Modern Measurements in Presence of Audience

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Abstract

To measure impulse responses in rooms and free fields is a daily Job for acousticians but mainly this is done in unoccupied cases. Results for the occupied case are derived by use of simulation software or still by using sophisticated hardware tools. Using a newly developed multithread algorithm speech, music or any other signals from a microphone input and from a mixing console can be utilized to obtain impulse response data for further evaluation.
Transferring measurement results to a handheld device, like the Apple iPhone, allows for walking through a venue and evaluating electro-acoustic and room acoustic quantities easily and at any position.
In a soccer stadium in presence of more than 50.000 visitors the measurements have been done even as a function of the degree of occupancy. The method will be explained in detail and the need conditions are described. All factors of influence are discussed to obtain results to derive impulses responses and in post processing reverberation time STI values or other criteria.

1. Introduction

Measuring acoustic properties in empty spaces is done in concert halls, theatres, sport complexes or other facilities since decades and belongs to the typical jobs to do before a reconstruction of the building starts or before changes of the installed equipment is proposed. For measurement purposes normally special equipment has been used, but nowadays more and more computer with special software including needed AD/DA converter are used. The figure 1 shows a block diagram of such a typical measurement chain:

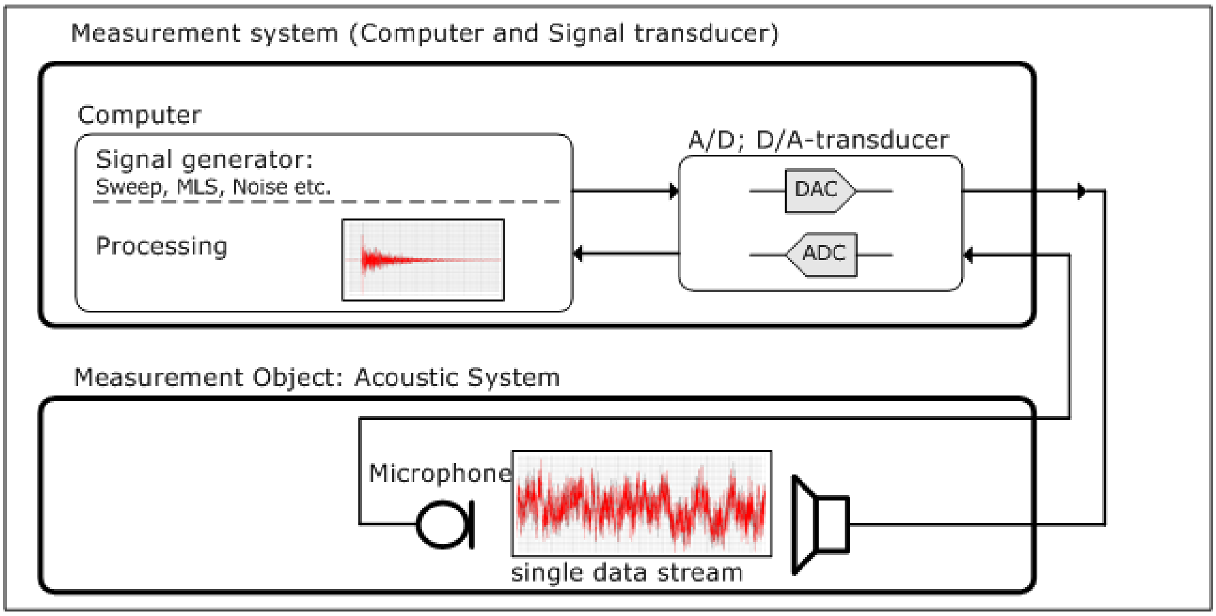


Fig. 1: Typical measurement chain by using a computer

Figure 1 shows, that the acoustic system to measure (room, open air space, even a transducer) is excited with a sweep, MLS or simple noise signal. A measurement microphone will pick up the single data stream and by simple FFT routines and postprocessing an impulse response is derived. But this cannot be done in occupied spaces, because the measurement signal over hours is very strong annoying and people could feel subjectively harmed by the signal.
So a method has been developed to derive impulse responses from signals radiated into the corresponding space in presence of the audience. These are music or speech signals used during or before the performance or the event. This kind of signal are expected and accepted by the audience and are available for measurement purposes too.
The next chapters will describe the way to use such kind of signals for measurements.

2. Real time deconvolution method

By substituting the single data stream by a continuous one and the application of this mentioned real time deconvolution (RTD) algorithm /1/ with a refreshment rate of 10/sec a dynamic impulse response figure can be derived. In figure 2 the excitation happens like in figure 1 with sweeps, MLS or Noise signals and will lead because of the broadband character of such signal to perfect results for the derived impulse response.

