Proceedings of the Institute of Acoustics

SOME PRACTICAL LIMITATIONS OF STI METHOD

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INTRODUCTION

In the course of our work and a research project for speech intelligibility prediction, we have come across a number of limitations and potential problems.

This Paper seeks to introduce three such anomalies.

Problem 1 - Sound System Frequency response - RASTI Method
As part of our work we are called upon to audit voice evacuation systems to BS 7443. This Standard specifies the system speech intelligibility as better than 0.5 STI when measured using the RASTI method as detailed in IEC 268-16 (BS 6840: Part 16). BS 6840 quite clearly states the limitations of the method and outlines the RASTI requirements.

One requirement is as follows.

The system under test shall have:

"A wide band speech transmission (typically 200Hz to 6kHz) as the method is based on the assumption of an essentially unlimited speech spectra."

Most voice evacuation systems do not enjoy this extended frequency response and so the RASTI method strictly is not valid. The problem is further exacerbated by the fact that BS 6840 suggests that if the conditions for a RASTI test are not met then the full STI method should be used. A full STI covers the octaves 125Hz to 8kHz.

A limited frequency range system that did not satisfy the criteria necessary for the RASTI method would almost certainly fail a full STI for that very same reason.

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Problem 2 - Frequency Response - Effects of Noise
Most systems installed in public places cannot be audited when the public are present and hence the measurements are made under quiet conditions, some allowance can then be made to extrapolate the intelligibility under noisy conditions.

This is done by assuming that the modulation reduction factors within the measurement matrix result from architectural acoustic disturbances only, e.g. it results from the first term $\frac{1}{\sqrt{1+[2\pi F \frac{T}{13.8}]^2}}$

of

$$m(F) = \frac{1}{\sqrt{1+[2\pi F \frac{T}{13.8}]^2}} \cdot \frac{1}{1+10^{(-S/N)/10}}$$

where: m(F) = the reduction in modulation at the modulation frequency F
F = the modulation frequency
T = the early part of the reverberation decay
S/N = the signal-to-noise ratio in dB.

It may be therefore assumed that by applying the second term . $\frac{1}{1+10^{(-S/N)/10}}$

as an operator on the terms within the modulation/channel matrix will provide a fairly reliable estimate of the STI under normal occupied conditions.

In practice, of course, the modulation reduction factor changes most rapidly as the signal-to-noise ratio approaches unity (see fig. 1). The octave band signal-to-noise ratio clearly must depend upon the frequency response of both the signal and the noise.

Octave band differences in frequency response therefore can make a dramatic difference to the octave band modulation reduction factor (and hence STI) when systems are operated at small signal-to-noise ratios.

Measurements taken at large signal-to-noise ratios are almost independent of the frequency response of the system and hence care should be taken when extrapolating this data.

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Consider fig. 2. This shows the effect of increasing noise on a system with a 20dB dip in its frequency response in the 2kHz and 4kHz octaves. The frequency response of the system is represented by the continuous horizontally-stepped line.

This line may be thought of as moving up and down thereby increasing or decreasing the signal-to-noise ratio. The values within the figure represent the average channel transmission index. As the response line moves upwards the noise level increases and the calculated STI reduces.

Two effects can be seen. Firstly, the calculated STI is better than one might expect from a system with such a massive loss in these important octaves. Secondly, the calculated STI, based on the measured 'empty' is optimistic compared with the detailed calculations taking the frequency response into account.

Clearly therefore great care has to be taken in extrapolating the data from 'measured empty' measurements.

Problem 3 - Late Reflections

During July this year we were called upon to investigate a speech intelligibility problem at the Royal Tournament held in Earls Court Exhibition Centre, London.

We have been involved with this venue for many years and have accumulated considerable data including STI measurements at similar events.

The problem came as quite a surprise as the audio system has remained unchanged for a number of years during which time complaints were rare.

The problem was instantly apparent. There was an extremely disturbing flutter echo which turned out to be between the floor and ceiling. This effect can be clearly seen in the impulse response taken in the arena as shown in fig. 3.

