Applying the Benefits of Unamplified Acoustic Music to Performances with Amplification

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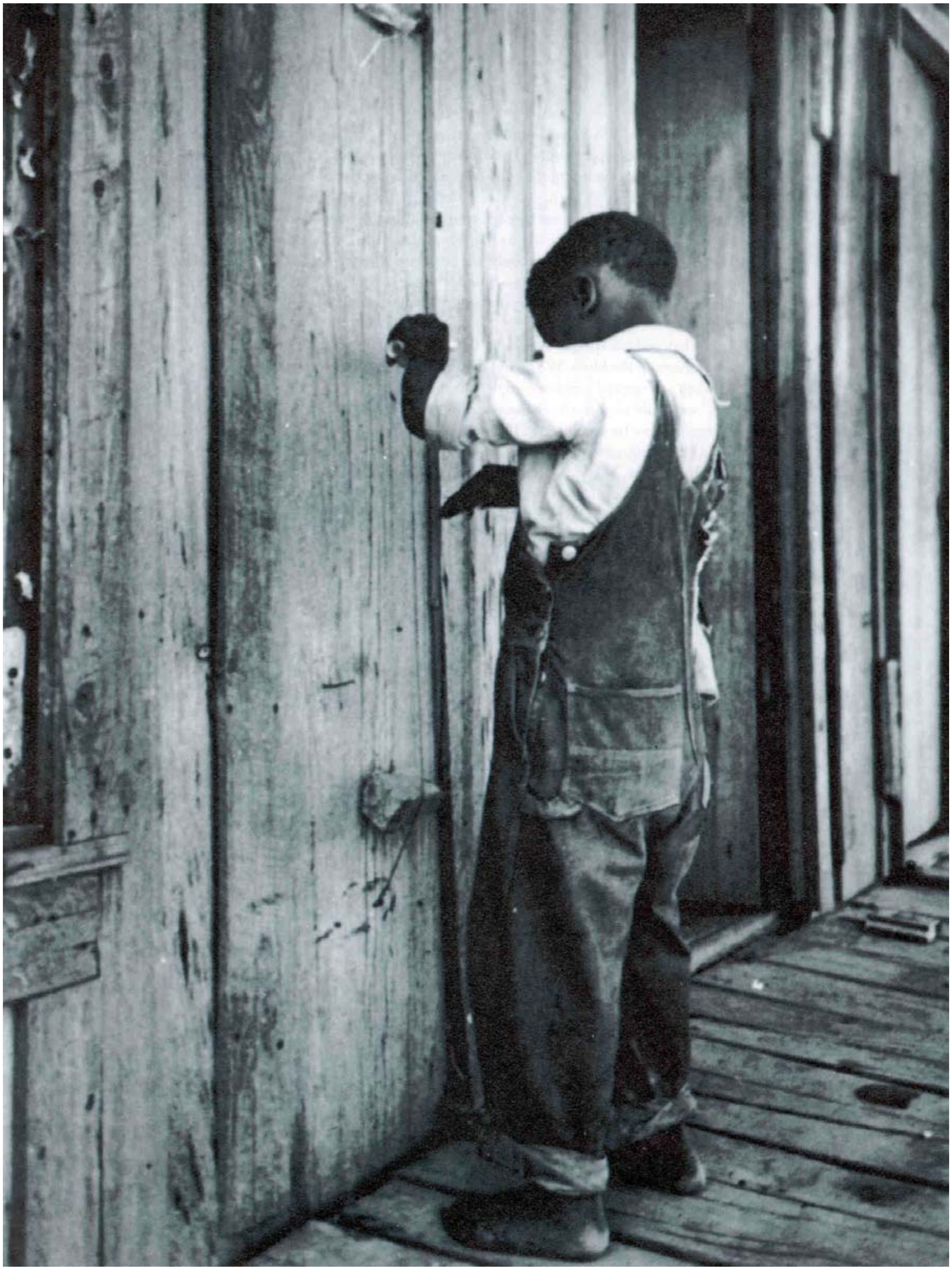

Child playing one-stringed instrument.

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Summary

IN unamplified musical performances, we hear instruments and voices arriving from different directions according to their locations on stage. We can follow and appreciate even highly complex passages because the sound of each player comes from a different direction, a phenomenon further enhanced by the fact that the sonic arrangement we hear corresponds to the visual arrangement we see. The musicians are in complete control of the music, and play with the confidence that the sound they create on stage is what is projected outward to their audience. Moreover, apart from the musical instruments themselves, there is very little equipment to encumber the musician. From street corners to village squares, salons to places of worship and concert halls, these basic benefits have been enjoyed by musicians and audiences alike for thousands of years.

Then, in the twentieth century, an explosion of new musical styles was accompanied by the technological means to disseminate music via radio and the phonograph. Listeners flocked to live performances of the new styles, where amplification was used initially to lift individual instruments and voices, but soon became an integral part of the rapidly evolving musical styles themselves.

To reach ever-larger audiences with higher sound levels in the 1960's, an approach to amplification was developed that is still the dominant approach today. In our research, we found that this approach succeeded in making performances louder, but at the same time stripped them of the historically evolved benefits of acoustic music. In this approach, audiences see musicians arrayed in an ensemble, but they no longer hear them that way: instead, the instruments and voices all come from a loudspeaker located off to one side of the stage. Lyrics are often unintelligible and instrument sounds garbled or simply missing. Musicians are so isolated that they have almost no idea what their audiences are hearing. Sound levels on stage and in the audience are often uncomfortably, even dangerously loud. And last but not least, the equipment required is so complicated and cumbersome that many musicians spend the majority of their time on the logistics of performing instead of actually performing.

To address these problems, we have developed an entirely new approach to amplification based on a novel sound source that succeeds in applying the historical benefits of acoustic music to amplified performances. Our research shows that this solution greatly enhances the musician's ability to play, and the audience's ability to hear and appreciate amplified music. In addition, we found the solution drastically reduces the amount of equipment and simplifies its use, freeing musicians to spend their time playing, and less time transporting, configuring, and operating their amplification equipment.

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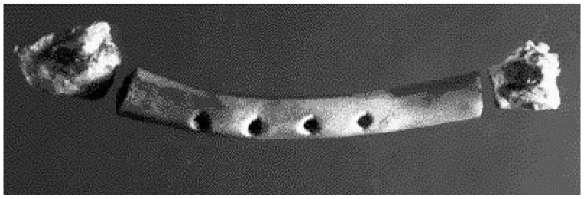
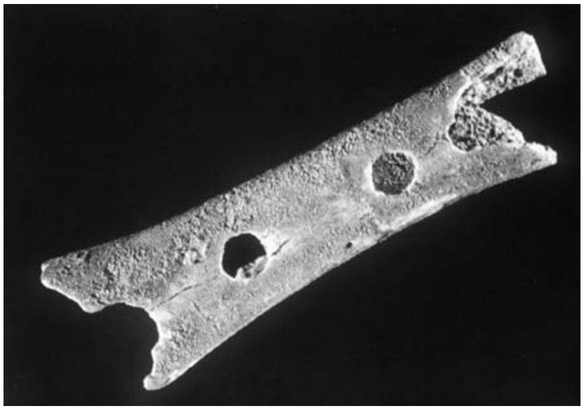
Introduction

CREATING and enjoying music are a fundamental part of being human. For example, no present-day culture exists without music as one of its central activities.[1] And recent archeological discoveries show that music has been a part of the human experience for an extraordinarily long time. Sophisticated flutes have been unearthed from a culture in China that thrived about 9ooo years ago,[2] a number of musical instruments have been found from the Upper Paleolithic era (3o,ooo - 4o,ooo years ago)[3] and what is almost certainly a bone flute has been found at a Neanderthal site in Slovenia dating to at least 5o,ooo years ago.[4]





Ancient Aurignacian (Upper Paleolithic) bone flute (top) and a flutelike object from a Neandrathal campsite in Slovenia from more than 5o,ooo years ago (bottom) are shown.

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1 Pinker, Steven, *The Language Instinct: How the Mind Creates Language*, Perennial Press. p. 214 (2ooo).

2 Juzhong Zhang, Harbottle, G., Changsui Wang, Zhaochen Kong, “Oldest playable musical instruments found at Jiahu early Neolithic site in China”, *Nature*, Vol. 401, 366 - 368 (Sept. 1999).

3 White, Randall, “Representation, Technology and Society Before Lascaux,” first published in *Archéologue-Nouvelle Archéologie*, (1996).

4 *The Origins of Music*, Ed: Wallin, Merker, & Brown; MIT Press, Cambridge / London (2ooo).

In another field of science, neuroscientists are now beginning to understand how our brains respond to music. One of the things they have found is that powerful musical experiences map to the same part of the brain associated with activities related to reproduction and survival.[1] Music, like language, appears to be inseparable from what it means to be human.

Numerous musical innovations have occurred over the millennia: musical instruments were invented and refined, new musical styles were created, and performance spaces were built and their acoustics tuned to musical advantage, among many other developments. What also evolved was a set of acoustical benefits inherent in the musical performance that aided both performer and audience.

Our research shows that these historically evolved benefits were largely lost in amplified music performances beginning in the latter part of the twentieth century, when amplification systems were developed to satisfy the requirements of very large audiences in venues such as stadiums and outdoor music festivals. This same approach to amplification was then quickly adopted by musicians playing in small and medium sized venues, and remains the dominant approach used today.

The implications on both performing and listening to musical performances stripped of the historically evolved benefits of acoustic music are presented and judged to be serious in their nature and magnitude. And finally, it is shown how an entirely new approach based on a novel sound source can effectively restore the historically evolved benefits of acoustic music to amplified performances.

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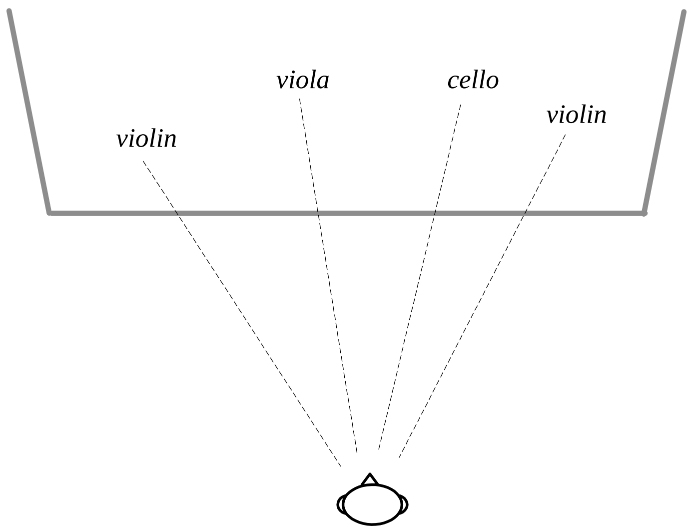
[1] Blood, A. & Zatorre, R. "Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion," *Proceedings of the National Academy of Sciences*, Vol. 98, No. 20, (Sept. 2001).

Brief History of Amplified Music

Unamplified performances

IN an unamplified musical performance, a rich and diverse sound field is created by the arrangement in space of the players and their instruments. Musicians and members of the audience hear the sound of each instrument coming from a different direction, and this direction corresponds naturally to what they see.



