AES 19th International Conference on
Surround Sound Techniques, Technology, and Perception
June 21-24, 2001, Schloss Elmau, Germany

THE AMBIOPHONE
DERIVATION OF A RECORDING METHODOLOGY OPTIMIZED FOR AMBIOPHONIC REPRODUCTION

RALPH GLASGAL

Ambiophonics Institute
4 Piermont Road, Rockleigh, New Jersey, USA
glasgal@ambiophonics.org
www.ambiophonics.org

Ambiophonic surround systems reproduce both existing and new 2-channel music discs with unprecedented spatial realism. This paper extends this binaural technology concept to recording. It describes microphone, live recording and studio monitoring techniques that take advantage of the foreknowledge that playback will be Ambiophonic to produce music recordings of exceptional "you-are-there" concert-hall realism, fortuitously and optimally, still needing just two media channels.

INTRODUCTION

There exists an affluent, elite group of classical music lovers, high-fidelity enthusiasts, audiophiles, and musicians who value realism in music reproduction above all other considerations. Ambiophonics, a public domain technology supported by the non-commercial Ambiophonics Institute, is a no holds barred methodology designed to appeal to such devoted listeners and displace stereophonics as their preferred route to audio nirvana. Thus Ambiophonics is deliberately configured to enhance acoustic and virtual music recording and reproduction and makes no compromises in fidelity to accommodate movie sound tracks, off-stage direct sound sources or listening by large groups.

The goal of Ambiophonics is to deliver to one or two home listeners a realistic replica of the concert hall experience. In this context, realism does not necessarily need to equate to accuracy. A recording made in Carnegie Hall but played back in Avery Fisher Hall can seem very real but is not accurate. Ambiophonics aims to provide a concert-hall, opera house, church, cathedral, theater, rock pavilion, etc. musical experience, at home that the brain will accept as real. Real, not accurate and not necessarily perfect just as real concert halls are not ideal.

The Ambiophonic method [1] combines an exploitation of under-appreciated psychoacoustic principles [2, 3, 4] with the basic rules of good musical performance-space design [5,6,7] to create believable concert-hall soundfields in a home listening room. Ambiophonics moves the listener into the same space as the performers by accommodating to individual pinna characteristics, [8,9] minimizing interaural correlation at the listening positions, abandoning the traditional stereo loudspeaker triangle (including the center speaker in 5.1), generating early reflections and reverberant fields from a library of stored real-hall impulse responses, and using room correction/treatment technology to insure that listening room early and late reflections are essentially inaudible. Fig. 2

Ambiophonic reproduction of music combines crosstalk cancellation, [10] novel speaker placement and shape, and real hall ambience convolvers (Ambiovolvers) feeding surround loudspeakers to achieve the holy grail of binaural technology i.e. delivering to each ear an almost exact replica of what that ear would have heard if it had been at the

microphone position during the live performance. Fig. 1

The reason that there are already so many references cited in just the first few paragraphs of this paper is that I would be the first to concede that there is nothing about Ambiophonic technology that I did not find in the existing literature after I thought to search for it. That there is nothing new under the sun is not as extraordinary as that all this preexisting research has been so resolutely ignored.

Ambiophonics has been shown [1,11] to be remarkably compatible with and able to reproduce existing two channel classical music LPs, CDs and DVDs with realism, despite the variety of microphone, equalization, mixing, and panning techniques employed. If we define stereo as Blumlein did just meaning reproduction via the equilateral speaker triangle, rather than including all two channel recording methods, it is clear that most two-channel recordings are not usually, if ever, inherently stereo. That is, there is nothing basic in the recording process, using microphones or virtual sound processors, that relies on the facts that the localization will be by phantom imaging, that stage width will be restricted to the angle between the speakers, that there will be pinna angle errors and head shadowing errors for central sources, unpredictable comb filtering, rear and side ambience coming, instead, from the front, and so on.

While recording engineers in control rooms may monitor their creations using the stereo triangle there is little they can do to compensate for these problems in their mixes. Almost all panning programs for virtual reality recordings are likewise deficient in most of these areas. Thus one can say that many so-called stereo recordings can be made to sound more realistic using a binaural technology to play them back than they normally would. Most existing recordings are not inherently stereophonic, (in the reproduction sense) even if two channel.

The question has arisen as to whether there is a psychoacoustically ideal recording method one should use when one knows that the subsequent reproduction will, in fact, be Ambiophonic. The other question considered here is whether this ideal Ambiophonic recording method is practical when compared with the usual two-channel recording techniques, including the optimized recording method for 5.1/7.1 surround reproduction so ably devised by Dr. David Griesinger and elucidated in several papers available on his web site [12] and the OCT system advocated by Günther Theile [13].

This paper also suggests how the monitoring of Ambiophonic or even other recordings should be done during the setup, editing or mixing phases of the record production process.

MUSIC VERSUS MOVIE RECORDING

In contrast to movies, where the scene and the acoustic venue change every ten seconds and planes fly overhead and the phone rings in the back room, during a concert, musicians normally do not move about the stage, and the acoustics of the auditorium remain stable for the duration of the performance. Furthermore there are no direct sound sources off stage and the stage width seldom subtends more than say 150-degrees as seen from a good seat in the orchestra.

Thus, it makes little sense from an information theory standpoint to make provision for capturing off stage direct sound or recording the hall ambient response over and over for every note that is played. If you measure the equations of the hall at the best seat in the house for several locations on the stage then it is not necessary to measure and record any hall sound during the performance. One measures the impulse response of the hall before or after the recording session, with or without an audience, or uses a library of the impulse responses of the great halls of the world. Then one uses a mathematical process, called convolution, to operate on the direct sound to generate the surround ambience that would be generated by that hall for the music being played.

The Ambiovolver parcels out the early reflections and the reverberant tails to the appropriate speakers in the domestic concert hall. Fig.2 The process is scalable and the numbers, locations, and frequency responses, of the surround speakers are not critical. The process of convolution, in contrast to microphones, nicely insures that no direct sound can get into the surround speakers. Recording engineers do not have to worry about the ratio of direct to reverberant sound in the hall or main microphones and the main microphones, as we shall see, can be placed without regard to the hall critical radius or the directionality of the bare microphone. Convolution of a stored impulse response makes it unnecessary to use microphones to record hall sound and also eliminates the need for media (SACD, DVD) surround tracks.

