The challenges in achieving good sound coverage in stadium-style auditoriums

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Over the last several years the most popular trend in theatre design has been the steeply-raked seating plan known as “stadium” style seating. Two key features of stadium seating are its multiple risers and unobstructed sightlines. As any moviegoer who has seen a film in one of these houses can attest, stadium seating adds a certain degree of involvement with a film, similar to that of attending a sporting event. While this room design may be more appropriate for some genres of films than others, there is no question that it adds excitement and a way for exhibitors to differentiate their multiplexes from their competitors who do not build stadium houses.

Stadium seating plans must be examined for their potential impact on other aspects of theatre design and the moviegoing experience itself. Architects and building designers can detail the budgetary and space utilization issues which arise from stadium seating. Another area where the impact of stadium style theatre design can be quite dramatic is sound coverage. This is also an area which has been little explored. But with some careful analysis and intelligent sound system design and installation, the visual benefits of stadium style seating can be enjoyed without sacrificing excellent coverage for every seat in the house.

The two areas of sound which are most affected by the steep seating area is 1) overall effectiveness of the surround array, especially at the rear of the house, and 2) the vertical coverage of the screen channel speakers.

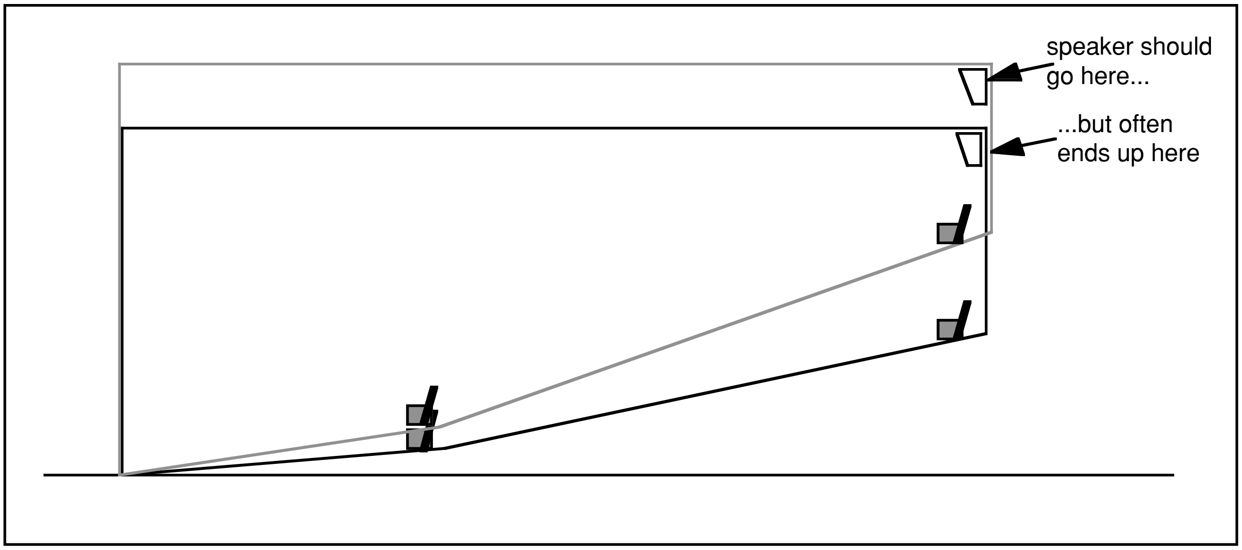

Figure 1. Typical slope seating area (bold line) and stadium-style slope (light line).

Figure 1 shows a side elevation of an hypothetical theatre with a standard slope (outlined in bold line) and a much steeper slope (outlined in lighter line), representing stadium style seating. The first thing that becomes apparent in this illustration is that the ceiling of the entire room needs to be elevated if we are to maintain roughly the same “headroom” (in the physical sense, not the electrical sense!) at the last row of seats. But what happens in practice, however, is that the ceiling height is not usually raised, so the actual floor-to-ceiling height at the rear of the house is sometimes very low, often less than 3 meters. This creates an issue for rear of house surround speakers, since their placement may end up to be very close to seated patrons. When the speaker is located very close to the audience, the chances of the audience “localizing” to an individual speaker are increased. With conventional soundtrack design of the surround channels (where surround channels provide the “ambience” of the on-screen images), localization to the surround speakers is usually distracting and can “break the spell” of the film experience. The most obvious solution would appear to be to use much smaller speakers at the rear of the house. The problem with that approach is that it runs contradictory to the evolution of surround channel soundtrack trends. Digital sound sources have given us not only stereo (“split”) surround channels, but also the capability to put much higher sound pressure levels and wider bandwidth (deeper bass) sound signals into the surround speakers, and this capability is more and more used by film directors. Both demand higher power handling and better bass response from the surround speaker. This is turn usually dictates a *larger*, not a smaller, surround speaker.

