which were expected with these communication systems.

Fig. 1 shows one set of results he obtained. It may be clearly seen that as the bandwidth decreases so does the intelligibility.

Perhaps the most dramatic effect may be observed when the bandwidth is reduced to 870Hz - 2.5kHz and then further reduced to 1.3kHz - 1.9kHz.

Davis [2] *et al* have suggested that the 2kHz band provides up to 32% contribution to speech intelligibility. Since both of the data sets include a significant proportion of the 2kHz band we may not have expected such a difference in the ultimate achievable speech intelligibility.

From the data and the experimental methods we have been able to deduce the signal-to-noise ratio. The data has been represented in this format in fig. 2.

The work of Egan *et al* was concerned with many different bandwidths corrupted by different noise spectra. In all cases it clearly determined that the greater the bandwidth the better the articulation score. It is worth noting that a bandwidth of 130Hz - 9.2kHz scored significantly better than 340Hz - 3.9kHz, as did 550Hz - 2.5kHz score better than 870Hz - 2.5kHz.

Hence we may also infer that the lower frequencies play a more important role than was previously thought.

STI

It is possible to infer from the concept of STI the effect of bandwidth. To this end we have carried out the following theoretical exercise.

Firstly consider:

$$m(F) = \frac{1}{\sqrt{1+\left(\frac{2\pi FT}{13.8}\right)^2}} \cdot \frac{1}{1+10^{\frac{-S/N}{10}}}$$

We may then recap that calculation of STI involves the solution of 98 data points generated by the 14 modulation frequencies and the 7 octave bands (125Hz - 8kHz).

Since our investigation (and that of Egan) was concerned only with the presence of noise and not reverberation time, we may rewrite the equation above as

$$m(F) = 1.\left(\frac{1}{1+10^{\frac{-S/N}{10}}}\right)$$

and hence since the modulation frequency does not form part of the equation we need only consider 7 data points (one for each octave) rather than 98.

Mindful of a comparison with Egan's work we used signal-to-noise ratios from -5dB to 30dB in 5dB steps.

The computations were carried out in the normal manner with the accepted octave band weightings [3] applied. The weights were as follows:
0.13, 0.14, 0.11, 0.12, 0.19, 0.17 and 0.14 for the octave bands 125Hz to 8kHz.

To truncate the bandwidth, a weighting of zero was applied to those octaves outside the bandwidth under consideration.

The data is presented in terms of %syllable articulation converted from the STI result as shown in fig. 3.

Fig. 4 shows the effect of successively truncating the lower octaves and it can be seen that as the bandwidth reduces so does the syllable articulation.

Fig. 5 shows the effect when the upper octaves are successively truncated.

Fig. 6 shows the effect when truncation occurs from both upper and lower octaves.

Fig 6 is perhaps the clearest demonstration of the effect of bandwidth and the importance of both low and high frequency components.

COMPARISON BETWEEN WORK OF EGAN AND STI

The technique used in the STI analysis can be extended to the work of Egan.

The difficulty is that since Egan did not use the ISO octaves, the octave weighting cannot be directly applied. We therefore deemed to adopt a simple pragmatic approach and consider the proportion of the octave weighting which is contained within test bandwidth. To avoid any implied resolution this apportionment was restricted to one-thirds.

For example, for a bandwidth of 550Hz - 3.9kHz the entire weighting was used for octave bands 1kHz and 2kHz with a value of 0.06 and 0.08 ascribed to the 500Hz and 4kHz octaves respectively.

Fig. 7 shows the results by Egan and those obtained using the STI weighting.

DISCUSSION

Given the uncertainty between the methods and results we believe the correlation between the work of Egan and that using STI weighting to be remarkable. There is however a clear difference.

The STI method truncates the result for S/N ratio in excess of 15dB (noise only). Of course, if the acoustic term $\dfrac{1}{\sqrt{1+\left(\dfrac{2\pi FT}{13.8}\right)^2}}$ had been included

then increasing the S/N ratio above 15dB would have shown an improvement.

Having said the agreement is remarkable, we should be mindful of the uncertainties. From Egan's work there is a little doubt in regard of the signal-to-noise ratio used but perhaps the greatest uncertainty relates to the %Articulation. Again his methods are not well defined. We have assumed that syllable articulation (by Egan) is equitable to CVC logotoms.

