Loudspeaker & Room Interactions

What happens to sound in its environment

By Pat Brown

Previously, the sound radiation from a loudspeaker was characterized graphically in three dimensions. *(Tech Topic, June 2004 issue)* Recall that the loudspeaker was placed on a "positioner" and rotated at a fixed angular increment. At each "stop" the sound pressure level was measured and recorded.

The resultant spherical radiation data was used to yield a number of useful metrics for determining whether the loudspeaker is suitable for a specific application. The loudspeaker is treated as a "point source" with directivity – an oxymoron, true, but still useful in concept. It can be placed into a virtual room to approximate the interaction between the two by calculation.

What happens when output hits that ceiling, that floor, those walls?

The acoustic environment is a big variable in the "what will it sound like?" equation. Reflected sound usually accounts for far more of what we hear in a room than the direct sound from the loudspeaker. If it is ignored, there can be some big surprises in the quality of the sound reproduction.

Let's look at how the loudspeaker radiation balloon might interact with a three-dimensional virtual model of an auditorium, yielding some insights into whether a sound system design is likely to meet its objectives.

IDEAL APPROACH

Before pressing on, understand that the objective of all of this effort is to approximate what the combination of the room and sound system will sound like in advance. The best way to answer this question is to place the sound system into the room and listen to it – a powerful design technique, and one that I use when practical and possible. It's the only design approach that includes all of the variables that affect the outcome.

Anything short of the listening process is an approximation. Many sound system performance failures can be averted if the designer spends a few hours in the space with some loudspeakers and a trained ear/brain system. (Of course, if the room doesn't exist, this method is obviously impossible.)

The next best approach is to build a physical scale model of the room. Architects do this to convey what the outside of the building will look like. Acousticians can do it to determine what the inside will sound like. The acoustical properties of a 1/10th scale model could be measured using the same techniques used to measure a full-sized room.

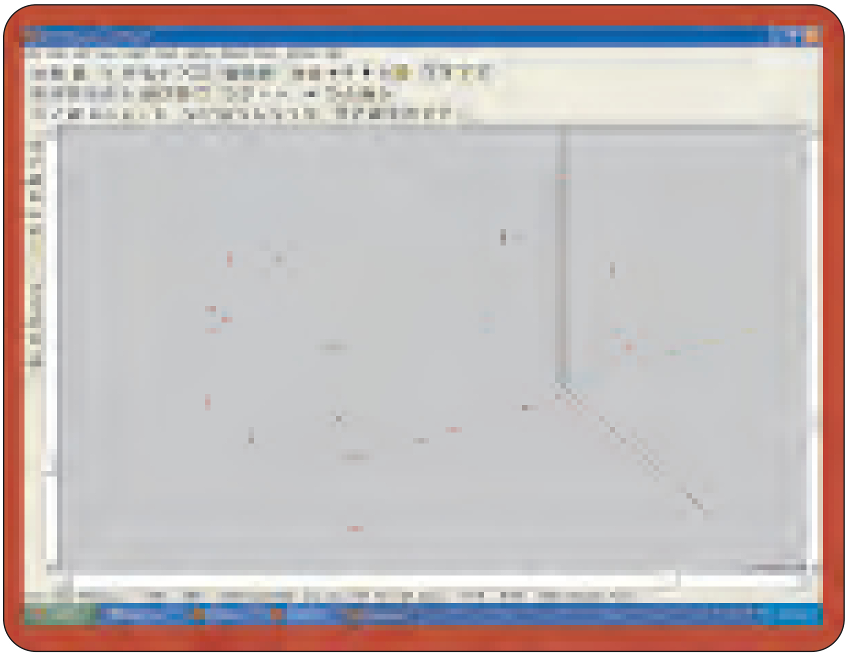

Figure 2: Each point (vertex) represents the intersection of two room surfaces (EASE).