The flutter was repetitive at 205ms which accurately corresponded to twice the centre height of the space.

The problem was caused by the installation of a new thermal ceiling which has a hard surface, the old ceiling was acoustically fairly absorbent.

However an additional problem came to light when STI measurements were made.

The measured STI on this occasion was in the region 0.55. Prior to this year, the measured STI was always in the region 0.50 to 0.60.

The latest measurements therefore indicate that there has been little change in the STI although subjectively the intelligibility had deteriorated. It should be understood that in previous years there were very few complaints but this year, following the installation of the new ceiling, many complaints were received.

Examination of the modulation reduction matrix provides the answer to this apparent anomaly. 205m.sec. corresponds almost exactly to 5Hz which is the modulation frequency which is showing a significant improvement. Fig. 4 shows this effect graphically. A significant improvement can be seen in the modulation reduction factor at 5Hz and 10Hz modulation frequency.

This effect has been verified by making laboratory measurements using delay lines. Equipment was set up as shown in fig. 5. Fig. 6 shows the effect of a delayed signal at 200ms with varying amplitude. Very little effect can be observed with the delayed signal at -10dB with respect to the direct. As the delayed signal is increased in amplitude, an improvement can be seen at 5Hz and 10Hz whilst there is clearly a negative effect at 2.5Hz and additionally at 8Hz modulation frequency.

Fig. 7 shows the same experiment but with the introduction of noise (the signal-to-noise ratio was set at +3dB). In this instance much the same effect can be observed however, as the delayed signal increases the negative effect at 2.5Hz and 8Hz becomes more apparent but with increasing delayed signal this effect actually reduces resulting in an improved 'measured' STI. A similar effect may be seen in fig. 8 which includes the effect of reverberation.

With direct signal only (delayed signal set at -50dB) the modulation reduction factor decreases with modulation frequency characteristic of reverberation dependency. However, as the delayed signal increases there is an apparent decrease in the modulation reduction factor (also STI) until the delayed and direct signals are the same whereby continuing to increase the delayed signal produces a significant improvement in the modulation reduction factor. With a delay-to-direct ratio of +9dB the effect of the disturbance becomes apparently beneficial producing an STI which exceeds that of the 'reverberation only' measurement.

CONCLUSIONS

We believe these effects demonstrate the need to be cognisant of the measurements' shortcomings and the necessity that these measurements are only carried out by those competent to do so. This is particularly apparent in the case of the introduction of a delayed signal which could give wholly misleading information. It also demonstrates the worth of seeing the full modulation reduction matrix rather than just the single derived STI.

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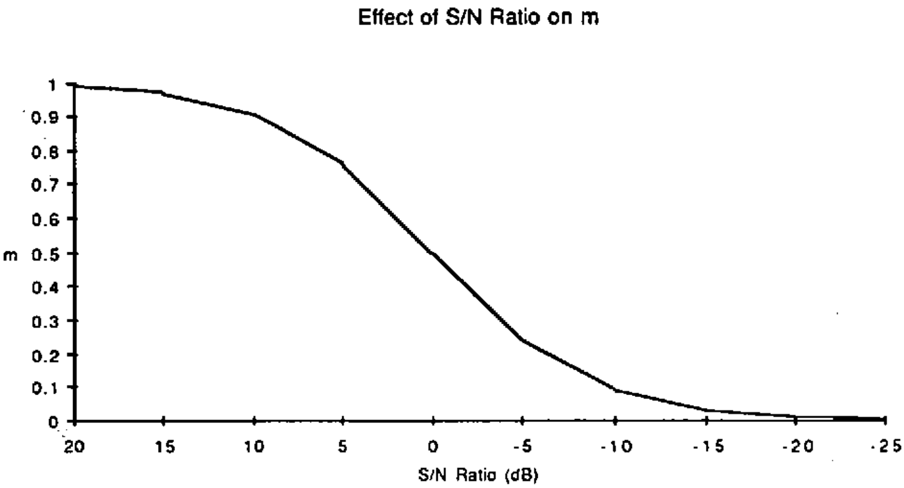