A solution may be to use smaller, yet higher power handling speakers whose level can be adjusted independently of the rest of the room's surround array.

Sound coverage from loudspeakers is usually discussed in terms of basic geometry. Room design, likewise, is very easily adaptable to concepts of geometry since most rooms are symmetrically designed as some form of six-sided volume. The geometric discussion of sound coverage is complicated by the fact that sound emanates, or is "dispersed", from speakers at different geometrical patterns depending on frequency. It is difficult to direct the coverage of low frequency sounds, and high frequency sounds can be somewhat directed by the physical structure of the loudspeaker device; in cinema applications, this is usually a "horn" device, which has a defined coverage pattern. The typical pattern of a cinema horn is 90 degrees in the horizontal plane and 40 degrees in the vertical plane. With a well-designed horn, beyond the 90 by 40 degree coverage pattern, the sound level drops off rapidly.

Because stadium seating affects the vertical elevation of the seating area, it is easy to see that some adjustment will need to be made in vertical horn aiming to obtain optimal coverage in stadium houses.

If we first look at the typical non-stadium house (fig. 2), we can see that aiming the horn in the typical fashion where the centerline is aimed at the last row of seating provides good coverage from front to back. This is because the farthest rows of seats are directly "on-axis" receiving the most direct sound from the screen speaker, and the closest rows are "off-axis". Because the speaker is nominally a 40 degree vertical pattern device, patrons seated off-axis receive less sound, but this is offset by the fact that they are seated closer to the speaker.

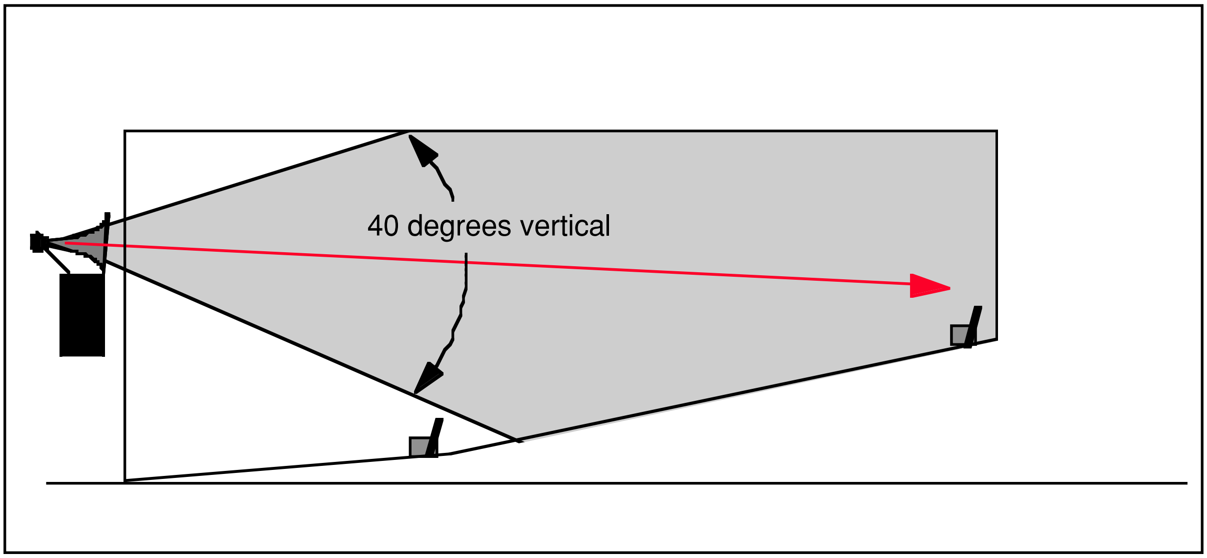

Figure 2. Typical non-stadium house, vertical coverage pattern.

Now if we look at a more steeply sloped seating area, all other things kept equal without re-aiming the horn, we can see that the front row is now in the direct pattern of the horn (at ear height), and so the sound level may be too high in the front compared to the rear; in audio terms, we have lost some degree of the natural attenuation of the off-axis sound versus the so-called "inverse square law" loss of sound due to distance toward the rear of the house (see NOTE or SIDEBAR). In other words, the sound is now less evenly distributed throughout the theatre.

