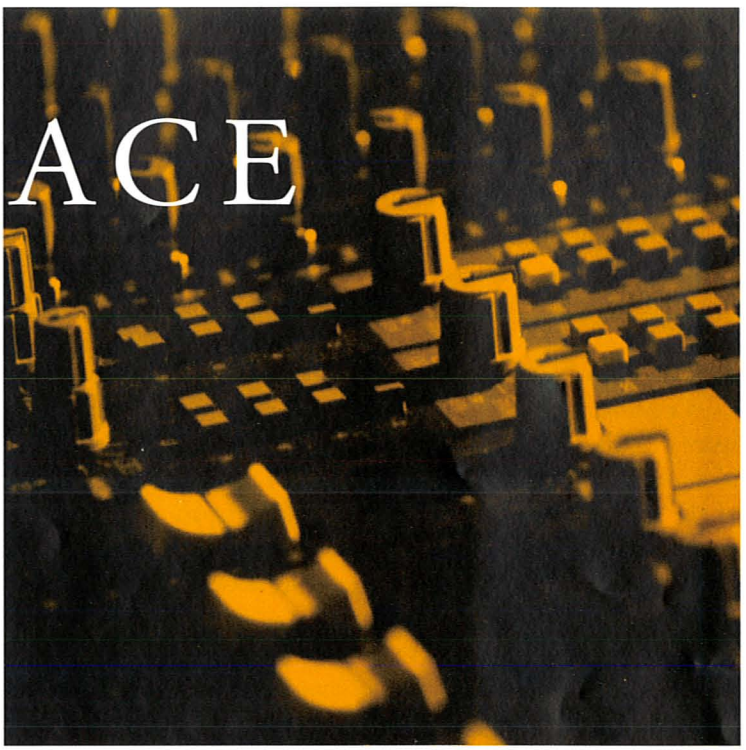
THE DRAMATIC

AUDITORY SPACE



by

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INTRODUCTION • THIS ARTICLE PRESENTS CONCEPTS DEVELOPED REGARDING SOUND CONTROL AND PLACEMENT, AND THE RELATIONSHIP OF THE AUDITORY SPACE SURROUNDING THE AUDIENCE AND THE DRAMATIC PRODUCTION. IT'S PURPOSE IS TO ASSIST IN THE DEVELOPMENT OF THE "SPATIAL" REPERTOIRE OF THE SOUND SCORE DESIGNER. SINCE THE POSSIBILITIES FOR THE ELECTROACOUSTIC MANIPULATION OF SPACE HAVE INCREASED SO GREATLY WITH THE ADVENT OF NEW TECHNOLOGIES, THE SOUND SCORE DESIGNER NEEDS TO DEVELOP THE ABILITY TO WORK WITH SOUND IN THE THEATRE IN THREE DIMENSIONS FROM BOTH A TECHNICAL AND AESTHETIC PERSPECTIVE.

We will explore the basics of space in sound score design, with attention to various acoustic decisions, and will demonstrate how various effects and moods can be created.

The first section of this article deals with aesthetic concerns of the spatial environment and learning to think in three dimensions for dramatic productions. In the second section, specific variables used to manipulate the auditory space for the dramatic production will be considered. Techniques for implementing the spatial manipulations will be discussed in the final section.

THINKING IN THREE DIMENSIONS

Although the use of the auditory space in theatre productions is as old as theatre itself, modern technology has greatly enhanced the possibilities for which the space may be used. In many ways, the modern sound score designer is on the threshold of new possibilities in space, the "final frontier" of sound. Auditory space can be a very dangerous element to manipulate in a production, however. Usually when the auditory space has been misused, the audience is distracted from the essential experience of the dramatic production. For this reason, remember that the spatiality must always serve the themes and dramatic structure of the production.

Of primary concern in the question of how the auditory space of a theatre services the themes and dramatic structure of a production is the relationship between the visual space of the dramatic production and the auditory space of the dramatic production. Generally speaking, the auditory space and the visual space are configured to being as close to being the same as possible. The most frequent problem encountered when the two spaces are shared is the need for the audience to localize the sound to the same apparent acoustic perspective as the visual the sound is reinforcing. The two most common examples of this are the sounds that stage props make on stage, and music that underscores the action on the stage. In these cases, when the sound comes from a source other than the visual element it reinforces, the result is a momentary distraction of the audience that may detract from their involvement in the production.