In unamplified performances, regardless of where the listener is located, sound is heard coming from the directions of the individual instruments – directions that furthermore correspond to what is seen.

The perceptual benefit of having sound from sources in a multi-source environment come from different directions has been extensively studied in the field of psychoacoustics and is known there as the *cocktail party effect*.[2] Other studies show the significant benefit that comes from being able to see and hear a source at the same time, a benefit of special importance in a multi-source environment.[3]

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[2] See, for example, Bronkhorst, A., "The Cocktail Party Phenomenon," *Acustica*, Vol. 86 (2ooo), pp. 117-128.

[3] Sumby, W. H., and Pollack, I., "Visual Contribution to Speech Intelligibility in Noise," *Journal of the Acoustical Society of America*, Vol. 26, No. 2, (March, 1954).

Furthermore, in acoustic music, musicians perform with the knowledge that the sound they produce on stage is the sound that radiates out to their audience. The musicians are in complete control of their sound and can adjust their playing according to what they wish to project to their audience.

Last, the equipment preparations required to play acoustically are quite modest. With few exceptions, musicians carry their instruments to the performance, and can almost immediately start playing. The focus is therefore almost entirely on music, not on equipment.

The scene in an unamplified performance is dominated by the players and their instruments. There's little other equipment to clutter the scene, either for the musicians or their audiences.

Considering all of these benefits, it is reasonable to conclude that the unamplified performance environment is one that is highly conducive to the creation and appreciation of music. These benefits have evolved over thousands of years, and in general are enjoyed by acoustic groups of all kinds – from folk groups, to barbershop quartets, church choirs, and symphony orchestras – and their audiences.

Changes in musical performance

IN the United States and elsewhere, the twentieth century was characterized by explosive population growth, redistribution of populations away from the countryside and into the cities, the industrial revolution, and World War, among other things. New recording and broadcast technologies made it possible to reach large populations as never before.

The radio and phonograph made it possible to distribute music to huge numbers of people, and created a large new population of listeners eager to hear live performances of popular musical styles.

In the case of music, the introduction of radio and the phonograph created enormous new markets for the many new and rapidly evolving musical styles that accompanied the social changes of the century. For example, the important musical innovation of Jazz spread from New Orleans to the rest of the country in part because of the reach of radio and the phonograph. The growing number of enthusiasts that resulted in turn created a tremendous demand for live musical performances of the new music.

To meet the demand, the new styles were performed for larger groups who came to dance and socialize, not just listen to the music. The days of the aristocratic class quietly listening to what we now call classical music were rapidly eclipsed by the interests of a large and growing middle class eager for great live entertainment. Even the back-porch and town-square folk music practiced by so many American immigrants started to give way to live performances of Jazz, Blues, Swing, Country Western, and Big Band music, to name just a few of the styles.

Musical performances were being given to larger and larger audiences, eager to do more than just politely listen to music.

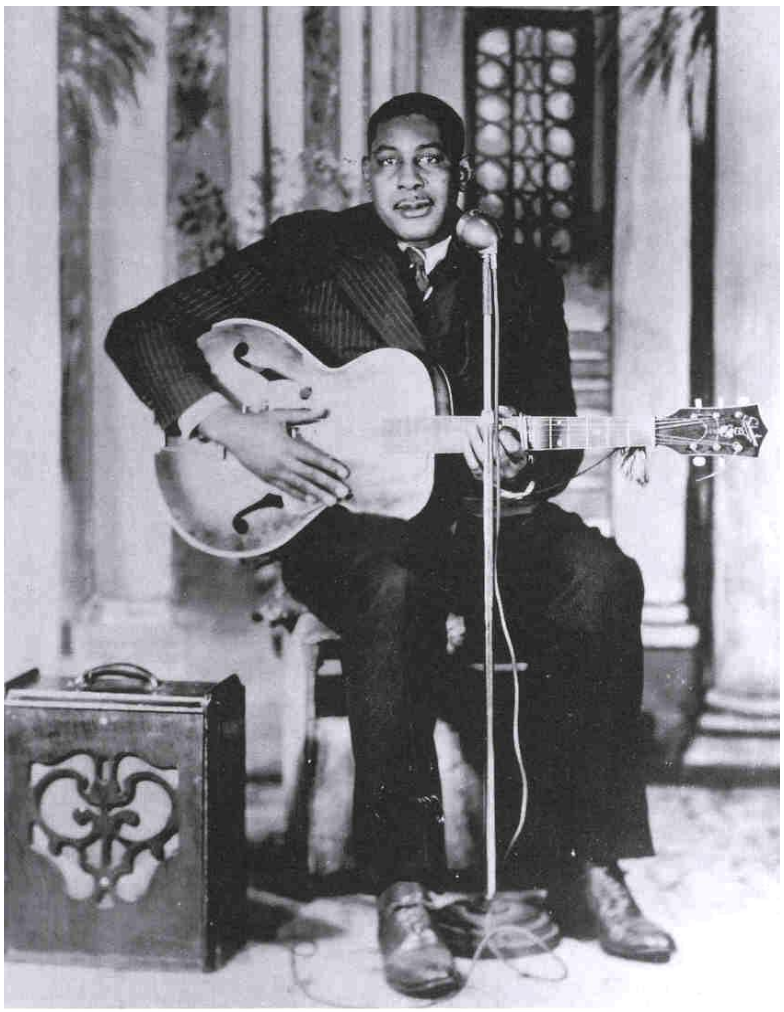
To be heard above the excitement, many unamplified musical groups got larger in order to get louder: horn sections, percussion, strings, and more were all used to create a louder, more impressive and entertaining sound.

Many bands got bigger in order to entertain larger audiences.

The individual-instrument approach to amplification

THE initial approach to amplification was a natural extension to playing acoustically. This was the era of 'individual-instrument' amplification, and it was the dominant approach until the 1960's.

In this approach, a loudspeaker was used to increase the volume of individual instruments. For example, the guitar was amplified to add volume to an acoustical instrument that could not otherwise be heard in many situations. Electronic amplification also became a way for smaller musical groups to entertain larger audiences more economically.

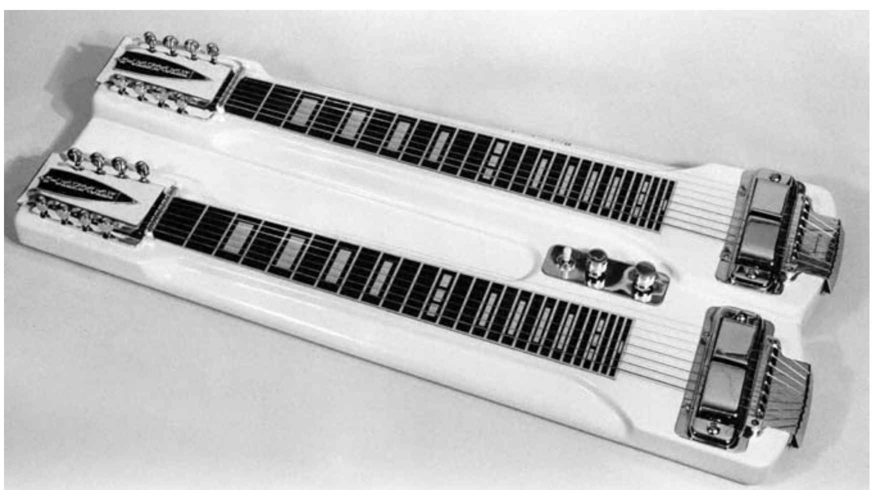


Early amplification was used on instruments like the guitar, and for increasing the volume of singers.

By the middle of the twentieth century, the guitar, bass, piano, and voice, among others, had all been amplified, helping smaller groups to achieve the higher levels needed for dance halls and nightclubs.

Amplification helped smaller groups play to larger audiences.

Moreover, new instruments were invented that *only* worked when amplified; the entirely electric Hawaiian guitar (also known as the lap steel guitar) became an extremely popular instrument in the middle part of the twentieth century.



Amplification spawned the development of new musical instruments that were not simply amplified acoustical instruments, but had new tones that did not exist before. A double-necked all-electric lap steel guitar is shown.

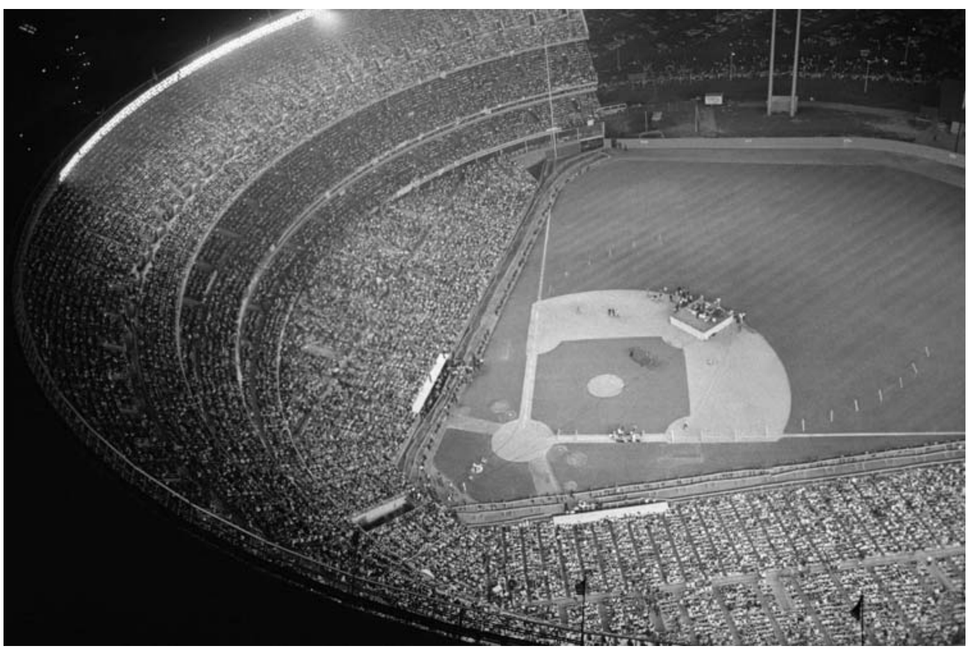
And musical styles were emerging and evolving *because* of amplification. No longer important only as a tool to increase the level of certain instruments being played within existing musical styles, amplification was actually catalyzing the evolution of important new musical styles.

While amplification of individual instruments was being used more and more, the way amplification was being used was essentially an incremental extension to the unamplified performance. Individual instruments were made louder, but little else changed: the sound came from multiple directions; the sound came from where the eyes said it should and vice versa; musicians played with the knowledge that what they created on stage was what was projected to their audience; and the focus was very much on making music because the amount of equipment needed was still modest.

Bigger venues, louder music

BY the late 1960's, economic growth, the baby boom, and advances in broadcasting and recording technology meant that huge audiences were being reached with music as never before. Popular new musical styles like Rhythm and Blues, Rock & Roll, and Soul were played at the higher volume levels allowed by amplification. Thirst for live performances of the newest styles continued to increase.

