Applying Aural Research: the aesthetics of 5.1 surround

Jim Barbour

School of Social and Behavioural Sciences, Swinburne University
email: jbarbour@swin.edu.au

Abstract

Multi-channel surround sound audio offers a richer perceptual experience than traditional stereo reproduction, recreating three-dimensional aural soundfields. Understanding the limitations of human auditory perception and surround sound technology may assist the exploration of acoustic space as an expressive dimension.

1 Introduction

Research and development into new digital audio software and hardware has resulted in multi-channel digital audio recording technology that allows the creation of immersive aural environments reproduced by multiple loudspeakers arranged around and above the listening position. The audio delivery platform offered by the Digital Versatile Disc has provided the facility for musicians, composers and sound designers to produce three-dimensional audio works in studio environments and to have them recreated in distant listening rooms. The technical quality of digital audio allows the recording, delivery and reproduction to be transparent to a listener, removing the aural artefacts of analogue technology. No longer are we aware of the sound of the medium itself, the hiss and scratches of mechanical sculpture.

However, digital audio technology has presented new challenges to aural artists. Recording engineers, producers and musicians who are familiar with the paradigm of stereo are experimenting with surround sound technology, unsure of how to best use the new medium to deliver a three-dimensional immersive soundfield to consumers. This paper will explore some of the audio research that lies behind the current debates among sound professionals about the aesthetics of localization, spatial impression and envelopment, and will present some of the solutions that have been achieved by audio producers. References will be made to music releases and sonic art to illustrate some of the aural possibilities. Despite significant limitations inherent in the 5.1 surround sound specification, it is the position of this paper that it represents an opportunity to deliver an exciting and immersive aural experience to a consumer today.

2 Consumer Surround

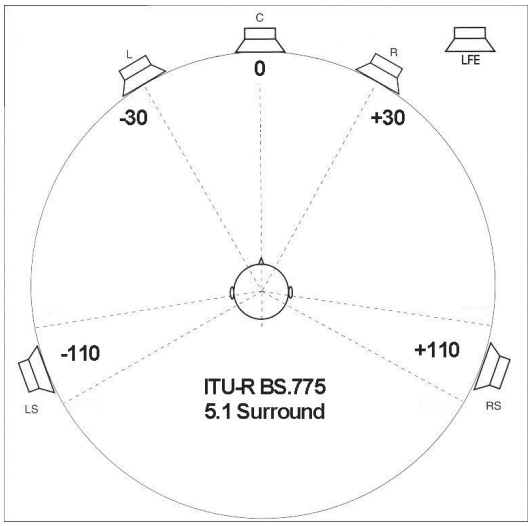
For many decades, it has been a goal of many audio practitioners to deliver the immersive, three-dimensional soundfield of the real world, or of their creative imagination, to listeners in their home environment.

2.1 Quad: 1970s

The development of multi-track tape recorders in the 1970's led to successful experiments with four channel quadraphonic recording, which succeeded in capturing and reproducing a high quality three-dimensional soundfield in a controlled studio environment. However, all efforts to deliver it to listeners in their homes failed. In reality, the delivery medium of vinyl was not aurally transparent, since we could hear disc noise and scratches, which destroyed any illusion of an immersive soundfield. Consumers who had purchased the quadraphonic reproduction equipment, including expensive turntable cartridges, amplifiers and extra loudspeakers, were so disillusioned by the poor quality that the concept died a marketplace death that still resonates today.

2.2 DVD:1990s

This immersive soundfield could not be delivered into consumer's homes with any significant success until the digitisation of video and audio permitted the introduction of the Digital Versatile Disc (DVD) format in the mid 1990's. The technical specifications for DVD-video include the audio standard ITU-R BS.775 (ITU 1993), known as 5.1 surround sound. This utilises five full range loudspeakers distributed around a listener and a low frequency sub-woofer loudspeaker, as shown in the accompanying diagram.



