Reverberation Time

with XL2 Sound Level Meter

The XL2 Acoustic Analyzer measures the reverberation time T in octave and one-third octave band resolution. The step-by-step procedure to measure the reverberation time is described in the XL2 user manual. This application note describes additional technical basics and details to be observed for standard compliant measurements.

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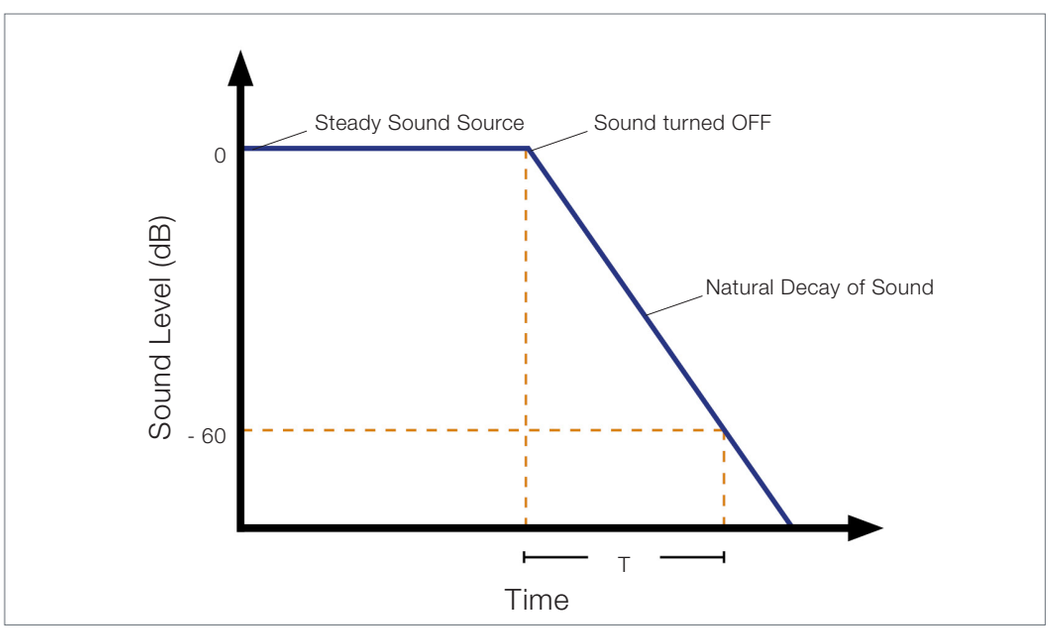
What is Reverberation Time?

Reverberation time is the time required for sound to “fade away” in a room. Sound waves will repeatedly bounce off reflective surfaces such as the floor, walls, ceiling, windows or tables and return to the listener position. This is particularly noticeable in a church, for example, where the sound may be heard for several seconds while it fades away.

In principle, reverberation time is the time required for the sound pressure level to decrease by 60 dB after the sound stimulus signal abruptly stops. The sketch below visualizes this basic principle of a reverberation time measurement.