BREAKING THE FOURTH WALL

In theatre parlance, the fourth wall is traditionally the invisible wall that separates the actors from the audience, especially in the proscenium theatre. Many experiments in bringing the sound "out into the audience" have taken place over the years with varying results. Unfortunately, in most cases, sound that breaks the dramatic auditory space; i.e., the actor's space behind the fourth wall usually calls attention to itself and away from the dramatic experience. This is not to say that the fourth wall is not to be broken. There are many occasions in dramatic productions for the audience to be 'immersed' in sound. One of the most common types of immersion is the use of a very diffuse surround system to create a spatiality around music that appears to emanate from the visual picture of the stage. Tomlinson Holman discusses the purpose of this type of system in an earlier article about film surround sound:

> The objective of surround speakers and their installation is to envelop the audience with non-directional sound through the use of a large number of small, broadly dispersive loudspeakers with overlapping patterns. This approach is directly opposite to that taken for the screen (stage?) speakers, where the objective is the highest ratio of direct-to-reflected sound possible, consistent with uniform audience coverage. The surround field should be as diffuse as possible; we do not want the audience to be particularly aware of where the sound is coming from, which is precisely what we do want from the screen [stage?] speakers.
>
> This is because there is no meaning for sound images which are not associated with the picture. [1]

If the visual picture the audience encountered in theatre was always confined to the area behind the rectangular proscenium arch, there might never be a need in the modern theatre for any other type of surround system than this. However, in the modern theatre, the visual images often tend to spill outside the confines of the proscenium picture frame compared to the two dimensional projection screen in which the film is trapped.

Sets are designed that envelop the interior of the entire theatre, including the audience. Scenes are played all over the theatre, and are not confined to the traditional picture frame of the proscenium. The desire to involve the audience in the experience has led to the creation of a great number of thrust theatres. But the vital truth of Holman's point remains. It is extremely hard to justify sound existing outside the visual action whether it is confined to the picture window of a proscenium or spread out over a great portion of a theatre.

Unless carefully handled, sound that is specifically localizable outside the visual picture is more likely to distract the audience than pull them into the production. You always run the risk of "showing the audience how technically sophisticated you are" at the expense of their involvement in the production. Unfortunately you might be creating an awesome sonic event, only to distract the audience from the theatre they came to experience.

As discussed earlier, the auditory space must always support the production, not detract from it. However, this does not mean that the theatre does not afford excellent opportunities to effectively envelope the audience with sound. In the next section, the auditory space of the dramatic production will be considered. Techniques for implementing the model will be discussed later.

WHAT IS SPACE?

The very concept of space is one that has enthralled philosophers for ages. Yet how we define space, and how we think about space, will have a profound effect on how we use space in the theatre. The space of the three dimensional world is one thing, but the minute we consider how we perceive "space" we run into major problems. For example, how can one pitch be "higher" or "lower" than another and yet still be perceived as having the same tone (i.e., the octave)? If one sound occurs so many seconds after another, are the two sounds spatially separated also? Does the loudness of a sound "fill" the auditory space as mass fills the visual space? How can two tones occur simultaneously in the same place?

Géza Révész denied that a special auditory space existed on the grounds that auditory space does not conform to visual and tactile space:

> The space that becomes alive through sound entirely lacks the essential spatial characteristics of optical space, such as three-dimensionality, spatial order, multiplicity of directions, form, and above all occupancy by objects; it has no direct relation to the world of bodies, is related to neither of the two sensory spaces which we are given (visual and tactile space), either in its structure or in its phenomenal elaboration; it knows no geometric relation, and possesses no spatial fitness [2]

Victor Zuckerkandl thought, on the other hand, that music transcends the normal three dimensionality associated with space; music even transcends the spatial depth and localization abilities of the ear because our perception of the location of an object is not the perception of the sound, but of the source of the sound. [3] Heidegger defined space as "that whence something encounters me." [4] Musical tone perception is not a "thought" experience like reading a book; it is something that encounters me from without. The process of being encountered from without involves the tone coming from someplace:

> In tone, space itself...is in a unique way directed toward the hearer; is experienced as in motion toward him....More and more in the concept of physicists, space appears as itself entangled in physical event. Space that is less and less distinguishable from the dynamic field that fills it; space that curves; space that expands—to such a space, in any event, the adjective "flowing" is not essentially foreign. [5]

