

Understanding and Installing an Ambiophonic System

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Abstract: Recordings of music and film soundtracks contain cues used by the ear/brain to localize sound. Home or studio reproduction using conventional stereo, 5.1, 7.1, or 10.2 distorts these cues and creates false ones. The result is *localization distortion*, which degrades horizontal and depth imaging of direct and ambient sound, degrades clarity of instruments, colors the sound, and greatly reduces size and depth of the sonic stage. Localization distortion can be reduced to very low levels by a technology called Ambiophonics. Ambiophonics, at its simplest, consists of crosstalk-cancelled playback by two closely-spaced, front speakers. The result is that one can now hear at home what the recording microphones hear—and what the microphones hear is greatly improved horizontal and depth localization; solid, clear, three-dimensional imaging; less colored sound; improved clarity and tonality; improved transient response; and a sonic stage that is very deep and very wide—at least 150 degrees—compared to the 60-degree wide stage of the stereo equilateral triangle. Ambiophonics does not artificially increase the width and depth of the stage. Instead, it reduces localization distortion to such low levels that one can hear the width and depth that was actually recorded on the disc. Details are discussed for setting up an Ambiophonic system with 2, 4, or 6 speakers.

First there was mono and then there was stereo. Using just one speaker, monophonic reproduction sounds like all instruments are located at the speaker. Using two widely-spaced speakers, stereophonic reproduction sounds like different instruments have different locations—with the locations stretching from one speaker to the other. Having different locations for different instruments is so highly valued that stereophonic reproduction—now almost 80 years old—and offshoots such as 5.1 and 7.1 have become standard in the home reproduction of music and movies. But stereo and its offshoots do far from a perfect job of localizing sound and their imperfections limit the quality, the believability, and the realism of the reproduction. A new technology—called *Ambiophonics*—fixes most of the problems with stereophonic reproduction. Ambiophonics is based on almost a century of psychoacoustics research on how the ear/brain localizes sound. This historical research, combined with current research, tells us how

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conventional stereo destroys good sound localization and how to fix the problem. Ambiophonics fixes most of stereo's problems by using crosstalk reduction with two *closely-spaced* front speakers—separated only 20 to 30 degrees. Yet the sonic stage created can be 150- to 180-degrees wide! Just how this can happen is a wonderful tale of how laboratory findings can produce unexpected and beautiful results.

In Part 1, we explain how stereo reproduction distorts the sound field and how Ambiophonics restores it. In Part 2, we explain how to maximize the performance of an Ambiophonics system. Those already familiar with the problems of stereo and the advantages of Ambiophonics might skip to Part 2.

Part 1: Problems with Stereo Reproduction and How to Fix Them

Sound Localization

To understand how stereo distorts instrument localization and how Ambiophonics corrects it, we need to understand first how the human ear/brain localizes sound. The ear/brain uses three primary cues to localize sound: interaural loudness differences (ILD), interaural time differences (ITD), and changes to the higher frequencies of the sound by the pinna, the curly shell surrounding the ear canal (pinna localization cues).

Interaural Loudness Differences (ILD). With live music, if a violinist is playing a violin in front of you, the loudness at both ears is about equal. If the violinist is standing on your right, the violin sound in your right ear will be louder than in your left. Such loudness differences at the two ears from the same sound source are a cue for the sound's location. ILD cues work well only for signals with energy between 90 Hz and 1,000 Hz.

Interaural Time Differences (ITD). If the live violinist is not playing directly in front of you but to your right, the violin sound will reach your right ear a little earlier than your left ear. The reason is that the violin is just a bit closer to your right ear than your left. Such a time difference between sound arrivals at the two ears from the same source is a cue for the sound's location. Like ILD cues, ITD cues work really well only for signals with energy between 90 Hz 1,000 Hz.

