THE INVERSE SQUARE LAW

ARCH 426

LECTURE 6

Architectural Department

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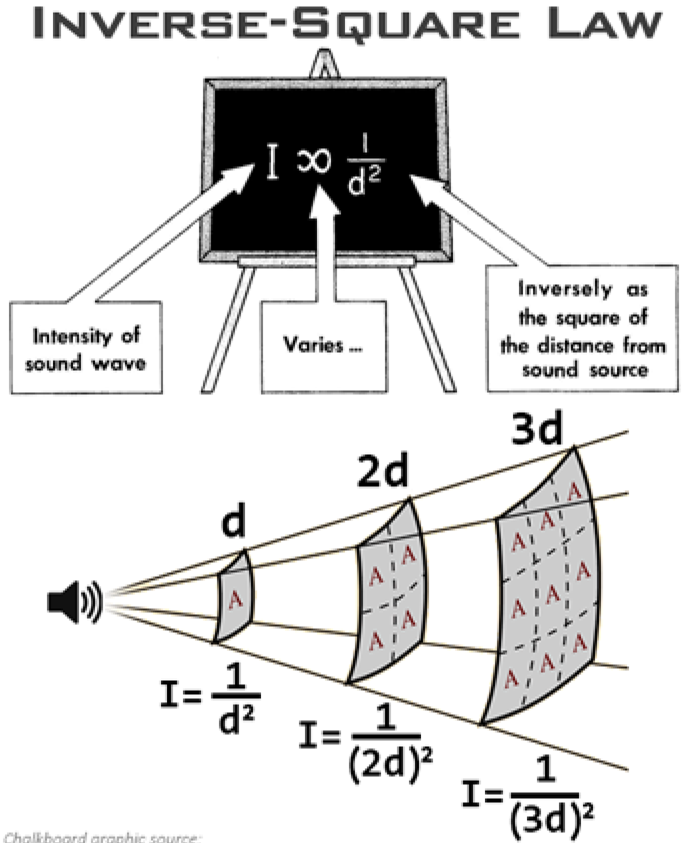
The INVERSE Square :

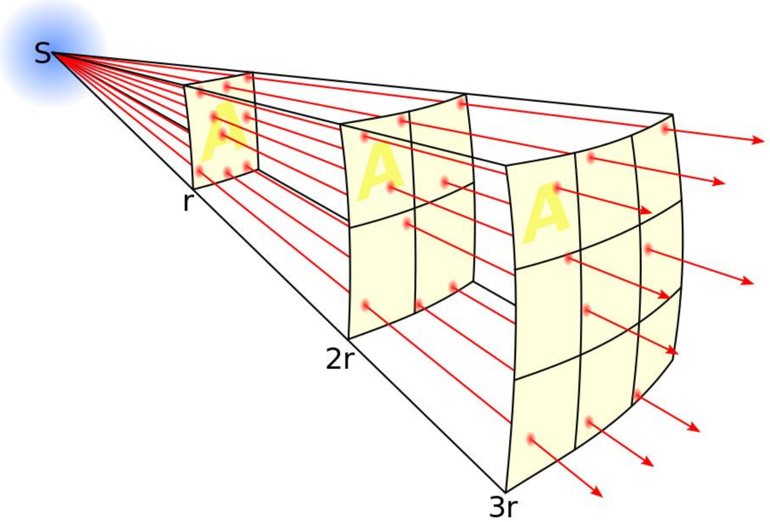
- A. Every time the physical distance between you and the sound source doubles in distance, the sound will be 6 dB lower (softer).
- B. The opposite holds true too. As the distance is cut in half, the sound will get louder by 6 dB

- **Here is a very basic example:** Start with a sound source that is
- ---------3-----------86dB
- -----------6-----------80dB
- -----------12----------74dB
- -----------24-----------68dB
- **Thus less 6dB softer when distance doubles and louder when moves towards the source.**

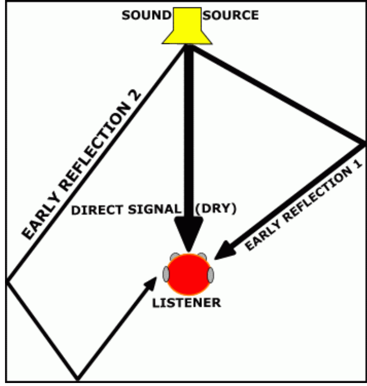
$Spl=20Log(p/pref)$



Chalkboard graphic source:
http://www.vias.org/crowhurstba/crowhurst_basic_audio_vol1_018.html



