Introduction

We are now entering the Third Age of reproduced sound. The monophonic era was the First Age, which lasted from the Edison's invention of the phonograph in 1877 until the 1950s. during those times, the goal was simply to reproduce the timbre of the original sound. No attempts were made to reproduce directional properties or spatial realism.

The stereo era was the Second Age. It was based on the inventions from the 1930s, reached the public in the mid-'50s, and has provided great listening pleasure for four decades. Stereo improved the reproduction of timbre and added two dimensions of space: the left – right spread of performers across a stage and a set of acoustic cues that allow listeners to perceive a front-to-back dimension.

In two-channel stereo, this realism is based on fragile sonic cues. In most ordinary two-speaker stereo systems, these subtle cues can easily be lost, causing the playback to sound flat and uninvolved. Multichannel surround systems, on the other hand, can provide this involving presence in a way that is robust, reliable and consistent.

The purpose of this seminar is to explore the advances and technologies of surround sound in the consumer market.

1. How we hear 3-D Sound?

Human hearing is binaural (based on two ears), yet we have the ability to locate sound spatially. That is, we can determine where a sound is coming from, and in most cases, from how far away. In addition, humans can distinguish multiple sound sources in relation to the surrounding environment. This is possible because our brains can determine the location of each sound in the three-dimensional environment we live in by processing the information received by our two ears.

The principal localization cues used in binaural human hearings are Interaural Intensity Difference (IID) and Interaural Time Difference (ITD). IID refers to the fact that if a sound is closer to one ear than the other, its intensity at that ear is greater than at the other ear, which is not only farther away but also receives the sound shadowed by the listener's head. ITD is related to the fact that unless the sound is located at exactly the same distance from both ears (i.e. directly in front or back of the listener), it arrives at one ear sooner than the other. If the sound reaches the right ear first, the source is somewhere to the right, and vice-versa. By combining these two cues and other related to the reflection of the sound as they travel to our eardrums, our brains are able to determine the position of an individual sound source.

2. Surround Sound Formats

The principal format for digital discrete surround is the "5.1 channel" system. The 5.1 name stands for five channels (see figure 1 below) (in front: left, right and centre, and behind: left surround and right surround)of full bandwidth audio (20 Hz to 20 kHz) plus a sixth channel which will, at times, contain additional bass information to maximize the impact of scenes such as explosions, etc. this channel has only a narrow frequency response (3 Hz to 120 Hz), thus it is sometimes referred to as the ".1" channel. When added together, the system is sometimes referred to as having "5.1" channels.

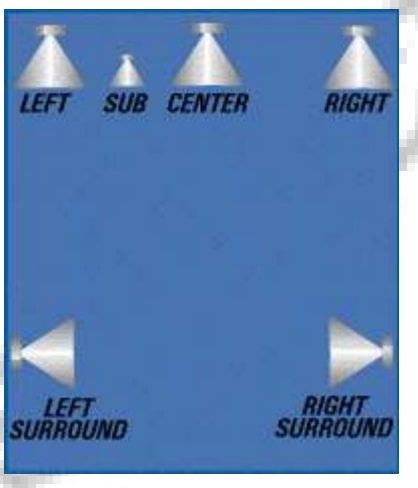

Figure 1. Speaker configuration for a 5.1 system

Presently, digital 5.1 sound format is most prevalent in movie theatres and home entertainment systems. In the movies, there are three main formats – Dolby Stereo Digital (DSD) by Dolby, DTS System by Digital Theater Systems and Sony Dynamic Digital Sound (SDDS) by Sony. These three formats are currently used in about 4,000 movie theatres. The DTS system is in the largest number of theatres, and Sony's SDDS is in the fewest. However, the number of SDDs equipped theatres is increasing quite rapidly and could overtake the number of DSD installations in one or two years.

On the home entertainment front, there is only one big name at the moment, and that is Dolby. Here, Dolby's format is known as Dolby Surround Digital. DTS has recently proposed a system for placing 5.1 channels of data-compressed audio on a laserdisc (LD), but at the moment no DTS demos of their new format using also 384 kb/s is available.