Pinna Localization Cues. The frequency response of a live violin consists of a complex pattern of frequency peaks and valleys. Before the violin sound enters your ear canal, it bounces around the curls, cavities, and folds of your pinna (ear shell). Frequency components over about 1,000 Hz interact with these structures and the pattern of peaks and valleys changes enormously. Moreover, the sound from a live violin located at your left will bounce differently around the left-ear pinna than will the sound from the same live violin located directly in front of you. (Actually, if the violin is located at just the correct spot on your left, it will have a direct shot at your ear canal and pinna shadows and resonances become less important.) So the frequency response of the live violin measured at the entrance to your left ear canal changes with the violin's location. The brain uses these changes in response patterns as location-finding clues. Very small horizontal changes in the violin's location can produce changes so great in the pattern of peaks and valleys that one might view the pinna as an exquisitely sensitive direction finder that converts minute changes in the direction of incoming sound to overwhelming changes in the frequency response pattern. Even a person with only one functioning ear has some ability to identify the location of most natural sounds. The pinna locates both transient sounds, like clicks, and continuous sounds.

You have two pinnae. For a given violin location, the pinnae create quite different response patterns. The brain interprets each single ear pattern and possibly the difference between the patterns as a location cue. When the violin is off center, the difference between the patterns will be very large indeed. Move the violin a little to the left or right and the patterns and thus the differences between them can change greatly. This location detector is so sensitive that subjects can detect a change as small as one degree in the horizontal location of impulsive clicks or speech sibilants.

If a music reproduction system is to produce the correct pinna cues when playing a violin recording, then in theory the speaker reproducing the violin must be located where the violin is supposed to be. If the live violin is on your left, the speaker reproducing the violin must be at that same angle on your left. If the violin is supposed to be directly in front of you, as is the case with most soloists, the speaker reproducing the violin must be directly in front of you. If the speaker reproducing the violin is not where the violin is meant to be, then the pinna cues produced by the speaker will be incorrect for the violin's location. As we shall see below, getting the pinna localization cues correct is a nasty problem for any music reproduction system.

How Stereo (and 5.1, 7.1, etc.) Messes Things Up

Conventional stereo (and its offshoots 5.1, 7.1, etc.) creates an illusion, akin to an optical illusion, that does a fair job of localizing sound. But it does not do an excellent job. Consider a typical home stereo system with the speakers and the listener forming an equilateral triangle—that is, the speakers are separated by a 60-degree angle as viewed by the listener. This stereo system does several things that prevent lifelike sound localization. More complex systems such as 5.1, 7.1, etc. have the same problems. The problems are acoustic crosstalk, comb filter effects, incorrect pinna cues, incorrect ILD and ITD cues, and inconsistent localization cues.

Acoustic Crosstalk. You are listening to a live violinist playing directly in front of you. Both ears hear the violin. The sound at your left ear is similar to but not exactly the same as the sound at your right ear. There are many reasons for the slight sound differences but they are not important now. What is important is that the live violin has produced two versions, two presentations, of the violin sound – one at your left ear and one at your right ear. This is OK because your ear/brain has spent all its life learning to fuse two sound presentations such as this into one image—so what you perceive now is a single, live violin. Now consider a typical stereo recording of the same violinist. The recording is engineered so that the violinist will appear to be located directly in front of you, halfway between the two speakers. To accomplish this, the two channels of the recording will have similar loudness and will arrive at your ears at about the same time. The problem is that your left ear hears both speakers and your right ear hears both speakers—and the four sound presentations are not exactly alike in level, arrival time, or frequency response. Your ear/brain now has *four* versions to fuse into a single violin. If your left ear heard only the left speaker and your right ear heard only the right speaker, then your ear/brain would be back in the familiar territory in which it must fuse just two presentations into a single image. The trouble is that your right ear hears the left speaker and your left ear hears the right speaker. This is called *acoustic crosstalk*, where each ear hears the speaker on the opposite side. Your ear/brain did not evolve to deal with four presentations of the same sound source.

Crosstalk produces incorrect head shadows for center images, reducing the lifelikeness of the image. *Head shadow* refers to the reduction of mid and high frequencies as sound travels around and over the head to the far ear. When listening to a live instrument directly in front of you, sound travels to the ears with only a small impact from the intervening fleshy part of the face, that

at the ears to a value smaller than that produced by a live source at 90 degrees. Finally, pinna cues at the 30-degree speaker location are incorrect for an extreme side source. Hence, extreme side sources get folded inward and get lumped together at the 30-degree position where the speaker is located.