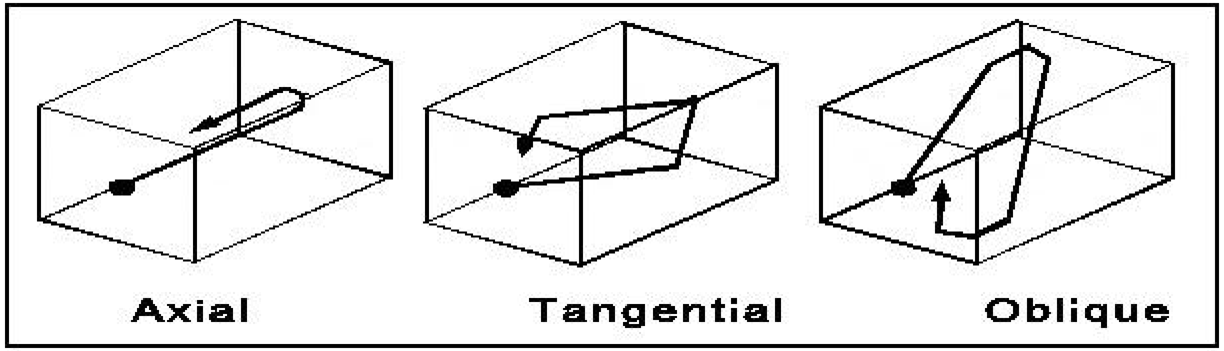
The Critical Distance:



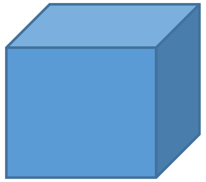
- **Critical Distance:** In the glossary of audio terminology, "critical distance" defines the point at which **direct sound energy and reverberant sound energy** have **the same SPL**. A **one-to-one energy ratio** has been located.
- A. The inverse square law only hold up as long as the measurements are taken between the direct sound source and the point at which the critical distance is found.
- B. **In a highly-reverberant room**, critical distance may be achieved quite close to the **sound source or a loudspeaker**. This, however, is usually not a good arrangement. In most cases, the 1:1, critical distance ratio should never be found *within the essential seating areas of a venue*.
- C. If found outdoors, critical distance may be a considerable distance from the direct sound source. This is because a reverberant field generally doesn't exist. It's more likely a variant of critical distance will be found at the point **where the direct sound and the ambient noise become equally loud.**

The Room Modes:

- **Room modes** are the collection of resonances that exist in **a room** when **the room** is excited by an acoustic source such as a loudspeaker. Most **rooms** have their fundamental resonances in the 20 Hz to 200 Hz region, each frequency being related to one or more of **the room's** dimension's or a divisor thereof.



The Room Modes:



- 1. **A room with very simple geometry, i.e. a "cubed" rectangle, will almost always have the fewest number of resonant, modal frequencies. While this may sound like a good thing, it is not. The optimum goal is nearly the exact opposite. It is desirable for room modes to be reasonably-dense, and evenly spaced, throughout the *LF wave*-region of the frequency spectrum**.
- a. A room with dense, evenly-space modal resonances will be perceived as having more "warmth", or a "warmer" sound. This is generally a good feature.
- b. These resonances must also be damped and contained in duration. This means the decay time of the various modal resonances must be well controlled so they properly match the venue's desired T60 range, and the audio material being performed or presented.
- 2. One other important goal is to minimize the excess strength of any specific modal frequency, or cluster of frequencies. When this is an issue, very targeted **absorption or diffusion treatments may be required**.
- **3. Room ratios are the primary controlling factor related to the density and spacing of the modes.**
- It is not overly difficult to calculate the room modes of an empty, rectangular room, having a flat floor and ceiling. It is, however, extremely difficult to calculate room modes for a room with complex geometry
- **Room dimensions typically start from the ceiling hard boundary.**
- **If we use the golden ratio then this will produce a room with dimensions based on the ceiling height, then to the width of the room and next the depth of the room.**
- **With an eight foot tall ceiling, based on the Golden ratio we would use 1: 1.62: 2.62, this would be a room with a ceiling height of 8 foot with a width of 13 feet and a depth of 21 feet!**

The Room Modes:

- Naming the three room modes:
- A. In a rectangular room, modes are calculated based on three possible geometric pathways of sound reflection. Those pathways are called: axial, tangential and oblique.
- 1. These words define the reflective pathways traveled by *LF waves*, depending on whether they bounce between two, four or six walls.
- a. A two-surface bounce is defined as an axial mode.
- b. A four-surface bounce is defined as a tangential mode.
- c. A six-surface bounce is defined as an oblique mode.
- 2. Don’t try to remember these terms, just be aware they are real and are the basis of room mode calculations.

