

# VOICE ALARM SYSTEMS FOR EXHIBITION CENTERS: DESIGN, PREDICTION AND VERIFICATION

T Steinbrecher Bose Professional Systems, Friedrichsdorf, Germany

## 1 INTRODUCTION

The prediction and the verification of the speech intelligibility of sound systems for emergency purposes remains a challenging task for the electro-acoustical engineer. Despite the progress in loud-speaker technology, DSP and measurement equipment, evolving standards raise the bars and require the designer to thoroughly investigate his system designs for compliance. Additionally, more and more verification measurements are performed on the final systems, since relatively easy-to-use meters for testing intelligibility exist<sup>1</sup> and are increasingly used, also by non-acoustical experts.

In a continuation of earlier work by the author<sup>2</sup>, this paper attempts to summarize the process that was applied to accurately predict the achievable intelligibility in an (ongoing) project in Hamburg, Germany, where sound systems for several exhibition halls of the new trade fair (Messe Hamburg) were designed. This process is characterized by a matching procedure where simulation models were calibrated using measurements of the reverberation time of comparable reference rooms during the actual construction phase. For an exemplary hall, the simulated predictions for the intelligibility are compared to measurements of the installed system. The objective measurement method used for assessing the intelligibility was the Speech Transmission Index STI<sup>3</sup>, that was determined both employing the STIPA method using modulated noise signals as well as by measuring and post-processing the system's impulse response as gathered with sweep (chirp) signals (also known as the 'Schroeder' method<sup>4</sup>).

## 2 HAMBURG TRADE FAIR

### 2.1 General

The new trade fair in Hamburg has been successfully developed over many years, resulting in major new construction activities in order to increase the gross area as well as to update the technical infrastructure to the needs and requirements of today's customers. Demolition and new construction began in 2005 as a continuous step-by-step process in which one hall was re-built after another in order to continue running trade shows during the renovation. A total of approximately ten halls will be re-built at the end of the construction phase in 2009, resulting in a total area of about 85.000 square meters, a 30% increase from former dimensions. Figure 1 shows an overview about the whole area of the trade fair in downtown Hamburg in it's current construction stage (Nov 2007).

The halls, walkways and entrance areas - while similar in height and ceiling construction - span a large range of sizes, from about 4000 sqm (Hall A2) to about 13000 sqm (Hall B6). With a maximum length of about 210 meters, hall B6 is the largest in size. Ceiling heights vary and are typically at either 17 or 23 meters. Table 1 shows a summary about the various halls, their basic dimensions as well as some properties of the simulation models and reverberation times for empty and occupied conditions. Figure 2 shows isometric views for a selection of simulation models of six halls that sound systems were designed for.

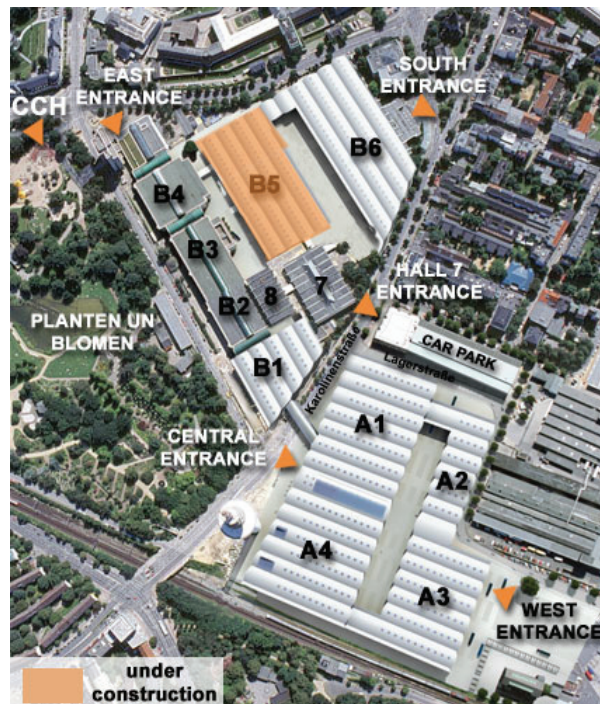


Figure 1: Current state of construction (picture from Messe Hamburg website)

Hall	Floor Area [m <sup>2</sup> ]	Height [m]	Room Volume [m <sup>3</sup> ]	RT empty, full [s]	Planes [#]
A1	80x140	23	225000	7 / 3.5	440
A2	35x115	17	61000	6.5 / 3.5	170
A3	80x115	17	142000	4.5 / 3.0	240
A4	80x120	23	175000	5.0 / 3.0	430
B5	80x120	17	145000	4.5 / 2.5	560
B6	80x210 (150)	17	220000	4.5 / 2.7	650
B7	80x140 (95)	17	145000	4.2 / 2.5	590
Entrance	40x45	23	26000	3.5 / 2.5	250
Mall - A	25x60	23	32000	6.0 / 4.5	25
Mall - B	20x75	23	25000	n/a	155
Loggia	6x140	17	10000	2.5 / n/a	100

Table 1: Overview of room dimensions, acoustics and model complexities

## 2.2 Room Acoustical Conditions

All new halls are built based on a common grid and very effective pre-manufactured building elements. Especially the wooden ceiling construction with a concave cross-section is common throughout the trade fair and can be found in every hall. The ceiling elements are of multi-purpose functionality and provide the only available acoustical absorption in the unoccupied halls. The absorption is achieved by open slits between adjacent panels and a magnesite bounded wool wood acoustic panel ('Heraklith') behind. The true absorption coefficients could not be directly verified but estimated to be rather low, in the region of  $\alpha = 0.2 \dots 0.4$  at mid frequencies, as could be verified

during the matching process described below. The remaining surfaces are mostly acoustically reflective: concrete (painted) floor, lightweight concrete walls and the installation infrastructure (e.g. HVAC). Typically, the only additional absorption area during exhibitions or trade shows is the actual exhibition equipment, the audience attendees and typically, a little bit of carpet on the aisles.

