Exploration of the Height Dimension in Audio Reproduction

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Abstract
Multi-channel surround sound audio with added height loudspeakers offers a richer perceptual experience than traditional stereo or 5.1 reproduction, recreating truly three-dimensional aural soundfields. Based on human auditory perception, surround sound technology may assist the exploration of acoustic space as an expressive dimension.

1 Introduction

There is growing interest among composers, audio designers and music recording companies to use height loudspeakers to increase the sonic possibilities for audio reproduction, including enhanced realism of spatial location, spatial envelopment and improved sound stage detail. Music recording company MDG from Germany are releasing DVD-Audio discs with height information, and note:

> The reflections of even the subtlest sounds from the ceiling and floor will reliably tell us how large a room we are in. (MDG, 2001, 8)

Widespread acceptance of the ITU-R BS.775-1 specification for five loudspeakers mounted on the horizontal plane plus a low frequency enhancement loudspeaker has seen the growth of home theatre systems incorporating DVD-Video and 5.1 surround sound. The introduction and growing adoption of the new commercial formats of DVD-Audio and SACD[1] now offer the ability to deliver audio recordings in uncompressed, high-resolution multi-channel formats. This paper proposes an extension of the 5.1 standard to include two full-range loudspeakers mounted above the listening position. Acoustic perception studies underpin this proposition and there are examples of elevated sources, recording techniques, delivery formats and commercial applications.

1.1 Binaural Discrimination

Blauert [6] described the head-related system of spherical co-ordinates using the horizontal plane, frontal plane and median plane, with angles of incidence for azimuth and elevation, Figure 1. For the horizontal plane, numerous studies have investigated the perceptual relationship between inter-channel differences, phantom image locations and panning law accuracy, including [12] [16] [27]. Sound source localization in the horizontal plane and the frontal plane primarily relies on binaural discrimination due to inter-aural amplitude, inter-aural time and inter-aural spectral differences, with the exception of the median plane where inter-aural differences are zero for a normal listener. Research into localization in the median plane, [5] [6] [21], concluded that three requisites were necessary for an auditory stimulus to be accurately located in a vertical space: (a) the sound must be complex, (b) the complex sound must include frequencies above 7000 Hz, and (c) the pinna must be present. Our ability to localize sound sources on the median plane relies primarily on pinna effects. According to Blauert [5][6] and others, the curves and ridges within the pinna reflect different frequencies depending on source elevation.

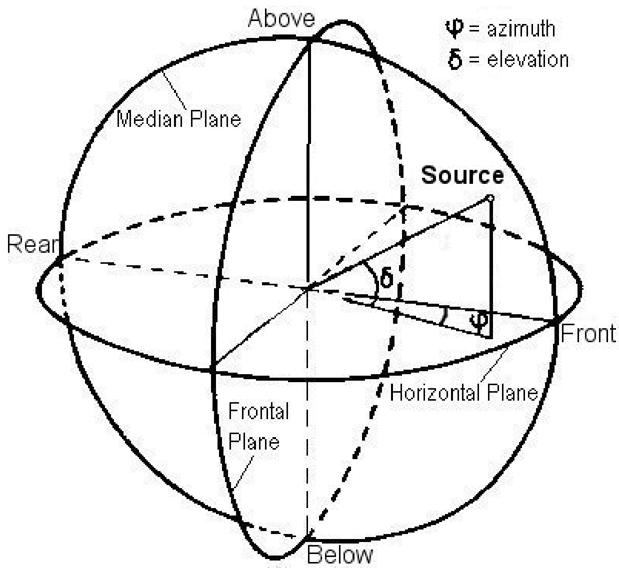

Figure 1: Three-dimensional planes (after Blauert)

2 Aural Perception of Elevated Sources

The author conducted a series of experiments, reported at an AES conference [3], investigating aural perception of phantom images in the vertical hemisphere generated by two loudspeakers using inter-channel amplitude differences. The key findings of these experiments are illustrative to further discussion of the exploration of height in reproduction. Using a custom built metal frame, two carefully matched loudspeakers were placed at different locations above and around the listening subjects. A short soundtrack consisting of male speech and reference pink noise was played and subjects indicated where they perceived the sound source to be. Results for each pair of loudspeakers

[1] Super Audio Compact Disc

show the median location for the perceived source and the deviation among the subjects tested. Where the deviation is large, it indicates a significant difficulty in accurately locating the source, referred to as localization blur. While more positions were tested than are presented here, following are the key results.

