You Are Surrounded
A Brief Guide Through the Maze of the Surround Sound Formats

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INTRODUCTION

This paper provides an overview of surround sound technologies and serves as a general analysis of the state of the art. We briefly review the history of multi-channel audio, consider surround sound applications, explain playback formats, and examine the mechanics of surround. We conclude by looking at what the future may hold for multi-channel audio technology.

HISTORY

Early surround sound technology was driven mostly by the movie industry. Here is a brief chronology of multi-channel milestones.

In 1940, Disney Studios developed the first multi-channel playback system for the original release of *Fantasia*. Named "Fantasound," the system was remarkably innovative. Aside from introducing the concept of multi-channel playback, Fantasound invented such indispensable mixing tools as the pan-pot, the click-track, overdubbing, simultaneous multi-track recording, and multi-track playback. Not bad for one movie.

World War II slowed down the development of entertainment technologies, and the movie industry returned to stereo until 1976. That year, the movie *A Star is Born* was released in Dolby Stereo, featuring four audio channels encoded into two channels on the film's soundtrack. Then, largely due to Dolby's efforts, innovation leaped forward.

- In 1977, *Star Wars* was offered in Dolby's "Baby Boom" format, which featured left, center, and right channels, along with one limited-bandwidth surround channel and two Low-Frequency Effects (LFE) channels.

- In 1979, *Apocalypse Now* hit theaters in Dolby Split Surround, the first implementation of the format known as "5.1."

- Another notable milestone, the release of *Return of the Jedi* in 1983, gave rise to THX certification process, ensuring a standard of playback quality across a variety of surround setups in theaters.

- *Dick Tracy* premiered in 1990 with the first surround sound format based on compressed audio. The format was called CDS, short for Cinema Digital Sound.

- Modern surround sound for movies began in 1991 with the introduction of Dolby Digital, which utilized a compressed digital stream known as AC3. Digital Theatre

Systems (DTS), a competing standard, first appeared in the movie *Jurassic Park* in 1993.

- The most recent of modern standards, the Sony Dynamic Digital Sound (SDDS), was introduced with the release of the movie *The Last Action Hero* in 1994. The film featured the first 7.1 system. SDDS is still available only in theaters.

CURRENT STATE

Today, big-screen releases carry several formats, most notably Dolby Digital, DTS, and SDDS. While theater reproduction systems vary, DVDs containing music and movies have settled on Dolby Digital as the standard default audio track. Some DVDs also offer a DTS soundtrack in addition to Dolby Digital.

Audio standards continue to be updated in step with technology. In film surround, the new DTS 96/24 offers higher sampling frequency and bit rate, while DTS ES and Dolby Digital EX both offer sonic improvements and an increased channel count. Appendix 2 summarizes the surround sound formats in use today.

APPLICATIONS

History suggests that surround sound is the exclusive domain of the movie industry. However, a movie theater is just one place where multi-channel audio can be heard. The following is a list of the main applications of this enhanced multimedia experience.

Movies

Here, the applications of surround sound seem intuitive: events on the screen, such as an airplane flying overhead or a person running across the screen, should be properly represented in the corresponding audio soundtrack, providing the viewing audience with a rich audiovisual experience. The audio in *Terminator 2* is a prime example of surround technology being used to produce loud, action-packed sound, which was typical of the movie sound design in the 1990s. Recent movies such as *Hero* and *Crouching Tiger, Hidden Dragon*, have offered a more refined, equally outstanding auditory aesthetic.

Recorded Music

Many older stereo recordings have been remixed and released in the 5.1 format. Since the listener is so used to the original stereo sound, there has been controversy as to the effective use of additional channels in these mixes. In the past, there was no consensus on the type of information placed into the back and surround channels. Some remixes have put percussive sounds in the rear speakers, thus using 5.1 as a novelty as opposed to a means of producing a higher-quality mix. The controversy, though, is similar to when the music world experienced the change from mono to stereo; it will take some time for aesthetic rules to emerge. The present consensus among professionals is to use the extra channels to widen the stereo field and add ambience, thereby placing the listener in a new acoustic space.