Fig. 1

Noise Level, dB	125	250	500	1000	2000	4000	8000	STI Shaped Freq Response	STI Flat Freq. Response
80	0.500	0.500	0.500	0.500	0.000	0.000	0.500	0.320	0.500
70	0.833	0.833	0.833	0.833	0.167	0.167	0.833	0.593	0.833
60	1.000	1.000	1.000	1.000	0.500	0.500	1.000	0.820	1.000
50	1.000	1.000	1.000	1.000	0.833	0.833	1.000	0.940	1.000

Frequency, Hz

Fig. 2

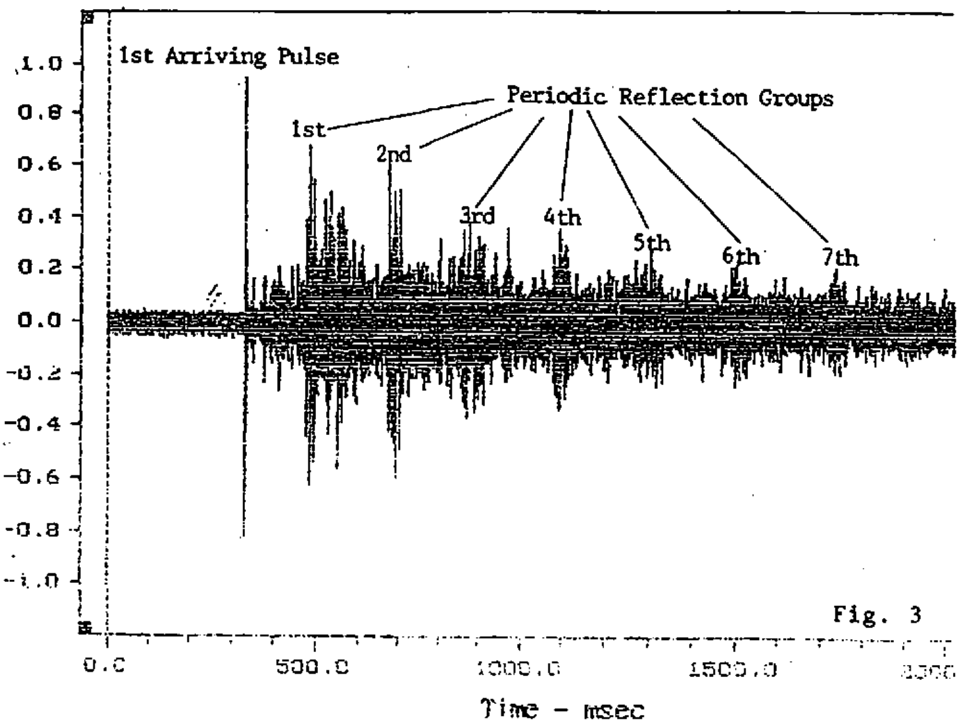

1st Arriving Pulse
Periodic Reflection Groups
1st
2nd
3rd
4th
5th
6th
7th
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0.0
500.0
1000.0
1500.0
Time - msec

