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INTELLIGIBILITY IN PUBLIC ADDRESS AND SOUND SYSTEMS

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INTRODUCTION

The problems and parameters that affect intelligibility are better known than understood. There have been as many attempts at quantifying this effect as there are monuments as tributes to those who paid no heed to this vital parameter. The best known and probably the most reliable is the concept of %ALcons, which is a measure of the percentage of consonants lost. This method was devised and proposed by Messrs. V.M.A. Peutz and W. Klein whose findings were published in the Audio Engineering Journal, December 1971. It is based on the fact that it is the consonant sounds in our speech that determines intelligibility.

The Peutz and Klein work has over the years been extended and modified in the light of technological advances and the formula given below is the generally accepted format:

$$\%ALcons = \frac{200D^2RT^2\ (N+1)}{VQM}$$

where: D = distance to the listener in question; RT = reverberation time of the space in seconds; N = number of loudspeaker groups identical to the prime group; V = volume of the space in cubic metres; Q = directivity of loudspeaker; M = a modifier, generally chosen as unity relates to audience absorption.

The %ALcons method is without doubt the most reliable aid available when designing sound systems destined to large reverberent spaces; in fact where the ratio of reverberation time and volume are the major influencing factors. This method should not, however, be regarded definitive. There are many other factors that influence the degree of intelligibility provided by public address systems.

Knudsen produced the following expression:

Percentage Articulation = 96 R_l, R_r, R_a, R_s.

Where R_l is the reduction factor owing to inadequate loudness, R_r the reduction factor owing to reverberation, R_a the reduction factor due to ambient noise and R_s the reduction factor due to room shape.

In the light of the %ALcons expression and experience this expression may be expanded thus.

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Articulation = f $(R_l, R_r, R_a, R_s, R_n, R_t, R_i, I_q, I_m)$

where:
- R_l = the reduction factor for inadequate loudness
- R_r = the reduction factor for extended reverberation time
- R_a = the reduction factor for ambient noise
- R_s = the reduction factor for the shape and size of the space
- R_n = the reduction factor for increased number of sources
- R_t = the reduction factor for differing arrival times for individual sources
- R_i = the reduction factor for reflections from surrounding surfaces
- I_q = the improvement factor for the directional properties of the source
- I_m = the improvement factor for optimisation of audience absorption.

The above expression cannot be readily reduced to a simple single numeric answer, but it does serve as a guide when deciding on the format of the system.

This paper is mainly concerned with R_n, R_t, I_q and I_m and the way in which they are used in the %ALcon expression.

%ALcons Equation
From an examination of the %ALcons expression an increase in the number of sources degrades the intelligibility; it is also apparent that by reducing the value of N, D must necessarily increase and since this is a squared term, the next result must be detrimental. Closer examination reveals that if the expression is apparently optimised for D and N, there still remains the question of Q, which for a number of close sources must decrease and therefore any apparent advantage is quickly lost. The above is of course without reference to R_t which must be affected by the number of sources.

I am of the opinion therefore that except in exceptional cases the value of N should be reduced as far as possible if good or very good articulation is required.

Impulse Responses
Further evidence for this premise is available by consideration of the impulse response of the space. It has been shown that intelligibility may be related to the ratios of early and total energy. This ratio is called definition (Deutlichkeit) and is given by the following equation.

$$D = \frac{\int_0^{50\,ms} [g(t)]^2\,dt}{\int_0^{\infty} [g(t)]^2\,dt} \times 100\%$$

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where: D = definition and g(t) in the impluse response of the space.

Figs. 1 and 2 show temporary amplitude responses (echograms) taken in a London theatre. Fig. 1 was taken using a single multi-element source and Fig. 2 with two column loudspeakers mounted each side of the proscenium arch. Clearly the intelligibility should be superior with the single source.