ITU-R BS.775 5.1 Surround specification

With the extraordinary acceptance and purchase by consumers of the DVD-video format, which now numbers more than 50 million players worldwide, there is a platform for the delivery of high quality multi-channel audio into any listening environment. However, audio researcher Francis Rumsey, author of the book *Spatial Audio* and chairperson of the committee that developed the ITU 5.1 standard, identified a problem for the audio community:

> Although 'purist' sound engineers find it hard to accept that they must use a layout intended for movie reproduction, …, most pragmatists realise that they are unlikely to succeed in getting a separate approach adopted for audio-only purposes and that they are best advised to compromise on what appears to be the best chance for a generation of enhancing the spatial listening experience for a large number of people. (Rumsey, 2001, 18)

3 Psychoacoustic Phenomena

Aural research has identified the parameters to be used for a qualitative assessment of the 5.1 surround sound process. According to Rumsey, the 'psychoacoustic phenomena that appear most relevant to the design and implementation of audio systems' are source perception (identity and location), spatial impression and acoustic envelopment. (Rumsey, 2001, 21) Of these, source localization appears to be the most difficult to accurately deliver with a sound reproduction system, but equally, it is the most interesting for many sound practitioners. Therefore, let us consider localization in detail first, since many of the findings for localization affect our perception of spatial impression and acoustic envelopment.

Acoustic space is generally considered to be a sphere with our head at its centre. (Carpenter and McLuhan, 1970, 67) Our perception of the identity, location and distance of a sound source can be aided by visual cues, but is built on binaural discrimination and our experience of the variations in the loudness and timbral qualities of a sound source at different distances. The perception of the environment in which we hear the sound source is based on our perceptual memory of different acoustic spaces, built from the experiences of hearing the reflections of sound waves from surfaces within spaces, and the direction, timbre and loudness of those reflections.

4 Two Channel Stereo

Our experience of high quality audio has been mediated by the stereo paradigm for more than thirty years, based on the implementation of two-channel recording and reproduction through two loudspeakers. It has been stated by the results of considerable research into loudspeaker placement that the ideal listening position is at the apex of an equilateral triangle where the distance between the two speakers is equal to the distance from each speaker to the listener.[1] This position, approximately two to three metres from the speakers with an angle between the speakers of sixty degrees, (±30º from the centre front), is often referred to as the reference listening position or 'sweet spot'. At this reference position, it is possible to perceive with relative accuracy the location of a reproduced sound source within the front arc of 60º.

> Two-channel stereo … is essentially limited to reproducing both sources and reverberation from an angle of about 60º. This is adequate for many purposes as the majority of listeners' attention is likely to be focused in front of them when listening to music or watching television. (Rumsey, 2001, 64)

4.1 The Failings of Stereo

Stereo reproduction has delivered accurate localization within the front arc, but only limited envelopment. Directional perception between the two loudspeakers is only an artificial or phantom image, since there is no true loudspeaker source at that position. If the position of the listener changed to be closer to one loudspeaker, the proximity to the closer speaker would make the sound from that loudspeaker arrive sooner and be louder than the sound from the more distant loudspeaker. Due to this change in

[1] For more detailed information concerning stereo loudspeaker positioning, see Holman's *5.1 Surround Sound, Up and Running*, (2000), Boston: Focal Press, or Eargle's *Stereophonic Technique* (1986) AES.

precedence and relative loudness from the two loudspeakers, the phantom image of the source would appear to shift toward the closer loudspeaker, destroying accurate localization.

There is a timbral change for phantom images due to acoustic crosstalk, with the sound from the left loudspeaker arriving at the right ear slightly later than the sound from the right loudspeaker, and vice versa. Mid to high frequency colouration results with the effect most pronounced for central images. Some research and experimentation has focussed on extending the directional cues to beyond the 60º arc using anti-phase signals mixed into the stereo channels, sometimes referred to as 'trans-aural stereo'. (Rumsey, 2001, 74) This research has analysed the perceptual effects of acoustic crosstalk from, for example, the left loudspeaker to the right ear. Rumsey outlines the possibilities for extended azimuth localization:

> Crosstalk cancelling systems perform this task by feeding an anti-phase version of the left channel's signal into the right channel and vice versa, filtered and delayed according to the HRTF characteristic representing the crosstalk path. The effect of this technique can be quite striking, and in the best implementations enables fully three-dimensional virtual sources to be perceived, including behind the listener, from only two loudspeakers located at the front. (Rumsey, 2001, 75)

4.2 Stereo Envelopment

Another component of the sound source reproduced through the loudspeakers is the enveloping reflections of the original sound source in its acoustic space. For a listener in the reference position, the two loudspeakers will reproduce the enveloping soundfield of the original recording with reasonable accuracy, allowing the listener to perceive the location of the source and some illusion of spaciousness as soundfield depth within the front arc. However, as the listening position changes to be closer to one speaker, the perception of the acoustic space will collapse due to precedence and loudness changes.

5 ITU 5.1 Surround Sound

The development of 5.1 surround sound provides two separate possibilities to extend the soundfield beyond the front arc of 60º, and to provide enhanced envelopment and more accurate and stable localization of sound sources. The front centre channel is equidistant between the main left and right front loudspeakers and impacts upon imaging in the front arc of 60º. The left and right surround loudspeakers provide the possibility to extend localization beyond the front arc into the full horizontal 360º.

> Surround sound provides an opportunity to create something that works over a much wider range of listening positions than two-channel stereo, does not collapse rapidly into the nearest loudspeaker when one moves, and enhances the spatial listening experience. (Rumsey, 190)

For each of these additional loudspeakers, there are some advantages and disadvantages to their use.

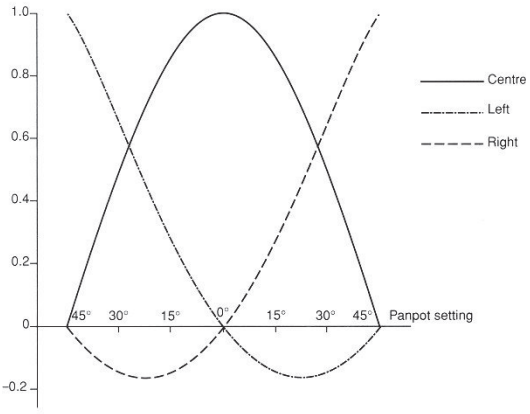
5.1 Centre Channel Advantages

The centre channel loudspeaker provides a solid, real central image to a soundfield created across the front left-right arc. When sounds in the centre of the soundfield are reproduced through the centre loudspeaker, there will be a reduction in the impact of the precedence effect, allowing a broader reference listening position. This is valuable for music only listening, but is considered crucial when the audio is tied to images, for example in film or television reproduction. The total soundfield image is therefore more stable across the front arc. Also, timbral modification is reduced with the introduction of a centre loudspeaker, since there is a real sound source producing one set of sound waves travelling to the ears, rather than the two sets of sound waves for stereo creating the phantom centre image.

5.2 Centre Channel Disadvantages

For some practitioners, a sound that is reproduced through the centre loudspeaker only can be a nuisance, with sounds too focussed at that position, confined to the loudspeaker. To overcome the problem of central focus, it has been suggested (Holman, 2000, 86) that some of the centre channel sound should 'bleed' into front left and right to de-focus the source, or possibly reverberation should be added into front left and right. While this may overcome some of the problems of focus, it does partially destroy the accurate localization that is possible with a centre loudspeaker. The issue of centre loudspeaker position is also relevant when it is difficult to place the loudspeaker in the true centre position due to screen limitations, for example when a television occupies that spot, and the depth or height of the resulting centre loudspeaker position may compromise the quality of the sound.

While many audio practitioners are attempting to recreate an accurate soundfield, there are also many creating an illusion of localization using mono sound sources that are positioned or panned according to amplitude or time differences between loudspeakers. When using two-channel stereo only, the amplitude panpot law that has been found to be most effective psychoacoustically is a –3db reduction in each channel for the centre position, and greater than –40db at the extremes of the left and right loudspeakers. (Rumsey, 2001, 177) This amplitude law has been easy to implement in recording consoles and very simple to operate. However, there is significant difficulty in panning left to right when there is a centre channel. According to Michael Gerzon, his research concluded that true psychoacoustic panning across the left-centre-right sound stage should include frequency and amplitude variations, with out-of-phase amplitude components for the extreme ends. (Gerzon in Rumsey, 2001, 178).