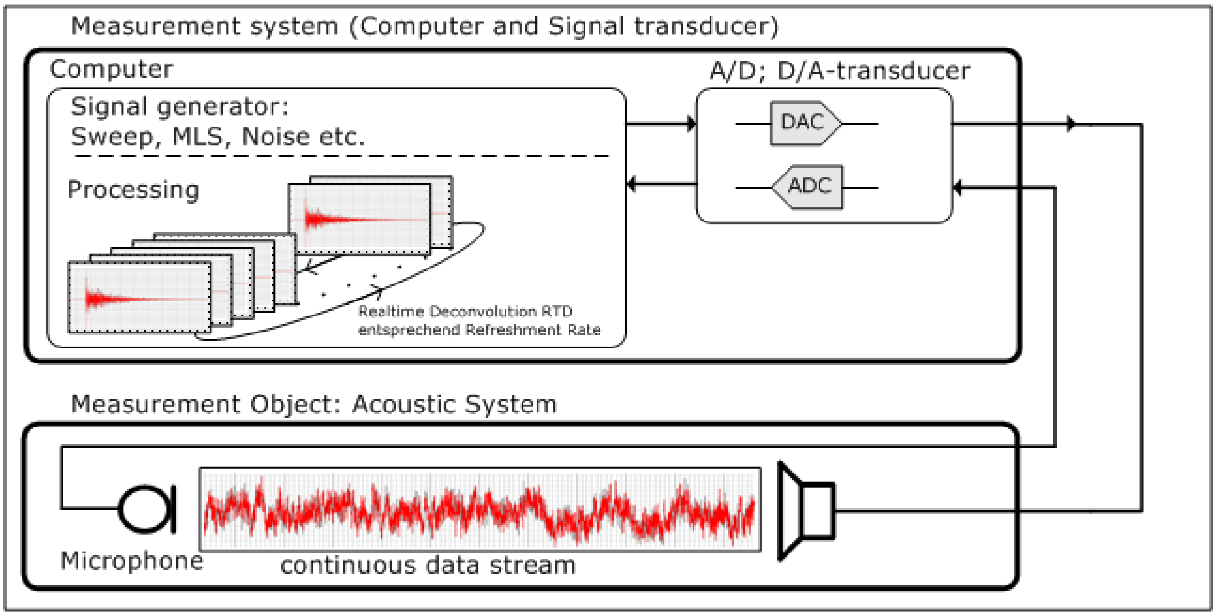


Fig. 2: Application of the real time deconvolution method to standard measurement signals

But what about the use of music or speech signals instead of standard measurement signals? The needed measurement block diagram is shown in figure 3.
The continuous data stream consists of music or speech signals, which don't show in contrast to standard measurement signals some drawbacks:

- No broadband behaviour
- Limited signal to noise ratio
- Signal not continuously, containing pauses and breaks
- Irregular in time and frequency
- Contains level fluctuations

To overcome these drawbacks the following features are used during the RTD procedure:

- Use of band pass filters to suppress unwanted frequency ranges
- Skipping of pause in the reference signals
- Use of SSA filters (Spectrally Selective Accumulation filter /2/)
  This filter extracts valid data and rejects noise, interference and perturbations. The SSA filter realizes three actions:
  - Signal Threshold Filter
    - Data only used when critical S/N reached
    - Excludes unexcited frequencies from subsequent processing
    - Threshold spectrum can be measured or entered
    - For reference and signal spectrum applicable
  - Excursion Filter
    - Compares new transfer function measurement with existing
    - Deviating values outside tolerance are discarded/suppressed
    - Provides high immunity against temporary perturbations
  - Coherence Filter
    - Coherence: Linear relationship between input I and output O

By application of all these routines excellent impulse responses may be derived from music or speech signal recordings, see figure 3.

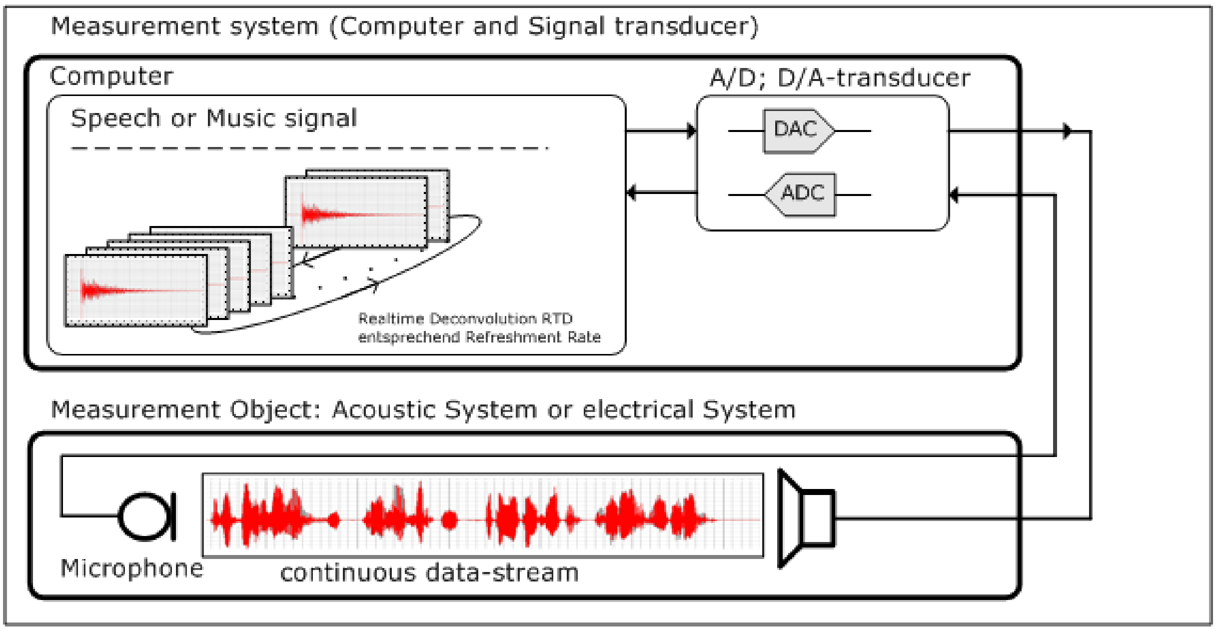


Figure 3: real time deconvolution by using music or speech signals

In the next chapter the application of the method is shown in a soccer stadium in presence of 50.000 visitors.