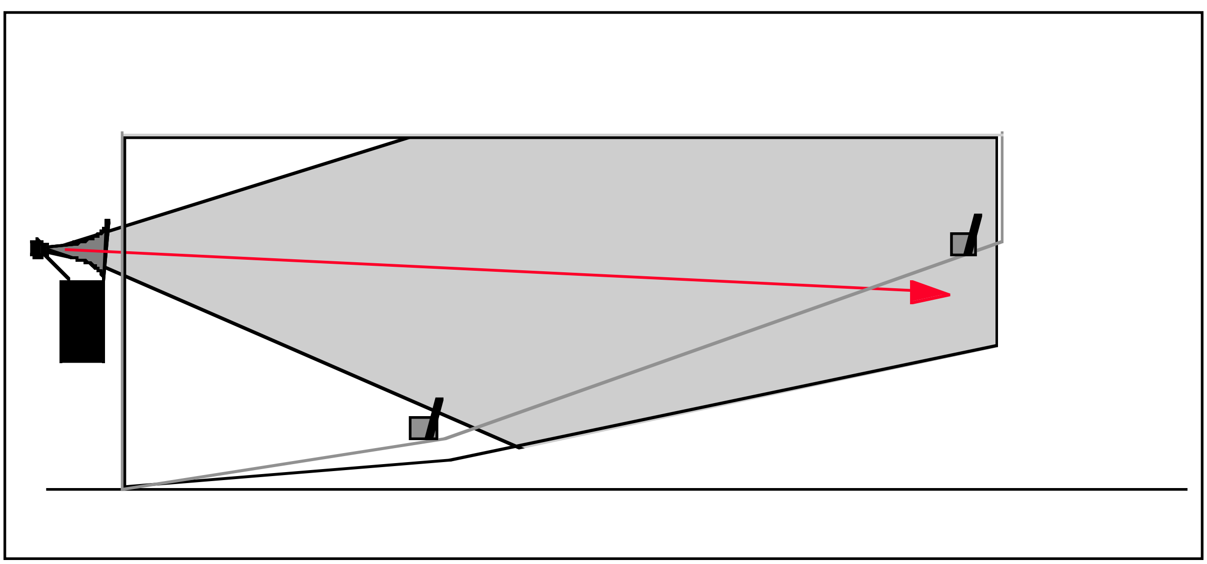

Figure 3. Stadium house, without adjusting horn aiming.

What seems apparent is that we must lift the altitude (or vertical pitch) of the horn to aim approximately at the last row of seats. This allows us to re-gain the off-axis vs. loss due-to-distance advantage. Now we can see that the first row of seats is once again conveniently off-axis relative to the 40 degree vertical pattern of the horn, and yet much of the direct on-axis sound is heading to the rear of the house. However, this new angle poses two complications. Much of the sound energy is being directed to the relatively-low ceiling. This means that, depending on ceiling height relative to the seated patrons, an excess of sound can be reflected back to the seating area, causing potential adverse effects on dialog intelligibility. This problem can be minimized if the ceiling surface is treated with materials to be high frequency-absorptive, and is "stepped" to break up sound reflections which may occur.

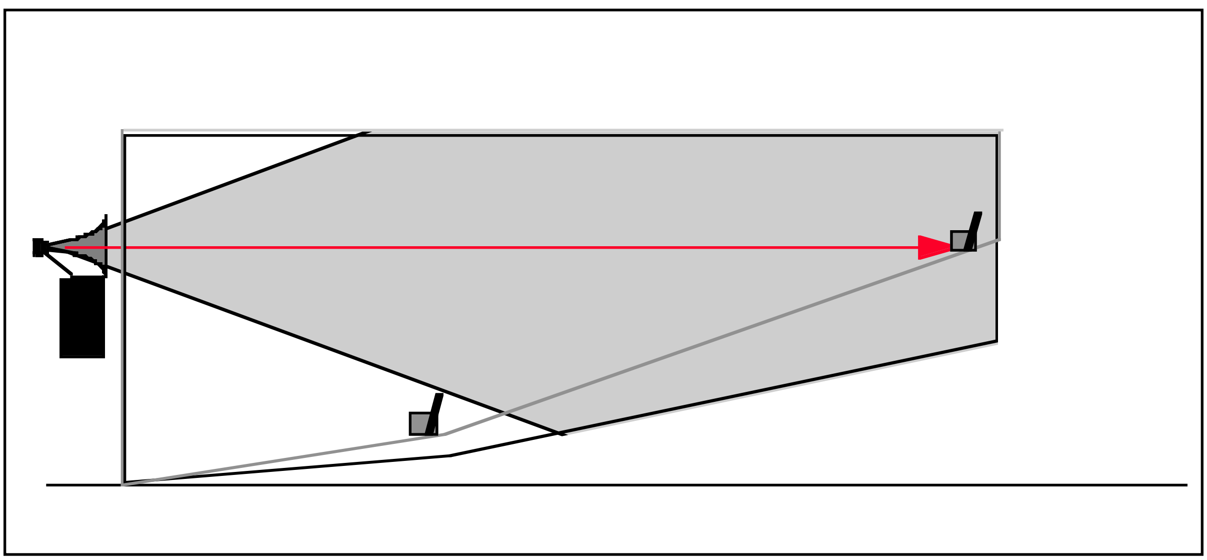

Figure 4. Stadium house, horn aimed parallel to ceiling.
Note that horn is also parallel to screen.