Level Decay by 60 dB

The reverberation time measurement is defined in the following standards

- ISO 3382-1 for performance spaces
- ISO 3382-2 for ordinary rooms
- ASTM E2235

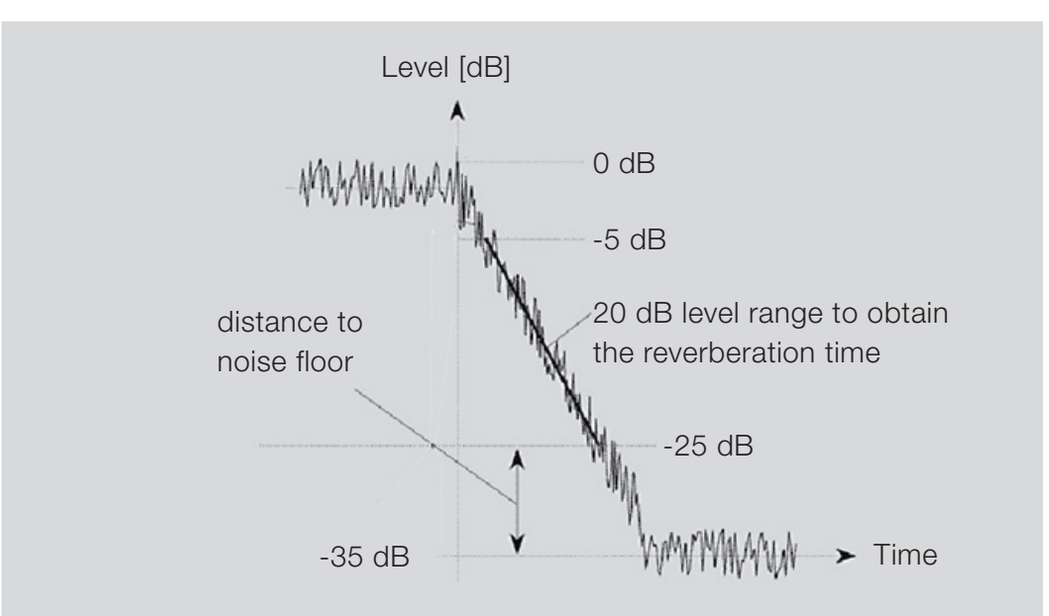
The actual measurements span across 63 Hz to 8 kHz in octave band resolution and 50 Hz to 10 kHz in 1/3 octave band resolution. Rooms have individual absorption capabilities for each frequency, so the reverberation time values within each frequency band will vary.

Why measure Reverberation?

Reverberation is a key parameter when qualifying the acoustic status of a room. Particularly, too much reverberation may have a negative impact on the intelligibility of speech. On the other hand, too little reverberation will reduce the rich, warm acoustic sound from an orchestra in a concert hall. Also, the sound pressure level from noise sources can be enhanced while the privacy of a room can be decreased by reverberation in a room. Furthermore, reverberation time is measured to determine the room absorption correction value required in many acoustic measurements, such as sound insulation and sound power.

Measurement Methods T20 & T30

By way of example, say the ambient noise floor in a room is 45 dB. To measure a linear decay of 60 dB, we need to ensure that the decay measurement ends 10 dB above this noise floor (so the linearity of the sound decay is not significantly influenced by the ambient noise). An additional 5 dB headroom is required to detect the start of the decay. Adding these levels together, we require a test signal level of 45 + 60 + 10 + 5 = 120 dB across the whole frequency spectrum. This is technically often not feasible, particularly at low frequencies.



Reverberation Time Measurement with T20 Method

In practice, therefore, we measure the time taken for the reflections to decay by 20 dB or 30 dB in accordance with the ISO 3382-1 standard. If the decay is acceptably linear, these readings can then be linearly extrapolated to a decay of 60 dB. The reverberation time measurement method used is identified as T20 or T30 respectively.

T20

- The measurement requires a relatively small dynamic measurement range of ~35 dB above the noise floor for each frequency band.
- RT60 (T20) = 3 x time measured for a 20 dB decay

T30

- The measurement requires a dynamic measurement range of ~45 dB above the noise floor for each frequency band.
- RT60 (T30) = 2 x time measured for a 30 dB decay

For a lower measurement uncertainty (i.e., better measurement accuracy)

- T30 is better than T20
- 1/1 octave band resolution is better than one-third octave resolution
- 5 cycles are better than 3 for each measurement position
- 5 measurement positions are better than 3 in the room

However, if the background noise is too high and/or the sound source is not loud enough to create 45 dB above the noise floor, then T20 may be the better option.

Mathematically, reverberation time is calculated from a linear least-squares regression of the measured decay curve.

- If the overall reverberation time is short (e.g. < 0.3 seconds) the room acoustic is referred to as being “dead”. For example, a room with thick carpets, curtains and upholstered furniture may have such an acoustic character.
- If the overall reverberation time is long (say more than 2 seconds) the room acoustic is referred to as being “live” or “echoic”. For example, a large empty room with painted plaster walls and a tiled floor may have such an acoustic character.