Fig. 3

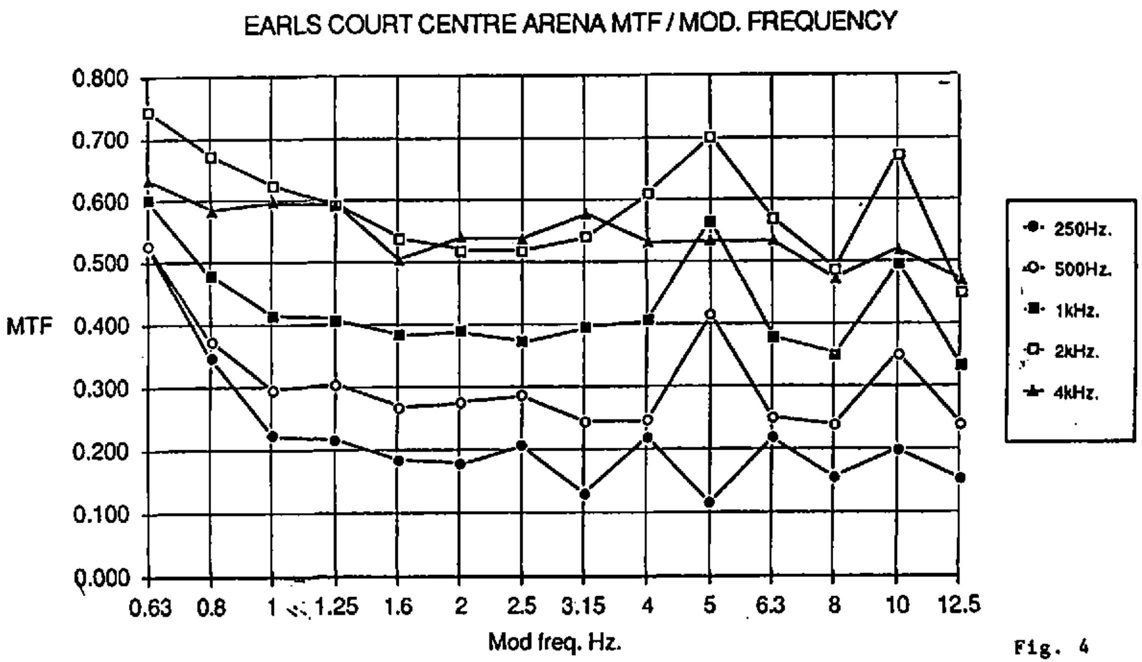
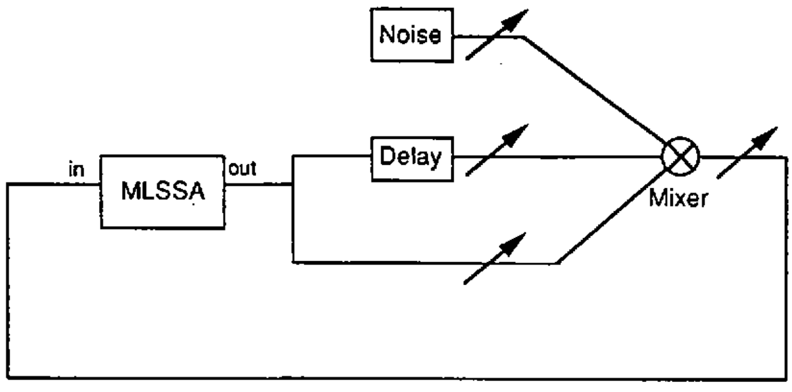

EARLS COURT CENTRE ARENA MTF / MOD. FREQUENCY
MTF
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.63
0.8
1
1.25
1.6
2
2.5
3.15
4
5
6.3
8
10
12.5
Mod freq. Hz.
250Hz.
500Hz.
1kHz.
2kHz.
4kHz.