We would also point out that as the bandwidth reduces so does the agreement although the trend is always similar.

OCTAVE BAND IMPORTANCE

In the assessment of the effect of bandwidth, there is an implied relative octave band importance.

Considerable work has been carried out and the results published. It is worth briefly examining the importance placed on octave bands by others. Three sets of data are available, Houtgast and Steeneken, French and Steinberg and Davis.

Fig. 8 shows the weightings expressed as a percentage. It can be seen that a considerable difference of opinion apparently exists. This, of course, would materially affect the effect of bandwidth. It should be noted however that the writers are uncertain that in this comparison, like is compared with like.

Additionally, fig. 9 shows the effect of applying the various weightings and comparing it with the work of Egan *et al.* It may be noted that the Houtgast and Steeneken weightings provided better apparent agreement.

CONCLUSIONS

Our theoretical investigation was necessarily limited but the results do inspire us to proceed with our investigation.

Davis *et al* have emphasised the 2kHz octave and ascribe little or no importance to octaves either side of 500Hz and 4kHz.

We believe that there is evidence to suggest that both the lower and higher octaves are important and furthermore that whilst the 2kHz octave band is of primary importance that it does not contribute as much as was earlier thought.

Finally, we should remind ourselves of two important facts.

Firstly that restricting the bandwidth radically affects the attainable speech intelligibility. This has considerable connotations in voice evacuation systems and compliance with BS 7443 (Sound Systems for Emergency Purposes).

In some cases, by restricting the system bandwidth by the use of inexpensive loudspeakers may preclude compliance with the magic 0.5 RASTI. Some makes of loudspeakers designed primarily for this market have extremely restricted bandwidths which not only invalidates the RASTI measurement procedure as detailed in BS 6840: Part 16 but would return a low STI result.

Secondly bandwidth has serious cost implications. The lower octaves affect the size and weight and hence cost.

We are further of the opinion that the investigation we propose is worthwhile and hopefully will provide some usable data.

References

[1] J.P. Egan and F.M. Wiener
On the Intelligibility of Bands of Speech in Noise.
Jasa Vol. 18 No. 2:1946

[2] Don Davis
Synergetic Audio Concepts Sound System Engineering Class Manual - Fall 1994

[3] T. Houtgast & H.J.M. Steeneken
Review of the MTF Concept in Room Acoustics and its Use for Estimating Speech Intelligibility in Auditoria
Jasa Vol. 77 No. 3:1985

