The Implementation Of Ambisonics For Restoring Quadraphonic Recordings

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0. Introduction

0.1 Project Introduction

Over the decades, scientists have continuously tried to invent methods and produce equipment that would allow for the capturing and playback of sound. From the early days of the gramophone, they have strived to improve the quality, expand the mediums' storage, and improve music distribution. All of those goals have been met and will continue to have their expectations raised, but there has been one feature of audio technology, which still needs to be resolved. The feature is the ability to accurately reproduce the captured sound in another location but still allowing the listener to experience the recording's original sense of space and atmosphere identically.

From the early days of Mono, to the improved Stereo, unsuccessful Quad, currently popular 5.1, to the even larger and more complicated cinema surround sound systems, the aim has been to provide sound playback that would be able to emerge as coming horizontally all around the listener. Ever since the time of Quad where four or more loudspeakers were placed around the listener, surround sound was very much a reality, often having impressive results, but unfortunately those results were rarely the desired ones. For reasons that are explained in this thesis, all the above mentioned audio reproduction systems lack the ability to accurately reproduce a recorded sound-field.

As early as the 1970s when Quad was introduced, another sound reproduction technology was invented, providing what its creators and enthusiasts would explain with far superior capabilities, even compared to systems available presently. The technology titled Ambisonics, is by some considered to be the most powerful soundfield reproduction technology, making the majority of other systems seem 'primitive'. Detailed information and the history of Ambisonics is covered in this thesis.

Recording studios, audio engineers, and other companies have been offering services for restoring Quad recordings, making them compatible with the present surround sound technologies. The recordings are transferred onto new mediums such as DVD, allowing consumers to enjoy their favourite Quad recordings without using the outdated technologies of Quad such as the turntable.

Richard Elen, one of the original members of the team that created Ambisonics has suggested that Quad recordings can be converted into Ambisonics. This conversion he states can improve the experience of Quad, thereby correcting some of the faults that caused Quad to fail as a commercial system.

This project intends to experiment and test whether Richard Elen's theory is correct. Quadraphonic material will be converted into Ambisonics. The two systems will be compared by data collected from a group of people who rank each system on criteria that is explained later on.

If the process proves to improve the Quad material, it could then be advantageous to those who have their Quad records transferred onto new mediums like DVDs. If this theory proves to be correct and beneficial, it may in turn be made available to those studios and individuals who offer recording mediums transferring services.

0.2 Order Of Presentation

Chapter one focuses on background information and history of the relevant technologies that are dealt within this thesis. The technologies are Quad and Ambisonics, covering their history, technical information, capabilities, and market success. While discussing these two surround sound formats, simple principles of human hearing are explained in order to indicate what factors resulted in the success or failure of these systems. The chapter is followed by making reference to an expert audio engineer's statement suggesting that Quad records can be restored and improved by converting them into Ambisonics. Testing if the proposed conversion can improve old Quad material is stated as the main objective of the project. The Chapter is then followed by an overview of the selected research methods that will be used to test the conversion's results. The chapter ends with a summary and conclusions of the entire chapter.

Chapter two covers every step of the preparation for the experiment. It discusses the creation and trial of the pilot questioner, the corrections to the pilot questioner, the collection of the Quad material, conversion of the Quad material into Ambisonics, and any additional editing. Furthermore there is discussion regarding the selection of loudspeakers used for the experiment, the location of the experiment and any additional preparations. The chapter ends with a summary and conclusions of the entire second chapter.

Chapter three focuses on the data collected from the experiment and how it was compiled and formulated. Graphs generated by the data are used to visually demonstrate the results of the experiment, and in depth analysis is used to explain the results and the possible reasons for those results. The section ends with a summary and conclusion of the chapter.

Chapter four discusses the overall success of the project's steps and processes. Critical analysis into whether the appropriate research methods were chosen for the project, and whether they were carried out with careful pre-planning in order to prevent inaccurate results will be covered. The second part of this chapter will discuss and summarize the results of the experiment, considering also the results and thinking of explanations as to the reasons for the results. Proposed areas for further research and related recommended studies will be covered before the chapter is concluded with a summary and conclusions about the entire research project.

Chapter five is the glossary containing terms of a technical nature that may be beyond the knowledge of the average reader. Such terms include acronyms, and abbreviations.

The following five chapters include a bibliography list, reference list, electronic reference list, and a list of other sources used for the completion of the thesis.

The last two chapters include the acknowledgments, and the appendices section.

0.3 Key Terminology

Loudness: The human perception of sound intensity.

Localization: The action of sensing the origin and direction of sound.

Pan/Panned/Panning: Shifting a sound within a speaker array. Placing a sound so as to appear to come from a desired position in the listening area. Example, panning a sound to appear as moving from the left loudspeaker, through the centre, and ending up at the right loudspeaker.

Phantom Image: Sound that appears to be projected from an area between two loudspeakers. The listener would experience an illusion that an actual loudspeaker exists between the two loudspeakers.

Phase: "The degree of progression in the cycle of a wave, where one complete cycle is 360º. Waveforms can be added by summing their signed amplitudes at each instant of time. A cycle can begin at any point on a waveform having the same or different frequency and peak levels to have different amplitudes at any on point in time. These waves are said to be "out of phase" with respect to each other. Phase is measured in degrees of a cycle (divided into 360º) and will result in audible variations of a combined signal's amplitude and overall frequency response (Huber & Runstein 1995p.478)."

Reverb/Reverberation: The effect of sound reflecting against the surfaces of an environment. Reflected signals arrive at the ear or microphone in delayed mode compared to the direct sound signal, giving the sense of space and atmosphere of the performance area. Has a similar effect to that of an echo.

Sound Image/Sound Field: An atmosphere sensed by a listener in a real environment or as a result of an audio playback system. Sounds can be heard with sense of space and dimension.

Speaker Array: Configuration of loudspeakers positioning. Shape of listening area set by the shape of the loudspeaker boundary.

Surround Sound: Audio system with three or more loudspeakers placed around the listener in an attempt to create a sense of sound arriving from all directions.

Sweet Spot: The ideal listening position in an audio playback environment, usually in the centre of a listening area.

0.4 Delimitations On Project's Scope

Being a thesis project written for an academic course, restricted time and resources have resulted in limitations on the project's scope.

The project aims to compare the localization of original Quad recordings, against the same recordings after being converter into Ambisonics. According to an expert of this industry, the converted version should enlarge the Quad Sweet Spot to fit the entire listening area of the Ambisonics version. The project's experiment will mostly focus on this possible enhancement.

In addition, while testing the above theory, data will be collected and later analyzed, comparing the localization differences provided by different formats of Quad. These formats will be CD-4, QS, and SQ.

While the literature investigation of this report covers the history and information on both Quad and Ambisonics, the scope of the report is not to provide the full details of the technologies. Full historical and technical information on each of the technologies are far too broad and detailed to be covered in this project. The fundamentals of both systems can be very complicated and go beyond the purpose of this project. Therefore, the systems will be covered in detail, but not to the fullest.

In Quad itself, there were several methods available allowing four audio channels to be fitted onto two and then recovered back onto four channels. This report will not cover them all, but instead will cover the three most popular ones, CD-4, SQ, and QS. The report covers enough information about Quad and Ambisonics to enable the reader to understand the proposed method for restoring Quad recordings. For those who wish to learn more on those two technologies, additional reading materials will be provided at the end of chapter four.

1. Background Information

1.1 Quadraphonics

1.1.1 The Birth of Quad

For several decades scientists have been trying to capture the acoustic qualities and sounds of an environment or event, storing them on a medium that would eventually be used to recreate the same environment but in a different location. In the early stages, this was possible by capturing sound through a single source such as a microphone, and during playback hear the captured sound through a single loudspeaker. This is known as "Mono" sound. Even though the technological breakthrough was fascinating, the results were poor. Playback through a single loudspeaker sounded far from realistic and not even close to recreating the acoustic properties of the recorded environment. Sound appeared to be coming out of a single direction, the loudspeaker's cone.

With the arrival of "Stereo"sound, two channels of audio were simultaneously recorded, and during playback they would be assigned to two separate loudspeakers. One was placed on the left side and the other on the right side but, both at a sixty-degree angle from each other and facing inwards to the listener. The results of stereo were far better and listeners could experience a better dimension and atmosphere of the recording. Sounds seemed to originate from anywhere between the two loudspeakers.

So far both mono and stereo sounds offered an experience of looking towards a performance. In order to recreate a performance with the listener feeling as being part of the performance rather than looking at it, the sound system needed to be able to project sounds in a three dimensional manner. Sounds needed to reach the listener from every direction. In mono and stereo this occurred, but sounds that reached the listener from directions other than the speakers' cones, were nothing but reflections of the speaker feeds against the listening room's walls.

In fact some loudspeaker manufacturers designed loudspeaker cabinets that utilized this reflection process. When using these cabinets, sound was projected from the front of the speaker, but most of the sound was projected from the back of the cabinet. The sound from the front of the cabinet would reach the listener directly. The sound from the rear of the cabinet would reflect against the walls of the room or hall, reaching the listener with a slight delay and with changed characteristics. As a result of this effect the listener experienced a better atmosphere and a greater sense of reverb.

This method had satisfactory results but in order to achieve accurate and true surround sound enabling the listener to feel as if he or she was on the performance stage, the system would need to project sound from all directions. This would have to be direct sound and not a result of room reflections. The first step was to add a third loudspeaker to a stereo set-up, placing the loudspeaker directly behind the listener at a distance equal to the one between the listener and the two front speakers. The listener would now experience two-dimensional sound, but the addition of even a fourth loudspeaker would provide a much more stable image.

In the late 1960's, the four loudspeaker system was born, titled "Quadraphonics." The system also went by the names "Quadrophonics," "Quadrisonics," and "Quadrasonics," but it became most widely known as "Quad." The four speakers were placed at the four corners of the listening area facing inwards towards the centre of the listening area. In some cases the speakers did not face the centre of the listening area but instead, the front two speakers directly faced the rear two speakers but there was no standard specified.

Apart from the difference in the speaker direction identified above, both set-ups had the speakers placed at the corners of the listening area and as a result both set ups were titled as "Square" arrays (Figure 1.1.1.A). The four signals and corresponding loudspeakers were titled LF (Left Front), RF (Right Front), LR (Left Rear), and RR (Right Rear). Another speaker configuration known as the "Diamond" arrangement had the four speakers placed at the North, East, South, and West directions of the listening area (Figure 1.1.1.B). The diamond configuration was not promoted during the early stages of Quad for two reasons. Firstly, even though it gave an accurate front image, the image was drastically changed with the slightest side-to-side movement of the listener's head. Secondly it was not compatible with stereo playback because of the speaker positioning (Eargle 1976).

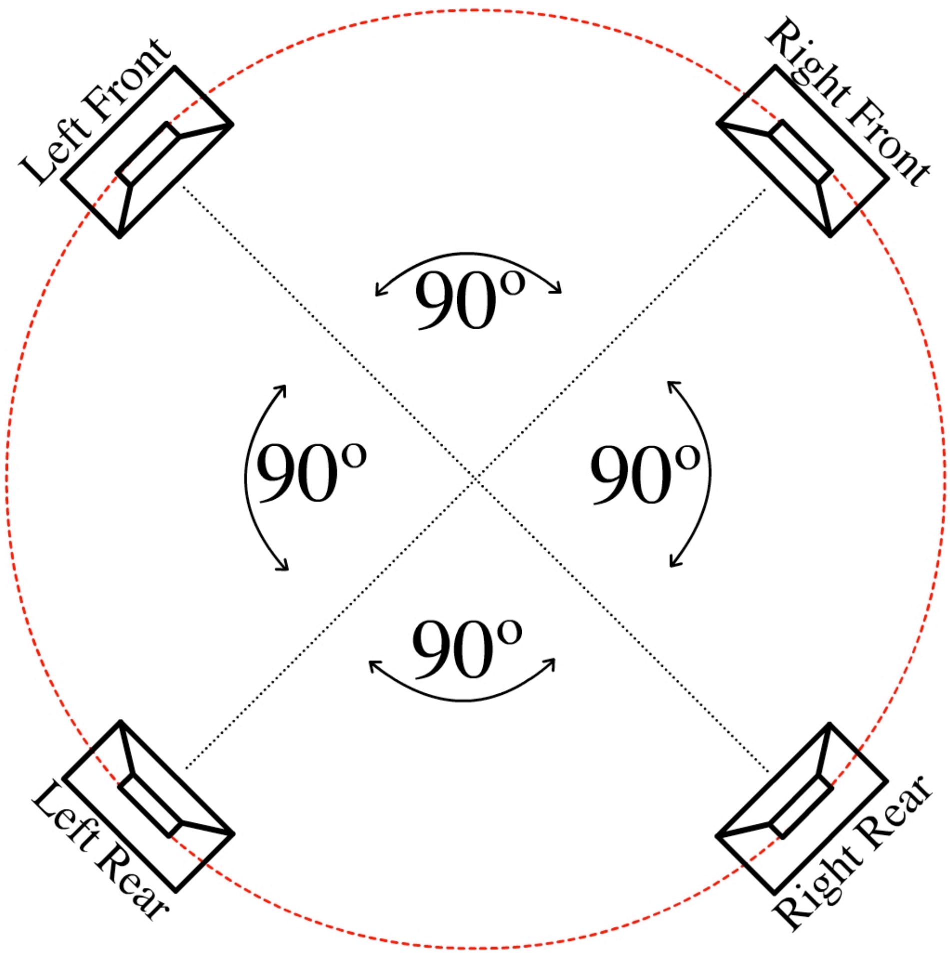


Figure 1.1.1.A: Loudspeaker positioning for the Quad "Square" configuration.

