Sound masking systems effectiveness in open offices estimation from speech transmission index measurements

Stanislav Julianov Filipov, Snejana Georgieva Pleshkova, Ivajlo Hristev

Abstract **— Noise control in open offices must be focused at reducing disturbance noise which will increase the speech privacy. There are no regulations about the acoustical design of open offices in Bulgaria. Usually the room acoustics is controlled by techniques high room absorption, desk baffles, office furniture, workstation positions and masking sound. The interaction between these techniques is complicated, because the speech privacy is studied at different distances from a speaking human. The aim of this study is to evaluate the speech transmission index and A-weighted speech level when sound masking system is available and applicable in open space premises. The examined model is created in real open space environment and the measurement results are obtained from sound analyzer which will give the degree of the effectiveness of sound masking systems. Recommendations for the acoustic ambience of open offices are suggested.**

Index Terms **— sound masking systems, speech transmission index, speech privacy, open office, noise.**

1.INTRODUCTION

From early 70"s open offices are very popular, and they successfully become the preferred format of open space for a wide range of work tasks. The old school designs was implement stand-alone baffles and boring furniture, but now this is replaced by ergonomic workstations that are frequently qualified to as cubes. In these days there are modern ways to experiment with innovative designs such as team zones and other position scenarios where the entire open space is acoustically planned. However the most important remark of modern open plan offices is the consistence of different width and length but with constant height. The regular open offices are less costly to build and less costly to rearrange to meet the accommodation requirements. There are always people that will complain for lack of privacy and increased distraction but generally one well planned acoustical design will make office workers more efficient and concentrated. Optimizing the acoustical design of an open office can be a complex task because of the number of design parameters – Reverberation time - T30 [1], Early Decay Time – EDT [2], Clarity - C50 [3], Speech Transmission Index – STI, and Rapid Speech Transmission Index – RASTI [4]. For this reason were invited the sound masking systems which are using wide spread noise to mask the ambient noise especially in closed premises like the open offices. Using DSP processor for masking source and measurement equipment we can examine RASTI, STI and speech level of a certain open office. In this topic we will demonstrate the importance of STI parameter in any open office design and how it's dependent from masking systems. In this article will be examined the masking effectiveness by first measuring the STI in open office with his actual geometry without masker and then we will do the same measurements with masking omnidirectional source switched on. Finally we will compare the results from the both measurements.

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2. METHOD FOR SPEECH TRANSMISSION INDEX EVALUATION USED FOR ESTIMATION OF SOUND MASKING SYSTEMS EFFECTIVENESS IN OPEN OFFICES

Standard IEC-60268-16 [5] defines the method for the estimation of speech intelligibility and gives a rating called STI (Speech Transmission Index) that is close to the subjective intelligibility score. The same standard also defines a simplified method for the estimation of speech intelligibility called RASTI (Rapid Speech Transmission Index). The value of STI can be within 0 and 1.High value of STI means high speech intelligibility and vice versa. The STI analyzes the modulation transfer function with 14 modulation frequencies (from 0.63Hz to 12.5Hz, 1/3 octave apart) and in seven octave bands (from 125Hz to 8 kHz). The STI rating is obtained by summing and averaging the Modulation Transfer Function - MTF as described later. The RASTI analyses only 9 modulation frequencies (0.7Hz, 1Hz, 1.4Hz, 2Hz, 2.8Hz, 4Hz, 5.6Hz, 8Hz, 11.2Hz) in only two octave bands (500Hz and 2kHz). The procedure for calculation of the STI rating from given MTF is as follows:

$$Xi = 10\log\left(\frac{mi}{1-mi}\right), \text{ S/N ratio} \qquad (1)$$

where:

Values of Xi are limited to ±15, If Xi > 15 then Xi = 15, If Xi < -15 then Xi = -15.

The STI method states that signal to noise ratio in the range

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from -15dB to +15dB are linearly dependant on intelligibility rating in the range from 0 to 1. That is why; S/N ratio is converted to transmission index – TI

$$TIi - \frac{Xi + 15}{30}, \qquad (2)$$

where:

X_i – Signal to Noise ratio

The average value of TI_i for an each octave band (Octave transmission index-OTI) is defined with following equation:

$$OTIn = \frac{1}{14}\sum_{i=1}^{14} TIi \qquad (3)$$

where:

n = 1,2,….7

Finally, the STI rating is given by the equation:

$$STI = \sum_{n=1}^{7} \alpha n OTIn - \sum_{n=1}^{6} \beta n \sqrt{OTIn \times OTIn+1} \quad , \qquad (4)$$

where:

αk and βk are weighted factors which are experimentally determined for male and female speech

Table 1 - Weighted factors for male and female speech - IEC 60268-16

requency	125	250	500	1000	2000	4000	8000
α_{male}	0.085	0.127	0.230	0.233	0.309	0.224	0.173
β_{male}	0.085	0.078	0.065	0.011	0.047	0.095	0
α_{female}	0	0.117	0.223	0.216	0.328	0.250	0.194
β_{female}	0	0.099	0.066	0.062	0.025	0.076	0

STI values are in the range from 0 to 1. Equivalent subjective ratings are given in Table 2.