3. Real time Deconvolution method applied in a stadium

3.1 Earlier measurements

To check the method under real conditions measurements in a soccer stadium have been used. In this stadium the sound system has been installed in 2005 and measurements according figure 1 had been done in the empty stadium. Based on the results of these measurements calculations had been done to extrapolate the results for the occupied case

and for different occupation cases. The results did confirm the partly bad results in the intelligibility numbers with the subjective realized impressions. Some areas in the stadium have been insufficient covered by the sound system and the visitors did claim about bad intelligibility. In discussions with the stadium owner and the constructor company of the stadium additional absorption has been installed to decrease the reverberation time under the roof and that way to increase the speech intelligibility.
New measurements again in the empty stadium did confirm the positive effect of these room acoustic measures.
But anyway the client of the stadium wanted to obtain measured results in the occupied stadium and not extrapolated ones. Therefore the new RTD method explained above was carried out the first time in a full occupied stadium.

3.2 Measurement procedure in the occupied stadium

Because this kind of measurements have been done the first time the day before the game the whole measurement procedure has been done in the empty stadium to compare the RTD results with the normal impulse response measurements done according figure 1 the same day.
First at all 16 so-called representative measurement seats have been selected together with the client to check there the quality of the sound coverage, see figure 4 on next page.
At these 16 places measurement microphones have been installed and normal impulse response measurements in the unoccupied stadium have been done.
The same day the measurements with the RTD method have been done at the same positions. The block diagram of this measurement setup is shown in fig. 5. As shown the sixteen radio microphone signals are recorded via UHF receiver on a 24 track digital HD recorder. Additionally a reference signal is recorded the same time too. This reference signal is a music or speech signal radiated into the stadium before the actual game starts. The content of these signal sequence is more or less unimportant. Important is only the bandwidth of the signal samples. With signals, only containing a limited frequency response, broad band impulse responses cannot be derived.
This first day the noise floor was pretty low and could be neglected. The sound system did operate under the usual setting conditions, so the masking effect occurring at very high SPL values could be neglected too.
All the measured data streams have been recorded on the HD recorder. To make sure that the data streams are usable for the later post processing some checks in the Postprocessing mode have been done. These intermediate results have been compared with the result of the standard measurements (see figure 6) and did confirm the RTD measurement results.

The next day the soccer game took place. The same settings according fig. 5 have been used. The only one difference was that the 16 microphones (at the same positions as the day before) have had to be watched by 16 persons, sitting close to the microphones.
From the point of view of masking effects we could again neglect it, because the sound level of the system was not higher as 95dB(A) in average. But the influence of noise has had to consider. Therefore during the one hour recording time before the game started the occupancy rate has been estimated by making photos of the stands and estimating the arrived visitors. Fig. 7 shows such a photo of the EAST stands 30min before the game did start.

Parallel to these recordings the noise floor has been measured continuously. Additionally the 16 microphones had been calibrated, so in the breaks of the signal stream of the sound system the noise floor has been verified too.

