SDA™ Surround Technology White Paper

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Our goal was simple enough; provide an engaging surround sound experience with the absolute minimum number of loudspeakers. The result of our work, the Polk Audio SurroundBar™, achieves this goal with a single, multi-driver loudspeaker located under (or over) the TV screen. We decided to name the technology behind this achievement "SDA™ Surround", because it traces its roots to the legendary Polk SDA (Stereo Dimensional Array®) loudspeaker systems of the late 1980's.

SDA™ Surround technology relies on a mixture of acoustical engineering, psychoacoustic principles and a little magic. The original SDA technology, developed in the early 1980's, was a two-channel technology intended to overcome a fundamental problem of stereo reproduction. SDA™ Surround utilizes the same basic principles but expands the technology to allow for reproduction of surround sound without the need for rear speakers. In fact, it is possible to reproduce surround sound from just a few closely spaced drive units located directly in front of the listener. This technology requires no reflecting surfaces or special speaker placement and can be connected to any surround sound receiver. It will work well in almost any room of any size or shape and will deliver a surround sound experience for almost all listener locations.

While the surround sound experience offered by SDA™ Surround can be very satisfying and dramatic, it is not intended to take the place of a properly installed, high performance, hard-wired 5.1 system. It is intended to make excellent surround sound available for anyone who cannot or prefers not to install rear loudspeakers. Because of the psychoacoustic principles on which the technology is based, SDA™ Surround does achieve exceptional continuity side-to-side and front-to-back so that sounds closely follow the action suggested on screen. It also delivers consistent soundstage depth, even

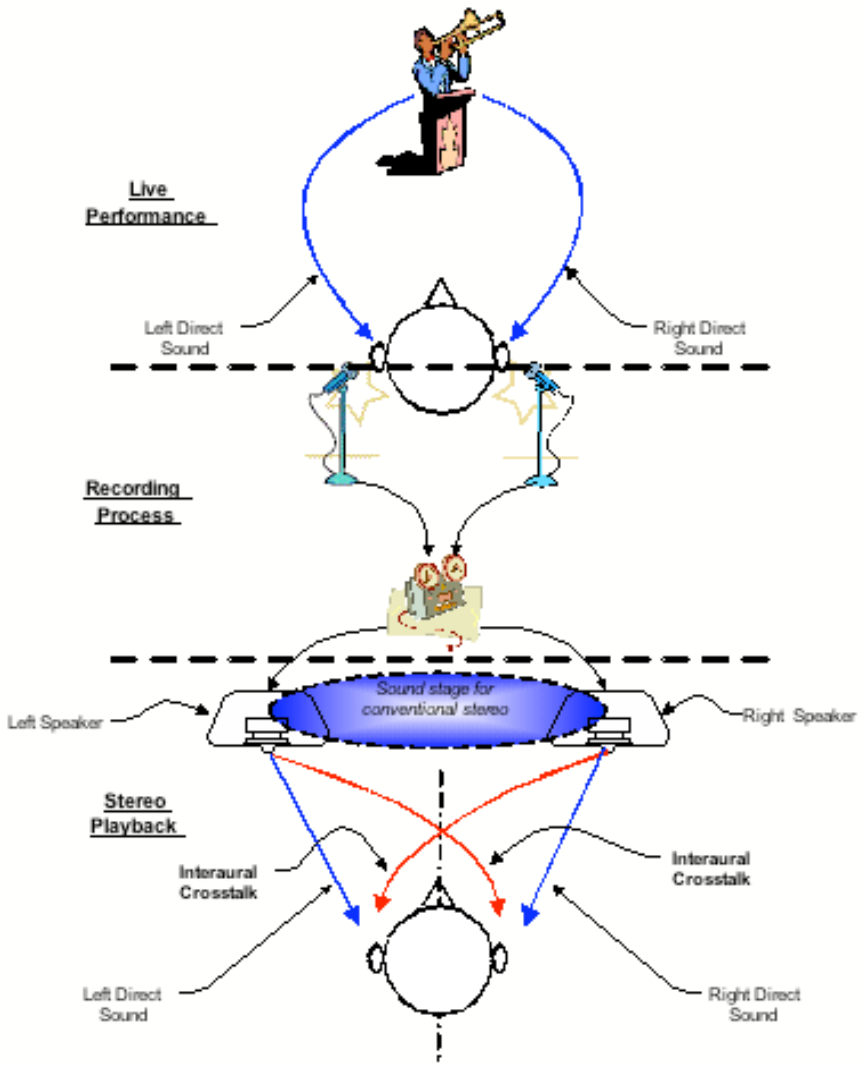
directly to the sides, a quality only achieved by the best conventional hard wired systems. This quality makes SDA™ Surround seem more like having dozens of speakers around you providing smoother and more immersive surround sound. But, the main goal of SDA Surround is to make it possible for you to enjoy surround sound in places where you thought it would just not be possible or desirable to set up the usual five or six speakers. If that's what you're looking for then the SurroundBar™ with SDA™ Surround may just be the answer you've been looking for.

