Tech Topic

First-Order Approximations

Peter Mapp made an especially insightful statement during a break at the Architectural Acoustics Measurement and Prediction seminar. It was one of those "gold nuggets" that come along without warning or provocation that seems to perfectly describe the state of the situation. The class had just finished an exercise on correlating a reflectogram generated by a room modeling program to actual measured data of the same space. Peter remarked:

"We must remember that these are only first-order approximations of what is really happening."

Simple, but profound, this statement reinforces the conclusions made by other acoustics researchers in that the behavior of an orderly event like an impulse will become less predictable with increasing time. Modeling programs excel at determining the arrival time and level of the direct sound field from a sound source. The first few reflections are also fairly predictable, resulting from simple geometrical relationships between the source and receiver positions. As time progresses, the reflected field becomes increasingly diffuse and it becomes impossible (and possibly unnecessary) to attribute specific reflections in the model to specific reflections in the measured data. There are at least two reasons:

1. There are simply too many factors affecting the outcome.

2. Errors in the calculation of a reflection path compound as the reflection order is increased.

Manfred Schroeder found the same principle at work in his studies of room modes. Modes higher than 6th become diffuse and unpredictable. The first few axial modes (the most significant regarding sound reproduction) are relatively predictable and are based mainly on simple geometric relationships between parallel room surfaces. The higher modes become increasingly diffuse and evade accurate prediction. This allows us to use simple methods for determining the first few modes, which fortunately are more profound in their effect on sound reproduction than those at higher frequencies. In similar fashion, the first few specular reflections in an enclosed space can be estimated with simple geometry. As the reflection order increases, the energy becomes increasingly diffuse and evades accurate prediction by simple ray tracing or image-source methods alone. Other factors, such as surface scattering, must be considered. This increasingly complex behavior is of more interest to acousticians than sound system designers, and can be considered with greater accuracy with high-end programs such as CATT-Acoustic™ or the Aura™ module of EASE 4.0™. Fortunately, any reflection that is likely to be a cause of concern for a sound system designer will likely be of relatively low order (3 or less). Later reflections, such as flutter echoes, are begat by early reflections, so dealing with the early ones also addresses the late ones.

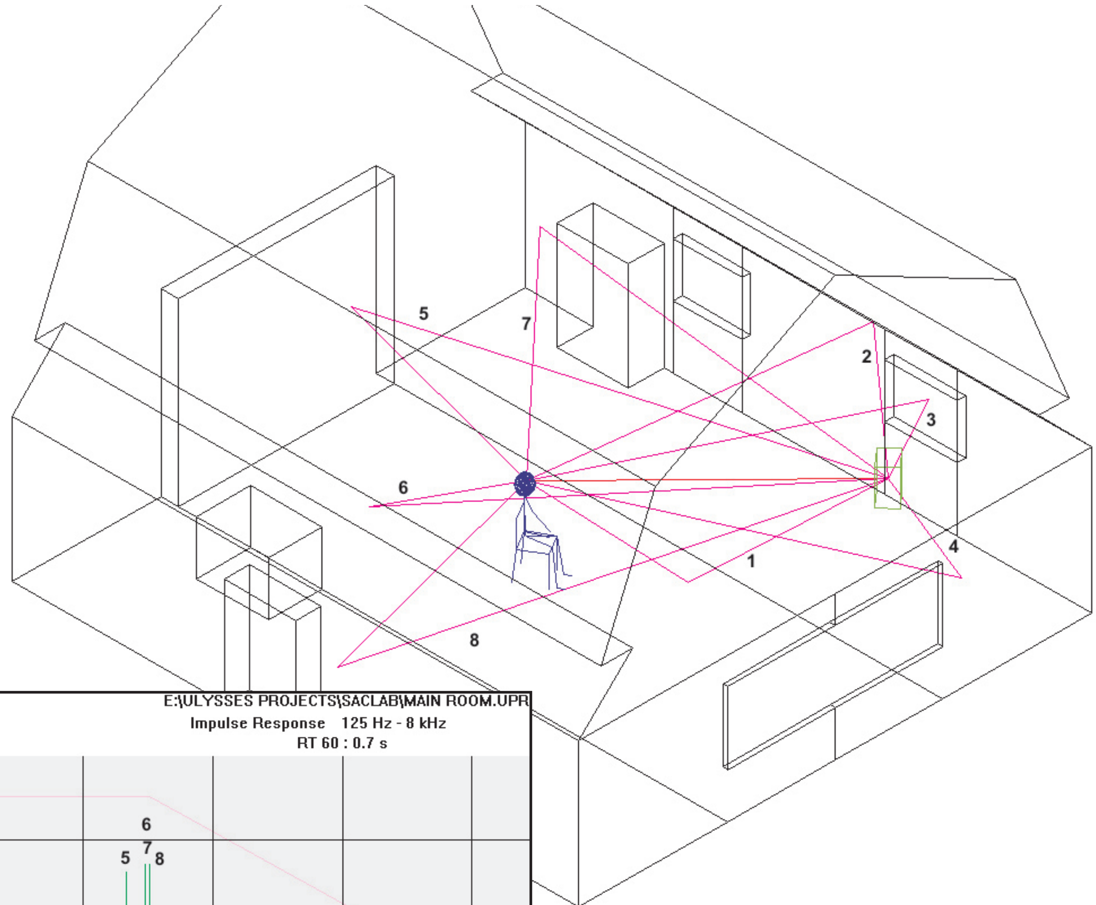
Given the computing time required to consider reflections out to the Nth order, sound designers should consider concentrating their efforts on dealing with the first few bounces (author's opinion). This results in a significant reduction in processing time, increased accuracy in identifying the offending surfaces, and the revelation of acoustic events that are most likely to affect the performance of the sound system. Also, it is much more likely that a client can be sold on treatment for major acoustic events (like a rear wall reflection) than for subtle ones.

