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STANDARDS FOR ACOUSTIC MEASUREMENTS – WHO, WHY AND WHERE NOW?

Amber Naqvi Adrian James Acoustics & IoSR, University of Surrey, UK
Adrian James Adrian James Acoustics, UK

1. INTRODUCTION

Standardisation of Room Acoustics and electroacoustics measurement is considerably less advanced or widely accepted than in other fields of acoustics. Indeed, there are significant disagreements between leading practitioners even as to which parameters to measure. This paper considers the wide range of current measurement techniques in the context of existing standards. As part of a larger study a comprehensive survey of acoustic consultants' approaches to measurements and standardisation – especially to ISO 3382[1] - was carried out, results of which are summarised. Based on the feedback of the survey, areas for action are suggested.

2. CURRENT MEASUREMENT TECHNIQUES

During the past two decades, conventional analogue measuring hardware has been widely replaced with digital computer-based instrumentation. Nevertheless, some of the traditional measuring techniques still keep their place, mainly because acoustic transducers (i.e. loudspeakers and microphones) continue to be analogue. This section presents a brief review n of the various current measurement techniques and instrumentation. It must be noted that the room measurement techniques reviewed in this document are the well-established and broadly-used ones. Over the years many acousticians have developed customised techniques, based on their personal experience and preferences.

The most common measurement of reproduced sound systems is frequency response, typically a plot of sound pressure level against frequency. In room acoustics, however, measurements are normally in the time domain as key acoustic parameters such as reverberation time, early decay time and room reflection patterns are time-based independent variables. The third domain used is the energy domain although this is rarely used in room acoustics.

Steady-state measurements - The Real Time Analyser (RTA) first appeared more than thirty years ago, and based on its use steady state measurements have dominated the audio industry for decades. Steady-state measurements are easy to perform and understand. The frequency spectrum of the system being measured can be acquired by feeding a known test signal (pink or white noise) into the system, and spatial variation can be assessed by walking around the room with a hand-held RTA to see the variation in different frequency bands at different locations. Even this, however, this only describes the system in the steady-state situation. This is helpful in electro-acoustics but for room acoustics most of the signals we are interested in measuring are not steady-state. For example music and speech are essentially transient in character.

Impulse response – The impulse response was developed to measure the response of a room to transient signals. Of particular relevance is the Delta Function, mathematically defined as an infinitely short impulse which contains equal energy at all frequencies and so has a flat frequency spectrum. Approximations to this type of impulse (although obviously not infinitely short) are widely used in large room measurements. A gunshot, starter pistol or balloon burst can generate a peak amplitude of 144 dB at 1 metre, with a duration of the order of 1 msec. The impulse response is recorded via a microphone and played through a set of octave filters to obtain reverberation time decay curves. A common problem associated with this type of measurement is the lack of energy to excite large spaces in the impulse at low frequency bands.

Tone burst - Another type of measurement called the tone burst is well established. Using tone bursts, selective measurements can be made in the time domain by gating techniques. It is also known that microphone calibration and loudspeaker measurements can readily be made in ordinary rooms with this method. A tone burst is produced by rapidly turning a tone on and off with electronic gating circuit. The spectrum of the tone burst depends on the duration of the burst - the shorter the pulse, the wider the spectrum until the infinitely short pulse theoretically would give an infinitely wide, flat spectrum. The one important requirement, when using this method is that the geometrical set up of the microphone and source is such that reflections from room surfaces do not obscure the desired signal.

Time Delay Spectrometry (TDS) - The basic operating principle of TDS is based on a variable frequency sweep excitation signal and a receiver with sweep tracking with that signal. A critical third element is an offset that can introduce a time delay between the swept excitation signal and the receiver. When TDS was first introduced, the advantages of this arrangement over any other technique of the time were manifold. By offsetting the receiver to the source swept sine wave one could, for the first time, look at individual room reflections exclusively without interference or noise from the rest of the spectrum. Also, full signal energy was applied over the test time throughout the swept spectrum. This was in direct contrast to other methods where high amplitude, wide band signals were used which often resulted in driving elements into non-linearity or ultimately in damaging loudspeakers.

Fourier Transform – The introduction of microprocessors in the measurement chain allowed digital conversion of data between time and frequency domains through Fourier transforms. The Fourier series is a useful tool for determining the frequency content of a time-varying signal. However, Fourier series always require a periodic time function. To overcome this shortcoming, Fourier evaluated a series for a waveform period approaching infinity. The function that resulted from this approximation is known as the Fourier Transform. This was effective but calculation-intensive, and measurements were seriously limited by the computing power available.

The ***Fast Fourier Transform (FFT)*** is an iterative computational procedure that reduces the number of multiplications required because of certain symmetries which exist in the algorithm. By its use, the computation time is radically reduced and computer capacity is used more efficiently. Over the past two decades several systems using FFT as their operating principles having digital filtering have been introduced. These include the commercially produced TEF and MLSSA analysers.