A spark-gap generator can simulate an acoustical point source, and a very small microphone can be placed at a listener position. Acoustical modeling of this nature has been done for at least a half-century, and is still done today for acoustically important spaces such as concert halls.

But with all their advantages, scale models are impractical for most designs due to cost and time considerations. There are also serious problems associated with the scaling process. The room absorption must be scaled, so carpet may be replaced by felt. The room surface detail must be scaled, so an intricate surface may need to be approximated by a smoother one.

Further, the speed of sound must be scaled, so the model may be made airtight and filled with an inert gas. And, the source directivity must be achieved, which is darn near impossible, so a point source (i.e. spark gap) is used instead. Once the model is completed to the desired accuracy, impulse response measurements are gathered at various listener positions.

BURST OF ENERGY

The impulse response is simple in concept – a burst of energy is fed into the room from a specified position, and the resultant reflections are measured at another specified position. The "hand clap" test is a simple implementation of this technique. The impulse response is shown in **Figure 1** using a decibel vertical scale.

Each high-frequency room reflection appears as a vertical spike on the display. Lower frequency reflections are more smeared in time, and are usually masked in the display by the high frequency events. They can be observed by filtering the impulse response with 1/1-octave filters. Once the impulse response is known, the room's response to any stimulus can be determined.

A more practical method for reflection prediction is to build a virtual model on a personal computer. In the illustrations, the modeling program used to produce each plot is listed. (The sources for the applications are listed in the sidebar on page 62.)

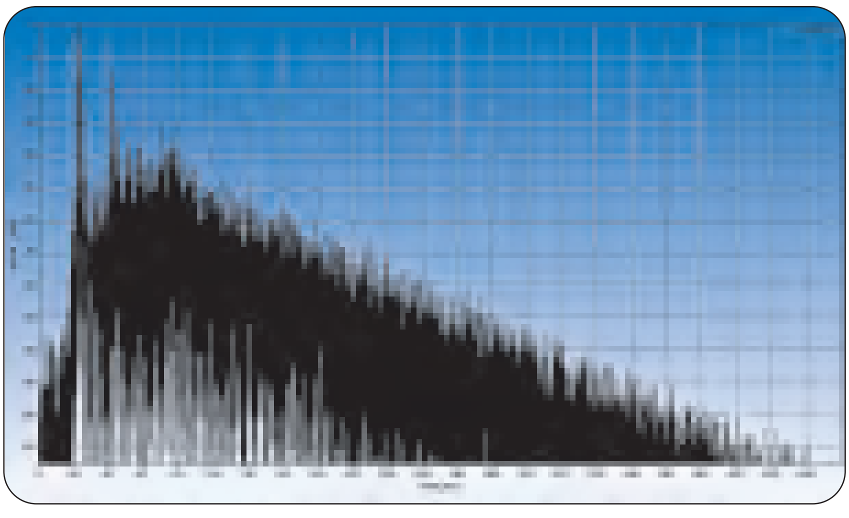

Figure 1: The measured log-squared impulse response of a large auditorium (WinMLS).

A physical room is a three-dimensional entity comprised of a number of surfaces. The surfaces can be simple planes or smooth curves. Computer-generated room models can only use flat planes, so curved surfaces must be approximated.

The room model is constructed by placing reference points (called vertices) using an X, Y, and Z coordinate system. (**Figure 2**) The vertices are joined together to form planes. (**Figure 3, next page**)

Each plane is then assigned an absorption coefficient that describes how much of the sound is absorbed (turned into heat) upon an encounter with the surface. If a point source were placed somewhere in the model, the exact distance to each reflecting surface can be easily calculated.

It's physically proven and widely accepted that the energy attenuation of sound as it radiates outward from a source is at a rate of 1/r2 where r is the distance from the source to the point of observation. This inverse-square law (ISL) rate of level change is true for a point source (infinitely small) in a free-field environment (no boundaries or other obstructions).

In practice, the ISL applies to the far-field direct energy radiation from a sound source. It provides a pretty good approximation of what will happen to sound from most loudspeakers. Special types of sound sources (i.e. line arrays and planar arrays) are handled in different ways.