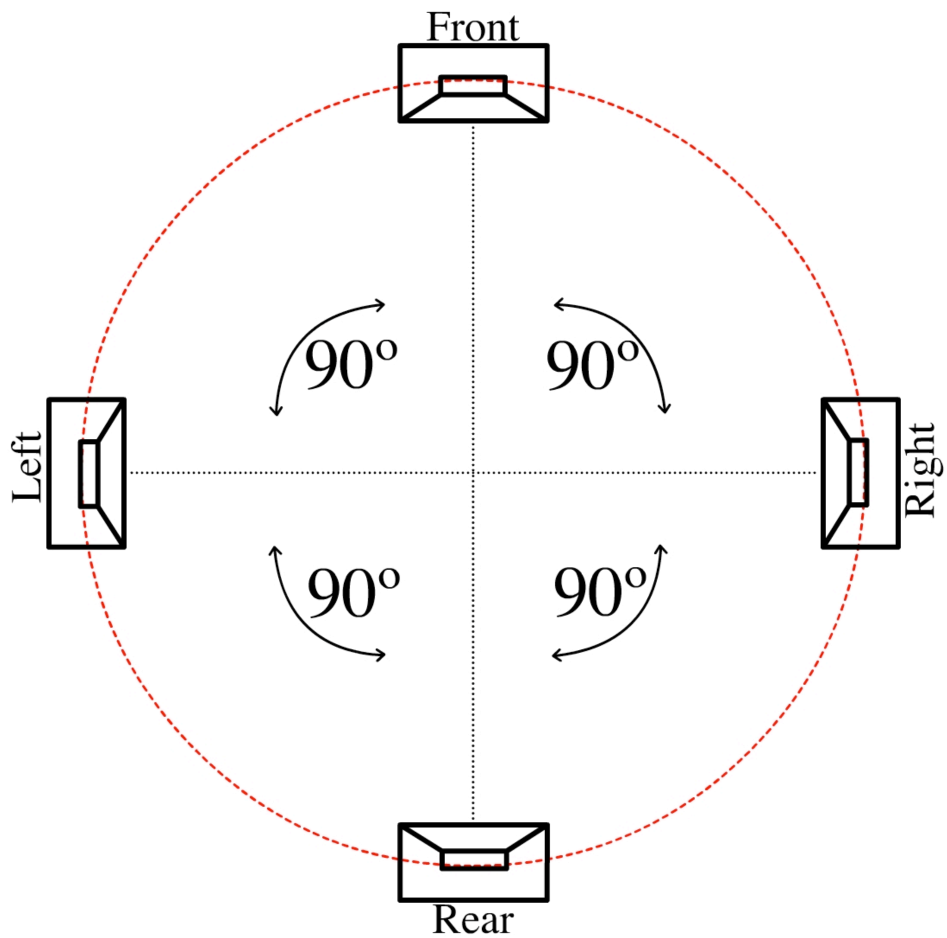


Figure 1.1.1.B: Loudspeaker positioning for the Quad "Diamond" configuration.

1.1.2 Real Images and Phantom Images in Quad

Quad attempted "to create the illusion of sound arriving from any direction in the horizontal, or azimuthal plane of the listener (Eargle 1976, p.84)." Unfortunately adding four speakers all around the listener did not satisfy the attempt. This was due to the lack of balance between real sound images and phantom sound images. Real images are the sounds that appear to be coming from the direction of the loudspeaker, while phantom images are the areas in between loudspeakers that sounds seem to come from. An example would be in a stereo situation, where sounds coming from the left and right loudspeakers make the real images. The sounds that appear to originate from between the two loudspeakers make the phantom image.

In the standard stereo loudspeaker positioning the two loudspeakers face inwards to the listener at a 60-degree angle (Figure 1.1.2.A). This allows for a stable phantom image. If the loudspeakers are spread more than 60 degrees, then the phantom image starts to disappear and a "whole" starts to appear in the centre of the two loudspeakers. An equal signal applied to both the left and the right speakers would result in the signal appearing to originate from the area between the two loudspeakers, as if a centre loudspeaker was there. That area would be considered to be a phantom image.

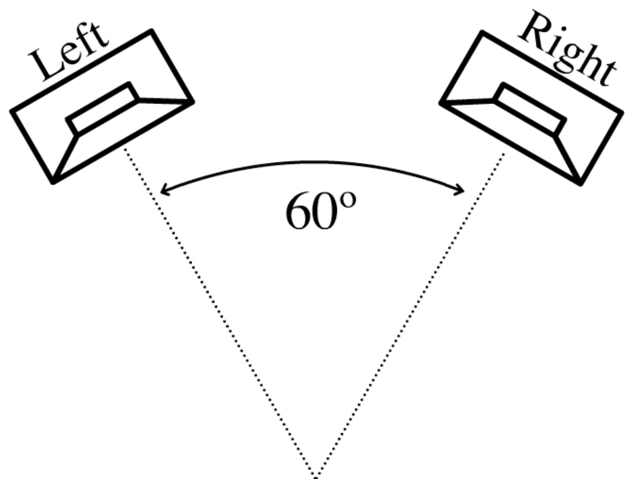


Figure 1.1.2.A: Stereo loudspeaker set-up with stable and accurate imaging.

In Quad where the four loudspeakers are placed at each corner of a square shaped listening area, (Figure 1.1.2.D) the spread between the loudspeakers would be greater than the 30 degrees of stereo. In fact they are 90-degrees apart from each other, three times more than the stereo set-up. The results were easily noticeable-wholes in the images between each loudspeaker. Sounds intended to originate from any of the four loudspeakers would be accurate but phantom images are not the same all around. The phantom image in the front of the listening area was quite accurate, while the rear phantom image was not as accurate. A sound intended to appear as originating from the rear centre could result in the sense of the sound originating from overhead instead. Imaging on the left and right was practically nonexistent.

With such shortcomings in accurate imaging, Quad resulted in the listener experiencing a "ping-pong" effect. If a Quad recording contained a sound that was intended to move from the left rear to the left front at a constant speed, the listener would hear the sound remain at the rear right speaker until suddenly in a quick motion the sound would move to the left front loudspeaker. This event of sounds appearing to be sucked into the loudspeakers was the result of poor accuracy in the phantom images and is referred to as the "ping-pong" effect.

In a situation where eight loudspeakers were placed at equal angles and distances to form a listening area in the shape of an octagon, (Figure 1.1.2.B) the accuracy and stability in the image would be acceptable. This is because the angles between the loudspeakers are half in magnitude of the ones in Quad. More importantly, in an environment where there are twice as many loudspeakers as in Quad, there are more real images to compensate for the inaccuracy of phantom images. Similarly, if six loudspeakers were symmetrically placed around the listening area (Figure 1.1.2.C) the accuracy and stability of the sound image would not be as good as the one found in the eight loudspeaker set-up, but better than the one experienced in Quad.

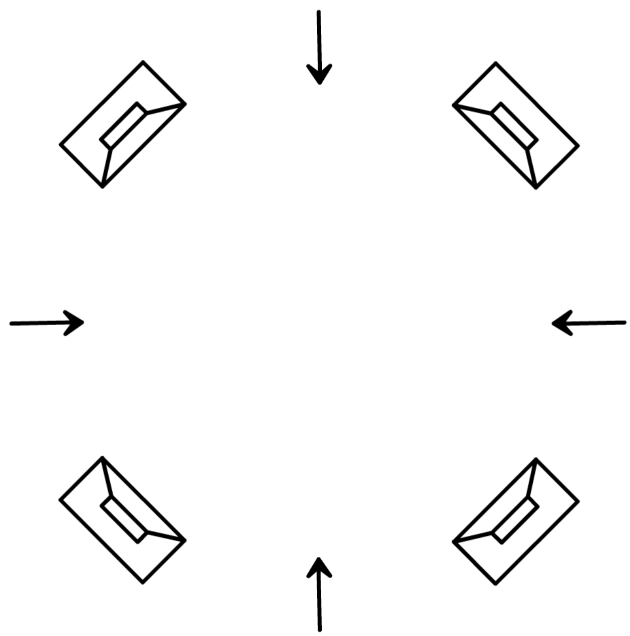


Figure 1.1.2.B: Quad Square loudspeaker set-up with inaccurate phantom images.

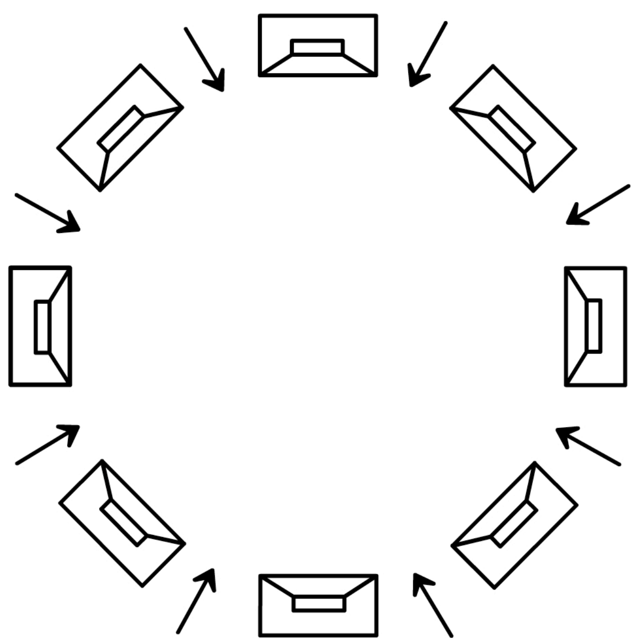


Figure 1.1.2.C: Octagon loudspeaker set-up with accurate phantom images (Arrows indicate phantom images).

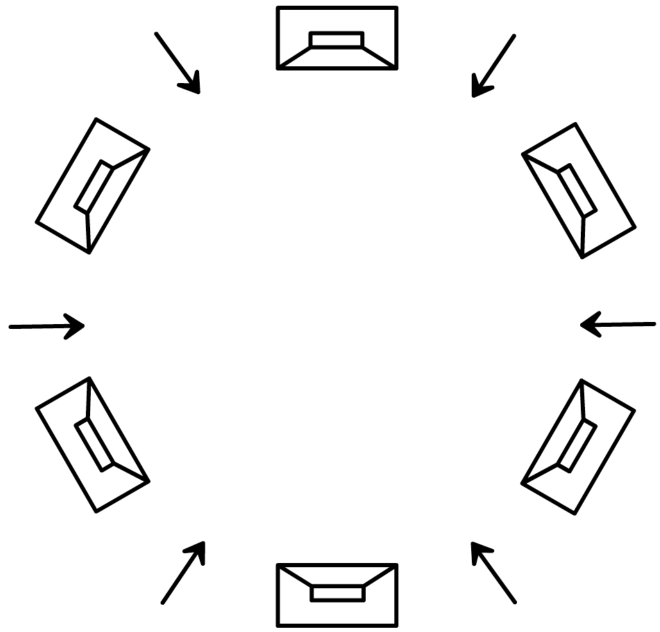


Figure 1.1.2.D: Hexagon loudspeaker set-up with less accurate phantom images.

Even though Quad had its shortcomings, at the time it was still considered a major improvement in audio reproduction, by providing a two-dimensional listening experience. A system with more than four loudspeakers would have been better, but convincing consumers to re-equip their homes with new sets of six or eight loudspeakers would be a failure. In fact promoting Quad was not a great success partly for this reason. It was not till three decades later that consumers have started to invest in systems that utilize more than two channels. More importantly at that time period, finding a method to store four channels of audio for Quad on a popular medium was a challenge. Even when the challenge was solved, the solution had its flaws and limitations. Storing six or either channels would have been practically impossible at the time.

1.1.3 Mediums for Recording and Distributing Quad

At the time, four-track open-reel tape decks were available, which could be used for storing Quad recordings. In addition, eight-track cartridges could be used for Quad material. Even though both of these mediums were available and suitable for Quad, the majority of the public was using vinyl and FM radio for their music needs. Both the vinyl and FM radio were only capable of storing two-track material such as stereo. Fitting the four-track material of Quad onto two-channel capable mediums would prove difficult, but it was not long before the solution came around.

1.1.3.A Matrix

A method called “matrix” allowed for four channels of audio to be combined into two channels with the use of a matrix encoder. The two channels could then be pressed onto vinyl or broadcast on FM radio, just like stereo material. With the use of a matrix decoder, the original four channels of Quad could later be extracted out of the two channels. This technique was also referred to as “4-2-4”, as four channels were stored in two, which could later be expanded into four again.

Matrix Quad material offered another significant advantage than storing Quad on four-track open-reel tapes or cartridges. In order for Quad to become popular and for the public to invest in upgrading their personal sound system, Quad records had to be backwards compatible with stereo and mono. This means that if one had not upgraded their sound system equipment to support Quad, they would still be able to play a Quad record on their stereo or mono set-up and experience stereo or mono accordingly. Once they upgraded their set-up to support Quad, playing the same material would result in Quad surround sound.

Several organizations and companies developed their own matrix systems. Those systems included the Regular Matrix (RM), 45J by the National Research Development Council, Stereo 4 by Electrovoice, Dynaquad by Dynaco, and Matrix H by BBC. The most popular two were Stereo-Quadraphonic (SQ) by CBS, and QS by Sansui. Matrix systems differed by adjusting different amounts of dominance in different areas of the speaker array based on psycho acoustic phenomena. Also, different systems handled channel cross-talk and channel separation differently. While combining four channels into two, and back again into four was possible, signals from other channels would “leak” onto other channels. Some matrix systems provided better separation between certain areas of the speaker array over the other areas (Robjohns 2001).

1.1.3.A.1 The SQ Matrix

The CBS created the SQ matrix while considering three main phenomena that relied on psycho acoustic principals. Scientists and audio engineers at CBS decided on the various configurations and standards that would be utilized by SQ matrix encoders and decoders in an attempt to overcome three problems of human hearing.

The first phenomenon is called “front source dominance.” This occurs when all four loudspeakers in the speaker array are playing the same signal at the same amplitude, but nearly only the front loudspeakers appear to be playing. The shape of the human head and ear create an acoustic shadow that results in the rear loudspeaker to only make the front loudspeakers appear louder. This occurs especially at high frequencies. At the same time, the rear loudspeakers’ signals reflect of the room surfaces and later reach the ears. This slight delay in arrival of the reflected signal causes the brain to assume the direction of the sound is the same as the signal that arrived earlier from the front loudspeakers.

The second phenomenon titled “back image contraction” results in the rear image of Quad to appear to be one third of the size, even though the rear loudspeakers are the same distance apart as the front loudspeakers.

The third phenomenon titled "quadrature image shift," relates to phase shifting and its results to localization. When a signal is playing through two loudspeakers the image will appear to be in the centre. As phase in increased for the signal of one loudspeaker, the image will appear to move in the direction of that loudspeaker. Once the phase is increased to 90º, the image seems as coming directly only from the side which the phase is applied to (Runstein 1976).

The SQ matrix focused on left and right channel separation, while signals leaked onto both left and right loudspeaker of the opposite direction. For example, the left front signal would not leak into the right front loudspeaker feed, but it would leak into both the left rear and right rear loudspeaker feeds. A signal intended for the right rear loudspeaker would not leak into the left rear loudspeaker, but would leak into the left front and right front (Eargle 1976).

1.1.3.A.2 The QS Matrix

Sansui developed the QS matrix that provided a 3dB separation amongst the channels of adjacent loudspeakers and perfect separation amongst diagonally opposite loudspeakers. Separation amongst the front, rear, left, and right phantom images was at 7.7dB. Because the channel separation was equal amongst either side of each loudspeaker, there was a reinforcement of the real images.