Inconsistent Localization Cues. Sound localization depends on ILD cues, ITD cues, and pinna cues. There are two kinds of pinna cues: (1) cues based on the response of a single pinna by itself to a sound event and (2) cues based on the responses of both pinnae. Everyday experience shows that sound localization is better when both pinnae are used but it is not yet clear how the brain makes use of the two pinna responses. Nevertheless, if a sound reproduction system is to provide excellent sound localization, it must reproduce all the localization cues and the cues must provide consistent information about the direction of a sound source. The reproduced sonic image will seem less realistic if some cues say that the source is up front and other cues say that the source is at your side. Yet this is exactly what stereo and its offshoots do. We have seen that stereo provides incorrect pinna cues for a center-stage instrument—because the sound is actually coming from side speakers. Stereo speakers that are 30-degrees off center provide correct pinna, ILD, and ITD cues only for instruments that are exactly 30 degrees off center. For a center-stage instrument, stereo speakers provide corrupted ILD/ITD cues (because of crosstalk) and incorrect pinna cues (because speakers are located at the sides). All of the localization cues have problems—and they are not even consistent with each other. Your ear/brain did not evolve to deal with this jumble of inconsistent localization cues. This inconsistency degrades the clarity and realism of all instrument locations except at 30 degrees. Some listeners have difficulty detecting stable central phantom images—the images jump left or right. If 5.1 or 7.1 recordings were mastered so that the center speaker alone reproduced center-stage instruments, and side speakers alone reproduced side sounds, then all localization cues would be consistent and correct. But this would amount to 3-channel mono and acoustic music does not usually benefit from being mastered this way.

How Crosstalk Reduction with Closely-Spaced Front Speakers Fixes Most Problems

Crosstalk Reduction. Electronic circuits that reduce crosstalk in stereo speakers have been available for decades. Over the years, they have grown in the precision and sophistication of their design, resulting in more complete crosstalk reduction and fewer unpleasant side effects. Ambiophonics employs a laboratory-grade crosstalk reducer called RACE (Recursive Ambiophonic Crosstalk Eliminator). In addition to PC versions, RACE has recently become commercially available in certain products of TacT Audio, such as the TacT Ambiophonics digital processor, TacT 2.2 XP, and TacT TCS. All crosstalk reduction circuits are based on the same principle: Sounds from the right speaker are cancelled at the left ear by a carefully timed, 180-degree out-of-phase cancellation signal launched by the left speaker. Sounds from the left speaker are cancelled at the right ear by a carefully timed, 180-degree out-of-phase cancellation signal launched by the right speaker. If crosstalk cancellation is successful, then the left ear hears only the left speaker and the right ear hears only the right speaker. The cancellation has usually been done at a very broad range of middle frequencies, the size of the range being adjustable in the more sophisticated cancellation circuits such as RACE. The timing of the cancellation signals is quite precise and assumes that the speakers are equidistant from the listener. The four presentations of a sound source that result from conventional stereo are now reduced to the two presentations we experience when listening to live music. Crosstalk reduction flattens the frequency response of both the center and side stage. Stereo crosstalk produces ILD/ITD chaos for any location except at the speakers. This narrows the stage considerably compared to the width heard by the recording microphones. Crosstalk reduction eliminates ILD/ITD errors and

side speakers will be discussed in Part 2.

Stereo crosstalk produces comb filter effects. With equilateral stereo, combing can start below around 1,000 Hz. As the speakers are moved closer together, the start of the combing moves up in frequency. When speakers are as close as Ambiophonics specifies, combing occurs at such high frequencies that it is either inaudible or virtually inaudible.