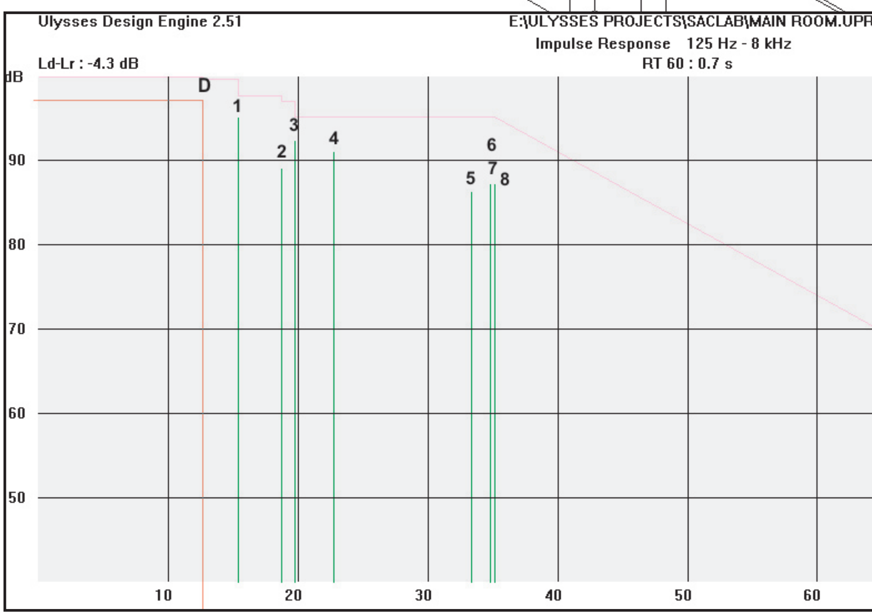
These conclusions will significantly affect the choice of a room modeling process for the system designer. Sound system designers should be mainly concerned with evaluation of the direct sound field and lower order reflections, and simple statistical consideration of the late energy in the room (author's opinion). Investigations into the subtleties of room behavior (i.e. surface scattering, diffraction) require significantly more "horsepower" than simulations done for the purpose of designing a sound system. As with all of the tools that we use in audio, the platform must be appropriate for the application. One should not "overkill" a simple project, nor "over simplify" a more complex one.