1.1.3.B The CD-4 Carrier

Using a matrix encoder at one end and a matrix decoder at the other end was a way to fit four channels of material onto two-channel mediums but still allowing the listener to experience four-channel surround sound. This was not the only method and was not the best way. The Victor Company of Japan (JVC) developed a different method for 4-2-4 transmission and distribution. The technique was called "CD-4" as well as "Quadradisc." CD-4 was not considered to be a matrix system, but a carrier system. It allowed for full recovery of the initial four channels with absolute channel separation.

Just like an ordinary two-channel vinyl where the left channel was stored on the left side of the record groove and the right channel was stored on the right side of the record groove, the Quadradisc stored music in the same manner. The unique feature of CD-4 was that the signals stored on each side of the record's grooves actually contained the information for the left rear and right rear loudspeakers as well. The left side of the groove contained the sum of left front and left rear signals, and the right side of the groove contained the sum of the right front and right rear loudspeaker signals. The signals had a frequency range of 30Hz-15Khz.

In addition each side of the record grooves contained a high-frequency carrier signal. The 30Khz signal was a modulation made up of the difference between the front and rear signals on each side of the groove. The signals on the left wall of the groove were compared to the carrier signal of the left side and the channels were successfully separated. The same process occurred with the signals on the right wall of the record's groove. This was the same technology used for the transmission of stereo signal over FM radio. A single signal was transmitted, which contained the sum of both the left and right channels. The FM receiver produced a carrier signal at a frequency of 38KHz that was used to separate the left and right channels from the single transmitted signal.

When the record was played over a standard stereo set-up, the left front and left rear signals were projected out of the left loudspeaker, and the right front and right rear signals were played through the right loudspeaker. In mono, the signals from all the loudspeakers were heard at the same level as the left and right groove that were already the sums of the front and rear, as equally combined. Neither of the 30KHz carrier signals will be heard, as anything above 20KHz is inaudible by the human ear.

In order to playback CD-4 discs with full surround capabilities, additional equipment were required compared to the matrix systems. Most turntable cartridges and styli were only capable of reproducing frequencies up to 20KHz since anything of higher magnitude humans cannot hear. The use of a standard cartridge and styli would not allow for four loudspeaker-playback as they would not pickup the 30KHz carrier signal. It was thus necessary to use the Shibata stylus with a cartridge that would allow for a frequency response up to 45KHz. Secondly a small device, the demodulator, was required to extract the four channels. A few manufacturers later developed amplifiers that had a demodulator built-in (The institute of High Fidelity 1974).

Quadradiscs provided better channel separation than the matrix systems, as well as stereo and mono compatibility. Apart from those advantages, the system also had its downfalls. The frequency response was limited to 15KHz. Due to additional space required to cut the high frequency carrier signal grooves, the entire record needed to be cut 3dB lower than ordinary vinyl. Due to the high frequency response of CD-4, during the cutting process of the master copy, the process needed to be carried out at half speed. This was because the cutting heads at that time were not capable of cutting grooves of such high frequency with efficiency. Unlike matrix systems that could be transmitted over the radio, the FCC did not permit for the transmission of Quadradiscs (Runstein 1976).

1.1.4 The Failure of Quad

The two additional loudspeakers, two additional amplifier channels, and in cases additional demodulator, phono cartridge, and stylus were quite a big investment for the average consumer to make. This was one of the reasons for the failure of Quad as a popular surround sound amongst consumers.

Apart from the economic demands of setting up a Quad system, other requirements contributed to the system's lack of acceptance. At the time when stereo was popular, most households would not place even the two loudspeakers in the appropriate position. They did not want to have a set of loudspeakers ruining the room's appearance and instead placed them in positions where they least interfered with the room's equipment. Expecting consumers to dedicate a room of the house to having four loudspeakers positioned in the shape of a large square listening area, seemed too demanding for the time.

Furthermore, another problem for the promotion of Quad was the large variety of formats. Not only where there too many formats, but many of them were incompatible with the others, each requiring separate equipment for playback. For the average consumer who was not familiar with the differences in matrix systems, choosing a system that was not supported by the record label of his favourite brands would have resulted in a regretful investment. Even though a few manufacturers later produced amplifiers that allowed the user to select the matrix with a single turn of a knob, this was only a solution for the use of matrix systems.

However, those who wished to invest in carrier systems such as CD-4 needed to purchase new phono cartridges, styli, and a demodulator. With the increasing popularity of the record format and its support for Quad, the use of open reel tapes as a medium of distributing Quad decreased, leaving open reel tape decks owners with a soon to be outdated equipment. The confusion about the technology was even noticeable by the fact that there were so many names for the same technology: Quadraphonics, Quadrophonics, Quadrisonics, Quadrasonics.

The biggest reason for the technology's failure was its lack of accuracy and realism in representing a sound field. At the time it was considered to be a good step in achieving surround sound, and it did fine, but not realistically or accurately enough to convince the public to use it. In order for the listener to experience even the slightest sense of accuracy in Quad, he or she would have to sit at the very centre of the listening area, known as the 'sweet spot.' Even slight movements of the listener's head would result in significant changes in the surround image.

By the end of 1975, most of the electronics manufacturers were offering up to fifty percent discounts on Quad equipment in an attempt to clear out their stocks. Soon followed the announcement of companies such as Radio Shack, Harman Kardon, Sherwood, and others, that they discontinued their Quad products. Sansui was the last company to continue manufacturing and introducing new Quad hardware till August of 1977. Enthusiasts and audiophiles continued arguing that the technology was still alive all the way till 1979, but after, that the number of those individuals began to decline. It wouldn't be till two decades later that surround sound would become popular again (Morton n.d.).

1.2 Ambisonics

1.2.1 The Creation Of Ambisonics

Noticing the short comings of audio playback technologies such as Quadraphonics, a group of British researchers in the early 1970s decided to invent a surround sound technology that would "enable a musical performance to be captured on tape or another medium, for transmission via available or future distribution media to the consumer, and where it would be replayed in a conventional living room in which as far as possible the original sound and acoustic environment of the original performance would be recreated (Elen 1 n.d.)." The team made up by researchers including Michael A. Gerzon from the Mathematical Institute in Oxford, and Professor Peter Fellgett of the Cybernetics department at Reading University, set out to create the surround sound system that was going to make up for the errors and shortcomings of other systems. The technology was to be called "Ambisonics" meaning "surround sound" (Elen 1).

1.2.2 The Ambisonics Technology

Conventional audio systems try to produce a sound field by utilizing amplitude changes to localize sound sources. Amplitude change is only one of the several techniques that the human ear and brain rely on to localize sound. These techniques are used for localization at different and at times overlapping frequencies. For frequencies between 150Hz and 1.5Khz, humans rely on phase for localization. From 300Hz and 5Khz, we use loudness. In addition, for frequencies above 2.5Khz, other localization techniques are used.

To achieve a satisfactory spatial image using a conventional stereo set up, the two speakers must be set at an angle of 60 degrees. If the two speakers are set at a wider angle, a gap starts to appear in the middle of the stereo image. This is a result from using only amplitude changes.

In Quadraphonics, where four speakers are set 90 degree apart from each other and relied on only amplitude changes for localization, the results were poor. The front image was poor, the rear image was even poorer, and there was hardly any localization on the sides. When a sound was panned around the listener in a constant circle, the sound seemed to be sucked into the speakers, creating a 'ping-pong' effect. In addition, sound could only be placed at the perimeter of the speaker array, not allowing for sounds to appear outside or within the speaker array. The best results were achieved by sitting at the very center of the speaker array, an area in audio terms known as the "sweet spot." The sweet spot in Quadraphonics is very small.

Ambisonics was invented with the use of psychoacoustic and physic principals. To ensure its capabilities Ambisonics went far beyond from simply using loudness for localization. As a result, it has been said that Ambisonics have the most accurate localization than any other system to date. Sounds can be placed virtually anywhere, and the sweet spot usually covers the entire area within the speakers. It has been said that at times, imaging can be experienced even while standing outside the speaker array. Interestingly enough, by the mid 1970's, Ambisonics offered a full three-dimensional sound, something which has been offered by other surround sound systems but only in recent years.

The core of Ambisonics lies in the B-Format. The B-Format is made up of four audio channels titled W, X, Y, and Z. These four channels hold all the information required to playback full three-dimensional sound. Channel W is an omni-directional signal. The other three channels hold spatial information in the method of sum-and-difference, similar to the original stereo technique invented by Alan Dower Blumlein in the 1930's. Channel X holds information similar to a figure-of-eight microphone facing the front side (front minus back). In the same manner, channel Y faces the left side (left minus right), and channel Z faces the up side (up minus down).

These channels can be played through an Ambisonic decoder to drive virtually any number and configuration of speakers. Unlike other systems where the number of speakers driven depends on the number of channels available, Ambisonics has no limitations. The decoder extracts from the B-Format channels a set of interrelated speaker feeds. The speakers work together to recreate the sound field as accurately as possible. Because Ambisonics is based on a mathematical formula, the decoder can supply interrelated speaker feeds for nearly any speaker positioning. This feature is definitely an advantage over conventional surround sound systems.

1.2.3 Ambisonic Formats

If Ambisonics was to ever become a popular system, it would have to be compatible with many of the systems available at the time. There were two challenges that had to be resolved before the system had any possible commercial success. The first was that up to that date there was no form of media widely used by consumers that could store the information of the four separate tracks that make up the Ambisonic B-Format. The second challenge was that in order to experience Ambisonics, the listener was required to have a B-Format decoder to drive the speakers. Without the decoder, one could not listen back the recording through a conventional stereo and mono system.

The solution to the above challenges was similar to the method used by Quadraphonics namely, to store four tracks on two-track mediums. By using either of phase, amplitude change, frequency change, and summing/difference techniques, four channels could be encoded into two. Those two channels could then be printed on a medium such as vinyl, and when the listener played the vinyl back using special Quadraphonic equipment, all four channels could be extracted to feed four speakers. In addition, if the listener did not have special Quadraphonic equipment, the playback of stereo or mono was still possible with the use of standard stereo or mono sound equipment.

The developers of Ambisonics decided to come up with a matrix system that would allow Ambisonic material to be stored on two tracks as well as offering both stereo and mono compatibility.

> *"The BBC was experimenting with surround sound at the same time and they adopted Matrix H (presumably the eighth one they came up with: it was allegedly based on QS principles) for experimental surround broadcast. The Ambisonic team also developed a number of matrixing schemes, with varying names: the BBC's Matrix H and the Ambisonic team's 45J matrixing system were combined as Matrix HJ. Work done on the Nippon Columbia UD-4 ("universal Discrete 4-Channel") quad system were also brought into the mix, along with research by Duane Cooper at the University of Illinois, and the final result was referred to as*

> *"UHJ" ("Universal HJ"). This is sometimes referred to as "C-Format" (*Elen 1 n.d.*)."*

The UHJ format in its full state contained four channels titled "Q", "T", "R", and "L". When all four channels were available, the listener would experience full three-dimensional sound. Channel "Q" could be removed loosing the height information, and the remaining three-channel version UHJ would provide a very accurate horizontal surround image. Channel "Q" could also be band-limited to result in a 2.5-channel UHJ that still provide good horizontal imaging. Finally, the most common UHJ form was the 2-channel UHJ. Even though the results were not as significant as with the 3 or 2.5-channel UHJ, the surround image was still good.

The different UHJ configurations required a UHJ decoder but when the 2-channel UHJ was played back over a standard stereo system with no decoder, the listener would experience a "3D Super-Stereo" sound.

> *"In this case, the phase and level relationships in the signal, which are based on aspects of the way in which the brain localizes sound sources in nature, lead to a certain amount of "aural decoding" in which the brain tries to make sense of the signals by giving them surround positions and a "super stereo" effect that goes way beyond the speakers (*Elen 1, n.d.*)."*

Mono capability is achieved by summing up channels "L", and "R" of the two-track UHJ.

In recent years with the development of multi-channel mediums such as Digital Versatile Disc (DVD), and Super Audio Compact Disc (SACD), the need to create a UHJ mix can be avoided. The recent 5.1 surround sound configuration has become the standard sound amongst many homes and studios. The configuration officially known as the ITU-R BS 775-1 Recommendation and set by the International Telecommunications Union specifies the official loudspeaker positioning for 5.1 surround sound (Figure 1.2.3.A) (Lund 2000). The set-up is made up of five channels titled Left, Centre, Right, Left Surround, and Right Surround. There is also the use of an optional subwoofer enclosure, which can be placed anywhere in the listening area since humans cannot determine the direction or origin of low frequencies. Ambisonics would have to adopt to take advantage of this new standard in a way that would reach the majority of people.

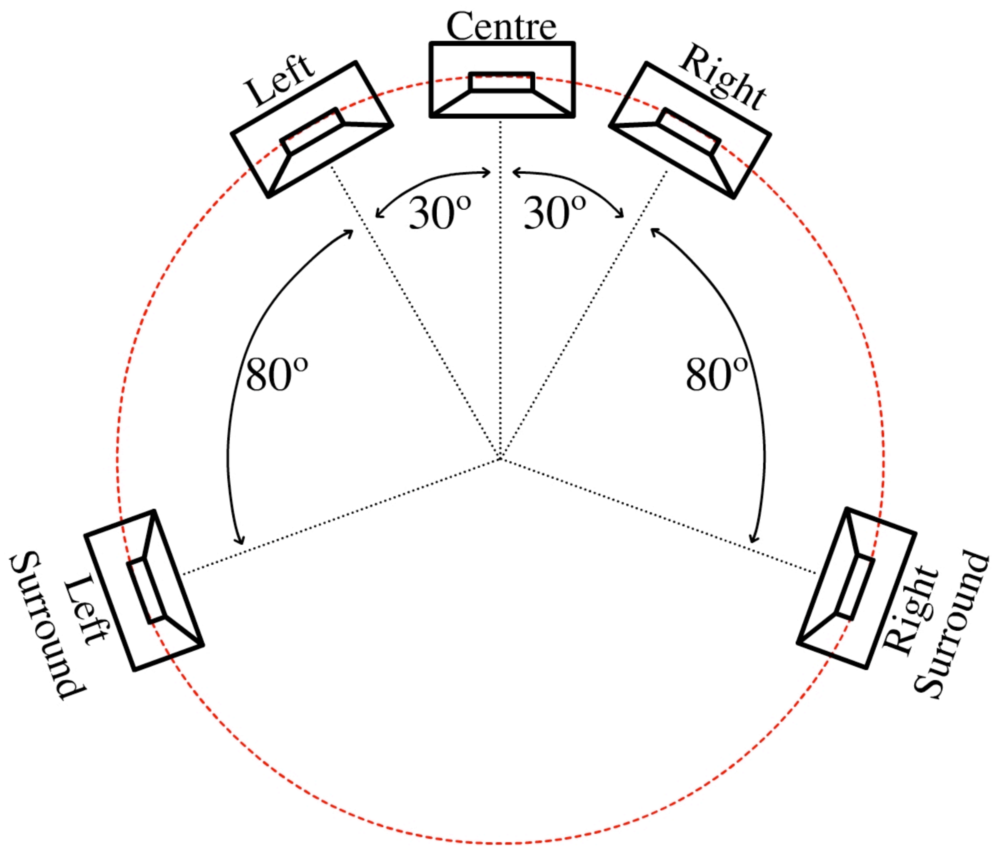


Figure 1.2.3.A: Loudspeaker configuration according to ITU-R BS 775-1.