Close-spacing of front speakers is the real innovation of Ambiophonics over previous crosstalk-reduction technologies. Stereo's speakers produce head shadows which, like fingerprints, vary greatly across people. Hence, effective crosstalk elimination is just not possible for side speakers. (Recall, head shadow consists of mid and high frequency losses as sound travels around the head to the far ear. To cancel a signal at the far ear, the cancellation signal must be programmed with the same frequency response as the signal it is meant to cancel. This is not possible since head shadows vary greatly.) Since effective crosstalk elimination is not possible for side speakers, side-speaker head shadows will always interfere with center images. If one moves speakers close together to eliminate side-speaker head shadows, it is still desirable to eliminate crosstalk, that is, to make the left ear hear only the left speaker and the right ear hear only the right speaker. Fortunately, head shadow from a front speaker is so slight that it can be ignored by the crosstalk cancellation software. The software need consider only the delay and attenuation as sound goes from a front speaker to the far ear—and this is quite doable. Indeed, with RACE crosstalk reduction, the user adjusts delay and attenuation until the widest stage is heard. Crosstalk cancellation is then maximum for that user. Thus, close-spacing of front speakers makes effective crosstalk cancellation possible. Moreover, close spacing eliminates side-speaker head shadows, satisfies the pinna for the center stage, gets ITD and ILD cues correct for the entire stage, greatly reduces or eliminates audible combing, and avoids stereo's unconvincing center imaging. And now that the speakers are close together, you absolutely need crosstalk cancellation or the stage will be 20 degrees wide, if that!

An additional benefit of closely-spaced speakers is that they can be far from the side walls of the listening room. If a speaker is too close to a side wall, the delay between the direct sound from the speaker and the first reflection off the side wall that hits the listener may be short enough to produce comb filter effects. Moving speakers away from the walls can reduce combing. Reducing combing from side wall reflections and increasing the delay of side wall reflections can improve imaging and reduce coloration of the sound—although side-wall reflections have proven to be less harmful to Ambiophonics than to conventional stereo.

One might view Ambiophonics this way: Conventional stereo and its offshoots 5.1 and 7.1 suffer from acoustically-produced localization distortion. Ambiophonics is designed to greatly reduce this distortion. Ambiophonics not only lets you hear the music as it was actually recorded but as it would have sounded if you were at the main microphone location during the performance. You can enjoy the same wide-angle perspective as the main microphones or a first-row center concert goer.

Audible Benefits of Ambiophonics

Ambiophonics produces two improvements in the sound—spatial improvements and clarity/tonality improvements. The spatial improvements include the creation of a wider, deeper stage with better horizontal and depth imaging. The spatial performance is well understood. One can measure ILD and ITD cues recorded by studio microphones and mathematically predict where the listener will hear the image. One can also predict the change in image location when the ILD

improved imaging, greater clarity, and improved tonality. Listen long enough to get used to the sound. Then press the button that returns the sound to conventional stereo. The shock of the change will be like a slap in the face.

Recording engineers should use Ambiophonics with their studio monitoring speakers if they want to hear what the microphones hear. Just like home speakers, studio speakers used in a stereo triangle produce such localization distortion that an engineer cannot hear it when his microphone placement for a piano produces a piano that sounds 70-feet wide when reproduced on a system without localization distortion.

We are fortunate to have a legacy of a half century of stereo recordings—a cultural treasure. Stored on those CDs and LPs are a wealth of localization information and a level of clarity/tonality that we cannot hear until we use playback systems having very low levels of crosstalk. Converting one's system to Ambiophonics will provide the opportunity to listen to old friends with new ears.

Crosstalk-Reduction Circuits/Software

When a crosstalk-reduction device launches a cancellation signal from the left speaker to cancel the right-speaker signal at the left ear, the cancellation signal is unfortunately also heard by the right ear. Early crosstalk reducers, such as the Carver/Sunfire Hologram and Lexicon's Panorama, were content to cancel the right-speaker signal at the left ear and to ignore the fact that the cancellation signal was heard by the right ear. Current laboratory-grade crosstalk-reduction devices such as RACE are designed to cancel the cancellation signal arriving at the right ear with a cancellation signal launched by the right speaker. Then the cancellation signal launched by the right speaker is heard by the left ear and must be cancelled at the left ear. And so on. A crosstalk reducer designed to cancel all the cancellation signals is called *recursive*. RACE is recursive. A cancellation signal is cancelled by a signal that is about 2.5 dB softer when launched by the speaker. In RACE, this value is adjustable. The cancellation of cancellation signals could go on forever. But the amplitude of the cancellation signal decreases at each step and is finally terminated by RACE when the digital value of the sample is all zero. It is usual in concert halls to refer to reverberation time, which is the time it takes for the reverberation to fall 60 dB after a single musical note is terminated. 60 dB down is almost inaudible. Humans can easily detect differences in reverberation time and the same applies to crosstalk cancellation. The cancellation must continue until the cancellation signals are no longer of psychoacoustic significance.