BEHAVING LIKE LIGHT

How does sound "act" when it's radiated from a sound source into a room? One approximation is to consider it to behave like a ray of light. For our purposes here, we'll consider an idealized ray model where the sound wave will be approximated by laser beams emanating from a point source to a selected listener position. There are two approaches in common use.

The image-source method considers each room surface to act like a mirror, where angle of incidence equals angle of reflection. (**Figure 4**) A calculation algorithm determines which surfaces will produce a reflection that will eventually strike the listener position.

One could simulate this process with a laser pointer and a hand-full of small mirrors (I've actually done it this way in small room studies). The image-source method is an excellent way of approximating the first few reflections that arrive at a listener position.

The later energy arrivals are usually calculated using ray tracing. This is a statistical approach, meaning that many thousands of rays are radiated into the model in the hopes that all of the significant reflections will be captured. This likelihood increases statistically with the number of rays emitted – use too few and you will miss some – use too many and the prediction will take too long.

Ray tracing has some computational advantages over the image-source method for high reflection orders (large numbers of bounces). Many prediction platforms combine the two methods to approximate the total sound decay in the space. While acousticians are often concerned with point source (omni-directional) sound behavior, sound system designers need to include the effects of source directivity.

It's now time to merge the balloon data from the loudspeaker into the process. The emitted rays can be weighted by the attenuation balloon to consider the effect of loudspeaker directivity.

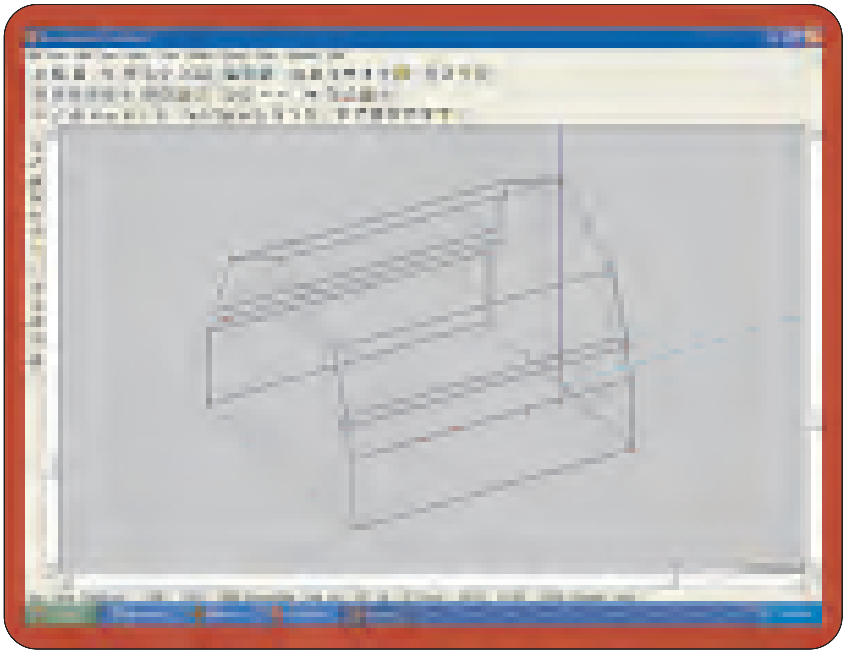

Figure 3: The vertices are joined to create the room faces (EASE).