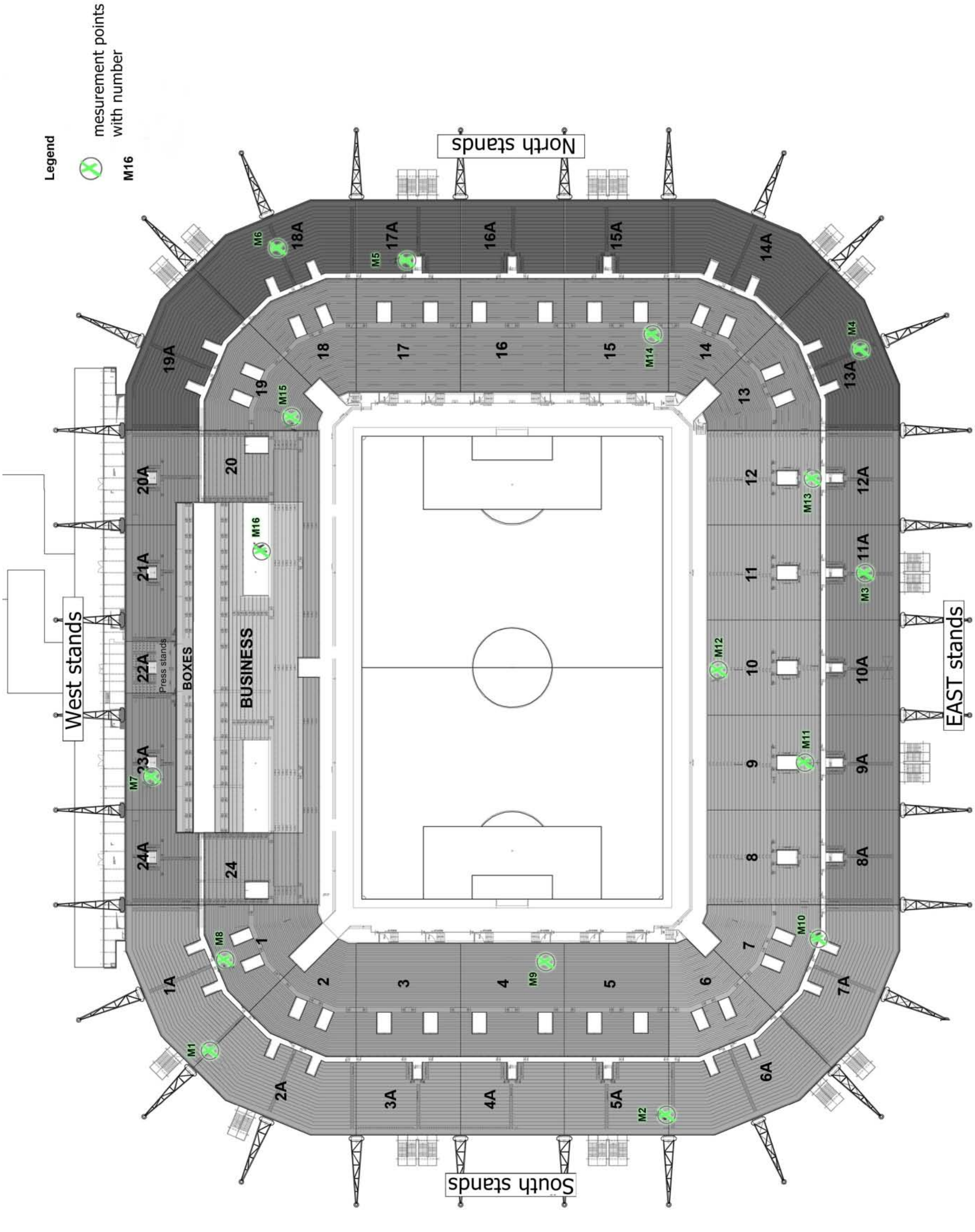


Fig. 4 Measurement positions in the stadium

