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PREDICTING AND MEASURING SPEECH INTELLIGIBILITY IN ROOMS

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Abstract

About ten years ago, a well-known concept - the Modulation Transfer Function MTF - has been adapted to the field of room acoustics. It can successfully be used for predicting or measuring speech intelligibility in rooms. The MTF in room acoustics characterises the quality of sound transmission between two points in a room, by specifying the reduction of the original fluctuations in the signal (more specifically: the reduction of the modulation depth as a function of modulation frequency), brought about by interfering noise and/or reverberation. The relevance of this approach for speech intelligibility has been verified by a multi-language test: it was found that the results of the MTF-analysis (in which an MTF is converted into a single index, the Speech Transmission Index STI) relate well with the mean results of various intelligibility tests for different languages. The accessibility of the MTF-approach for architects and acousticians has been substantiated by: (1) the development of a calculation scheme for predicting the STI from the design specifications of a room and (2) the development of specific equipment for measuring the STI in actual conditions.

1. Introduction

In 1973, the concept of the Modulation Transfer Function (MTF) was introduced in room acoustics (Houtgast and Steeneken, 1973). The MTF characterises the sound transmission between two points in a room. From the MTF, an index can be derived (the Speech Transmission Index, STI), which is found to relate well with the effect of that particular sound transmission path on speech intelligibility.

After a brief review of the MTF approach (section 2), the present paper is concentrated on two issues: the development and validation of a STI-measuring device (section 3), and the implementation of a computer model, based on the ray-tracing principle, for predicting the STI from the design specification of an auditorium (section 4).

2. The modulation transfer function

The MTF-approach and the definition of the Speech Transmission Index (STI) are fully described in ref. 2 (Houtgast, Steeneken and Plomp, 1980). The principle is illustrated by Fig. 1. A test signal is generated at a specific position in an auditorium (typically a talker's position) and received by microphone at another position (typically a listener's position). The sound transmission between these two points is characterised by the degree of preservation of the intensity modulations of the original signal. Parameters are (1) the modulation frequency F (typically from 0.5 to 16 Hz) and (2) the frequency band covered by the noise carrier (typically an octave band, with a center frequency

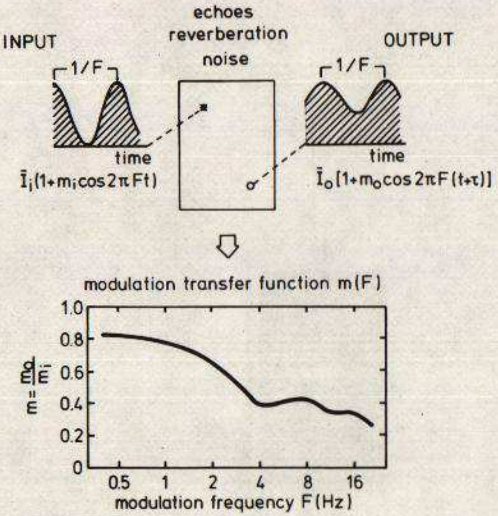

Fig. 1. The modulation transfer function specifies the reduction of the original modulation as a function of modulation frequency when a signal is passed between two points in a room. An additional parameter is the frequency band covered by the noise carrier (typically octave-band filtered noise).

from 125 Hz to 8 kHz). Such a set of data on modulation transfer can be converted into a single index, the STI, which relates to the degree in which the intelligibility of speech is affected when passed between these very two points in the auditorium. For further details, the reader is referred to ref. 2.

3. A STI-measuring device

For many practical applications in evaluating auditoria, the range of the two parameters involved in the measurement of modulation transfer can be reduced considerably. On that basis a measuring procedure has been adopted which includes only two octave bands (center frequencies 500 Hz and 2 kHz) and, within each octave band, only four or five modulation frequencies, respectively. This limited approach leads to the index named RASTI (Rapid Speech Transmission Index). A RASTI-measuring device is illustrated in Fig. 2. A main feature of the measuring procedure is the test signal, as generated by the source, containing all relevant information *simultaneously* (octave bands and modulation frequencies). Thus, in evaluating an auditorium, the source is placed at a representative position with the test signal switched on continuously; for the receiving part located at any position in the audience area, a measuring period of about 12 sec suffices to obtain a RASTI-reading.

A detailed description of this measuring procedure is given in ref. 3 (Houtgast and Steeneken, 1981), which also presents an evaluation of the RASTI approach when compared with the results of intelligibility tests performed for several languages. A characteristic finding of that study is illustrated by the present Fig. 3, indicating the good correlation between RASTI-values and the mean (rankordered) intelligibility scores as obtained by seven laboratories.

