Physics 1240 Course Notes **Tues, Thurs 4/11, 4/13/06**

Last time: Waves in pipes
Today: Begin architectural acoustics
Next time: Sabine's formula

Outline

- Qualities for room acoustics
- Acoustical Intimacy
- Source width
- Reverberation
    - Definition of Reverberation Time
    - Typical reverberation times
- Sabine's formula

Paul Horn, "Inside the Taj Mahal," **Track 10**

Concerto for Oboe, Violin and Orchestra in C Minor, Johann Sebastian Bach, Philharmonic Hall, 1966, Issac Stern, violin, Harold Gomberg Oboe, Leonard Bernstein, Harpsichord, **Track 4**

Concert Hall Acoustics

Architectural acoustics has a bit of a dubious history. Much of the science of room acoustics dates back to the early 1900's and Wallace Sabine, a Harvard professor who in 1895, took on the task of improving the acoustics in a poor-sounding lecture hall at the Art museum. Prior to that time, there was no science to it, and architects simply tried to imitate good sounding halls. Sabine became famous with the excellent sounding Boston Symphony Hall which he helped design (one of the best in the world). However, the track record of architectural acoustics since then has been spotty. The classic example is Philharmonic Hall that opened in 1962 in Manhattan and was a miserable failure! It was re-designed, re-opened and renamed Avery Fisher Hall in 1976. There is an interesting NY Times article on fairly recent successes (11/9/97) if you are interested in reading about this further.

The big problem facing architectural acoustics in general (not just for concert halls!) is trade-offs between visually pleasing design and use of space and the acoustics. As important, are constraints due to financing or the preferences of the people making the decision. Typically, if you are building or overhauling a concert hall, compromises must be made between parties:

1) The sponsor, usually a committee or executive board, provides the architect and acoustical consultant with basic constraints (location, size, number of seats, type of performances, other uses, etc.)

2) The architect and acoustical consultant work out a rough conceptual plan and then meet with the sponsors. The sponsors then have input and make final decisions on finances.

Other compromises:

1) Often, the architect is most interested in making visual artistic impact.

2) Multiple uses: Theater, Lecture, Choral, Orchestral, etc.

This give-and-take between the architect's interests, sponsor interests, and good acoustics is why the final result can be uncertain. If only architects were blind and sponsors had a lot of money! However, visual cues and senses other than hearing do play a role in our enjoyment of a concert. If visual cues are not consistent with what we hear it just isn't quite as good. Headphones just aren't the same as being there!

Can you give some criteria or qualities that are needed for good room acoustics?
Say moderate size, 500 seats, musical performance, lecture hall, theater, etc.

Qualities for Room Acoustics

Volume - The sound must be loud enough for everyone to hear.

Well distributed sound - The sound must be *well distributed* among the seating locations.

Clarity - no echoes, not too much reverberation.

Low background noise - HVAC systems, traffic noise, etc.

Envelopment - The sound appears to be come from all directions. The surround-sound effect.

Performer satisfaction

Good reverberation

These criteria are what we might call just acoustical common sense. We can design for them knowing absorption properties of building materials and how to estimate reverberation time. We will discuss reverberation time more later. But, it is a measure of how long the sound lingers in the room. Precisely, it is the amount of time it takes for a sound to drop 60dB.

These 7 items listed are more-or-less common sense. They are important and not addressing them can mean disaster, but it does not get at what makes a truly exceptional listening experience. We'll now discuss two additional qualities that are critical in designing an exceptional concert hall: 1) *acoustical intimacy*, 2) *source width*. In the late 60's Stanford researchers identified what distinguished concert halls in Europe with exceptional acoustics from the rest.

Acoustical Intimacy

Smaller rooms sound better. Or, at least it is much easier to design a small room that sounds good, then a large one. Why? Listeners simply prefer acoustical intimacy. But, how do we get this effect? You can actually judge a room size even if you cannot see. This is sensed by hearing the arrival time of *direct* and *reflected* sounds. Studies have found that the audience must hear a significant amount of reflected sound early. That is, early reflections must be no more than about 25 milliseconds. (See Figure)

See the work of Leo Beranek, *Concert and Opera Halls: How They Sound* (1996). Published by the Acoustical Society of America

Acoustical Intimacy is perceived by hearing the arrival time of *direct* and *reflected* sounds not too far apart. Studies have found that the audience must hear a significant amount of reflected sound early for a good listening experience. That is, early reflections must be present, strong and must be no more than about 25 milliseconds. (See Figure)

A clear direct sound is critical because we associate the location of a sound by where it comes from first. This is known as the precedence effect. This is a real problem if you are close to a one speaker of a stereo system. You will perceive the sound is coming from the close speaker even if you set the balance way towards the further away speaker.

Source Width

Another very important quality that is also related to early reflections of sound is the quality of *source width.* In 1969, Stanford researchers Damask and Mellert, and later Schroeder and collaborators did studies using dummy-head microphones (a nice account can be found in Pierce's book) that showed the following:

Listeners like differences in the sound (or slight delays) going to the left and right ear.

The term source width leads you to think we are talking about distances between the performers on stage, and to some extent this has an effect, but these dimensions or more-or-less fixed. When the paths of early reflections are different lengths we get differing delay times and this is the more important contributor to the source width (and we can design this in by choosing appropriate dimensions and materials). Both of these criteria result in the so-called "shoe box" design used by the most highly rated concert halls. **Long, Tall and Narrow**. It is interesting that the most expensive seats (center) are the ones that may suffer from a lack of source width. How can you design to improve this?