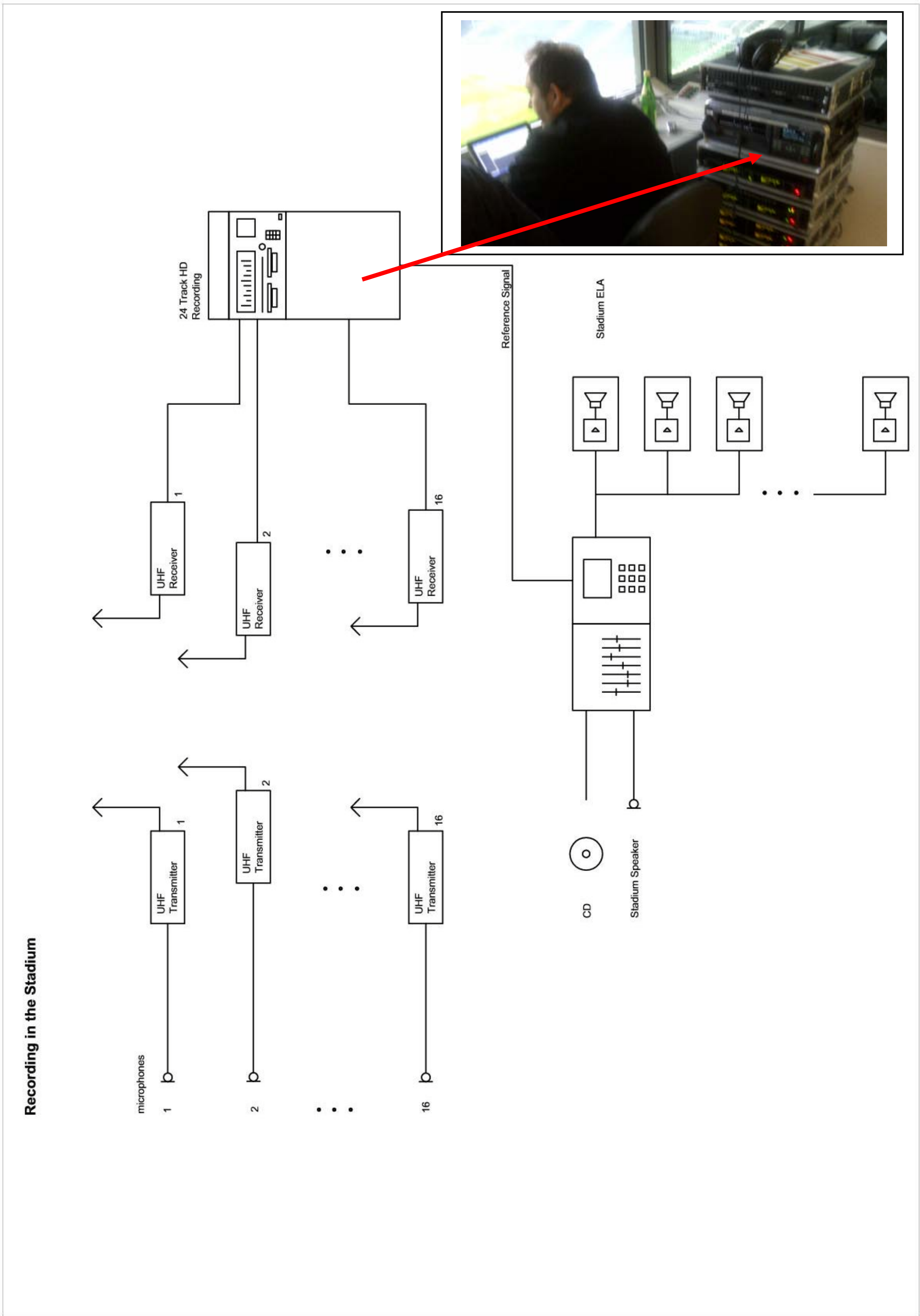
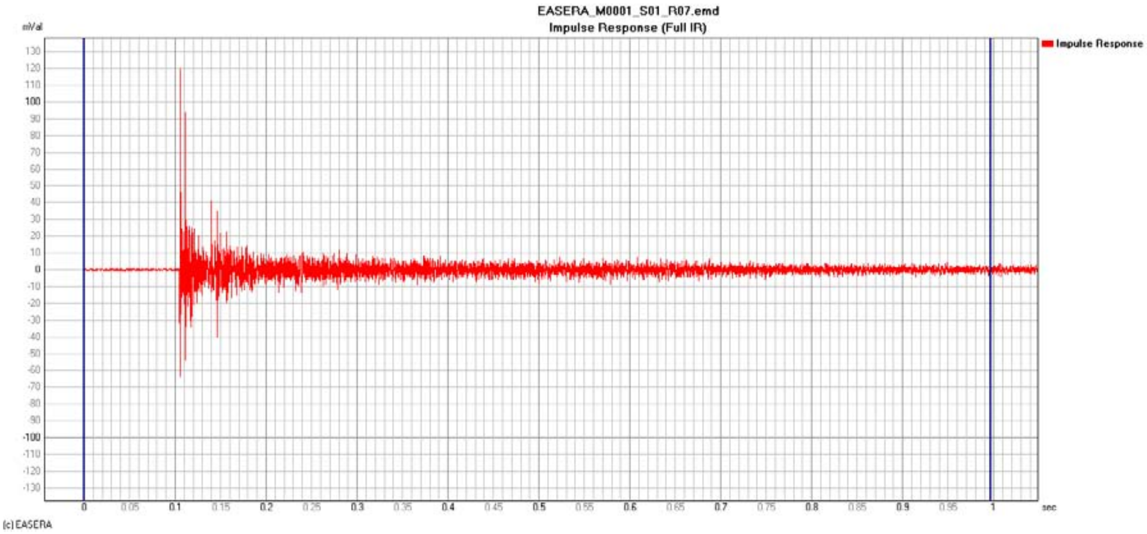
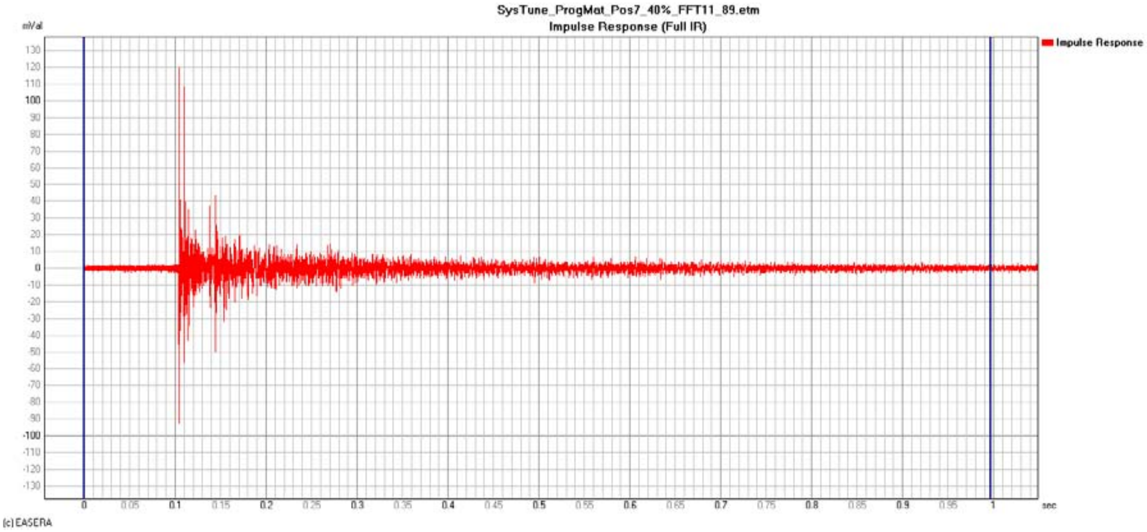