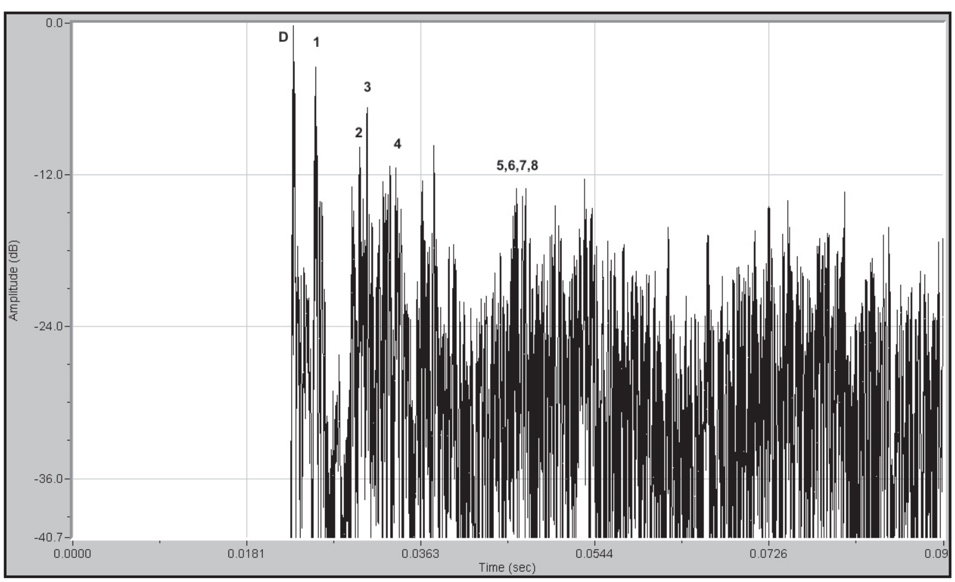
The comparison between predicted and measured impulse responses on the following pages was performed with Ulysses™. The measurements were made with SIA Smaart Acoustic Tools™. Similar applications should yield similar results.

First-Order Reflections

The Syn-Aud-Con shop provided an ideal location for the comparison, due to size, availability, and control over measurement conditions. The geometry is irregular and asymmetrical - not a simple "shoebox." A dodecahedron loudspeaker was used as the sound source.