In the case of Ambiophonics, as opposed to 5.1, it is normally up to listeners to decide how great a hall they need to recreate to be satisfied. They may select

the hall and the number of ambience speakers. Note that even a poor hall can seem as real as a good hall. However, there is nothing to prevent recording engineers from providing the impulse response of the hall they recommend or stating the address of the hall in the eventual Internet library they wish the listener to use. It is also possible or inevitable that the media player will control the convolver in this regard. The process would then be transparent to the unskilled user.

Another major advantage of hall ambience convolution over trying to record and deliver multichannel surround ambience is that both the locations and the number of the surround speakers in the home system are flexible, scalable, and not critical. It is ludicrous to think that two-surround channels as in 5.1 can emulate a concert hall or provide even marginally acceptable envelopment. Damaske and Ando [6] say five is the bare minimum but bare minimums are not the audiophile way. Research [7] has shown that concert hall listeners are pleased when ambience comes from lateral, rear, overhead and frontal directions in that order of importance and that such ambience should be as uncorrelated or diverse as possible. As a start in this direction, DVD-A can support four ambience channels if 5.1 is not used, and, indeed, Chesky Records and MDG have already released such discs.

I hope shortly to be able to report on experiments with dual membrane electrostatic panels. Such a dual panel can emit both ambience stimulated from the left of the stage and ambience stimulated from the right side of the stage convolved for the same angle saving speaker space and cost. Such membranes are transparent to sound and so do not cause serious, erroneous early reflections. Alternatively, the signals for the same surround angles can be mixed electronically and applied to a single speaker to save on space, speakers and amplifiers.

But there is no known real-time four-surround speaker microphone placement theory that can deliver the kind of realism that audiophiles rightly demand, although Ambisonics comes close. However, Ambisonics requires more than two media channels, does nothing for the existing library of two channel LPs and CDs, and is more sensitive to speaker location and response.

There is the minor question of reproducing surround applause when concerts in front of audiences are recorded. The Ambiophonic method will cause any rearward direct sound picked up by a microphone to come from the front and after convolution to also correctly come from the surround speakers. If this is considered to be a serious defect, then it is possible for record producers to code discs in the future to mute the front channels during applause intervals or whenever only a convolved rearward direct sound effect is desired. Eventually disc codes would also be able to control the Ambiovolver without having to use any additional media channels to steer rear sound effects to specific surround speakers without including hall reverberation.

THE PSYCHOACOUSTIC BASICS

It is not necessary to understand precisely how the ear/brain system works or how concert halls work if we simply deliver to the home listener a reasonable replica of what that listener's eardrums would have been exposed to if they were at the live concert recording session. Fig. 1 This, of course, is the basic premise of binaural technology [4] and defines Ambiophonics as a "you-are-there" methodology.

There are no shortcuts. If realism (or biological naturalness is perhaps a better term in this context) is a priority, then you had better insure that in any recording/reproduction chain that there will be at least one and only one set of pinna (your own) [1] and one and only one head shadowing function (which need not be your own).

AMBIOPOLES

It is no secret that the traditional stereo triangle encompasses the psychoacoustic defects already mentioned above. Again, these include a reliance on the shaky and non-linear phantom image illusion, a limitation in stage width to the angle between the speakers, confusion of the pinna direction finding mechanism due to comb filtering, [14] erroneous head shadowing for central sources and localization contradictions due to discrepancies between single pinna localization and interaural localization cues. Details on these topics and references are available in the lengthy but free book, downloadable from [1].

To avoid these psychoacoustic pitfalls, Ambiophonics uses two speakers directly in front of the listener to reproduce all front stage sound including any frontal, early reflections and proscenium reverberant tails. The combination of these two speakers and the software that drives them I call an Ambiopole. Fig. 2 An Ambiopole is designed to externalize the binaural effect using loudspeakers. The Ambiopole reproduces only direct stage sound and microphone captured frontal ambience. With the loudspeakers directly in front of

the listener and hopefully head spaced there is only negligible head shadowing effect, no pinna angle error for the key central part of the stage, no need for phantom imaging and no HRTF compensation required. Since the signal delivered to the ears is truly normal binaural, there is no serious limitation as to stage width up to about 150 degrees at which point the pinna begin to say the stage is narrow despite the binaural interaural time and intensity cues. [14]

Even if the source material is not acoustic or synthesized using virtual reality methods and panning algorithms, it is still better to reproduce such music without stereo psychoacoustic distortions such as crosstalk and pinna angle error. Such electronic music can also be convolved to set it in a pleasing, lively ambience.

Of course, as is inherent in earphone binaural listening, some means must be used to keep the left and right signals separate at each ear. A straightforward method proposed and tested in [1, 14] was a simple mechanical barrier and for perfectionists this is still a valid way to go. But now we have crosstalk cancelling software and fast DSP algorithms that can do the job in real time. [10, 11] In contrast to earphone binaural no head tracking is required. In contrast to most earlier crosstalk elimination methods, no HRTF filters are required. One is free to move ones head without prejudice just as in a concert hall. One can also get up, and walk about within the circle of surround speakers (hopefully horizontal line sources or panels) but still feel that one is in a hall with a stage up front.

The ideal Ambiopole uses speakers that are line or point sources, that don't spray sound to the floor, rear wall or ceiling causing bogus early reflections, and that if two or three way are time coherent so as to make the crosstalk cancellation more accurate. With the speakers so close together the sweet area is larger than the critics of crosstalk cancellation usually suggest and is comparable to the size of the sweet spot in a high-end stereo system. Experiments I have done with horizontally omnidirectional Ambiopoles enlarge the sweet area enough to allow two people to sit side by side and one can move along the center line eight feet or so without losing the stage which is seldom possible using the stereo triangle or LCR arrangements. I have also successfully used two-meter tall, one-meter wide full range electrostatic panels that are slightly concave. These focus sound at the listening area and behave like collimated sound sources. It is likely that shaped NXT panels may also prove quite practical in this application.