Zuckerkandl was forced to reject Révész's position because Zuckerkandl felt that an experience which did not conform to the conditions of visual and tactile space and to the propositions of geometry could qualify as spatial:

> The dogmatism of the attitude becomes even clearer when, from the admission that "'spatial' in the realm of tone must mean something entirely different from what it does in the realm of visual and tactile perceptions," the conclusion is drawn that hence there cannot be space in the realm of tone. The reasonable conclusion would seem to be that there might be other primary sources of information concerning spatiality besides sight and touch; and if it is divergent information that they disclose, this can only be one more reason for subjecting it to a close scrutiny and using it for all it is worth. [6]

Two concepts emerge from this discussion that challenge sound score designers to reconsider the function of space in theatre. First, the degree to which auditory space is tied to the visual space inherently limits our ability to accurately perceive the many possibilities of auditory space. Second, when we reshape our perspective of the theatre to consider the dramatic experience in terms of a communication from without to within, we open up new possibilities for manipulating the auditory space.

It is only when we learn to rethink our understanding of auditory space that we can begin to rectify the paradoxes of the dramatic space, such as rectifying the acoustic of the dramatic space with that of the physical acoustic of the theatre. Too often our approaches to the utilization of space in theatre are based around a kind of brute-force re-creation of a sonic experience that occurred in another acoustic. However, this technique is doomed to failure. A scene in a play calls for a car to pull up to the door of the house we see on-stage. But we don't hear a car pull up in a driveway, we hear a car pull up in a theatre, and the dramatic illusion that had been so carefully crafted visually has been shattered.

An understanding of the use of space in theatre has to begin with an understanding of the relationship of the dramatic auditory space (i.e., the auditory space suggested by the production) and the physical acoustics of the theatre to the perceived space of the audience, (i.e., that from which something encounters them). In theatre, when we can learn to focus our dramatic space on the sounds themselves and not on the source of the sounds (e.g., naturalism), we can develop a whole new approach to the use of the dramatic auditory space.

Auditory space is entirely relative; we know nothing about the space we are in until a sound is made. Once a sound occurs in space, our ears can make a quick comparison of the sound and the information contained in the "after-sound," and relate information about the size of the room, the type of materials used, the shape, etc. In theatre, this is a limiting factor in our perception of the physical space in that we can usually make the room sound larger, but it is often quite difficult to make the room seem smaller. This limitation is most severe for those who would attempt faithful reproductions of natural sounds. It only serves as a starting point for those who tend to be interested in the other direction, i.e.,

exploring the relationship between the physical space, the dramatic space, and the combination of the two, which is the space perceived by the theatre audience.

THE BASIC TOOLS AND TECHNIQUES OF SPACE

A good place to begin to examine this relationship is with the fundamental tools available to the sound score designer for manipulating the space perceived by the theatre audience.

• SCALE

What is the size of the apparent acoustic? The apparent acoustic will contain a combination of the audience's imagined perception of the dramatic auditory space and their very real perception of the physical acoustic space of the theatre. What is the size of the world of the play? What is the visual size and mass of the objects that occupy the visual space of the play? The audience can imagine the dramatic space and the mass that fills it to be theoretically different than the acoustic defined by the physical size of the theatre, or at least until an auditory spatial clue distracts them. What is the real size of the theatre? Remember that everything must be done possible to focus the attention of the audience on the scale of the dramatic auditory space of the production.

• PERSPECTIVE

How close is the audience to the dramatic action? The audience is generally made to believe that they are much closer to it than they physically are. The size, shape and reverberant qualities of the theatre can be made to help accomplish the same objective in the auditory domain, by placing as much as possible of the audience within the critical distance from the visual picture, and by keeping the physical size of the theatre under control.

Where is the sound located in the 360° plane of the horizontal or the 180° of the vertical? If the audience is kept relatively unaware of the acoustic of the theatre, the sound score designer now has a hemisphere with which to work. Sounds can be made to sound further away than the supposed boundaries of the theatre, and sounds can be made to appear closer. Sound can also be used to mask the physical auditory space and create an apparent auditory space that is different (such as is attempted with electro-acoustically enhanced reverberation systems), or to create an impression of spatiality that is not relative to any known acoustic (such as a film surround sound system).