Table 2 - STI - equivalent subjective rating

STI	Equivalent subjective rating
0,0 < STI < 0,3	Bad
0,3 < STI < 0,45	Poor
0,45 < STI < 0,6	Fair
0,6 < STI < 0,75	Good
0,75 < STI < 1,00	Excellent

The short version of *STI*, or *RASTI* (*rapid speech transmission index*) uses only 9 data points:

$$RASTI = \frac{1}{30}\left\{ 15 + \frac{1}{9}\left(\sum_{i=3,6,9,12} SNapp(Fi,500Hz) + \sum_{i=2,5,8,11,13} SNapp(Fi,2000Hz) \right) \right\}, \qquad (5)$$

where

signal-to-noise ratio is

$$SNapp = \frac{10\lg m}{1-m} \ , \qquad (6)$$

where:

m is modulation transfer function.

The measurement model that was implemented correlates with the subjective experience of speech distraction was applied in Sofia city at eCommera [6] open office – figure 3. A studio monitor (Philips 22AH587) supplied with STI-PA signal was used to simulate a speaking office worker. It was placed into one workstation, and the measurements were carried out along a straight line that passed over several workstations (Figure 1). The length of the measurement line varied between 4 and 15.5 meters and included at least eight workstations. The sound source and measurement microphone were at a height of a sitting human's ear, 1.25 meters from the floor. For masker source was used omnidirectional sound source installed at 2.5 meters from floor between the workstation at the center of measurement line. We applied the concept of the modulation transfer function and speech-to-noise ratio (6) to obtain a speech transmission index (STI). During the measurements, detailed information on the office was collected (eg, room geometry, absorption coefficients of surfaces, dimensions and properties of screens and furniture, and layout metrics).

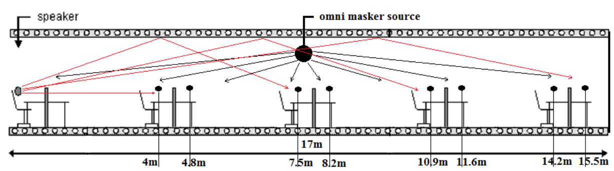

Figure 1. *Principle of the model. Reverberant speech (red arrows), and masking sound (black arrows)*

3. Measurement Results

The measurements were made in open plant space environment with Noise level 37 dB(A). The speaker was feeding room with STI-PA reference signal generated by NTI MR-Pro. The STI value was measured as shown in Figure 2 block diagram. The measurements are performed by NTI XL2 audio analyzer – Figure 3 and for the masking source a dodecahedron was used. For the modelling, the background noise level, room geometry and early decay time T10 were recorded.

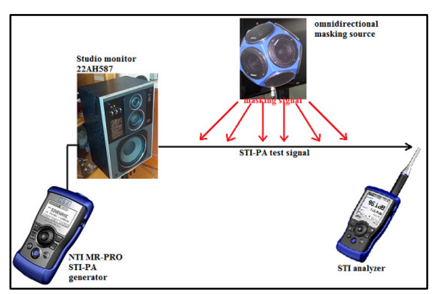

Figure 2. *Block diagram of STI test bench*

NTI XL2 and MR-PRO specifications [7] are:

- Single value STI and CIS test result in accordance with IEC 60268-16, ISO 7240-16, ISO 7240-19, DIN VDE 0828-1, DIN VDE 0833-4, BS 5839-8
- MR-PRO–Output 12.5 Ohm balanced, Imax=10 mA

The workstations of the examined space represent typical open office environment. In general, background noise levels are too low, ceiling absorption materials are not used, and desk separators are missing. In order to have acoustically good open office with high speech privacy, the signal-to-noise ratio should be close to zero or even below it. According to MTF theory, the reverberation time should be very long to obtain low *STI*. However, this is not recommended in offices because people start to complain about poor conversational acoustics. Long reverberation will lead to inherent rising of voice level which, in turn, will reduce speech privacy. Therefore, it is recommended to have a short reverberation time in offices and in this case T30 is 0.60 sec at 1kHz. To reach high speech privacy, masking noise with equalized spectrum will be added simultaneously with the measurement sti-pa signal.