Live Concerts

A live concert mixed in surround uses the surround speakers to widen the stereo field and sometimes to put the crowd noise back into the PA. Another live application is to change the acoustic characteristics of a room. A common method suggests adding delays and reverberation across the sound field to make a room sound larger and more reverberant. Using this technique, a mixer can make a small string quartet sound as if it were performing in a large concert hall.

Video Games

Game audio attempts to put the player inside the game; thus, the sound sources must be spatially correct at all times. For instance, if a monster is roaring to the left and the player turns in the direction of the beast, the sound field must change, moving the monster roar to the front. Panning moves must be programmed into the game and occur in real time, with no audible latency. The resulting options can take up a great deal of disc space and tax the game's CPU engine, but the real time factor is vital to maintaining the player's suspension of disbelief.

Both DTS and Dolby have low-latency surround formats that deal exclusively with game sound. DTS Interactive can be found on select Playstation 2 titles, and Dolby Digital Live can be found on select PC games as well as select console game titles.

Broadcasting

Surround sound can be found in television broadcasts and sports arenas. Sports venues have a number of speakers installed around the perimeter and are perfect for multi-channel audio presentation. On the field, carefully placed microphones pick up small nuances of a game, like a basketball swishing through a net or a bat hitting a baseball. These sounds are typically mixed back into the PA. Recently introduced multi-channel microphones from such companies as Holophone and SoundField create an instant surround stream that in many cases does not need additional processing.

Television broadcasting in surround is another exciting development. When watching a televised event, viewers can, from the comfort of their own recliners, feel as though they were really there in the audience witnessing the event firsthand. Such broadcasts are recorded via multiple microphones or a single surround microphone and are typically transmitted via Dolby Digital.

MAIN PLAYBACK FORMATS

The industry has settled on three main surround formats: 5.1, 6.1, and 7.1. The left digit in the name reflects the number of full-band speakers, while the right digit refers to the number of Low-Frequency Effects (LFE) channels. Dolby's compression scheme encodes LFE information in 1/10 of the normal speaker bandwidth, hence the ".1" in the name.

A 5.1 setup consists of six channels, clockwise in the picture below: Left, Center, LFE, Right, Right-Surround, and Left-Surround. A 6.1 setup includes all of the above and adds the Center-Back channel, which may be represented by two physical speakers carrying the same information. A 7.1 setup offers two back speakers (Left and Right) instead of one. Figure 1 shows correct positioning of the speakers for all three formats.
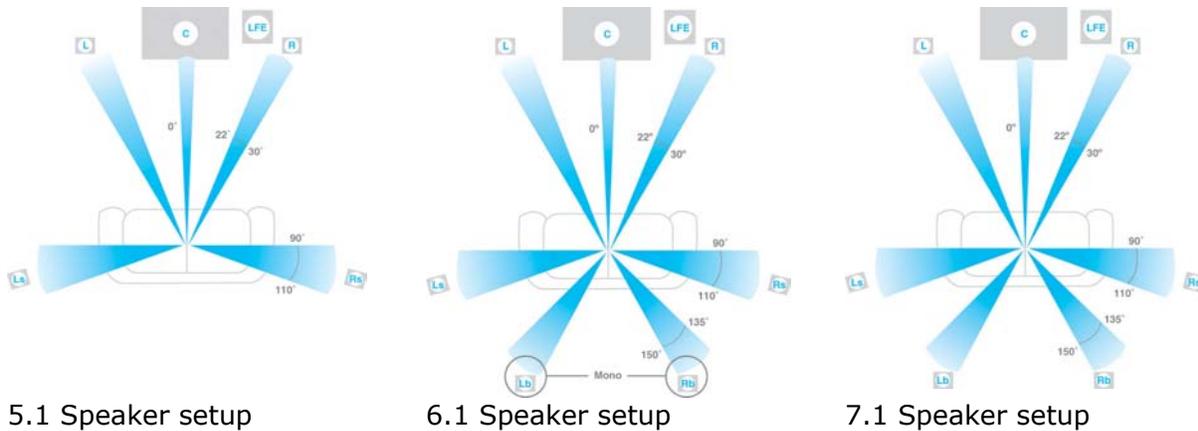
| 5.1 Speaker setup | 6.1 Speaker setup | 7.1 Speaker setup |