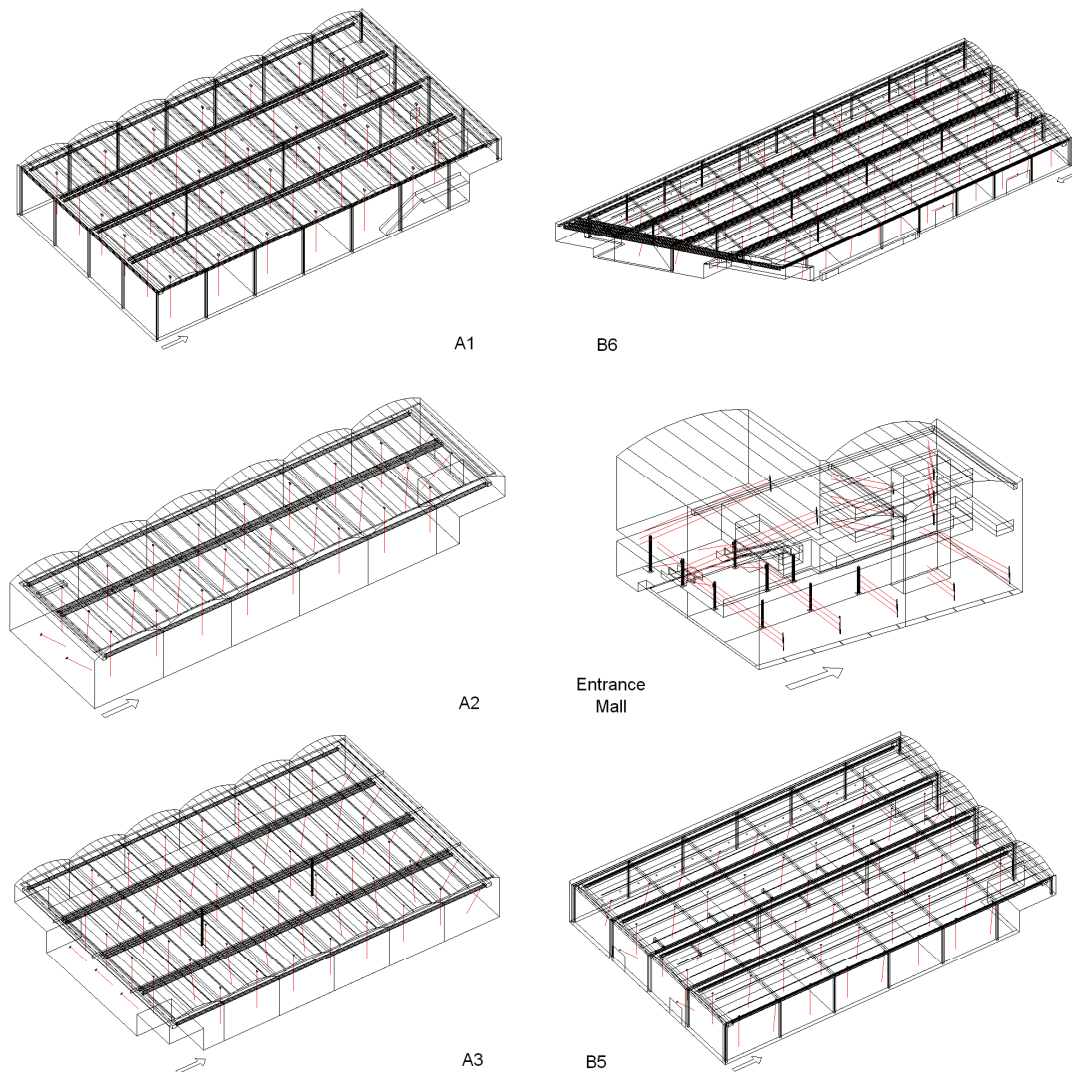


Figure 2: Exemplary simulation models of six halls (the length of the arrow depicted is 10 meters)

Fortunately, the acoustical conditions do not vary too much between rooms with comparable dimensions and ceiling heights, thus allowing to quite safely transfer experience gained from one room to another. For the exhibition halls with the lower ceiling, the typical reverberation times are 4 to 5 seconds for the empty halls and 3 seconds for the occupied conditions. For the larger halls with a ceiling height of about 23 meters, the reverberation times are typically 5 to 7 seconds (empty) and 3 to 3.5 seconds (occupied), see also Table 1. Figure 3 shows an overview of measurements for various reverberation times in hall A1 while Figure 4 shows the spread of measured RT-20 over 25 measurement locations in the same hall (a sweep based measurement system, Monkey Forest, was used for this purpose).