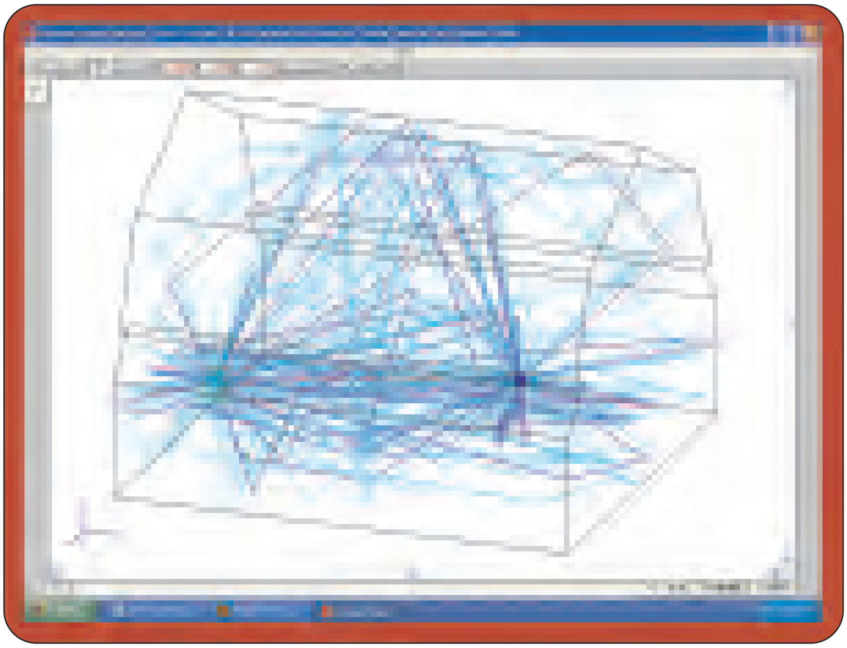

Figure 4: A sound source and listeners are placed into the space (Ulysses).

PLATFORMS USED IN THIS DISCUSSION:

Measurement
WinMLS – www.winmls.com

Prediction
EASE – www.renkus-heinz.com
Ulysses – www.loudspeakers.net
CATT-Acoustic – www.catt.se

PITFALLS & CAVEATS

One should never extol the benefits of the prediction process without warning about the shortcomings.

Sound versus light – Sound doesn't act like a laser beam. The beam describes the center of the area that the wave hits, but the actual area is larger. The treatment of a room surface must be suffi-

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ciently large to cover the desired spectrum, which can mean a very large area at low frequency (long wavelengths).

Scattering – Reflections beget reflections. When sound strikes a surface, it doesn't just bounce in one direction. There is a scattering effect wherein the reflecting surface acts like another sound source.

So, a better approximation of sound behavior would be to place another point source at each reflection point revealed by the beam. This would become computationally cumbersome after only a few bounces. Some prediction platforms ignore this effect altogether, and others use sophisticated algorithms to approximate it. If the intent is increasing the realism of acoustic predictions, consider the effects of scattering.

Diffraction – If the wavelength of a sound wave is large relative to the physical size of the object that it encounters, it will tend to pass around the object as though it were acoustically transparent. Diffraction is why you can stand behind a column and still hear sound from a loudspeaker. The effect is frequency-dependent and not fully considered by computerized room models.

Modal Sound Behavior – The behavior of sound at very high frequency can be considered using a ray model. This model becomes increasingly inaccurate indoors as frequency is reduced, and is completely inappropriate at low frequency. So, current room modeling techniques are (generally) limited to the upper two decades of the audible spectrum (200 Hz to 20 kHz).

How might sound behave in our idealized room model? The loudspeaker is placed at the desired position and a listener seat is selected. An algorithm creates rays that emanate from the loudspeaker, bounce off of the room surfaces, and arrive at the listener position some time later. The reflection order is user-determined. **(Figure 5)**

Low orders (less bounces) will identify the major problem reflections, while high orders (more bounces) will produce a more realistic "tail" on the impulse response. The time required for the calculation is determined by the complexity of the room and the desired reflection order.

The computation time can get quite long if the model is too complex, a common mistake made by users of these platforms. Each ray is attenuated by the travel distance and the absorption from each surface that it strikes.

More sophisticated algorithms will also produce some "scattering" on each wave encounter with a surface, the amount being user-selectable. This is the current "state-of-the-art" of acoustic prediction and it is in its infancy.