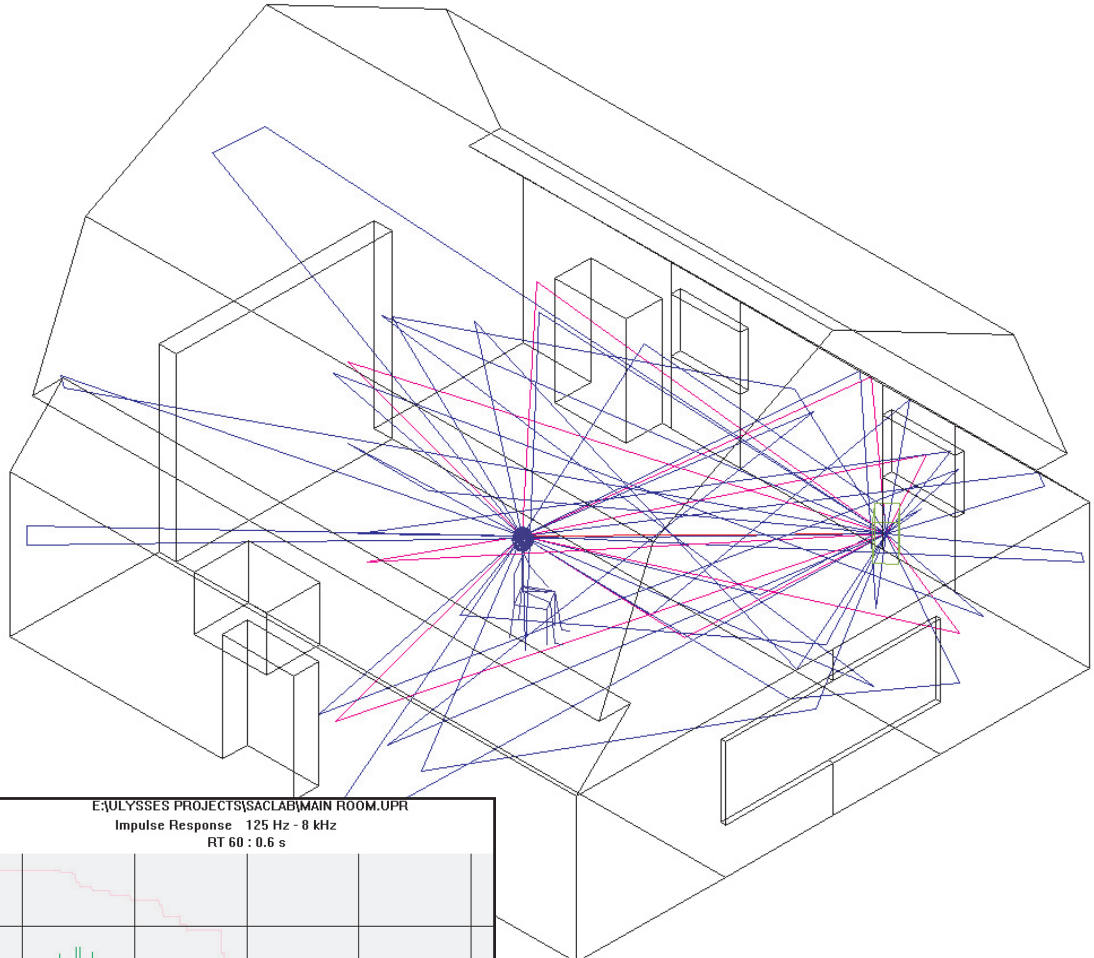


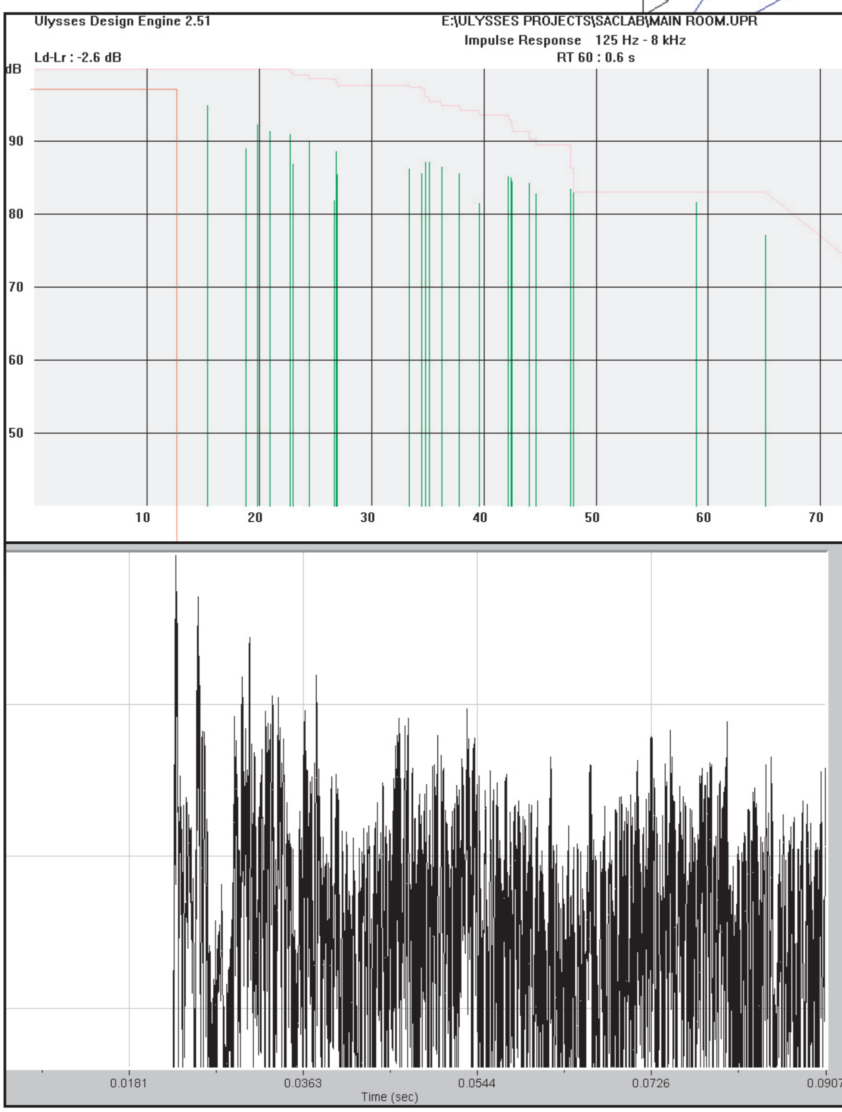
As might be expected, the first -order reflections were fairly predictable. A total of eight significant specular reflections arrived at the listener position. They are numbered in the room model, predicted reflectogram and measured reflectogram. Some of the "grass" in the measured data is due to room details that were omitted from the model for simplicity (fixed shelves with boxes, etc), as well as surface scattering that is not considered by this application. The reflections in the measured data that are not in the predicted reflectogram are of higher order (see p. 26 and 27).