Original SDA Technology:

The problem targeted by the original SDA technology is a phenomenon known as Interaural Crosstalk (or IAC). Interaural Crosstalk is a fundamental problem not only for stereo reproduction but for any system with more than one speaker. It is because of IAC that we hear the positions of the speakers in a stereo system. It is also Interaural Crosstalk that restricts the sound we hear to the area between the speakers.

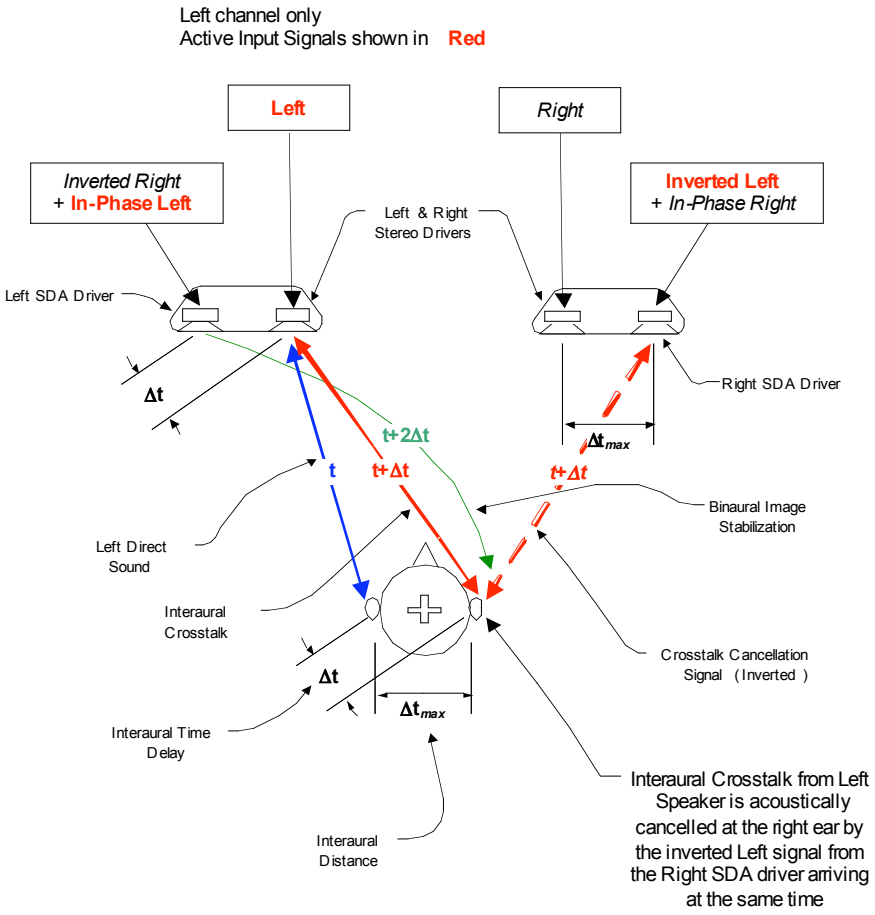
We hear the direction and location of sound sources based on the small differences between the sounds that actually arrive at each of our two ears. Our brain measures and processes those subtle differences in a way that allows us to accurately determine where a sound source is located. For example, suppose we go to a concert and put a microphone at each of our ears to record exactly what we are hearing. Those recorded sounds contain all of the characteristics of the instruments and voices in the performance. But it is the differences between the sound recorded at our left ear, compared to what is recorded at our right ear, that contains all of the information about the positions of the instruments, the size of the concert hall, etc. Now we go home and play it back over a pair of stereo speakers. The sounds recorded at our left ear are played back from the left speaker and the sounds recorded at our right ear are played back from the right speaker. But what do we actually hear when we sit down to listen? Of course the sounds recorded at our left ear and played back through the left loudspeaker arrive at our left ear just the way they are supposed to. But there is nothing to prevent those same sounds from reaching our right ear also. In the same way, the sounds recorded at our right ear and played back over the right speaker arrive at our right ear but also cross over to reach the left ear. Instead of hearing just what was recorded at the concert, each of our