Ambisonic material could be delivered as a four channel UHJ, but a decoder would still be required to drive the speaker feeds if the listener wants to have more than the a "3D Super-Stereo" sound. Instead of creating UHJ decoder units or adding UHJ decoding capabilities to the DVD and SACD players in the form of DSP (Digital Signal Processing) chips, it would be cheaper and more successful to create another format which would require no processing.

This format developed is known as the "G-Format." It is based on the "B-Format+" which is an advanced form of the initial Ambisonics "B-Format." Due to the fact that Ambisonics has the ability to drive any configuration of speakers, the material can be decoded to drive a 5.1 set-up. The speaker feeds could then be mastered onto a DVD. This process creates the G-Format, which can be played back over a 5.1 set-up with the use of any DVD player. There is no need for any Ambisonic decoding by the consumer.

The downfall of this format is that there is no height information, and the speakers must be positioned strictly according to the 5.1 standards. But the downfalls can still be made up for. It is possible to extract the original B-Format out of the G-Format, including height information. This would then allow users with dedicated Ambisonic hardware to utilize the full benefits of Ambisonics, such as driving any configuration of speakers.

In addition, mediums such as DVD and SACD allow the use of a set of additional two-channel tracks. During the preparation process of the G-Format, it is possible to also simultaneously create a two-channel UHJ mix for the spare tracks on the mediums. This way, those who have a 5.1 set-up could enjoy the G-Format Ambisonic mix, and those who use a standard stereo set-up would experience the Super-stereo effect of the two-channel UHJ. The medium combining both G-Format and two-channel UHJ are titled "G+2" (Elen 2).

An extra benefit of the G+2 format is that in standard audio production, the creation of an audio DVD requires tow separate mixes. One for the 5.1 set-up, and the other for the plain stereo mix. With the G+2 format, only one mix is necessary and once that mix is ready, virtually any configuration of speaker arrangements and formats can be generated with substantial results.

1.2.4 Recording Ambisonics Live

Recording a live performance or environment in Ambisonics requires a special microphone. The microphone is called "SoundField Microphone" and is manufactured in England by SoundField Research. Under the grill of the microphone a tetrahedral array of capsules will be found. These capsules capture audio in the B-Format, which are then fed into a special pre-amplifier that is designed to work with the multiple capsules.

The availability of a pre-amplifier which also acts like a processor, allows the user to rotate and tilt the soundfield both during the recording, and after the four B-Format channels have been recorded. Additional possible manipulations include the ability to move front and back inside the soundfield, or totally change the tetrahedral capsule behavior to capture sound in different polar patterns such as cardioid, and omni. The processor also allows for the outputs of a two channel stereo mix that can be used with conventional stereo set-ups. Similar processors extract the appropriate channels out of the B-Format to drive the presently popular 5.1 surround sound set-up.

1.2.5 Mixing Ambisonics

So far it was possible to create Ambisonic recordings by capturing live performances with the Soundfield microphone. But for the technology to gain popularity and have any chance of becoming an industry standard, it had to be made possible to produce Ambisonic material in the conventional multi-track studio environment. Experts began to design equipment to allow for this production capability.

In the early Eighties, Chris Daubney designed an Ambisonic mixer which was built by Alice Stancoil Ltd. Richard Elen was part of a group of experts who designed and built pan pots and other hardware that could be used with conventional audio engineering equipment, to add Ambisonic mixing capabilities.

Later on a company in Reading, England called Audio & Design Recording, produced the Ambisonic Mastering Package. It was this set of equipment that allowed for proper

Ambisonic mixing to take place. Designed by Dr. Geoff Barton, the package was made up of three separate rack processors and a professional studio Ambisonic decoder of B-Format with 3 or 2 channel UHJ material. In late 1983, the first studio with full multi-track Ambisonic recording and mixing capabilities was established. It was in Crunchfield Manor in Berkshire of England. It was only ten miles away from Reading, which was the location for the Ambisonic Technology Centre. This made it an ideal location for both using and trying out the latest products.

One of the units was a Pan-Rotate processor that featured eight pairs of continuously rotating knobs. One of the knobs in each pair, allowed for a signal to be panned around the listener within the circumference of the speaker array. The second knob in each pair set the distance of the sound from the centre of the speaker array. The first of the above mentioned knobs could be used to place a sound northwest of the listener, and the second knob to move the sound from the circumference of the speaker array closer to the centre of the array or further away from the edge of the speaker array. An extra feature was the rotating knob, which allowed for the entire soundfield to be rotated. Each of the other eight set of knobs could be set as “pre” or “post” this rotator knob.

At the backside of the Pan-Rotate processor unit there were the individual inputs for the eight channels which were controlled by the eight sets of knobs. Four outputs on the backside provide the feeds of the final Ambisonic B-Format mix created within the unit. In addition, there are eight more inputs that make up two sets of B-Format signals inputs. One of these sets of inputs is a pre-rotator, and the other set of inputs is a post-rotator. These two options can be used to link similar units together.

The second unit the “B-Format Converter” was a simple unit with no controls other than the power switch. It took feeds from four console groups and an auxiliary send, and used the console pan pots to pan across each quadrant of the sound field depending on the pair of groups selected. This unit also provided output for a B-Format signal (Elen 1, n.d.).”

The third rack was the “Transcoder”. Its main function was to create UHJ signals from B-Format material, but it could also be used in another way. The user could input two stereo channels such as a front and rear stage like in Quadraphonics. Two knobs on the front panel allow to set the width of both the front and rear images, resulting in a simple Ambisonic mix in UHJ format.

In 1983 Keith Mansfield’s album titled *Contact*, was the first album to be mixed with Ambisonics. It was part of the KPT Music Library and was pressed on vinyl material by Nimbus Records. The following year, under a collaboration between KPM and Nimbus, the first Ambisonic mixed Compact Disc was released. It also was the third Compact Disc made in the United Kingdom, titled *Surprise, Surprise*, by Chin & Cang.

1.2.6 Failure To Gain Popularity

With all the benefits and clear advantages of Ambisonics, some may wonder why the technology is not more widely used in audio production. Technically, the creators of the technology have done a great work, but where they have failed is promoting and convincing the market to use it. The creators did not have the required funding to make an attempt at marketing the system, and so they approached the National Research Development Corporation. The NRDC was an organization funded by the English government, which took inventions from inventors who lack the funding to promote the their own inventions. The organization would then approach investors and companies and attempt to get them to licence the invention. If the invention was licensed, then the profits would go to the inventors, with the NRDC earning a share of the income.

The NRDC being an organization which specialized in licensing inventions, had the funding and resources to deal with such matters, but not good enough for Ambisonics. If the invention being licensed were one that could be best dealt by having an exclusive licensee, then having the NRDC handling the negotiations would be an ideal action. For Ambisonics to succeed, it would need to become an audio system standard used by as many licensees as possible. This is where the NRDC failed to successfully promote Ambisonics. Ambisonics needed a large-scale promotion to persuade record labels, equipment manufacturers, artists, producers, and the public to use the advanced system in order to succeed. Live demonstrations, exhibitions, and press conferences are just some of the promotional methods needed. The NRDC was more suited for dealing directly with single licensees.

As time passed, eventually Nimbus Records became the first licence holders. Nimbus Records was a record label that focused on producing classical recordings utilizing authenticity and the simplest and cleanest signal path during the recording process. The use of the SoundField microphone proved to be a great tool. Other companies that eventually became licence holders included hardware manufacturers Calrec, Audio & Design Recording, Maple, Avesco, and Mimin.

Most of those companies lost or gave up the licence, months after obtaining it, without creating any Ambisonic products. Nimbus Records was the only licence holder who has held and contributed to the development of Ambisonics throughout the entire period of three decades, and eventually became the exclusive licence holder. The label tried to approach Japanese electronics manufacturers in order to persuade them to include Ambisonics in their home theatre products. Mitsubishi was the first company to pick up on Ambisonics creating the DA-P7000 system. It worked entirely on digital components, offering UHJ decoding as well as Dolby Surround material. It also allowed for the conversion of Dolby Surround material to be converted into UHJ. Finally, the unit included a feature where signals could be processed to provide ‘Super Stereo’ to any type of signal whether UHJ or normal audio. Other manufacturers soon followed such as Onkyo and Meridan, manufacturing home theatre components with Ambisonic capabilities.

Some may argue that the failure for Ambisonics to gain market popularity, was not the NRDC's fault. In the early 1970s when the NRDC and the Ambisonics community was pushing to promote the technology, only the SoundField microphone was available for Ambisonic production. Artists and record producers who had creative ideas of music production and required the hardware to mix in Ambisonics, were not available till the 1980s. While they waited for the Ambisonic mixing hardware to become available, several years passed, and eventually Ambisonics itself seemed to disappear (Elen 3).

1.2.7 The Future of Ambisonics

With the rapid growth of computer processing power, computers can be used to encode and decode Ambisonics. Especially with the large market of computer based audio production software, the development of software, which would allow recording studio engineers and producers to record and mix Ambisonics would without a doubt be the most appropriate way for Ambisonics to gain market success. Software based mixing tools would be more affordable and easier to distribute through the Internet, compared to t he bulky and expensive Ambisonic mixing hardware of the 1980s. In fact software developers and audio enthusiasts have already developed such software. Most of them come in the form of plug-ins for popular audio sequencing software widely used in the recording industry.

Even though most software are impressive and carry out the processing successfully, none are yet good enough to attract the attention of the majority of recording professionals. It seems to be only a matter of time before a well developed plug-in for the already popular audio sequencing software packages is made available by an organization that has the appropriate resources and funding to promote Ambisonics. Until such software is released, Ambisonics will remain to be used and be admired by only those who have been lucky enough to come across it in the past, realising its powerful capabilities (Elen 3).

1.3 Research Objective

> *"The question is often asked, "Can I convert existing 'quad' recordings to Ambisonics, or at least to UHJ?" The answer is a decided "Yes!" In fact there are several techniques using existing Ambisonic equipment…In general, transcoding (or "re-encoding") quad recordings will give a result in which the experience in the quad "sweet spot", ie the acceptable listening area is significantly enlarged. In addition you may get a better feeling of the acoustic environment if the techniques used on the original recording captured them. In certain cases you may experience better localization and find individual musical components easier to discern (Elen 4, n.d.)."*

It is this statement which this project aims to examine. If this conversion truly improves the stability of Quad material, then the process can be beneficial for restoring Quad records. Recording studios and other companies in the audio industry offer services for transferring Quad records onto DVDs, allowing consumers to playback their old records over the presently popular 5.1 loudspeaker configuration.

The Quad records are played back through the appropriate matrix system decoder, and the four decoded channels are assigned to the left, right, left surround, and right surround channels respectively of the DVD. This transfer is degrading the surround sound image. The four channels used on the DVD are intended to be played back over a 5.1 loudspeaker configuration, which is different to the original Quad loudspeaker positioning.

By creating a G-format mix of a Quad recording, when played back over a 5.1 loudspeaker set-up, a virtual Quad speaker array should be formed, allowing the playback of Quad material without having to rearrange the positions of the loudspeakers in the 5.1 configuration.

In addition, if Richard Elen's statements prove to be correct and there is an improvement in the surround sound image stability, there will be a second advantage to using this conversion. Most importantly if the sweet spot of the original Quad recording is enlarged after the conversion, then this in itself would be a good enough reason for Ambisonics to be applied to restoring Quad records.

The research aims to compare original Quad recordings of different matrix and carrier systems, to their Ambisonics converted versions. Individuals will be seated within the listening area of both a Quad and a 5.1 configuration, and data will be collected regarding their perception of each version.

The data will then be compiled and structured in spreadsheets. Using the spreadsheet data, graphs will be generated making it easier to analyse the results. Based on those graphs, conclusions will be made regarding whether converting Quad material truly improves the experience of quad or not.

1.4 Research Methods

For a research to be properly carried out, it is recommended to follow certain procedures and standardised methods, to ensure the validity of the results. A project can use a single method or several in order to be completed. The most appropriate research method for this project would be an experiment with the use of a survey instrument to collect the data from the respondents.

"Experimental research is the only type of research that can truly test hypothesis concerning cause-and-effect relationships (Gay 1996, p.342)." This research used this cause-and-affect technique by moving people within a listening area and having them rate audio samples. The cause was moving the listeners to different positions in the listening area, and the effect was the rating they assigned to each audio sample depending on the location they were at. This process is described in detail in section 2.8. "An experiment is only valid if results obtained are due only to manipulated independent variable, and if they are generalizable to situations of the experimental setting (Gay 1996, p.345)." The manipulated variable in this experiment was the listening position. The audio samples were constant as they were simply repeated in the same manner for all the participants regardless of their listening positions. Other constants were the positioning of the loudspeakers, the volume of the audio samples during playback, the room, and many more.

Obtaining the information from the participants was done with the use of questioners. Questioners are a tool of the Survey research methods, which focuses in collecting information from individuals through several means. The questioner is just one of them, and the most appropriate one for this experiment. "Survey research involves obtaining information directly from a group of individuals. More often than not, it includes interviews or questioners... (Dane 1990, p.120)."

The survey research method contains several tools, which can be used. These include in-person interviews, telephone interviews, in-person questionnaires, postal questionnaires, and others. "The main difference between various surveys will be their scope. A typical survey would involve one or more of the following data-gathering techniques: structured or semi-structured interviews, self-completion or postal questionnaires, standardized tests of attainment or performance and attitude scales (Cohen & Manion 1994, p.83)."

The experiment requires for the respondents to listen to specific audio material through specific loudspeaker configurations, which will be set-up at by the researcher at a designated location. Therefore the survey tool cannot be one that allows for completion at a location other than the designated area. This eliminates the possibility of using a questioner that can be distributed through the post or Internet.

An in-person interview would also not be suitable, as the interviewer would have to speak during the playback of the audio samples, distracting the respondents. Secondly, the interview tool would allow for only one respondent to be interviewed at any one time, making the entire data collecting process more time consuming. Lastly, the use of verbal communication can lead to biased responses as a result of the interviewer's tone of voice and dialogue.