The time scales do not line up exactly, due to scaling contraints in both Acoustic Tools and Ulysses. The early reflection levels can be useful for checking the absorption coefficients that are assigned to the room faces in the model.

Second-Order Reflections

Second-order reflections are those that bounce twice between the source and receiver positions. Losses are due to absorption on the reflecting surfaces, as well as spreading losses due to the inverse-square law.





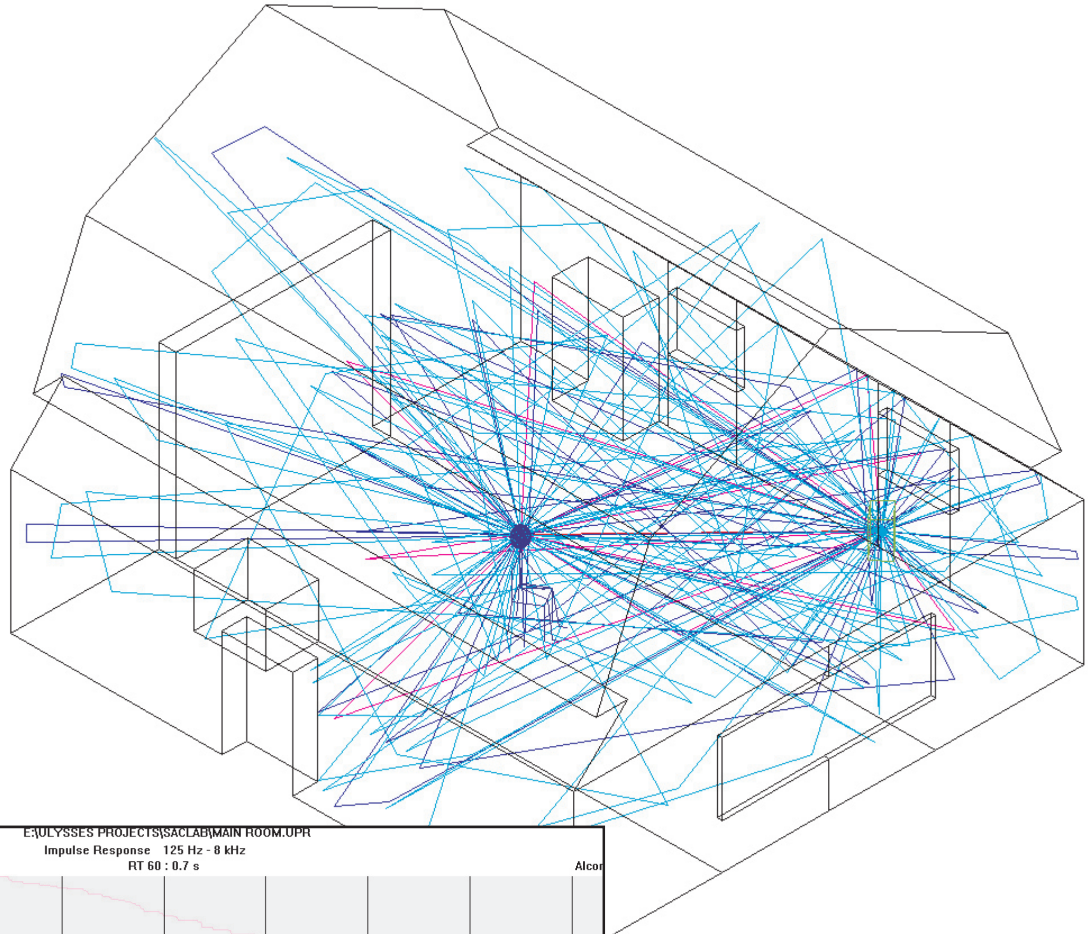
The blue rays represent the second-order reflections in the 3D room model. Predicted and measured reflectograms are at left. The reflection density is already high enough to make it difficult to ascribe specific reflections in the room model to specific measured reflections. The purpose of the model is shifting from identifying discrete reflections to estimating decay time metrics such as EDT.