All three aforementioned formats have one thing in common, i.e. thay all use data compression. This is the only way to get 5.1 channels of discrete audio (with video) onto laserdisc, HDTV, or the upcoming digital video disc (DVD). However, this compression, is unlike computer data storage compression which uses "lossless" compression. All three audio formats uses lossy compression (DTS allows either "lossless" compression, "lossy" compression or a combination of the two, depending on the usage.). On carriers such as HDTV and DVD, there is room to store only about 10% of the original data; the remaining 90% must be thrown away and cannot be recovered in playback. This is the essence of "lossy" compression.

3. DSD

In 1987, the standardization process for a high definition television (HDTV) system began formally in the United States of America. For the system's audio, four or more discrete channels were considered preferable. However, the technology available then was not sufficient to achieve this feasibly; to do this would have required at least twice the bit-rate of compact disc digital audio. It was then that Dolby AC-3 was conceived as a multichannel audio coder.

In movie theatres, AC-3 is used in their film sound format, Dolby Stereo Digital. In the home, Dolby Surround Digital is also based on the AC-3 coding. The "AC" of ac-3 stands for Audio Coding. Audio coding is most often referred to as "perceptual coding". This simply means that the coding seeks to eliminate data that can't be discerned from normal listening, while maintain all the data that can be heard.

While AC-3 was first conceived to be used for HDTV in the US, it was actually implemented first in movie theatres. In the movies, AC-3 was known as Dolby Stereo Digital. This makes it practical to provide multichannel digital sound with 35 mm prints. For backward compatibility with theatres that are not AC-3 equipped, the analog tracks of the movies need to be retained. Thus it was decided that the new digital optical track be placed between the sprocket holes.

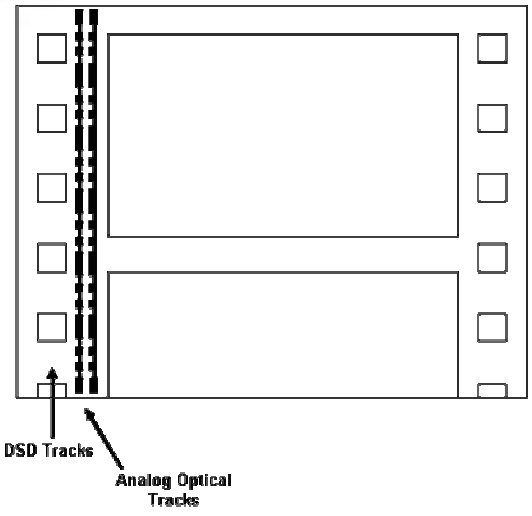

Figure 2. DSD has digital tracks between the sprocket holes

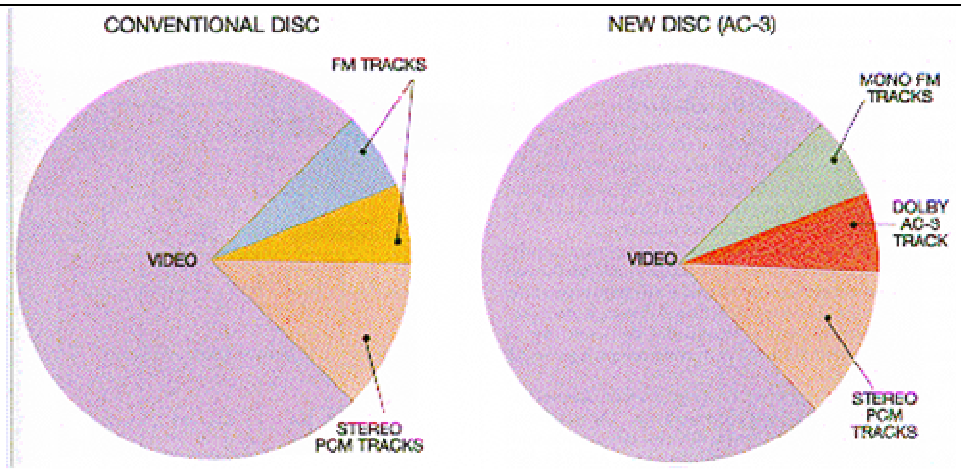

Figure 3. AC-3 on Laserdiscs

Table 1: DSD Technical Specifications

Analog Outputs	Left, Right, Center, Left Surround, Right Surround, Subwoofer
Frequency Range	20 Hz to 20 kHz ± 0.5 dB Bass effects channel: 20 to 120 Hz ± 0.5 dB
Dynamic Range	120 dB
Sampling Rate	32, 44.1, and 48 kHz supported
Data Rate	32 kb/s to 640 kb/s, including 32 kb/s for single mono channel, 192 kb/s for two-channel audio, and 384 kb/s for 5.1 channel on DSD
Compression	10:1