• STEREO

The use of recordings that have been processed for stereo reproduction is another way of creating an auditory space that does not physically exist. One of the most common criticisms in the theatre is that "stereo" is inappropriate for an audience because it only creates appropriate images for those sitting in the center between the two speakers. In this sense, it is usually inappropriate to refer to two channel sound in theatre as stereo. Stereo in theatre parlance is not 'stereophony' for imaging purposes but rather the use of two channels and two loudspeakers for added spatiality. It is important to remember, then, that the goal of stereo in the theatre is not so that the audience can precisely locate the source of the sound (use individual speakers and intelligent acoustic design of the scenery for this), but to give the sound added spatiality.

• MOVEMENT

How does sound move rhythmically in the space? What is the speed, tempo, and direction of the movement? So far the discussion has predominantly been based on the perception of stationary acoustic environments and stationary acoustic sounds that emanate from the environments. The situation gets much more complicated in execution when the audience is to perceive sounds that move through the dramatic auditory space. Sound can either be made to move with the visual picture or in its own dramatic space—encountering the audience from without, and not tied to a recognizable source.

It is very difficult to make a sound move through space to accompany a visual picture. The key to creating movements such as this is to focus the audience's attention on the speed or tempo of the movement within the dramatic context of the scene rather than on the source of the sound. In a quiet, romantic scene, the train may be pushed into the dramatic distance and move across the dramatic picture very slowly. In a highly energetic fight scene, the train might move closer to the action and orchestrate the fight with the rhythm of the wheels and the speed with which it passes. In either case, it is necessary to estimate transition times accurately within the dramatic scale devised.

• MOVING SOUND IN STEREO OR MONAURAL PANS

There are two basic ways to cause a sound to appear to move to an audience member. The first is to physically pan the source between an appropriate number of loudspeakers. The disadvantage of this technique it that it requires an infinite number of theoretical point source loudspeakers to realistically recreate the movement. The second is to make a stereo recording and then play the sample back over a pair of loudspeakers. The disadvantage of this technique is that different parts of the audience will perceive the movement in different ways. For example, those left of center will image further to the left, and those to the right of center will image further to the right. However, audience members will be all be able to gain an enhanced perception of the relative size of the sound compared to a monaurally recorded sound.

Sometimes the best solution is to pan stereo images. This allows the audience to perceive a more detailed size of the sound, and yet track its movement accurately. In cases where accurate imaging is required by every member of the audience, multiple loudspeakers may be necessary.

• IMMERSION

Is the sound confined to the stage or is the audience immersed? It is extremely important to understand how the production style supports the spatiality of the sound. As a general rule, most sound occurring within a production tends to be localized within the area defined by the stage picture. However, there are many times when it is viable to "immerse" an audience in sound. Blackouts and dark scenes which imply a dramatic visual world above and behind the audience support the use of surround sound.[7] Fantasy scenes, and dream scenes are also favorably disposed to the use of surround sound. Any scene which makes use of the entire visual space around the audience (or at least within their peripheral vision) may support the use of surround sound.

TYPES OF SURROUND SOUND

Their are two general extremes in the use and perception of surround sound: total diffusion in which the sound appears to be coming from all directions at once, and sound which is specifically localized in the hemisphere around the audience.

• FILM SURROUND SOUND

In between these two extremes lies the type of surround sound typically encountered in film surround sound: sound which is localized to the screen (or stage) but which has been enhanced by a sound system which surrounds the audience, and provides additional spatiality in a manner approaching omnidirectionally. Two possible examples of applications of such a system to theatre:

• PRESENTATIONAL STYLES-PRESHOW, INTERMISSION AND POST SHOW MUSIC

Preshow, intermission, and post show music can be enhanced with the use of this type of surround sound. Again, the visual picture might dictate the location of the main speakers. If the stage is hidden with a grand drape, it is a good indication that the spatial location of the sound should not pull focus to the stage. In these cases, speakers located above the proscenium (sometimes the reinforcement system can be used) are a convenient place to locate the source. On the other hand, if the scenery has been carefully illuminated to allow the audience to study it during the preshow, it may be more appropriate to image the preshow to the scenery.