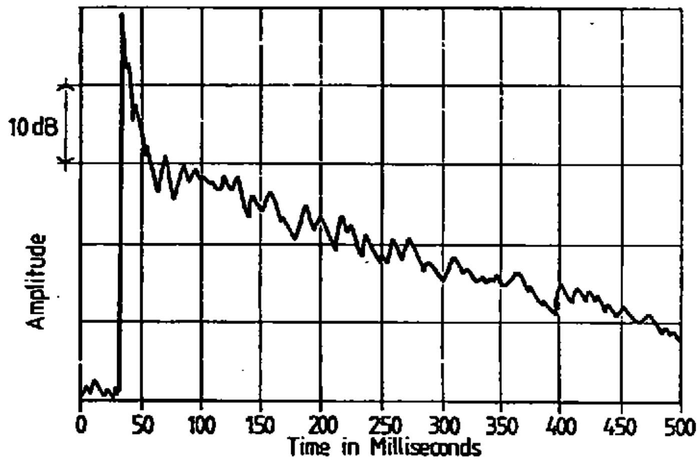

Fig. 1

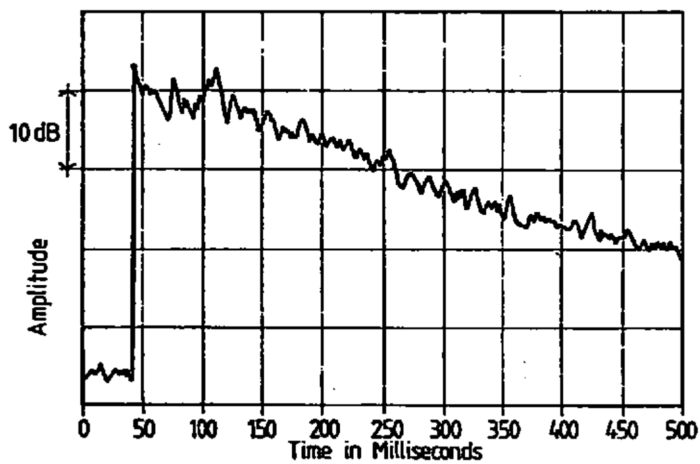

Fig. 2

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Figs. 3 and 4 show an extreme case of this effect, taken at Earls Court Exhibition space, London during the Royal Tournament.

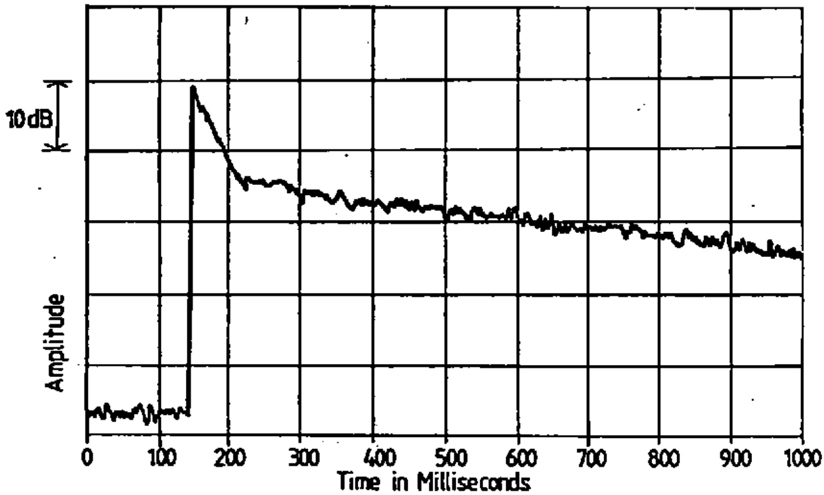

Fig.3

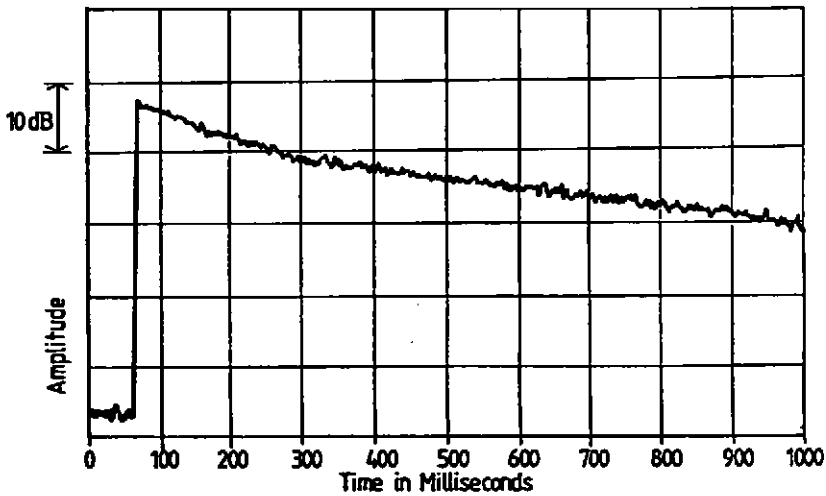

Fig.4

Earls Court is equipped with two sound systems, one comprising over 70 large column loudspeakers evenly distributed at a height of 20 metres and the other a single multi-element central cluster flown at a height of over 30 metres. Fig. 3 and 4 show the impulse response of the central cluster and distributed system respectively. Once again it can been seen that the intelligibility offered by the central cluster should be very much better than the distributed system. Listening tests confirm this, during this and last years tournament complaints by the audience were almost non-existent and confined to critism of level where as prior to the installation of the cluster a large number of complaints followed each performance generally aimed at intelligibility.

Calculated values of %ALcons are also supportive. For the central cluster theory suggest a %ALcons of between 10% and 15% whereas for the distributed system it is in excess of 50%.

The %ALcons formula takes no account of the varying arrival times of the individual sources, fig. 5 shows a further impulse response taken at Earls Court using the distributed system with delay lines referenced at one end of the arena. The measurement was taken at the reference position. The impulse response would indicate a further degradation of intelligibility at this position.

