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Reverberation

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Reverberation is one of the essential qualities of an auditorium, concert hall, and any other site intended for listening to speech and/or music. It determines the quality of the perceived signal and allows for the venue's classification as “dead” or “alive.” Reverberation is easy to measure and is a starting point for the designer of a room or venue.

Ever thought about why people like singing under the shower? Or why our voice appears amplified in the bathroom? And then, if we are in the open, our voice sounds so much weaker? It has a lot to do with sound reflections on the surfaces surrounding the source and receiver.

Let us go back to our high school physics and the chapter on sound in grad school that we tried to go through as quickly as we could (and forget later). There was something about those air molecules bouncing against the other and the sound propagating as the waves spread out on the water surface when disturbed by a falling stone.

The sound propagates freely until it reaches an obstacle, most of the time a wall and/or ceiling (See Figure 1). It gives origin to three phenomena: part of the energy is reflected, a part is transmitted through the wall, and part is absorbed and transformed into heat and vibration. The proportion of each of the three depends on the physical nature of the wall. If the wall or obstruction is soft and porous, it absorbs a large portion of the impinging energy, which occurs inside an audiometric room. However, it is heavy, massive with a smooth surface, then most of the energy is reflected, reinforcing the energy in the room or enclosure. This is the case with shower walls and the reason for the voice to appear reinforced. We all become opera singers!

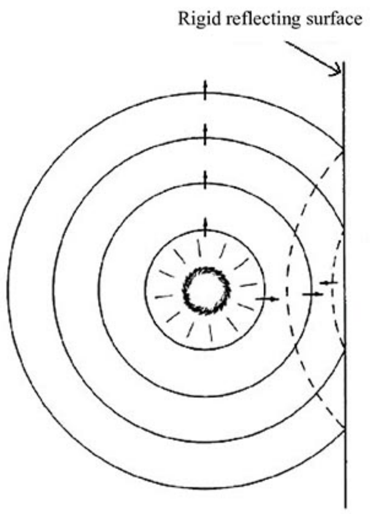

Figure 1. Sound propagates freely until it reaches an obstacle, such as a wall or ceiling.

If the room is sufficiently large, sounds bounce around. This degrades speech intelligibility, such as in an underground car garage. Something similar happens in the old medieval churches, where the quality of speech is very poor. Improving intelligibility in similar environments is a serious problem that requires acoustical and architectural, and engineering skills.

Speech and Music

What do speech and music have in common? Both are a form of sound and comprise similar frequency ranges, even though the range of music is much wider. The time patterns of the sound levels continuously vary, as does the frequency content. In the case of speech, there are frequent pauses at the ends of relative clauses and sentences.

In a room with many reflections, once the sound has been produced, it doesn't disappear immediately even if the sound source stops. It travels through the air, and when it reaches an obstacle, part of it is reflected back. In an enclosed space, such as a room, an auditorium, or a theatre, the sound is reflected many times, losing energy after each reflection until it is finally inaudible.

Let us suppose an impulsive sound has been generated at the podium in the concert hall, and suppose there is a listener in the middle of the hall. There will be a direct sound that will arrive with the speed of the sound, roughly 340 m/s. Then, sounds reflected from all the surrounded surfaces will start to arrive one after the other with a delay that is a function of the long distances they are covering. The human ear cannot distinguish among sounds arriving at the ear within 10 ms after the original sound. So, all (early) reflections within this interval are perceived as a continuation of the original, thus reinforcing and enlarging it.

Figure 2 shows what is happening when a piano's key (in a concert hall) is pulsed, and the sounds (direct and reflected) arrive at a listener. The first direct sound is heard, and shortly after, the first reflections are heard… then all the other reflections arrive with diminishing sound levels. After a certain time, all-acoustic energy is absorbed by the walls, ceiling, and public, and the sound disappears.