Maximum Length Sequence (MLS) – Perhaps still the most widely used commercially available room measurement analyser, MLSSA is based on a type of test signal called a Maximum Length Sequence (MLS). MLSSA measures a linear system's impulse response using a pseudo-random MLS stimulus. MLS has both theoretical and practical advantages over other test signals. Unlike white noise, MLS is non-random and exactly repeatable. Therefore, the need to measure the stimulus input simultaneously with the system output is no longer required. Also, due to the low crest factor, MLS measurements provide very high signal-to-noise ratios. MLS signals are well suited for efficient computation of very long impulse response, as sometimes required in large rooms. When a large FFT is applied to this extended wideband impulse response the result is a wideband transfer function with fine frequency resolution.

MLSSA also offers a unique function called the Adaptive Window™ which is used primarily for performing in-room frequency response measurements that reflect the ear's subjective perception of spectral balance. Another useful function of this windowing technique is that "anechoic" loudspeaker frequency response measurements can be performed in ordinary rooms. This system also offers four different types of FFT rectangular windows to optimise frequency domain resolution depending on the measurement type.

The disadvantage of MLS is that it is only accurate for time-invariant systems. Therefore, this method cannot be used to measure rooms while the acoustics are changing. For example the performance of sound enhancement systems such as SIAP, LARES and ACS (which are normally time variant systems) cannot normally be measured by this method. It is apparent from the above review that measurement techniques differ significantly. Each has its merits and problems, and no technique is ideal for every situation. This complicates the standardisation of room measurement techniques.

3. MEASUREMENT ERRORS AND UNCERTAINTIES

The various measurement techniques described in the previous section are riddled with systematic errors and the resultant measurements acquired from these methods have a certain element of uncertainty attached to them. In this section, different processes used to minimise these uncertainties are discussed. These are primarily associated with impulse response measurements.

3.1 Impulse response measurements and windowing

Theoretically, an delta function can be approximated by a rectangular impulse, the duration of which is short compared with the period of the highest spectral component. However, in practice, this is not possible as most loudspeakers are unable to reproduce impulsive signals correctly. Also, to obtain a sufficiently high signal-to-noise ratio, the energy of the excitation signal must not fall below a certain limit. This is the main reason for applying FFT windows to impulse response data.
There are two basic types of windows, rectangular and non-rectangular. The most common rectangular types are cosine windows, also known (rather confusingly) as Hann or Hanning windows and full- or half- Hamming windows. Other modern optical windows such as Blackman-Harris and Kaiser-Bessel are now employed in most modern measurement equipment. These offer a better trade-off between spectral limits and frequency resolution.

3.2 Reverberation time measurement errors

The issue of uncertainty in reverberation time measurements is far greater than any other type of acoustic measurement. For example, regardless of the type of instrument used, the decay slope is generally determined in the range –5 to –35dB relative to the level of the exciting noise (whether impulsive, such as a gunshot, or steady state, such as pink noise through a loudspeaker). Many different approaches have been taken to the evaluation of an average slope from curves which are far from straight, which they normally are in real rooms. In particular, the evaluation of the initial decay slope is subject to considerable errors due to irregular level fluctuations, which are superimposed on the general fall in level and which can be considered to be complicated beats.

The integrated impulse response, used in many instruments, was first proposed and applied by Schroeder and is the method preferred in ISO 3382. The impulse response is integrated between zero and infinity, which by mathematical derivation means that a single impulse measurement represents an infinitely averaged result. The only drawback with this type of impulse is the problems associated with the interpretation of the infinite upper limit of integration, as the original formula does not account for any acoustical or electronic background noise. For example, if the finite integration time is chosen to be too long, the recorded decay curve will have a tail which limits the useful dynamic range of the instrument and if chosen too short it will cause a downward bend of the curve, which will produce different results.

3.3 Recent research

Relatively little work has been carried out on the assessment of errors and uncertainties in room acoustic measurements. This may be because if the difficulty in assembling the personnel and equipment to compare several different measurement techniques in a given venue. Another factor may be that error assessment is not seen as pure research, yet few consultants are likely to have the time, resources or incentive to carry out such work.

John Bradley at the National Research Council in Canada carried out an ingenious comparison of results obtained using different signal processing techniques[2]. This comprised a round-robin exercise in which three different room acoustic conditions were synthesised by a digital reverberator. This was circulated to 15 participants in the USA, Canada, Japan and Europe who measured acoustic parameters using 23 measurement systems. One benefit of this approach was that it isolated differences in the signal-processing techniques without introducing errors from different source or microphone types or locations.