ears also hears some of the sounds that were meant to be heard only by the other ear and vice versa. (See Fig. 1) Those extra sounds that cross to the opposite side of the head to reach the other ear are known as Interaural Crosstalk and they were not part of what you would have heard at the actual concert. The effect of IAC is to tell your brain where the loudspeakers are located while, at the same time, covering up the original recorded sound source location information. Once your brain knows where the loudspeakers are all of the sounds seem to come only from the loudspeaker locations and the space in between. This is nothing like what you heard at the original concert and is one of the major reasons why even the best conventional playback systems still don't quite sound like the real thing.

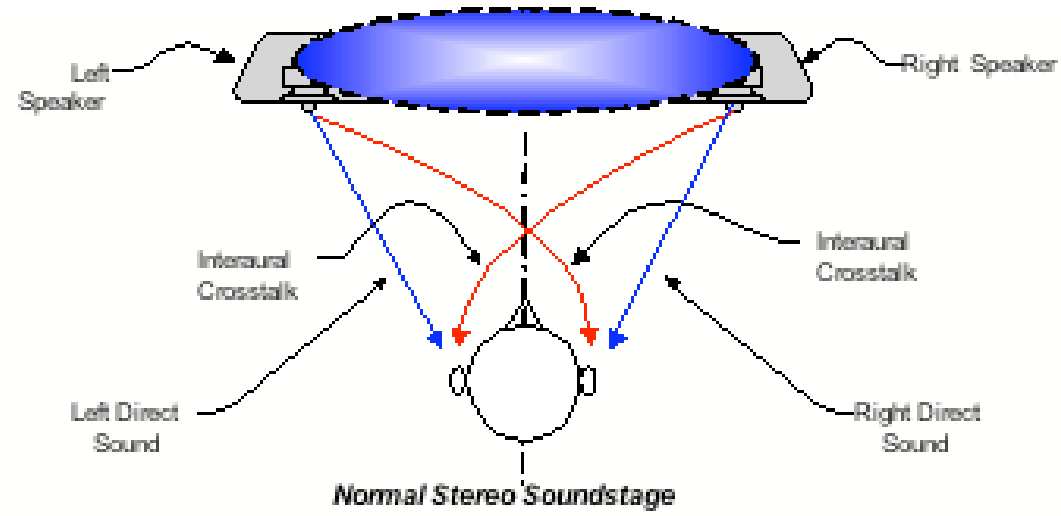


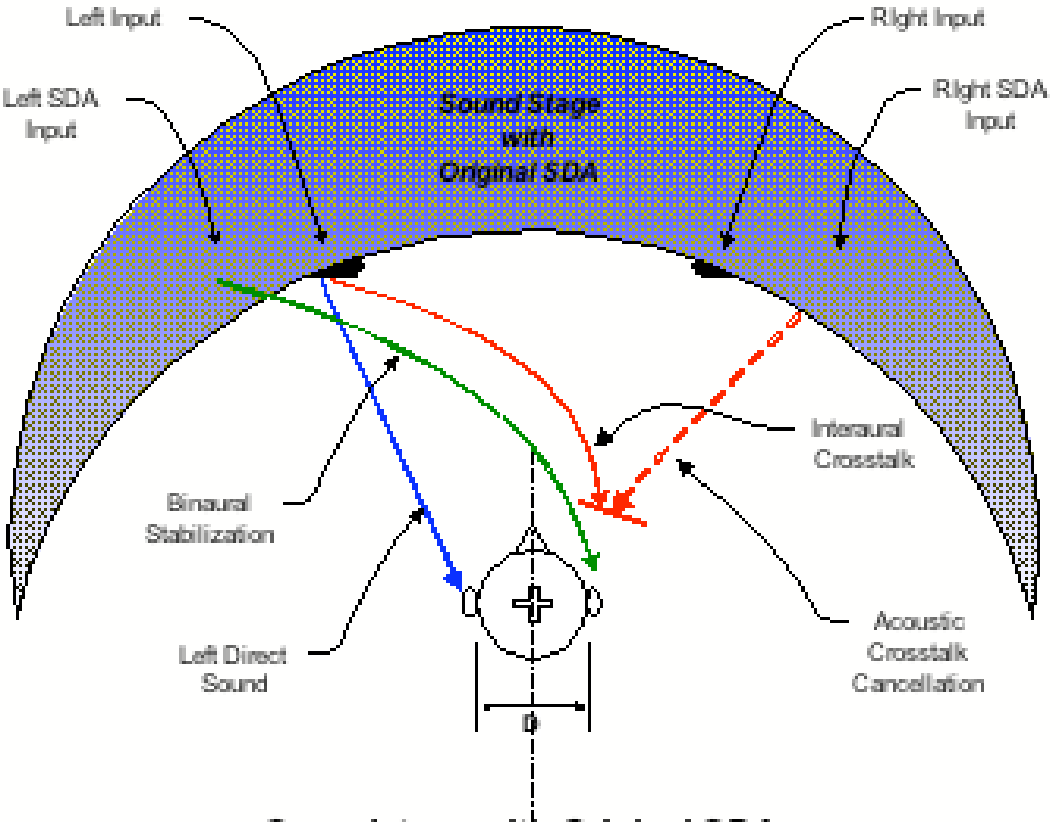
Interaural Crosstalk
Fig. 1

The problem of IAC has been understood from the earliest days of stereo and by the mid 1970s advances in electronics made possible the introduction of a number of devices intended to electronically cancel IAC. While these electronic devices were somewhat successful in eliminating IAC, they all suffered from severe limitations, including the need for a very precise arrangement of the speakers as well as a very narrowly defined listening location. In addition, for reasons we did not fully understand at the time, most people did not find these devices pleasant to listen to. In contrast, SDA™ used a system of extra drive units placed at the same distance apart as the space between your ears (also known as the Interaural Distance) as the basis for an acoustic system of Interaural Crosstalk Cancellation. (See Fig. 2) The additional "SDA" drivers received an inverted version of the stereo signal from the opposite channel. The geometry and spacing of the drive units insures that this inverted Crosstalk Cancellation Signal arrives at the ear at the same time as the unwanted Interaural Crosstalk and acoustically cancels it. The