Room Acoustics Considerations for Loudspeaker Systems in a Large Reverberant Space.

John O'Keefe

Aercoustics Engineering Ltd.
50 Ronson Drive, Suite 127
Toronto, Canada, M9W 1B3

Introduction

The Galleria in Toronto is a monumental space with an internal volume of approximately 90,000 m^3. The acoustics in the building are comparable to very large rooms such as the cathedrals of Europe or domed stadia in North American and Japanese cities. As such, the Reverberation Times are three or four times longer than they should be for good speech intelligibility or musical clarity. This means that in most places in the room, useful early reflected sound is overwhelmed by detrimental late sound. Preferred Reverberation Times for speech and amplified music range from 0.7 to 1.5 seconds. Satisfying this criterion in a large venue such as the Galleria is simply not possible.

The Galleria has very low speech intelligibility and musical clarity levels. Like other very large spaces, perceived clarity decreases as the sound pressure level of the loudspeaker system is increased. To provide enough direct and early sound to listeners, a significant number of loudspeakers are required. The philosophy is that wherever one stands in the Galleria there should be a loudspeaker nearby. The loudspeaker(s) must be close enough that direct or early reflected sound is greater that the later reverberant sound. The danger with this approach however is that loudspeakers far away from the listener may generate sound that is interpreted by the ear as late or detrimental. This then is the fundamental dilemma associated with very large rooms: increasing the number of speakers means that some people will be exposed to better direct and early sound. For people located elsewhere in the room these same loudspeakers will introduce detrimental late sound.

Measurement Procedure.

The objective acoustic measurements we have performed in the Galleria include: Reverberation Time (RT60), Early Decay Time (EDT), and Distinctness (D50) and Speech Transmission Index (STI)

Measurements were performed with a MLSSA System manufactured by DRA Laboratories. The room was insonified with a dodecahedron source complete with 12 75 mm diameter loudspeakers and a single 12" loudspeaker in a separate bin. Room responses were measured with an omni-directional microphone at source-receiver distances doubling in distance, i.e. 1, 2, 4, 8, 16, 32 and 64 m.

At each location measurements were performed at four different source levels, increasing in amplitude at 10 dB steps. This was done to determine if increased sound levels had an effect the acoustics of the room.

Results

The results of our measurements are shown in Figures 1 and 2. For comparison, we have also shown the RTs in other large rooms such as St. Paul's Cathedral, London. The comparison confirms that the Galleria is similar to these very large spaces, none of which are known for good acoustics.

As pointed out above, practical experience in the Galleria suggests that speech intelligibility decreases as the sound level is increased. To investigate this phenomenon, a series of Speech Transmission Index (STI) measurements were performed at different sound levels. The results are not what some might expect. For the most part, speech intelligibility neither increases or decreases with sound level. The exception is the STI values for the lowest sound level where the ambient HVAC noise has affected the data.

The reason why the measurements do not agree with so called practical experience appears to be because we have used a single loudspeaker for the measurements as opposed to a distributed loudspeaker system like the one currently installed in the Galleria. A single source approach was chosen because it afforded the power of simplicity, not only for our measurements on site but, much more importantly, in our analysis that followed.

Analysis

In essence, the problem in a large room such as the Galleria is that there is too much late sound and not enough early sound. It would seem to make sense therefore to extract and examine the direct, early and late components of the sound measurements we have performed. This, by the way, is not a unique approach. It is the basis of the revised theory of sound in a room as proposed by Barron & Lee[1].

For the analysis, the following temporal thresholds have been assumed:

Direct	0 to 1 ms
Early	1 to 50 ms
Late	50 ms to ∞

The analysis was performed on broadband (unfiltered) data and the results are shown in Figure 2. Three simultaneous models are used to describe the sound in the Galleria, presented below with their R^2 values:

$$Direct = L1 - 15.43462r \qquad (R^2 = .96)$$
$$Early = L1 - 11.99859r - 1.74 \qquad (R^2 = .97)$$
$$Late = L1 - 2.717000r - 10.04 \qquad (R^2 = .92)$$

where: $L1$ is the sound pressure level 1 m. from the source
r is the distance from the source in m.