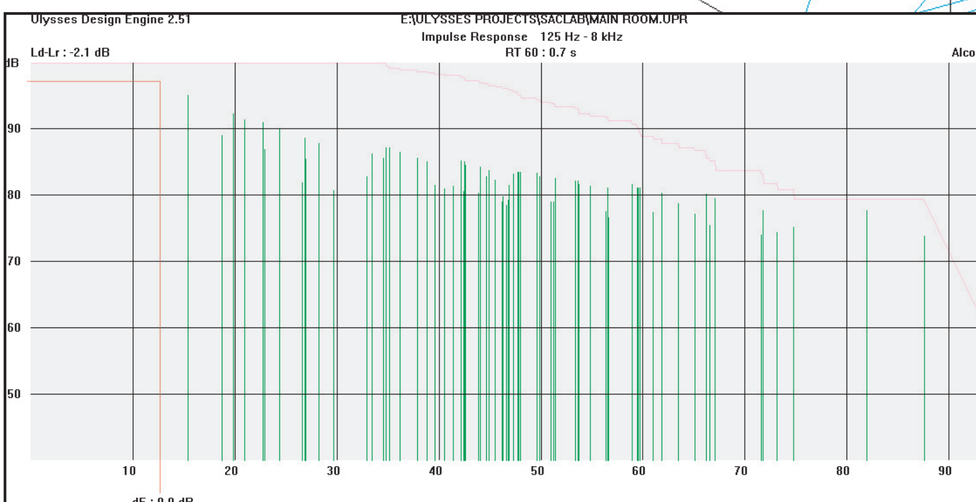
Simple image-source and ray tracing algorithms do not account for the fact that in an actual room each reflection acts like a discrete sound source that emits rays in many directions. As such, the burden of calculation should increase significantly with increasing time, as each bounce would produce many more rays into the model.

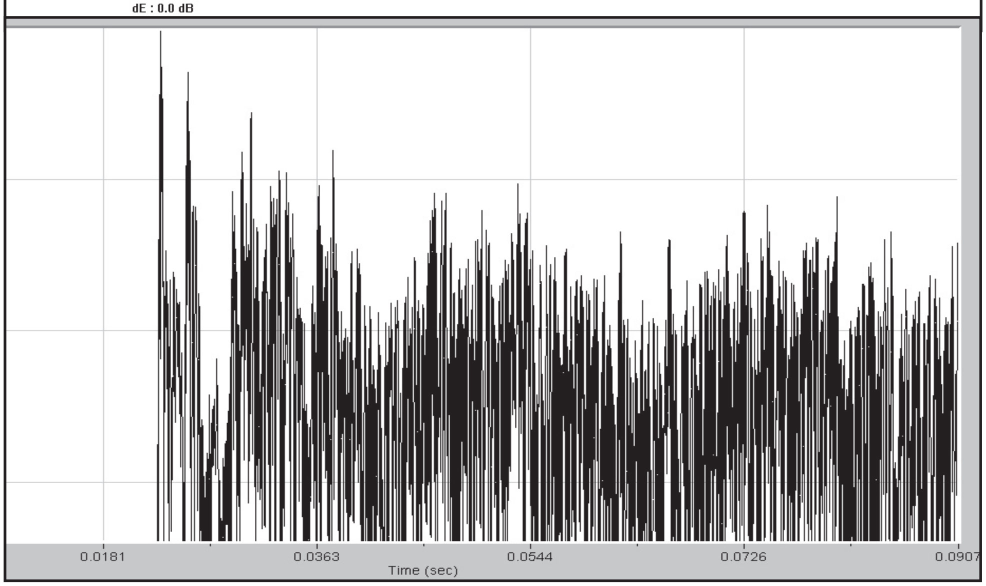
Third-Order Reflections

The third-order reflectogram reveals the worst-case scenario for the level of a specular reflection at a listener position. We consistently observe that in measured data the higher order reflections are seldom as high in level as those predicted by the model. This actually works to the advantage of the sound system designer, whose concern about the significance of a singular reflection increases with level. Ray tracing and image-source methods generally over-estimate the reverberation time T_{30} - often by significant amounts. Again, this works to the benefit of the sound system designer as the system will work better if the actual T_{30} is lower than the one that the system was designed for.