4. DTS

DTS was introduced to the public in 1993 with the release of Jurassic Park. Presently, over 5000 theatres worldwide are equipped with DTS playback equipment and over 100 movies to date have been DTS encoded. The DTs format for movie theatres, also known as DTS-6, and the format proposed for home entertainment, are quite different. We will discuss the former first.

In cinemas, operation of the DTS system is automatic and fail-safe, and is compatible with all existing theatre processors. DTS is a sound format that stores the digital sound track on two CD-ROM discs. This is unlike DSD or SDDS that encodes the digital track on the print itself. The 35 mm prints released for DTS films have normal, conventional, optical sound tracksas well for backwards compatibility, and as a fail-safe backup.

What is unique to DTS is the optical timecode that is squeezed between the optical soundtrack and the film frame.

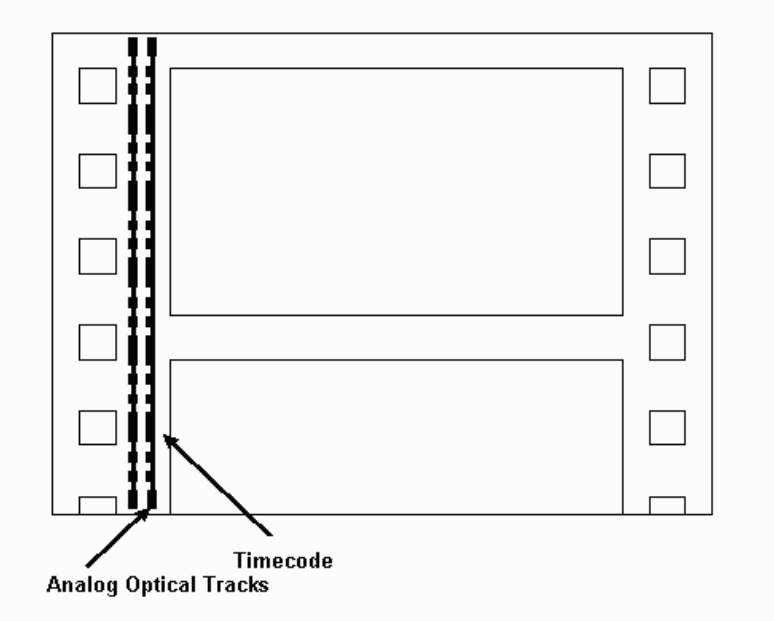

Figure 4: Timecode is between optical soundtrack and film frame

This is to allow the system to read the timecode on the film and play the correct sound for each frame of film projected. Thus the sound track stays in sync if there are missing or damaged frames (a small read-ahead buffer is used). This also means that edits and non-digital trailers are automatically accommodated. If at any time the DTS processor is unable to retrieve valid digital soundtrack data, it immediately switches to the normal analog soundtrack. Also, the film leader contains some header information which allows the DTS processor to check that the correct discs for the film are loaded into the CD-ROM drives.

DTS uses a coding algorithm known as Coherent Acoustic Coding (CAC). This algorithm codes 20-bit linear PCM audio data, but at a bit-rate lower than that required for audio CDs (705,600 b/s). this has been achieved with the first implementation of CAC, which allows 6 channels of transparent quality 20-bit audio to be recorded on a standard CD or LD.

In the home theatre, DTS just made an entrance about an year ago. Then DTS proposed a system for placing 5.1 channels of data compressed audio on a laserdisc, using the full data space currently occupied by the digital Pro Logic tracks. The only problem with the DTS scheme is that it limits backward compatibility; consumers without the required DTS decoder can only listen to the analog tracks. This is rather unlikely, as it would require a laserdisc to be released in multiple versions – DTS and AC-3.