EFFECT OF BANDWIDTH AND NOISE ON SPEECH INTELLIGIBILITY

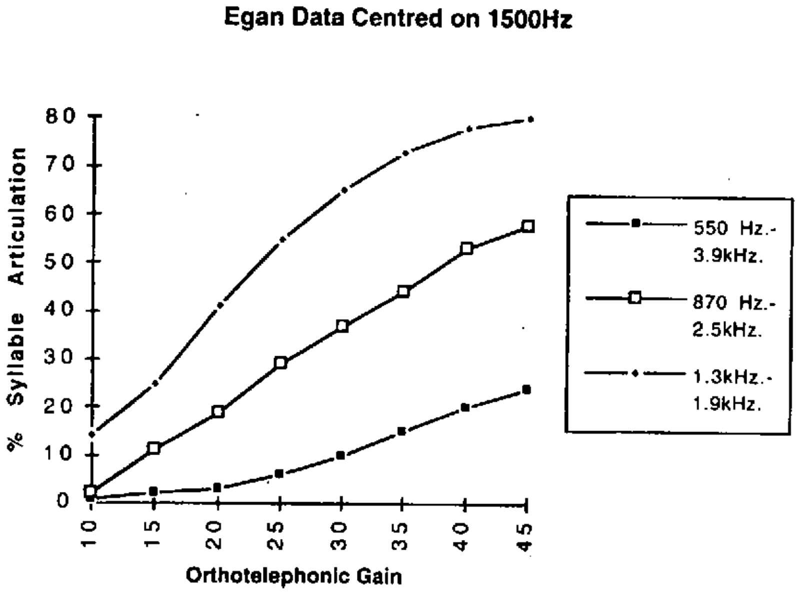

Fig. 1

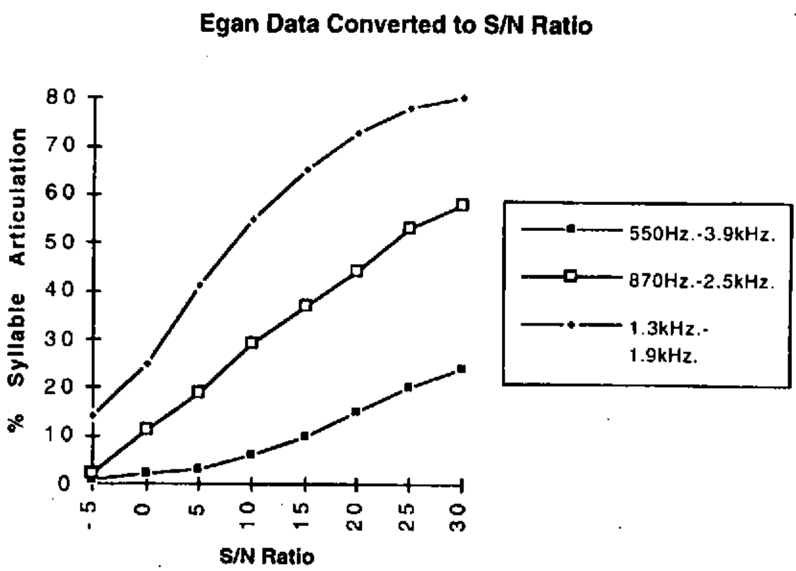

Fig. 2

EFFECT OF BANDWIDTH AND NOISE ON SPEECH INTELLIGIBILITY

Relationship between STI and Other Measures

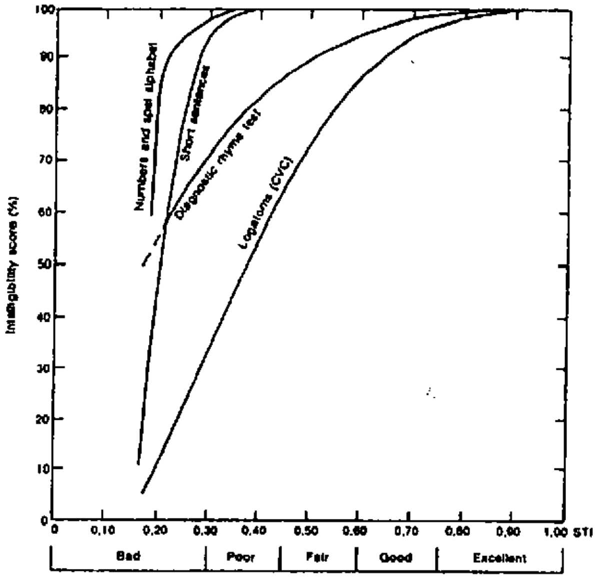

Fig. 3