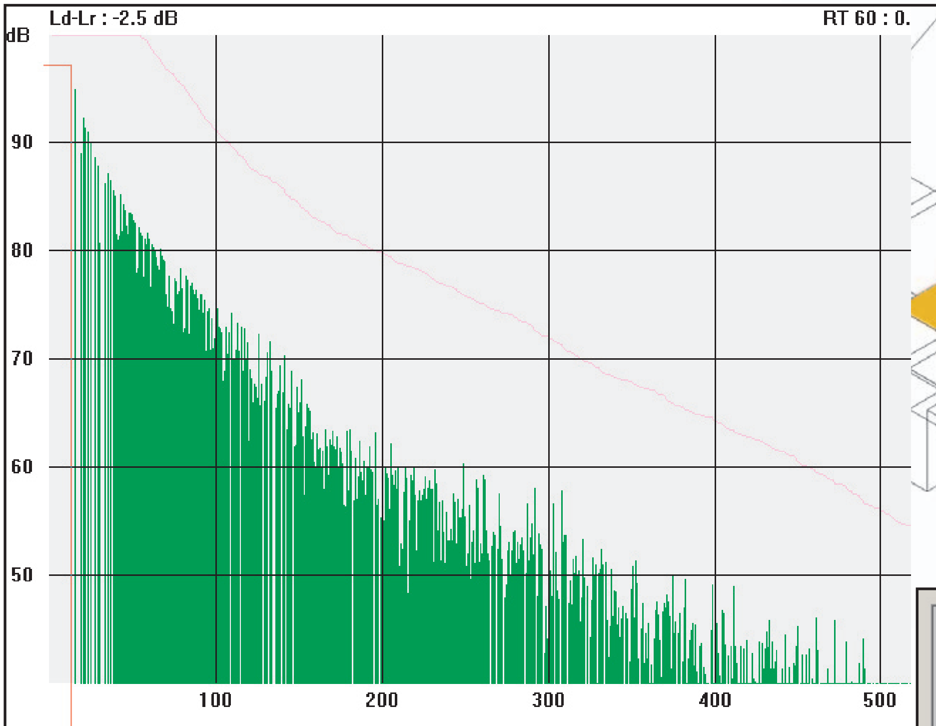
Even with an excellent room modeling program, the sound system designer must develop an intuition for when the predicted results don't line up with real-world results.

