Reverberation Time?

M. Barman, A. Gambino, R. Ramakrishnan and J.C. Swallow
Barman Swallow Associates
Suite 301, 1 Greensboro Drive
Rexdale, Ontario

1.0 Introduction

Reverberation Time (RT_{60}) defines the rate of decay of sound energy in a room which in turn is directly related to the overall sound absorption in the room. RT_{60} is the transient response (the statistical time domain analysis) of the room which is assumed to be convertible to the steady state decay (the statistical frequency response) of sound in the room with distance. The concept is simple and suitable as a descriptor for room acoustics. The detailed evaluation and measurement of RT_{60} however is full of tricks and traps. The problems associated with the evaluation of RT_{60} are described first. The difficulties associated with the field measurement of RT_{60} are highlighted and the methods usually applied to overcome these are also discussed. Several methods and instrumentation systems for reverberation time measurements are compared and a cost effective procedure is presented.

2.0 Theoretical Evaluation

Attempts have been made in the recent past, with limited success, to calculate RT_{60} by detailed evaluation of the sound decay from a specific source location using methods such as ray acoustics, finite element schemes etc. However, the concept of RT_{60} is more commonly derived from the theoretical model of a room with statistically uniform sound energy density. The room is assumed to be large enough, box like in shape and the surfaces treated relatively uniformly. The sound field is then diffuse when a sound source is turned on and decays uniformly when the source is turned off. Sabine [1] derived a simple formula to calculate the reverberation time which is:

$$RT_{60} = 0.161 \cdot \frac{V}{\alpha S} \tag{1}$$

where V is the volume of the room in cu.m., S is the total room surface area in sq.m. and α is the average absorption coefficient. Norris-Eyring [1] modified Sabine's formula to account for extreme cases of absorption:

$$RT_{60} = 0.161 \frac{V}{-S.\ln(1-\alpha)} \tag{2}$$

Real life situations of course are never that simple. Two problems are immediately obvious in the above formulations: the proper absorption coefficients of material used in the space [2] and the actual distribution of the absorptive material in the room. Even if one assumes that the correct values of absorption coefficients are known, the actual distribution of the material in the room can make a lie of the RT_{60} evaluations. Some attempts have been made by methods such as Fitzroy's [3], where the separate calculations for 3 pairs of opposite surfaces are combined together to provide one value of RT_{60}. The Fitzroy formula is:

$$RT_{60} = 0.161 \frac{V}{S} \left[\frac{S_v}{\alpha_v} + \frac{S_t}{\alpha_t} + \frac{S_l}{\alpha_l} \right] \tag{3}$$

where S_v and α_v represent the area of a pair of opposite surfaces and the absorption coefficient and similarly for the other two surfaces. A significant difference in the RT_{60} values from Eqs. (1) and (3) probably is an indicator that neither equation provides the correct answer, since the measured values are likely to be dependant on the source - receiver location combinations.

Other field conditions such as dominant echoes, flutter echoes or slow decay of vibration induced on lightly damped surfaces tend to produce measured RT_{60} values that are larger than the theoretically evaluated values. The theoretical under estimation of RT_{60} values is particularly acute in relatively soft rooms.

Similarly, problems are also encountered where spaces are either too small or the aspect ratios, the ratios of length to width to height, are large. In small rooms, statistical energy analysis is applicable only if sufficient number of room modes are present in the frequency bandwidth of interest. Most measurement standards consider the magic number of 10 (ten room modes) to be suitable. The problem is equally complex in large aspect ratio rooms especially if some of the surfaces are highly absorptive. In the extreme cases one can think of open plan offices with highly absorptive surfaces or manufacturing plants with acoustic roof decks. For these rooms, steady state measurements (in the frequency domain) have often indicated decay of sound larger than 6 dB per doubling of distance from the source. There is no equivalence in RT_{60}.

In spite of all the problems highlighted above, no other simple enough descriptor is available at present to replace RT_{60}. One still talks of "a concert hall with RT_{60} of 1.8 secs," as if true for all frequencies and true for all source-receiver combinations in the hall. A number of other design indices such as AI (Articulation Index), STI (Speech Transmission Index) and a whole list of design curves for acoustically sensitive spaces are based on RT_{60}. Some day RT_{60} may be replaced but not until theoretical calculation methods, measurement techniques and design indices are readily available for use.

3.0 Measurement Methods of RT_{60}

The traditional method of exciting the room is with an impulse source, gunshot or otherwise, and a recording of the decay of the sound pressure level (SPL). Alternatively, a loudspeaker providing a stationary random noise source is cut-off and the decay recorded. More recently the source has also been a pseudo-random noise (maximum length sequence) played through the loudspeaker. In the last case the cross-correlation between input and response is calculated from which the decay curve can be calculated. Fourthly, a source of sound power can be initiated and the SPL rise curve recorded. This method is rarely used and will not be further considered.

The time for 60 dB of decay can be calculated from the SPL/time curve. A portion of the curve is used because usually 60 dB of decay is not available, the first 5-10 dB is usually not straight and the curve will often contain two slopes. Lately the initial portion of the curve, the first 5 to 15 dB, is often used because of its importance in assessing room acoustics. The "real" RT_{60} can only be determined as accurately as the measured slope of the curve. An alternate method, developed by Schroeder [4], reverse integrates the SPL/time curve from a suitable point above the background to T=0. This provides a more accurate slope.