geometry also insures that proper cancellation will occur regardless of how far apart the two speakers are or how far away the listener sits. Based on the results of our research the Crosstalk Cancellation Signal was limited to a range of frequencies with longer wavelengths which are psychoacoustically important for image location. This gave the original SDA systems the ability to provide reasonably effective crosstalk cancellation over a considerable range of seating positions left to right as well as front to back. Additional research led to the incorporation of Binaural Image Stabilization to eliminate the possibility of "one ear only" sounds which do not normally occur in nature. This acoustic system for eliminating IAC provided flexibility for the locations of both the loudspeakers and the listeners. Continuing research into the psychoacoustic factors most important for the cancellation of IAC and the preservation of musicality led to the refinement of SDA technology over a period of more than 15 years and a dozen different products. The Signature Reference Theater (SRT), the last system incorporating SDA technology and produced from 1995 to1996, was called by one reviewer, "The Ultimate Loudspeaker System".



"SDA" System for Acoustic Cancellation of Interaural Crosstalk (Left channel signal input only) Fig . 2



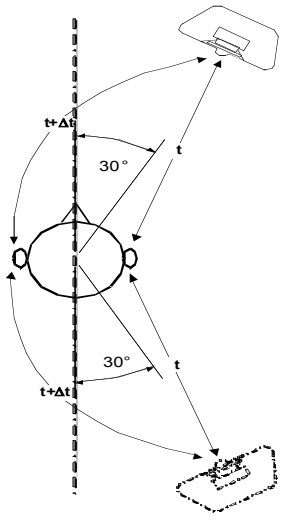


Soundstage with Original SDA
Fig. 3

SDA™ to SDA™ Surround:

The benefit of eliminating (or at least substantially reducing) IAC is that you now hear the original recorded information about the locations of the instruments and the acoustics of the concert hall unrestricted by the locations of your playback speakers. The original SDA systems were capable of reproducing a complete 180 degree front soundstage from a single pair of front loudspeakers located only a few feet apart. So, how do we get from here to a single multi-driver speaker that reproduces 360 degree surround sound? First, we need to know a little more about how our sense of hearing works.