The first thing to notice in Figure 2 is that at short distances, that is less than 7 metres, the direct and early sound is greater than the late sound. If the early sound is louder than the late, one would expect good speech intelligibility. The STI measurements at less than 7 m indicate that this is in fact the case. Beyond 7 metres the late sound predominates and there is a corresponding decrease in speech intelligibility.

The second salient feature of Figure 2 is that the slope of the late sound is less than the slopes of the direct or early sound. This means that as one moves away from the source, the detrimental late sound persists while the important early sound dissipates. This begins to explain the reason why speech intelligibility and the overall acoustic impression can decrease as the sound level is increased.

The important difference between a single loudspeaker system and a distributed system with several loudspeakers is that the distant loudspeakers generate sound that a listener will interpret as late or detrimental.

To quantify the acoustical implications of a loudspeaker array, a simple mathematical model of the Galleria's acoustics has been developed. Using the three formulae shown above, the model calculates the 50 ms Distinctness coefficient (D50) for a given location depending on the number of loudspeakers and the distance from the listener to the closest loudspeaker.

The model shows that for 4 speaker array, spaced at 2 m intervals, a listener must be within 8 m of the nearest loudspeaker to obtain a D50 of 0.6 or better. If the spacing between the 4 speakers is increased to 10 m, the listener must be within 4 m of the nearest loudspeaker. When the number of speakers is increased to sixteen, the effect of loudspeaker spacing becomes insignificant for listeners located more than 2 or 3 m from the nearest speaker. Beyond that point D50 levels are unacceptably low.

This suggests the PA system design must ensure that no matter where one stands in the room, there will be a loudspeaker within 3 m (9 ft). To achieve this, a system of satellite loudspeaker stations has been proposed[2]. If implemented, it will be linked to the central sound system by a new infra-red broadcasting system similar to that used for hearing impaired systems.

References

1. Mike Barron & Lee Jong Lee, J.A.S.A., **84** (2) pp. 618-628 (1988)
2. Philip Giddings, **Engineering Harmonics** Report, 17 January 1994.

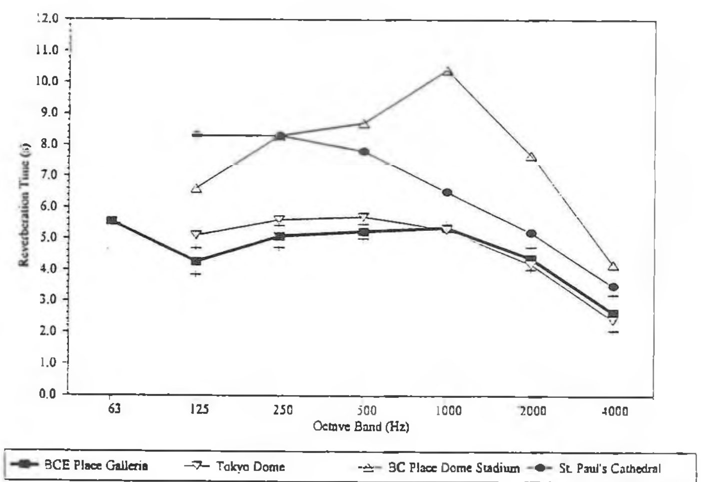

Figure 1 Reverberation Time vs. Frequency.

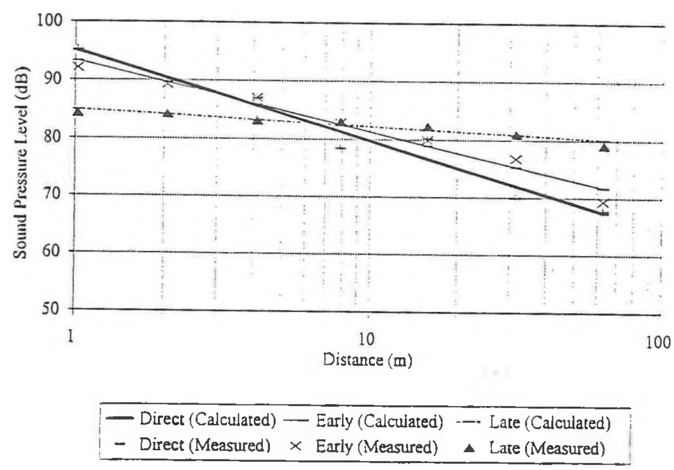

Figure 2 Regression Analysis of Direct, Early and Late Sound.