Popular musical groups playing in the new styles were able to sell enough tickets to fill larger venues able to accommodate thousands of fans. But now the higher sound levels consistent with the new styles had to be delivered to much bigger audiences.



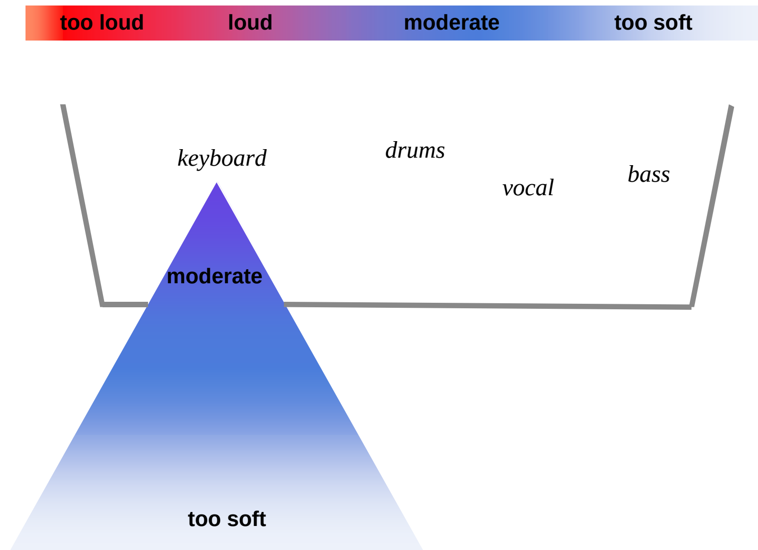
Larger audiences such as this one for the legendary appearance of The Beatles at Shea Stadium in 1965 placed new demands on amplification equipment.

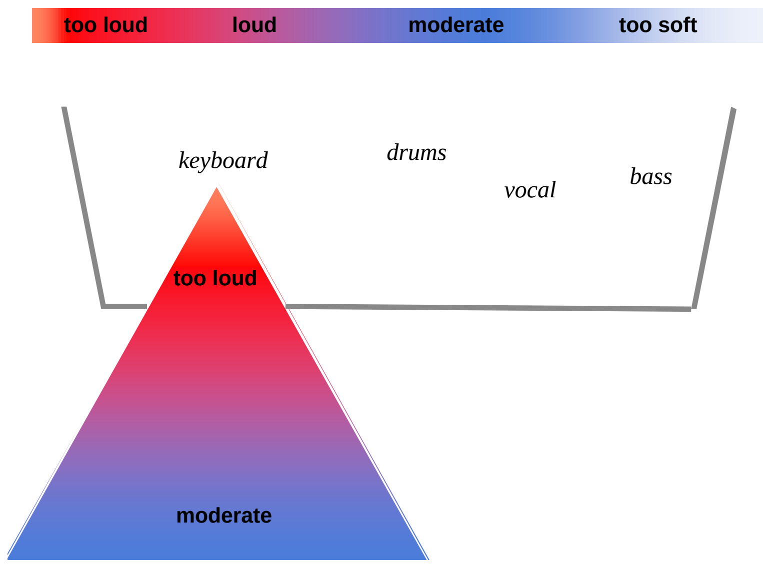
Bands and promoters alike struggled to entertain the larger audiences. For example, although The Beatles concert at Shea Stadium in 1965 was the result of the huge commercial success of the group's recordings, the audio system used did not deliver the desired sound levels to the majority of the audience. The individual-instrument approach to amplification clearly was not adequate.

Limitations of the individual-instrument approach

THE problem of filling large venues using the individual-instrument approach can be traced to a fundamental property of the loudspeakers used to amplify the instruments and voices. Loudspeakers used to amplify music are very loud at close range, but they then decrease rapidly in level with distance.[4] Our research found that if the desired level is set on stage, it is not loud enough in much of the audience area, especially in a larger venue, and conversely, setting the desired level in the audience means exposing the musicians to painful sound levels on stage; or the re-amplification of sound through microphones and instrument pickups would lead to a phenomenon called feedback – the uncontrolled squealing or howling sounds caused by excessive amplification.

[4] In the field of physical acoustics, this is known as the *inverse square law*, whereby sound intensity drops by a factor of four with each doubling of distance from the source.





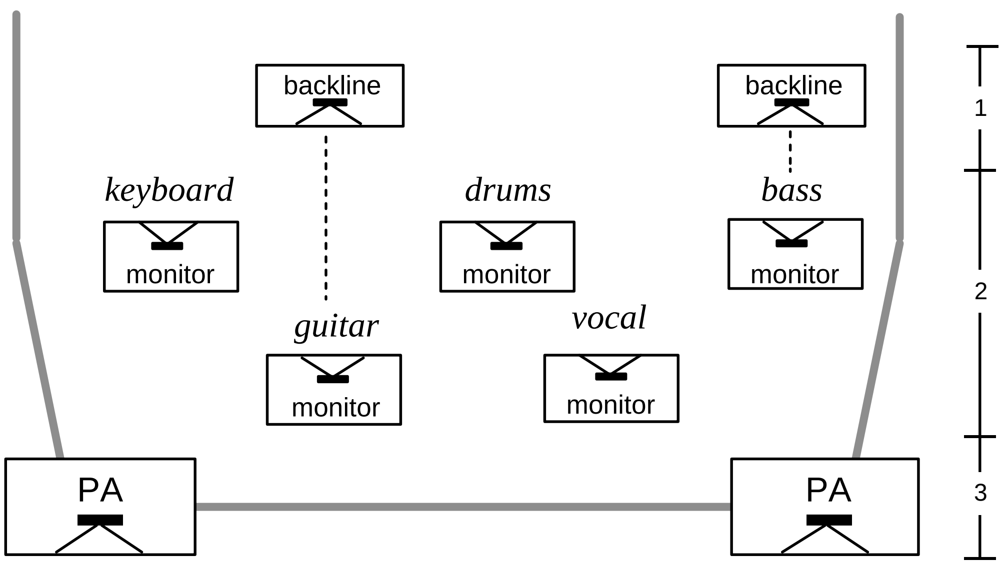
Loudspeakers decrease rapidly in level with distance from the stage. If a moderate level is set on stage, the sound in the audience is too soft (top). Conversely, increasing the level of the speaker in the audience to a moderate level means excessive levels on stage and squealing from microphones and instrument pickups (bottom).

To solve this problem, another approach to amplifying live music was developed. This approach helped create higher sound levels in large-audience venues without producing excessive levels on stage, but as our research found, largely erased the historically-evolved benefits of acoustic music. By the late 1960's a turning point had been reached – one that meant obsolescence for the individual-instrument approach to amplification and rapid growth for the new approach.

Triple-System Amplification

Shea Stadium to Woodstock

BY the historic Woodstock festival in 1969, four years after The Beatles played Shea Stadium, the sound-level-for-large-audience problem was being addressed by an approach we call *triple-system amplification*. By the 1970's the triple-system approach became the standard approach used in larger concert performances. Musicians everywhere began using what commercially and artistically successful musicians used, and the sound equipment industry responded by making smaller triple-systems for groups of almost every size and almost every budget. By the early 1980's the triple-system approach had become the standard for groups playing in venues of virtually any size, and it remains so today. The approach was to split the amplification system into three separate sound systems.



The three separate amplification systems comprising a triple system are shown: the backline system (1) is a holdover from the earlier individual-instrument approach because these amplifiers are considered an essential part of certain instruments' sounds. The monitor system (2) is pointed away from the audience and towards the musicians, and is intended to give each musician their own mix. The PA system (3) projects sound into the audience but not onto the stage.

The backline system

The first of the three systems in a triple system is called the *backline* system, and is a holdover from the era of individual-instrument amplification. Backline instrument amplifiers, mainly used to amplify electric guitars and basses, are considered an essential part of those instruments' sounds and so have been retained.

Backline speakers (to right) are shown behind the band. Certain musical instruments like electric guitars and basses are plugged into backline amplifiers, which are considered an essential part of the instrument's sound.

The monitor system

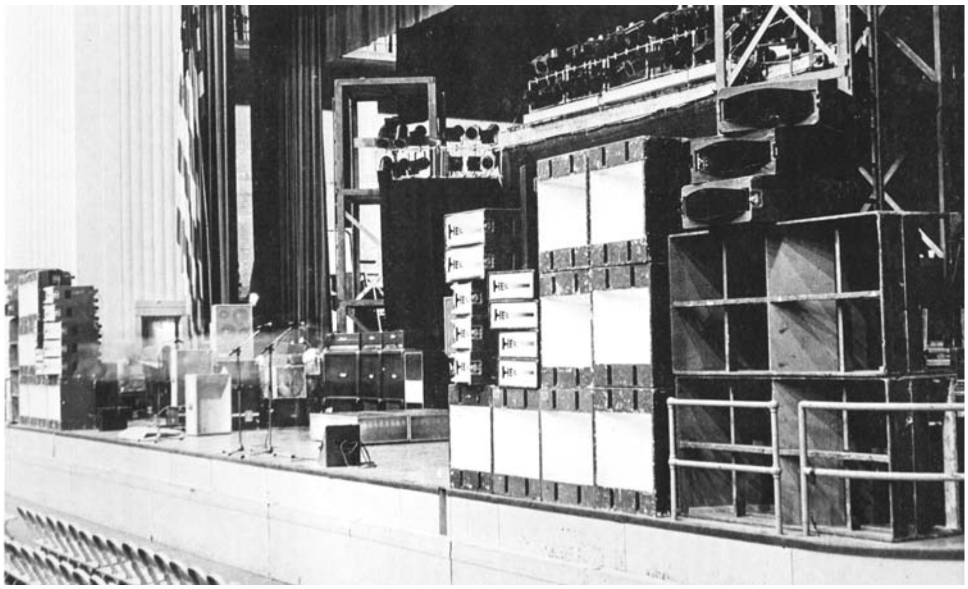
The monitor system consists of speakers arranged near to and aimed at individual musicians. Various voice and instrument signals are mixed together, amplified, and sent to the monitor speakers so musicians can hear themselves and some of their bandmates.

The monitor system consists of speakers placed close to the performer and are used to amplify various instruments and voices for an individual musician. (A backline bass guitar amplifier is also shown middle-left.)

Recently, another kind of monitor system has become popular – the in-ear monitor. In this approach, the monitor signal is sent by radio to hearing-aid-like devices that are inserted into the musician’s ears. In most other respects, in-ear monitors are like traditional monitors.

The PA system

The PA system consists of directional loudspeakers arranged on the sides of the stage and positioned such that their sound beams are focused towards the audience but not onto the stage. The intent is to supply higher sound levels to the audience without radiating high levels to the musicians on stage.



An early example of a concert PA system is shown. A collection of directional loudspeakers stacked together on each side of the stage projects sound mostly to the audience.

Problems with the Triple-System Approach

OUR research shows that triple-system amplification solved one problem – achieving higher sound levels in the audience area without making it too loud on stage – while creating others and erasing the historically-evolved benefits of acoustic music.