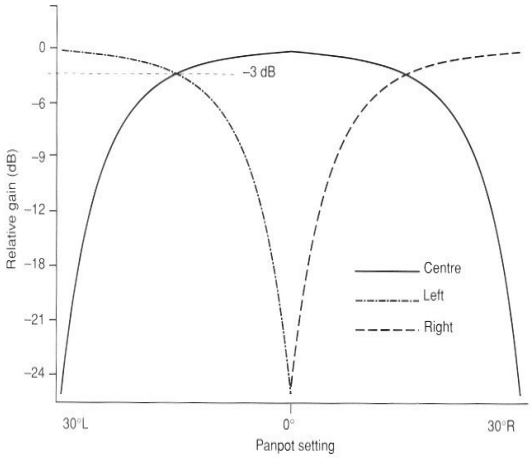


Gerzon's psychoacoustic panning laws

While this may be optimal, it is very expensive to implement in recording consoles, except in some of the latest generation of digital audio consoles. Instead, the most common implementation is pair-wise amplitude panning, as Rumsey described:

> Typical three-channel (or more) panpots are rather crude devices, tending to work on simple positive-valued gain relationships between pairs of channels at a time, treating each pair of speakers (left-centre or centre-right) as a straight amplitude-panned pair as in two channel stereo. (Rumsey, 2001, 180)

Rumsey's pair-wise –3db panning laws:



5.3 Surround Channels

Let us now consider the possible uses for two surround loudspeakers, positioned according to the ITU standard at ±110º from front centre. As Rumsey states:

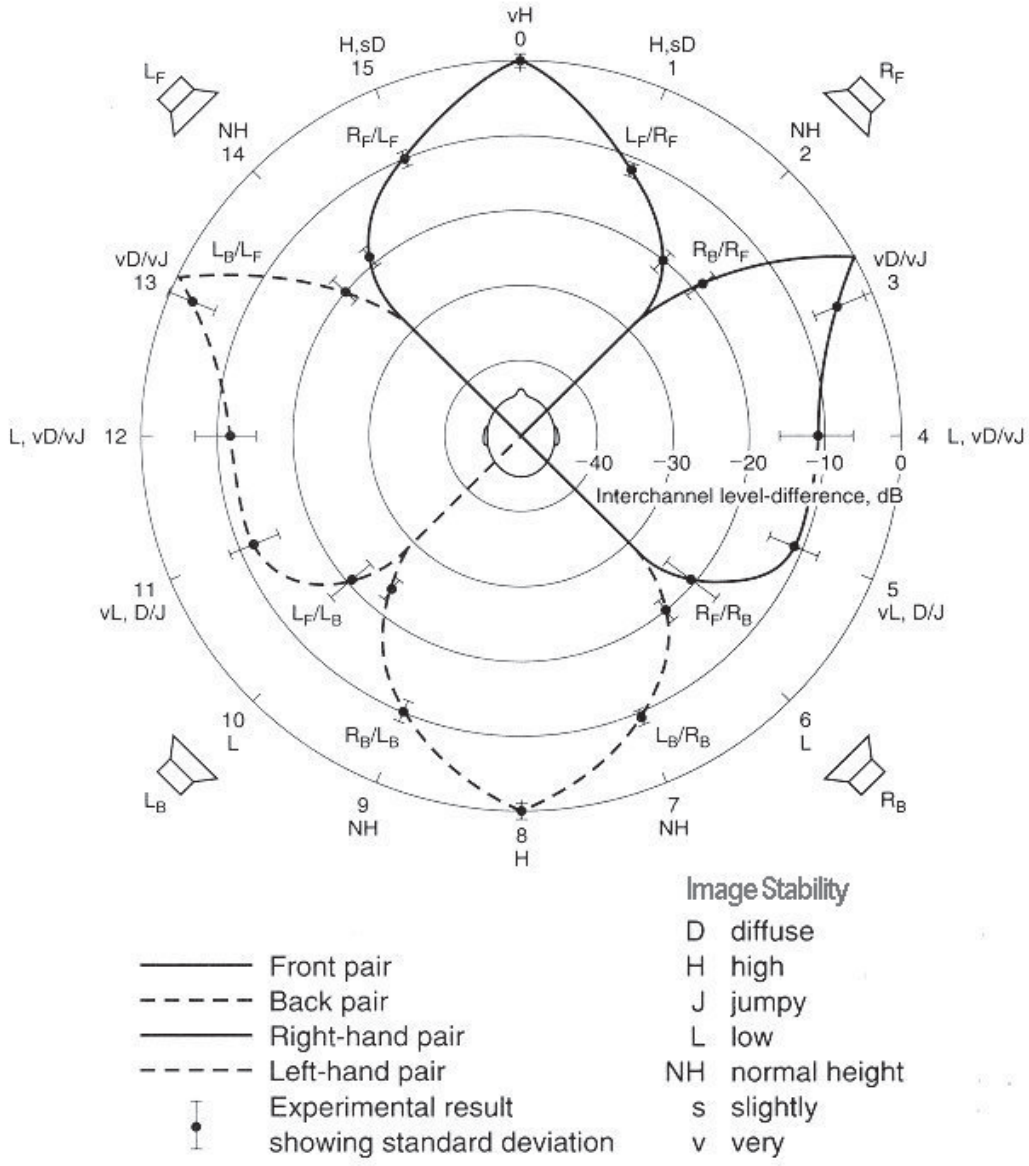
> ...the primary intention for these (surround) channels is for non-localisable ambience and effects information that adds to spatial impression. In the words of the ITU standard: 'it is not required that the side/rear loudspeakers should be capable of prescribed image locations outside the range of the front loudspeakers'. (Rumsey, 127)

