MEASURING SPEECH INTELLIGIBILITY IN CLASSROOMS, WITH AND WITHOUT HEARING ASSISTANCE.

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1 INTRODUCTION

Good speech intelligibility within classrooms is essential in order to be able to teach effectively and to promote understanding. The introduction of Bulletin 93 has highlighted the need for a controlled acoustic environment and for good speech intelligibility. The Bulletin generally adopts an indirect approach to intelligibility by specifying reverberation time and background noise level criteria. (eg < 35 dBA LAeq30min and <0.6 or 0.8 seconds RT) rather than by specifying an intelligibility criterion directly. However, for open plan areas and study spaces an intelligibility target is specified in terms of STI, and is set at >0.6 STI. Extensive experience gained by the primary author in testing sound systems, suggests that STI measurements are often prone to a number of error mechanisms and a brief study of the classroom situation suggests that this also may be the case. Furthermore, there is a wealth of evidence that indicates reverberation time to be a generally poor indicator of intelligibility, though this tends to relate to larger spaces. A number of case histories and examples of potential STI measurement errors are discussed, together with examples and comments relating to the assessment of hearing assistive systems for hard of hearing students.

2 INTELLIGIBILITY MEASUREMENTS IN CLASSROOMS & ASSEMBLY HALLS

2.1 Source & Measurement Techniques

When measuring the potential, natural (ie un-amplified) intelligibility of a classroom, study space or hall etc, it is essential that the measurement system correctly incorporates the directivity and directional characteristics of the human talker. It has been shown that failure to do so can lead to significant error [1]. An informal survey carried out by the authors, suggests that it is common practice not to use such a device (eg a head and torso or head simulator) but most commonly to employ an omni directional loudspeaker or at best a small 'head sized' loudspeaker instead. A number of investigations were therefore carried out in order to ascertain the likely degree of error that such practice may incur.

Figure 1 compares the directivities of a human talker with an omni directional source and small, head-sized loudspeaker. As the figure shows, the omni directional source underestimates the directivity of a human – particularly at high frequencies. This could lead to a theoretical underestimation error of around 0.1 STI. However, in practice, typical omnidirectional acoustic test sources are not so well behaved and so the error may well vary considerably with frequency. Figure 2 for example that shows the ripple in the polar for a typical 'Dodec' loudspeaker test source. Whereas at 1 & 2 KHz the device is reasonably well behaved, at 4 kHz and above, the polar exhibits considerable angular spl fluctuations of up to 9 dB.

As can be seen from the upper curve of figure 1, the head sized loudspeaker unit becomes too directional at high frequencies, even when a cross-over and small tweeter are employed. (Denoted by negative slope in the directivity > 4 kHz). A theoretical error of around 0.15 STI can therefore be expected. (Using single cone devices although preferable for more accurately replicating a 'point source' generally become even more directional and hence potentially erroneous).

Figure 3 shows the measured error in STI between a 4inch loudspeaker and Head simulator. The mean error for the three positions presented is 0.1 STI. A mouth simulator is sometimes used instead of a head, but this can also lead to errors, as shown in figure 4. Here the angular error, in terms of measured STI, is shown.

2.2 Occupied Vs Unoccupied Measurements

One of the problems with measuring intelligibility is that it is difficult to do this with the classroom occupied. Some brief tests were therefore carried out to see how much effect occupancy might make. The measurements were made in a typical late1960s type classroom, under quiet, high signal to noise conditions (> 15 dB in each octave band) using a head simulator conforming to ITU Recommendation P58 [2]. The results are shown in Table 1 below.

Condition	Position 1 (A)	Position 2 (OA)	Position 3 (OA)	Position 4 (180)
Unoccupied STI	0.81	0.71	0.77	0.78
Occupied STI	0.82	0.79	0.76	0.76
Difference	- -	0.08	- -	- -

As can be seen from the table, room occupancy made very little difference to the measured STI. Most of the differences in the results lie within the measurement error. However, a notable difference was observed to occur at position 2, off axis at the rear of the room. The averaged reverberation time (500-4kHz) was found to decrease from 0.54 seconds to 0.43 seconds.