Ideally, the use of an in-person self-completion questioner would best suit the scope of this project. It would have to be completed by the respondents while in the designated listen area with the researcher playing the audio samples. The advantages of this survey tool are that more than one respondent can participate at one time. Also, unlike with interviews where the results can be biased, there is less verbal communication between the interviewer and the respondents, avoiding any influence on the results. "It is a method of obtaining large amounts of data, usually in a statistical form, from a large number of people in a relatively short time (McNeill 1985, p.18)." "The aim of a survey is to obtain information which can be analyzed and patterns extracted and comparisons made (Bell 1993, p.10)."

The questions that are included in the questioner can be of two types: 'Open' or 'closed'. Open questions are ones that allow for the respondent to answer with the ability to summarise and describe. The type of reply will be qualitative. Closed questions are the opposite. There are restrictions on the answers that the respondent can have. The questions are followed by a list of possible answers and the respondent has to select one or more. This sort of questions result in quantitative results, and for that reason they will be used on the questioner of this project.

By collecting quantitative data, compiling the results in categories will be easier, and will allow for a statistical analysis. Graphs can be generated from these statistics, allowing for easier conclusions to be drawn.

"One of the first rules of survey research is to know what kind of information you want to collect. The survey instrument should be designed on the basis of a research hypothesis…(Dane 1990, p.121)." It is essential that a pilot version of the survey is designed and tested. Any complications or errors with the phrasing and formation of the questions will become noticeable, and this is the exact reason for this short run of the survey. Corrections will be made to the initial questioner to become the final questioner, suitable for the full-scale survey.

1.5 Summary And Conclusion

Chapter 1 begins with the history of audio technology and the technologies that have over history attempted to change the way we recreate a performance or acoustic environment within another area. Starting with "Mono" sound, the single loudspeaker which even though at the time was a revolutionary move in sound reproduction, had poor results as sound appeared to come out of a tiny whole in the wall. The chapter then moves onto "Stereo" sound, utilizing two loudspeakers which is still today the most widely used configuration.

At that point Quad is introduced. The configuration of four loudspeakers placed all around the listener in an attempt to represent surround sound. The chapter describes the configuration and positioning of the loudspeakers, and the technical aspects such as matrixing systems, which were sued to fit four channels into two, allowing for the later extraction of the four initial channels again. Phantom images and the problems that faced the technology, along with the unsuccessful marketing attempts are discussed.

The next section of the chapter introduces Ambisonics, a surround sound system invented at the same time period as Quad, but far more advanced. The history of the invention is discussed, and followed by the technical aspects that make it the advanced system it is. The different formats and their compatibilities are explained before the project's objective is stated. The section ends with an explanation to the reason for its lack of popularity.

Testing whether by converting Quad recordings into Ambisonics can improve the surround sound image and localization is stated as the objective. It begins with a quote from an Ambisonic expert Richard Elen, who suggests that such conversion can be beneficial. The author sets out to test just that. If the results and their analysis prove the theory to be accurate, then this process can be recommended to recording studios and other organizations who offer services for transferring Quad records onto DVDs for compatibility with the present technologies.

The chapter ends with an explanation of the research methods that were used and supported along with the reasons for those choices. The choices were to use a form of pure experiment for its cause-and-effect approach. The loudspeaker positioning, audio samples, listening room and other factors were left as constants while the participants were asked to keep changing their listening position while rating the samples' surround sound imaging accuracy. Questioners being a tool of the Survey research method were used to collect the data from the participants.

2. Field and Laboratory Methodologies

2.1 Creation of Pilot Questioner

Before starting with the questions, the questioner form should start off with a brief description regarding the survey and instructions on how to complete it. These instructions should be written using simple language and avoid using technical terms in order for all the participants to easily understand. Care needs to be taken to avoid using language and phrases that might give a biased feeling about any aspect of the process.

Participants may hesitate or avoid to accurately complete questioners if they feel that their privacy is not protected. For this reason, the first paragraph of the questioner stated that their information will only be used for the purpose of this project and therefore will not be passed on to any third party.

That was followed by a brief description of the project and the instructions for completing the questioner. At the end of the instructions they were informed that if they had any questions, they could ask the person conducting the questioners for assistance. In the event where verbal explanation was required, the individual carrying out the questioner should ensure to give the explanation to all the participants identically.

> Thank you for taking the time to participate in this experiment. All the information you will provide will be strictly used for this experiment only and not shared with any third party.
>
> The experiment aims to test the effectiveness of different surround sound systems. You will be seated in a chair within an area surrounded by speakers. Three pairs of music tracks will be played back over the speakers. After each pair of tracks is played, you will need to rank each track in terms of surround image accuracy and ease of localization.
>
> Circle number 1 if you feel there is a poor sense of surround imaging and inaccurate localization. Circle 5 if you feel the imaging and localization is great. Circle the any of the numbers in between 1 and 5 according to your perception of the sound. Please note that you are not judging the tracks according to the musical performance, quality, or music style preference.
>
> On the desk that you will be seating there will be a sticker with either a letter “A”, “B”, or “C”. Fill out the section of the form according to the desk you are sitting on. When you have completed the questions for the three pairs of tracks, you will do the same procedure while seating at each of the remaining desks.
>
> If you have any questions, do not hesitate to ask for assistance. Thank you

The first five questions on the questioner were common questions regarding the respondent’s information and background experience with audio and surround sound. These questions were included to determine whether there were any patterns in the results of those who claimed they have had previous experience with surround sound. The results of a respondents who claimed to have had experience with producing surround sound, might show that they have noticeably different answers than those with no experience.

"There are three different types of information that can be obtained from survey respondents, the participants in a survey research project: facts, opinions, and behaviours (Dane 1990, p.121)." All the questions up to this point are trying to get facts. "A fact is a phenomena or characteristic available to anyone who knows how to observe it. Often called sociological or demographic characteristics, facts include such variables as age, race, gender, income, and years or education. Facts are anything that can be verified independently (Dane 1990, p.121)."

1) Name:

2) Email address:

3) Contact Number:

4) Are you an audio enthusiast/engineer/expert/audio engineer student?

Yes No (Circle your choice)

5) Have you had any previous experience with surround sound systems/technologies?

Yes No (Circle your choice)

(If yes then please give a brief description in the space below).

It was on the second page where the most important data would be collected. Tables such as the one below were used instead of individual questions. As explained on the first page of the questioner, each of the three fields corresponded to one of three seats within the listening area, each labelled with a paper as 'A', 'B', and 'C'. The respondents were required to sit in one of the seats and fill out the corresponding table.

Short portions of a songs would be played through the loudspeakers set-up in the room (More details on the loudspeaker configurations in upcoming sections). A pair of samples of a song would be played and the respondents were required to rate each sample. The rating of the samples should be "in terms of surround image accuracy and ease of localization." This means they would be judging whether the instruments seem to be coming from an accurate and realistic distance and direction from where they were sitting. They would circle the numbers 1 to 5 on the left of the table. They would circle number 1 if they felt the surround sound was poor in sense of direction and realism, and circle 5 if they thought it is great. The instructions warn that they should not judging the tracks according to the musical performance, quality, or music style preference.

Seat A						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5

Seat B						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5

Seat C						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5

Once the first pair of samples has been ranked, they would repeat the process for another two pairs of samples. Once the three pairs (six samples all together) have been ranked, then the respondents would switch seating position and repeat the process again filling out the table, which corresponds to the seat they were sitting at. The process will be repeated once again until each respondent has filled all the three tables corresponding to the three available seating positions.

Finally the questioner ends with a last question, asking whether the respondents are interested in receiving a final copy of the thesis. This is not part of the data to be analysed, but just an option for those respondents curious about the project they took part in and contributed.

Questioners were shown to four individuals to read and provide feedback. One of the individuals was familiar with audio engineering and found the instructions and questions to be fine. The other three individuals who saw the pilot survey had no audio engineering experience and claimed to have a difficulty understanding the criteria which they had to rate during the experiment. They suggested that there is easier explanation of the criteria that the sound samples need to be rated by.

2.2 Creation of Final Questioner

There were two options to correct the problem and make the instructions easier for those who are not familiar with audio engineering terms. The first option was to include definitions of the terms "Surround Sound Image", and "Localization". It was chosen not to do this in order to keep the instructions at length, and to avoid individuals making assumptions on the definition.

The second option, and the one which was used was to remove terms such as the ones above and to describe the judging criteria using simple language. The following section of the instructions changed to the following paragraph:

"After each pair of tracks is played, you will need to rank each track in terms of surround image accuracy and ease of localization…Circle number 1 if you feel there is a poor sense of surround imaging and inaccurate localization. Circle 5 if you feel the imaging and localization is great. Circle the any of the numbers in between 1 and 5 according to your perception of the sound."

"After each pair of tracks is played, you will need to rank each track in terms of instrument balance and location. This means you will be judging whether the instruments seem to be coming from an accurate and realistic distance and direction from where you are sitting…Circle number 1 if you feel the surround sound is poor in sense of direction and realism, circle 5 if you think it is great."

The questioner was finalized and ready to be used in the experiment.

2.3 Collection Of Quadraphonic Material

The first step for creating the material that would be tested, was to find original Quad recordings. The first difficulty came as there are very few such records available, and usually considered as collector's items. A few recordings were found on the online bidding website eBay, but due to their rare availability, most were being sold at high prices. Furthermore the author was hoping to find the same album in three versions of matrix and carrier systems: QS, SQ, and CD-4. Such high expectations were going to be hard to satisfy because most record labels used only one format. Even if such an album was ever released in all of the three systems, Quad being such an out of date format it would be very difficult to meet the high expectations.

After searching in several stores that specialize in second hand records, there were only two records, of different bands, and same matrix format, therefore not being of any use. Talking with the sales people at these stores, it was understood that no such records would be available.

The next step was to search on the Internet for groups and individuals who collect such records. Mr. Tab Patterson was found in Texas, America who is a Quad enthusiast. I came across his website which advertises services of transferring records and in particular

Quad records, on to new mediums such as CD and DVD. He was contacted by email explaining the project and enquiring as to whether he had the Quad material that the author was searching for. Furthermore, he was asked if he would be willing to create a CD-ROM with audio files of the individual four-channels of each Quad record.

Fortunately Mr. Patterson had a song in all the three requested formats: QS, SQ, and CD-4. In addition he accepted to create the CD-ROM. Using the appropriate Quad decoding hardware, he transferred the individual channels into his personal computer at the sampling rate of 44.1Khz and bit-depth of 16-bits. The CD-ROM was burned with 16 files: four audio channels for three Quad systems. The files had titles such as "CD4_FrL.wav", which meant that it was the signal for the front left loudspeaker of the CD-4 version. Other file names included "QS_RrL.wav", being the rear left channel of the QS version. The other files followed the same pattern of labelling.

The song is called "Cherokee" from Enoch Light's Big Band Hits of the 1930s and 1940s. He used a Fosgate Tate 101a decoder for the SQ matrix version, A Sansui QSD-1 decoder for the QS matrix version, and a Marantz CD-400 demodulator for the CD-4 carrier version.

2.4 Creation Of Ambisonic Material

So far the Quad material had been collected and transferred into a format which was more suitable for editing and playing back as there was no need for a decoding anymore. The challenge at this point was to convert the Quad channels into Ambisonics.

Richard Elen's article titled "Transcoding "Quad" Recordings to Ambisonics" suggests that Quad is converted into a two-channel UHJ format. He explains how this can be done with the use of the rack-mount 'Transcoder' hardware unit. Unfortunately the author of this thesis did not have access to that unit. Being aware that there are some small computer software developed for such conversion, the author sent an email to Mr. Elen, asking which software would suit the desired task.

In his reply Mr. Elen wrote:

> *Hi, and thanks for your question.*
>
> *Bearing in mind the present availability of multi-channel digital audio distributions systems, I do not believe that transcoding quad recordings to 2-channel UHJ would serve a purpose today. You could simply play the recordings back as they were originally made, and recover their original intent. This is already common practice with DVD and DTS-CD material. The only purpose of processing quad recordings to UHJ was to make them available to people who did not have "discrete" quad equipment, and do it better than previous matrixing systems.*

You could transfer a quad recording direct into B-Format using either hardware (eg the original Pan-Rotate unit) or the increasing number of software solutions out there such as those from Thomas Chen. In this case you would place the four sources in the corners of a square at maximum radius. What you would then do would be to decode the B-Format to ITU 5.1 speaker feeds ("G-Format") using a Vienna decoder (preferably, or a regular one if not available). Again this can be done with Thomas's software or that from other people. The result would be able to be mastered to any of the current 5.1 digital disc formats.

The benefit of this would be that the B-format panning would create a "virtual quad array" that could be reproduced over a standard 5.1 system, thereby replaying the discrete quad original in a standard 5.1 replay system more accurately than simply playing the quad source through the LF, RF, LS and RS speakers in the 5.1 array, these not being in the right places in an ITU configuration.

Please bear in mind that while it is possible to generate a "B-Format" signal from UHJ, this is only truly possible if you have a 4-channel UHJ original. In the case of a 3-channel UHJ original there is no vertical information, so you can do planar conversion (fine for quad). But if you only have 2-channel UHJ as a source you CANNOT recover true B-Format from it, even planar only, as there is a significant amount of information missing due to the compromises inherent in encoding B-format down to 2-ch UHJ.

As 2-channel UHJ in particular is no longer necessary, and the compromises involved were far greater than in systems we are now able to work with, I do not think anything would be achieved by attempting what you propose.

Quad-to-G-Format, however, as described above, could be quite useful.

I hope this helps...
--Richard Elen

With this in mind, there was no longer the need to convert Quad into a two-channel UHJ, but five-channel G-Format. It was with this email that the project took a change in direction to consider whether the conversion would be beneficial to companies and individuals who already offer services for transferring Quad material on DVD.

Dr. Thomas Chen was then approached by e-mail enquiring about the availability, cost, and other information regarding the software he had written. The email also briefly explained the project. He replied with plenty of information regarding the software and its price, which unfortunately was beyond the budget of this project. Fortunately, he offered to do the conversions of the Quad into G-Format for free.

Mr. Patterson was provided with Dr. Chen’s postal address and asked to send the CD-Rom containing the Quad channels to Dr. Chen in California, America.