STI Data Lower Octave Truncation

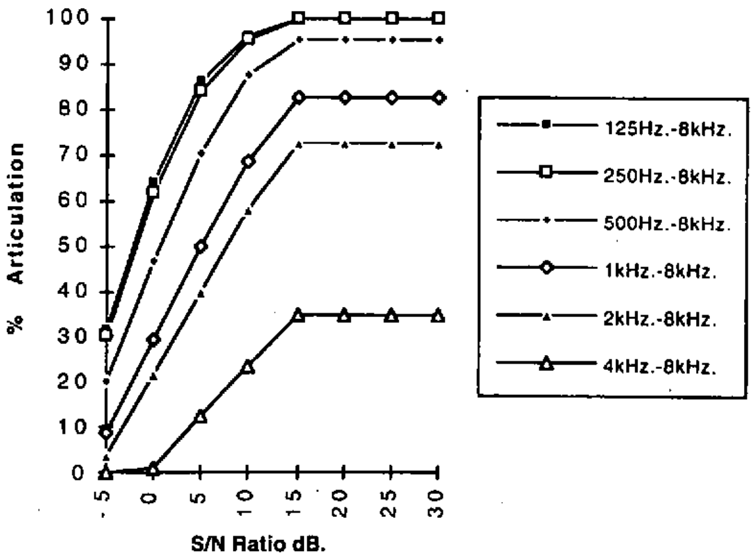

Fig. 4

EFFECT OF BANDWIDTH AND NOISE ON SPEECH INTELLIGIBILITY

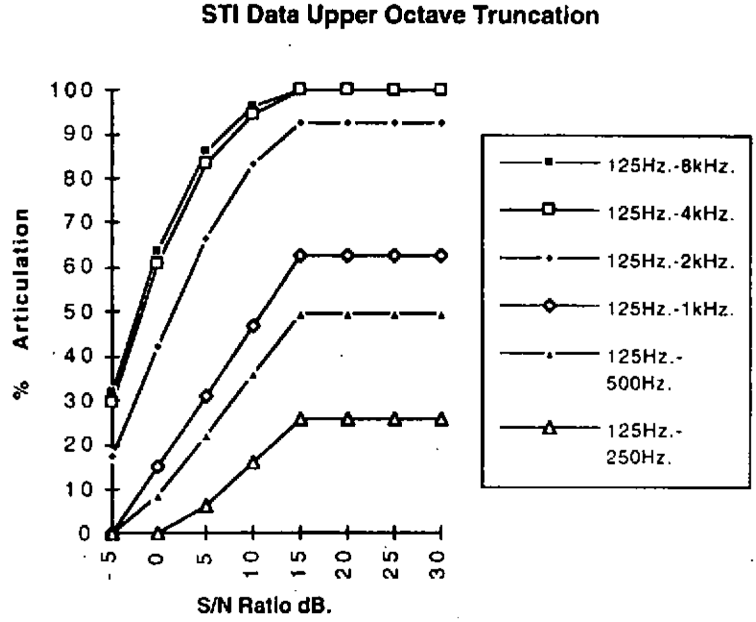

Fig. 5

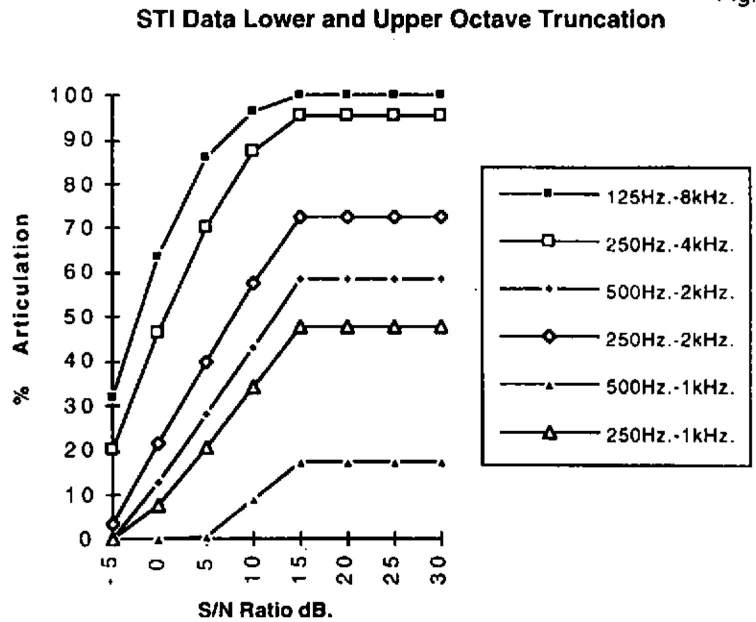

Fig. 6

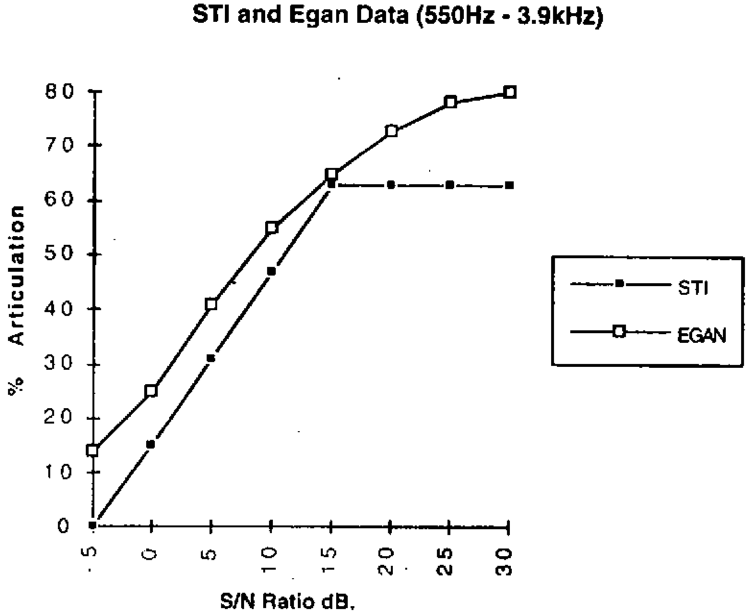
STI and Egan Data (550Hz - 3.9kHz)
% Articulation
80