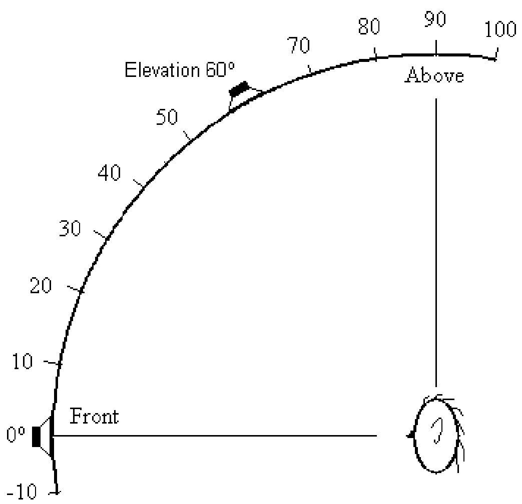

Figure 2: Loudspeaker locations for median plane test: 0°- 60°

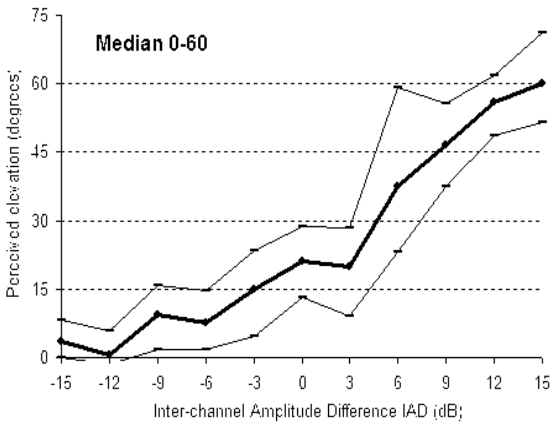

Figure 3: **Median Plane 0°- 60°**:
median and standard deviation

For phantom images on the median plane with loudspeakers at 0° and 60°, Figure 3, the median of perceived locations was weighted towards the 0° elevation loudspeaker until the inter-channel differences were above the mid point, with wider deviations in the middle positions indicating a significant localization blur.

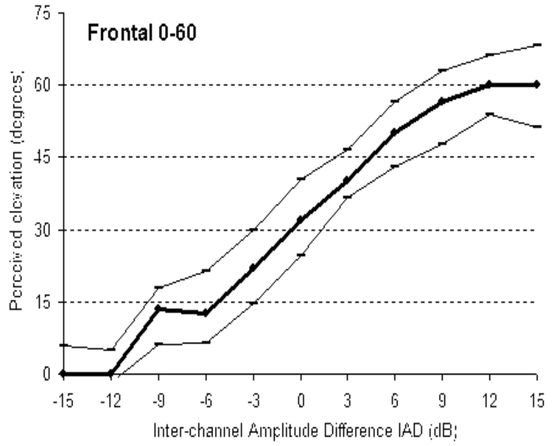

Figure 4: **Frontal Plane 0°- 60°**:
median and standard deviation

However, for the frontal plane, Figure 4, the results were more evenly spread across the range of inter-channel differences, with a consistently smaller localization blur than for the median plane. In discussions with subjects, there was still a blur for the frontal plane but there was greater confidence in perception than for the median plane.

Figures 5 and 6 show results for tests with the loudspeakers mounted at 60° and 120° above the subjects, measured on the median and the frontal planes.

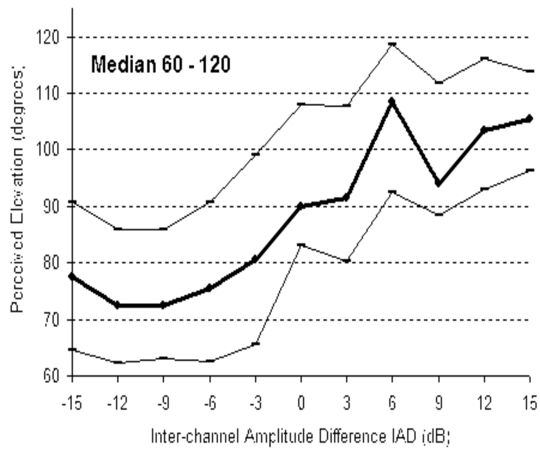

Figure 5: **Median Plane 60°- 120°**:
median and standard deviation

For inter-channel amplitude differences on the median plane, Figure 5, the ability to perceive locations is very poor, with significant inaccuracy in median locations and significant localization blur. It could be concluded that the effects of the pinna are breaking down at these elevations.