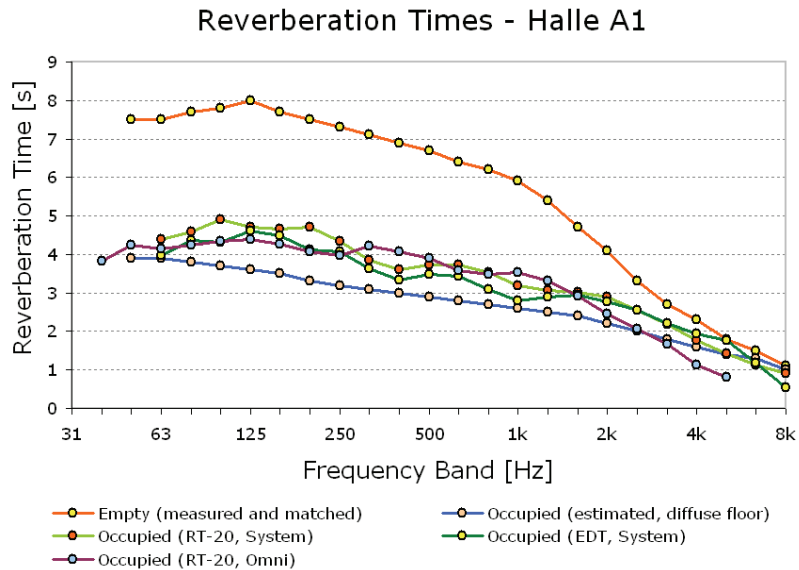


Figure 3: Various reverberation times for hall A1

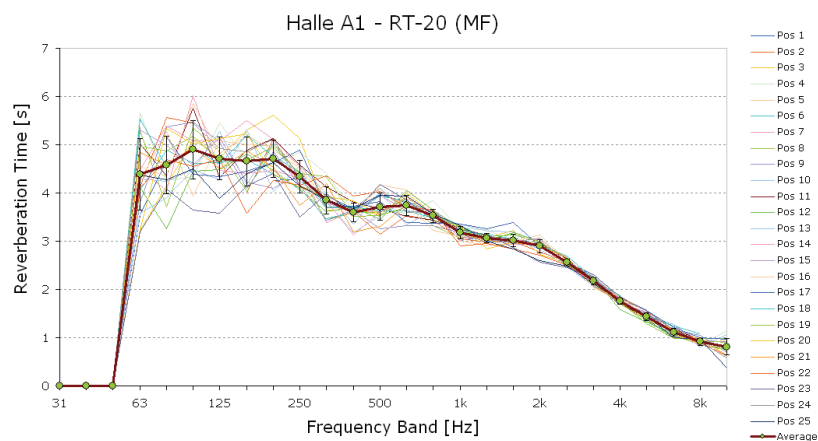


Figure 4: Measured RT-20 for 25 positions in hall A1

### 3 REQUIREMENTS AND DESIGN PROCESS

#### 3.1 Requirements

The author got involved into the project at a stage where construction had already begun and simple loudspeaker systems as specified in the pre-planning phase had already been installed in the first finished hall. They failed to perform as originally specified, thus new systems had to be designed and installed quickly. Cost was an important factor initially, so one of the main requirements was to not over-design the system and find a cost-effective approach instead.

It was agreed by the responsible parties that the intelligibility requirements from EN IEC 60849<sup>5</sup> shall be met in the typically occupied halls (including exhibition equipment, booths, etc.): the average value of the Speech Transmission Index minus one standard deviation shall be higher or equal to  $STI = 0.5$ , which equals 0.7 on the CIS scale<sup>6</sup>. Since EN IEC 60849 references the 1998 version

of the STI standard that did not yet include level-dependant masking effects at high SPL's, these masking effects were also not considered in prediction or measurements.

Besides the intelligibility specifications, it was required that the systems may also be able to play back background music, thus a suitable low frequency response (at least down to 80 Hz) was required. (For hall A1, which is analyzed below, fullrange systems with a frequency response down to roughly 60 Hz were installed).

### 3.2 Design Process

For the main halls, an initial comparison between basic system approaches was performed: Centralized clusters with either waveguide- or array-based loudspeakers were tried as well as classical distributed systems suspended from cable trusses available in the ceiling. Despite advantages in achievable intelligibility, all centralized designs were abandoned due to problems with obstructed coverage in case tall exhibition elements (boats are not uncommon) or 2-3 story booths are present. Also for redundancy reasons, distributed approaches were chosen for the main halls. Bose 402-II loudspeakers (a four-driver speaker array) were used in 12-13 meter height in the halls with the lower ceiling and reverberation time, while Bose LT 9403 loudspeakers (3-way, dual-waveguide 90°x40°, Fullrange) were used in 17-18 meter height in the large halls (A1, A4) with the larger ceiling height. A significant design restriction was that the loudspeakers shall be mounted along the existing cable trusses and also fit symmetrically into the grid of lighting elements that were suspended from the same truss while, at the same time, avoiding collisions with other elements (Steel beams, HVAC, etc.).

Most of the final system approaches for other parts of the area (entrance halls, walkways, malls) incorporate other design approaches, mostly employing decentralized line arrays of 1 to 3m length. Unfortunately, most are not yet installed and measured at the time of the writing of this paper.

In an attempt to minimize risks and to avoid a second disappointment / failure of another sound system design only after installation, the procedure described below was agreed on and executed, resulting in a high confidence in the initial simulations and STI predictions. Because design phases, the various measurements, construction and system installations in various parts of the area all overlapped, a subsequent approach was chosen:

- Reverberation times (RT) were measured in an empty hall.
- The equivalent computer model was equipped with an initial set of (textbook) absorption coefficients and was matched to the measurements of the empty hall, replicating source locations in the Ray Tracing algorithm used for the RT prediction.
- This matched model was used to predict STI for the empty condition and also modified to reflect the anticipated RT60 for an occupied condition. Typically, the STI requirements were met with a little safety margin, leaving headroom for changes in the final occupied RT. The results were documented accordingly.
- As soon as the schedule of exhibitions allowed performing measurements of the room and the installed system under the conditions of a real exhibition, both reverberation times and STI-values were determined in order to verify the predictions and make changes to the models if necessary.
- Typically, the absorption coefficients of the exhibition surfaces needed to be re-adjusted slightly to match the measured reverberation times and the STI-predictions needed to be re-run and compared to the measurements.
- If applicable, the determined corrections to the absorption of exhibition surfaces was copied to other models of comparable dimensions (e.g. hall A1 to A4).
- This process was repeated for the major types of hall (ceiling heights).

Figure 5 shows typical perspective views of the interior of some of the simulation models that were finally used. As can be seen, even the HVAC infrastructure was modeled. This was not only neces-

sary because of the total surface area (the metal sheet tubing has about 50% of the surface area compared to floor or ceiling), but also because of potential collisions with any loudspeakers.