However, for most users of surround sound systems, it is the possibility of specific localization at the sides of and behind a listener that most excites them, offering the potential to deliver an aural experience that goes far beyond the limitations of the stereo frontal image. As classical recording engineer Richard King said in a recent edition of *Mix* magazine:

> When you work in surround a lot, your ear gets used to it after a while and you might even think it's not really working. Then you flip it back to stereo and see the dimension you're missing. It's like night and day. (King, 2000, 48)

5.3.1 Accurate Side and Rear Locations

The greatest practical difficulty in using surround loudspeakers lies in this desire for accurate localization at the sides and behind the listener. However, it is difficult to create images where there are no loudspeakers due to a lack of significant interaural differences, leading to poor phantom images and poor image stability. In his book *Spatial Audio*, Francis Rumsey cited research undertaken by Paul Ratcliffe at the BBC in the 1970s to identify localization and image stability for a square, quadraphonic loudspeaker arrangement, which produced this diagram:



Ratliffe, 1974, BBC Research and Development

There are several important points to consider in this diagram. Firstly, the soundfield across the front arc, in this case ±45º, has strong image stability and clear localization with a precise phantom centre and distinct left or right positions at –25db between channels. However, as soon as the location moves beyond the front arc to incorporate the rear loudspeakers on either side, the image stability becomes poor and the perceived position is very different to the panned position. For example, on the left side, when the front and rear loudspeakers have equal amplitude, the perceived position is approximately 67º from front centre, rather than the expected 90º. Interestingly, for the rear arc, there is

clear localization and good stability, very similar to the front arc.

> (Ratliffe) concluded that phantom images based on amplitude differences between side pairs were poorly localised and that sources appeared to jump rapidly from front to back rather than panning smoothly down the sides. This is attributed to the difficulty of creating interaural differences of any significance from differences between loudspeaker pairs to the same sides of the head. (Rumsey, 2001, 33)