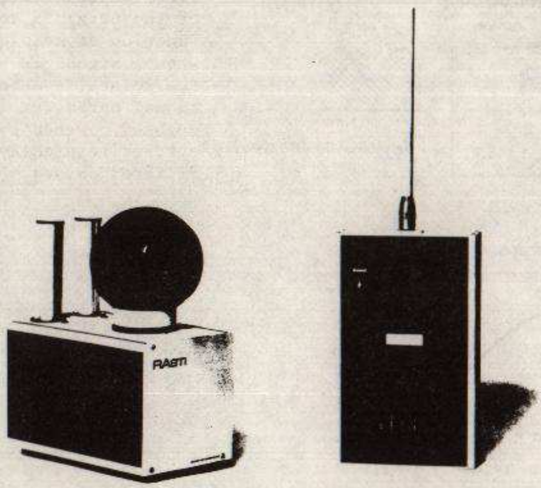

Fig. 2. Signal source and receiving part of the measuring equipment RASTI.

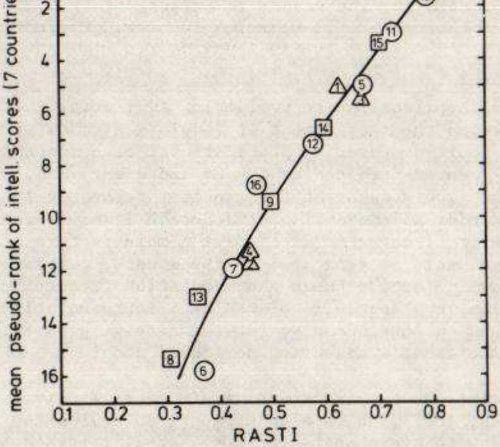

Fig. 3. The relation between RASTI measurements and intelligibility-score data as obtained for 16 auditorium conditions.

4. STI-prediction by ray-tracing

For the purpose of predicting the STI in the design stage of an auditorium, a computer model has been developed based on the ray-tracing principle, as described in ref. 4 (van Rietschote, Houtgast and Steeneken, 1981). The room is defined by the geometrical and acoustical characteristics of its boundary planes. The talker is simulated by a point emitting a large number of rays (typically 7000) which are traced along their path within the room, and the audience is simulated by an area of spheres (radius typically 1 m) being "hit" by the rays, resulting in a STI value for each corresponding listener position.

Although essentially a ray-tracing model, it accounts for the influence of (partly) diffuse reflections by following the lines of statistical room acoustics: that proportion of a ray which is reflected diffusely is assumed to decay as dictated by the room's mean free path and mean absorption coefficient. Also, it was found useful to terminate the actual tracing of a ray after typically four reflections, and to treat the remaining part according to the rules of statistical room acoustics as well. This has resulted in a model of a hybrid nature, combining ray-tracing acoustics (assuming purely specular reflections) and statistical room acoustics (assuming a purely diffuse sound field).

One example of the results of such calculations is presented in Fig. 4, referring to a block-shaped room (30 x 20 x 10 m) with an absorption coefficient

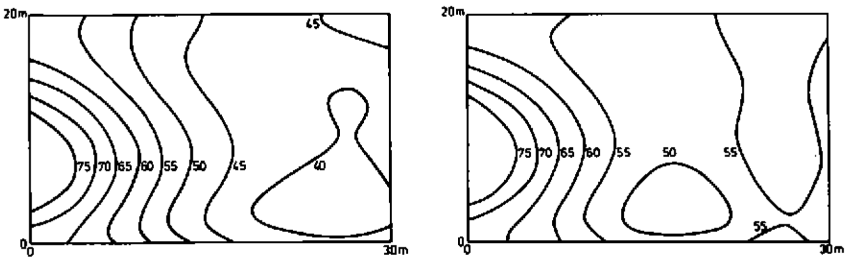

Fig. 4. A family of iso-RASTI contours as obtained from a ray-tracing based computer model, illustrating the difference when the back wall has been tilted at an angle of 79 degrees (right-hand panel).

for the floor of 1.0 and for walls and ceiling of 0.054. The source is located at a height of 2 m, 3 m from the front wall and 8 m from a side wall. The listeners (spheres) are arranged in a 10 x 7 grid at a height of 1.5 m, and the resulting STI values for the 70 locations are presented in the form of iso-STI contours. The right panel illustrates the effect of tilting the back wall at an angle of 79 degrees. The results of these type of calculations, obtained for many other conditions as well, have been verified by scale-model measurements of the STI (van Rietschote, Houtgast and Steeneken, 1979).

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