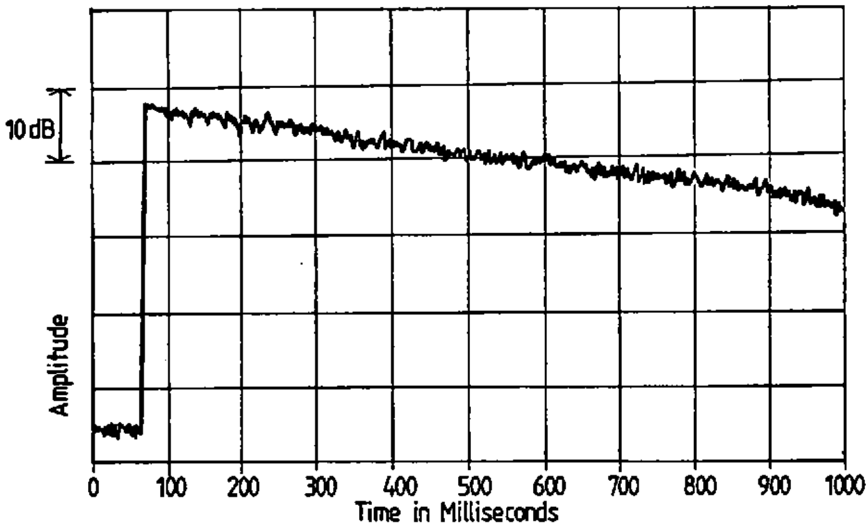

Fig. 5

A favourable impulse response does not necessarily guarantee acceptable intelligibility. Fig. 6 shows an impulse taken with a central cluster as a source in a London Theatre. In fact this response was taken as part of an investigation to determine the course of poor intelligibility.. Examination of the response reveals a strong secondary reflection approximately 30ms after the direct sound. This reflection was sufficient to promote poor intelligibility.

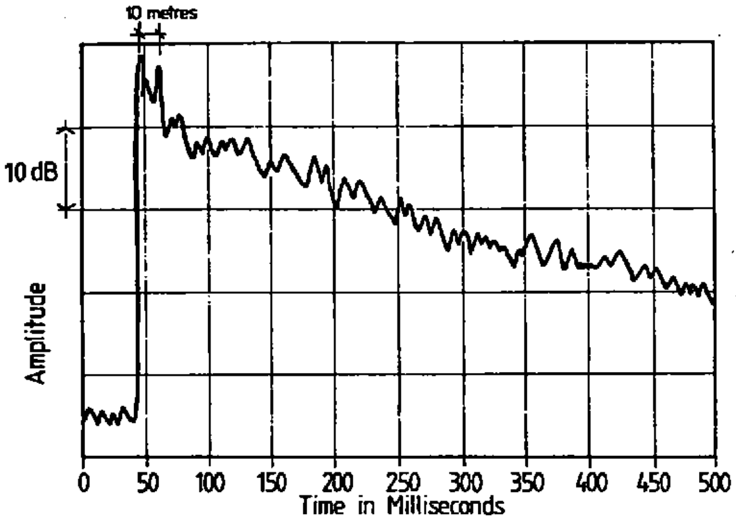

Fig. 6

This would suggest that considerable care is exercised when evaluating this data.

Intelligibility Calculations

Impulse responses may be used to evaluate an installation and provide useful information for subsequent projects. They cannot be used however prior to the event as a design tool. Estimation of intelligibility and confirmation of system design still remains the most important factor. As I stated earlier in my opinion the %ALcons concept is perhaps the most reliable design tool.

Interpretation of the formula is not a simple straight-forward matter. The parameters D, R_t and V are self-explanatory and require no explanation.

There are two basic approaches to calculating the %ALcons for a multi-element central cluster. The first is to consider N = 0 and calculate a composite Q for the cluster and to evaluate M in the normal prescribed manner. The second and most reliable is to calculate the %ALcons on axis for each of the cluster elements and to evaluate an equivalent N (N_E). The calculation of N_E is a relatively straight-forward matter, assuming that each of the cluster elements is not identical then the relative acoustic power outputs of each element may be calculated, and this total compared with the element in question.

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The N equivalent may be calculated from:

$$N_E = \text{Antilog}\left[\frac{\sum_1^N Pwl - Pwl\ ref.}{10}\right]$$

This concept may be taken one step further by including the absorption on the first reflecting surface and assume that the reverberent level is caused by the first reflection.

The %ALcons formula may be used substituting the value of N_E for N and using M = 1.

Conclusions

The most reliable method of estimating articulation is the %ALcons concept; however, it should be clearly understood that this method does not take account of reflections and differing arrival times if a distributed system is involved. At best, considerable care should be taken when matching the loudspeakers to the space.