More than thirty years after its appearance, musicians told us that with triple systems they routinely struggle to hear themselves and their fellow musicians on stage. They talked about the frustration of wearing earplugs because sound levels have become so dangerously loud. They complained that they have no idea what their audiences are hearing. And they spoke at length about the time-consuming, technically complex, and often frustrating effort required to set up and sound-check their amplification system.

Audience members told us that lyrics are often difficult or impossible to understand, and that instrument sounds are garbled or simply missing. They reported that the sound is often unpleasantly loud.

In the analysis that follows, it is shown how the principles of acoustics and psychoacoustics can be used to understand the root causes of these complaints.

Loss of directional information

IN the field of psychoacoustics, there is a fascinating and much studied property of human auditory perception called the cocktail party effect.[5] *Listeners rely on this property in environments where there are multiple competing sound sources, such as a cocktail party. Amazingly, and without the use of our vision, we can concentrate on any one talker and usually understand what they are saying. For example, we can turn our attention to a talker on our left and hear and understand what that person is saying. Alternatively, we can turn our attention to someone on the right, and hear that talker. However – and this is a crucial point – if those same two talkers are moved to the same location in space so that their voices come from the same direction, our ability to distinguish what either one is saying is greatly diminished.*

5 See, for example, Bronkhorst, A., "The Cocktail Party Phenomenon," *Acustica*, Vol. 86 (2ooo), pp. 117-128.

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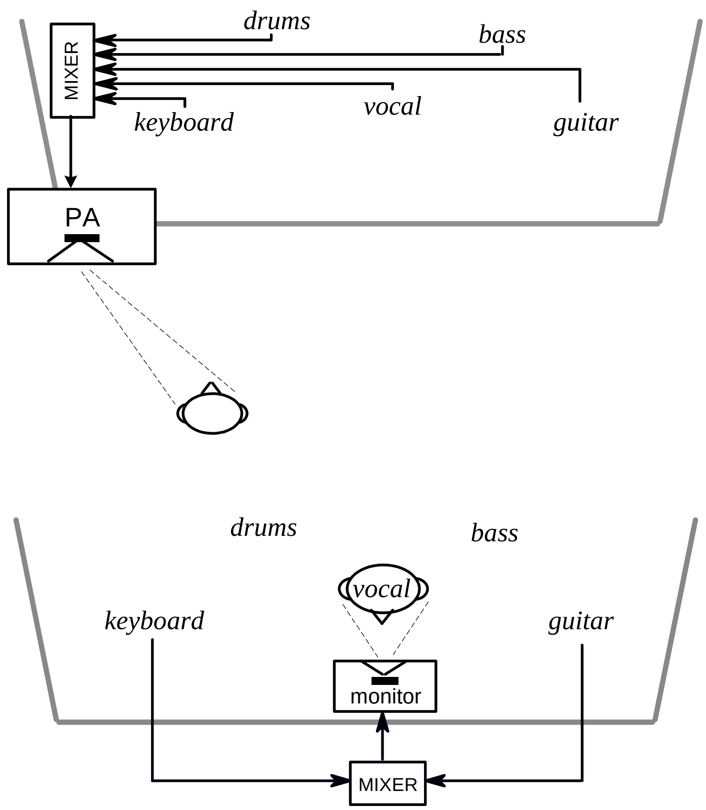
[6] See, for example, Bronkhorst, A., “The Cocktail Party Phenomenon,” *Acustica*, Vol. 86 (2ooo), pp. 117-128.

In the triple-system approach, however, voices and instruments are combined electronically in a mixing console into a single composite electrical signal. This signal is then amplified and sent to the PA speakers, which project the composite signal to the audience. In such an arrangement, the audience hears all of the voices and instruments coming from the direction of the nearest PA speaker,[1] and thus cannot benefit from the cocktail party effect. The same situation is true on stage for the musicians. Signals from multiple instruments are electrically combined and emanate from single direction: the monitor speaker closest to the musician. They too are unable to benefit from the cocktail party effect.



In the triple-system approach, voices and instruments are electrically combined and emanate from the PA speakers (top). The sound arrives from the same direction, making it harder for our hearing system to differentiate them. Similarly, musicians hear the sound of multiple instruments from a single location – the monitor speaker (bottom).

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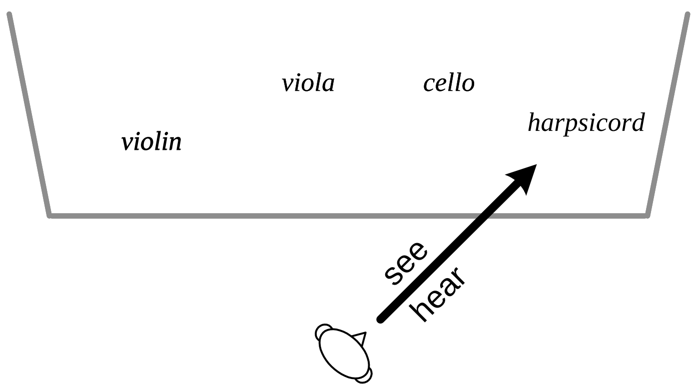
[1] Although both PA speakers are on, we localize to the nearest one because of a property of our hearing called the ‘precedence effect’. For more on this property, see for example, Cremer, L., and Muller, H., *Principles and Applications of Room Acoustics,* Volume 1, p. 494.

We found that the loss of spatially distributed sound sources in triple systems is one important reason musicians complain of not being able to hear well from their monitors, and members of the audience complain of difficult to understand lyrics and garbled or missing instruments.

Loss of auditory-visual integration

IN most environments, there is a strong connection between what is heard and what is seen. In nature, sound usually comes from the direction the eyes say it should. And conversely, things usually appear from where our ears tell us they should. We instinctively connect what we hear with what we see in order to gain a deeper understanding of our environment. When we do, it is well known that we actually hear better.[1,2]

This same ability also enhances our appreciation of music. In an acoustic music performance, if we hear something of particular interest, such as a solo, we automatically turn our heads to connect what we are hearing with what we are seeing.

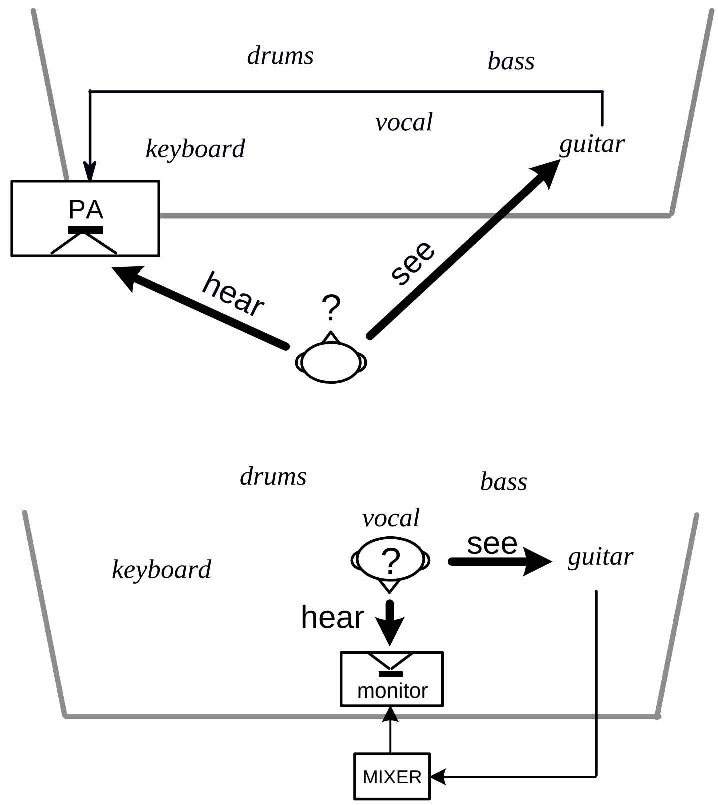


In an acoustical performance, instruments are heard and seen from the same direction, creating a natural synergy between the principle senses. When we hear something that interests us, we can simply turn to connect it with what we see and proceed to a deeper level of understanding.

1 See for example, Sumby, W. H., and Pollack, I., "Visual Contribution to Speech Intelligibility in Noise," *Journal of the Acoustical Society of America*, Vol. 26, No. 2, (March, 1954).

2 Massaro, D. W. and Stork, D. G. "Speech Recognition and Sensory Integration" *American Scientist*, May-June 1998.

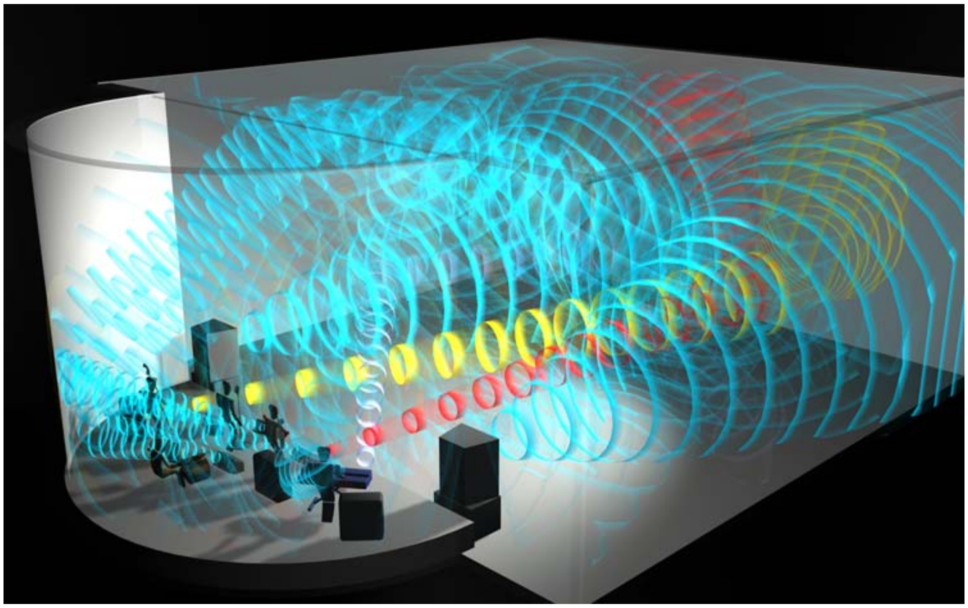
In the triple-system approach to amplification, however, the voices and instruments are electronically combined and emanate from a single location – the nearest PA speaker for the audience, and the nearest monitor speaker for the musician. Under these circumstances, neither musician nor audience member knows which way to turn to connect sight with sound, and therefore must work at making this connection. Audience members told us they spend time visually hunting for which musician is making the sound that has stimulated their interest. Musicians reported that it is easy to lose critical music cues, and miss out on the musical ideas of their fellow players because they're busy trying to connect sight with sound.



In the triple-system approach to amplification, the audience hears the sound of an instrument from the nearest PA speaker instead of the direction of the instrument (top). Musicans hear sound from their monitor but visually the player is elsewhere (bottom).