Figure 1. Correct Speaker Positioning in Home Theater Setups

In home theater systems, the 5.1 format is used most often. Since the release of DTS ES and Dolby EX, some 6.1 soundtracks have become available but have not yet reached widespread use, possibly due to a large installed base of 5.1 systems. The 6.1 and 7.1 systems are more often found in large movie theaters.

MECHANICS OF SURROUND

A surround sound system is more complex than the typical stereo system. Producers and consumers of multi-channel audio content should be aware that improper setup might completely negate the benefits of the additional channels, minimizing the return on investment. Encoding and decoding, backward compatibility, captured and artificial sound, bass management, and virtual surround are all part of the mechanics of surround.

Encoding Process

Encoding is the process of taking a master recorded in multi-channel surround and compressing it for transmission to a surround playback system. As noted above, all commercially available DVDs offer at least Dolby Digital and sometimes DTS as well. The two schemes mainly differ by the data compression ratio: Dolby Digital uses 12:1, while DTS uses 3:1. Encoders are commercially available in hardware and software versions, and they work by equalizing, compressing and embedding the multi-channel content into a digital stereo pair. High-end encoders allow manual control of crossover points to fit a variety of playback environments, while automatic encoders pick average settings.

The main advantage of the encoding process is the ability to play the encoded stream back either over regular stereo speakers or on a 5.1 playback system. This is achieved by embedding the additional channels into a stereo pair via a perceptual coding process in such a way that they are masked by audible program material. The encoded stereo stream is easy to transmit via a variety of traditional transmission mediums, such as CDs, stereo broadcasting, and movie soundtracks.

Decoding Process

Decoding is the process of converting the encoded stereo stream into multi-channel surround by extracting the embedded channels. Most modern receivers and computer soundcards have built-in decoders.

Appendix 1 illustrates how a signal is encoded, transmitted, and decoded in various formats.

Backward Compatibility

Older formats did not offer this feature, but modern surround formats are designed to be backward compatible with standard stereo equipment. This allows encoded surround information to be played back on regular stereo speakers without perceivable loss of quality, since perceptual coding techniques used in the process operate on the masked (inaudible) portions of the program material.

Captured vs. Artificially Created Surround

While it is somewhat surprising that movie soundtracks are still based on artificially created surround environments, the obvious reason for creating artificial sound is the unmatched flexibility the studio offers in positioning and controlling the sound source. However, several microphone companies, notably Holophone and SoundField, have introduced multi-channel microphones designed to capture surround sound naturally as it occurs. The growing popularity of home theaters makes live capture attractive for sports broadcasting, newsgathering, and location recording. Since surround microphones are undergoing miniaturization, live multi-channel capture will likely rise in popularity in the coming years.

Bass Management and LFE

"Bass management" refers to the selection of program material destined for the LFE channel, which is commonly, but incorrectly, referred to as the "subwoofer." The LFE is intended to carry only low-frequency special effects, such as dinosaur footsteps and explosions, but not the bass frequencies of the main program material, such as low frequency music. The THX specification imposes restrictions on the LFE channel, setting its volume to +10dB compared to other channels and limiting its bandwidth to 80Hz. The other channels are, by definition, wideband and are designed to carry the entire spectrum, including the bass.