The result is an echogram for the listener position. (**Figure 6**) It's an approximation, but one that has sufficient accuracy to identify many of the problems that plague rooms and sound systems.

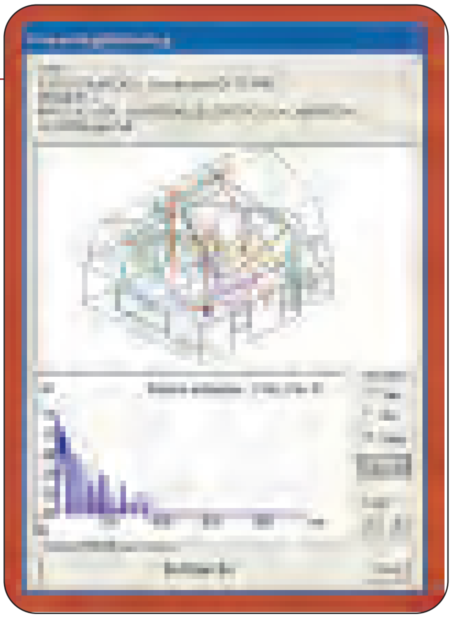

Figure 6: The room is scanned by the sound source and each "hit" on the listener position produces a spike on the echogram. The plot shows a single ray that bounces many times before hitting the listener. The full calculation repeats this process thousands of times (CATT-Acoustic).

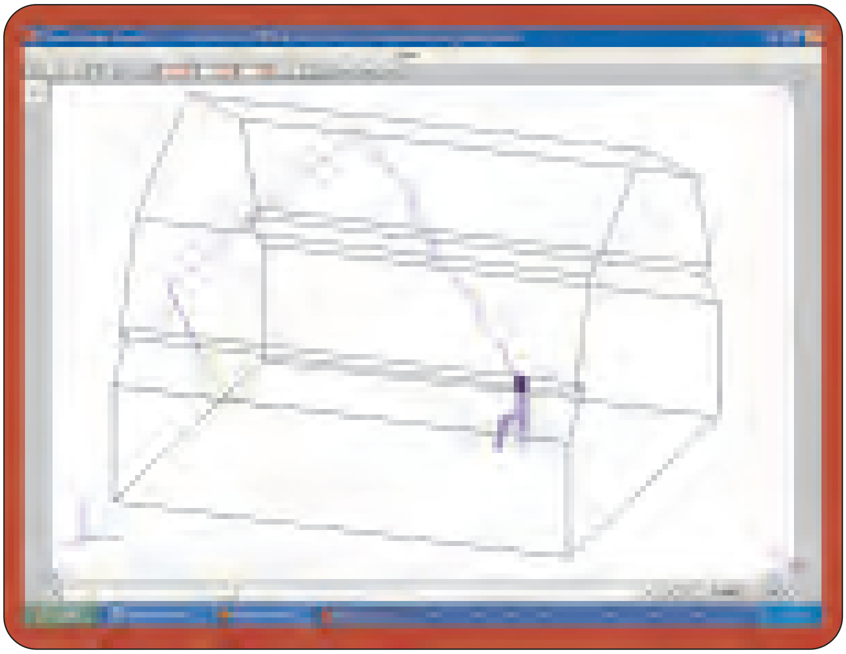

Figure 5: The reflected sound field is calculated by beaming energy into the room. The beams are weighted by the loudspeakers directivity balloon (Ulysses).

YOUR HOMEWORK

I have provided a very big picture of the prediction process. If all of this turns your crank, you should proceed to get some evaluation versions of the various platforms and investigate further.

Advance warning: this has the potential to eat up a lot of your free time, make your spouse angry, generate as many questions as answers, and make you discontent with every project that you work on from this time forward.

But it's also a lot of fun and very intellectually engaging, so go for it! ■

Pat and Brenda Brown own and operate Syn-Aud-Con, conducting training seminars around the world. For more info go to www.synaudcon.com.