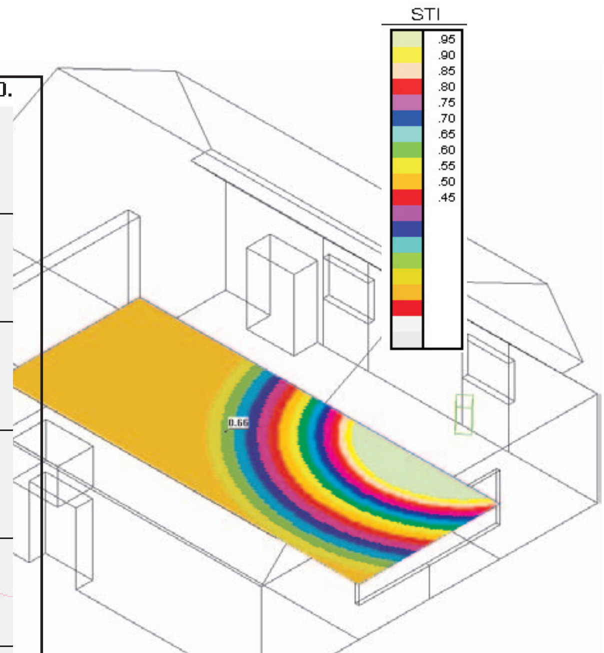


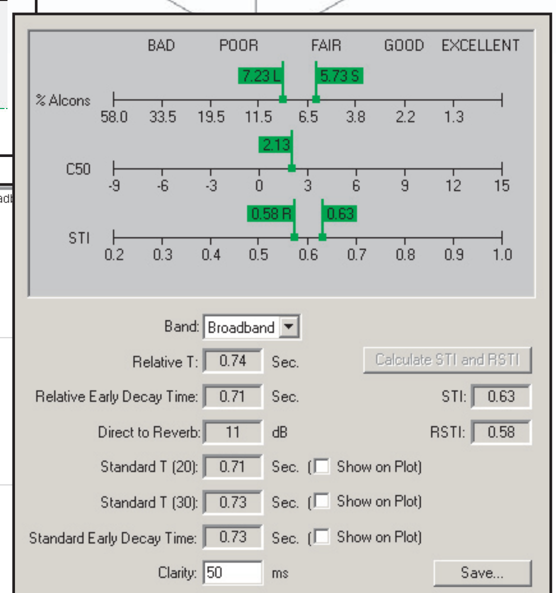


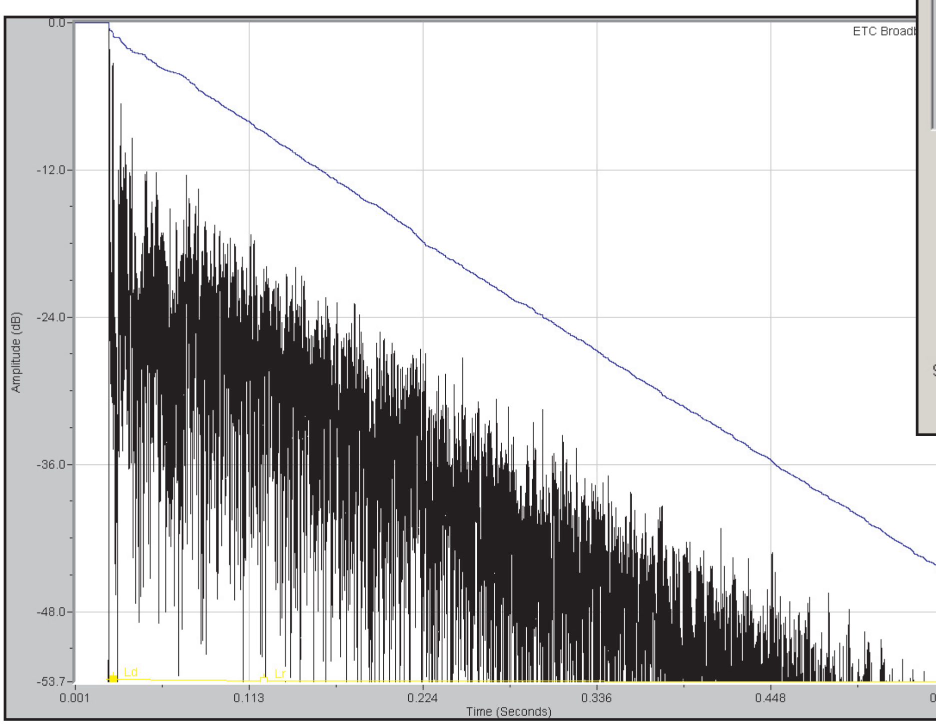


A 40-order reflectogram (software limit) was calculated with Ulysses and compared to the complete measured impulse response. This is broadband data, and would be more meaningful and instructive if broken down into octave bands - an exercise that is beyond the scope of a Tech Topic. Attendees of our Architectural Acoustics Measurement and Prediction seminar leave with complete room models and measured data for several projects. This allows them to conduct more detailed investigations into the accuracy of both the modeling and measurement processes should they desire.









What good is a room model if we don't use it to estimate the quality of speech? The room model predicted an STI = 0.66, which is pretty close to the measured 0.63 at the listener position. Noise was not considered in either the measured or predicted data. I felt the score was a bit low compared to subjective impression.

This is the room modeled in this study. It was cleared of its (movable) contents for the purpose of measurement.

Some General Conclusions Regarding Room Modeling:

From this study and many others like it, we can draw some conclusions about the role of room modeling in sound system design. Here are a few of the major ones:

1. Room models can yield information about the direct and early-reflected sound fields in an enclosed space that can influence the selection and placement of loudspeakers. Both of these fields have subtleties that are easily missed by intuition alone.

2. There are many aspects of sound behavior in an enclosed space that are not currently predictable by any program. This does not eliminate the need to predict, but should remind the designer that models only provide estimates that are based on what the designer has considered in building the model, and what the calculation algorithm considers when executing the math - both "human" limitations to accuracy.

3. There is a point of diminishing returns on model detail. For estimation of the major acoustic events, keep it simple.

4. For *sound system design purposes*, the direct and early-reflected fields should be modeled to determine coverage. Very early and very late reflections of low order, as well as statistical decay should also be considered.

Modeling programs provide first-order approximations of sound behavior in a space, but the first-order events usually have the most impact on what is heard by the listener. These are calculators that allow trained and experienced practitioners to simulate possible scenarios regarding loudspeaker placement and room geometry. Their accuracy is limited both by shortcomings in the ability to predict acoustical data as well as by deficiencies in the understanding of the user. Accurate acoustic predictions are still as much a function of the designer as they are of the software used. One must understand electroacoustics to effectively use the programs. Only then can the programs increase one's understanding of electroacoustics. *pb*

A special thank you to Bengt-Inge Dalenback (CATT-Acoustic) for sharing his insights in many email exchanges during the preparation of this Tech Topic. His writings on diffuse reflection (available from www.rpginc.com) are recommended reading for anyone using computer modeling to predict the performance of listening spaces.