The brain uses the small difference in arrival time of a sound first at one ear, then the other, to calculate the direction of the sound. For example, if a sound arrives at your right ear before arriving at your left ear, it must be coming from somewhere to your right. If the time delay for the sound arriving at your left ear relative to your right ear is about 250 milliseconds, then the sound is coming from a location about 30 degrees to the right of center.



The difference in arrival time from Right ear to Left ear (Interaural Time Delay) determines the direction of the sound . But , the delay is the same whether the sound is in front of or behind the listener .

Fig. 4

The greater the time delay, the further to the right. The smaller the time delay, the closer to the center. Zero time delay means the sound is right in front of you. Or, zero time delay could mean that it's right behind you. Whether the sound is directly in front or directly behind, it still arrives at both your ears at the same time, (i.e., with zero time

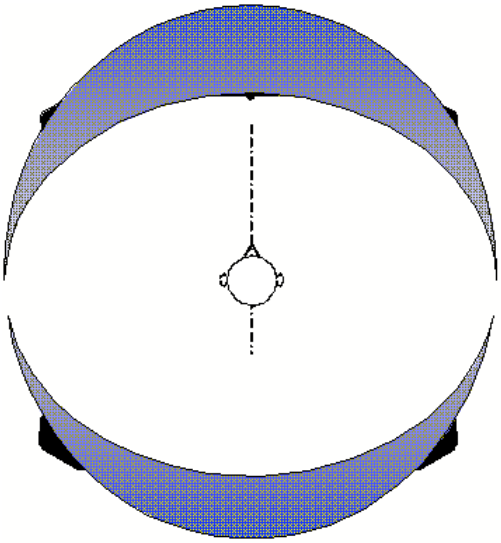
delay). This ambiguity also occurs for sounds located to either side. (See Fig. 4) In our example, a time delay of 250 milliseconds would be the same for a sound 30 degrees off center, either to the front or to the rear. But how can we tell if a sound is front or rear? It is the shape of our ears that does the trick. The asymmetry of our ears changes the frequency response of sound arriving from behind us so that they sound different than if they were in front. This is also, generally, how we determine whether a sound is above us or below us. In fact, for each possible direction of arrival at our ear there is a unique frequency response characteristic or sonic signature. So long as we are somewhat familiar with the sound, such as the voice of someone we know or a door slamming, we can easily and accurately determine high or low, front or back, which direction it's coming from. These directional signatures, including the associated time delays, are known as Head Related Transfer Functions or HRTF's.

In theory it should be possible to electronically synthesize the correct HRTF to make a sound coming from a loudspeaker in front of you seem like it's coming from behind you. The achievement of "virtual" surround sound should be as simple as feeding the surround channels to a pair of front speakers with the correct electronic HRTF reformatting so that they sound like they're behind you rather than in front. Not surprisingly, numerous devices have attempted to use the power of digital signal processing to do exactly this: electronically synthesize the proper HRTF's to make two front loudspeakers seem as though they are reproducing the sound of five loudspeakers surrounding you. Many PC's include "virtual" surround algorithms such as Virtual Dolby®, SRS® and others. As was the case 20 years ago with attempts to electronically cancel Interaural Crosstalk, many of the same fundamental problems have prevented these all electronic "virtual" surround systems from working well in the real world. To function properly all of these systems require speakers with high enough performance to preserve the accuracy of the synthesized HRTF's and require that the speakers and listener must be located in exactly the positions that correspond to the synthesized HRTF's. In addition, complete synthesis of the correct HRTF's is extremely complex and difficult to implement, even with the fastest digital signal processors. The HRTF's are also somewhat different for each person, and those differences can mean that a system that produces a convincing surround sound illusion for one person may barely