Measurement Accuracy

The ISO 3382-2 standard specifies three levels of measurement accuracy. The main difference concerns the choice of signal source and the number of measurement positions.

Survey method

- There are no directivity requirements on the signal source.
- Measurements typically carried out in octave band resolution.
- The frequency range should cover at least 250 Hz to 2 000 Hz.
- The nominal measurement accuracy is assumed to be better than 10 % for octave bands.
- A short excitation or an impulse signal may be used as an alternative to the interrupted noise signal. Pink noise provides a better measurement accuracy than an impulse signal.

Engineering method

- For measurements in performance spaces: An omnidirectional speaker with identical radiation characteristics in all directions is required.
- For measurements in ordinary rooms: There are no directivity requirements on the signal source.
- Measurements may be carried out in octave band resolution or the optional one-third octave band resolution (part of the XL2 Extended Acoustic Pack).
- The frequency range should cover at least 125 Hz to 4 000 Hz in octave bands, or 100 Hz to 5 000 Hz in one-third octave bands.
- The recommended duration of excitation of the room equals the measured reverberation time in each frequency band.
- The nominal measurement accuracy is assumed to be better than
  - — 5 % in octave bands
  - — 10 % in one-third octave bands

Precision method

- For measurements in performance spaces: An omnidirectional speaker with identical radiation characteristics in all directions is required.
- For measurements in ordinary rooms: Requires an omnidirectional speaker.
- Measurements may be carried out in octave band resolution or the optional one-third octave band resolution (part of the XL2 Extended Acoustic Pack).

- The frequency range should cover at least 125 Hz to 4 000 Hz in octave bands, or 100 Hz to 5 000 Hz in one-third octave bands.
- The duration of excitation of the room needs to be sufficient for the sound field to have achieved a steady state before the source is switched off.
- The reverberation time measurement accuracy is assumed to be better than
  - 2.5 % in octave bands
  - 5 % in one-third octave bands

Sound Sources

Reverberation time measurements require a diffuse sound field in the room. This means that the sound energy of the test signal has to be distributed uniformly. A speaker with an omnidirectional radiation characteristic should be used for accurate measurements using a gated pink noise test signal. The recommended signal source kit consists of the DS3 Dodecahedron Speaker and the PA3 Power Amplifier. Survey method measurements may be performed with an existing installed speaker system using the Minirator MR-PRO as the signal source. Alternatively, an impulsive sound source may be used in accordance with ISO 3382-1. The ASTM E2235 standard does not allow impulsive sound sources.

DS3 Dodecahedron Speaker Kit

Sound insulation and precise reverberation time measurements require the use of an omnidirectional sound source. Omnidirectional sources radiate sound equally in all directions. Loudspeakers mounted on the surfaces of a polyhedron will give such a uniform, omnidirectional radiation.

The PA3 Power Amplifier includes a pink noise signal generator. This test signal is played through the DS3 Dodecahedron Speaker into the room under test. The test signal may be switched on and off by remote control. The test signal should be played for a long enough time period to ensure that a balance between injected and absorbed acoustic energy has been reached, i.e., the sound should be given enough time to reach all reflective surfaces in the room. The duration of the pink noise test signal should thus be at least equal to or longer than half of the measured reverberation time for each frequency band. As the room can never be “over-saturated” with sound for a reverberation time measurement, to be on the safe side, play the noise for least the time period of the estimated reverberation time test result. Each time the test signal stops, the sound level meter recognizes this interruption, measures the decay time, and calculates the reverberation time automatically.

DS3 Dodecahedron Speaker

The international standards ISO 3382-1:2009 and ISO 16283-1:2014 specify the directivity response of omnidirectional speakers. To give an adequate approximation of uniform omnidirectional radiation, it is stated that the dodecahedron (12 faces) is the preferred polyhedron.