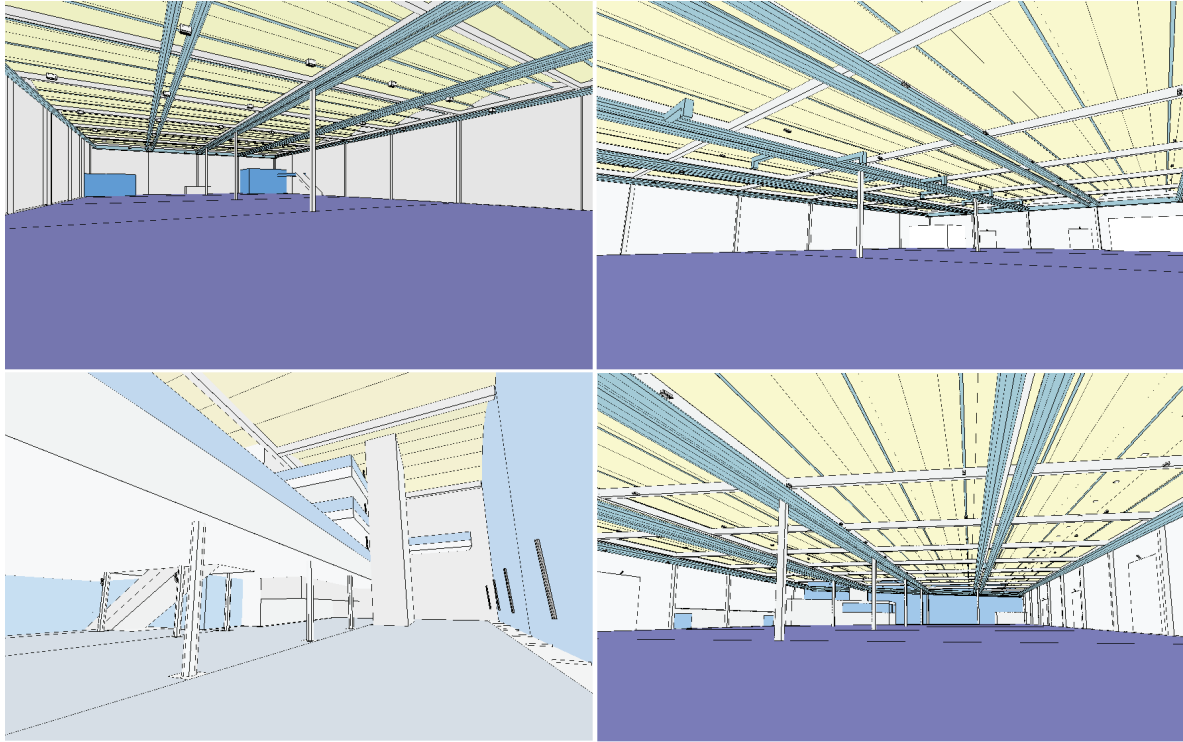


Figure 5: Interior perspective views of some of the simulation models. Clockwise from top left: Halls A1, B5, B6 and Mall A

## 4 SIMULATION

### 4.1 STI Prediction

For the prediction of the STI values in the simulation models, the current version of the Bose-software Modeler® (6.0.1)<sup>7</sup>, running under Windows XP, was used. In this program, the calculation of the MTF is performed for every sample point by Fourier transform of a computationally efficient form of the systems squared impulse response (Hybrid Energy Decay Curve, HEDC™, see<sup>8</sup>). The calculation of the STI is subsequently performed according to the original version of the STI<sup>9</sup>. For this study, also an alpha version of an upcoming software version was tested that also allows to predict the STI according to the latest standard changes from 2003<sup>3</sup>. Figure 6 shows a typical STI-prediction as the display of a coverage map including a histogram of the coverage statistics for hall A1.

Hall A1 has main dimensions of roughly 80x140x22 meters. The geometry of the simulation model contains about 500 surfaces and about 40 loudspeakers (each modeled as two sources). Using the most recent test version, it takes about 13 minutes to calculate an MTF- (impulse-response) based STI for about 1500 samples (the sample size in Figure 6 is 2.5 meters). The typical calculation time for the 25 locations under survey in this paper, is about 20 seconds. Conversions from Alcons or other statistical measures to the STI are not applied in the simulation software.



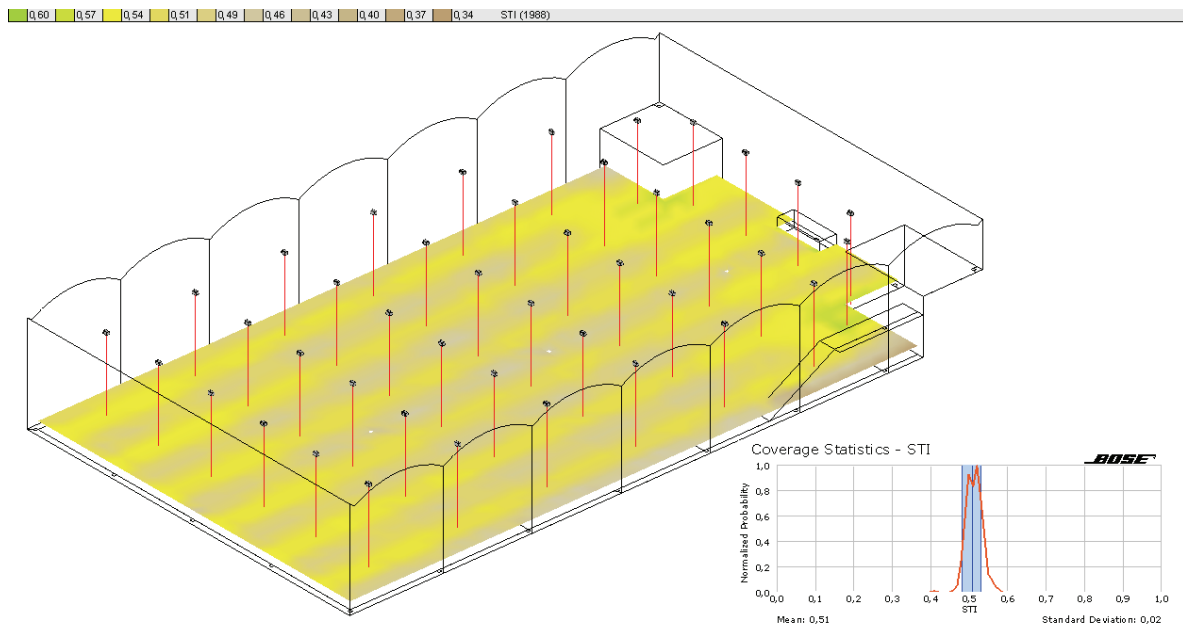


Figure 6: STI mapping for the main floor area (most surfaces de-activated to avoid visual clutter) together with a histogram of all the data displayed (roughly 1500 samples).