RACE PC configurations can be downloaded without charge from the Ambiophonics web site:

<http://www.ambiophonics.org/>

Part 2: Installing 2-Speaker, 4-Speaker, and 6-Speaker Ambiophonic Systems

The basic Ambiophonics system consists of two closely-space front speakers driven by RACE crosstalk-reduction software. The two speakers together are called an *Ambiodipole*. Virtually any type of speaker can be used to form an Ambiodipole. Like stereophiles, Ambiophiles can have preferences for particular speakers. **There is never a need for a center speaker.** In fact, a center speaker substantially degrades performance. Ambiophonics can be used with four speakers, two in front and two in back. One can add side speakers to the four-speaker system

amount of delay and attenuation depends on the angle to the speakers and the distance between one's ear canals. Since crosstalk cancellation requires the cancellation signal to be the correct magnitude and to arrive at an ear exactly when the crosstalk does, one must be able to adjust the crosstalk canceller to the particular attenuation and delay required by the speaker angle employed and, less importantly, to the size of the listener's head. For both RACE downloaded to a PC and TacT RACE, there are three user adjustments:

1. **Delay.** Delay represents the time difference in microseconds (μ s) between a sound's arrival at the near ear and its arrival at the far ear. The range of adjustment in RACE PC or TacT is from 20 μ s to 210 μ s. The front panel display for TacT's XTC mode measures delay in milliseconds, not microseconds. A millisecond is 1/1,000 second. A microsecond is 1/1,000,000 second. There are a thousand microseconds in a millisecond. Hence, the range of adjustment shown on the TacT display is from .02 to .21 milliseconds, abbreviated by TacT as .02 to .21msec. 70 μ s (.07msec) is average for most installations. Another way to view Delay is that a Delay of, say, 80 μ s means that when a speaker launches a signal to be cancelled at the far ear, the speaker near that ear will launch the cancellation signal 80 μ s later. A Delay value that is correct for a listener sitting centered will be incorrect if the listener moves off center. But there is no need to change Delay with reclining, head rotation, nodding, tilting, normal forward and back motion along the center line, or additional seating along the center line.
2. **Attenuation (Spread Factor).** Attenuation represents the level loss, in dB, between the near and far ears. (The level loss is due to longer path and facial absorption.) RACE for the PC shows an adjustment range from -1.5 dB to -4 dB. It is easier if one drops the minus sign and thinks of these values as positive. We will refer to the Attenuation range as 1.5 dB to 4 dB. An Attenuation of 1.5 dB means that there is a 1.5 dB loss in level between the near and far ears. In the TacT implementation of RACE, Attenuation is called *Spread Factor*. Spread Factor uses a different unit of measurement. Spread Factor values range from 0-100 and are inversely related to Attenuation values. The following table shows the conversion between Spread Factor and Attenuation.

Spread Factor	Attenuation
100	0.5 dB
90	1.5 dB
80	2.5 dB
70	3.5 dB
60	4.5 dB
50	5.5 dB
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Each unit of Spread Factor = 0.1 dB. The range of Spread Factor adjustment, 0-100, has a range of 10 dB. This corresponds to an Attenuation range of .5dB to 10.5 dB. A Spread Factor of 80 corresponds to an Attenuation of 2.5 dB. To convert Spread Factor to Attenuation, move the decimal point in the Spread Factor left by one digit (80 becomes 8.0) and subtract the value from 10.5. RACE PC does not provide Attenuation values higher than 4.0 dB. Too low an Attenuation, 0.5-2.0 dB (Spread Factor 85-100), produces unpredictable effects such as buzzing or abnormal localization. A Spread Factor between 80-85 (Attenuation between 2.0-2.5 dB) usually produces the best results. Another way to interpret Attenuation is that an Attenuation

of, say, 2.5 dB means that when a speaker launches a signal to be cancelled at the far ear, the speaker near that ear will launch a cancellation signal that is 2.5 dB softer. (The signals will have the same level but opposite polarity when they arrive at the far ear.)

- 3. Algorithms.** RACE crosstalk reduction operates between DC and 20,000 Hz. But this range can be reduced by the control called *Algorithms*. RACE software in the TacT 2.2 XP provides 10 algorithms. The following table shows, for each algorithm, the frequency range in which crosstalk reduction operates.