The DS3 Dodecahedron Speaker is such a powerful sound source with omnidirectional radiation characteristics. It consists of 12 loudspeakers of the same type, mounted to a dodecahedron-shaped chassis. The optimized frequency spectrum delivers a high level of equalized sound energy for precise reverberation time measurements. The emitted sound power is constant throughout the measurement and for several consecutive hours.

In the design of the NTi Audio Dodecahedron Loudspeaker enclosure, consideration was given to the practical advantage of transporting a smaller, lightweight enclosure, and providing sufficient sound power output, while ensuring a flat frequency response, and optimizing the spectral uniformity - and all this at an affordable price.

The omnidirectional DS3 Dodecahedron Speaker should be positioned at the typical sound source locations for the room e.g. for classrooms, at the front from where the teacher normally speaks. In performance spaces a minimum of two

speaker positions shall be used at a height of 1.5 m above the floor.

For small rooms or in case there is no typical sound source location, one source position should be in a room corner.

In very large rooms (e.g. concert halls) you may operate several Dodecahedron Speakers in parallel. For example, using two speakers increases the sound pressure level in the room by 3 dB.

Impulse Sound Sources

Typical impulse sound sources are, for example, a starter pistol, starter clapper board or bursting balloon. Such sound sources may be used for survey method measurements in performance spaces. The sound level meter measures the decay time and calculates the reverberation time automatically.

Various starter pistols may be used to generate an impulse in the room and trigger the reverberation time measurement. For example, customers may use the following models, both shooting blank or gas using a 9 mm caliber:

- HW37, manufacturer Weihrauch
- Chiefs Special, manufacturer Smith & Wesson

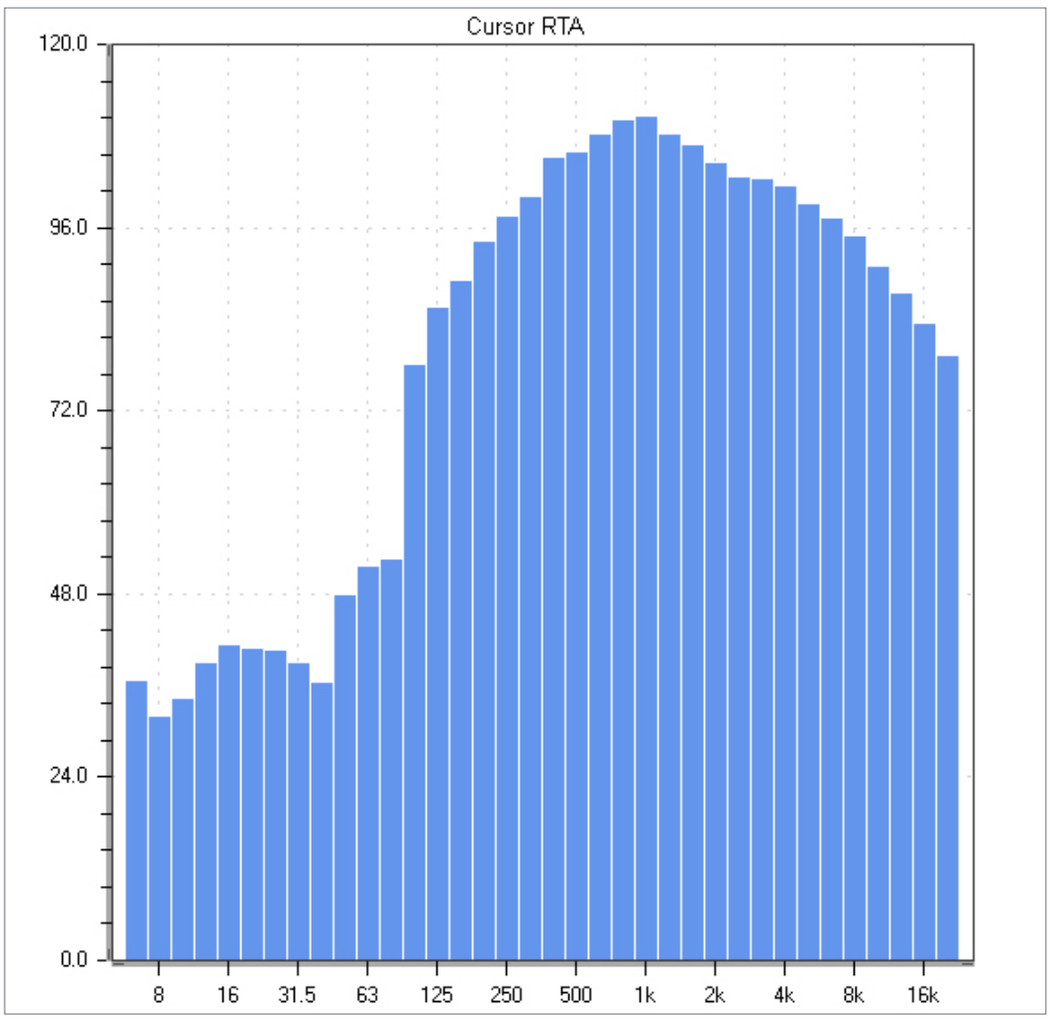
Warning: Using such a pistol in a closed room with approx. 800 m3 may generate an impulse sound pressure level LZImax of up to 125 dB.