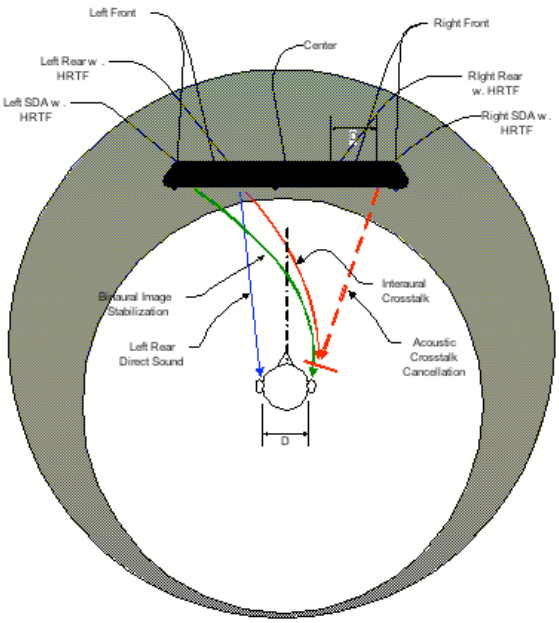
work for another. In contrast, the acoustic approach employed by SDA™ Surround relies only on those key features of the HRTF's that are common to everyone. And, the geometry of the system is based on the spacing between your ears, a dimension which is almost constant throughout the population. This provides tremendous flexibility in speaker placement and listener location and works equally well for almost anyone with normal hearing. In addition, SDA Surround recognizes that movement of the listener is an important part of the surround sound experience. The acoustic signals from SDA Surround that reach the listeners ears dynamically reinforce the surround sound experience as the listener turns or moves their head.

As previously described, original SDA technology canceled Interaural Crosstalk and created a very wide soundstage by using an extra set of drive units located about one head width outside the drive units reproducing the normal Left and Right front channel signals. SDA™ Surround applies this same arrangement to the drive units, reproducing the Left and Right rear channels' signals. The extra drive units reproduce two signals, one which cancels the rear channel Interaural Crosstalk and one that binaurally stabilizes the sonic image over a continuous range up to 90 degrees left and 90 degrees right of center depending only on the content of the recorded material. The head-width based geometry of the system means that the system functions properly regardless of how far apart the left and right rear channel drivers are located or how far away you are sitting. As with original SDA, these cancellation and image stabilizing signals are limited to a range of psychoacoustically significant frequencies, mainly in the midrange. The use of a carefully determined frequency range for these signals contributes to the natural sound and highly musical performance of SDA™ Surround and means that the system delivers a credible surround sound experience over a much broader range of listening locations. However, unlike original SDA™ each of these signals, including the main left- and right-rear channel signals, is modified by its own specialized front-to-back transformation filter built-into the crossover network. For each of the signal components, a separate front-to-back filter transforms the signal such that when they are combined acoustically at the listeners ears the resulting sounds have characteristics associated with a sound originating from behind you rather than in front. To make the system robust and setup tolerant, our

psychoacoustic research has identified several key components of the front-to-back HRTF transformations that are quite consistent from person to person and have nearly identical characteristics over a broad range of sound arrival directions. Coincidentally, many of these key HRTF components lie within the same range of frequencies found to be psychoacoustically important in the original SDA for the cancellation of Interaural Crosstalk. In SDA Surround filters containing the key HRTF components are combined with crosstalk cancellation signals, binaural image stabilization signals and acoustical delays to achieve both cancellation of IAC and front to back soundstage transformation within the same head-width based acoustical geometry used for original SDA. As with original SDA, this system works much more sympathetically with the way that we hear and offers a more natural surround sound experience over a broader range of seating locations than purely electronic attempts to synthesize a virtual 5.1 system. Additionally, of course, the system works for almost anyone with normal hearing. A side benefit is that these specialized front-to-back filters are much simpler and can be accurately implemented with many fewer components or, in the case of the SurroundBar™, without any active circuitry at all.



Sound stage for conventional 5.1 surround sound system
Fig. 5



Sound stage with SDA Surround
Fig. 6

Enjoying SDA™ Surround:

Perhaps the most important benefit of SDA Surround is the unique quality of the surround sound experience it is able to provide. Because it is able to provide a continuous sound stage around the listening area, even directly out to the sides, SDA Surround is more like having dozens of speakers around the room rather than just five or six point sources. SDA Surround is not intended to take the place of a properly installed high performance 5.1, 6.1 or 7.1 system. However, SDA Surround does offer some qualities usually found in only the very best and most costly conventional surround sound installations.

Conventional 5.1 surround sound systems are far more sensitive to proper setup than most home theater customers realize. To really get that "full-immersion" surround sound experience the speakers need to be properly matched, properly arranged in the right locations and the levels and delays carefully calibrated for the listening location. Usually this doesn't happen either because the customer's room won't accommodate the right speaker locations or because they don't want to invest in custom installation services to properly install and calibrate the system. As a result many home theater customers end up with a surround sound system that really just sounds like a couple of speakers behind you and is far short of being a really immersive experience that genuinely surrounds you. The reason it often ends up this way also lies in the fundamentals of how we hear. If there are two speakers in front of you playing the same thing it seems like the sound is coming from somewhere in between them. That's called a phantom center image. The same thing happens if there are two speakers behind you, the sound seems to come from somewhere between them. But, what about two speakers to one side, front and back, playing the same thing? Because both speakers are to one side and your ears are on a different axis, your brain doesn't create a phantom center image. Instead your attention is drawn to whichever speaker is slightly louder or slightly closer. This is why sound often shifts abruptly from front to back in surround sound systems where the levels and channel delays are not precisely calibrated for the listening position or when room considerations force placement of one speaker closer than another.