Algorithm	Operating Range	Algorithm	Operating Range
A-1	DC - 20,000 Hz	B-1	DC - 20,000 Hz
A-2	200 - 9,000	B-2	200 - 20,000
A-3	300 - 9,000	B-3	300 - 20,000
A-4	400 - 9,000	B-4	400 - 20,000
A-5	500 - 9,000	B-5	500 - 20,000

A-series algorithms affect both the high- and low-frequency limits of the operating range. B-series algorithms affect only the low-frequency limit. A-1 and B-1 are identical in effect. Neither restricts the operating range. Having A-1 in the A series facilitates comparing full range operation to the other A settings. Having B-1 in the B series facilitates comparing full range operation to the other B settings. The algorithms in the PC version and the TacT version of RACE are identical in concept but RACE PC provides fewer algorithms.

How to Use the Three Adjustments. Even more than stereo, Ambiphonics is a tweak-and-listen enterprise. The basic principle is this: Normally all tweaks and changes in settings will be heard only as slight changes in the width of the stage. When the stage is at the widest, crosstalk reduction parameters have been optimized for the conditions at hand and crosstalk reduction is at its maximum. But you may prefer less than maximum crosstalk reduction for certain recordings or to suite your taste. Begin with the following settings and experiment from there: Delay = 70-80 μ s (TacT Delay = .07-.08msec), Attenuation = 2.3 dB (TacT Spread Factor = 82), and Algorithm B-1. (Note that Delay values for TacT's new Ambiphonics unit change in .02msec increments.) Neither Delay nor Attenuation (Spread Factor) settings are all that critical if not pursued to excess.

RACE assumes that the sound from a speaker arrives at the far ear with a fixed and predictable delay and loss in level. These two values depend on the angle to the speakers and the size of one's head. As the angle to the speakers gets wider or one's head gets larger, the attenuation gets larger and the delay gets longer. With the speakers about 20- to 30-degrees apart (measured from the midrange drivers), a Delay of about 70-80 μ s is usually correct for most people and speakers. Changing the Delay to, say, 60 μ s or 90 μ s will probably not be audible. You should experiment as described below to get the stage you like. Attenuation is usually correct when set to around 2.3 dB (Spread Factor around 82) but again try varying it to get the widest stage. If you have a recording of a string quartet and the violin and cello appear to be 200 feet

sound instruments) for the front two speakers. Such a recording can be reproduced Panambiophonically to create a domestic concert hall which lacks only ceiling reflections to mimic fully the hall in which the performance was recorded. Such recordings are now being made on an experimental basis. The rear channels can include rear instruments for unusual musical effects or sound effects if the recording is a movie soundtrack.

One can try Panambiophonics without cost by downloading RACE from the Ambiophonics site and configuring Audiomulch with dual RACE chains in a PC. The RACE chains look the same but will have different inputs and outputs for 4.x and the settings for the chains should be slightly different. One can also obtain Panambiophonics commercially from TacT Audio, which includes it in their TCS and Ambiophonics models. With either RACE PC or TacT RACE, provision is made for switching easily between 2.x (Ambiophonic) and 4.x (Panambiophonic) modes. The TacT boxes come with demonstration 4.0 DVD and SACD surround music samplers.

A 6.x system simply adds side speakers to the 4.x configuration. The side speakers are added to tickle the ears with side pinna cues and provide a head shadow when a side source is reproduced. Since the pinna and head provide localization cues above roughly 200 Hz, side speakers need operate only in that range. Side speakers produce only a very small improvement in side imaging over a 4.x system. If you are engrossed in music or film, you may not notice the improvement. It is provided for perfectionists. Ideally, the side speakers should be turned off or limited to frequencies above 1,000 Hz when recordings made with the Ambiophone or other dummy-head recording microphones are being played. (An *Ambiophone* is a special microphone/recording set up using a baffled four-microphone dummy head without outer ears designed to maximize realism when played back on Ambiophonic systems.)