Th Ambiophonics Institute also strongly recommends room treatment and room/speaker correction. DSP based room correctors are now widely available and can correct most speaker responses and eliminate the worst of the bass room modes. At the high frequencies, absorbent room treatment is useful to avoid erroneous early reflections of direct sound. However, the presence of four (or hopefully more) convolved surround ambience speakers mostly swamps the Rt of the room. The small room essentially rereverberates the hall tails adding a few tenths of a second to the convolved reverberation time which is difficult to detect. However, a similar case cannot be made for spurious early room reflections and so room and recording studio treatment remains highly desirable.

Software add-ons to the Ambiopole software can also be used to compensate for the microphone technique used to make the recording such as ORTF, spaced omnis etc. [11] Once you have heard what an Ambiopole, combined with room correction and Ambiovolver surround ambience can do for ordinary LPs, CDs, SACD, or DVDs it is hard to be satisfied with stereo, 5.1, or 7.1 sound reproduction. [11]

THE AMBIOPHONE

If you know that the hall ambience for the surround speakers is going to be convolved from a real hall impulse response then it is clear that one only needs to record the direct sound from the stage. We also know that binaural technology obviates the need for a center speaker and in any case, the use of an Ambiopole makes recording such a signal, futile.

Remember the basic precept for "you are there realism". You want to deliver to the ears of the home listener the same sound that he would have heard had he been at the position of the recording microphone during the performance. In the case of a symphony orchestra being recorded in a real concert hall there is no reason not to put the recording microphone at the best seat in the hall, say fifth row center. But what kind of main two-channel microphone are we talking about?

First we do not want this microphone to pick up any sound from the sides, rear or ceiling of the hall because the bulk of the hall ambience will be recovered by convolution and we do not want any off stage early reflections or reverberation tails coming from the front speakers during reproduction. So let us assume that the microphone sitting in the fifth row is reasonably baffled to the rear, sides and overhead with high frequency sound absorbing material. If the

microphone pair is baffled this way, then we can use uncolored, high quality omnidirectional microphones to good effect. We can also ignore such parameters as the recording angle and indirect ambient pickup in deciding on placement.

Since this is a binaural technology, the microphones are naturally head spaced. A sound from the center of the stage is picked up and goes from each microphone directly to the corresponding speaker in front of the equivalent ear of the listener. The perspective that the listener will hear is the same as that of the microphone and depth cues remain largely intact. So far we have adhered to the basic rule of Ambiophonics that there be only one set of Pinnae in the chain, the ultimate listener's. Combine Figures 2 and 3.

We observe that in the case of central stage sound there is no erroneous head shadow involved since the sound sources, the microphones and the speakers are front, center and in line so that very little sound is colored by having to go around the head to reach a pinna.

However, when a sound originates from the side of the stage there will be no head shadow function, (or interaural level differences in the case of omnis) and the rule is that there must be at least one and only one. The answer is to mount the two omnidirectional microphones on the surface of a head shaped ball so that as sound from the sides of the stage impinges on the microphone position a head shadow will be produced. Fig. 3 On reproduction the sound will still be coming directly from the front so there will not be a second head shadow introduced. Such a microphone already exists and was conceived by Günther Theile [15]. It is called the Theile Sphere or the Schoeps KFM-6. There is also no reason why an Ambiophone or KFM-6 using cardioids would not also work. Although their use could exaggerate the head shadow and thus distort the far sides of the stage image this would be an area where recording engineers could continue to express their artistic sensibilities.

While a microphone shaped less like a sphere and more like an average head without outer ears might be preferable, head shadowing is not as critical as pinna function. The reason seems to be that sound passes around the head over the top, around the back, under the chin, past the nose, and in many more different ways as the head is moved. [4] Thus it is largely the delay and attenuation that is significant in head shadowing not a particular individuals pattern of peaks and nulls as in the case of the pinna. Remember, realism not absolutism.

Sounds that come from the extreme sides during reproduction the stage will reach the pinna from the wrong angle. Thus this microphone and speaker technique cannot produce a stage width of a full 180-degrees for live recordings. But up to 150 degrees or so, the naturalness of the stage and the ease of localization are quite apparent. One can observe that at the angles around 70 degrees to the side, the ear canals are not much shadowed by the outer ear and the pinna responses are smoother. [8, 9] The pinna seem to be meant to be somewhat more sensitive to sound from the front and rear middle so, if there is going to be an error in the system, it is better to have it at the front-side extremes, as in Ambiophonics, rather than in the median plane, as in stereo.

The theoretically perfect Ambiophone is thus a baffled two channel pinnaless dummy head microphone placed at the best seat in the house. With multichanneI DVD-A or SACD it would be theoretically, if not legally, possible to record with Ambiophones placed at say the fifth, tenth, and twentieth rows so that the home listener can have a choice of seats in the hall. (Figure 3) Ideally the impulse responses from these same locations would be available to recreate the precise ambience.

I appreciate that stereo recording engineers are hopelessly addicted to spot microphones. However, in Ambiophonics it is difficult to mix spots into the two main channels, and still maintain the same fifth row center perspective and include the required head shadow. In the Ambiophonic recordings produced so far, the use of a spot microphone in one of them was painfully obvious. In the case of studio recordings of relatively small pop ensembles the use of spots would make less difference. As discussed below, the use of Ambiophonic studio monitoring systems would likely make the demand for spot microphone use by musicians much less likely.

An Ambiophonic spot microphone method has been proposed by Studer and Prof. Angelo Farina. One measures the impulse response of the stage at each point where a directional spot microphone is to be placed. This is done by launching a test signal from the stage to the Ambiophone and measuring the two-eared impulse response. After the recording is made the spot microphone signal can be convolved with each impulse response and added in to the appropriate left and right main Ambiophone channels.

I should observe however, that for concert hall realism this added complexity should never be needed. If the conductor thinks an instrument is not prominent enough during a concert or recording session he/she has presumably done something about it by moving the instrument forward or using risers. One could also elevate the Ambiophone to get a better view of the stage than most of the audience has. In general, trying to improve on concert hall practice is likely to please only some of the listeners some of the time.