While in general reproducibility was quite good, for some of the parameters there were wide discrepancies in the results gained and the report concluded that some of the systems tested would provide very misleading assessments of room acoustics, and that room acoustic measurement systems should not be used without some validation of their accuracy. This is a matter which clearly must be addressed by standardisation, yet such standardisation is very difficult to achieve or impose because of the wide range of techniques used, so that it is not easily possible to define one system as "right" and another as "wrong". An exchange of correspondence with Bradley has revealed that further work on comparisons in real rooms has not advanced since the publication of the report in 1996, largely due to lack of funding.

Most recent technological developments might be expected to be a function of developments in computing, but in fact the amounts of data handled by most acoustic measurement equipment are relatively small and computing power has not been an issue since the availability of 20386 processors with maths co-processors. The most significant development in recent years is probably in the development of binaural measurement techniques, and the research relating these to subjective response.

4. ROOM ACOUSTICS - EXISTING STANDARDS

4.1 The need for standardisation

There is no very clear divide between consultancy and research in room acoustics. In addition, much of room acoustics revolves around design and, like architectural design process, is therefore affected by the individual tastes and opinions of the designers as much as by the science of the subject. In spite of a wealth of publications on the subject there is still disagreement even between leading acousticians as to which acoustic parameters are relevant in different types of room and as to how those parameters should be defined and measured. A good example of this is the discussion of the IACC parameter in Annex B of ISO 3382, whereas all other parameters were included in Annex A, apparently because of a disagreement on the standards committee as to whether IACC should be included.

None the less there is a broad consensus of opinion on most of the parameters of importance in many circumstances, particularly in small-room acoustics, and these parameters are often used in specifications and commercial applications. Examples of such cases would be :

- Where one consultant is employed to develop a set of required criteria or performance specification for a room, to be designed by others – for example, in a design competition or in a "Design and Construct" tender process

- Where a sound system is to be installed in a room, the system designer requires certain acoustic information about the room.
- Where the suppliers of specific sound reproduction systems will only allow these system to be used in rooms which meet strict acoustic standards (e.g. there are very stringent requirements for the use of Lucas THX systems in cinemas and studios)

In all of the above cases it is important to know that the data supplied is, as far as possible, independent of the equipment, methodology and staff used to acquire the data. To achieve this, some degree of standardisation is necessary. The following standards are relevant :

- ISO 3382 :1997 (=BSEN ISO 3382:2000) "Measurement of reverberation time of rooms with reference to other acoustical parameters"
- ITU-R BS 1116. 1999: 'Method for objective measurements of perceived audio quality', International Telecommunications Union.
- IEC 60268/16 : 1998 (replaces IEC 268) "Objective rating of speech intelligibility by speech transmission index"

For reasons of space only ISO 3382 is considered here.

4.2 ISO 3382

ISO 3382 :1997 (=BSEN ISO 3382:2000) "Measurement of reverberation time of rooms with reference to other acoustical parameters" is a very wide-ranging standard, intended to cover measurements in all types of room. Many aspects of the standard, however, are clearly written with auditoria and large rooms in mind. It is important to note that the standard only standardises reverberation time measurements – all references to other room acoustics parameters are in the annexes, which are for information only.

Because of the very large range of rooms, equipment types and contexts within which reverberation time may be measured the standard it is, in many cases, unable to be proscriptive or precise. Many recommendations are simple common sense, such as the need to make a note of the occupancy and conditions in the room when measurements are taken. Others are, however, extremely proscriptive, e.g. the specification for graphical presentation of results, (e.g. a requirement for the abscissa to show frequency at a scale of 1.5 cm per octave). It is unsurprising therefore that so many responses to the questionnaire stated that they measured "generally in accordance with the principles of ISO 3382", rather than following it to the letter. Our experience is that if ISO 3382 is interpreted literally, few if any organisations actually comply with the standard. On that basis it would seem more logical for such a document to be a guidance document or code of practice.

One aspect of ISO 3382 attracting comment is the requirement to use only omni-directional sound sources for all types of measurements is convenient for standardisation, but not necessarily realistic. Few, if any, of the real sound sources for which rooms are designed are omni-directional. All of the acoustic parameters measured in a room will depend, to some extent, on the directivity and "aim" of the source although the magnitude of the variation has not been investigated in depth. Computer modelling of room acoustics generally uses virtual sources which closely model the directivity of the source that the room is designed for, e.g. speech, loudspeakers or musical instruments. Invalidating measurements with such sources would make it impossible to compare predicted and measured results for realistic sources.

Similarly, the requirement to use only omni-directional microphones for all types of measurements is convenient for standardisation, but not necessarily realistic and may be over-proscriptive. The human ear is not omni-directional and, especially if other room parameters are also being measured, measurements may be made with a head-and-torso simulator. In most rooms the effect of microphone directionality on measured reverberation time is probably very small.