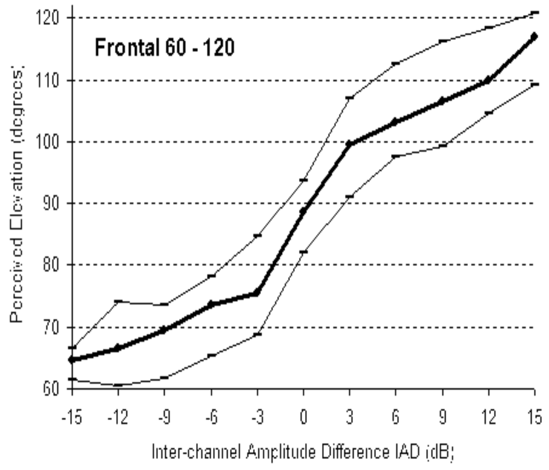

Figure 6: **Frontal Plane 60°- 120°**:
median and standard deviation

However, in the frontal plane, Figure 6, median locations correspond well with inter-channel differences and standard deviations are relatively small. This result would be consistent with inter-aural differences playing a large part in location, as the angle between the loudspeakers is equivalent to the 60° angle subtended by the horizontal stereo loudspeaker locations. However, the degree of localization blur for the vertically mounted pair is greater than for a horizontal stereo pair, according to the results published in [12], [16] and elsewhere.

Comparing front and overhead median plane perception, the front arc has a higher degree of accuracy in the perceived elevation and less localization blur. This difference between front and overhead localization on the median plane is consistent with pinna effects, where sounds from the front are reflected from the pinna into the ear canal whereas sounds from above and behind are not well reflected.

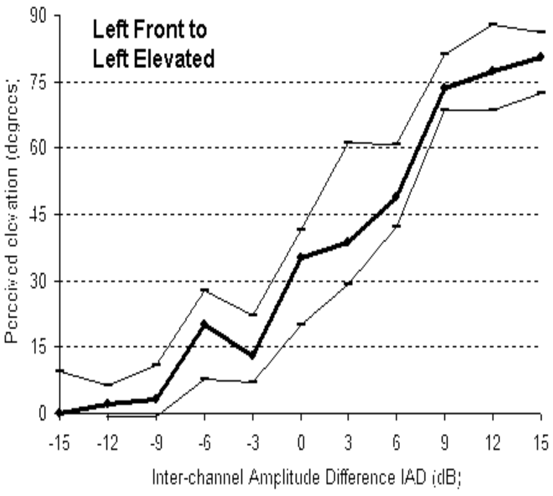

Figure 7: **Left Front to Left Elevated:**
(azimuth 90° elevation 60°)
median and standard deviation

Figure 7 presents the results for loudspeakers mounted at Left Front (azimuth 30° elevation 0°) and Left Elevated (azimuth 90° elevation 60°), showing there is a good degree of accuracy in perceived locations, though with some localization blur.

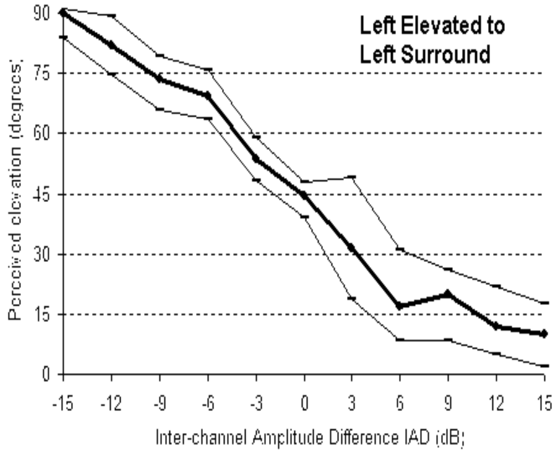

Figure 8: **Left Elevated to Left Surround:**
median and standard deviation

Figure 8 shows elevation perception behind the listener from the Left Elevated loudspeaker down to the Left Surround position. Similar to the front elevation perception of Figure 7, there is accurate median locations with localization blur increasing as the phantom image moves to the rear.