Another complication that results is an increase in behind-screen sound reflections. Anyone who has ever been behind a perforated screen while sound is coming out of the horn knows that a lot of sound is simply reflected back into the horn and into the rear area behind the screen. When the horn is aimed higher and approaches a zero degree tilt (horn mouth is parallel to the screen), this represents the absolute worst case of detrimental behind-screen reflections, because a high percentage of the sound will be reflected right back into the mouth of the horn and reflected off of it, and proceed out through the perforations to the audience. The result is degradation of sound quality and dialog intelligibility.

Many horn designers have been experimenting with (and using with some degree of success) a new family of horns, often referred to as "asymmetrical pattern" horns. In contrast to "constant directivity" horns, which radiates sound in a controlled yet symmetrical "pattern", these horns are used specifically to radiate more energy in one part of its coverage pattern than another. This may offer the ability to direct sound to the rear of the house without sending an excess of energy to the ceiling, and still keep the front row out of the direct on-axis pattern of the horn (see figure 5). Also, we can retain some degree of "tilt" of the horn, avoiding the zero degree pitch and the detrimental reflections which result.

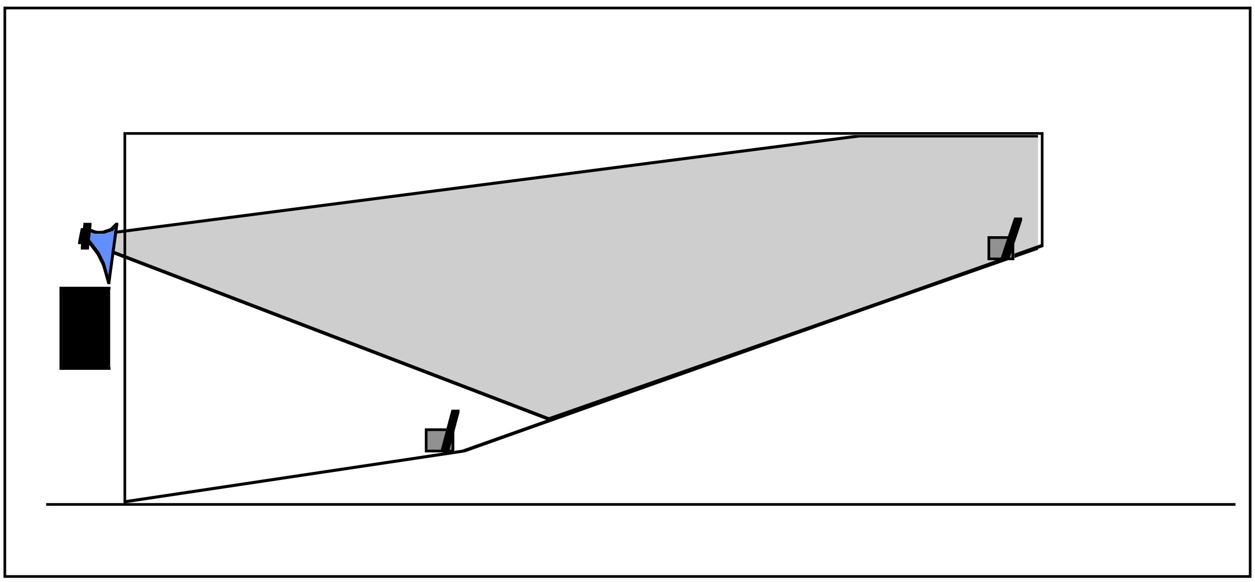

Figure 5. Stadium house, asymmetrical horn coverage. Note that horn can still be pitched downward because asymmetrical pattern disperses more energy in the "top" of its pattern.

It may be stating the obvious to note that we are in the midst of a rapidly changing exhibition environment, fueled by a large number of high quality films and a dramatically changing technological landscape. It is important that all aspects of improvements in theatre and sound system design be considered *together*, so that synergistic breakthroughs can occur and bring yet higher levels of enjoyment to the moviegoing public. The trend of stadium style auditoriums is one example where, when room and sound system designs are considered together for their mutual costs/benefits, we can continue to keep our industry a prosperous one.

NOTE or SIDEBAR:

The “**inverse square law**” is a formula used to calculate the loss of sound pressure level due to a listener’s distance from a speaker. The formula is $\Delta dB = 20Log(d_1/d_2)$, where ΔdB (change in sound pressure level measured in decibels) is equal to 20 times the “log” of the distance from the speaker to the first row of listeners (d_1) divided by the distance from the speaker to the last row of listeners(d_2). Other factors affect the actual change in level, such as room temperature, humidity, presence or absence of sound reflections, etc. The inverse square law formula calculates only the loss due to distance.