Dr. Chen received the CD-ROM and created B-Format versions of the Quad files, as well as G-Format files. He burned the files onto another CD-ROM, including a text file with the following message and sent it and the CD-ROM containing the Quad files to the author of this thesis:

> *I have included the B format files generated from the quad signals. They are known as BW, BX, and BY. These are then decoded into G format with the azimuth for decode at +/- 45 degrees, +/- 110 degrees and 0 center. I have processed them with shelf filters. The X is filtered with a shelf filter of +4dB and a turnover frequency of 150 Hz. The Y is also filtered with a shelf filter of the same quantity and frequency. Both X and Y have hi frequency shelf filter of -10dB at 7000 Hz. They are 12dB/octive slope filters.*
>
> *The final files are in G format and are known as GL(left), GR(right), GLS(left surround), GRS(right surround) and GC(center).*

Once the author received both the CD-ROMs, they were computer converted from '.wav' file format, to '.aif'. The conversion was mainly done for compatibility purposes, because from this point onwards, a different computer operating system would be used, as well as different software. The next step was to 'normalize' the mixes. This was done in an attempt to have all the songs in the experiment playing at similar volumes. This way the volume between tracks could be avoided as conflicting with the listeners' perception of localization. The four channels of the original SQ Quad mix were imported into Pro Tools, each placed in a separate audio track. The tracks were 'grouped' and 'normalized'. It was important that all the tracks were grouped before normalizing them so that the process would normalize the entire mix as one, setting the amplitude in respective to the other tracks. Otherwise if the tracks were not grouped, the tracks would have been normalized as individual channels, making all the channels as loud as possible before distorting and therefore changing the original Quad mix balance.

The same process was applied to the QS Quad and CD-4 Quad mix, as well as on all the corresponding versions of the G-Format converted Quad mixes. These six mixes which would then be the final samples used in the experiment, were backed up on a CD-ROM. A copy of that CD-ROM can be found attached at the end of this thesis.

2.5 Loudspeaker & Amplifier Selection

Following the creation of the audio material that would be used in the experiment, the focus turned to the remaining preparations needed to carry out the experiment. A search began for a set of nine loudspeakers in order to prepare a speaker array consisting of a Quad (4 loudspeakers) configuration along with a 5.1 (5 loudspeakers) configuration. Both would be positioned on the circumference of a single listening area. All the loudspeakers needed to be identical in brand, model, and specifications in order to ensure that the audio playback performance is same all around the surround sound image. If these were not identical in specifications and performance, the experiment results might have been affected.

Similarly, the amplifiers required for driving the nine loudspeakers would have to be of identical specifications too, for the same reasons. Due to the small availability of amplifiers that can handle nine separate channels for amplification, two separate bunches of speakers would need to be used. Units supporting five-channel amplification are presently widely available because of the growing popularity of 5.1 home cinemas. Two of these could be used, setting one to drive the four channels of Quad, and the second unit to drive the five channels of the G-Format.

The first step was to search for access to nine identical active studio monitors, which are recording studio quality loudspeakers with built in amplification. These would provide an easy solution to the need for separate amplifiers, and in addition provide great quality of playback. Unfortunately there was no free of cost access to such equipment, so the next step was to seek cost quotes from stores. Disappointingly, the required cost was beyond feasibility.

Not being able to get access to studio quality loudspeakers, the focus of the search shifted to consumer loudspeakers and amplifiers. Only a set of five loudspeakers and one five-channel amplifier were available at no financial expense, so the author began to once again seek rental options for a set of identical loudspeakers and amplifier. Not only there were no identical equipment available, but there were no rental companies renting home theatre packages of any type either.

The only possible option at this point was to purchase the required equipment, use them, and sell them as second hand once the experiment data have been collected. After some consideration, this would prove to be the best alternative. A pair of Creative Inspire 5.1 5300 surround sound systems were purchased (Figure 2.5.1). Each of the systems includes five small sized loudspeakers, which project the middle and high frequency ranges. Also included is a sub-woofer for the low frequencies. The sub-woofer enclosure has a built in amplifier that drives the sub-woofer as well as the five loudspeakers. The channel audio inputs and speaker feeds are located at the rear side of the sub-woofer enclosure.

Figure 2.5.1: Five small sized loudspeakers and the single sub-woofer/amplifier of the Creative Inspire 5.1 5300 system.

There were several advantages of ending up using this solution of equipment for the experiment. Firstly, since the specifications and performance capabilities of these surround sound systems were of a consumer standard, the results of the experiment and the data collected would correspond to the majority of the public who in fact are consumers. High quality loudspeakers and amplifiers are not commonly found in the average consumers' homes. Results achieved by low quality loudspeakers tend to be even better with high quality loudspeakers, but the case is rare the other way around.

Secondly, the performance between the two sets of the loudspeaker packages would have better possibilities of being truly identical as they were brand new. If equipment had been rented, the different amounts and type of use by previous users could have altered the performance of each set.

Lastly, the financial aspect of the project was to the author's advantage. Since the equipment could be sold again after the completion of the project, most of the initial costs would be re-covered. The uncovered costs would be approximately the same as in the situation of renting the equipment, with the advantage that the bought equipment could be used for as long as was necessary till the experiment was complete.

2.6 Selection of Location for Experiment

The experiment had to take place in a closed room with enough space to set up a decent sized speaker array. At the same time, the location needed to be one that could have access to a decent amount of individuals who could be asked to volunteer in participating with the experiment. The place chosen was classroom 4 on the first floor of the SAE (School of Audio Engineering) College in Sydney. The room's size allowed for a speaker array similar to one that would be found in a normal home cinema set up. In addition, there were audio engineering students who could be approached and asked to participate in the experiment.

2.7 Setting Up of Equipment

The two boxes of the Creative Inspire 5.1 5300 loudspeakers were taken to room number four. The room was measured and the centre was marked by sticking a small piece of masking tape on the floor. This point of the room would be the centre of the listening area for the set up. From that mark, another piece of masking tape was arranged on the floor at a distance of two meters from the front of the room. During this process, a measuring tape and a protractor were used for the sake of accuracy. The same was done towards the rear side of the room at two meters distance, and again the same process at two meters to the left and right of the room. Strips of masking tape were laid on the floor from the centre mark, to the two-meter marks in the four directions, creating a cross shape four meters in diameter on the floor. At this point the markings would be the basis for making a circular shaped listening area with a radius of two meters.

The next step was to place four stripes of two-meter long masking tape from the centre of the room towards the outside, at every 45 degrees from the lines of the existing cross shape on the floor. The ends of these stripes indicated the positioning for each of the four loudspeakers of the Quad configuration. Another two stripes were placed on the floor at 30 degrees on either side of the front line of the cross shape. These two new lines indicated the position for the left and right loudspeakers of the 5.1 configuration while the initial front line of the cross shape on the floor indicated the position for the centre channel of 5.1. At $\pm$ 110 degrees from the centre line, two meter stripes of masking tape were placed to indicate the position for the 5.1 left surround and right surround loudspeakers respectively.

Thereafter nine small desks were placed at the corresponding positions for the loudspeakers of both the Quad and 5.1 systems. On top of the desks, each of the nine loudspeakers was placed facing towards the centre of the listening area. There was no need to place anything between the surface of the desk and the loudspeaker to have the loudspeakers at the same elevation as the ears of the listeners inside the listening area. This was not necessary because the loudspeakers stood on small stands which were facing slightly upwards to match the elevation of the listeners' ears.

Three chairs where then strategically placed within the listening area. First chair was placed directly in the centre of the listening area. The second chair was placed at half the distance of the listening area's radius (1 meter away from both the centre and edge of the listening area) towards the right side. The third chair was placed at the very edge of the listening area (2 meters away from the centre) towards the left side. All the chairs where facing the front of the loudspeaker array. A piece of masking tape was also added to each chair, for labelling purposes. The chair in the very centre was labelled as "A", the chair at half the distance from the centre was labelled as "B", and finally the chair furthest from the centre was labelled as "C".

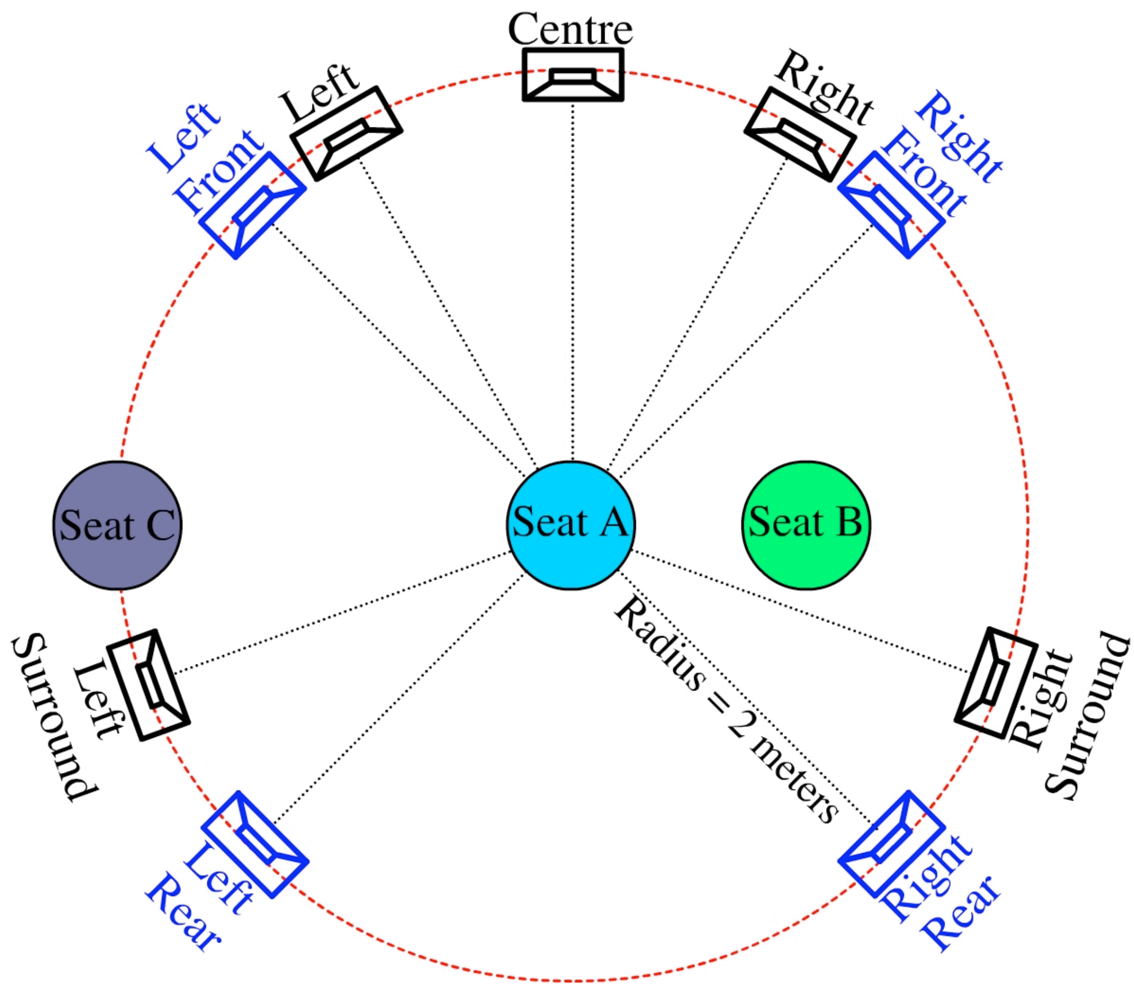


Figure 2.7.1: Set-up of both Quad and 5.1 configurations sharing the same listening area of a 2-meter radius. The Quad configuration is indicated by the blue colouring, while the black colouring shows the 5.1 configuration. The coloured circles indicate the positions of chair A (light blue), B (green), and C (purple).

For identification purposes and to avoid confusion, a piece of masking tape was placed on top of each sub-woofer/amplifier enclosure. One enclosure's masking tape had "G-Format" written on it, and the other had "Quad" written. The markings would help with the wiring of the each enclosure to drive the loudspeakers of each surround sound system.

At the back of the sub-woofer/amplifier enclosure there were five output connections. The connections were labelled "L" (Left), "R" (Right), "C" (Centre), "LS" (Left Surround), and "RS" (Right Surround). On one of the enclosures, each output was connected by wire to the input of the corresponding loudspeaker of the 5.1 set up. The same was done with the outputs of the Quad sub-woofer/amplifier enclosure, connecting the outputs to the corresponding loudspeaker. Unlike the wiring of the 5.1 where all the outputs where used for connecting loudspeakers in the Quad wiring only, the "L" (Left), "R" (Right), "LS" (Left Surround), and "RS" (Right Surround) connections were used as there was not a "C" (Centre) channel in Quad.

So far, all nine loudspeakers were connected to their appropriate sub-woofer/amplifier enclosure, but there were no sources connected to either of those enclosures to provide the audio signals. The audio material and signals for the amplifiers would be provided through a sound card connected to a computer.

The soundcard used was a MOTU (Mark of The Unicorn) 1224, featuring eight inputs and eight outputs. Clearly this did not provide enough outputs to drive the nine loudspeakers separately. The solution was to use “Y” shaped wires. These wires allow the transfer of the same signal to two sources from a one-jack-connection. On one end of the wire there was one jack, and on the other side there were two jacks. Five of these cables were used to overcome the shortage of individual outputs on the sound card.

A “Y” cable was inserted into output number 1 of the sound card. Each of the two jacks at the other end of the cable were connected to the “L” (Left) input of each sub-woofer/amplifier enclosures. The second “Y” cable was inserted into output number 2 of the sound card, connecting to the “R” (Right) inputs of each sub-woofer/amplifier enclosure. With this method, output 3 on the soundcard was connected to the “LS” (Left Surround) inputs, and output number 4 to the “RS” (Right Surround) inputs. Output 5 on the soundcard was connected to the “C” (Centre) input of only the sub-woofer/amplifier enclosure that would drive the 5.1 set up.

The sound card was connected to a computer that along with a computer monitor was set on a desk in front of the listening area. Using MOTU’s Digital Performer 3.0 audio sequencing software, the audio samples that were going to be used for the experiment were prepared. The four channels of the Quad material were imported into the software and each channel was placed on a separate audio track in the sequencer. The LF channel was placed assigned to output 1 of the sound card and the RF was assigned to output 2, LR to output 3, and channel RR to output 4. This was done for each of the three Quad formats, saving each session separately.

Similarly, sessions were created for the G-Format material. The channels were imported and assigned to the individual outputs of the sound card, the same way as the Quad material. The only difference was the addition of the centre channel of the G-Format, which was assigned to output 5 of the sound card.

All the saved files of both the Quad and the G-Format sessions were placed on the desktop folder within the computer’s operating system. They were numbered 1 to 6 as the following table indicates.

File name	1	2	3	4	5	6
Format	G-Format CD-4	Original CD-4	G-Format QS	Original QS	G-Format SQ	Original SQ

The songs used were too long to be used for the experiment. In order to reduce the length of the audio material, all the six sessions were edited to create start and stop markers.