Confusion stems from the reliance of inexpensive consumer surround systems on the LFE speaker to carry bass information in addition to low-frequency effects. For cost reasons, these systems are typically shipped with one large low-frequency speaker and five small speakers, which are incapable of reproducing the entire audio spectrum. While saving system cost, designers are forced to find a compromise and move the speaker crossover point to a higher frequency, such as 200Hz, effectively erasing the difference between the subwoofer and the LFE. The higher crossover frequency isn't compatible with professional surround encoders, which separate bass and effects at 80Hz, and results in a "mushy" bass response due to the clashing crossovers. The less expensive the speakers, the more "mush" in the low end. Advanced receivers have a variety of bass management settings to compensate for the actual speakers in use. Of course, the ideal surround setup includes full-range speakers on all channels but the LFE.

Multi-Channel Surround Decoded from Stereo

There is a way to play legacy stereo content on 5.1 home theater systems with an illusion of surround sound. Several systems create this illusion by extracting some audio information from the stereo pair and routing it to the surround speakers, allowing consumers to enjoy stereo music and movies on multi-channel surround sound setups. Both Dolby and DTS offer this type of synthesized surround, namely with Dolby Pro Logic II, Pro Logic IIx, and DTS Neo 6. Results vary, as the process is fundamentally artificial, and the source positioning decisions made by the algorithm can be hit or miss, but it's still better than stereo.

Virtual Surround

"Virtual Surround" works the opposite way. This technology refers to creating an artificially synthesized surround environment from a regular stereo playback system. This application involves additional psychoacoustic processing to create the illusion of surround sound originating from only two speakers (or headphones). Either stereo program material or multi-channel surround program material can be taken as the basis for this processing. Existing formats for this include Yamaha Silent Theater, QSound, Dolby Virtual Speaker, Dolby Headphone, DTS Virtual, SRS Circle Surround, and Circle Surround II. These technologies rely on the construction of the human ear to create spatial cues that lead us into thinking that the sound originates outside the speakers or headphones.
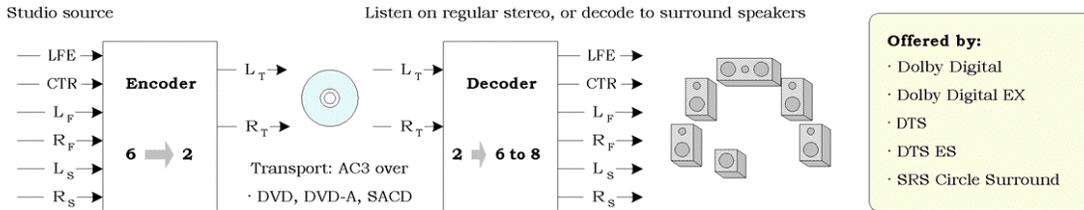
LOOKING AHEAD

Today's installed base of home theaters is large, and surround has become a mainstream consumer technology. As component cost continues to go down and consumer equipment increases in complexity, it is reasonable to expect the emergence of new surround standards with a higher channel count, capable of enveloping the listener within a more sophisticated surround picture. We expect that recent advances in computer and video game technology will lead to even greater developments in surround sound, while innovations in surround microphones will bring multi-channel recording within the reach of average consumers, and will undoubtedly change how home and professional movies are made and heard.

SUMMARY

Since its early days, multi-channel audio has drastically changed the ways entertainment is delivered. Surround sound has itself undergone numerous format changes since Disney introduced the first surround playback system in 1940. Today, it is found in three main formats: 5.1, 6.1, and 7.1. As audio companies continue to improve sound quality and find new ways to deliver multi-channel audio, one can expect an even more complex consumer experience in the years to come.
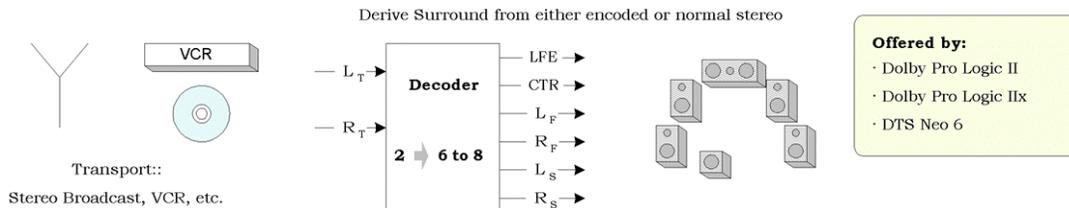
Appendix 1. Surround Encoding, Decoding and Transmission
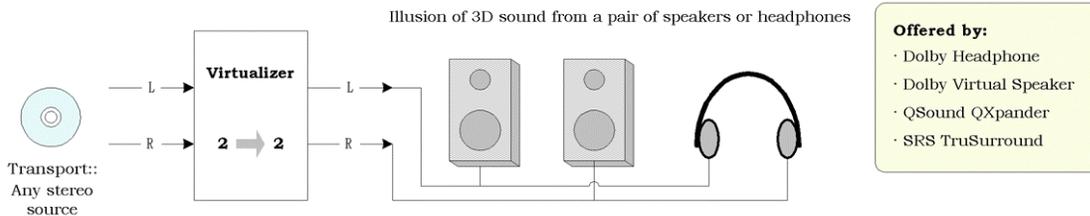