Fig. 4



Schematic Diagram of Equipment Fig. 5

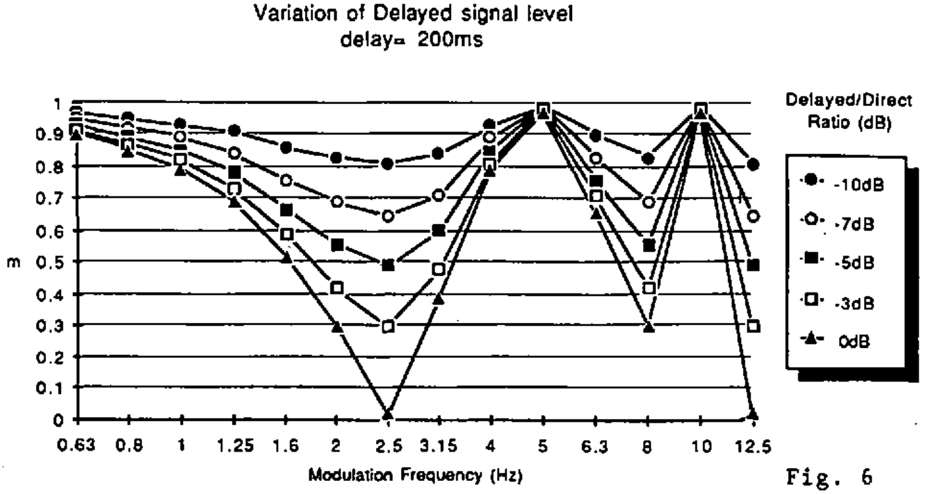


Fig. 6

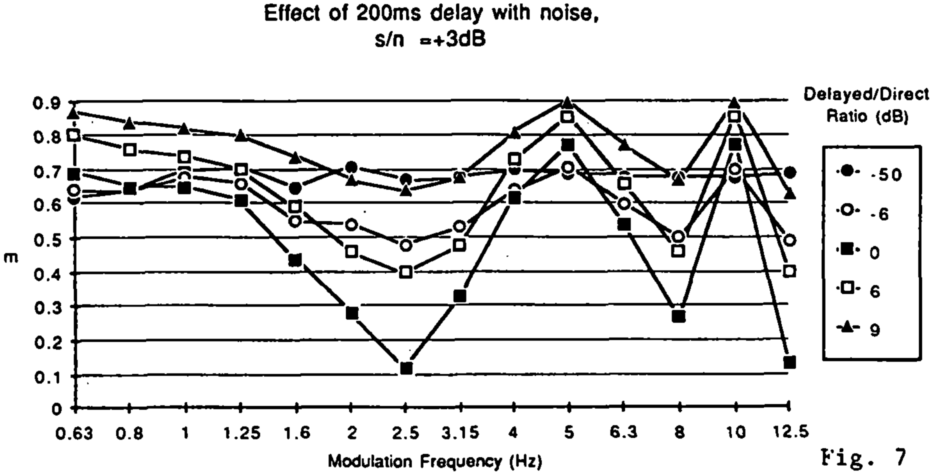

Effect of 200ms delay with noise,
s/n =+3dB
m
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.63 0.8 1 1.25 1.6 2 2.5 3.15 4 5 6.3 8 10 12.5
Modulation Frequency (Hz)
Delayed/Direct
Ratio (dB)
-50
-6
0
6
9

Fig. 7

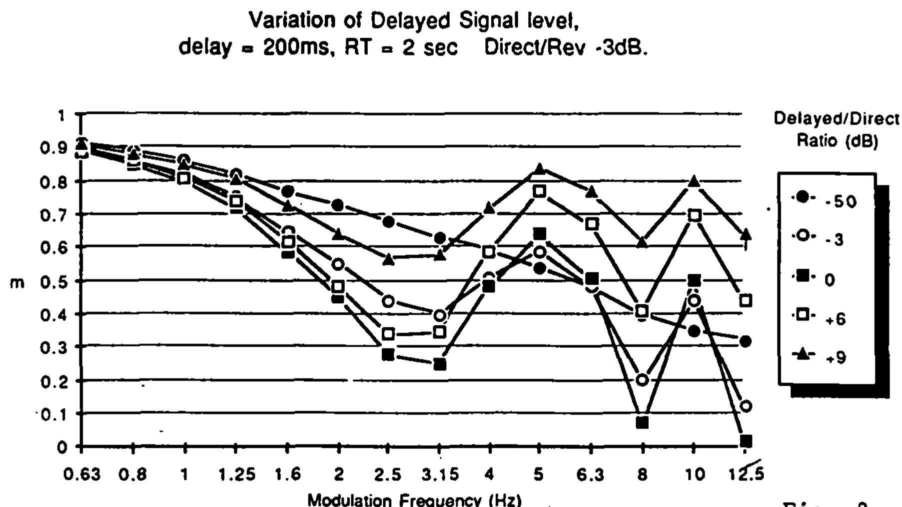

Variation of Delayed Signal level,
delay = 200ms, RT = 2 sec Direct/Rev -3dB.
m
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.63 0.8 1 1.25 1.6 2 2.5 3.15 4 5 6.3 8 10 12.5
Modulation Frequency (Hz)
Delayed/Direct
Ratio (dB)
-50
-3
0
+6
+9

Fig. 8