Excessive reverberation

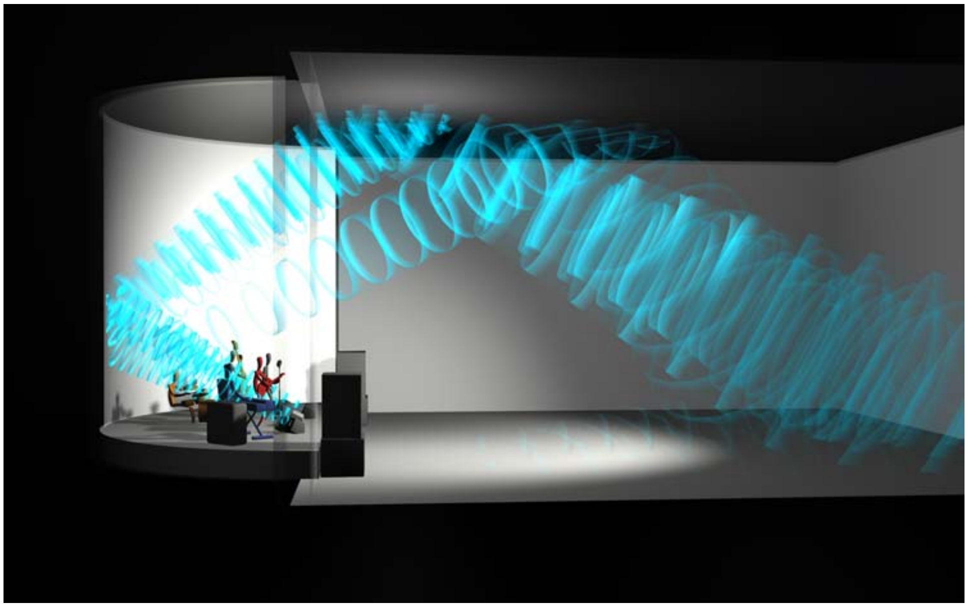
We found that triple-system amplification can create excessive reverberation because the three independent speaker systems flood the room with reflections that return to listeners as reverberation. Excessive reverberation means that lyrics become more difficult to understand and musical detail is lost.[1] The problem gets progressively worse as the full complement of PA speakers, monitors, and backline speakers are added.



Excessive revererberation can be created by the sound from multiple speakers flooding the upper walls and ceiling with unwanted sound, which returns as reverberation.

[1] For a good introduction to the effects of reverberation on speech, see Steeneken, H. and Houtgast, T., "A Review of the MTF Concept in Room Acoustics and its Use for Estimating Speech Intelligibility in Auditoria," *Journal of the Acoustical Society of America*, Vol. 77, No. 3 (1985).

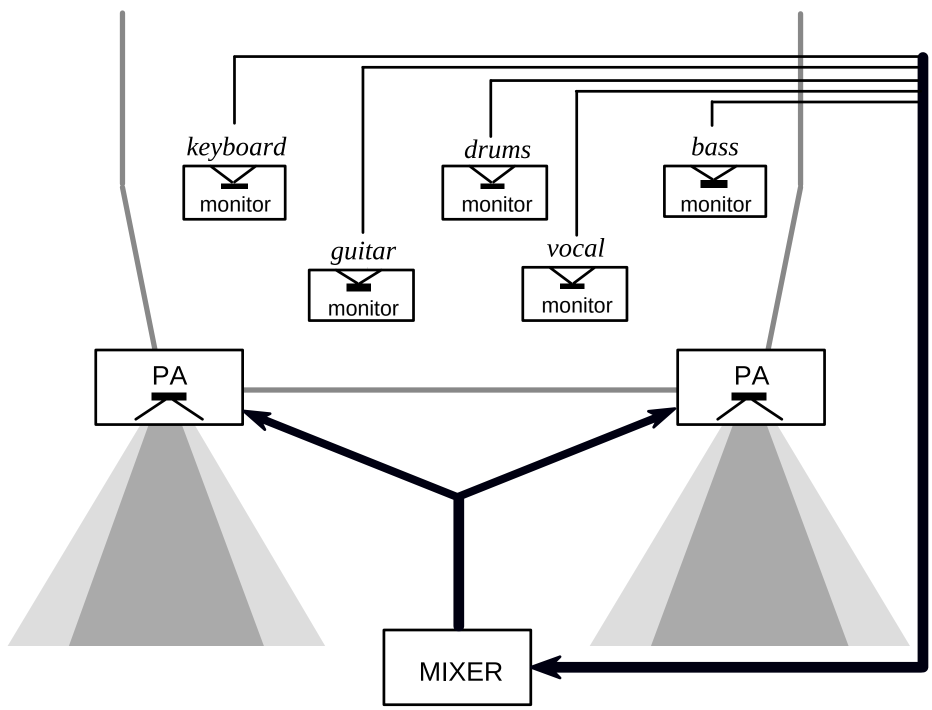
Monitor speakers are especially problematic when it comes to generating reverberation: pointed towards the back wall and angled upwards, the sound is reflected to the ceiling and then into the listening area of the room.



Monitor speakers are textbook examples of how to create reverberation.

Musicians not in control of their music

IN the triple-system approach, the mixing console is used to electronically combine the instruments and voices into a single electrical signal that is then sent to the PA speakers. The mix is created by a sound operator typically positioned in the audience. Because the directional PA speakers are deliberately aimed away from the stage, the musicians hear little, if any of the sound that's being created for their audience. Instead, they hear a completely different mix of sound coming from the backline and monitor systems.



A mixer is used to combine the instruments and voices into a single electrical signal, which is then sent to the PA speakers. Because the PA speakers are highly directional, the musician hears little or nothing of what the audience is hearing.

In such an arrangement, the musicians initiate the sound, but then they immediately lose control of it to the person operating the mixing board. They do not control how they sound to themselves through their monitors, and they do not control how they sound to their fellow musicians through the other musicians' monitors. And yet the person who *does* have control over the monitors cannot hear the changes they are making because they are not on stage. We observed many situations where musicians tried to visually signal the sound operator to make adjustments to the monitor mix while trying to play at the same time. And musicians interviewed as part of this research spoke at length about the difficulty they have in getting the right sound in their monitors.

In the case of the PA-mix for the audience, musicians cannot hear the changes the sound operator has made to their sound, and cannot therefore know if their artistic intent is being met. The musicians we worked with said that their assumptions about the sound in the audience are often wildly incorrect, something they said they only discover after the performance by asking people, *"How did we sound?"*

Excessive loudness

IN our research, we found that the problems already described – the inability to use the property of our hearing system known as the cocktail party effect, the difficulty connecting sight with sound, the problem of excessive reverberation, the inability of musicians to control their own music, and the inability of musicians to know what their audiences and fellow musicians are hearing – all contribute to the problem of excessive sound levels. Musicians told us that when they are struggling to hear, and be heard, they naturally react by increasing their volume. And when multiple musicians are reacting this way, the music gets louder and louder to the point that many musicians and audience members are wearing earplugs during performances.

In addition to the well-established relationship between excessive sound levels and permanent hearing damage,[1] it has been shown in psychoacoustical studies that at higher sound levels, our ability to hear detail is lost, and our ability to understand lyrics is seriously diminished.[2] Our conclusion is that musicians are increasing their volume to hear better but when they do, they are hearing even less well.

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[1] For a good introduction to hearing loss from excessive sound levels, including amplified music, see the information provided by the *House Ear Institute* at www.hei.org.

[2] See, for example, Pickett, J. M. and Pollack I., "Masking of speech by noise at high sound levels," *Journal of the Acoustical Society of America*, Vol. 30, No. 10, pp. 955-963.

Amount and complexity of equipment

IN the triple-system approach, there are numerous speaker enclosures, power amplifiers, mixing consoles, electrical cables, and more. The equipment for even a small band is usually more than musicians can fit in their automobiles, so a van or truck must typically be used. Musicians told us that it is a major effort to load the equipment into a vehicle (or vehicles), transport it to the venue, then unload and carry it to the performance area.

Sound equipment must often be loaded into a truck or van for transportation.

After load in and set up, hours of work are usually required to complete the task of wiring all the equipment together: cables are needed to connect instruments to backline instrument amplifiers and mixing consoles, mixing consoles to amplifiers, and amplifiers to speakers. All of the connections must be checked and any problems detected and repaired before the performance. The whole process must be repeated in reverse after the performance is over.

A typical mixing console has about 500 controls.

Hours of work are often required to get the three different amplification systems used in a triple system set up and checked out. Here, PA speakers are hoisted into a van after the performance.

Additionally, sound equipment consumes valuable space on stages of often limited size. As a result, we found that musicians are often confined to very small areas, literally boxed in by their sound equipment. And once set up, the equipment often obscures sight lines between audience and stage. This has the effect of reducing the number of good viewing locations in the audience.

A stage is often crowded with sound equipment, leaving little space for the musicians, and interfering with sightlines.

Before triple-system amplification, we estimate that musicians spent approximately 90% of their time playing and only 10% on the equipment necessary to play. Today, we estimate that ratio has been reversed. This has an obvious impact on a musician's ability to improve his playing because equipment issues reduce rehearsal and practice time.

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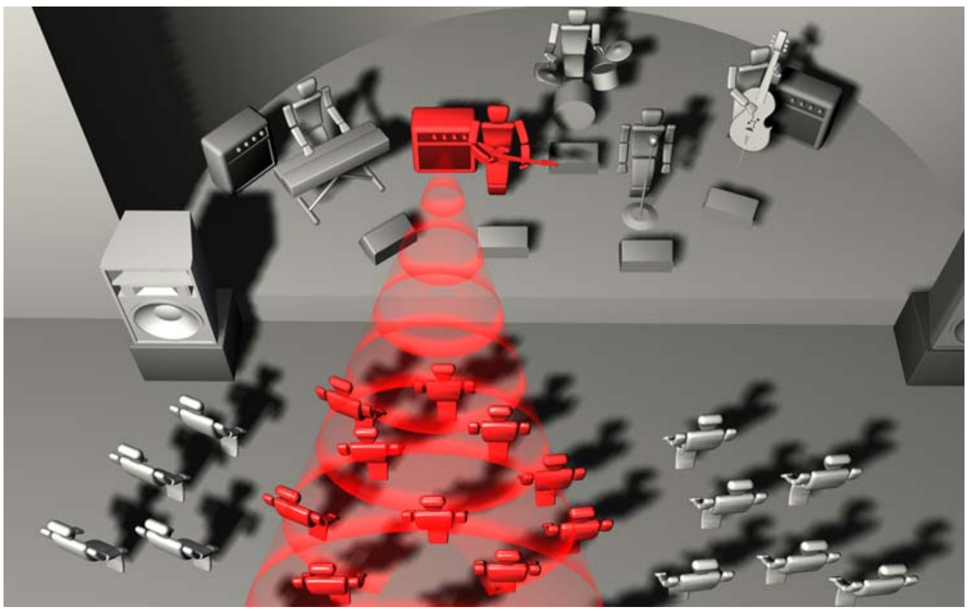
Additional problems with triple systems

Acute directionality of backline instrument amplifiers

Backline instrument amplifiers are the source of some remarkable musical instrument sounds, especially from the electric guitar, but we found that at the same time, they are the source of some very real acoustical problems.

We observed that guitar players almost never stand right in front of their backline amplifiers. Musicians told us the reason is that these speakers are so directional that the sound level and tone directly in front is often incredibly harsh. But some audience members are on axis and get excessive, often unpleasantly loud guitar sound.