## 4.2 Model Analysis

Three different approaches for determining the reverberation times were analyzed in the simulations (for a combined display of reverberation times, see Figure 3):

1. Measurements using an 'omni' source on the floor (interrupted noise method).
2. Measurements using all loudspeakers of the installed sound system (sweep method).
3. Initial estimations using absorption coefficients for the occupied floor that were adjusted based on measurements of an occupied hall (with a lower ceiling).

For each subset of measured reverberation times, the reverberation was re-matched in the respective models by making adjustments to the (occupied) floor surfaces. The STI-predictions were re-run and compared to the measurements of the STI at 25 locations in the actual installation. For each test situation (RT), the errors between simulation and measurements were noted and evaluated. For the model with the smallest differences to the measurements, also comparisons of MTF responses at individual locations were performed. Due to the amount of data, a detailed report about such micro differences will have to be postponed for a future paper. An exemplary comparison is shown in Figure 12.

With the installed sound system as the excitation source and a sweep-based measurement system (Monkey Forest), both the EDT and the RT-20 were derived from the integrated impulse responses and matched models evaluated accordingly. Again, it is worth to repeat that the primary analysis for the STI was subsequently performed according to the original STI method from 1988<sup>9</sup>, applying a genderless speech spectrum and different frequency weighting. As it turned out for this example, the differences between the old and new weightings resulted in changes in STI in the order of 0.01 to 0.02 at a "nominal" value of 0.50.

## 5 MEASUREMENTS AND COMPARISONS

For the STI measurements, both STIPA (NTI meters) as well as an impulse-response based approach applying sweep signals were used. The correlation between the measurement methods was good and typical differences (under comparable situations) were found to be very small (mean error:  $< 0.01$ ).

Figure 7 shows a scatterplot that compares the results of STI measurements in 25 locations. STI values determined using the new frequency weighting (1998 and 2003 standard revisions) tend to be 0.02 STI higher than when determined using the original frequency weighting from the 1988 standard version. This is best seen in the histogram that is contained in the same figure, showing the actual differences. Measurements via the impulse response are described with the year of the weighting applied. These were post-processed such that masking effects were not taken into account. Within the used measurement system Monkey Forest, it is possible to evaluate the STI according to the different frequency weightings (1988 vs 1998) as well as with various masking options. These capabilities were used to generate the data for '1988' and '1998' shown in Figure 7.

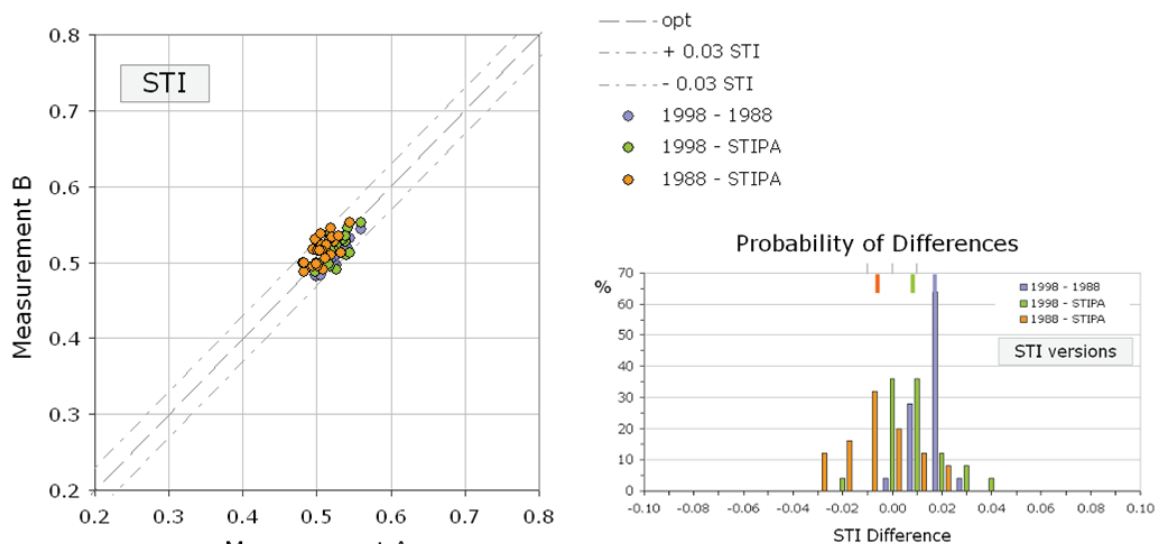


Figure 7: Scatterplot for the various STI measurements as indicated by the legend together with a histogram of the differences. The mean differences, as indicated by the colored bars at the top edge of the graph, are: -0.007 (1988-STIPA), +0.009 (1998-STIPA) and +0.017 (1998-1988).

For each of the four RT values (Omni source, System EDT, System RT-20 and the initial estimation), STI-scatterplots and histograms of the errors between simulation and measurements were calculated (see Figure 8 and Figure 9).