Fig. 5 Measurement setup for the RTD measurements in the stadium



a) Standard impulse response measurement with EASERA



b) Measurement results of RTD Postprocessing with SysTune

Fig. 6 Comparison from impulse responses

Based on the evaluation procedure acc. Fig. 7 the following table 1 has been created:

Time	South stands	West stands	North stands
14:25	20%	8%	15%
14:30	22%	15%	19%
14:35	25%	17%	21%
14:40	33%	19%	24%
14:45	45%	27%	28%
14:50	55%	39%	33%
14:55	64%	46%	48%
15:00	72%	54%	55%
15:05	85%	62%	60%
15:10	90%	75%	70%
15:15	94%	84%	82%
15:20	98%	96%	96%
15:25	100%	100%	98%
15:30	100%	100%	100%

Table 1: Occupation level before start of the game (3:30pm was start of the game)

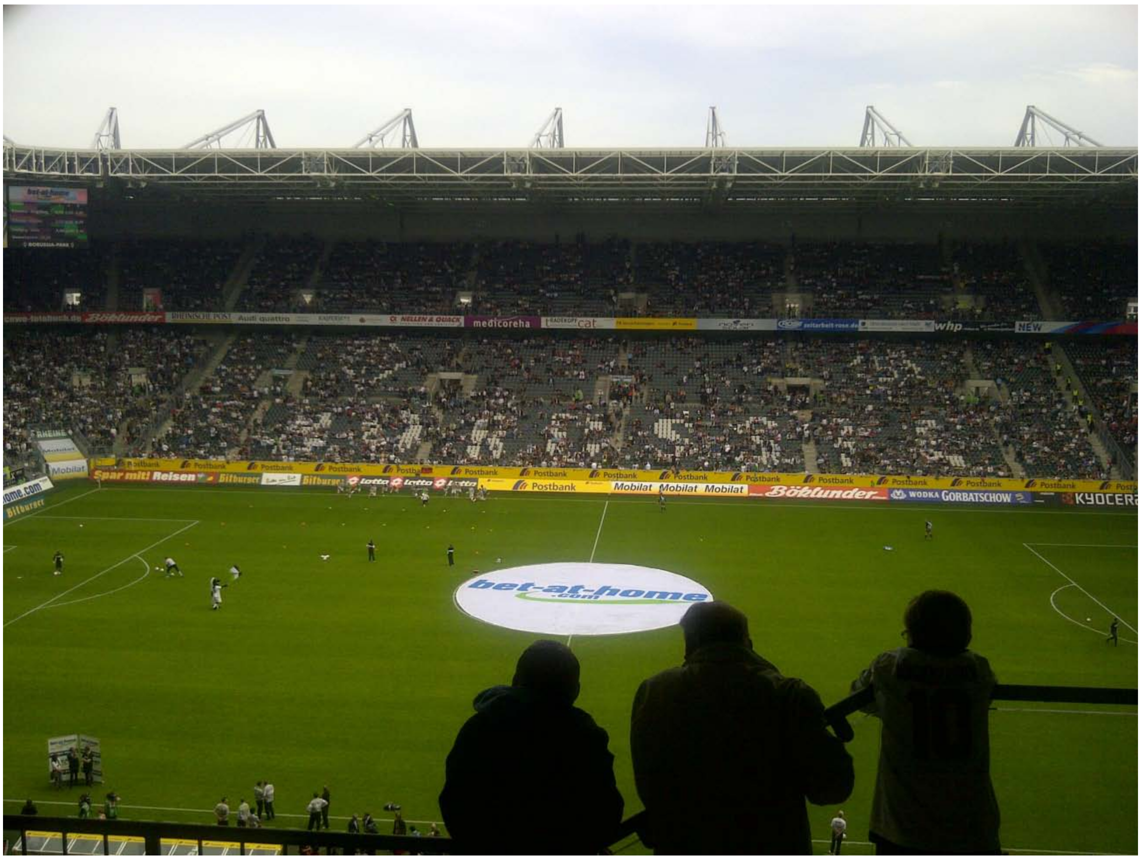


Fig. 7: View to half occupied EAST stands

According to figure 5 all 16 + 1 (reference) channels have been recorded. Afterwards the measurement had been finished.

3.3 Postprocessing in the laboratory

The Postprocessing in the laboratory has been done according figure 8.

Each stream of the 16 tracks of the hard disc recorder are send one by one always together with the parallel recorded reference signal to the Real time deconvolver in the Systune software. As a result an impulse response could be derived from each data stream. By knowing the recording time these impulse responses could be shown as a function of the degree of occupancy. By further Postprocessing the Intelligibility values STI could be derived and the noise floor influence could be considered.
The results are shown in the next chapter.

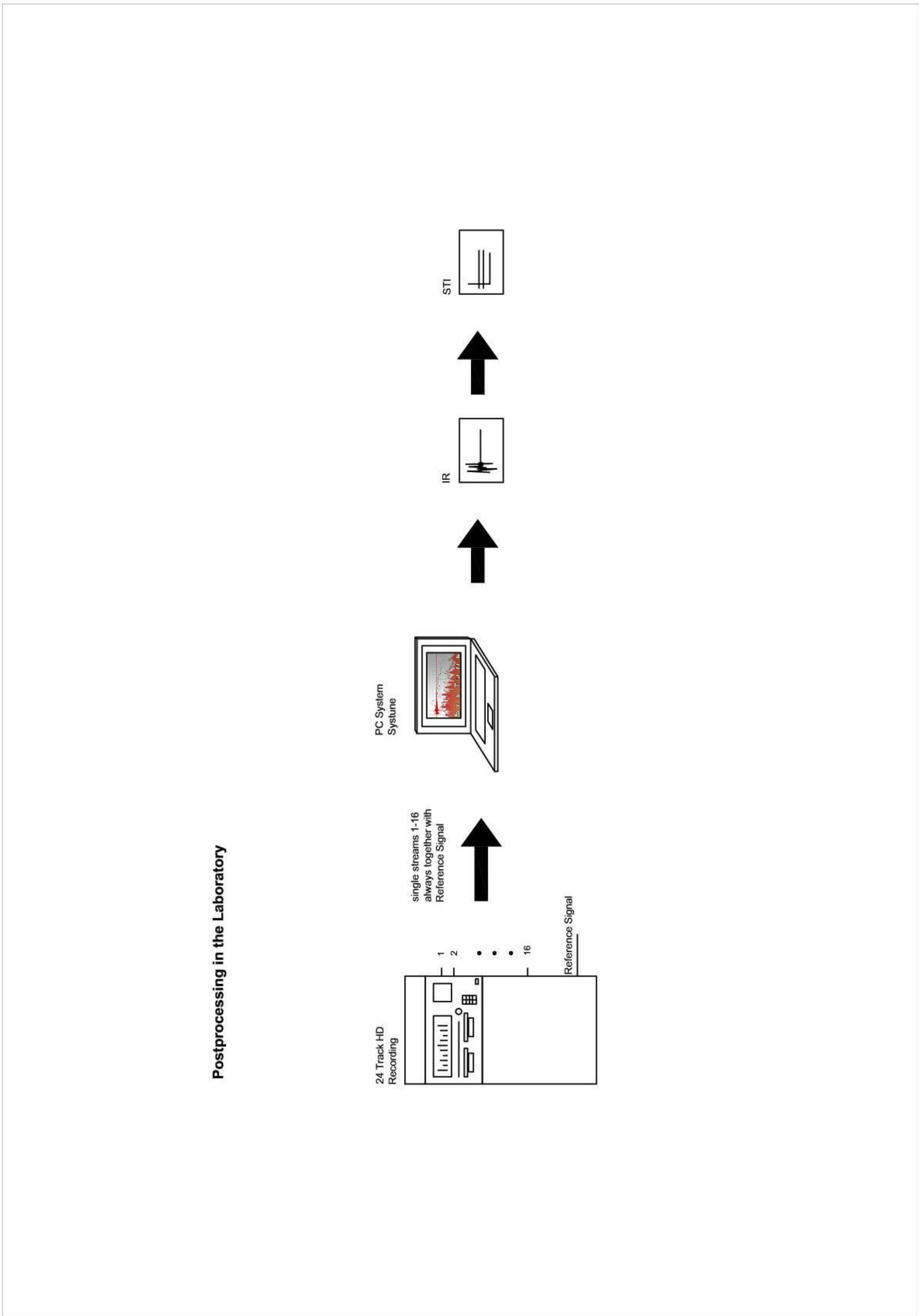


Fig. 8: Postprocessing in the laboratory

4. Results of the measurements

4.1. Reverberation time

By consideration of table 1 the reverberation time as a function of occupancy has been calculated. The results are shown in Fig. 9.