• UNDERSCORES

Sometimes the director will want to try to draw the audience into a scene by enveloping the audience in sound. In these cases, the sound should still be imaged to the appropriate part of the visual picture, yet a omnidirectional surround sound system will be used to provide the additional spatiality. This must be done with extreme care, however as it is not acceptable for the spatiality of the sound to distract any member of the audience from the scene—including audience members unfortunate enough to have purchased their seats right next to a surround sound speaker.

• LOCALIZED SURROUND SOUND

An omnidirectional sound system is somewhat different from a localized surround system in its directional requirements, its use of audio delays, and its power capabilities. In a surround sound system no single member of the audience should be able to locate an individual loudspeaker. The sound should either appear to come from the stage, but somehow "envelop" the audience, or appear to be omnidirectional. In a localized surround system, the audience should be able to accurately perceive the location of the sound. Often the sound will move about the audience, and the audience should all be able to track the movements of the sounds through space. This requires that delays be used only to make the apparent acoustic delay from all surround speakers arrive at the center of the audience at the same time. The final requirement of this type of system is that each loudspeaker may be called upon to reproduce levels equal to those of the stage speakers.

• MOVEMENT AND RHYTHM IN LOCALIZED SURROUND SOUND SYSTEMS

In a localized surround sound system a sound can be made to image any place it is possible to place a loudspeaker. The accuracy of the audience's perception of the movement of a sound is limited by the number of loudspeaker and loudspeaker locations available. However, it may be shown that it can be difficult to move sounds through space with complete rhythmic accuracy due to the various delay times between each audience member and the different loudspeakers.

For example, sixteenth notes at a tempo of 120 beats per minute occur every 125 milliseconds (1/120 minutes per beat x 60 second/1 minute x 1 beat/4- 16th notes = .125 sec/16th note). This would represent a path length difference between two speakers and an audience member of 1130 ft/sec x .125 sec. = 141.25 feet. If the path length difference between two loudspeakers and an audience member is 141 feet, the rhythm will be off when the sound moves by as much as a sixteenth note. This may seem like an extreme case, as real world path length differences are not typically this high. However, rhythm is maintained with a much greater accuracy than plus or minus a sixteenth note. Some players play "ahead of the beat," while some play "behind the beat" and even a very slight deviation from the tempo would ruin the feel of the music. This may be a good reason to either limit the path length differences between the speakers and the audience, or to limit the amount of rhythmic information in the moving sound.

EXECUTING THE DESIGN

With the dramatic tools of scale, perspective, movement, and immersion, the sound score designer has the ability to control the audience's perception of space and develop a relationship of the auditory space to the visual space. Perhaps the two most important factors which influence the auditory space are the architecture of the theatre, and the loudspeakers reproducing the Sound Score.

• THEATRE DESIGN

Theatres are generally not designed with surround sound in mind. They have balconies, they are too wide, they have low ceilings at the rear of the house, the aisles are usually where the best sounding seats are, etc. These are typical problems encountered in most theatres. However, the two most important factors to consider in the design of a theatre for surround sound are the relationship between the audience and the speakers, and the overall size and shape of the theatre.

• THE RELATIONSHIP BETWEEN THE AUDIENCE AND THE SURROUND SOUND SYSTEM

To effectively create a surround sound that is perceived as omnidirectional, the audience must not be located too close to a loudspeaker (remember that the Haas effect for the delayed speaker suggests that its level must be less than 10 dB higher than the original, or stage sound). The closer the audience member is to the speaker, the shorter the distance to increase the level of the close loudspeaker. For instance, if the center of the audience is 50 feet away from a surround speaker, neglecting room effects, at 25 feet the sound pressure will be up 6 dB due to inverse square law effects. This increases to 12 dB at 12.5 feet and 18 dB at 6.25 feet. If I set the surround level while sitting in the center seat, the level at 10 feet away from the loudspeaker will be so much greater than that coming from the stage that I will tend to localize on the surround. Surprisingly, it is not unusual in modern theatres to have the surround sound loudspeaker within ten feet of an audience member.

Equally distracting is the location of a surround sound loudspeaker too close to the audience when the surround sound is used for localized images. In this case, the closer one gets to the loudspeaker, the more aware they are that

they are listening to a single loudspeaker, or as Zuckerkandl would say, to the source of the sound. This, in itself, can be distracting. However, when the sound moves or is reproducing stereo recordings, the imaging will become seriously distorted the closer the audience is to any single loudspeaker.