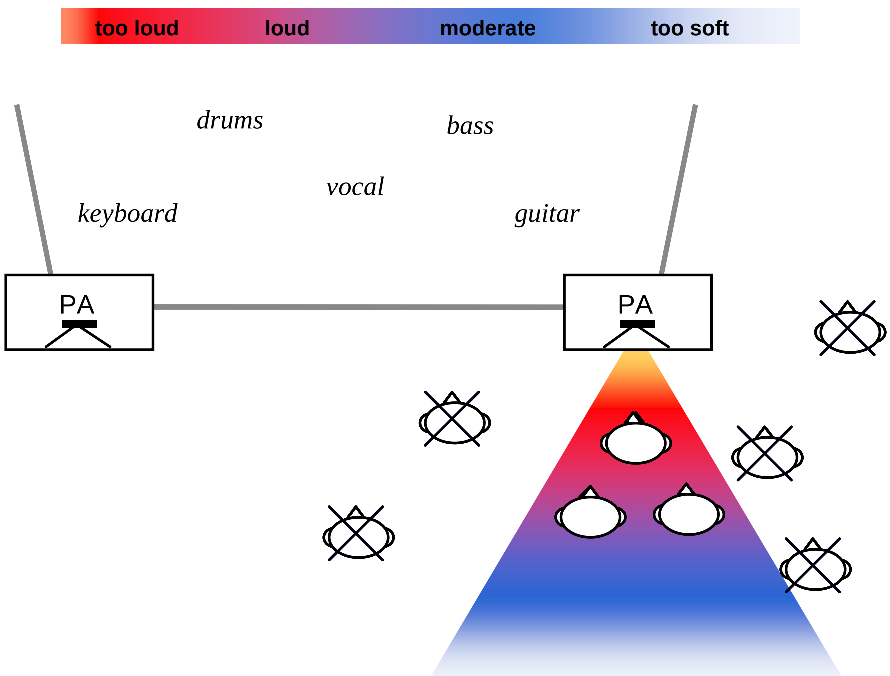


Backline instrument amplifiers are acutely directional. The guitarist usually stands to the side of this harsh beam of sound. Members of the audience that are on axis hear sound dominated by the guitar, at often painfully high volume levels.

Musicians told us they experience the same effect. If they are on axis of the guitar beam, the sound is harsh and loud and dominating. If they are off axis they hear a dull version of the instrument – a version that guitar players say is unrepresentative of the tone they have carefully created. We have concluded therefore that the only one who is getting the right guitar sound is the guitarist.

Directional PA speakers

PA speakers are purposely made directional so that their high intensity sound beams are directed at the audience and away from the musicians on stage. We found that this beam of high intensity sound often makes it uncomfortably loud in the front of the audience area, and not loud enough in the rear. It also produces areas of muffled sound to the sides where the beam is not focused, further contributing to the problem of hard-to-understand lyrics and garbled or missing instrument sounds.



PA speakers are directional and rapidly fall off in sound level with distance. Only some of the listener locations therefore experience the right tone or level. Many other locations are too loud, too soft, or outside the directional pattern of the speaker, where sound is muffled.

A New Approach

WITH the problems created by the triple-system approach to amplification in mind, a new technology was pursued by a group of researchers at Bose whose purpose was to address these problems by applying the natural and historically evolved benefits of acoustic music to performances with amplification.

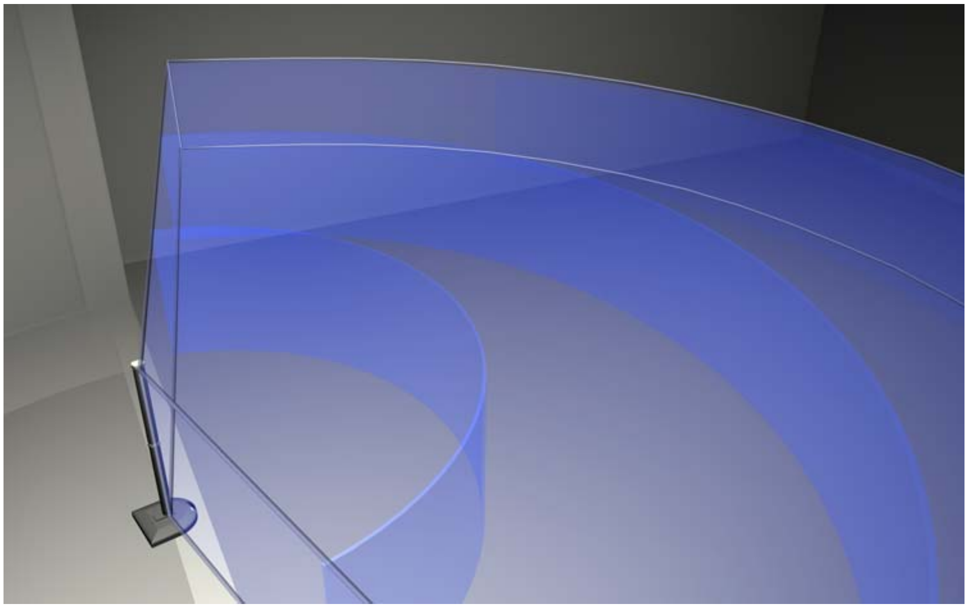
Conventional vs. Cylindrical Radiator™ loudspeakers

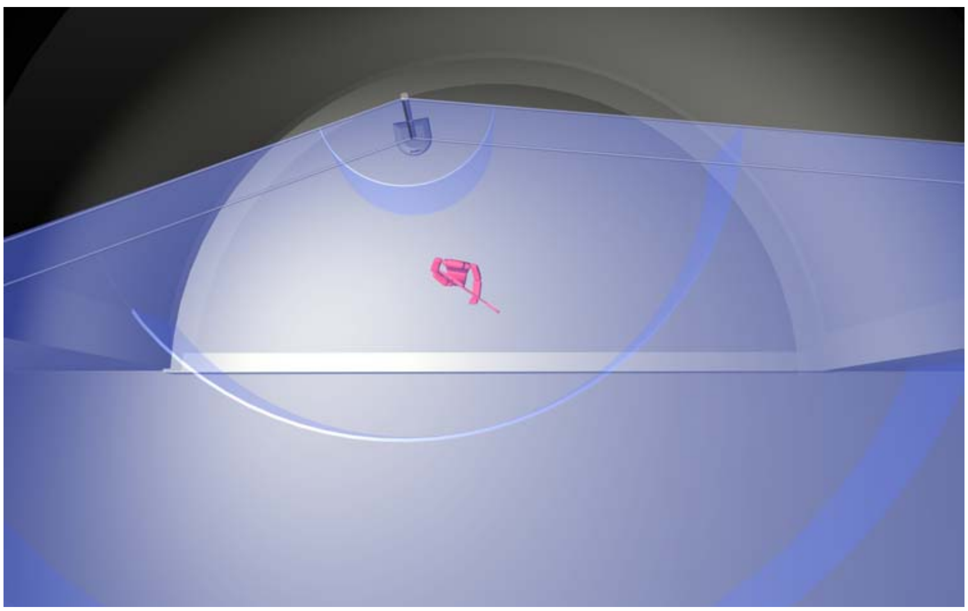
TO understand the insight that led to the new technology, recall that the fundamental reason sound amplification systems changed to the triple-system approach in the 1960s was to entertain larger audiences with higher sound levels. To have retained the original individual-instrument approach and at the same time achieve enough level in larger audiences would have meant exposing the musicians to excessive sound levels or triggering microphone and instrument-pickup feedback (or both).

> A conventional loudspeaker radiates sound in three dimensions: out, left and right, and up and down. Such a source retains only one-fourth of its sound intensity with each doubling of distance from the source. We hear this as a rapid reduction in sound level with distance. If a comfortable level is set on stage for the musicians, the sound is often not loud enough in the audience area. Conversely, if we approach a conventional source that is at a comfortable volume level in the audience, it soon reaches a level that is uncomfortably loud on stage. It is this fundamental property that makes these sources unsuitable for the challenge of creating sound that can serve both the musician and the audience at the same time without being too loud or soft for either.

Early in our research, the problems associated with the triple-system approach were discussed with Bose senior researcher Clifford Henricksen whom, in addition to being a noted acoustical and mechanical engineer, is also an accomplished composer, keyboardist, vocalist, and bandleader. Henricksen was already intensely aware of the problems with conventional amplification.

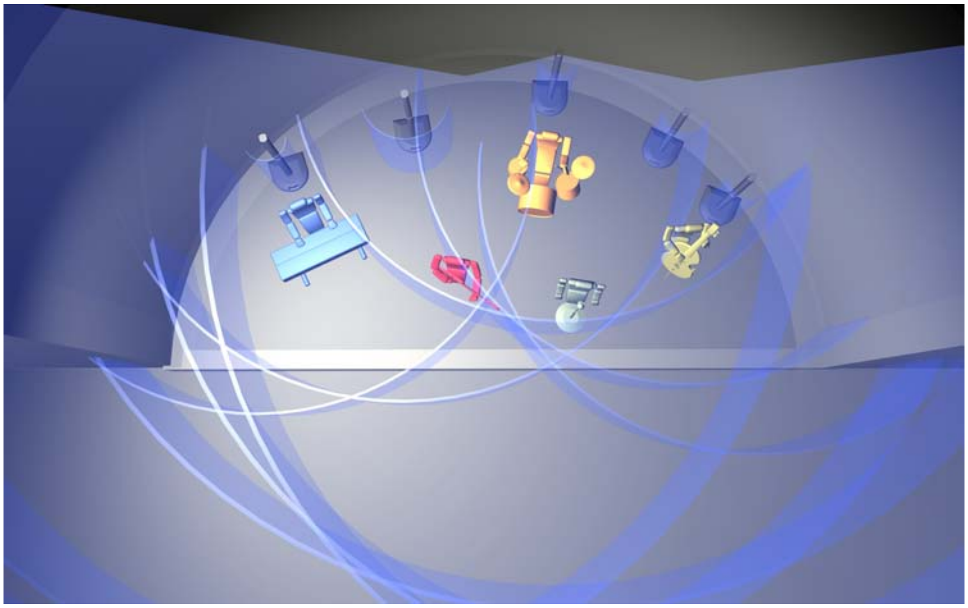
It was Henricksen who first thought that the properties of our Cylindrical Radiator™ loudspeaker might be used to address the problems of amplified music. He made an early prototype, and all those that heard its performance were deeply impressed. We could set the correct level in the audience and then move to the stage area and hear the level as increasing only modestly. We found that we could walk to within inches of the prototype and never have the feeling that it was too loud. Henricksen immediately set out to further test and refine the concept.





A Cylindrical Radiator™ loudspeaker radiates sound predominantly in two dimensions: out and to the sides, but very little up and down (top). Confining the sound energy to two dimenions versus three means that the sound level diminishes only modestly with distance from the source. The level from such a source can be set properly for the musician *and* the audience (bottom).