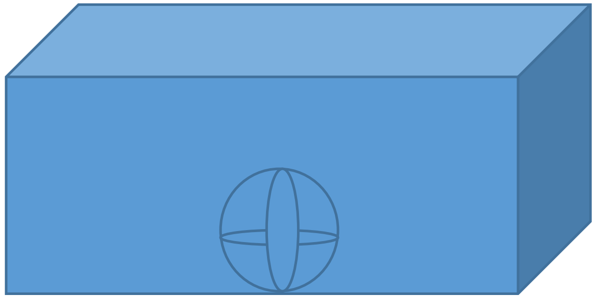
Room ratios:

- **Room ratios:**
- A. Primary room dimensions are expressed in terms of height, width, and depth (HWD). A room with dimensions of 8' x 20' x 30' has this set of ratios – 1.0:2.5:3.75.
- 1. The smallest dimension always represents the 1.0 place holder. The other dimensions are multiples of the first value. The sequence of the numbers is insignificant.
- B. There are many “optimum" ratio sets stated in the technical references. Here is one example: 1.0:1.4:1.9.
- 1. In this case the room might have a 10’ ceiling, and be 14’ wide and 19’ deep. This would be a very nice rectangular room shape to work with. Need a bigger room? Double all these dims so the room becomes 28' x 38', with a 20' ceiling. The ratio set stays the same.
- 2. Depending on the overall room size being planned, many other good-to-optimum ratios exist, so there are several options to be considered. Your friendly, local acoustician can help you find the best ratio set for your project.
- 3. Designing around one of the optimum ratios is not the only factor to consider, but it’s a good place to start if you are building a rectangular room that will be used for some type of sound generation or reproduction.
- a. If a venue is only going to be used for speech-range applications, the importance of using good room ratios is less significant.

Room Geometry

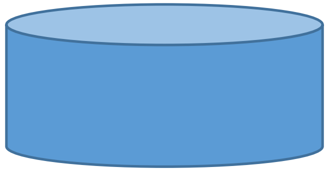
- **ROOM GEOMETRY - THE GOOD, BAD AND UGLY**
- It's very hard to separate these two fundamental topics: architectural geometry and AA. At the most basic level, it's safe to say that any room having complex, yet symmetrical, interior geometry will complement sound better than a room with simple and/or asymmetrical geometry.
- A. The rectangular, "**shoebox**" room is a very common shape; having only six major walls or faces. Each pair of walls are parallel. All corners are set at 90 degree angles; a very simple three dimensional shape, and typically, very cost-effective to build.
- B. **When a more complex interior geometry is suggested, we're talking about convex curves, acute and obtuse angles, tilted walls, alcoves, balconies, non-flat ceiling structures, sloped or stepped floors, etc.**
- C. With the concept of simple and complex internal geometries in mind, let's now consider various room shapes. The following list includes many possibilities. Not all are particularly usable, but they do illustrate many key acoustical concepts relating to the ideas being expressed.
- **Sphere** - The inside of a sphere is generally the worst acoustical shape. Because this isn't a practical building shape for most commercial venues, it is rarely seen, and not worth much further commentary.

Sphere.



- A. If you are seriously considering the design of a spherical room, one of your first phone calls needs to be to an acoustical consultant. There will be much work required to make this shape sonically tolerable.
- B. Conversely, the outside of a sphere is an excellent shape when located inside of almost any room. It becomes a very effective, **convex diffuser. .**

Cube and Cylinder Shape



- **Cube** - This is the worst of the realistically-usable room shapes. The problem is that all three dimensions are equal, and that each of the three dimensions are parallel. Though it may not be obvious, a cube-shaped structure will result in all kinds of nasty sound problems if it has hard, reflective surfaces.
- A. Massive echo problems, and very-poorly distributed room modes, are the main issues with this shape. Much work will be required to make a cubed room sonically viable.
- Cylinder - A round room with a flat floor and ceiling. This is a difficult shape for any sound-related activity.
- A. Without significant absorption or diffusion materials incorporated into the vertical walls, this footprint will likely be unusable for public assembly. Oval rooms have very similar problems.
- B. The primary issue with cylindrical and oval rooms is the focusing of sound, toward a fairly small area, near the center of the arc radius. This is caused by the concaved side walls. Once again, much work will be required to make this shape sonically feasible.