• THE SIZE AND SHAPE OF THE THEATRE

As mentioned before, most theatres are poorly designed to allow the proper execution of a surround sound system. In the first place, most theatres are too large, (e.g., above about 600 seats) to give the audience a common surround sound experience. The ideal auditorium would not require sound reinforcement (although it should be possible to use sound reinforcement for aesthetic purposes). In one ideal sense, it would be possible to position the surround loudspeakers far enough from the audience so that each loudspeaker sees the entire audience as a point destination (i.e., the opposite of a point source). In this case each person in the audience hears the same surround sound information. (See Figure 1.)

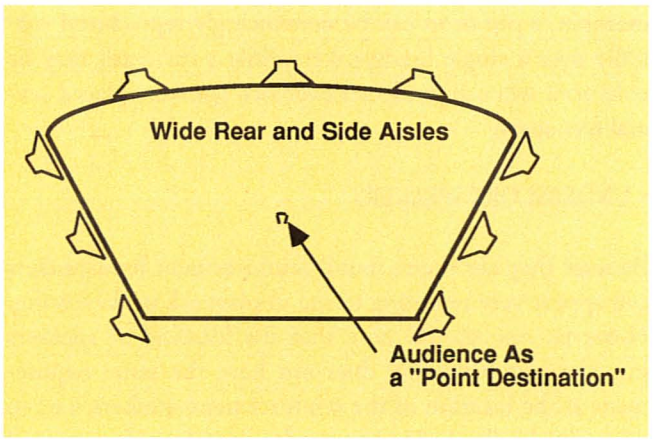

Figure 1.

This would help ensure that every member of the audience would share the same spatial perspective. Obviously this is neither practical nor desirable for a number of other acoustical considerations, but the fundamental idea can be modified to produce a reasonable compromise.

A more practical arrangement would include continental seating surrounded by a minimum ten-fifteen foot aisle which surrounds the audience on all three sides (left, right, and rear), with relatively high ceilings (i.e., no balconies!) Continental seating is useful for getting the audience moved as close together as is humane. It is always dismaying and interesting to note the number of theatres (both legit and movie) that place the aisles where the best auditory seats in the house might be (usually as a compromise between fire regulations and the producers desire to get as many seats into the theatre as it can possibly hold)! Large aisles and high ceilings surrounding the audience allow the placement of loudspeakers at a reasonable distance from any single audience member: [8] (See Figure 2.)

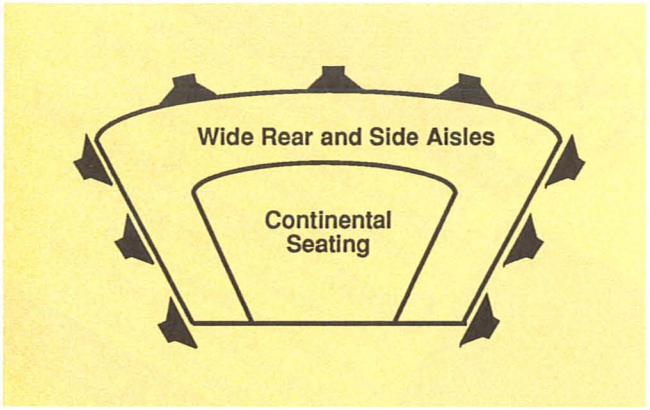

Figure 2.

In the above example, it has been noted repeatedly that the ideal building architecture for surround sound is a rarity in theatre. The purpose of this discussion is two-fold, however—to encourage builders of new theatres to consider the needs of the auditory space, and to suggest an ideal relationship that sound score designers may struggle towards in the endless quest to make do with the space available. Hopefully given any space, a sound score designer can use this model to make better informed decisions about where to place surround sound speakers.

SPEAKER REQUIREMENTS

Different types of loudspeakers and loudspeaker systems may be needed in any dramatic production. These will be examined in the next section. The first speakers that need to be considered are those associated with the visual picture of the stage. The second set to be considered are those associated with the surround sound system.

• LOCATING SCORE LOUDSPEAKERS WITHIN THE SCENERY

Unfortunately the sound system used for reinforcement is really only useful in smaller theatres for pre-show, intermission, or obviously presentational forms of sound playback. Sounds whose source needs to be perceived by the audience as part of the dramatic action must have their speakers located within the scenery to create images that do not distract from the rest of the performance. Two different types of speaker systems may be required on the stage: one to reproduce naturalistic effects, and one to provide musical underscoring.