One strength about DTS's system is that it uses far less compression, operating at a rate of 240 kb/s per discrete channel or 1.4 Mb/s for 6 channels. That means that DTS might just sound better. However, this data rate would never work on DVD. To have any hope of getting on DVD, the new DTs format would have to be limited to the same 384 kb/s data rate as Dolby

AC-3. the laserdisc compression scheme would not do. DTS has now developed a new format using a variable data rate with an average of 384 kb/s.

The technical specifications of DTS are as follows:

Table 2: DTS Technical Specifications

Analog Outputs	Up to eight channels: Left, Right, Center, Left Center, Right Center, Left Surround, Right Surround, Subwoofer
Frequency Range	20 Hz to 20 kHz Bass effects channel: 20 to 80 Hz
Dynamic Range	up to 145 dB
Data Rate	up to 1.4 Mb/s
Capacity of each CD	100 minutes
Compression	About 4:1

5. SDDS

Sony Dynamic Digital Sound is the newest of the three formats to hit the market. The system was released in early 1994, and kits were made available to dubbing studios and film printers to adapt industry standard film printing equipment so as to provide an easy ability to record and print SDDS films.

Sony's format is currently only available for movie theatres, and there is no word that Sony intends to port the SDDS system over to the home entertainment line.

SDDS is aimed to prove complete compatibility with any setup, the system, although inherently 8 tracks can have 4, 5.1 or 6 discrete track mixes placed on the system and the system decoder will interpolate and spread the sound to other channels, if available, without user intervention. The reverse is also true – the system can be used in a 4, 5.1 or 6 track auditorium and the system will convert the data correctly without user intervention.

Similar to DSD, SDDS puts the digital tracks on the film itself, not on separate CD-ROMs. Here, the digital tracks are placed outside the sprocket holes on both sides of the film

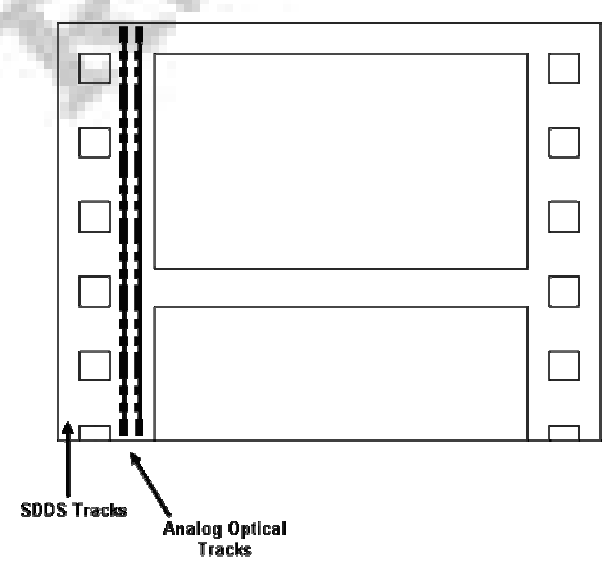

Figure 5: SDDS has digital tracks on the outside of the sprockets

Since the optical tracks are retained, the system is backward compatible with existing Dolby optical surround systems. SDDS uses a 5:1 compression technique and uses an algorithm that maintains 100% data redundancy. This enables quite large flaws in the print to survive.

The technical specifications are as follows:

Table 3: SDDS Technical Specifications

Analog Outputs	Up to eight channels: Left, Right, Center, Left Center, Right Center, Left Surround, Right Surround, Subwoofer
Frequency Range	5 Hz to 20 kHz ± 1
Dynamic Range	105 dB
Sampling Rate	44.1 kHz
Channel Separation	> 80 dB
Compression	5:1

THX IN 5.1

The THX Sound System was developed in 1982 durint the production of *Return of the Jedi.* The system was developed by Lucas film's corporate technical director Tomlinson Holman; thus the new sound system was referred to as the Tomlinson Holman eXperiment. THX is a sound system designed specifically to reproduce film sound exactly as it was recorded by the film maker. THX systems are more 5.1 ready than most other systems. Home THX have always employed separate amplifier channels for two surrounds, because THX controllers apply "decorrelation" to cover Pro Logic's mono surround signal into two spacious "steriozed" surrounds. So with a THX system, it is already using the stereo amplification that DSD or DTS required for surround channels.