Measurements using the NTI STIPA meters (with these meters, masking effects are always considered and can not be disabled separately) were carefully adjusted in level to make sure that level-dependant masking effects at high SPL did not yet kick in while maintaining a sufficient SNR to the background noise to allow a "noise-free" result to be obtained. Figure 10 shows the mean STIPA measurement level together with the background noise present during the measurement time. A sufficiently high SNR ( $> 15$  dB) is achieved at all speech frequencies and ensures that background noise does not deteriorate the results. The mean STIPA level was 85 dB (unweighted). Figure 11 shows the basic curve for level-dependant masking in the STI-method for both zero and two sec-



onds of exponential reverb together with an indication of the measurement level used here. As can be seen, at the applied measurement level of 85 dB(-), the effect of masking is negligible.

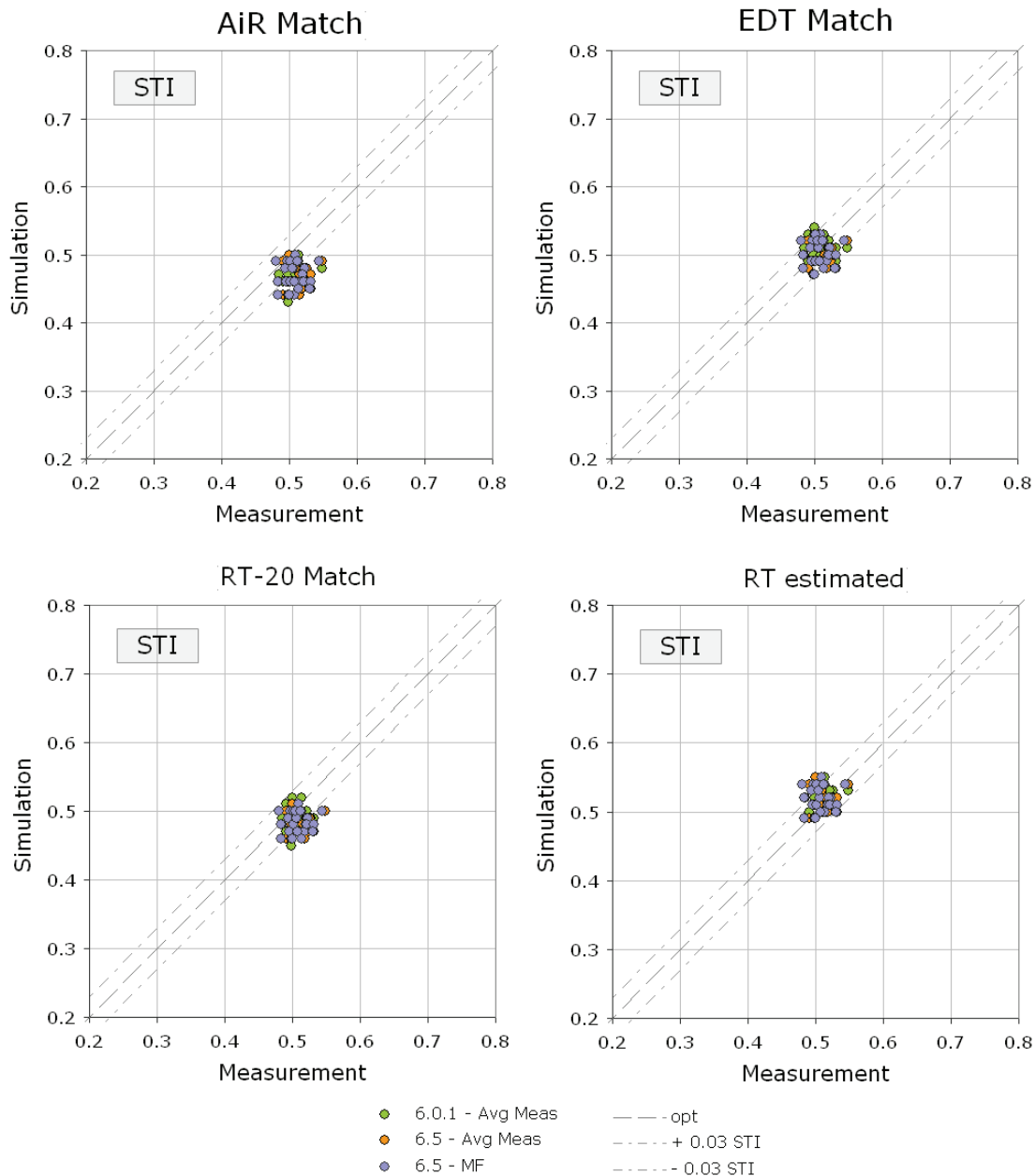


Figure 8: Scatterplot for the four simulation runs with models matched to the method. Compared are simulation results for the standard and development version of Modeler (virtually identical) vs the average measurement result as well as the dev version versus the IR-based method alone. Note: “AiR Match” in these graphs denotes the measurements performed with an “omni” source at various floor locations.