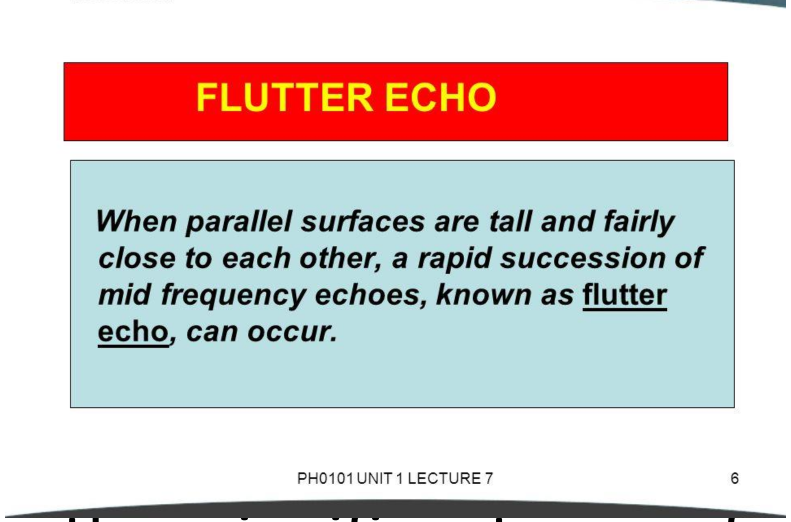
DOME

- **Dome** - Picture a literal dome or a cylinder with a domed roof. These shapes have all the same issues as the sphere and cylinder, but are even worse because of the concave ceiling. Again, without the addition of specific acoustic treatments, these shapes are nearly unusable for most public activities.
- A. **If at all possible, never build a commercial space with a dome- or pyramid-shaped ceiling. This may look creative and artistic, but it will almost always result in a room that doesn't work well for good sound reproduction.**
- B. If it must be done, be sure and include an acoustical consultant on your engineering team, and a budget for some "creative" acoustical treatment within the envelope of the dome or pyramid.

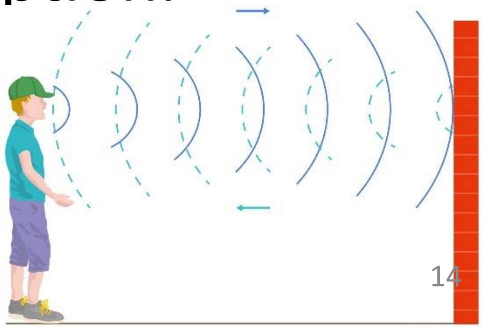
Rectangle (2D floor plan)

- Rectangle (2D floor plan) - This is probably the most common shape for commercial venues. Picture the common shoebox geometry, as referenced above.
- A. The geometry of a rectangular room is simple and obvious. Hopefully, the height, width and depth dimensions will be different, and be designed around a good set of ratios.
- 1. Contrary to popular belief, parallel walls are not automatically a negative acoustical factor. However, there are potential problems if the room is not designed with some care beyond the basic construction requirements.
- a. As noted above, the HWD ratio set is the first item of interest. While there are a number of complementary ratio sets, there are also many sets that are quite bad. Whenever possible, try and preview the primary ratios you may be considering.

Flutter echo:



- B. Flutter echo:
- 1. In rectangular rooms, another significant area of concern relates to minimizing or eliminating audible echoes. Echo, sometimes called "flutter echo", occurs when sound bounces rapidly, back and forth, between hard, parallel surfaces.
- a. To minimize or eliminate discrete echo, any number of diffusive and/or absorptive finishes or treatments may be employed.
- b. Fear not. Flat, sound soak panels are not your only option.



Triangle (2D floor plan)

- Triangle (2D floor plan) - A true triangle is not a common building shape, but it does present one nice feature; the side walls are about as far from parallel as possible. Flutter echo shouldn't be a problem, unless it occurs between the floor and ceiling.
- A. Warning: Triangular- and pyramid-shaped rooms present modal problems, much like cube-shaped rooms. This is especially true for equilateral, triangular enclosures.
- Quarter-round and half-round (2D floor plan) - In recent years these shapes have become popular for performing arts and house of worship venues.
- A. While these shapes can be quite good when considering sightlines, and a need to put the audience as close to the stage as possible, they can present acoustical challenges too.
- B. Any concaved, interior wall surface presents an acoustical paradox.
- 1. If the concave surface is on the back wall of a stage, it may serve as an effective acoustical reflector, which may possibly enhance certain styles of musical performance.
- 2. If the back wall (opposite the stage) has a concave shape, it may not be a good acoustical element, and will probably need some specific treatment in order to minimize the negative effects (arc radii focusing) of the reflected energy bounding off the curved shape.
- 3. Regardless of the fact that the back wall is a true curve, or a facetted curve, the detrimental effects are similar.