Advantage

- lightweight and portable

Disadvantages

- may be inappropriate in the presence of children or in a church
- may not be permitted on airplanes
- may leave a smell of gunpowder residue in the room
- may unsettle dust in the room; e.g. requires cleaning after the measurements



Sample Gun Shot Spectrum

Alternative impulse sound sources are, for example, balloons, a clapper board or hand clapping. The challenge is that these sound sources typically generate insufficient sound energy in the lower frequency bands. Thus, the reverberation time cannot be measured in these bands.

The larger the balloon, the deeper frequencies it will cover, and the more sound energy it can produce. Make sure you use higher-quality balloons that are fit for purpose. Cheap children party balloons can be difficult to blow up, and may burst prematurely (at worst, in front of your client!). Also allow sufficient time, as a balloon of 1 meter diameter could take up to 5 minutes to inflate with an electric balloon inflator.

Hand clapping is often used for a quick initial indication of the reverberation time in the room. Take a look at the following videos of handclapping in different rooms:

https://www.nti-audio.com/en/support/know-how/how-to-get-a-feeling-for-rt60-value

Minirator MR-PRO

The Minirator MR-PRO is a test signal generator that can be used for survey method measurements. The generated audio signal may be played through an existing speaker system, e.g. in a large venue, or a portable speaker in one of the room corners. The MR-PRO generates a gated pink noise with a low crest factor. The on/off cycle time is adjustable from 1 to 10 seconds. The MR-PRO connects to the installed power amplifier and the test signal is played through the installed speakers. In addition, the MR-PRO offers a Glide Sweep signal with editable cycle time (< 1.5 seconds for reverberation time measurements using the XL2 Acoustic Analyzer).

Minirator MR-PRO

Measurement

The XL2 measures the energy decay spanned across 63 Hz to 8 kHz using the Schroeder method in octave resolution. The optional Extended Acoustic Pack enables one-third octave band resolution from 50 Hz to 10 kHz.

XL2 Acoustic Analyzer with
M4261 Measurement Microphone

Pink Noise Source

Using a pink noise signal source, we recommend an excitation of the room equaling the measured reverberation time in each frequency band. This is a simplified guide, e.g. if the reverberation time is 3 seconds, then power on the pink noise test signal for 3 seconds and off for 3 seconds. In detail the ISO 3382-1 standard states that the sound has to radiate at least half of the measured reverberation time for the engineering and precise methods. Due to the randomness of the pink noise, it is recommended to average over at least three decays at each position in order to achieve an acceptably low measurement uncertainty. The sound level meter averages the readings of all cycles automatically.

Impulsive Sound Source

Using an impulsive sound source, the XL2 has a feature that discards reverberation time results when a level overload condition occurs. This is in accordance with the ISO 3382 standard. Sometimes you might not be able to reduce the level of an impulse sound source; e.g. in a small room using a starter gun. In order to still get a reverberation time result in such a situation, this overload feature can be disabled by loading an empty file with the name “RT60allowOVLD.txt” in the root directory of the instrument. Note that such an overload condition may affect the reverberation time result.