It was clear from the experiments conducted that localization on the median plane is poor for phantom images generated by two loudspeakers, with inaccurate median locations and significant localization blur. Further, for sources above the subject on the median plane the results were particularly poor. This suggests that a single loudspeaker placed on the median plane and used for height enhancement would be of little benefit for vertical localization.

Localization of phantom images was consistently better on the frontal plane than for the median plane. As the angle of elevation for the height loudspeaker increased, the accuracy of localization on the frontal plane improved and the localization blur decreased. This is consistent with the increasing influence of inter-aural differences as the angle of elevation increased. Also, accuracy of localization ‘across the top’, from 60°-120°, reflects similar results to the standard horizontal stereo positions. As a consequence, it is proposed that two loudspeakers be mounted on the frontal plane, azimuth 90°, evenly spaced either side of the median plane, elevation 60°, to generate effective localization and height envelopment.

3 An Acoustic Audit of Height

In our everyday environment, there are many sound sources with a significant angle of elevation. The author has been conducting detailed listening to establish an inventory of real sounds with elevation characteristics, based on Acoustic Ecology principles articulated by Truax [28], Schaffer [23] and others. When specifically considering elevated sound sources, there are natural environments like open fields, forests, caves and seascapes, and constructed environments including city and suburban streets, under bridges, inside buildings and underground tunnels and trains. Within each environment, there are natural elevated sources like wind effects, flora and fauna, and technology sources like flying machines, tall ground-based objects, ceiling mounted loudspeakers and many more. Also important in the context of this paper are the acoustic reflections from the upper reaches of halls, cathedrals and concert venues where aural events are experienced and recorded. An extensive listing of elevated sound sources is beyond the scope of this paper, but a few common examples in Table 1 will illustrate key characteristics.

Elevated sound sources in the Open:
Aeroplanes:
very high: low frequency spectrum drone, slow and small Doppler shift, sound well behind visual position, some localization blur
low, barely above roofline, eg helicopter: high frequencies clear, sharp transients, rapid and wide Doppler shift, distance effects of amplitude and frequency spectrum very clear, precise localization
Birds:
unusual to be high, eg crows: low frequency spectrum of calls, slow change in position and sound
flying low: aurally appear and disappear very quickly, rapid Doppler shift, wing flapping heard when very close, precise localization
stationary in trees: bright spectrum of calls, precise localization
Inside buildings:
footfall above and floor creaking: low frequency spectrum, poor localization
fluids in utility pipes: low frequency spectrum, possible localization
rain on the roof: dull, muffled sound, no specific location
Performance venues:
direct sound from high galleries at the side, front or rear: clear full spectrum, precise localization
acoustic reflections: amplitude and frequency spectrum highly variable, imprecise localization, distinct echoes occasionally heard

Table 1: characteristics of elevated sound sources

Key factors identified in locating elevated sources in everyday environments are fundamentally the same as for ground based or horizontal sources. These include HRTF effects of inter-aural time, inter-aural amplitude and inter-aural spectral differences along with torso influences, distance effects of amplitude, spectral changes and the direct to reverberation ratio, and motion effects of Doppler pitch shifts, amplitude and spectral changes. The principle additional factor utilized for elevation perception is pinna effects. As identified by the experimental tests described above, when an elevated source lies on the median plane and would present difficulties in accurate location, a listener would further interrogate the auditory scene for additional information to resolve the location, for example, head turning.

4 Architectural parameters

To consider spatial enhancement as a starting point for incorporating height loudspeakers, it is useful to look at architectural parameters that are indicators of high quality acoustic environments for music performances. In his book, *Concert and Opera Halls: How They Sound*, [4], Beranek analysed the objective acoustic characteristics and the subjective critical acclaim of many venues throughout the world. He conducted a detailed survey of musicians, conductors and critics worldwide to develop a scale for the assessment of the quality of performance spaces. Key questions included assessments of spaciousness, clarity, reverberation warmth and character, and acoustic support for the performer. Simultaneously, he conducted testing of the venues to determine physical measurements of key acoustic properties.