Encoded/Decoded Multi-Channel Surround from a Multi-Channel Source (AKA "Discrete")

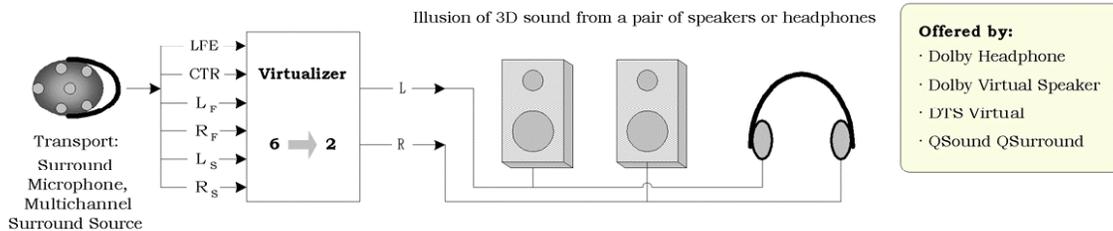Multi-channel surround encoded into a stereo stream (AKA "Matrix")

Virtual surround from stereo creates new spatial cues to generate an illusion of 3D Sound

Virtual surround from a multi-channel surround source relies on existing spatial information to create an illusion of 3D sound emanating from only two speakers or headphones

Appendix 2. Surround Sound Formats Currently in Use

The table below summarizes the currently available formats and their intended applications, number of channels, and types of source material.

Technology	Function	Possible source material for the Decoder	Decoded Channels
Dolby Digital	5.1 Surround	DVD, DVD-A, SACD, and Broadcast with encoded AC3 stream	6 (5.1)
Dolby Digital EX	6.1 and 7.1 surround	DVD, DVD-A, SACD with encoded AC3 stream	7 (6.1) or 8 (7.1)
Dolby Headphone	Virtualizer	Any non-encoded stereo or 5.1 surround source	2
Dolby Pro Logic II	5.1 Surround	Pro Logic II (audible stereo) or non-encoded stereo source	6 (5.1)
Dolby Pro Logic IIx	6.1 and 7.1 surround	Pro Logic II (audible stereo), non-encoded stereo or 5.1 surround source	7 (6.1) or 8 (7.1)
Dolby Virtual Speaker	Virtualizer	Any non-encoded stereo or 5.1 surround source	2
DTS	5.1 Surround	DVD with encoded DTS stream	6 (5.1)
DTS ES	6.1 surround	DVD with encoded DTS stream	7 (6.1)
DTS Neo 6	5.1 Surround	Any encoded or non-encoded stereo source	6 (5.1)
DTS Virtual	Virtualizer	Any 5.1 or 6.1 surround source	2
QSound Qsurround	Virtualizer	Any 5.1 surround source	2
QSound QXpander	Virtualizer	Any stereo source	2
SRS Circle Surround	5.1 and 6.1 surround	Encoded audible stereo or other stereo source	6 (5.1) or 7 (6.1)
SRS TruSurround	Virtualizer	Any stereo source	2

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