6. MORE ABOUT DOLBY

Next came discrete 5.1 channel Dolby digital, also used first in movie theatres, and now brought into the home via DVD and DVD-ROM, DTV (Digital TV), laser discs, digital discs, digital cables and satellite systems. Dolby has developed a new professional digital audio coding, Dolby E, specifically for DTV multichannel audio production and distribution. Dolby Surround is a matrix process that enables any stereo (two-channel) medium, analog or digital, to carry four-channel audio. Encoded program material is fully compatible with mono and stereo playback, while listeners with playback systems incorporating Dolby Surround Pro Logic decoding enjoy four-channel surround sound. The two tracks of Dolby Surround encoded programs are identified as Left total/Right (Lt/Rt) to differentiate them from the conventional stereo Left only / Right only (Lo/Ro) programs.

Dolby Digital, sometimes known as, “AC-3” for the technology on which it is based, is a perceptual coding for consumer applications that enables storing and transmitting from one to 5.1 audio channel at a low data rate. Dolby Digital audio is used for digital television, digital cable and DBS transmission, and for DVD nad laserdiscs.

A unique feature called “downmixing” makes it possible for any consumer playback system with Dolby Digital decoding, regardless of channel configuration, to play 5.1 channel Dolby Digital programs. Mono and two-channel consumer decoders automatically create mono, stereo or Dolby Surround Lt/Rt mixes “on the fly” from multichannel programs. Supplementary information known as metadata is added during production, post-production or transmission to identify a Dolby Digital soundtrack’s production format – mono, stereo, matrix or

discrete surround – and ensure proper playback. Other metadata parameters include *dialnorm*, which includes a constatnt dialogue keyed playback level for all program material and sources, and *dynrange*, which applies a predetermined amount of dynamic range compression when listening conditions warrant, such as late at night.

Dolby E is a new professional audio coding technology that allows a single AES/EBU audio pair, or a single pair of digital VTER audio tracks to carry upto 8 channels of audio for post-production and distribution purposes. Unlike Dolby Digital, which allows for only on encode/decode cycle, Dolby E, in part – because it uses a higher bit rate – allows multichannel programs to be decoded, processed, re-encoded and edited upto ten times without audible degradation prior to final Dolby Digital encoding and broadcast.

DVD Video Soundtracks

Dolby Digital is a mandatory audio coding for DVD-Video, meaning a Dolby Digital coded sound tracks (mono, stereo, Dolby Surround encoded two-channel or 5.1 channel) can be the only in addition to a disc. A itrack using an optional coding can be provided only in addition to mandatory tracks. All DVD players worldwide are equipped for Dolby Digital decoding.

DVD Audio Soundtracks

DVD Audio disc must conform to the DVD Video disc specification. If you intend to use this option to insure compatibility, with all existing DVD Video players, you should include either a Dolby Digital 5.1 (if your program is multi-channel) or PCM two-channel audio tracks. Because of its low bit rate, it is easy to

include a Dolby Digital version of the program in addition to the high-quality PCM and/or Meridian Lossless Packing (MLP) version that reside in the audio zone on the same disc.

DVD – ROM

Dolby Digital is now migrating to the PC platform as DVD-ROM drives become increasingly popular. While the demand for the new drives has been initially driven by the desire to playback DVD Video discs on PCs, software developers are now starting to support Dolby Digital 5.1 for their DVD-ROM game and multimedia titles.

About DTV Audio and Dolby E

Dolby Digital is optimized for the efficient delivery of audio to the end-listener, maintaining high quality through one encode (transmission) and decode(reception) cycle. It has not been designed to withstand the multiple encode/decode cycles usually required in the production, post-production and distribution of audio destined for DTV prior to transmission. Moreover, Dolby Digital of frames(32 ms) do not match video frames, making it impractical to edit programming with Dolby Digital encoded audio. As a result, Dolby Digital encoding must be the last step prior to transmission, with some other audio format (analog or digital) used upto that point. Dolby laboratories has developed a new professional digital coding, Dolby E. it allows a single AES 3 pair or a single AES pair that can be recorded by a digital VTR or Video server to carry upto eight channels of data plus Dolby Digital metadata with a sophisticated 10 or more tandem encode/decode cycles without audible degradation. In addition, Dolby E audio frames match video frames, facilitating smooth transitions during audio-

follow-video editing in the digital domain. Dolby E, is therefore, an ideal distribution audio coding for the production of programs destined for DTV, while Dolby Digital's low data rate makes it an ideal "emission" coding.