What these markers did was to allow for the playback of songs from the point in time where the ‘start’ markers were inserted, and to stop at the point in the songs where the ‘stop’ markers were inserted. These markers were set on all six sessions at the same point in time of all the songs. The time period between the markers was approximately thirty seconds long. Care was taken when selecting the thirty seconds region to be used. The selected portions of the songs were selected because there were changes in the music instrument positioning and panning in the surround sound image. This would provide for better demonstration of the systems’ imaging capabilities instead of playing sections of the song where there is no instrument movement.

The set up was tested to ensure everything functioned properly. A suitable volume level for the amplifiers was found and it stayed at that setting for the following couple of days until the experiment was finished. When both amplifiers were turned on, the audio material would play through all the loudspeakers. This was due to the method that the sound card outputs were connected to the amplifier inputs. Regardless of whether the Quad or G-Format sessions were played on the computer, the signals would play through both loudspeaker configurations, since the ‘Y’ cables used, fed the signal played by the computer to both amplifiers. The solution to this was to manually switch off the amplifier of the loudspeaker configuration that was not intended to be used. When a Quad session was being played on the computer, the amplifier of the 5.1 loudspeakers was switched off, and vice versa.

2.8 Experiment Process

Since the experiment was taking place in a room of the SAE Sydney building, students from the college were approached to participate in the experiment. Three people would be taken to room with the loudspeaker array and would be asked to sit in any of the three seats within the listening area. They were each handed a questioner and explained the procedure for the completion of the form. The explanation given was the same as the one written on the first page of the questioners. Further care was taken to avoid giving away any information that may have indicated that some audio samples may be better than others.

Once they had completed the questions on the first page of the questioner, they were played the six audio samples that were explained earlier. They were played in the same order as they were numbered from 1 to 6 (Track 1: G-Format CD-4, Track 2: Original CD-4, Track 3: G-Format QS, Track 4: Original QS, Track 5: G-Format SQ, Track 6: Original SQ). On the second page of the questioner they filled out the rating scales for each audio sample, under the box corresponding to the seat they were sitting at. A person sitting in the centre of the listening room would be sitting on seat “A” so would fill out the six rating scales for the samples under the section labelled “Seat A”.

When all the six samples were played to the respondents and rated by them, they switched seats and all the six audio samples were played again until the six rating scales were completed for the second listening positions. The entire process was once again repeated a third time while having switched seats again for the third time. At this stage all six audio samples had been played, heard and rated at all three different listening positions. The respondents selected on the last question of the form whether they were interested in receiving the results of the project and handed the forms back to the author. A total of seven groups of three people were tested, and an additional single person when no more people were interested in participating, making the total number of participants 22.

When there were no more people willing to participate, the equipment was collected. The collected completed questioners that can be seen in the appendices were placed in an envelope until they were used for analysis.

2.9 Summary And Conclusion

The first step in preparing for the experiment was to create the questioner. A pilot questioner was created in order to be tested with a small group of individuals. The aim was to receive feedback concerning the formation and wording of the questions, and not to collect actual results that would be used for analysis. Feedback was used from the respondents of the pilot questioner to create the final questioner to be used in the experiment.

Due to an unsuccessful search for Quad material in Sydney, the Quad material was obtained from a Quad enthusiast in Texas. Once he transferred a song in three different Quad versions onto a CD, the individual audio channels were now accessible by Dr. Thoms Chen in California who used software to convert the tracks into G-Format. Once the author received both copies of the Quad and G-Format versions, he selected the location of where the loudspeaker array would be set up.

A computer was used to play the audio tracks through a multi-channel sound card. The output feeds of the sound card drove two amplifiers, one driving five loudspeakers in the positions of a 5.1 configuration, and the other amplifier feeding four loudspeakers positioned in a Quad square configuration.

Participants sat at one of three available seats within the listening area. Six audio samples were played to them and they ranked each one out of five possible points regarding the accuracy in surround sound imaging and localization clarity. They then switched seats and repeated the process again, and switched seats one last time until they had rated all the audio samples while sitting at all possible seating positions.

A total of twenty two people participated in the experiment. Unfortunately there were no more people interested of willing to participate in the experiment. A larger number of participants would be an advantage for providing a more accurate analysis, but the author had to continue to the next step of the step of the project with what he had.

3. Data Compilation And Analysis

3.1 Analysis of Data

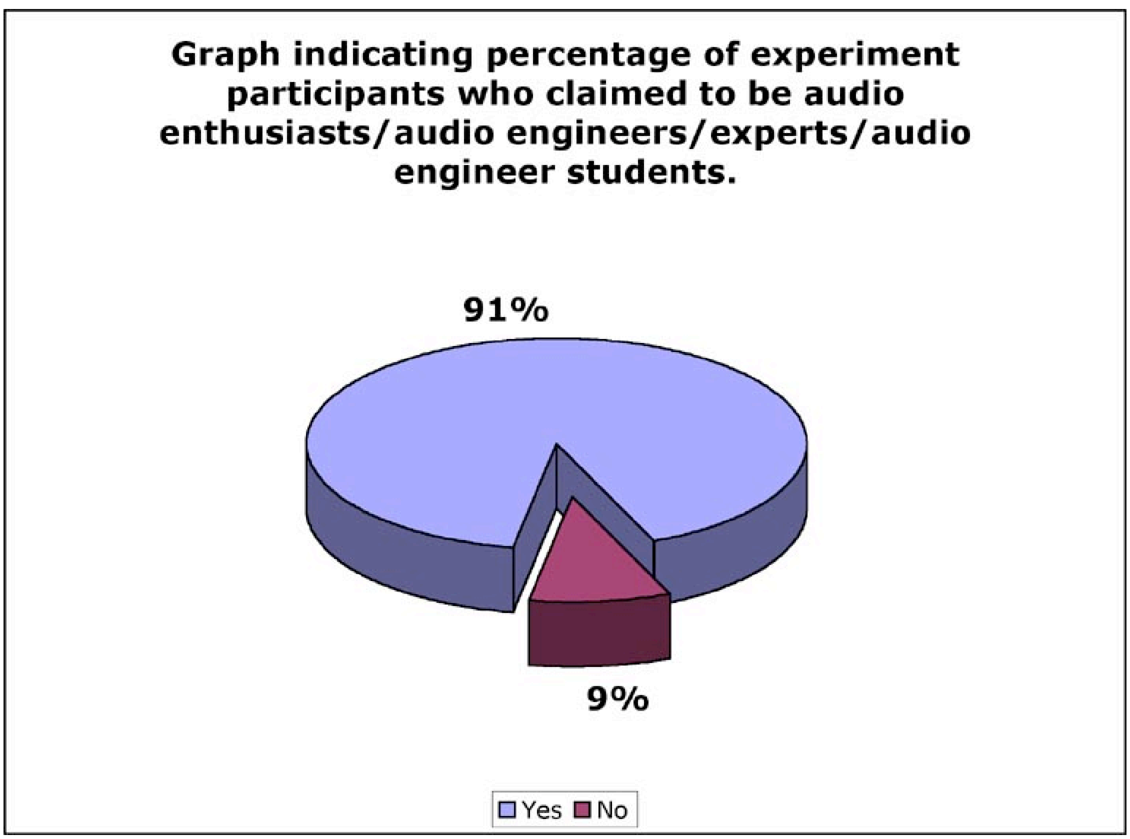
With all the data collected from the experiment, the next step was for the data to be tabulated. Using computer software, a spreadsheet was created with the information from all the completed questioners. The full spreadsheet is available in the Appendices chapter. At this stage the data was all compiled into mostly numerical charts, making it difficult to use for analysis or use for drawing conclusions. Patterns in the data began to become more easily visible as graphs were generated based on the chart's data. There are different methods of arranging data and creating graphs using the data. It was important to choose the appropriate methods for this analysis. Data from the first set of questions regarding the background experiences of the respondents was displayed by basic pie charts. The data regarding the ratings of the various surround sound samples were analysed and displayed by calculating the percentages of the ratings.

3.1.1 Demographics

The first three questions focuses on the respondents' name, and contact numbers and had no effect to the results of the experiment. Therefore there was no need to analyse their responses. Their purpose in the survey was for authenticity.

Question 4) *Are you an audio enthusiast/engineer/expert/audio engineer student?*

Yes No (Circle your choice)



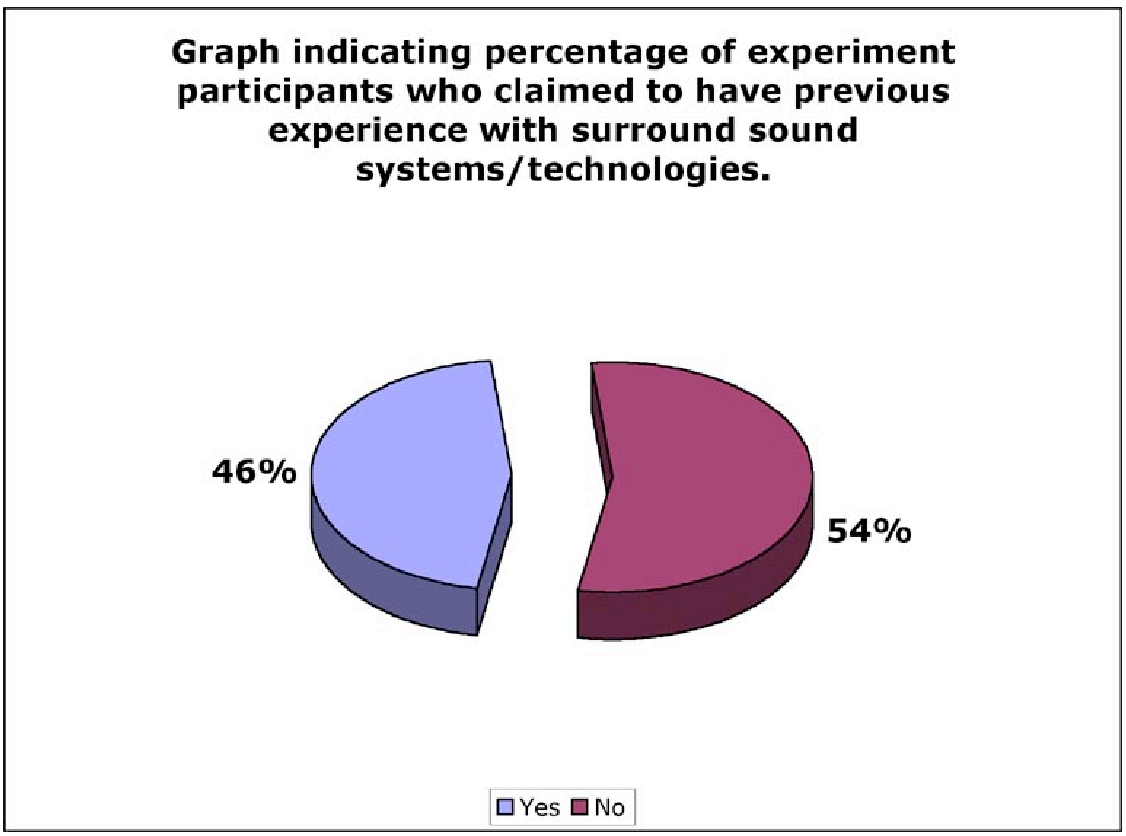
91% (20/22) of the participants stated to be involved with audio at a level higher than the everyday consumer. Only 9% (2/22) of them claimed not to have any significant experience with audio and therefore were considered to be ordinary consumers. The reason for the large number of audio enthusiasts was a result of the location for the experiment. The experiment took place in a room inside SAE College. It is a college specialising in teaching audio engineering, so most of the participants were students attending the SAE College.

This could have had an affect on the results as the listening capabilities of an audio engineer student might be better than a non-audio enthusiast. This though could not have made a big difference as the audio student participants had only recently commenced their course therefore not having had significant experience or practice to improve their hearing.

Question 5) *Have you had any previous experience with surround sound systems/technologies?*

Yes No (Circle your choice)

(If yes then please give a brief description in the space below).



44.5% (10/22) of the respondents stated they had previous experience with surround sound system and/or technologies. The remaining 54.5% (12/22) of them stated not having previous experience. Those who answered "yes" were asked to write what that past experience was. Most responded with experiencing it at home on a home theatre system, two mentioned the cinema, and two had experience with mixing surround sound in a recording studio environment.

Unfortunately there were not enough participants to allow for an accurate comparison between the results of those who answered "yes" and those who answered "no" in either questions 4 and 5. The benefit of such a comparison would be to determine whether trends or patterns of different results would appear due to the different levels of experience.

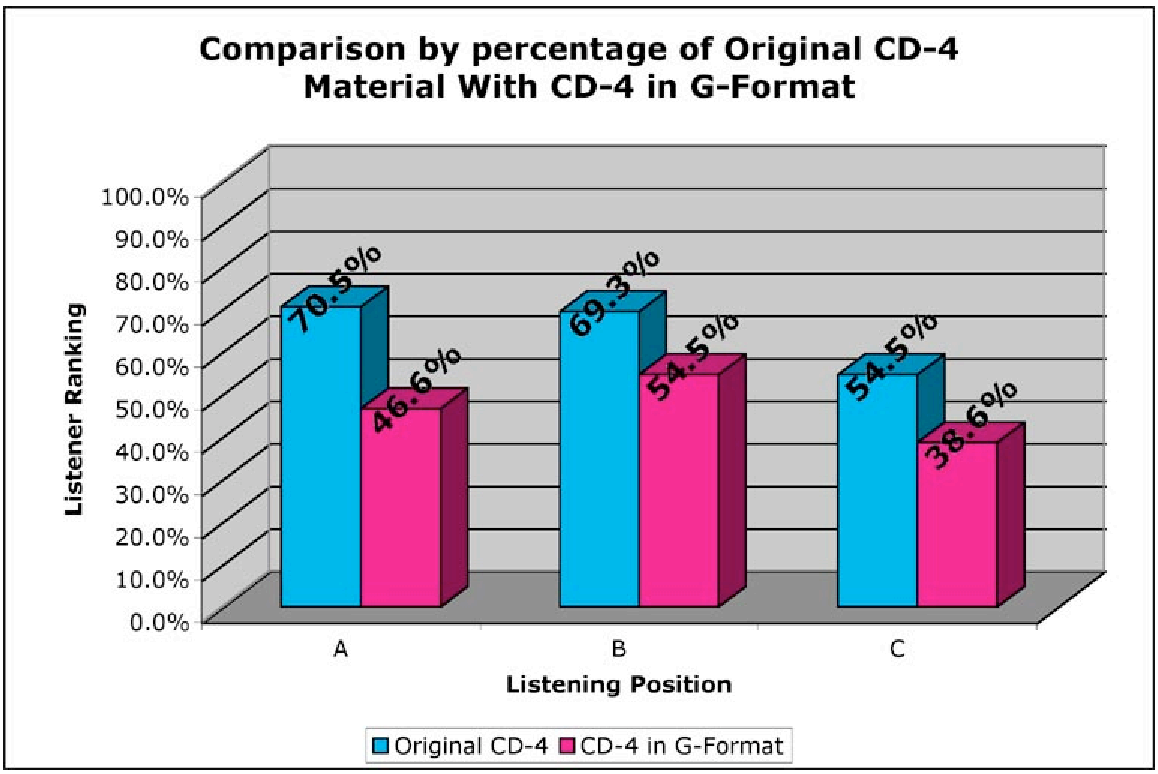
3.1.2 Conversion of Data Into Percentages

The rest of the analysis comes from the tabulated figures that represent the respondents' rating of each surround sound system from 1 to 5. The first method of analysis was in the form of percentage. The ratings for each audio sample heard at all the different listening positions were added. For example the Original CD-4 sample at listening position "A" final sum of the individual ratings was 84. In order to convert that figure into a percentage, certain procedures had to be carried out.