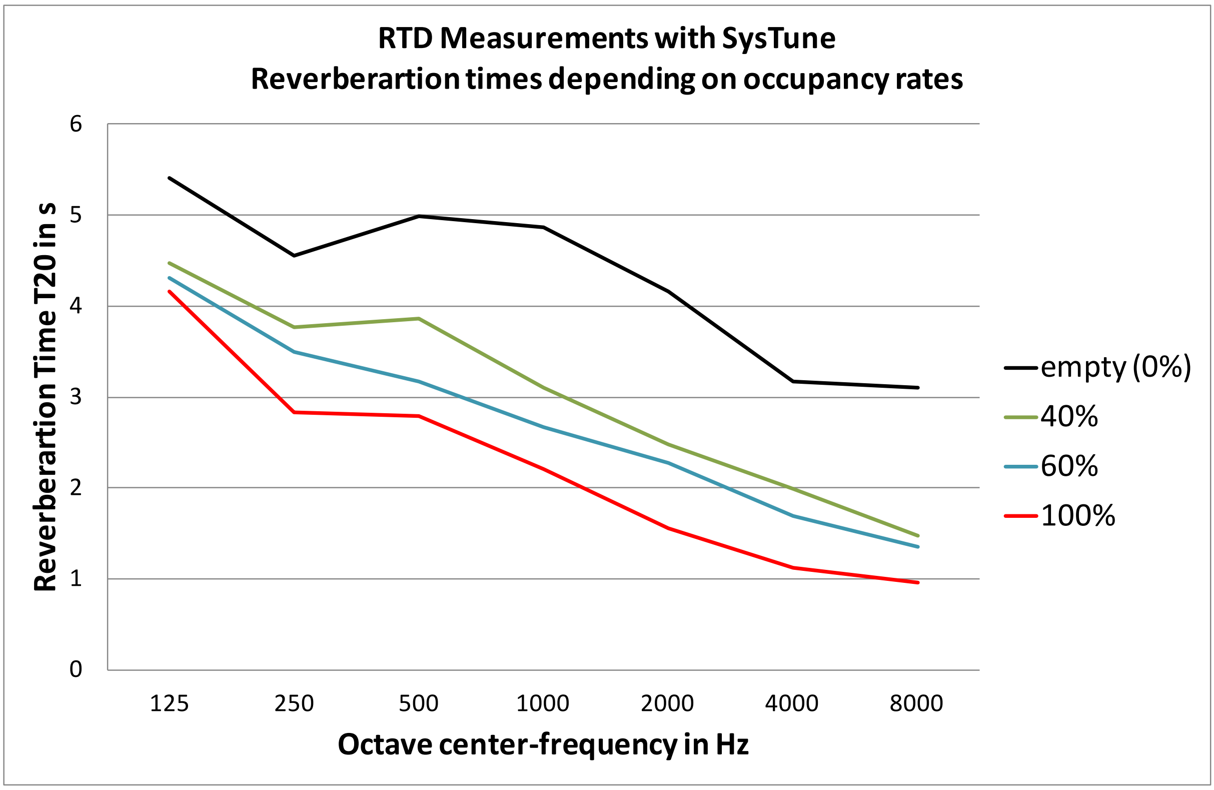


Fig. 9: Reverberation time vs. Frequency, occupancy rate as parameter

We recognize very high values in the empty stadium and lower one with increasing occupancy. It should be mentioned again that all these values are measured and not predicted as usually for the occupied cases of a stadium.

4.2 Intelligibility

The results of the Measurements of the first day in the empty stadium are shown in Fig. 10. Here the results are compared between measurements with the standard method by using EASERA and with the RTD method with SysTune. No value exceeds STI = 0.5.The deviations between the results at the 16 measurement positions are within the tolerance range of ± 0.02 STI.
In fig. 11 the measurement results are shown derived from RTD measurements in the occupied stadium. The higher the occupancy the better are the STI numbers. In the full occupied stadium only at the positions 7 and 16 the STI value of 0,5 is not exceeded.
It could be shown, that with increasing numbers of visitors in the stadium the intelligibility vales are also improved. In the case of 60% occupancy the STI values are in some positions worse as for 40%. Here the higher noise floor has a higher influence as the higher absorption values with 60% occupancy (see for instance position 9 and 12).