With such properties, Henricksen knew that there was no longer any justification for separate backline, PA, and monitor systems. The sound level in the audience could be made louder without becoming too loud on stage. A small number of Cylindrical Radiator™ loudspeakers – roughly one located near each musician – would replace all three systems. The approach would closely approximate the acoustics of an unamplified performance: the sound of each musician would come from the location of that musician, the musician alone would control his or her tone and volume, and only a small amount of equipment would be needed.



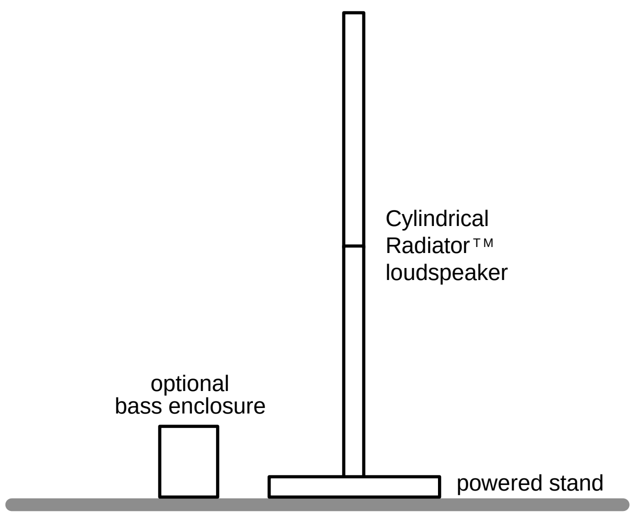
In the new approach, each musician, or nearly each, is equipped with one of the new Cylindrical Radiator loudspeakers. Such an approach closely approximates the arrangement and acoustics of an unamplified performance.

Refinements to the approach

WITH these insights in mind, a team set out to refine the approach. A number of acoustical prototypes and tests were conducted to optimize the performance of the Cylindrical Radiator loudspeaker.

A number of early prototypes of the Cylindrical Radiator loudspeaker are shown.

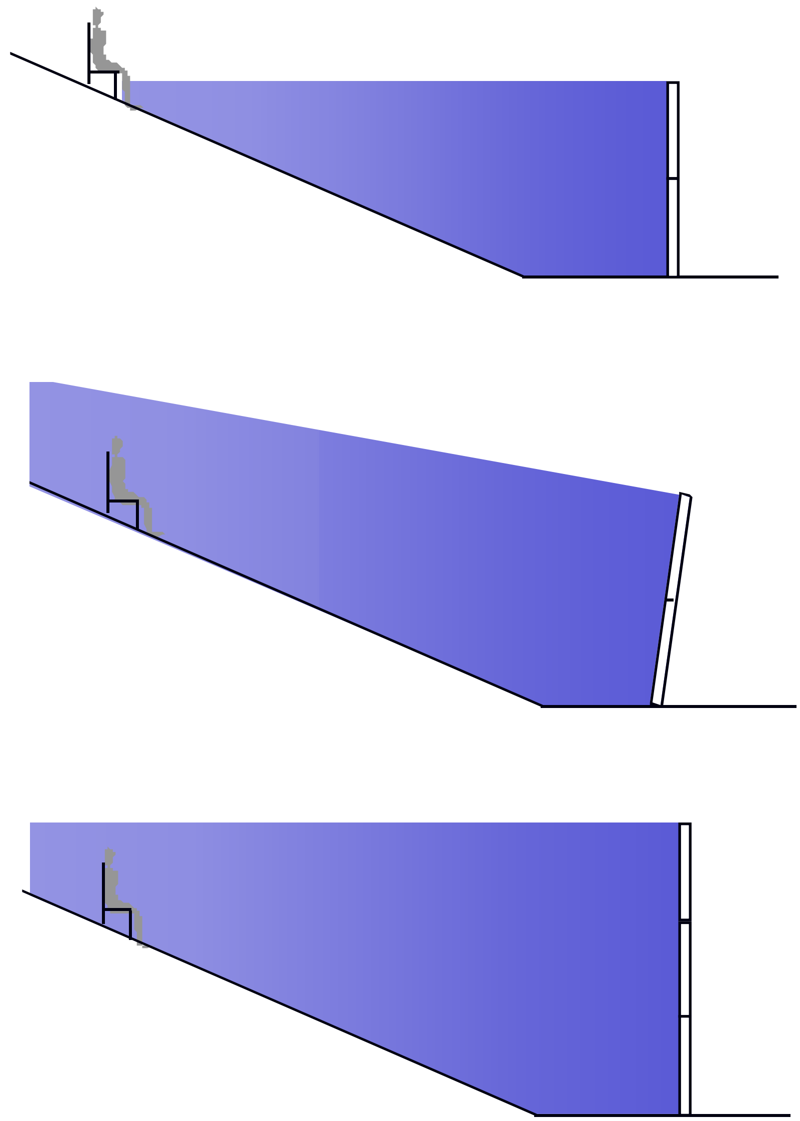
For instruments that require amplification in the bass and baritone ranges – the bass guitar or electronic keyboard for example – the team developed a separate loudspeaker enclosure to accompany the Cylindrical Radiator loudspeaker. A powered stand was made to support the loudspeaker and house power amplification and electronics adapting the speaker for a wide variety of musical instruments and microphones.



The powered stand holds the Cylindrical Radiator loudspeaker and houses amplifiers and electronics for use with virtually any musical instrument. An optional bass enclosure is for instruments operating in the bass and baritone ranges.

The devices are compact, and quickly disassemble, making them easy to transport. The electronics allow a microphone, musical instrument, or other piece of audio equipment to be connected directly to the powered stand.

For situations where the audience is seated above the height of the Cylindrical Radiator™ model L1 loudspeaker – for example, at the back of a sloped seating plane, or in balconies – testing showed that the source could be tilted with suitable hardware. Alternatively, the length of the Cylindrical Radiator loudspeaker can be increased.



Because of the unique radiation pattern of a Cylindrical Radiator loudspeaker, it is possible for a listener to be above the radiation pattern (top). With suitable hardware, the source can be tilted, thereby steering its radiation pattern upwards (middle). Alternatively, a longer source can be constructed, which has the effect of extending the height of the radiation pattern (bottom).

Acoustical and musical performance testing

Eight second-generation prototype systems were built to embody the numerous refinements made based on the testing of earlier prototypes. These prototypes were tested extensively with a variety of musical groups and in a variety of venues. In each case, the musicians were given a brief presentation of the technology, and were then aided by technicians during the normal pre-performance preparation period. In every case, an audience was invited; however, they were deliberately not told of the new technology because the researchers wanted an authentic audience reaction.

Musical styles tested:

- Rhythm & Blues
- Rock ‘n Roll
- Country
- Folk
- Pop
- Alternative
- Blues
- Jazz

Venue types tested:

- Small club
- Medium nightclub
- Large nightclub
- Civic auditorium
- Small theater (5oo seats)
- Large theater (2,ooo seats)[7]

[7] In the large theater, conventional PA speakers were used to reach distant seating areas.

The results obtained were an extraordinarily strong validation of the concept. Musicians spoke of a quantum improvement in their performance because they could hear themselves and each other. They were thrilled at being in complete control of their music, and spoke at length about the reduction in the amount and complexity of equipment. Many noticed immediately the fact that they were playing with greater dynamics (from very soft to very loud passages). The urge to turn up their volume was gone and thus the overall stage volume remained comfortable. They described the experience as being completely natural – more natural than anything they had experienced with conventional amplification equipment.

The prototype system tested extensively using a variety of musical groups in a variety of venues is shown in one of those venues.

A final prototype of the Cylindrical Radiator™ loudspeaker was built and additional tests conducted with musicians and audiences. A final set of refinements was made, and the product was engineered for manufacturing.

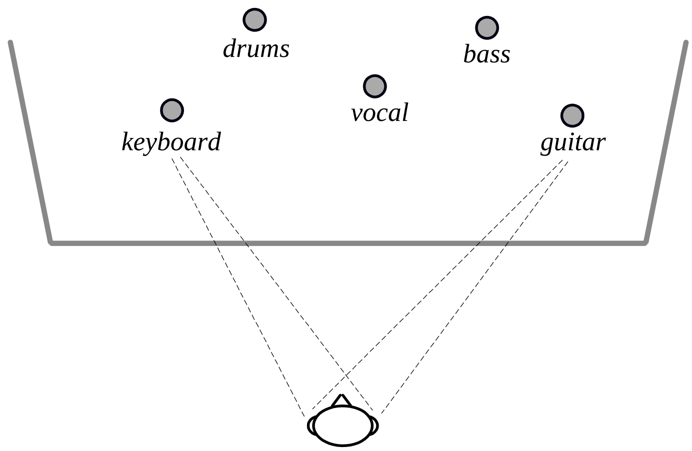
The final protoytpe of the Cylindrical Radiator loudspeaker is shown (with inventor Clifford Henricksen).

Fundamental advantages of the new approach

THE advantages of the approach based on the Cylindrical Radiator™ loudspeaker are comprehensive because both the primary and secondary problems characteristic of the triple-system approach are addressed.

1. Full use of the property of hearing known as the cocktail party effect

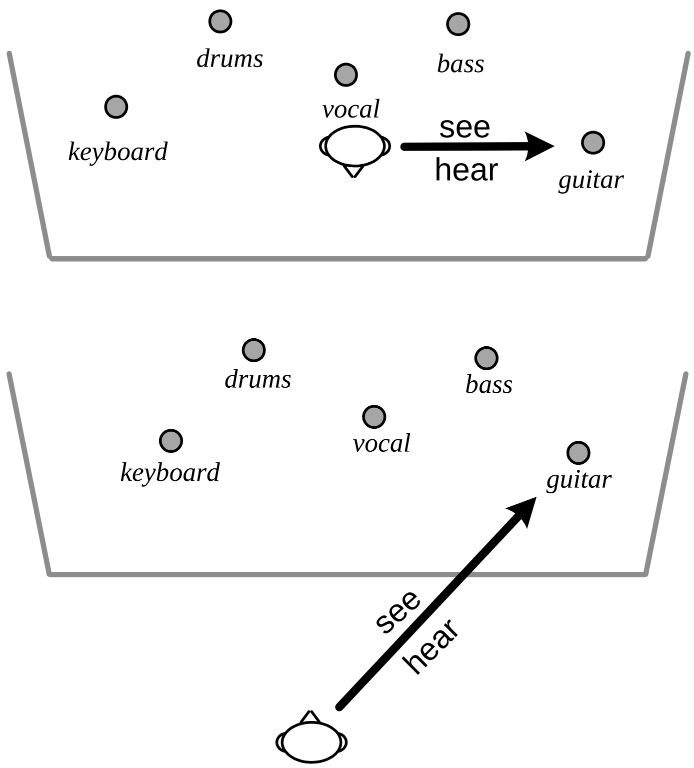
In the audience and on stage, regardless of location, the sound of each instrument or voice comes from a different direction. Thus the full spatial richness present in an unamplified performance is achieved. The full benefit of the cocktail party effect – the ability to pick out and appreciate individual instruments and voices because they are coming from different directions – is enjoyed by musicians *and* members of the audience.



In the approach using Cylindrical Radiator loudspeakers described here, the listener hears sound from the locations of each of the individual instruments, as in an unamplified performance.