5.3.2 Side Panning Inaccuracies

While these measurements were derived from a quadraphonic square arrangement, the findings can be applied within reasonable limits to the ITU 5.1 surround layout. Despite difficulties in smoothly panning along the side arcs, where the large angles make precise localization virtually impossible, what is the practical requirement for such precision in side panning? For many rock recordings, the individual sounds are often mono recordings that are amplitude panned to specific locations in the final mix. Remixing albums into a surround sound format that have previously been released in stereo represents a potential economic bonus for artists and record companies, but does present many challenges. For the producer and engineer, they must decide where instruments and voices will be located, and what acoustic space they will create for those sounds to exist in. This is not without artistic challenges, as engineer Elliot Scheiner explained in an article in *Surround Professional* in July 2000:

> I've got to admit that sometimes I'm a little frightened about where I'm going to pan things and how that's going to alter the mix for the band and the fans. I've been blasted for the work I did on [*Steely Dan* album] *Gaucho* - one critic said that I destroyed that record. (Scheiner, 2000, 30)

In this case, Scheiner placed saxophones and background vocals into the surround loudspeakers only, with some artificial reverberation added to rear and front channels. A listener is very aware that these sounds are coming from the surround loudspeakers, not from positions half way between the front and rear or the rear centre, that is, they are clearly localised at the loudspeaker position. This source perception is probably part of the reason why many fans of Steely Dan were unhappy with the surround mix, as it is very different to the original stereo mix, which had all sources in the front arc.

5.3.3 Loudspeaker Identity and Masking

Other problems that may arise with surround localization include precedence effects collapsing images to the nearest loudspeaker, and the sounds from the front loudspeakers masking rear sounds due to our visual focus reinforcing our forward facing perceptual preference. Also, as we considered for the centre loudspeaker location, if the surround loudspeakers are not properly sited in the home environment, any attempts at specific localization are further doomed to failure. It is for these reasons that many proponents of surround sound consider it essential that there is no attempt at distinct localization beyond a broadening of the front arc to perhaps 120º.

5.3.4 Surround Envelopment

In principle, film surround mixing aims to achieve aural spaciousness by placing ambience information in stereo into the surround loudspeakers with de-correlation between the channels. (Rumsey, 2001, 85) Only sounds that will not draw attention away from the screen will be placed clearly in the surround channels, and only for significant special effects. Many music-only releases are now also using this as a general principle, avoiding specific localization in the rear channels, and using reverberation and ambience to create a spatial impression and acoustic envelopment.

6 Acoustic Envelopment

Let us now move away from specific localization in a surround sound environment to consider how we may create the other two characteristics of an immersive three-dimensional soundfield, namely spatial impression and acoustic envelopment.

A sound rarely exists in isolation, even if it is the only source. There are likely to be surfaces within the space from which the sound will reflect. At each and every reflection, the timbre and loudness of the sound will change, as some energy is absorbed by the surface or partially passes through the surface. Depending on the distances between the source, the listener and any reflective surfaces, we will perceive an aural identity for the room, with characteristics of size, shape and surface materials. Rumsey defined our sense of spatial impression:

> Spaciousness is used most often to describe the sense of open space or ‘room’ in which the subject is located, usually as a result of some sound sources such as musical instruments playing in that space. (Rumsey, 2001, 38)

The complex patterns of reflections will surround and envelop us in a natural soundfield. The aural envelopment we perceive is aided by our ability to localize the original sound source and our ability to

perceive the aural spaciousness with no particular direction.

> Envelopment is a similar term (to spatial impression) and is used to describe the sense of immersivity and involvement in a (reverberant) soundfield, with that sound appearing to come from all around. (Rumsey, 2001, 38)

Human perception of acoustic environments is learned through a lifetime of experience of moving through different spaces and acoustically mapping the auditory characteristics into memory. Plenge identified our ability to perceive acoustic environments, noting that:

> Only a few seconds of listening was sufficient for calibration of a room's acoustic properties, which were stored for as long as the listener stayed in the room, and then cleared immediately upon leaving, so that the listener could recalibrate at once for a new acoustic environment. (Plenge, 1974, 44)