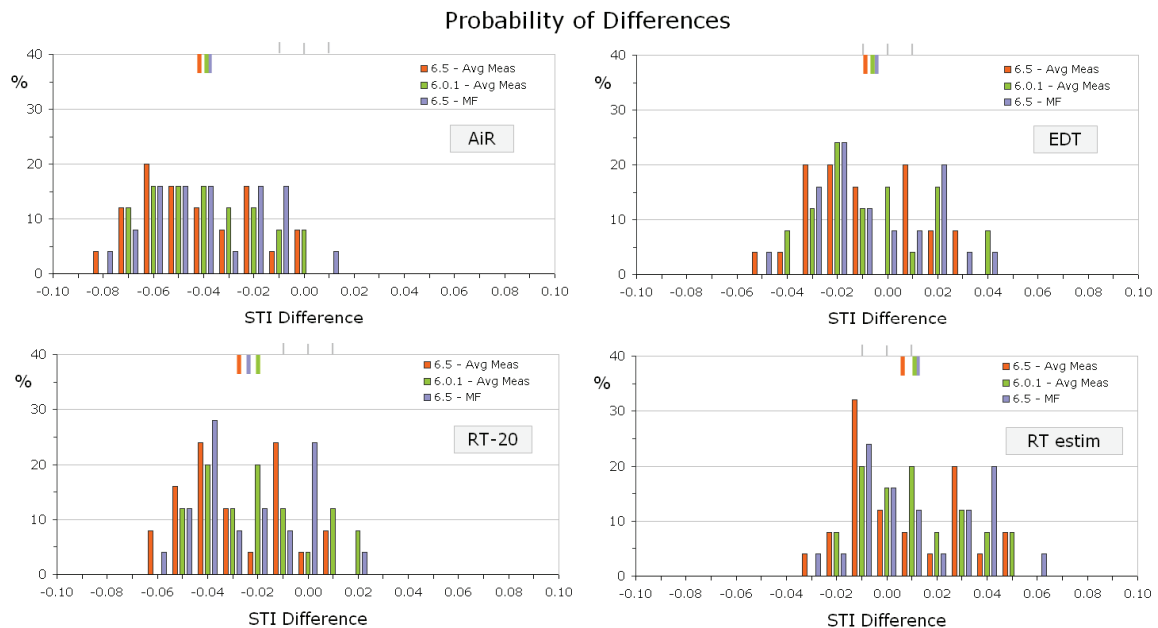


Figure 9: Histograms of the differences for the four simulation runs with the models matched to the reverberation method. The mean differences, as indicated by the colored bars at the top edge of the graphs, for Modeler 6.0.1 minus the average measurement result, are: -0.032 (AiR - Omni), -0.006 (EDT), -0.020 (RT-20) and + 0.011 (initially estimated RT). Note: “AiR Match” in these graphs denotes the measurements performed with an “omni” source at various floor locations.

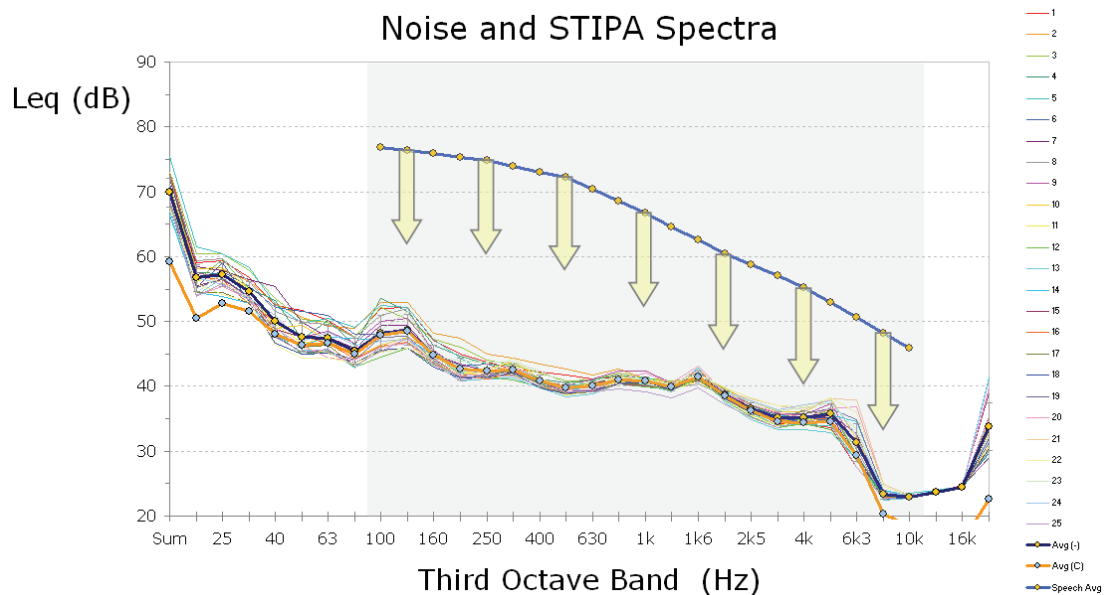


Figure 10: Third-octave band levels for background noise (25 locations and average) and mean STIPA signal level. Arrows indicate 15 dB SNR range at octave band center frequencies.

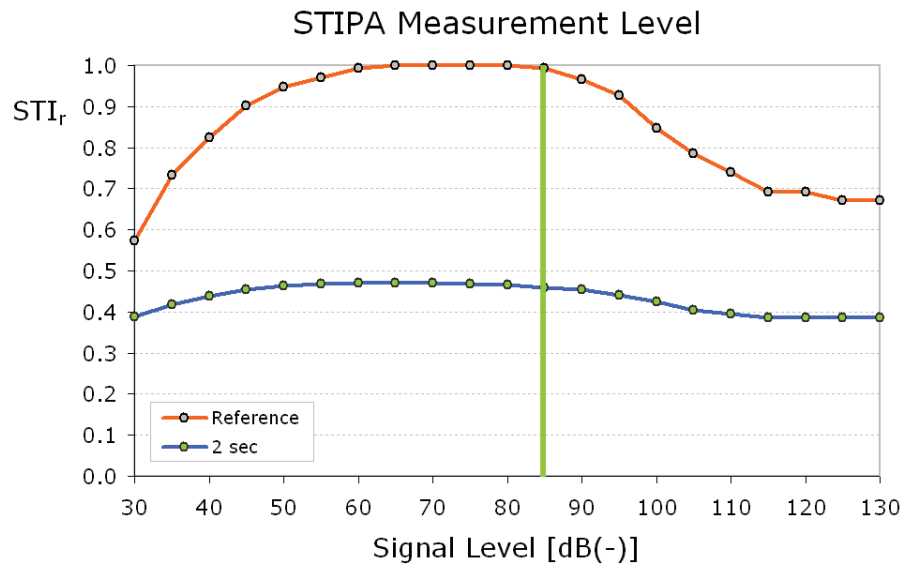


Figure 11: Third-octave band levels for background noise (25 locations and average) and mean STIPA signal level. Arrows indicate 15 dB SNR range at octave band center frequencies.