70
60
50
40
30
20
10
0
-5
0
5
10
15
20
25
30
S/N Ratio dB.
STI
EGAN

Fig. 7

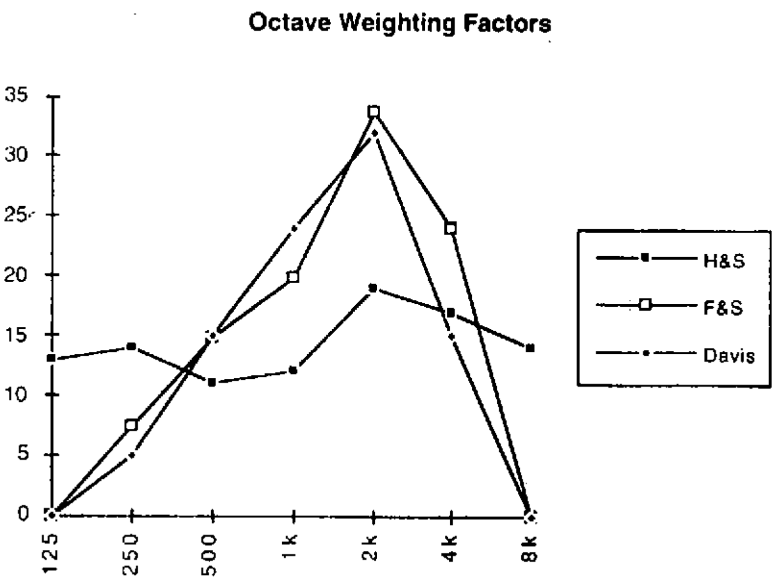
Octave Weighting Factors
35
30
25
20
15
10
5
0
125
250
500
1k
2k
4k
8k
H&S
F&S
Davis

Fig. 8

STI with Various Weightings and Egan Data (550Hz - 3.9kHz)

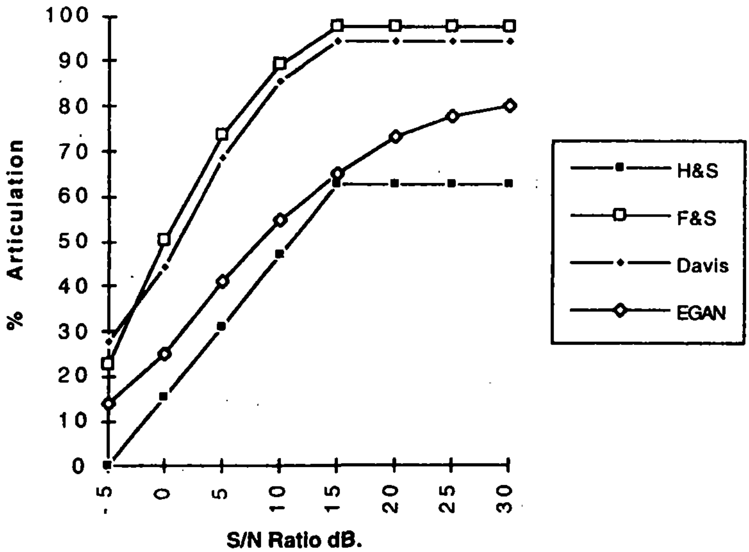

Fig. 9