Figure 3. *NTI XL2 sound analyzer at eCommera*

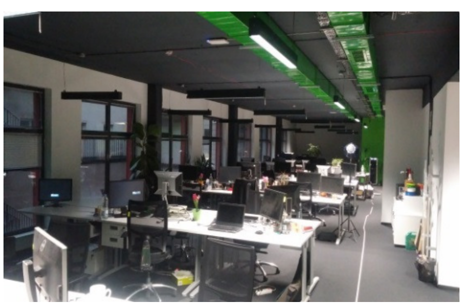

Figure 4. *eCommera open space, Sofia, Bulgaria*

In Table 3 are shown results from the STI measurements of the eight workstations. The results are obtained for the eight measurement points from figure 1. If we take a closer look at figure 5 we will see that it's obvious that the STI is getting lower when masker is on and also when the distance from speech source is getting higher.

Table 3 - *STI – results from measurements*

Position	STI masker OFF	STI masker ON	EDT @ 1kHz	T30 @ 1KHz	Noise level dB(A)	Masker Level dB(A)
pos1	0.75	0.67	0.69	0.77	36.7	47
pos2	0.72	0.6	0.61	0.75	36.7	47
pos3	0.69	0.54	0.59	0.8	36.7	47
pos4	0.68	0.52	0.95	0.66	36.7	47
pos5	0.6	0.46	0.73	0.75	36.7	47
pos6	0.63	0.49	0.75	0.71	36.7	47
pos7	0.64	0.52	0.84	0.73	36.7	47
pos8	0.61	0.48	0.88	0.75	36.7	47

Note that during the measurements the loudspeaker generates around 60 dB(A) level in real environment which is average level in normal conversation.

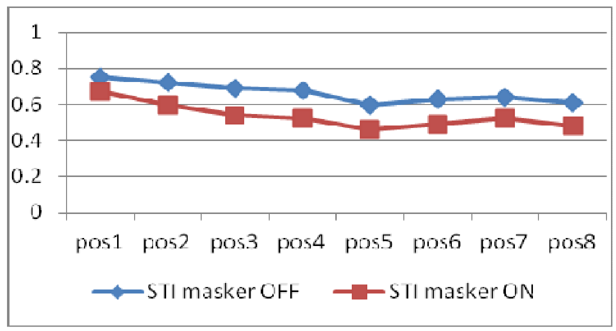

Figure 5. *STI between workstations in typical open office*

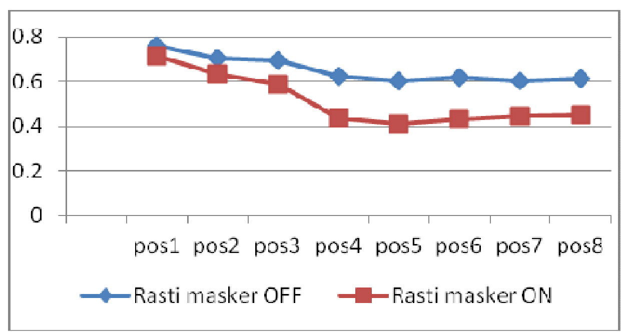

Figure 6. *RASTI between workstations in typical open office*

RASTI analyses only nine modulation frequencies while STI analyses fourteen. Looking at figure 6 we will see the distribution of RASTI which has lower values according to STI.

The last graph – figure 7 shows the STI versus distance. This maybe is the most important graph from design perspective point of view because here we have omnidirectional source but in practice the acoustic engineer will use built-in speakers in the ceiling. Knowing the directivity pattern of the loudspeaker and compare it to omni-source it will be not so complicate to adjust the position of the loudspeakers in the ceiling and to form a diffusion grid. At figure 7 we can see that STI has the most lower values at positions 3, 4, 5 and 6 which are more closer to the omni-source.

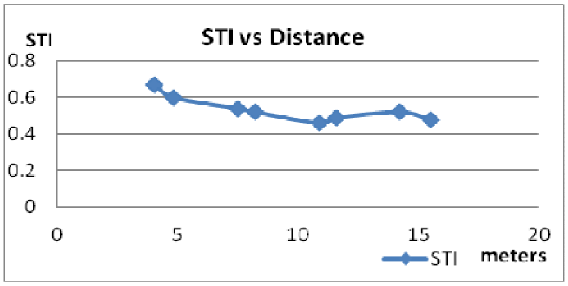

Figure 7. *STI vs Distance to speaker*

4. CONCLUSION

The results in this article are related to the thesis "Development of methods and algorithms for the study of acoustics systems for effective masking of sound sources" The obtained results can be used for future publications and also the results can be used as basis for the creation of practical methods for increasing the efficiency of masking sound sources. A simple and accurate model for the evaluation of masking system in open offices could be used. The examined results can be applied in the acoustical design of adjacent workstations in open space offices.

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