As is the case in Ambisonic recordings made with a Soundfield microphone placed at the best seat in the house, an orchestral concert recorded by Robin Miller of Filmaker Inc. from a 10th row seat in the hall (well beyond the critical radius) using an Ambiophone has a normal stage perspective. Both Ambisonic and Ambiophonic recordings demonstrate that close up main and spot microphones, thereby always getting a conductor's view are not necessary although it may be preferred in some situations.

MONITORING AMBIOPHONIC SETUPS

Even if you only want to monitor stereo or 5.1 recording and processing setups, an Ambiophonic layout can be advantageous. The most efficacious Ambiopole arrangement is the use a mechanical [14] version of the stereo dipole. Fig 4 This is simply two very small high-quality monitors such as satellite speakers placed against either side of a three-foot square one inch thick wooden panel. When you listen at the far edge of this panel to the front stage sound it is very easy to hear what the perspective is, what the stage width seems to be and any other anomalies such as echoes etc. The clarity of such a monitoring arrangement makes it easier for musicians to judge the quality of a trial playback. In the limited experience we have had so far with this, the performers have been quite pleased and asked for fewer changes than is normally the case in such situations.

Surround speakers should always be on and used when monitoring the live microphone setup or a trial playback. This is a good practice even if the recording is stereo, 5.1 or Ambiophonic. A simple four or six-channel hall surround convolver, driving small speakers in the control room, makes judging the quality of the sound being captured much easier to appreciate and facilitates getting a stamp of approval for both musical and engineering efforts. Fig. 4

I believe once recording engineers become familiar with the use of Ambiovolvers that they will find it much more realistic, trouble free, and cost effective to derive the surround signals for standard 5.1 or 6.0 recordings from the impulse response of the hall than to site microphones and hope to capture hall sound during the live session. Once the classical music public becomes used to programming their own halls at home, 2 channel live concert and opera recording engineers will have much less to fret about.

CONTRASTS WITH 5.1 RECORDING SETUPS

Figure 5 shows the Optimized Cardioid Triangle, OCT, method of 5.1 recording proposed by Günther Theile [13]. The left and right main microphones are supercardioids; the center microphone is a cardioid. Very directional supercardioids are used, despite their poor low frequency response and relative complexity, in order to reduce crosstalk between the sides and the center. The spacing between the left and right microphones needs to be just under one meter for capturing a full orchestra stage because of the presence of the center speaker which divides the stereo triangle into two halves thus requiring additional amplitude and time differences between the microphones to produce roughly the same phantom localization as two speaker stereo. Of course, the largest perceived stage angle in reproduction is still limited to plus and minus 30 degrees but the sweet listening area is enlarged.

Figure 6 shows a surround sound recording configuration for an orchestra proposed by Dr. David Griesinger of Lexicon. [12] It uses twelve microphones altogether and mandates that electronic reverberation generators be used to add early reflections to the stage spot and main microphones. The mixing and the formulation of the ultimate front and rear signal mix for engraving on the disc is left as a subjective process.

Compare these with the Ambiophone recording setup of Figure 3. Note that the impulse response of the hall will also have been measured at this point

In general, the fundamental conundrum in using microphones to record ambience, is that the main mic's are yielding a close up perspective while the ambience mic's are sampling part of say a 20th row sound perspective. If you move the ambience mic's forward to avoid this timing discrepancy, the direct sound pickup is likely to be too great. If the main mic's are moved back they may pick up too much reverb and the stage angle becomes too small. Thus, capturing ambience with microphones during the recording session will always involve compromises

and subjective opinion. This is not the audiophile way to go.

CONCLUSION

Just as there are those who prefer LPs to CDs there are those who will likely continue to prefer stereo to any form of surround sound including 5.1, 7.1 Ambiophonics or Ambisonics. Stereo (2.0) is an art form. It is like oil painting compared to photography. Photography did not make artists obsolete just as stereo did not replace mono (Think of telephones, public address systems, Caruso records, short wave or AM radio, etc.) so surround or Ambiophonics will not replace stereo. (Think of clock radios, small TVs, laptops, walkmans, waiting rooms, FM radio, cassettes, LPs, MP3, stereophiles, etc.) Another factor to remember is that most recorded serious music listening is a solitary experience; which is why so many earphones are still sold. (I ignore parties and dances where psychoacoustics is about as relevant as the St Matthew Passion.) Thus compromises in the quality of music reproduction systems made merely to enlarge the ideal listening area, do not seem reasonable to a majority of audiophiles.

However, the development of digital signal processors and algorithms able to process digital audio in real time, without audible harmonic distortion or noise, has made it feasible and practical for music lovers to enjoy and recording engineers to deliver greater realism in music recording. Recordings made with the Ambiophone or the Schoeps KFM-6 have been shown to provide binaural realism and a normal perspective when coupled with an Ambiopole and Ambioconvolvers. Such Ambiophonic recordings require no spot microphone support, panning algorithms, artificial reflections, HRTF manipulation and not only need just two media channels but work better if there are just two.

Since even existing LP and CD discs reproduce well Ambiophonically, the future of Ambiophonics rests as much or more with the reproduction side than the recording side. It is hoped that the audio industry will begin to offer dedicated processors for the home market that include effective crosstalk cancellers tailored to work with touching Ambiopole room correction, and Ambiovolvers supplied with the hall impulse response libraries needed to create great sounding domestic concert halls.

REFERENCES

[1] Ralph Glasgal. Ambiophonics, 2nd Edition. www.ambiophonics.org

[2] William B. Snow. Basic Principles of Stereophonic Sound. Stereophonic Techniques, An AES Anthology 1986.

[3] James Moir. Stereophonic Reproduction. Stereophonic Techniques, An AES Anthology 1986.

[4] Jens Blauert. Spatial Hearing, 1997 Edition, MIT Press. www.mitpress.mit.edu

[5] Y. Ando. Concert Hall Acoustics. Springer Verlag, 1984.

[6] Damaske & Ando. Interaural Crosscorrelations for Multichannel Loudspeaker Reproduction. Acoustica, Volume 27.

[7] Furuya, Fujimoto, Choi Young Ji, Higa. Arrival Direction of Late Sound and Listener Envelopment. Applied Acoustics. www.elsevier.com/locate/apacoust

[8] Henrik Møller, et al. Head-Related Transfer Functions of Human Subjects, J. Audio Eng. Soc., May 1995.