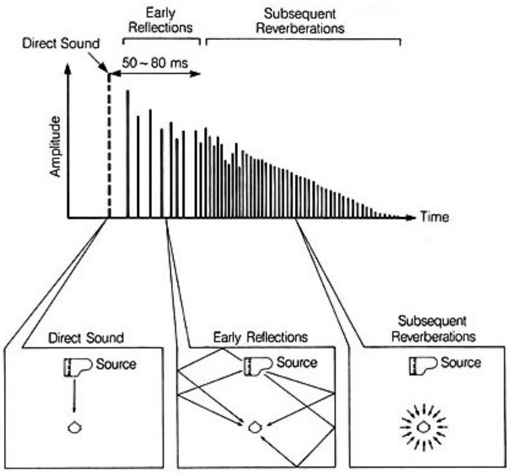

Figure 2. Sound levels of direct and reflected sounds.

The ancient Greek theatre builders have known this reinforcing effect. The floors of the theatres were sloped, and they introduced large reflecting surfaces on the back and the sides of the proscenium to compensate for the sound energy lost in the space. This was an enormous problem because these theatres had no ceiling. With the reflections, they were able to allow listeners to understand the soloists' speech and chorus in the large spaces they had to deal with.

The increase of the reflected sound can create a problem both with speech and articulation of music. In the case of speech, syllables merge one with the other reducing the intelligibility. This is a serious problem even today in large churches, for instance, where only people close to the speaker can understand him. Everyone can hear, but those far away hear the speech but cannot understand it. In music, something similar happens if there is too much reflected sound- reverberation makes fast passages muddled and lacking in clarity. There are some cases throughout the ages where the music may have changed to mirror the acoustic properties of that era's architecture.

To control the amount of the reflected energy, surfaces are covered with “acoustical” materials that are sound absorbers. Typical examples are the tiles used on the ceilings and wall coverings on sites as diverse as medical offices and supermarkets. The audiometric booths' walls and ceiling are covered with the same type of materials to reduce the interior noise reflections.

The question is how to decide how much acoustical material to introduce to make it acceptable for speech or music. We do have means for this, and this is where reverberation comes in.

As explained above, once the sound source ceases, the sound does not die instantly because of the reflections that keep on arriving. The greater the sound absorption is in place, the shorter is the duration of the reflected sounds. Measuring the duration of the sound after the source has ceased is how the acoustic of the enclosure or venue is characterized. Specifically, the Reverberation Time (also known as RT60) is defined as the amount of time (seconds) for a sound source to decrease to a level that is 60 dB quieter than its peak.

The measurement of the absorption is a measurement of time. Table I shows the optimum reverberation times (RT) for enclosures for different applications, and a schematic of the calculation of Reverberation Time (RT60) is shown in Figure 3.

Table 1. Reverberation Times for Speech and Music in Different Venues

RT (seconds)	Use
<1	Good for speech and classrooms, but music sounds thin
1.5-2.5	Good compromise for speech and for music
3-4	Good for music, but can lose some of its articulation
>8	Well suited for large cathedrals, organ music, and Gregorian Chants

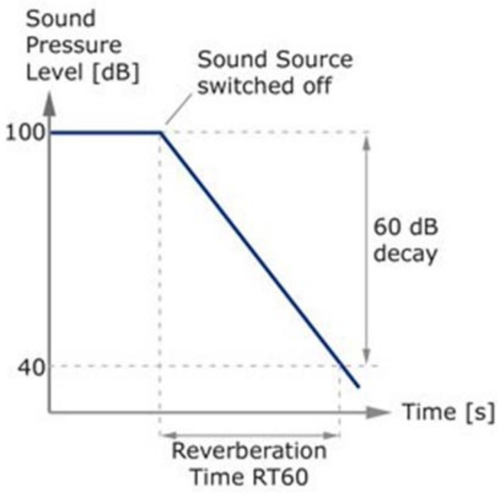

Figure 3. By definition, the reverberation time (RT60) is required for sound to be reduced by 60 dB from its original level.