3.1 Comparison of Methods

The impulse noise method is the least expensive and can be used with the simplest measuring instruments (Sound Level Meter + Level Recorder). A very short learning curve and very portable instrumentation make this easy for casual measurements. However, the source, even a gun shot, is non-repeatable and often provides low energy in the low frequencies resulting in a low signal to noise ratio. Often only the first few dB of the decay curve are generated at the lowest frequencies. Many measurements are usually required for averaging and for octave bands. The shock wave from the impulse source requires measuring at a distance. The lowest measurable RT_{60} is determined by sound energy in the impulse, filter ring and instrument response.

The use of a random noise source and a large loud speaker provides more energy in the low frequencies and can provide a larger length of decay curve at all frequencies. The same measuring instrumentation is used. However, for low frequency measurements large and/or multiple loud speakers and amplifiers are required. This has traditionally been the most reliable method.

Both of the first two methods can be used in conjunction with microprocessor based equipment such as Rion NA-29 or Larson Davis 820. These expedite the process by simultaneous and software driven calculations of RT_{60} in all octave or 1/3 octave bands.

Maximum length sequence methods are very attractive in that a single measurement can yield a large amount of other data in addition to RT_{60}. The RT_{60} can be calculated from any portion or length of the SPL/time curve and digital filters allow calculations for any octave or 1/3 octave band from the single test. Multiple test for averaging purposes can be easily conducted. However, the learning curve is quite long. The method requires a portable computer and the software is either proprietary (eg. MLSSA), and expensive or the software must be developed (very expensive). As with the random noise source large or multiple speakers and amplifiers are required. The capability and flexibility will appeal to the serious user willing to bear the cost and complexity.

3.2 Measurement Results

A large room (15000 m^3) with average amount of absorption characteristics was used as a test room. The room had the following surfaces: concrete floor; metal siding walls with perforated facing and fibreglass batts; and metal roof deck. The three procedures applied to measure RT_{60} were: (a) Pink noise source with RION NA-29 Sound level meter; (b) MLSSA source, B&K 2215 sound level meter and MLSSA software; and (c) Pink noise source with B & K 2230 sound level meter and B & K 2306 graphic level recorder.

The RT_{60} results are the average of measurements at four to five microphone locations in the test room. The results are shown in Table 1. It is seen that the three methods produce comparable results and one can therefore conclude that any one of the three methods could be used for the test room.

The variability of the RT_{60} with source and microphone location combinations is indicated in the results of Table 2. Procedure (a) was used to obtain the reverberation results. This large (30 x 20 x 25 m) room had absorptive material uniformly distributed over four of the six surfaces and contained several large diffusing elements. Since it satisfies the assumptions of Eq. (1) reasonably well, it is all the more remarkable that the reverberation time showed such a range.

3.3 Examples of Measurement Difficulties

There are a number of difficulties associated with reverberation time measurements in the field. Some of them have been mentioned earlier, but only two of the unusual difficulties will be discussed here. The two problems are associated with a highly absorbent small room such as a studio control room. The problems are due to overdriving an acoustically dead room with a loud source and due to the filter characteristics of the measuring equipment.

The steady pink noise source generally used in the measurements is set to produce relatively high levels of sound so that the signal-to-noise ratio is high. The high levels would usually excite various components in the room such as thin panels, air diffusers etc. The vibrations of these components could be sustained for a longer time than the actual reverberation time of the room. Such a scenario is common when air diffuser rings in a room with a low reverberation time. It is easy to overlook the secondary excitations since the resulting sound would be well below the overall steady state sound level. An example was a small dead room with design reverberation of 0.1 sec or less across the spectrum. The measured RT_{60} at 125 Hz was 0.19 sec and was 0.13 sec at 500 Hz. When damping material was added to the air diffuser to reduce the secondary vibrations, RT_{60} reduced to 0.14 sec and 0.09 sec at the two frequencies respectively. If secondary excitations are suspected, source generated by methods such as MLSSA may be better, since the room sound pressure levels could be kept low.

A second problem in a small room with RT_{60} of 0.1 sec or less is due to the transient decay rate of the octave or 1/3 octave band filter of the sound level meter. The filter decay rate for 60 dB of decay is usually more than 0.2 sec. The rise time of the filters is much smaller and the trick then is to use the rise time of the signal instead of the decay. However, the sudden 'switching on' of a speaker is impossible. The same is true for a gun shot. An alternative method is to reverse the recorded signal so that the decay signal appears as a rise signal when connected to the filters. The reverberation time (values as low as 0.02 sec) can thus be evaluated.

4.0 Conclusions

The general concept of reverberation time and the difficulties associated with its evaluation (both theoretical and measurements) were discussed in this paper. The different measurement methods commonly used in the field were described and compared.

References

1. L.L. Beranek NOISE AND VIBRATION CONTROL (McGraw Hill, New York 1971).

2. M. Hodgson, "Review and Critique of Exisitng Simplified Models for Predicting Factory Noise Levels," Canadian Acoustics, 19(1), 15-23 (1991).

3. D. Fitzroy, "Reverberation Formula which seems to be more accurate with nonuniform distribution of absorption," JASA, July, 1959.

4. M.R. Schroeder, "New Method of Measuring Reverberation Time," Journal of the Acoustical Society of America, 38, 329-361 (1965).

Table 1. RT_{60} Results in secs

	RT_{60}, secs in Octave Band	
Measurement Method	125 Hz Band	1000 Hz Band
MLSSA	1.21	1.51
PINK Noise & RION	1.43	1.68
PINK Noise & SLM + Chart	1.44	1.65

Table 2. Variability in RT_{60} Results

	RT_{60}, secs in Octave Band	
Measurement Location	125 Hz Band	1000 Hz Band
1	1.54	1.40
2	1.52	1.50
3	1.50	1.92
4	1.32	1.67
5	1.26	1.89