4.1 IACC

One important measurement in performance venues is the Inter-aural Cross Correlation coefficient, IACC, which measures the difference in reflection patterns from either side of a hall. In his book *Concert Hall Acoustics*, Ando [1] suggests that ‘all the available data indicates a negative correlation between the magnitude of IACC and subjective preference.’ (Ando, 1985, 77) This implies that a hall that has the greatest difference in architectural features between each side sounds most pleasing. Ando goes on to explain:

> Strong reflections from the ceiling and rear walls will increase IACC. But simply to absorb this is inadequate because we also need a sufficiently generous sound energy supply for the seats in the rear half of the hall. For this purpose, Schroeder proposed a highly diffusing ceiling to reflect most of the sound energy to the side walls, so that it would arrive at the listeners from a suitable direction for minimizing IACC. (Ando, 1985, 90)

Through careful consideration of the subjective assessments and objective measurements, Beranek established six orthogonal acoustic parameters and the range of variation of those parameters for the best venues in the world, acknowledging that the range of each variable was dependent on the style of music performed, for example, Baroque, Romantic, Modern or Opera. The percentage weighting indicates Beranek's assessment of the relative importance of each parameter.

Apparent Source Width (1-IACC)
prefer approx 0.7-0.9, 25% weighting
Early decay time: reverb to –10dB
0.3 – 0.4 seconds, 25% weighting
Surface Diffusion Index
0.9, aided by irregular surfaces, 15% weighting
Strength G for mid frequencies: 500-2000Hz
5dB louder than anechoic conditions, 15% weighting
Initial time delay to first reflection
Best at about 20ms, 10% weighting
Bass ratio: reverb time for 125-250Hz compared to 500-1000Hz
approx 1.2, 10% weighting

Table 2: Beranek's six parameters for acoustic excellence

In addition, Beranek suggested that there should be very little high frequency absorption in the hall, to aid brilliance in the sound, that the most important lateral reflections occur between 35°-75° from the front centre, and that any overhead reflections will add texture, especially when lateral reflections are low.

4.2 Early Reflections

By considering these parameters when composing or mixing for height, it is possible to make some important decisions that will influence the experience of a listener. If we wish to add the height dimension to a stereo or 5.1 recording, we need to consider the material being produced. If there is some reverberation already added to the recording, either from the performance venue or from electronic manipulation in a studio, it would not be desirable to add more reverberation from height channels. Since a listener in a venue is primarily hearing early reflections from above, we could process the recording through an 'early reflection generator' in post-production for reproduction through the height channels. By careful selection of the initial time delay and early reflection patterns, with no additional reverberation, a very realistic impression of height is achieved. Convolution using impulse responses recorded from vertical directions in different venues would also deliver realistic height impressions.

4.3 Multiple Processors

When manipulating electronic sources for reproduction through height loudspeakers, the principles applied to horizontal reproduction would also apply. For example, realistic early reflection patterns and reverberation can be created electronically using multiple stereo processors, one for each of front, surround and height, or even a mono unit for each loudspeaker position. Multiple units would allow different parameters for initial delay, early reflections and reverb time to be set for each dimension, and also allow greater de-correlation of the reflections, which would decrease IACC. No matter where in space the source may be positioned, the reflection patterns and reverb characteristics could track position and motion adding realistic spatial enhancement.

5 Three Dimensional Soundfield Recording and Reproduction

Recording natural sounds or performances for reproduction with height requires careful selection of microphones and their placement. There are numerous microphone techniques devised and tested for recording aural events for transmission by stereo or multi-channel formats, described in books, magazines, on websites and in conference proceedings, for example, Holman [13]. Depending on the taste of the producer and recording engineer, some incorporate coincident positioning of microphone capsules while others prefer spaced arrangements. For multi-channel recording incorporating surround information, there are additional microphones added to the stereo arrangements to capture spatial ambient information from the performance environment.

5.1 Critical Distance

A significant factor in venue recordings is the critical distance from the source, the distance at which the direct source amplitude matches the reverberant amplitude. Beyond this distance, any ability to specifically locate a sound source becomes virtually impossible, due to non-directional reverberation overwhelming the direct source information. Consequently, most multi-channel music recordings require some microphones to be relatively close to the source for reproduction through the front channels, allowing a listener to locate sources in the reproduced soundfield. Microphones positioned to record spatial envelopment are placed further from the source, carefully positioned to capture the characteristics of the environment for reproduction through the surround loudspeakers. However, most current techniques are predicated on capturing the horizontal soundfield, to be reproduced through a horizontal only loudspeaker system.