Whilst the above tests indicate the potential intelligibility under quiet conditions (which is a good start), such low noise levels are rarely found in practice. The general form of the STI equation however, enables the theoretical decrease in STI to be calculated as the ambient noise level increases and the signal to noise ratio decreases. Whilst at first this seems to be a simple and attractive idea, in practice it is rather more complex. In the UK, (unlike the USA for example) the primary source of noise in most classrooms is the children themselves. There are of course exceptions to this, but few schools have air conditioning and are generally fairly quiet unless built along side a main road or under an aircraft flight-path. Occupancy noise is highly variable and it is difficult to ascribe an overall level. Furthermore, speech is also a highly variable signal, typically varying by 12-20 dB on a short-term basis. Both L_{AeqT} and L_{CeqT} have been proposed as potential measures, with L_{Ceq} better matching the subjective impression of loudness. This leaves the problem of measuring the ambient noise level. In practice, a measure such as octave band L10 would need to be used in order to more accurately account for the effect of background noise. The L10 of the speech and noise signals could then give a more accurate measure of Signal to noise ratio and hence STI prediction.

A further element that must be taken into account when assessing the effects of noise on intelligibility, is the correct spectrum shaping of the test signal. The STI signal must be shaped to replicate either Male or Female speech or alternatively the composite original STI (CCIT) spectrum. (It should not be forgotten, that acoustic test sources such as a dodecahedral loudspeaker do not exhibit an inherently flat power spectrum and will require significant spectral correction. See figure 5).

2.3 Reverberation Time as an Indicator of STI

Although Reverberation time is generally considered to be a poor indicator of potential intelligibility [3], it was felt that within the small range of acoustic environments exhibited by classrooms, that it might possibly be more sensitive. Figure 6 shows a plot of average RT Vs averaged STI for a range of classroom type environments. The resulting graph shows, that there is a better degree of correlation between these two measures under these limited acoustic and volumetric conditions, although the correlation coefficient is only 0.899. It is interesting to note from the graph that reverberation times of 0.6 seconds and. 0.8 seconds (the maximum recommended values for primary and secondary school classrooms) relate to equivalent STI values of 0.75 and 0.68 STI respectively. The other point of interest is that a 1 second RT corresponds approximately to an STI of 0.6 STI, the minimum recommended. (NB It should be noted that the above measurement data was collected using an omni-directional source as apart of more general acoustic surveys. In reality therefore, as has been shown in section 2.1 above, it is likely that the STI values when measured with a head simulator would be a little higher than those reported).

2.4 Measurements in Larger Rooms & Assembly Halls

Although many modern classrooms appear to provide reasonable reverberation time control and intelligibility, the same can not be said for a significant proportion of assembly halls and other spaces. A recent case for example, where PMA were called in, related to a new school assembly hall (opened in March this year) where staff immediately complained about the acoustics and intelligibility. A survey showed the averaged speech band (500-4kHz) reverberation time to be 2.6 seconds. The average STI was just 0.45, with an omni source effectively indicating the same values as the head simulator - so far was the listening area into the reverberant field ! These measurements are by no means uncommon for multipurpose halls, but the irony in this case was not only was the hall brand new, it also belonged to the school containing the area’s regional hearing impaired unit ! The remedy, whilst relatively simple (120m^2 of sound absorptive panels) was disruptive, costly and should have been unnecessary.

A second interesting example of a problematic teaching area, was a school with a new drama and music studio. The floor area was approximately 12.5 x 15m and the reverberation time was 1.3 seconds. Whilst possibly a little long, this was not exceptionally excessive. The average STI across the room was 0.60, which enabled effective, though slightly ‘lively’ communication to take place. However, the room was seldom used, as teachers found it acoustically unacceptable stating that it was difficult to teach in. This would appear to be a case were perhaps reverberation time is a better indicator of acceptability than STI.

3 HEARING ASSISTIVE SYSTEMS

Hearing assistive systems can be divided into two basic forms. (1) General reinforcement for the whole class, sometimes referred to as 'Soundfield' systems' and (2) systems specifically intended to assist hard of hearing students.