5. ROOM ACOUSTICS - CONSULTATION AND SURVEY

A simple questionnaire was devised and sent by email to 42 leading acousticians active in the field of room acoustics measurements. The recipients included consultants and researchers worldwide as follows :

Category	Number issued	Number returned	Percentage of returns / recipients
Consultants, UK	12	5	42%
Consultants overseas	7	4	57%
Researchers, UK	3	3	100%
Researchers overseas	10	4	40%

For reasons of space the text of the questionnaire is not reproduced here, but some of the results are summarised below. This following does not therefore claim to be a statistically significant analysis, nor was the exercise intended for such analysis, but to raise and discuss relevant issues.

Approximately 25% of measurements were taken for research purposes, 75% for commercial or consultancy purposes. 38% of measurements related to the performance of electroacoustics systems, 62% to the acoustics of the rooms themselves.

Equipment used – signal sources
Some respondents used several types of sources so the results are shown in terms of absolute numbers rather than percentages.

Omnidirectional / dodecahedron loudspeakers	10
Other loudspeakers	7
Live orchestra	2
Gunshots / balloon bursts	3

Three respondents commented that they often used a sub-woofer loudspeaker in conjunction with a dodecahedron, to extend the low-frequency response.

Equipment used – microphones
Some respondents used several types of microphone so the results are shown in terms of absolute numbers rather than percentages.

Omnidirectional	12
Figure-of-eight	2
Head-Torso simulator	5
Binaural microphones	2
Variable directivity microphone	1

Measurement techniques
Some respondents used several techniques so the results are shown in terms of absolute numbers rather than percentages.

MLSSA	7
Other MLS	2
SMAART	2
TEF	1
FFT analyser	1
Custom-built Chirp system	1
Custom-built gated sine impulse	1
Custom, unspecified	2
B&K 2260	1

Parameters measured

Listing numbers would be misleading as a number of respondents merely stated "all available parameters" or "all listed in ISO 3382". The following trends were noted however

All respondents measured reverberation time

Most measured early decay time

Approximately 70% measured one or more of C80, D50, Ts, and G

Three measured LF

Six measured IACC or one of its derivatives

Five measured background or ambient noise

Three measured other parameters than those listed in the questionnaire or in ISO 3382, primarily for research purposes. These included "running reverberation", spatial variation of loudness, C40, C50, EDT-160, EDT–320, and "frequency response".

Averaging and statistical analysis of results

No respondents carried out spatial averaging as discussed in Section 7 of ISO 3382, and several pointed out that spatial averaging was not helpful when trying to characterise the behaviour of sound in a room as often they were seeking to determine the variation of parameters with source and microphone types and positions.

Verification and calibration

In general there is no consensus on the type and degree of calibration or system verification to be carried out. Few respondents did more than periodically calibrate the microphone system at a single frequency.

Compliance with standards

ISO 3382 - Five respondents stated that they always measure in accordance with ISO 3382, three "approximately in accordance" with it, one "when possible but often not" and three stated that they definitely did not measure in accordance with ISO 3382 and that they fundamentally disagreed with aspects of this standard. Six respondents either took issue with aspects of ISO 3382 or suggested additional areas which should be covered in the standard.

Conclusions from survey

The results showed that even in a relatively small sample of acousticians, a wide range of techniques and instrumentation is used to measure room acoustics. There is some consensus on parameters to be measured but little consistency in terms of compliance with standards. Calibration and verification of instrumentation is clearly neglected, with few respondents apparently giving much thought to verifications of the signal processing system itself.

6. CONCLUSIONS

ISO 3382 becomes due for review in 2002 and the study suggests that significant review is required. A thorough assessment of the differences in results gained using different measurement methods, and of the reproducibility of results with any one method, is a fundamental requirement if a standard such as ISO 3382 is to be of any practical value. Areas to be considered include: sound source type (e.g. loudspeaker directivity) and locations; microphone types and locations; and signal processing methodology (e.g. MLS, TDS etc)

A useful exercise would be to take measurements in real rooms under controlled conditions, using different types of instrumentation and different set-ups with each item of instrumentation, analysing the results and investigating the reasons for differences in these.

Good Practice Guide

The above work may reveal that a proscriptive standard is simply not appropriate or practicable, and that a set of guidelines or code or practice for different types of acoustic measurement in different types of room is required.

REFERENCES

1. ISO 3382 :1997 (=BSEN ISO 3382:2000) "Measurement of reverberation time of rooms with reference to other acoustical parameters"
2. Bradley, J.S. 1996 "An international comparison of room acoustics measurement systems", National Research Council Canada Internal report IRC-IR-714.
3. ITU BS. 1116, Methods for the subjective assessment of small impairments in audio systems, including multi-channel sound systems. International Telecommunication Union, Geneva, 1998.
4. ITU-R BS 1387. 1999: 'Method for objective measurements of perceived audio quality',International Telecommunications Union, Recommendations ITU-R BS 1387.

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