• NATURALISTIC EFFECTS

It always highly desirable to locate a sound effect loudspeaker as close to the apparent source as possible. The basic rule of thumb for sound effect loudspeaker location is that the loudspeaker should be located within 15° horizontal and 60° vertical of the apparent visual source of the sound for every member of the audience. This amounts to what may be considered a variation of the guidelines for standard acoustic sightlines, which suggest that the path from the audience to the loudspeaker should be acoustically transparent to the audience. The further the loudspeaker is located from the apparent visual source of the sound, the more distracting the sound effect will be.

Speakers mounted within scenery must also be "infinitely" baffled to prevent sound from resonating in the scenic structure in which the loudspeaker is located. In a recent production of *Romeo and Juliet,* loudspeakers were located in upstage vertical columns. When the sound score designer was unhappy with the sound quality, heavy duty absorptive material was packed around the cavity between the loudspeaker and the scenic structure, so that sound could not resonate in the column. The immediately noticeable result was an increase in bass response, and a greater clarity and "tightness" of the reproduced bass.

Ideally, sound effects whose source is significantly larger than the size of a loudspeaker should be recorded in stereo and reproduced over two loudspeakers in the set. For example, a pin drop can be convincingly reproduced spatially over a single loudspeaker, while a car crash may be enhanced when reproduced over two speakers placed several feet apart.

• UNDERSCORE SPEAKERS

Because they are there, sound reinforcement loudspeakers can appear very tempting to use to playback underscoring. However, one should note that the location of speakers providing underscoring does not have the same requirement as the location of the reinforcement speakers, i.e., to minimize feedback. Underscore loudspeakers do not need to be, nor should they be, located downstage of the microphones. The perceived source of underscoring loudspeakers should be from the center of the action or character(s) on the stage. Usually this means careful cooperation between the sound score designer and the scene designer to provide appropriate locations. The ideal location of loudspeakers in the scene is typically high enough to shoot over actors' heads but low enough to still be perceived as a part of the scene.

The ideal position for stereo, then, would be two speakers as close above actors' heads as sightlines will allow, but equidistant from the center line. If necessary, a center fill speaker could be added that would be a mono sum of the left and right loudspeakers. These tend to cover just about everything that happens either full stage or center stage, and are far enough from the audience that a large percentage of the audience receives a fairly wide image. For wide stages, it may help to augment the left and right pair with additional speakers stage right and stage left which then provides three spatial areas: left, center and right.

Also, since locating loudspeakers within the stage picture may place restricting demands on their size, larger speakers are sometimes added to provide additional punch to the underscore. This is usually not necessary for underscore, however, which is generally played back at a low enough level to remain "under" the actor's voice. Sometimes you may also want a near and a far pair to match the distance of the actors from the audience.

• LOCATING SPEAKERS IN THE AUDIENCE

When loudspeakers are located in the audience, two types of loudspeaker systems may be required: a system such as employed in film surround sound, and a system in which the audience is able to identify the auditory sources involved in the surround sound.

FILM SURROUND SOUND REQUIREMENTS

The guidelines for film surround sound systems have undergone extensive testing and development in the last ten years. The development of the THX criterion for surround sound systems includes many useful guidelines for live theatre surround sound systems that attempt to emulate the techniques of film. Tomlinson Holman summarizes these requirements: Given the need for broad dispersion and the fact that the speakers are used in multiples so no one speaker need handle undue power, the systems we have found most appropriate are modified versions of home bookshelf models.

The number of surround speakers, their spacing along the side and rear walls of the theater, and their height are calculated using formulas developed to ensure uniformity of coverage. The final requirement for the surround channel as a whole is that it have the same power-handling capability as one screen channel. An additional formula for calculating the required amplifier power is based on the number of surround speakers, their sensitivity, the average distance from the speakers to the center of the room, and the maximum sound pressure level required. To further minimize the need for post-installation tuning, surround speakers are now available with high-frequency response tailored to provide the ISO 2969 curve. [9]

Holman also discussed other requirements of film surround sound systems in a paper for the Audio Engineering Society:

1. A time delay was arranged such that the "surround" sound arrived later than the direct sound from the main-channel loudspeakers by 10-20 ms to utilize the precedence effect to promote localization to the front loudspeakers by suppressing localization of the later arriving signal.
2. The additional loudspeakers were wired out of phase with respect to one another to promote delo-

calizing them.