It is probably true to say that Soundfield systems have received a mixed reception. In many instances they have been installed in an attempt to overcome a poor acoustic environment and often therefore do little or nothing to help the situation. Indeed, their generally low directivity may actually further degrade rather than enhance intelligibility under poor conditions. However, there are a number of instances where, under good acoustic conditions, they are felt to improve communication and the vocal effort required by the teacher.

Assistive systems for the hard of hearing may be based on audio frequency induction loop principles (AFILS), where the students use their own hearing aids or Infra red or FM wireless systems, with special receivers. Induction loop systems, have in the past suffered from a poor reputation for reduced frequency response and interference. Modern, current drive techniques have completely overcome the problem and can exhibit good audio frequency response and fidelity, as for example shown in figure 7. This compares the frequency responses of similarly sized loops employing single turn current drive and multi-turn voltage drive techniques. The loss of high frequency information and therefore the corresponding reduction in intelligibility can be clearly seen for the older, voltage dive type of system. Overspill can be a major problem with induction loops, but again today's designs can largely overcome such effects. Loops also suffer from a reputation for causing interference with TV sets and video monitors. Whilst this can and does, happen, solutions are available to overcome the problem in most instances.

It is essential to measure the background magnetic noise level before installing a loop system. Ideally, the level should be less than –32dB (A weighted) re 400mA/m but adequate intelligibility may be achieved with magnetic noise levels of up to at –22 dB (Awt)

Infra red systems whilst overcoming many of the above problems, are considerably more expensive and require special receivers. However, multiple systems can be installed within the same complex without fear of interference / overspill.

A problem common to both types of system concerns the pick up of the wanted speech sounds. Whereas teachers can wear a lavalier / tie-clip microphone and so ensure pickup from close range, in many situations, a more distant microphone is required. Figure 8 shows a plot of STI Vs distance for a number of microphone types and shows how intelligibility can be improved by increasing the directivity (linear relationship) or reducing the distance of sound pick up (approximates to a square law relationship). Experiments were carried out in two different environments, a dance studio with a nominal reverberation time of 1.5 seconds and church / recital hall having a reverberation time of 2.5 seconds. Interestingly, the more reverberant space consistently produced the higher STI results, which again shows that reverberation time is not always a good predictor of intelligibility.

When measuring system STI, it is essential that the effects of any signal processing are fully understood and accounted for. Hearing assistive systems for example often include amplitude compression, which, depending on the compression characteristics and form of test signal can give rise to erroneous results.

4 REFERENCES

1. P Mapp, The acoustic and Intelligibility Performance of Assistive Listening and Deaf Aid Loop (Afils) Systems. AES 114th Convention Amsterdam, March 2003
2. ITU –T Recommendation P58, Telephone Transmission Quality – Head and Torso Simulator for Telephonometry. 1996
3. P. Mapp, Relationships between Speech Intelligibility Measures for Sound Systems, 112th AES Convention Munich 2002.

5 FIGURES

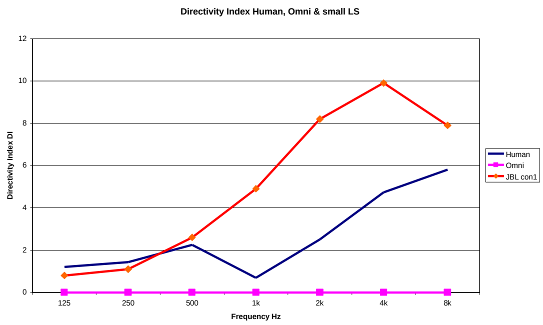

Figure 1 Directivities of Human Talker compared to omni directional source and small head sized loudspeaker.