Dolby Stereo

In this system, two more channels, centre and surround, exist apart from the left and right channels. The centre channel is placed between the left and right channels behind the screen, while the surround channel is at the rear of the audience. This is done by encoding centre and surround information on the two existing tracks of the film, and decoding the same using a suitable decoder and feeding the signals to separate speakers.

Encoder

The centre and surround signals are attenuated by 3 dB. The centre channel is then added between the left and right hand tracks. On the other hand, surround signals are again passed through a band pass filter, which is of the bandwidth 100 Hz to 7 kHz. This signal is again fed to a compressor, and the compressed signal is then phase shifted by +90 to the left hand channel. This forms the Dolby encoded stereo.

7. 5+2 CHANNEL SURROUND SOUND SPREAD STEREO

7 – Channel Surround Circuit

It creates a 5-channel real surround with the other two channels being totally virtual. This becomes possible by adopting a radically different approach – the output from the amplifier is split into lows and highs of frequencies and fed into separate speakers. The lows are fed to rear speakers and the highs to the front ones. One distinct feature is that the direction of speakers is directly opposite to that in the Dolby Surround System.

The circuit consists of only two capacitors that filter out any low frequencies, allowing only high frequencies to enter the circuit. The output is fed to surround speakers in the front. For rear left and right channels, the output from the amplifier is dropped to some extent by resistors and fed to speakers of the wire length used for surround speakers in the front. Speakers used for rear and surround channels are different as listed below:

Channels

Left and Right : The output from the amplifiers is dropped to some extent and fed to the left and right speakers. These speakers must be “woofers”. Woofers serve as dual-purpose speakers. One, they are used to reproduce signals from the left and right hand channels, and two, they are used to filter out any high frequencies. No capacitors are used to filter out these high frequencies.

Front Surround: This is obtained by allowing only higher frequencies to reach the front speakers. This is achieved through capacitors. The speakers employed are small, just 7.6 cm (3 inch) in diameter, and should be able to work as squaker as well as a tweeter.

This completes the description of the real channels created from the main channels. The other channels, namely the centre, the virtual left and the virtual right, are totally virtual. These are described below:

Centre: In any stereo system, the voice comes from the middle of the left and right speakers, however apart they may be. This is done by pre-recording the voices signals in equal amplitudes on both the tracks. So when played back, the voice appears to be emanating from the centre. Thus the centre channel is virtually available in any music system.

Virtual Left & Right: As evident from the fig, the virtual left and right speakers are between the front and rear speakers. Recalling the centre channel description, when the signals in the left and right-hand channels are equal, it appears to be at the centre. Similarly, if there is such a signal, equal in frequency and amplitude, which can be produced by both front and rear speakers, then it appears to be in the middle of those speakers. If the frequency of the signal is changing rapidly, the music seems to be swinging between the left and right virtual channels.