[9] Ronald M. Aarts. Phantom Sources Applied to Stereo-Base Widening. J. Audio Eng. Society, March 2000.

[10] Kirkeby, Nelson, Hamada. The Stereo Dipole. J. Audio Engineering Society, May 1998.

[11] Angelo Farina, Enrico Armelloni. Ambiophonic Principles for the Recording and Reproduction of Surround Sound for Music. Proceedings of the AES 19th International Conference.

[12] David Griesinger. The Theory and Practice of Perceptual Modeling. http://world.std.com/~griesngr/threedpm.pdf

[13] G. Theile. Multichannel Natural Music Recording Based on Psychoacoustic Principles. www.irt.de/irt/indexpubli.htm

[14] T. M. Bock, D. B. Keele. The Effects of Interaural Crosstalk on Stereo Reproduction. 1986 AES Preprints 2420A & B.

[15] G. Theile. On the Naturalness of Two-Channel Stereo Sound. J. Audio Eng. Society, Oct. 1991.

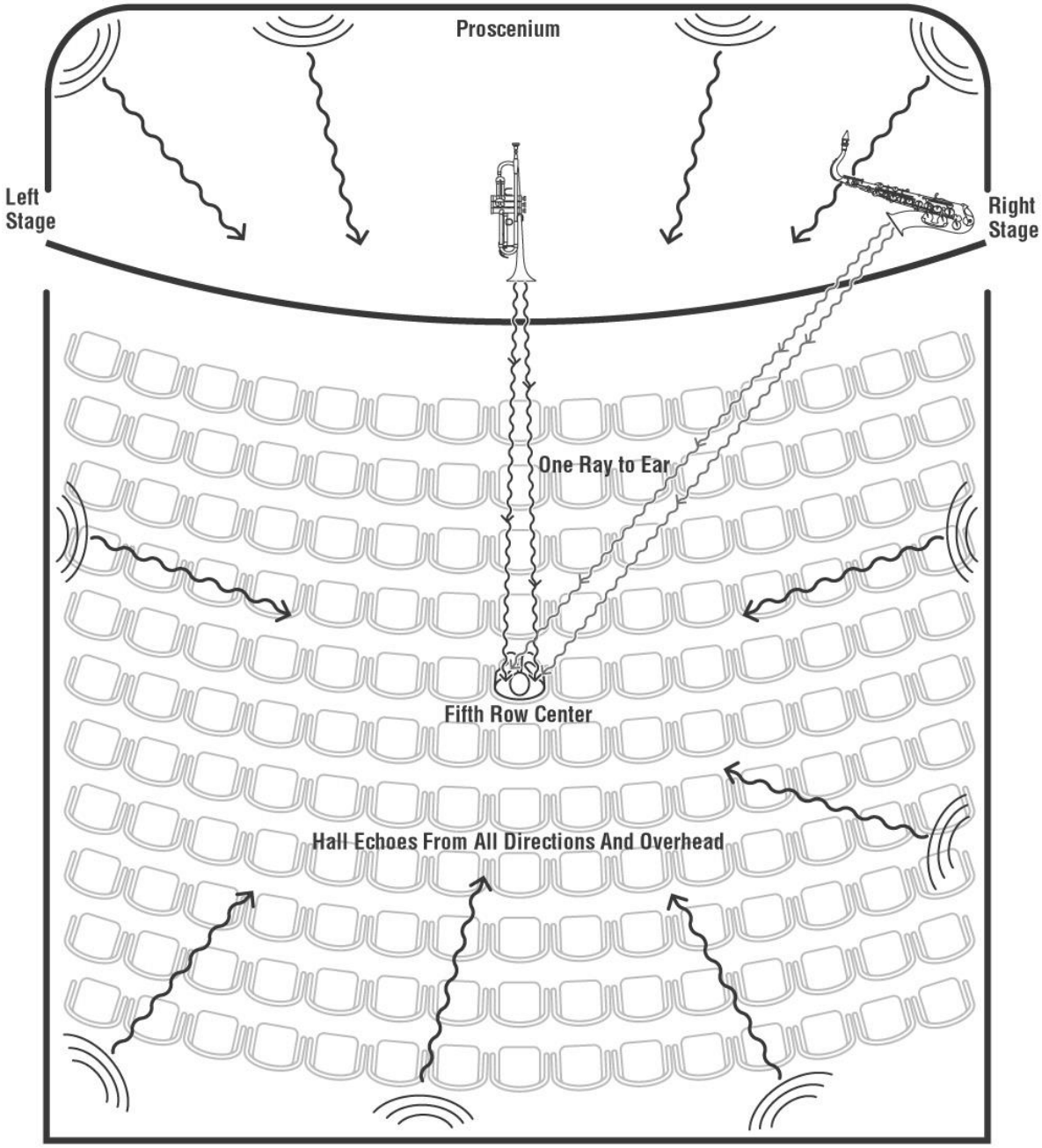

Figure 1: Normal Concert Hall Listening

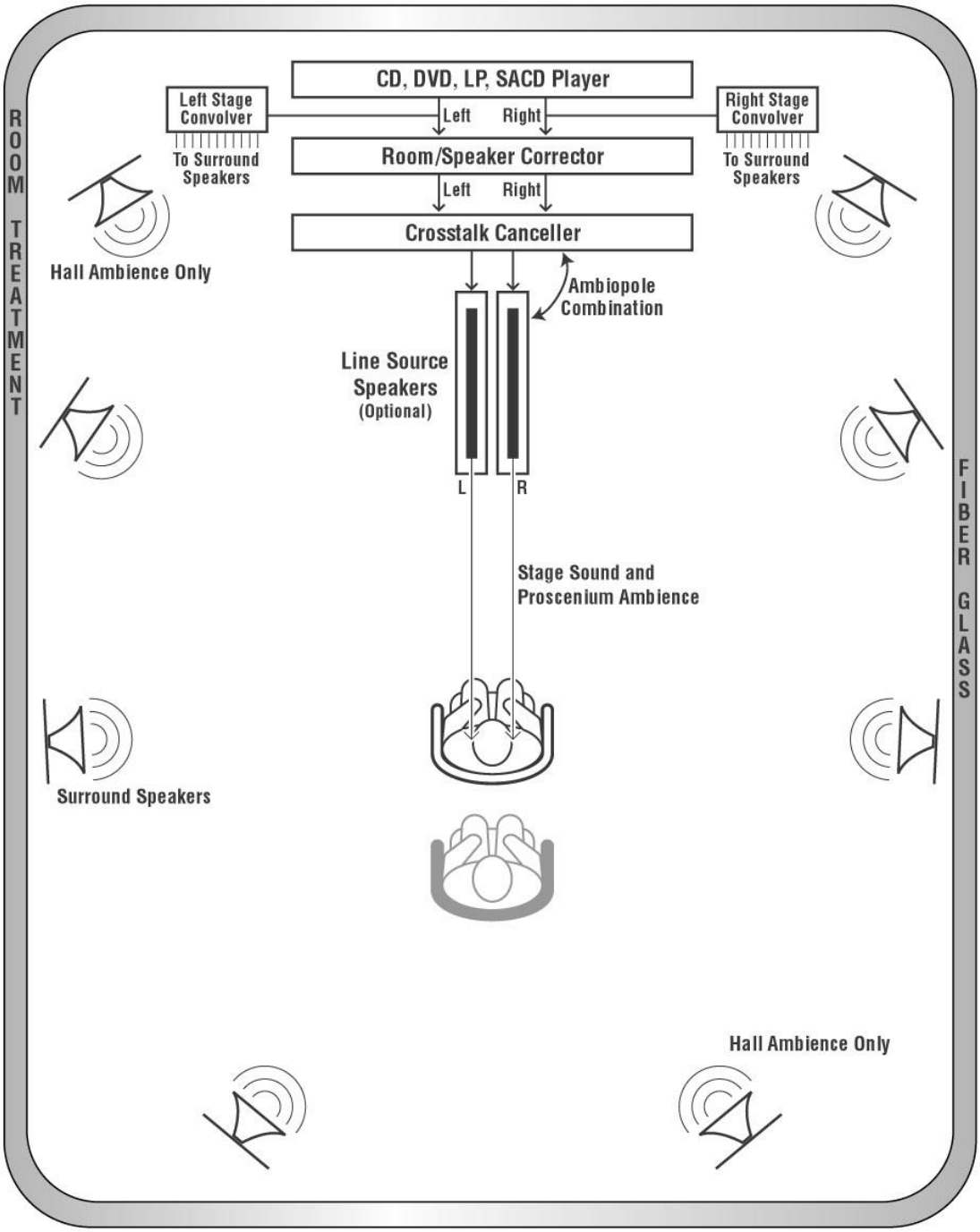

Figure 2: Ambiophonic Domestic Concert Hall Listening