5.1 B-format

The Soundfield microphone [24] uses four microphone capsules arranged as a tetrahedron to capture the full three-dimensional soundfield at that point. After electronic manipulation in the unit's preamplifier, four audio signals are produced, equivalent to three bi-directional microphones and one omni-directional microphone. Known as the B-format signal, these four signals are referred to as W (omni-directional), X (front-rear horizontal), Y (left-right horizontal) and Z (up-down). After recording, the B-format signals can be sent to loudspeakers using the angles of azimuth and elevation to determine the corresponding amounts of X, Y, and Z. For example, if eight loudspeakers are positioned at the corners of a cube, each would receive equal amounts of W, X, Y, and Z but with different polarity depending on their location, eg front is +X, rear is –X, etc.. (For a more detailed consideration of the Soundfield microphone and its uses visit the Ambisonics website [2]).

5.2 Irregular Arrays

In this way, a soundfield can be reconstructed with great clarity, though the number of loudspeakers required is large, with the cube example considered to be the minimum necessary. Important to this paper's focus, the loudspeaker array should be regular, with each loudspeaker matched by another in the opposite position measured through the listening position. Irregular arrays like the ITU 5.1 standard are not well suited to B-format reconstruction, though one solution has been published as the Vienna coordinates, or G-format, described by audio researcher Angelo Farina [10] in a private email and described below in section 6.1. While the Soundfield microphone does measure spatial information accurately, it is not well liked by many recording engineers because of its susceptibility to critical distance compromises. If it is close enough to accurately record the direct signal, it is not in the ideal position to record the ambient field. Consequently, recording engineers are supplementing a Soundfield microphone with either close microphones to enhance the direct sound, or distant microphones to capture the ambient sound.

5.3 Height Information

The Soundfield microphone captures height information, though critical distance problems also apply in this dimension. While the Soundfield microphone simulates bi-directional responses, the off-axis null is only approximately -15dB. If the microphone is placed near the source, the loud direct sound will dominate the quiet reflected sounds from above. To overcome this imbalance, engineers are experimenting with spaced microphones placed in front of and above the performers to capture the height information, using cardioid or shotgun microphones pointed away from the source. For environmental recordings, the Soundfield microphone is excellent for capturing the three-dimensional soundfield, and is particularly successful for reconstructing motion perception of a moving sound source. A major difficulty highlighted by some users is a relatively loud noise floor, which interferes with quiet sounds.

6 Panning laws

Moving mono sources around the three-dimensional acoustic space created with height loudspeakers requires careful control of the amplitude and polarity sent to each loudspeaker. Investigations by Craven [8] into the psycho-acoustic relationship of sounds panned between adjacent loudspeakers pairs suggests that pair-wise amplitude panning should be replaced by panning laws which take account of psycho-acoustic principles. In essence, this requires that sounds panned to one loudspeaker should have a small amount of inverted polarity in the opposite channel. If applied to stereo loudspeakers, a sound panned fully to the right at 0dB would be about –14dB inverted in the left channel. Experienced listeners will immediately recognise this phenomenon as enhanced width, with the phantom image appearing further to the right than the right loudspeaker. When applied to multi-channel applications, particularly with B-format recordings, there is enhanced localization throughout the 3D soundfield.

6.1 Enhanced Height Perception

This principle may also be applied to B-format recordings replayed through an ITU 5.1 system. As suggested by Farina [10], rather than assigning the W, X, Y and Z signals to their 'true' loudspeaker locations, for example, using the 30° settings for the left front loudspeaker, Farina suggested that 45° settings be used to enhance the perceived width. Similarly, for the surround loudspeakers located at 110°, the W, X, Y and Z settings for 135° should be used. This also increases the 'opposing' loudspeaker characteristics inherent in true B-format reproduction. For the height loudspeakers located at azimuth 90°, elevation 60°, it was suggested by Farina to use the true B-format signal settings for the Z signal, but to add a small component of –Z to the five horizontal loudspeakers, for example, elevation down 30°, to enhance the perception of height. After experimental investigation by the author, it is agreed that using these settings, the soundfield is enhanced and localization improved for recordings made with the Soundfield microphone. While these psycho-acoustic panning laws are difficult to implement in hardware mixing consoles, researchers are developing panners as VST plug-ins for implementation in audio software programs, see the Ambisonics website [29].