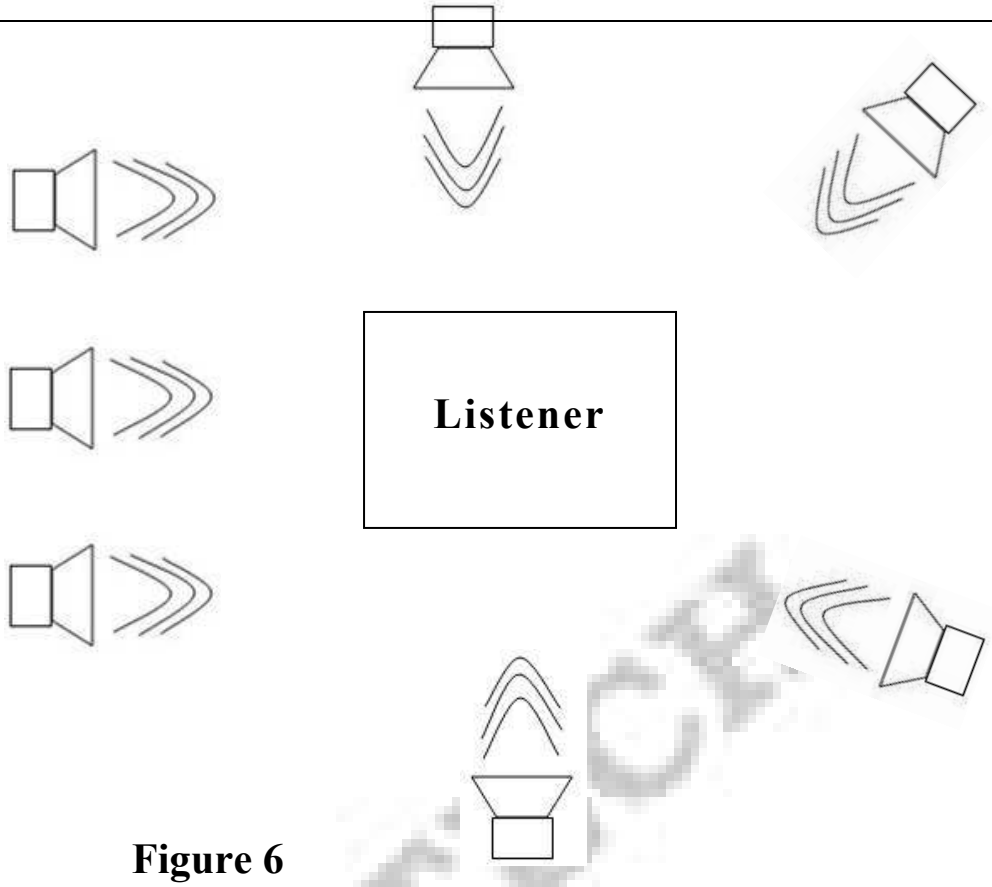

Figure 6

Delay

In surround sound systems, special ICs called bucket bridge delay devices are used to delay the surround channel than the main channel. Due to this, the signal appears in surround speakers a split second after the main channels. But, here the delay depends on pre-recording.

The delay is such that higher frequencies of music or voice are delayed and recorded. This kind of pre-recording is used to produce a delay-like effect. (eg. In the first song of A.R.Rahman's Album, *Vande Mataram*, one can clearly notice that a sentence first comes at a low frequency and after being compressed to a high frequency, comes again later). In this system, the low comes from the centre and the high comes later, from the front, left or right speaker.

8. INSTALLATION

The installation is very simple. Just take two small speakers and put them in the front as shown in fig. 5. Then connect the speakers with correct polarities as shown in the circuit. There may be a need to increase or decrease the value of the resistor, as the value of the resistor is the resistance of the wire used for front speakers, which may vary from experimenter to experimenter.

Distances between speakers installed by this author are given in fig. 7. To checks the correctness of the distance, one must listen to different songs, since songs vary in music, and so do effects. The listening area is in the middle as shown in fig 5., but this vary a little forward or backward, and the perfect position may be obtained after a few trials and errors. It should be ensured that the facing is totally opposite to that in other surround sound systems. And since the system is totally virtual, one should keep the head straight while listening.