It also explains why the setup is so sensitive. A system set up like this may deliver a good front sound stage between the speakers and a good rear fill directly behind the listener but will leave huge gaps in the soundstage to either side. This also explains the popularity of 7.1 systems and dipolar rear speakers amongst audiofiles and videophiles who want to fill-in the missing sides of the sound stage.

As we have already discussed, one of the main tasks performed by SDA™ Surround is to eliminate the Interaural Crosstalk that tells your brain where the speakers are located. In the front, this frees the soundstage from the actual locations of the front speakers and allows the sound stage to extend over the complete 180 degree arc from one side to the other. For the surround channels, SDA™ Surround takes this 180-degree soundstage and flips it so that it seems to come from behind you. The combination of front and rear 180-degree soundstaging is what gives the system its uncanny 360 degree ability to place sonic images far out to each side and to provide front to back continuity which can be difficult to achieve in conventional systems.

SurroundBar 6.1 and 7.1 Systems

However, it is possible to combine the best that both SDA™ Surround and conventional hard-wired surround systems have to offer. Perhaps the most completely immersive surround sound experience available can be achieved when SDA™ Surround is used with a hard-wired center rear speaker for the 6.1 channel or a closely spaced pair of rear speakers in a 7.1 system. Although SDA™ Surround by itself can deliver a very satisfying surround sound experience our experiments with these hybrid SDA™ Surround "Plus" systems may offer the ultimate in full immersion surround sound.

The SurroundBar™ with SDA™ Surround:

The simplicity of the head-width acoustic system of original SDA™ and key component front-to-back transformation filters used in SDATM Surround has given us the ability to implement this technology in a single completely passive loudspeaker that can be connected to any 5.1 receiver. Simplicity is, however, a relative term. The

SurroundBar uses seven small drive units, three tweeters and, with 39 elements, one of the most complex crossover networks ever manufactured. The enclosure is about 4.5" high, 5" deep, 40" long and is styled to match modern shallow screen TV's. It accepts inputs for all five channels; Left, Center, Right, Left Surround and Right Surround. A separate sub-woofer handles low frequencies below 80Hz. Usually the SurroundBar will work well with the default setup of your receiver. However, if you want to make sure, here are two recommended setup configurations to handle most situations.

Find “speaker setup” or “speaker configuration” in your receiver setup menu.

A. For best music performance and smaller rooms.
    1. Set subwoofer to “Off” or “”None”
    2. Set Left and Right speaker channels to “Large”
    3. Set Center and Rear channels to "Small”
    4. Connect the subwoofer using the high level (speaker level) inputs from the same Left and Right front amplifier channels that are connected to the Surround Bar.
    5. Set crossover, if selectable, set to120Hz.
    6. Set all delays to zero. Or, if the receiver asks for the distance to the speakers, use the same distance for all.

B. For larger rooms or to play the system louder.
    1. Set Subwoofer to "On" or "Yes"
    2. Set all speaker channels to “Small”
    3. Connect subwoofer to receiver subwoofer line-level output
    4. Set crossover, if selectable to 100 Hz
    5. Set all delays to zero. Or, if the receiver asks for the distance to the speakers, use the same distance for all.

The SurroundBar™ can be wall-mounted above or below a flat screen, table-top mounted below a screen, on a long shelf or attached to the top of a shallow screen. The best surround imaging will be on a line directly in front of the SurroundBar. Because of the geometry of the acoustic system, the SurroundBar will work well no matter how far away you are located up to about 30 feet. Surround images will be less specific as you move to either side of center, but the SurroundBar™ will always deliver a room filling surround experience regardless of where you might be. And, you will never have the problem of hearing too much sound from one speaker caused by a lopsided room layout. The SurroundBar™ will work well in situations where it would be impossible to mount rear speakers behind you, such as when you are sitting very close to a wall or where the room layout prevents you from properly positioning five speakers around your listening location.