6.2 Dual joystick spatializer

To further explore composing and mixing for height reproduction, the author has designed a dual joystick panner capable of sending a mono sound to any of six outputs. The configuration is matched to the author's preferred height loudspeaker positions of azimuth 90°, elevation 60°. It is currently an analogue device using six VCA's and control voltages produced by the two joysticks. The left joystick moves the sound around the four horizontal loudspeakers while the right joystick uses up-down movement to move the sound between the horizontal and the height loudspeakers, and the left-right movement to move between the two height loudspeakers. Using these two joysticks allows the producer or performer to play with the location of the sound throughout the spatial environment created by the six loudspeakers, and has proved to be fun to play with! Currently, the performance module has two sets of panners, four joysticks in total, and has proved useful for diffusion of stereo recordings. Future refinements could include using a Dumb Controller (after Fraiette [11]) to convert the control voltages to MIDI signals and interfacing it with software for more sophisticated movement, for example, multi-dimensional manipulation like matching the complex changes in the spectral patterns of a moving source, or adding more reverb as the height increases.

7 DVD-Audio and SACD delivery

For a reproduction system incorporating height loudspeakers to be commercially successful, there must be a readily available delivery format capable of carrying sufficient discrete channels of audio information to allow reconstruction of the three-dimensional soundfield. Two new delivery formats have been introduced in recent years, DVD-Audio and SACD, and both are capable of carrying six channels of high-resolution uncompressed audio. DVD-Audio is an extension of the DVD specification first made commercially successful with the DVD-Video application. While DVD-Video uses Dolby Digital AC-3 or DTS compression to deliver 5.1 audio, DVD-Audio uses virtually the entire bandwidth of the medium to carry multi-channel audio, based on PCM[2] recording technology. To deliver 24bit, 96kHz for six channels, DVD-Audio uses MLP[3] lossless compression [19], which is bit accurate on playback. Many music releases recorded specifically for this medium are using the six channels for 5.1 recordings, designed to be heard over home theatre systems. DVD-Audio also carries images, often song lyrics, band or recording information, as there is not sufficient bandwidth in the data transfer rates available for simultaneous video. Most DVD-Audio discs are dual layer, with the alternate layer carrying DVD-Video with AC-3 or DTS compressed 5.1 audio.

7.1 Universal Players

SACD is a competing format to DVD-Audio, using a different data recording technology, DSD or Direct Stream Digital, and is also capable of delivering six channels of high-resolution audio, equivalent to 24bit, 96kHz. SACD is also a dual layer disc, with the alternate layer carrying a stereo recording compatible with standard CD players. There is a limited capacity for images, but no video, and most SACD commercial releases are 5.1 recordings. While there is slow consumer adoption of either format and few releases available locally, the potential problem of two competing formats is being addressed by the latest generation of multi-format or universal players, capable of playing DVD-Audio and DVD-Video, SACD, standard CD and mp3 CD. Also, Minnetonka have released their Bronze authoring software for DVD-Audio at a realistic price of $US99, [18]. While this version does not allow access to the full potential of high-resolution audio using MLP, it is possible to burn discs with six channels of uncompressed 24bit, 48kHz resolution. As a consequence, it is possible for composers to use the DVD-Audio medium to deliver their compositions to listeners using up to six channels of standard-resolution audio.

8 Commercial releases

Several music recording companies are keen to explore height reproduction on their commercial releases, and have made important decisions concerning the format of their releases. After much discussion in trade forums, there is general agreement that music recordings do not require the centre channel or the LFE channel, both essential for cinema releases on DVD-Video. It is considered that a dedicated dialogue channel is not a critical requirement for music recordings, as the centre channel information is adequately reproduced as a phantom image created by equal left and right channels. Also, as most music listening will take place using full range loudspeakers, there is no need for the LFE channel to carry bass enhancement. Therefore, there are now two spare, high-resolution channels available for other information. These channels are being utilized for height information, with the method used for recording and reproduction varying between different companies.