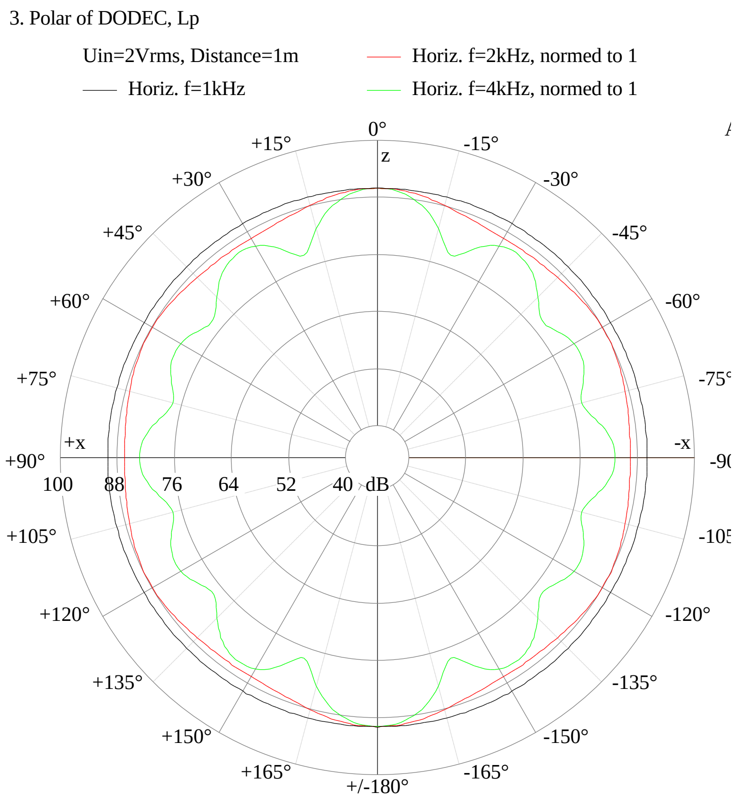

Figure 2 Typical Dodecahedral Polar response. Note 8-9 dB ripple at 4kHz

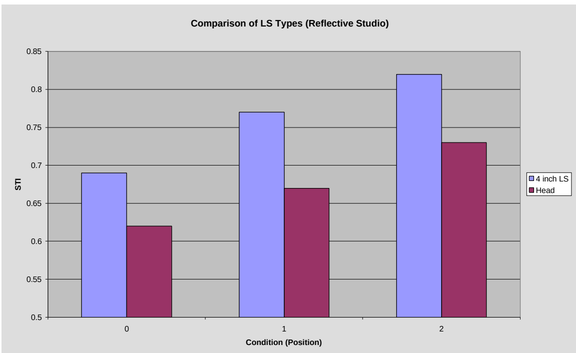

Figure 3. STI error between Head & 4 inch loudspeaker

Figure 4 Angular STI error between Mouth & Head Simulators

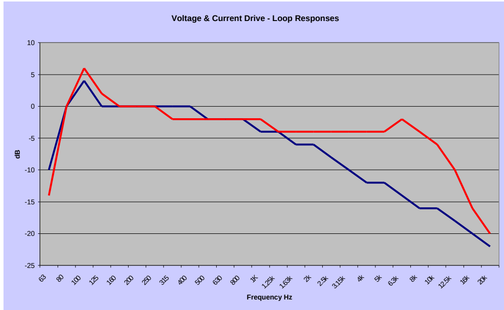

Figure 7 Current Vs Voltage drive for Deaf Aid Loop system

Figure 5 Typical Dodec Frequency Response

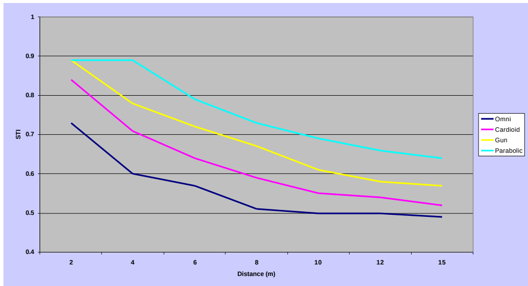

Figure 8 Effect of microphone distance and directivity on STI

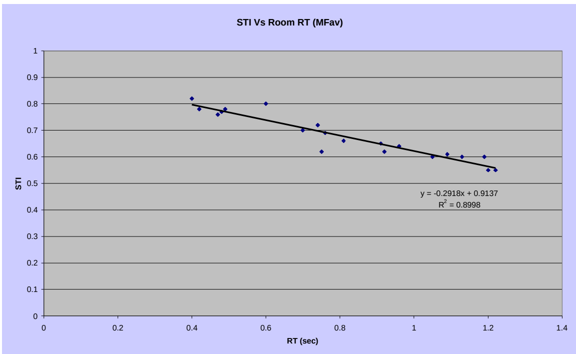

Figure 6 Correlation between STI & Classroom Reverberation Time.