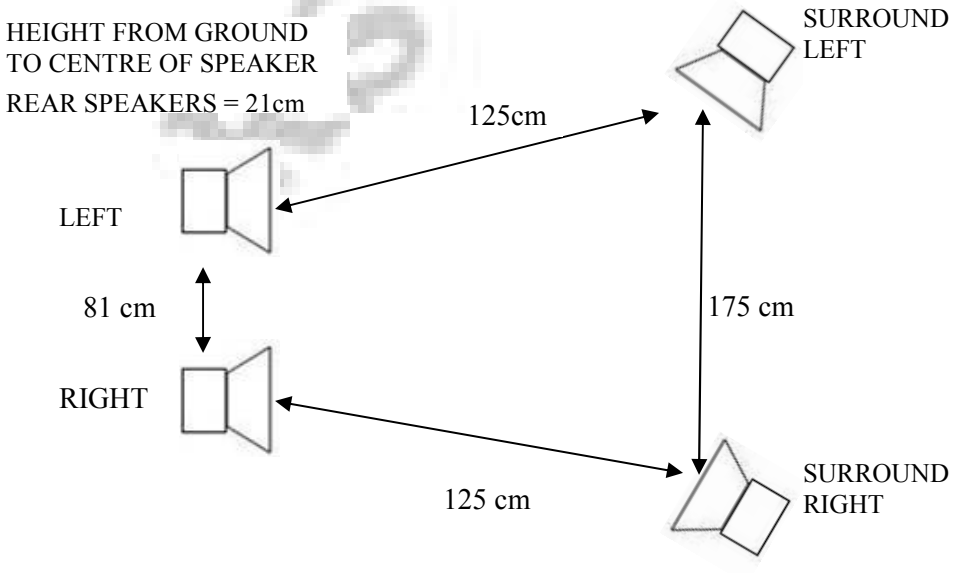

Figure 7.

9. APPLICATIONS OF SURROUND SOUND

Surround sound is the term to sound tracks, associated with films or other visual material, that use multiple loud speaker arrangements to envelop or surround the audience with aural(sound) information to give added realism.

Surround Sound and the Cinema

Typically, a number of different types of sound are recorded on separate tracks when the film is made: for example, dialogue, stereo music backing, sound effects. These are then edited and mixed together, as desired by the film producer, to give the desired audio effects on the final sound track.

The production of surround sound for film derives from the way it is shown in the cinemas. In cinemas, loud speakers are positioned behind the screen (which is usually specially pierced to transmit the sound) and these are normally fed with the film dialogue sound only. This helps to fix the actors' voices to the picture. Loud speakers on either side of the screen are usually fed with stereo music and sound effects. Additionally, further loud speakers to rear of the auditorium (all round the audience in some large cinemas) are used for ambience, atmosphere and special effects. Thus a minimum of four channels of sound – and often more – are used in the film making process.

Not all cinemas are equipped for surround sound films, and this was particularly true in the infancy of surround sound. In order to reduce the costs involved in film distribution, a 'compatible system' was evolved that 'encodes' all of the surround sound channel into two that can be played as a standard stereo sound tracks. The sound tracks can also provide a satisfactory mono sound.

Special decoding equipment is needed to separate the multiple surround sound tracks from the mixed stereo pair.

Surround Sound in the Home

It is possible to have surround sound in the home. Pre-recorded video tapes and laser discs are now available with surround sound encoding on stereo sound tracks, and the decoding equipment (albeit simpler than that used in the cinema) is also readily available. Most complex setup includes a centre (dialogue) loud speaker that should be positioned very close to the screen. Suitable decoders extract the centre information from the stereo signal and feed it to the centre loud speaker only.

Most commonly encountered encoding systems are reasonably compatible with the decoders that are being fitted to some televisions, video cassette recorders (VCRs) and Hi-Fi audio equipment in the home. Decoders are also available as separate units for use with existing audio and video equipments.

Surround Sound and Television

Some of the bought-in feature and television programmes broadcast by the BBC have been recorded with surround sound encoding. These encoded tracks are transmitted, using the NICAM stereo television sound system, into the home where viewers with suitable equipment can decode them. The BBC require all programs supplied to have stereo sound, but do not specify surround encoding. Since the material supplied is often supplied in an edited form for broadcasting, it is not possible to indicate which programme material has surround sound.

The spatial effects are often highly dramatic and the listener/viewer with suitable equipment will sooner recognize when a programme is made in surround sound. Many stereo recordings have sufficient phase-dependent information to 'fool' surround sound decoders and produce outputs from the various loud speakers. While not true surround sound, the effects can be pleasing with music and atmospheric material.

Most BBC drama, entertainment and sports programmes are broadcast with high quality stereo sound. Although some co-production programmes are made with surround sound encoding, currently the BBC has no plan to use it regularly.

10. CONCLUSION

With the amount of technological advances that are occurring in the field of surround sound, it will be no surprise, if the stereos we know become obsolete soon. The new proposed DVD has already chosen DSD as preferred format for audio. But with DTS becoming stronger, the format may just change. At present, Dolby, DTS and Sony are main players in the field, but remains to be seen what will happen in the near future.

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