MDG [www.mdg.de [17] have released music with the description '2+2+2', referring to front, surround and height, and suggest that:

> Three-dimensional portrayal of sound is thus an important step forward and in fact is an absolute prerequisite in the quest for natural music reproduction at home. (MDG, 2001, 8)

They have recorded music in a variety of venues using extra, dedicated microphones to capture height information. Their playback recommendations are for the front and surround

[2] Pulse Code Modulation
[3] Meridien Lossless Packing

loudspeakers to conform to the ITU 5.1 positions, and the height loudspeakers to be positioned directly above the front left and right loudspeakers, at azimuth 30°, elevation 30°. While this is not a large offset for the height loudspeakers, in auditioning MDG releases, the author's opinion is that there is an added level of spatial enhancement beyond the horizontal 5.1 system, particularly noticeable on recordings where the performance has been staged with risers for back sections of the orchestra and a choir behind and above the orchestra. And MDG believe:

> the listener.…enjoys an amazing sense of three-dimensional space and a logical, natural and stable sonic portrayal of instruments from almost all points within (and to some extent even outside) the area delineated by the speakers. (MDG, 2001, 9

Telarc [26] have released music with several different configurations for height reproduction. From information on their website, Telarc suggest that the height loudspeakers should be mounted on the side walls as close to the ceiling as possible, at the positions azimuth 90°, elevation approximately 45°. They also are uncommitted whether these height loudspeakers should be direct radiators, pointed at the listening position, or dipole radiators pointing front-rear. Auditioning several of their releases, it became clear they are not consistent with their production techniques. On one release, the height channels, formerly centre and LFE, were recorded as a stereo pair, with consistent imaging between the height loudspeakers. This recording reproduced beautifully on direct radiator height loudspeakers positioned as directed, adding a wonderful sense of spaciousness and envelopment to the recording. On another release, the centre channel carried substantially more reverberation than the LFE channel, and the combination of the pair did not appear to have a stable stereo image. This did not reproduce well on the height loudspeakers, with an imbalance due to clarity and direct/reverb differences.

9 Conclusion

The proposal for positioning full-range height loudspeakers on the frontal plane, either side of the median plane is supported by experimental investigation of acoustic perception. Architectural parameters that are indicators of high quality acoustic environments provide guidance for constructing three-dimensional acoustic spaces that will provide satisfying spatial envelopment and sound stage detail. Microphones and recording techniques provide excellent means to capture aural events for reconstruction through a sound system incorporating height loudspeakers. Investigations into psycho-acoustic based panning laws will assist in achieving realism in placing and moving sound sources throughout the acoustic space, and a joystick design provides a manual interface with the reproduction system. New delivery formats provide media for commercially releasing recordings and are already providing an opportunity to audition music recorded with height. Recordings and compositions by the author using height loudspeakers have created some enjoyable results for listeners when sounds are clearly located and/or are moving overhead. Also, different early reflection patterns and de-correlated reverberation from each height and surround loudspeaker provided the greatest perception of spatial envelopment. These results suggest that there would be significant interest among musicians and listeners for exploration of the height dimension in reproduction.

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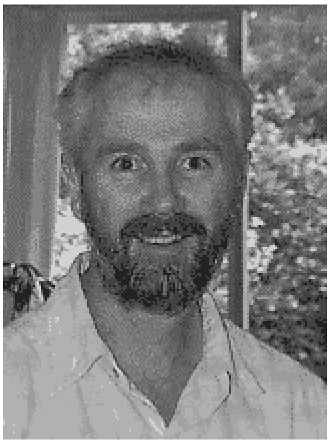

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Jim has extensive experience working in the audio industry in Australia and overseas, with more than twenty years as a music producer and recording engineer and many years as a production manager in commercial radio. After Electrical Engineering studies at Adelaide University in South Australia, Jim worked overseas and in Australia in recording studios and conservatories of music, producing audio for CD, vinyl, radio, film and television releases and is active in music performances and recordings. Credits include recording engineer for Men at Work's 'Business As Usual', Sound Supervisor for the Australian Opera, film music awards and advertising awards for radio production. Jim has designed and delivered training programs at Swinburne University of Technology in Radio and Multimedia. Jim is a member of the Audio Engineering Society, the Australian Forum for Acoustic Ecology and the Australasian Computer Music Association, and holds a Master of Communications and a Graduate Diploma of Education in Information and Communications Technology.