2. Restoration of auditory-visual integration

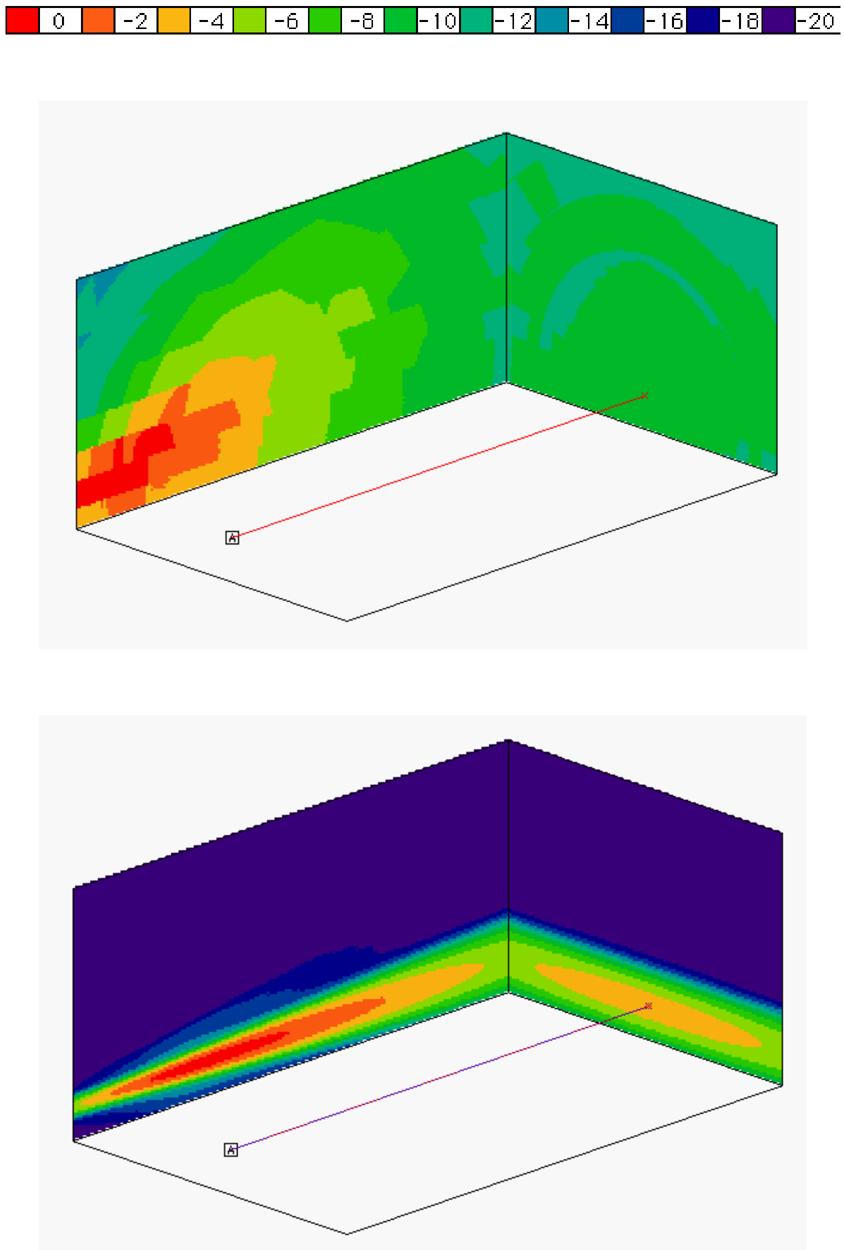
In both the audience and on stage, the visual and auditory fields are synchronized; as a result, the musician enjoys the sound of his fellow musicians coming from their proper directions, and audiences hear and see sound from the same direction. Musicians and members of the audience can therefore quickly reach the deeper level of understanding possible when both the auditory and visual fields are working in harmony.



In the new approach that uses Cylindrical Radiator™ loudspeakers, the integration of sight and sound is achieved for musicians (top) and members of the audience (bottom).

3. Less reverberation

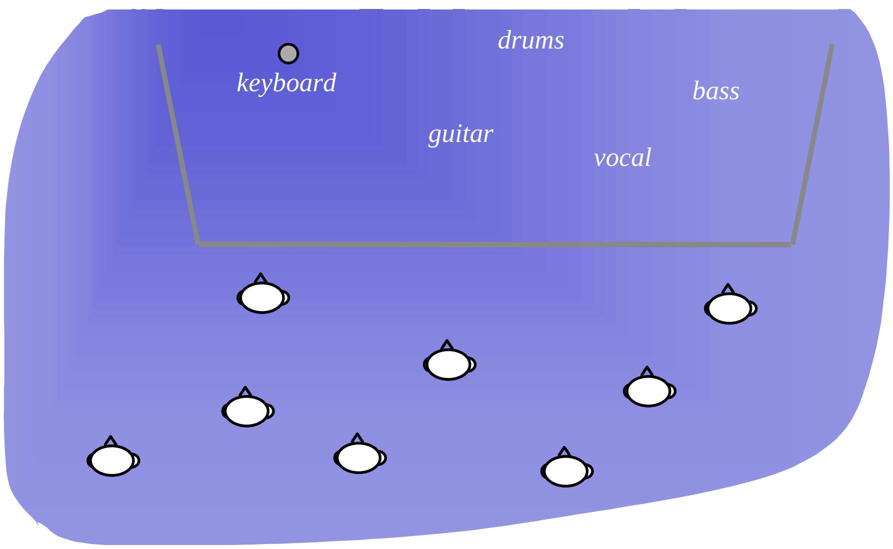
Cylindrical Radiator loudspeakers radiate sound predominantly to the front and sides but very little up or down. As a result, less sound radiates to the upper walls and ceiling where it returns to listeners as reverberation. Our testing showed that instrument sounds were clearer, and vocals more intelligible. Moreover, we found that the use of Cylindrical Radiator loudspeakers meant that the undesirable variation in sound typically experienced as a band moves from venue to venue was significantly reduced.



A typical conventionial speaker (top) radiates sound to the upper wall and ceiling of a room, producing reverberation that can harm the clarity of performances. (Each color change corresponds to a noticeable, or 2 dB, change in sound level.) A Cylindrical Radiator™ loudspeaker (bottom) does not produce as much reverberation because it radiates much less sound to reflective surfaces in the upper part of a room.

4. Consistent sound quality throughout the listening area

As an amplifier for musical instruments, the Cylindrical Radiator™ loudspeaker has fundamentally superior properties for musicians. In our research, musicians complained, for example, that guitarists sound good in only one location – where the guitarist is standing. Everywhere else his sound is too loud, too soft, too bright or too dull. With the Cylindrical Radiator loudspeaker, instead of radiating a beam outward toward only one player, sound is radiated almost equally to the stage and audience areas. In testing, players reported that they heard themselves better, heard fellow players better, and did not need to stay fixed in one location on stage to hear good sound.



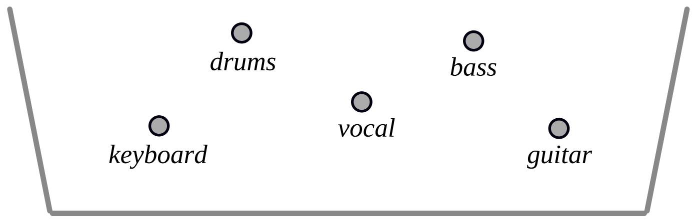
The radiation pattern of a Cylindrical Radiator loudspeaker is such that an instrument or voice sounds consistent across the stage and audience.

5. Artistic control restored to musicians

The musicians – and no one else – are in complete control of their music. In testing, musicians reported that they were able to play with confidence that the sound they made on stage was what was projected out to their audience. They said they were able to play naturally, mix themselves, and make adjustments to their playing necessary to optimize their performance.

6. Compact, easy-to-use equipment

Cylindrical Radiator™ loudspeakers are easy to transport and set up. Assembly takes about a minute. Then, the musician simply plugs in and plays. The only electrical cords are from the instrument or microphone to the speaker and from the powered stand to a power outlet. Sightlines between audience and stage are excellent.



Using Cylindrical Radiator loudspeakers involves compact, easy-to-use equipment that is easy to set up.

Summary of advantages for musicians and members of the audience

1. Advantages for the musician and musical group:

- The sound of the musician's instrument remains consistent over a very large area. The musician can move freely, thereby enhancing their interaction with fellow musicians and the audience. Musicians perform with little equipment on stage and enjoy better sightlines across the stage and to the audience.
- The radiation pattern of the Cylindrical Radiator™ loudspeaker is such that a musician's sound is heard by fellow musicians and by the audience. The ability to hear and be heard is a major benefit reported by musicians participating in musical-performance testing of this new concept.
- Musicians hear sound from the Cylindrical Radiator loudspeaker that is free from audible distortion. (Intentional distortion – for example from an electric guitar preamplifier or guitar modeler – is faithfully reproduced.)
- Each musician can enjoy the benefits of the cocktail party effect. Instruments and voices come from different directions, and can therefore be better heard and understood. Moreover, musicians can quickly use their eyes and ears together in order to deepen their musical experience because sounds come from the direction of the player.
- The radiation pattern of the Cylindrical Radiator loudspeaker produces little reverberation. As a result, instrument sounds are more clear and lyrics more intelligible.
- Testing of this new approach showed that musicians play dynamically but at lower average volume levels. The urge a musician feels to turn up his or her volume is greatly diminished because of the improvement in clarity and detail.
- The musicians are in control of the sound, as in an all-acoustic instrument performance.
- Sound equipment can be carried and set up in minutes.
- The number of electrical connections is few and easy to establish. The only audio connections are from the musicians' instruments or microphones to the Cylindrical Radiator loudspeaker.
- The sound equipment is visually unobtrusive, and consumes a relatively small amount of cargo space.

2. Advantages for the audience:

- The audience hears each instrument and voice from its position on stage, an arrangement that makes it possible for them to enjoy the benefits of the cocktail party effect. The listener can pick out and appreciate individual instruments and voices even in highly complex passages.
- The audience enjoys the benefits of eye-ear coordination. When something draws their attention sonically, they can instantly connect it with what they see, at which point they can concentrate on a deeper appreciation of the music.
- The audience hears instruments and voices more clearly because a Cylindrical Radiator™ loudspeaker's radiation pattern results in little reverberation.
- Audiences experience music that is dynamic but whose average sound level is comfortable.
- The audience has the pleasure of watching the musicians perform with little visual obstruction.
- The audience hears sound from the Cylindrical Radiator loudspeakers that is free from audible distortion.

Conclusion

THROUGH extensive acoustical and musical-performance testing, it is now known that a unique and unusual type of sound source arranged in a special and naturalistic way significantly improves live amplified musical performances. The application of the Cylindrical Radiator™ loudspeaker – approximately one for each musician on stage – allows the long-evolved benefits of the unamplified musical performance to be experienced with musical styles that use amplification.

Acknowledgement

THE author is grateful for the help of his friends and colleagues who read and commented on earlier drafts of this paper, and to all of his colleagues in the Bose Live Music Technology Group and Professional Systems Division.

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