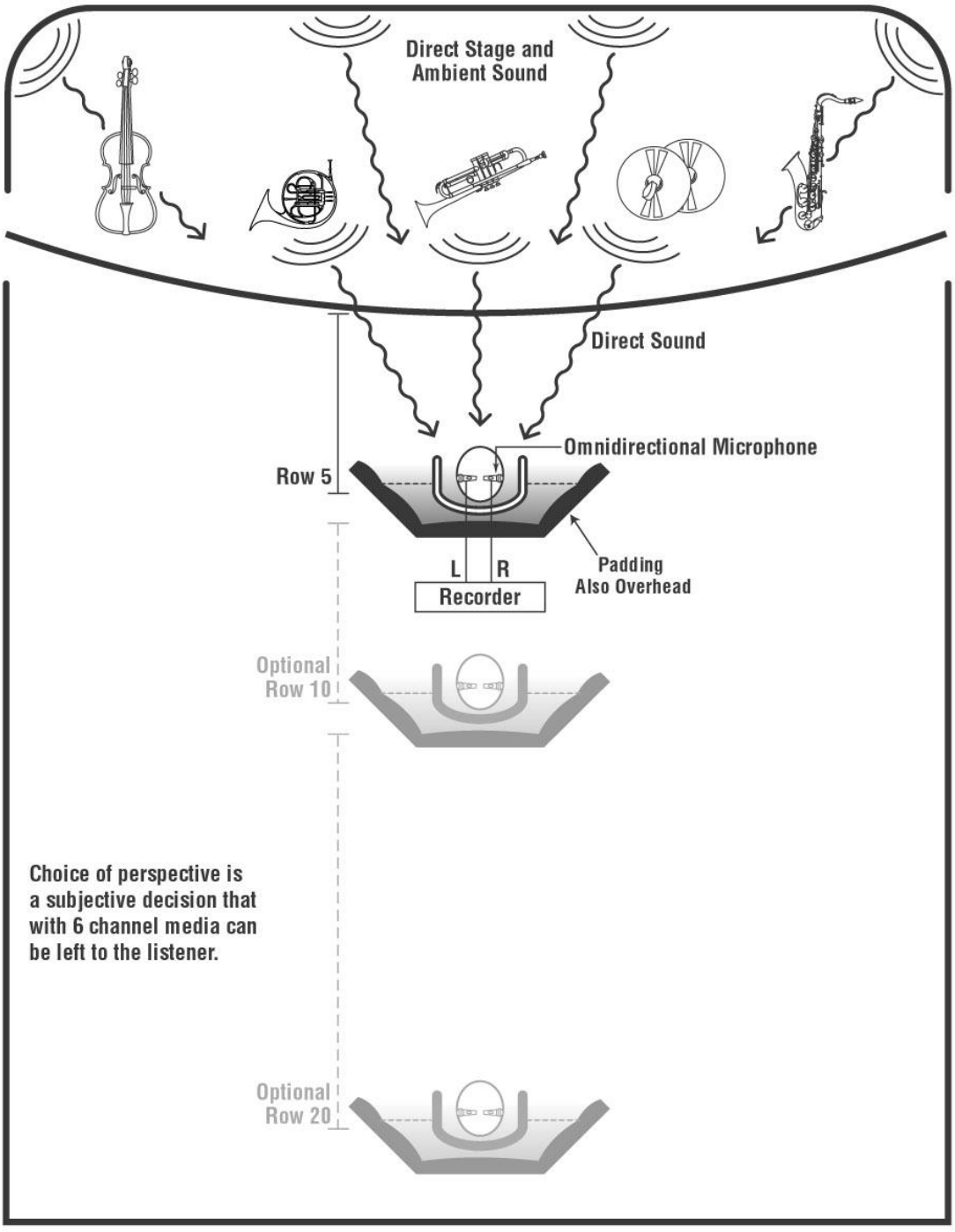

Figure 3: Recording with an Ambiophone

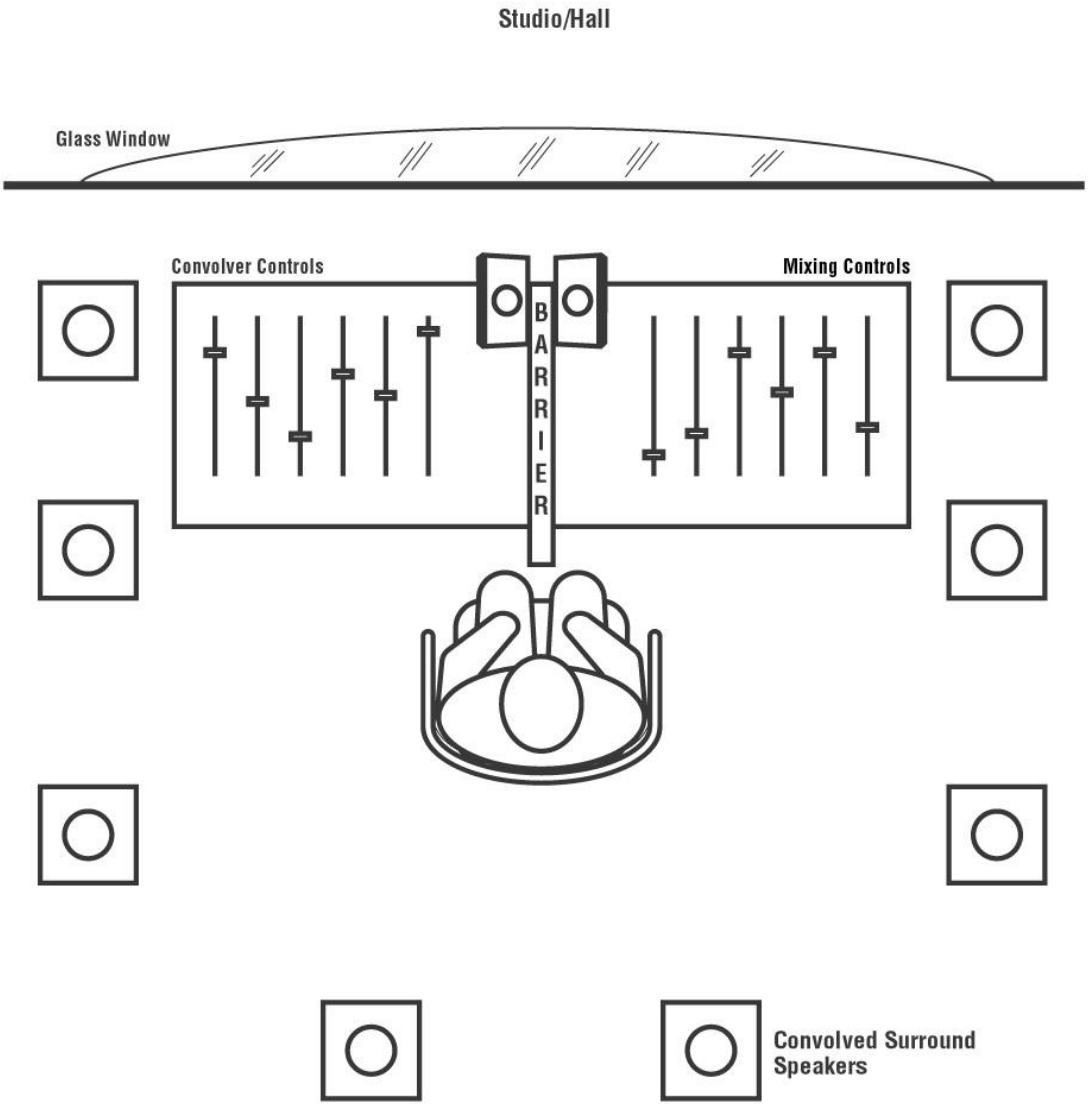

Figure 4: Ambiophonic Monitoring Station

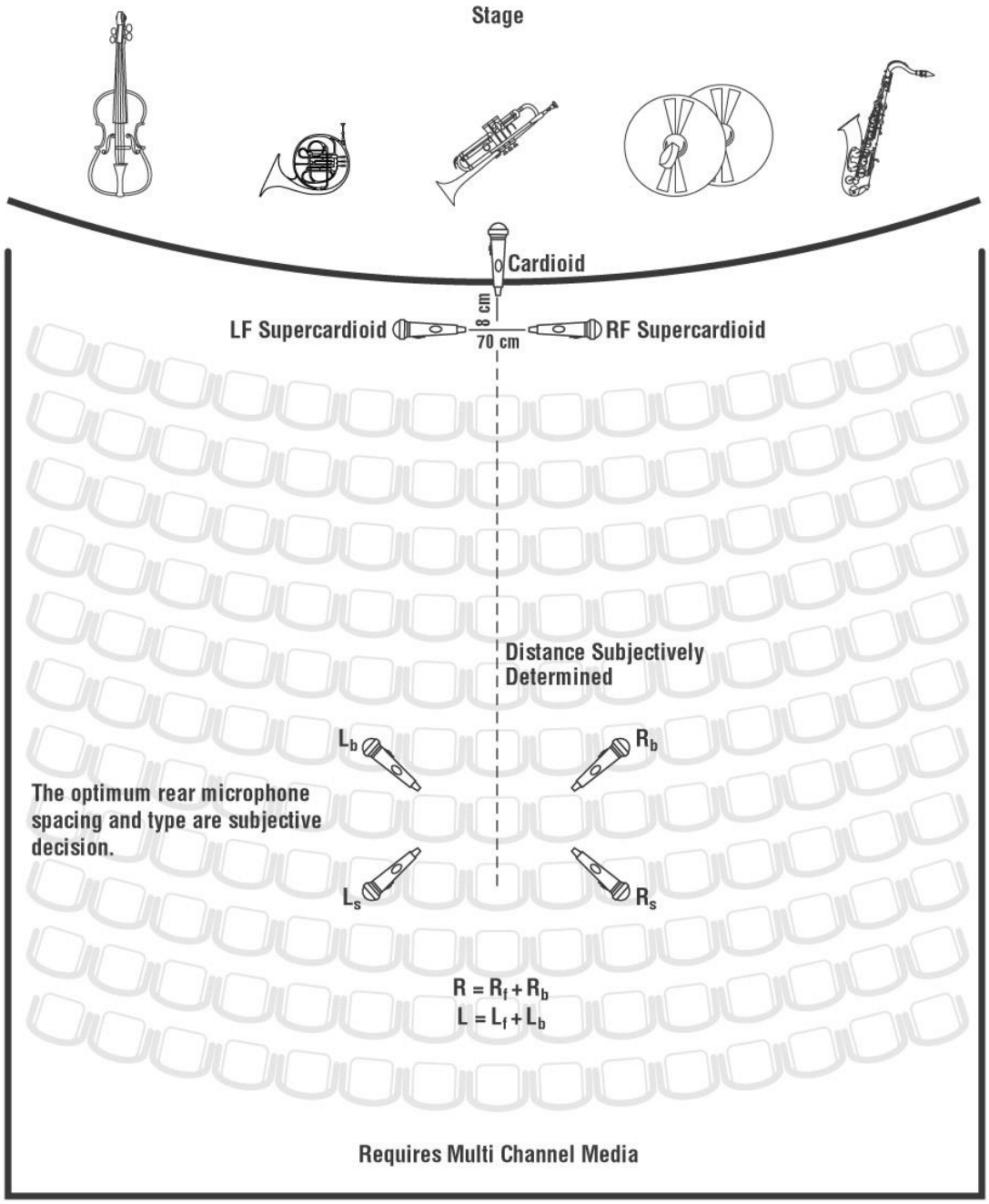

Figure 5: Optimized Cardioid Triangle (OCT)

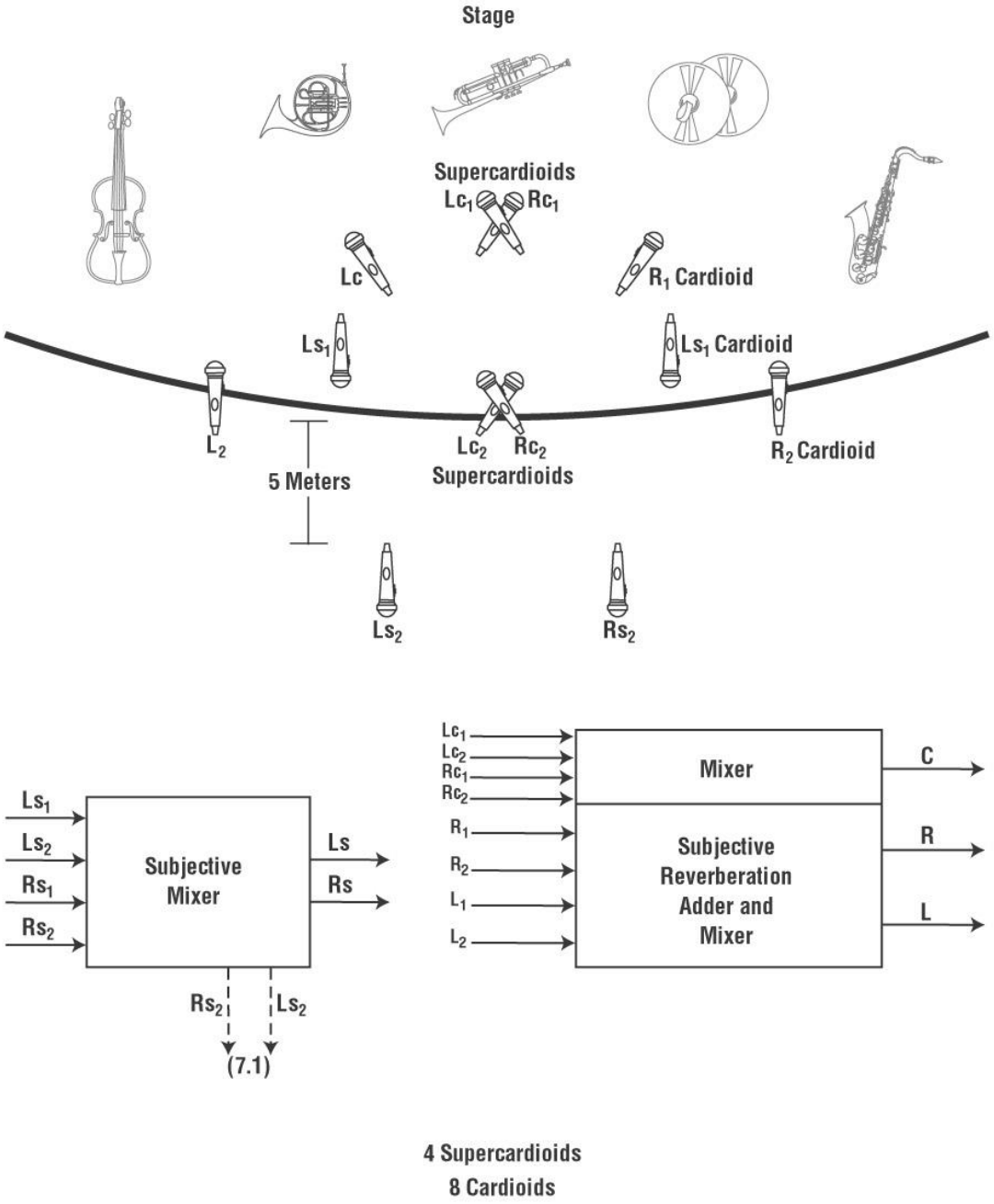

Figure 6: Dr. David Griesinger's 5.1/7.1 Recording Methodology