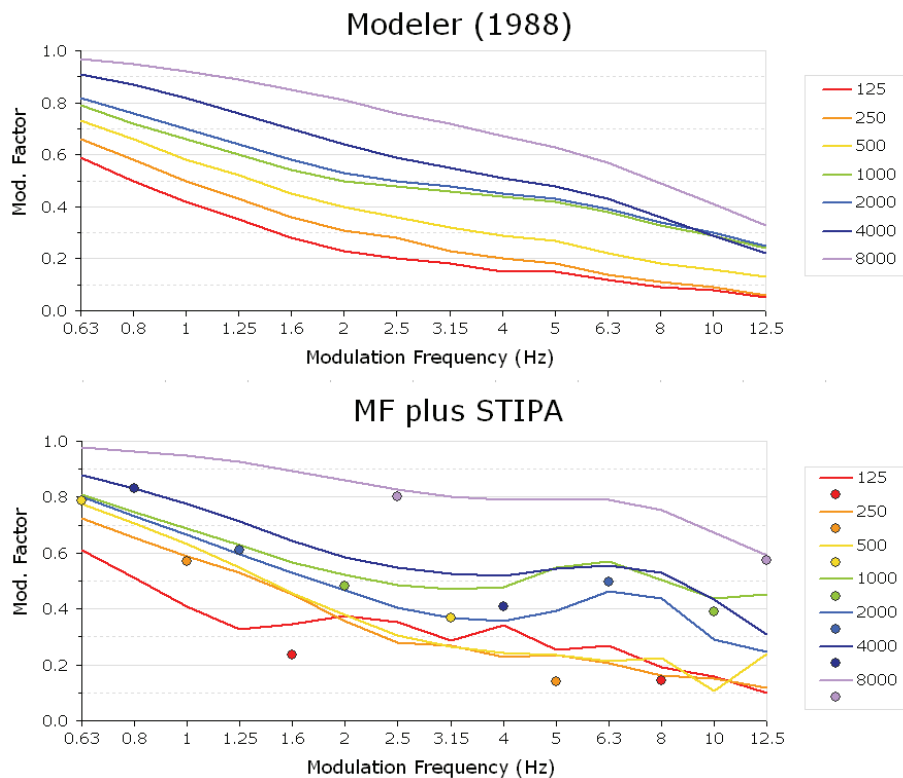


Figure 12: MTF's predicted and measured for the same location. Upper graph: Modeler. Lower graph: MTF from Monkey Forest (no masking reduction) with STIPA (NTI) sampling overlay. Measured MTF shows slight echo effect not picked up as strongly by the simulation.

## 6 CONCLUSIONS

STI simulation data for sound system of a typical trade fair hall was compared to results obtained using both the STIPA method as well as impulse-response based measurements using sweep excitation. The surveyed simulation models were matched with regards to the reverberation times measured in the real room, using various techniques, as well as early estimations. For the single example sound system covered in this report, all conditions showed only small differences in the range of -0.03 to +0.01 on the STI scale. Besides differences caused by the source used for the reverberation times measurements, the mean difference between simulation and measurement is also dependant on the chosen decay range for estimating the decay. The best agreement between simulation and measurements was obtained with a model that was matched using the EDT measured with the installed sound system as the excitation source.

For the limited set of data analyzed in this paper, it was shown that the accuracy of the STI-predictions in the simulation software was dominated by the parameters set for determining the reverberation time of the rooms from the measurements. The mean error between simulation and measurement was -0.01 to -0.02 STI for the test conditions that employed the sound system as the excitation source for the measurements of reverberation times. The largest mean difference of -0.03 STI was found for a model where the reverberation time was matched to a measurement with a source on the floor as opposed to the pendant-mount sound system installed.

Differences between STIPA-measurements and impulse-response based (full) STI were found to be very small and within the typical uncertainty of STIPA (0.01 to 0.02 STI).

It is hoped that more measurement data, also including non-distributed and line array based system designs, becomes available and can be evaluated in the upcoming months and years until all installations are finished and verified. Such an enlarged set of data may result in more general conclusions to be drawn that may be helpful in quantifying differences between simulations and measurements according to various versions of the STI standard.

## 7 REFERENCES

1. H.J.M. Steeneken, Jan Verhave, Stephen McManus and Kenneth D. Jacob, "Development of an Accurate, Handheld, Simple-to-use Meter for the Prediction of Speech Intelligibility", *Proc. IoA*, Vol. **23** Pt. 8 (2001).
2. Thomas Steinbrecher, "Speech Transmission Index: Computer simulation and recent standard developments in Germany", *Proc. IoA*, Vol. **26** Pt. 8 (2006).
3. International Standard EN (IEC) 60268-16 (2003), "Sound System Equipment – Part 16: Objective Rating of Speech Intelligibility by Speech Transmission Index".
4. M.R. Schroeder, "Modulation Transfer Functions: Definition and Measurement", *Acustica*, Vol. **49**, 179-182 (1981).
5. International Standard EN (IEC) 60849 (1999), "Sound Systems for Emergency Purposes".
6. P.W. Barnett, R.D. Knight, "The Common Intelligibility Scale", *Proc. IoA*, Vol. **17** Pt. 7 (1995).
7. Bose Modeler Design Program. <http://www.bose.com/modeler>
8. Kenneth D. Jacob, Thomas K. Birkle and Christopher B. Ickler, "Accurate Prediction of Speech Intelligibility without the Use of In-Room-Measurements". *J. Audio Eng. Soc.*, Vol. **39**, No. 4 (April 1991).
9. H.J.M. Steeneken and T. Houtgast, "A Physical Method for measuring Speech Transmission Quality", *J. Acoust. Soc. Am.*, Vol. **67**, 318-326 (1980).