The four speakers in a 4.x system will clearly outperform a 5.1 surround system. The 4.x system will provide seamless surround without hot spots, without sonic gaps between surround speakers, without localization to surround speakers, and with precise imaging at all angles including side and rear imaging. Again, even though 4.x does not use side speakers, **4.x provides better side imaging than 5.1, 7.1, or 10.2 systems.** 6.x Ambiophonics is only a hair better at side imaging than 4.x. Moreover, 4.x and 6.x Ambiophonic systems, with the front speakers flanking the screen, provide a fine center image for dialogue without needing a center speaker. But you do need to set the CD/DVD player to the no-center-speaker setting. The player will then split the center signal and add it to the main left and main right speakers. Similarly, if DTS or Dolby decoding is done in a processor, set it to divide the center channel equally between the left and right front channels.

The only TacT Audio unit that currently provides for side speakers is the TCS. To implement side speakers for the other TacT units, pass the front stereo pair through a Pro Logic decoder in an outboard receiver or processor feeding an amplifier. Attach your left side speaker to the left main speaker output and your right side speaker to the right main speaker output. Tell the Pro Logic unit that five full-range speakers will be used. That way, only side signals (labeled front left and front right) will be sent to the side speakers. The Pro Logic box will provide a volume control. See below for more details.

Two-Channel Media with 4 or 6 speakers

When playing two-channel media such as CDs or LPs, feeding a RACE signal to the rear speakers noticeably enhances stage width and depth—and makes all the various adjustments seem less critical. The front and rear RACE signals should be similar but not identical in order to

Correction of speaker and room deficiencies has always been part of Ambiophonic theory. Devices intended for speaker and room correction have been commercially available from TacT, Lyngdorf, DEQX, and so on. Typically, the function is simply called *room correction*. Those running RACE crosstalk cancellation on a PC will likely find compatible room correction software available in the near future. All TacT products that provide crosstalk cancellation (XTC mode) also provide room correction.

When assembling a system with both room correction and RACE crosstalk reduction, one must decide which should come first in the signal path. If the speakers and the room are identical for both channels, then it does not matter whether room correction is done before or after RACE crosstalk cancellation—as long as room correction is the same for both channels, which would be normal for this case. If the speakers and room are not identical for both channels, we believe that RACE crosstalk reduction should come first. The signal path would be:

program source > crosstalk reduction > room correction > amplification > speakers

TacT devices use the above signal path.

Consider what would happen if the room were dissimilar for the two channels and room correction were done first. Suppose, when measuring a 500Hz signal at the listening chair, the left channel has a 7dB peak and the right channel has a 4dB valley. The correction logic will therefore cut the signal to the left speaker by 7dB and boost the signal to the right speaker by 4dB so that the direct sound from the speakers sounds flat. Again, before the left signal even gets to the crosstalk canceller, room correction for the left channel will cut the 500Hz level by 7dB. The left channel of the crosstalk canceller will create a cancellation signal for the right speaker by inverting the polarity of the left signal, but the 7dB cut at 500Hz remains in this cancellation signal. This cancellation signal is intended for the right ear and when the right speaker launches it, it will be 7dB too low. Additionally, the cancellation signal fed to the right speaker was subjected to left channel room correction but not right channel room correction. Since the uncorrected right speaker has a 4dB dip, the total cancellation signal will be 11dB below what is required to cancel the original acoustically flat signal coming from the left speaker to the right ear. (This ignores head shadow and the corresponding XTC attenuation setting). Thus, doing room/speaker correction or any asymmetric equalization before XTC is not a good idea.

If crosstalk cancellation is done first, the subsequent room correction ideally makes both speakers identical in level and timing when measured at the listening chair and thus there will be no problem. Indeed, RACE will function at its best. The result will be a wider stage, cleaner localization, and a better sense of depth. When effective room correction follows RACE, one can think of the room correction as part of the circuitry of the speakers making them appear perfectly matched to RACE.

For almost all conventional home speaker systems, room correction will make a clearly audible improvement in Ambiophonic performance—even more so than with standard stereo. But if one is lucky enough to have excellent speakers properly located in an excellent room, one might not hear an important difference from room correction. In fact, if one is not careful, room correction can make the sound worse. For example, if the microphone is not equidistant from the speakers when measuring the room, then room correction might introduce time delay differences for the two channels that will degrade crosstalk cancellation. In a problem room, a broad, high