7 Applying the Research

The issue for sound practitioners then becomes how do they apply the principles of localization, spatial impression and envelopment to the task of producing satisfying immersive soundfields? Also, what is the capacity of the 5.1 surround system to deliver these soundfields to a listener in their home environment? There are perhaps three clear schools of thought concerning the extent to which the surround channels should produce clear localization as well as spaciousness and envelopment: classical music reproduction, rock and pop music releases, and sonic art and virtual reality. While it is acknowledged that these areas may overlap or further sub-divide, they will provide an opportunity to analyse three approaches to surround sound recording and reproduction. Rumsey argues that:

> The primary aim of most commercial media production is not true spatial fidelity to some notional original soundfield, although one might wish to create cues that are consistent with those experienced in natural environments. (Rumsey, 19)

7.1 Classical Surround

If there is one characteristic of classical music that remains almost religiously rigid, it is the strict protocol of performing classical music exactly as it was written. Performers spend many years perfecting their craft to play only the notes on the page at the tempo defined, with the differences between good and great performers judged by their skill at interpretation by subtle variations and expressive gestures. Similarly, listeners judge the quality of recordings based on similar subtle differences in acoustic clarity, space and definition. The Western paradigm of performance is well established with performers seated in front of an audience. We do not expect to hear a Beethoven symphony from a chair placed in the centre of the orchestra, and it is unlikely that the majority of classical music listeners would accept a surround sound recording creating this aural perspective. As classical producer Steven Epstein suggested in an article in *Mix* magazine, he doesn't 'want to be in the centre of the orchestra with the brass in the back and the fabric of the ensemble torn apart' (Epstein, 2000, 48). So the conventions of classical music are applied to performers and recordings alike, with most producers only using ambience in the surround channels.

7.2 Rock Surround

The initial interest in releasing music in the 5.1 surround sound format follows McLuhan's proposition that a new medium is used to distribute old content first, before new content emerges. The back catalogue of many music artists is being remixed into the surround format with some consumer success. It is the subject of much debate in music industry magazines concerning the techniques to be applied to the placement of sounds into the three dimensional space and the degree of envelopment that is both appropriate and desirable. Remix engineer Jake Nicely summed up one view on remixing well known albums in a recent article in *Mix* magazine:

> You still have to create a coherent acoustic space, and in the case of a record that a lot of people know and love, you have to be faithful to the original mix to a large degree or it won't sound right to people. You have to be respectful; you can't just have everything all over the place. (Nicely, 2000, 40)

7.3 Sonic Arts and Virtual Reality

Sonic artists have also been at the forefront of experimentation with digital audio technologies, using computer audio software to manipulate sounds in the realisation of their ideas. The advantages of digital audio recorders make them ideal to capture and process quiet natural sounds and aural environments with exceptional transparency and depth. Digital technology allows sonic artists to explore sound in ways that could not be achieved with analogue technology, including dissecting sound into smaller sections and layering sounds together to create unique new sounds. Sonic artists can also design their works using digital technology so that the audience can experiment with sound, creating interactive installations that allow the audience to hear their own unique aural environment.

7.4 Experimentation

The possibilities opened by the immersive qualities of digital surround sound are exactly the type of tools that many composers, musicians and sonic artists are seeking to influence their production process and to expand the sounds and spaces that listeners can perceive. For many years, composers and performers have attempted to create new and interesting environments in a live performance by surrounding an audience with performers or loudspeakers and creating unusual and unique acoustic spaces. Producer Steven Epstein knows of composers who are planning to use digital surround formats to realise spatially on disc what they're achieving in a live situation. (Epstein, 2000, 48) Engineer Jake Nicely is working with musician Bela Fleck to produce an album that sounds 'as if you were standing in the centre of a blue-grass jam session and all the players are around you'. (Nicely, 2000, 38) Producer Chris Steinmetz identifies exactly the different approach taken to digital surround sound by popular music compared to classical music, when he describes 'building the mix from the centre - being inside the soundfield, as opposed to the live situation where they have ambience in the back and are more conservative'. (Steinmetz, 2000, 44)

All these different approaches are valid in the context of exploring new ideas and techniques available with 5.1 surround sound delivery. Classical music production may well represent one end of a spectrum of views on digital surround sound, where the surround format is used to create more clearly the feeling of being immersed in the acoustic environment in which the performance has taken place. Mixing engineer Mick Guzauski recently completed the surround remix for Michael Jackson's Thriller album, well known to many millions of listeners worldwide for hits including Billy Jean and the title track. This was Guzauski's first experience of mixing for 5.1 and when asked for his first impressions, he replied:

> I actually found it easier to do than a stereo mix because you don't have the clutter that can build up just from having to put all the elements into two channels. Also, you could make the individual sounds bigger; you don't have to filter or EQ little portions of the range up or down to make it fit into a smaller soundfield. (Gazauski, 2001, 30)

7.5 Consumer Demand

Many listeners are purchasing the home theatre systems required for surround sound reproduction, are discovering that the new soundfield is exciting to listen to and are demanding more material be available. They may currently be prepared to pay a premium above normal stereo CD prices for the new format, but they are now more discerning about the quality of the technology. They can hear the envelopment of the three dimensional soundfield more clearly, and can hear every little nuance of every instrument. Producer Chris Steinmetz has a focus on where the technology is leading:

> But when the new generation gets in tune with this new format, they're so technically savvy they're not going to be worried about it, [new mixes of old favourites]. … Part of what's happening now is a generational switchover: some people who are used to having things in stereo don't want to hear 5.1. But there are a lot of young people who love the home theatre experience and they're dying to hear more in surround. (Steinmetz, 2000, 46)

7.6 Set-up Issues

Over reliance on the centre channel can cause reproduction problems when a home surround set-up uses poor quality loudspeakers or incorrect positions. If the lead vocal of a rock recording is mixed to the centre channel only, replay could become a 'karaoke' version with no lead vocal, or the vocal could be too loud or severely coloured through a low quality loudspeaker. Current consensus among audio producers from the pages of various industry magazines[2] tends to favour traditional left-right phantom imaging with reduced amplitude centre reinforcement, usually only for sources that are centre panned like lead vocals, bass guitar and snare and bass drum.

7.7 Adding Width and Height

Recording company Chesky has been experimenting with a completely different approach. They believe that the centre and Low Frequency Effects channels are redundant in an ITU 5.1 system used for music only reproduction, and have instead repositioned the centre and LFE loudspeakers at ±55º increasing the real width of the soundstage.[3] In their recordings, they have captured acoustic reflections from these directions and reproduced it in the listening environment, with critical acclaim. This represents a departure from the ITU specification that may be difficult for many home listeners to implement physically, since it requires more amplifier channels and more loudspeakers. Chesky's discs must also be clearly labelled so that consumers are not misled with incompatible product. Holman has also proposed delivering extra width and also height information, as the next development in aural immersion, but his 10.2

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[2] Magazines include *Mix*, *Audio Technology, Surround Professional* and *EQ*, see bibliography for details.

[3] For more information on Chesky recordings see www.chesky.com

system involves using ten channels for surround and height loudspeakers with two LFE sub-woofers, which is undeliverable using current technology. (Holman, 2000, 232) However, the idea of adding height information to enhance the horizontal dimension of 5.1 surround could be very exciting to sonic artists in particular, who are always seeking new opportunities to explore.

8 Conclusion

While deviations from the ITU specification for loudspeaker locations may be rich avenues for exploration, the focus of this paper has been on the possibilities offered by the original format. It is clear that there are many reasons why the chosen loudspeaker layout is not ideal for true aural immersion, with particular problems in the side and rear listening arcs. However, it is also very clear that there is now an audio standard that has been adopted by equipment manufacturers and embraced by consumers that has enormous potential to deliver an immersive and exciting aural experience. New delivery platforms including the Super Audio CD (SACD) and DVD-Audio offer improved audio quality for multi-channel reproduction. Software 5.1 encoders for DTS and Dolby Digital AC-3 are available for many music recording programs and as stand alone products. While there may be limitations, this should not deter audio practitioners from exploring the opportunities available today to expand listener's appreciation of the aural environment. And as composer David Worrall remarked recently on an email list:

> For example, once one has achieved sounds whizzing around in 3D, what else is there to do with surround, compositionally speaking? The answer is: many things, beautiful, profound and delicate. (Worrall, 2001)

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