People in the Room

In many rooms, the number of people present can have a strong influence on the reverberation time. Reverberation time measurements should be made in a room containing no people. However, a room with up to two persons present may be allowed to represent its unoccupied state, unless otherwise specified. If the measurement result is used for correction of a measured sound pressure level, i.e., for sound insulation or sound power, the number of persons present in the room should be the same for that measurement.

Distance Microphone to Speaker

The measurement shall not be strongly influenced by the direct sound from the speaker. Therefore, the formula below defines the minimum distance between the omnidirectional sound source and the measurement microphone.

Minimum Distance $D = 2*\sqrt{(V/(c*T))}$

with V = Volume of the room [m3]

c = Speed of sound [m/s] (at temperature of the room)

T = Reverberation time of the room [s]

For example, in a small hall, 10 meters by 10 meters with a height of 5 meters, and an expected reverberation time of 3 seconds, the microphone must be at least 1.4 meters away from the sound source.

$D = 2*\sqrt{((10*10*5)/(342*3))} = 1.4$ m

Microphone Position

In performance spaces the measurement microphones shall be positioned at the typical listener locations in the room, e.g. 1.2 m above the floor is the typical ear height of seated persons. The selected positions shall represent the entire space in the room. Symmetric microphone positions should be avoided.

The minimum distance to the nearest reflecting surface, such as a floor, wall or ceiling, shall be at least a quarter of a wavelength of the lowest frequency measured. e.g. 1 m to measure down to 100 Hz. For measurements down to 50 Hz, use a minimum distance of 2 m to the nearest reflecting surface.

Distance between Microphones

The microphone positions shall be at least 2 m apart for measurements down to 100 Hz. Use at least a distance of 4 m between microphone positions for measurements down to 50 Hz. This recommendation is based on at least a half wavelength of the lowest frequency measured.

Speaker & Microphone Positions

The minimum number of speaker positions, microphone positions and measurements in a box-shaped room, using the interrupted noise measurement method, depends on the required accuracy.

	Survey	Engineering	Precision
Speaker Positions	1	2	2
Microphone Positions	2	2	3
Measurements	2	6	12
Decays per Measurement	1	2	3

More positions should be used in case of a more complicated room geometry. The measurement starts by pressing the start/stop button on the Acoustic Analyzer and ends by pressing the start/stop button. It is recommended to measure at least three decays at each position; this reduces the statistical measurement uncertainty in the report.

Reporting

The Acoustic Analyzer stores all data on an SD card for direct transfer to a computer. Data reports and log files are stored in plain text format, which can be opened with any text editor (Notepad, Wordpad, etc). The data is tab-delimited, so dropping the .txt file into a spreadsheet application will conveniently show the results in columns.

Alternatively, an excellent reporting tool is provided by NTi Audio. The Room Acoustics Reporter is a PC software for the generation of professional reverberation time measurement reports. The software supports acousticians and experts in the visualization and detailed evaluation of measurement data recorded with the XL2 Acoustic Analyzer.

The following sample report presents the reverberation time in third-octave resolution. For simplification, a single figure mid reverberation time may be calculated by averaging the following bands:

- Octave band: 500 Hz, 1000 Hz
- One-third octave band: 400 Hz - 1250 Hz

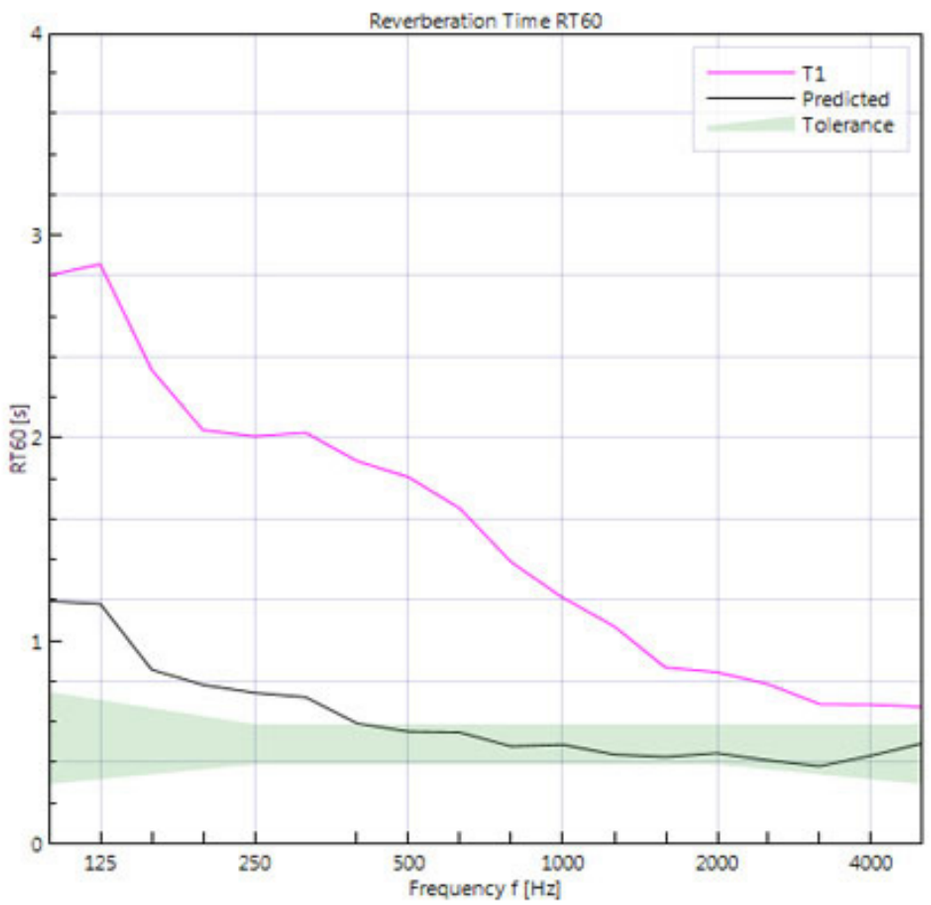
Reverberation Time RT60 in accordance with ISO 3382-2
Measurement of reverberation time in ordinary rooms

Client: Sample Inc
Date of test: 15/02/2019
Object: Office with wooden floor
empty room w/o furniture

XL2 Sound Level Meter: A2A-10929-E0 (M2230: 5742)
Room Volume: 50 m³ Room Surface: 70 m²

Freq f Hz	T1 RT60 s	Pred RT60 s
100	2.81	1.20
125	2.86	1.18
160	2.34	0.86
200	2.04	0.78
250	2.01	0.75
315	2.03	0.72
400	1.89	0.59
500	1.81	0.55
630	1.65	0.55
800	1.39	0.48
1000	1.21	0.49
1250	1.07	0.44
1600	0.87	0.43
2000	0.85	0.45
2500	0.79	0.41
3150	0.69	0.38
4000	0.69	0.43
5000	0.68	0.49

Mid		
400 - 1250	1.50	0.52



No. of test report: 1234
Date: 22/05/2019
Name: NTi Audio Inc.
Signature:

Typical Results

These are typical recommended reverberation time measurement results:

Location	Volume	Recommended
Recording Studio	< 50 m^3	0.3 s
Classroom	< 200 m^3	0.4 - 0.6 s
Office	< 1`000 m^3	0.5 - 1.1 s
Lecture Hall	< 5`000 m^3	1.0 - 1.5 s
Concert / Opera Hall	< 20`000 m^3	1.4 - 2.0 s
Church		2 - 10 s

Commonly, the reverberation time can be reduced with the introduction of absorbing materials such as thick carpets, curtains, upholstered furniture, or dedicated sound-absorbing panels. Furthermore, the presence of people in a room reduces the reverberation, and therefore produces a lower reverberation time value compared to the unoccupied room.