- Trapezoid (2D floor plan) - Like the quarter-round shape, the trapezoid room has one notable advantage: at least one set of walls is not parallel. This will help break up flutter echoes, and create more complex modal behavior in the *LF wave* region.
- A. The greatest disadvantage of the trapezoid shape is that the front and back walls are often either parallel, or one or both are built with a concave curvature. Both of these conditions will require further evaluation, and treatment, if not properly factored into the initial design.
- 10.10 Pentagon (2D floor plan) - The pentagon shape is this author's favorite because it's the shape that offers a large seating area, good sight lines, and no major, parallel or curved walls.
- A. As nice as this shape may appear on first glance, there are still potential acoustic issues to be considered. These are based on:
- 1. The dimensions of the wall segments Acoustics 101 for Architects Page 25 of 49 First Edition GraceNote Design Group © 2013 All Rights Reserved Revision 1.3.1
- 2. The symmetry of the layout
- 3. The height and potential slope angle of the ceiling
- 4. The potential slope angle of the floor
- 5. The location of various key elements such as a stage, and the seating layout

- Hexagon (2D floor plan) - More facets is not necessarily better. The hexagon plan falls back into the rectangular group of shapes because it has multiple, parallel walls. All the same precautions must be taken related to flutter echoes and room modes.
- 10.12 Heptagon (2D floor plan) - Much like the pentagon, a potentially good acoustical shape to consider. However, now construction costs start to climb, but with no real acoustical improvement.
- A. The heptagon shape also begins to more closely resemble a cylinder, which as noted above, can be problematic.
- 10.13 Octagon - See hexagon and heptagon.
- 10.14 Concave and convex planes - There is no question that architectural structures take on many other, more complex shapes than those outlined above. Therefore it is appropriate to summarize the relative merits of these two, plane curve shapes.
- A. Concave plane curves: Almost all concave planes are acoustically challenging, especially if they are finished with hard, reflective materials.
- 1. As noted earlier, concave surfaces can concentrate reflected sound energy into a fairly small area. The density of concentration, and the size of the focal point, are largely determined by the arc radius of the plane, and the overall size of the curved surface.
- 2. Focusing reflected sound is usually not desirable, and should be avoided in most situations. Yes, there are exceptions to this guideline, but they are rare, especially in multi-use facilities.
- B. Convex plane curves: Convex planes bring the exact opposite results, and are generally encouraged, where and whenever possible.
- 1. Convex planes are inherently diffusive, which is good. More often than not, convex planes result in improved acoustics and sound.
- 2. Faceted convex planes are less complementary, but still can be beneficial. The number of facets, and the arc radius of the curvature, will determine the relative benefits. More facets generally bring better results.
- 3. If a building's design is able to include two or more, mirror-image, convex planes, regardless of location, the need for additional diffusive or absorptive materials may be greatly minimized

Symmetry

- Symmetry - If the purpose of a room is to support live performances or the presentation of other useful, audible information, it helps tremendously to design a symmetrical interior shell.
- A. One of the prime goals and challenges, for the sound system designer, is that of delivering even sound coverage to all seating areas.
- B. There are significant performance, cost, and aesthetic benefits achieved when a room is designed with mirror-image symmetry along the center line axis of the stage or platform.
- C. Later, in the section on psychoacoustics (Section 16), the importance of "time" will be further developed. But in the context of symmetry, it is important to note these points:
- 1. Good quality sound reinforcement requires careful analysis and implementation in the time domain. A sound system that is not properly "time-aligned" is analogous to a photograph that is out of focus.
- 2. Every major building element or feature, which introduces significant asymmetry to the floor plan, ceiling, and/or the audience seating area(s), can add cost and complexity to a room's sound system requirements.
- a. Asymmetrical sound propagation generally translates into time-domain challenges that must be resolved.
- b. Additional sound devices, labor, structural points, and aesthetic anomalies, can all become unexpected challenges brought on by the need to support an asymmetrical structure. Obviously, each of these adds cost and technical complexity to any sound system.