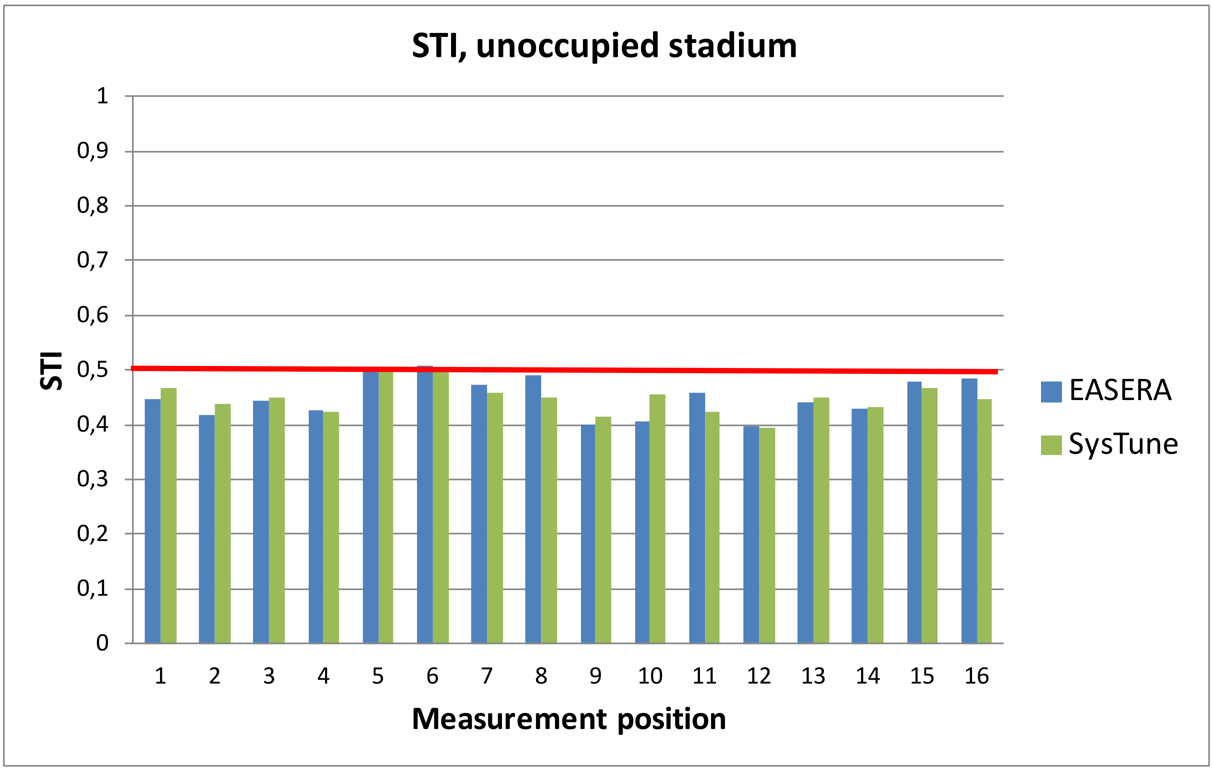


Fig. 10: Comparison of the STI Measurements in the empty stadium

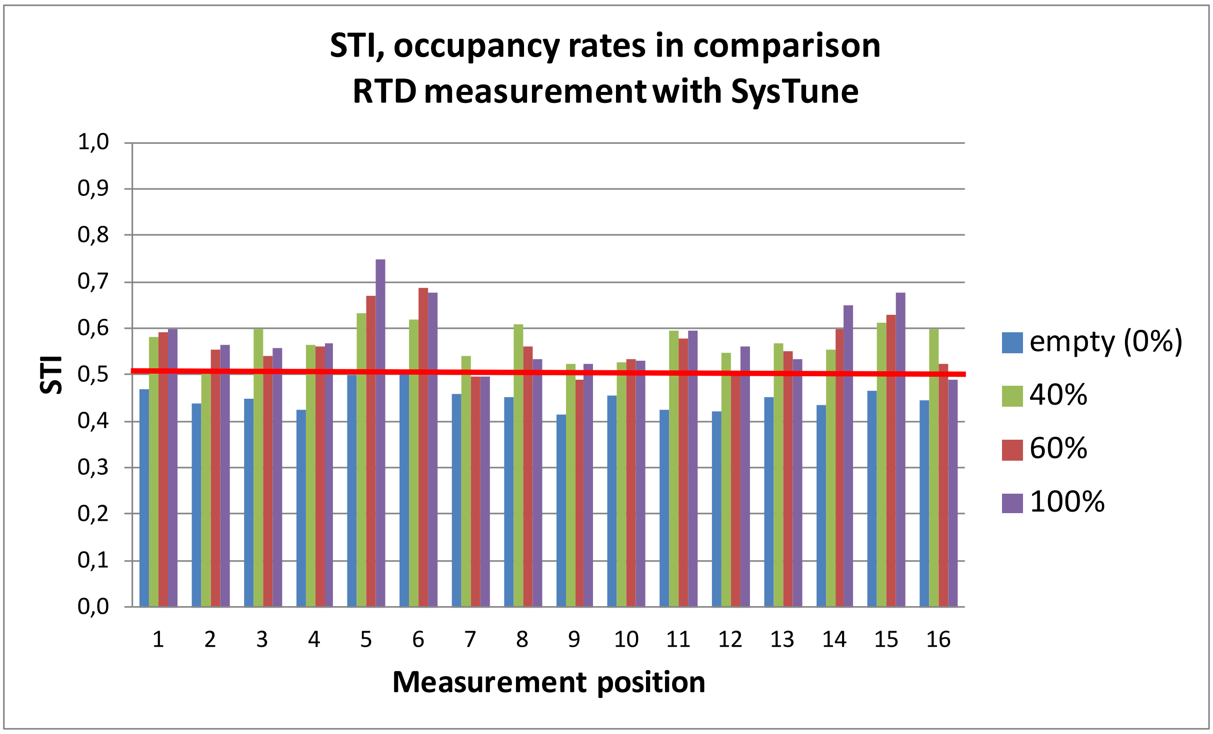


Fig. 11: STI Values vs. Degree of Occupancy

5. Summary

The new RTD method allows to measure reverberation time, Intelligibility numbers of STI and all other important measure to derive in occupied spaces. Any prediction for occupied situations by using computer simulation based on measurements in the empty case becomes obsolete. Next measurements are prepared to investigate the speech intelligibility in a dramatic theatre. Here the actor will carry a wireless microphone only to supply us the needed reference signal. His voice will not be amplified.

6. Acknowledgments

We are grateful for the supporting work by our teams at ADA and AFMG. We would like to thank Mario Sempf, Waldemar Richert, Enno Finder and Christoph Timm for their help.

7. References

/1/ German Patent: 10 2007 031 677, US Patent: 8,208,647

/2/ SysTune v1.2 Manual, http://systune.afmg.eu