3. The best location for the additional loudspeakers was not to the rear but to the sides, to promote differences in the reflected sound field at the ears.
4. The best directivity pattern for the "surround" loudspeakers was not the conventional forward-firing direct radiator, but rather dipolar radiation, with the principal lobes of the dipole pointed not at the listening area, but at the room surfaces, with the null in the radiation pattern pointed at listeners, again to promote delocalization." [10]

Later in the paper, Holman notes another interesting technique for decorrelating the sound:

> Another method was found which produced delocalization by decorrelation with minimum audible additional artifacts. That method is to introduce a slight pitch shift between left and right surround. On a/b comparisons, both naive and sophisticated listeners easily perceived a greatly enlarge spatial impression from the surrounds when such a shift was introduced. The amount of pitch shift is constrained, on the one hand, to be that which is large enough so that combing is inaudible and, on the other, such that an actual pitch change between left and right surrounds on tonal program material is minimal." [11]

• LOCALIZED SURROUND SOUND REQUIREMENTS

The major difference between the film surround sound system intended for live theatre is that the same speakers that are used in the surround sound system will often be called upon to create localized sounds with a much greater degree of sophistication than is possible in the limited domain of six channel film systems. Because of this, there is a need for these types of systems to be capable of reproducing sound pressure levels equal to the stage speakers.

This requirement often introduces the need for horn driven highly efficient loudspeaker systems that have directional patterns focused on the audience similar to the main stage speakers. However, the nature of the off axis response makes it necessary to use many more loudspeakers than might be necessary in a film surround sound system to still be able to create the omnidirectionality required for non-directional surround playback. The problem can again be minimized by controlling the distance between the closest audience member and the surround speaker.

CONCLUSION

This paper has been an attempt to explore some of the relationships between the needs of the dramatic space and the restrictions imposed by the acoustics of the physical space. The contradictions between the two spaces must always be resolved to allow the audience to focus their concentration on the dramatic space and not be distracted by unwelcome impositions of the physical space. When these considerations are understood, there is a tremendous opportunity to enhance the dramatic production with sound that fully utilizes the hemisphere typically available around each audience member.

The most promising aspect of sound for live theatre lies in the way that the theatre itself is changing—partially as a response to the implications of areas such as the auditory space. Theatre today is clearly much more self conscious, allowing the audience to revel in the fact that they are experiencing live theatre—not film. This recognition has made it much easier to explore the auditory space around an audience. It is a far cry from our understanding of the auditory space a couple of decades ago—in which the most extensive use of the space was typically a hopeless attempt to recreate the acoustics of another space.

As Zuckerkandl explored in his study of space, the sooner we are able to think about the spatiality of the sound itself, and not the spatiality of the source of the sound, the sooner we will be able to develop a new understanding and relationship with the auditory space. It is truly exciting that this seems to be the direction in which modern theatre is heading. **TD&T**

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Endnotes

1 Tomlinson J. Holman, "THX Sound System, Certified Hi-Fi for the Movies." *Audio* (September 1989) 70.

2 Victor Zuckerkandl, *Sound and Symbol,* trans. Willard R. Trask. (Princeton, New Jersey: Princeton University Press, 1973) 280-281.

3 Zuckerkandl 279.

4 Zuckerkandl 271.

5 Zuckerkandl 289-290.

6 Zuckerkandl281.

7 Note in this paper that we will use the term "surround sound" for lack of a better one. However, it should not be confused with the way the term is used in film sound. It simply means the audience is "surrounded" by the sound.

8 Editor Charlie Richmond also notes: "one other example of loudspeaker placement that almost meets the 'Audience as a "Point Destination"' criteria in a very simple manner: a position right at the apex of a high ceiling includes the majority of the audience at a single distance with almost equal volume and distribution and produces an almost perfect non-directional image since it is almost directly above both ears of all audience members."

9 Holman 70.

10 Tomlinson. J. Holman, "New Factors in Sound for Cinema and Television, *Audio Engineering Society* (Volume 39, No. 7/8, July/August, 1991) 532.

11 Holman *Audio Engineering Society* 537.