The maximum possible sum for each audio sample was 110 if all 22 participants chose to rank it as 5. The minimum possible sum was 22 in the event that all 22 participants rated the audio sample as 1. As a result, the range is 88 (110-22). In order to come up with the percentage, 22 was subtracted from each audio sample's rating total. In the case of the Original CD-4 sample it was 84-22=62. The result is then divided by 88 to calculate. This process is done for all the audio samples, and three bar graphs were generated, which are indicated below.

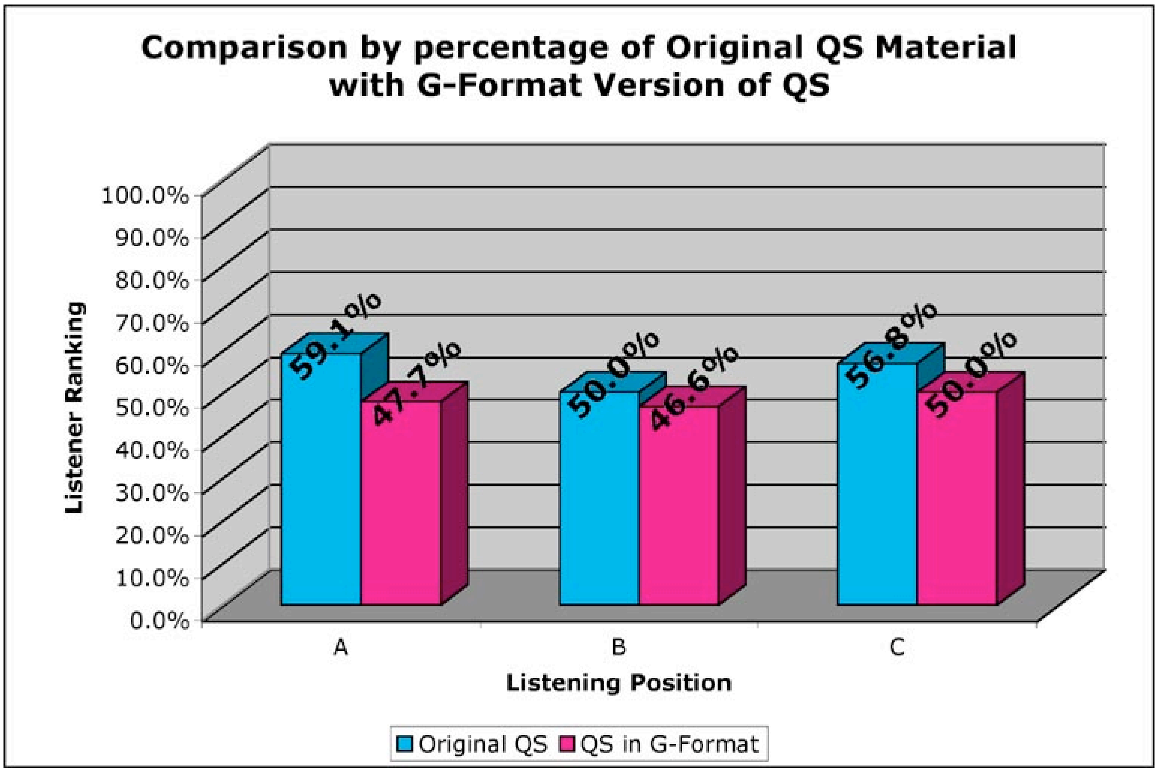
3.1.3 Original CD-4 vs. G-Format CD-4

This bar graph compares the Original CD-4 recording with the CD-4 material converted into G-Format. At all three listening positions, the original Quad recording had better localization and image stability that the G-Format version. As expected, the highest results were achieved by both versions at listening position "A" as it is in the very centre, where the sweet spot is at its best. Again, as expected the performance of the Quad recording diminishes as the listener sits at a greater distance away from the centre. The decrease in performance is not constant. It seems that the decline is greater the further the listener moves from the centre. Better analysis could have been possible if a larger variety of listening positions were examined during the experiment. Unlike the expected decrease in the Quad recording in relation to listening position, the G-Format version did not decrease. It appears that the G-Format had the best performance when sitting in "B" sitting position, at half way between the centre and the perimeter of the loudspeaker array.



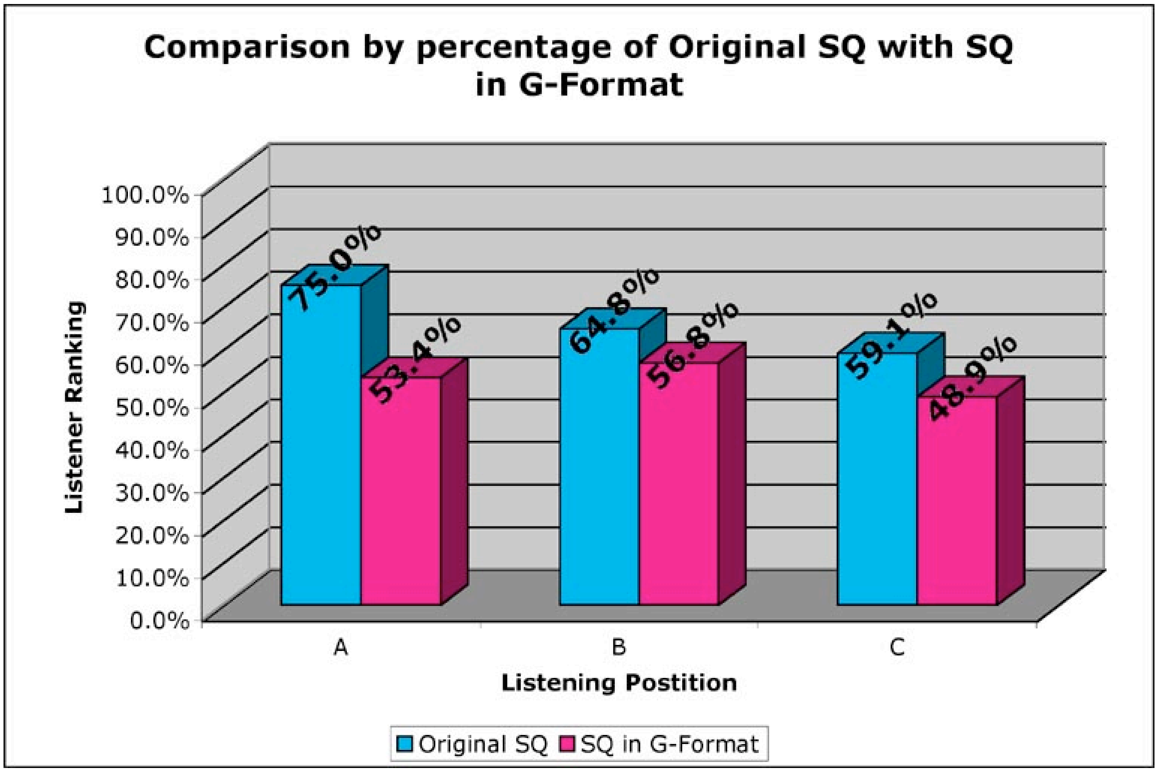
3.1.4 Original QS vs. G-Format QS

Similarly with the previous graph, the below graph displays the performance of original QS Quad material compared to the same material but converted into G-Format. Unlike the previously mentioned CD-4 system comparison where there was an obvious decrease in localization as the listener moved away from the centre of the listening area, both the QS and QS in G-Format differ. In both versions, listening position “B” had the lowest results. Surprisingly, the G-Format version had the best results at the very edge of the listening area, at listening position “C “, followed by position “A” at the centre. The results of the original QS version at position “B” had exactly the same results as the QS G-Format version at the further position of “C”. Most importantly, in all listening positions, the original Quad version had better localization results than the G-Format version.



3.1.5 Original SQ vs. G-Format SQ

Comparing, the original SQ version to the SQ in G-Format version had similar patterns to the CD-4 comparison, even though the performance values differ. There was a constant decrease in localization for the original SQ version as the listeners sat further away from the centre. The G-Format version though has the best results in position “B”, followed by position “A”, and lastly by position “C”. Once again the results of the original SQ version had better localization in all positions, but especially in position “A” where there is a significant preference for the original SQ version.



3.2 Summary And Conclusions

With all the data analysed it is now possible to come to conclusions regarding the results. In all instances the original Quad versions provided better localization and accuracy in surround sound image than their corresponding Ambisonic versions. This contradicts Richard Elen’s suggestion. According to his statement, the G-Format versions should have at least as good localization as the original Quad at position “A”. As the listener moves further away from the centre, the accuracy in the surround sound image should decrease at a much slower rate than the original Quad version. This is was not the case with these experiments. Explanations of possible reasons for the contradicting results will be discussed in chapter 4.

Moreover, when comparing the three different Quadraphonic systems and their accuracy in representing a soundfield, the one with the most satisfying results was the SQ in position “A”. It had the highest ranking for position “A” at 75%, followed by CD-4 at

70.5%, and lastly by QS at 59.1%. In terms of sweet spot size, CD-4 provided a larger sweet spot by dropping in imaging accuracy from positions "A" and "B" by only 1.2%, and then at position "C" by dropping with a steeper 14.8% in imaging accuracy. On the other hand, the SQ system, did not maintain the sweet spot as well. The drop in image accuracy between position "A" and "B" was a larger 10.2%, and between position "B" and "C" a small but still significant 10.2%. The drop in the SQ performance is greater than the CD-4, but still on average ratings, the imaging of SQ was higher than the CD-4. Therefore the SQ proved to be the best system of the three, followed by CD-4, and the QS last.

4. Conclusions And Recommendations

4.1 Project Procedure Conclusion

The procedures and steps followed from the early stages of the project have mostly been successful and appropriate for the project's aims. The creation and testing of a pilot questioner proved to be a good move as without the corrections made, there was a possibility that a number of experiment participants would not understand the objective. The actual process of carrying out the experiment was successful and only some of the following issues could have been done differently, even though some options may not necessarily have been advantageous.

The experiment could have been carried out by using any single Quad format, converting it to Ambisonics and then testing them against each other. However, the effort of preparing the Ambisonic material, acquiring the necessary equipment, setting them up, preparing the questioners, and convincing individuals to participate in the experiment was better justified when tests for more than one Quad system were carried out. The experiment could have been even more beneficial if even more Quad systems were tested but the author was fortunate enough to find the same song in three different formats of Quad. Furthermore, testing a larger variety of songs on different systems would have more accurately reflected on the performance of each system. On the other hand it can be argued that too many songs and systems would have been too time demanding on the participants to complete the questioners. In fact the time that was required for the completion of this experiment was by some participants considered too long.

The author was fortunate enough to have Dr. Thomas Chen to offer to convert the Quad recordings into G-Format, as author could not afford to buy the required software in order to carry out the conversion himself. Even if the author had managed to get a hold of a larger variety of Quad systems and songs, it would be uncertain whether Dr.Thomas Chen would be willing to commit that much time to converting the material to Ambisonics.

After the converted material was received, the author noticed an error with the conversion process, one that might have affected the results. Dr. Thomas Chen was meant to take the four signals of each Quad song and configure them in a square shape loudspeaker array within his software and output the G-Format signals. In the CD-ROM that Dr. Thomas Chen sent back to the author with the converted material, he had included a text file, stating the exact setting which he used to position and convert the Quad signals into Ambisonics. He states that he placed the two front channels at +/- 45 degrees, and the two rear channels at +/- 110 degrees. Unfortunately those angles do not result in a Quad square shaped loudspeaker configuration. For the conversion to be correct, the two rear channels should have been set at +/- 135 degrees. The +/- 110 degrees setting is the dimension of the two rear loudspeakers of a 5.1 set up. By the time the CD-ROM was received, there was not enough time to have the Quad material sent back again and have Dr. Thomas Chen convert the Quad material again, and so the author carried on with the experiment.

The analysis of the audio sample ratings was done in the form of percentages. The higher the percentage a system had been rated by the participants, then the better it was, and further analysis was carried out from that point onwards. Other methods could have been used to analyse the data, such as indicating the mode and mean values of each system. In fact calculations and graphs were generated based on those analysis methods, but the author decided not to use them.

The purpose of the experiment was to compare six versions of a song at three different positions and determine which offered the best surround sound imaging. The use of analysis methods such as mode and mean values would not add to the findings anymore than the use of percentage, and so they were not used. Actually, analysing with percentage figures it can be more accurate than working with mode or mean values. Mode and mean values would range from 1 to 5. A system whose rating was 80% and another that was rated 85% can easily be compared. If those two same systems were in the form of mean value, they would both have a value of 4, not being able to distinguish which performed better.

4.2 Project Results Conclusion

As mentioned with the analysis of the results, Richard Elen's suggestion did not turn out to be true. The performance of the Ambisonic versions was worse than of the original Quad versions at any of the listening positions. Furthermore there were no signs of an increased size in the sweet spot as it was suggested that it would happen. According to the analysis, converting Quad recordings into G-Format Ambisonics, does not improve any of the mentioned aspects, but instead decreases the image accuracy.

One possible factor that might have affected the results of the experiment is the previously mentioned error in the conversions process. When converting the Quad material into Ambisonics, the configuration for the rear two channels was set at the wrong angles. Instead of being set a +/- 135 degrees to conform to the 90 degrees that every loudspeaker should have in Quad, they were set at +/- 110 degrees, which is the positioning for a 5.1 configuration.

As a result, the rear image was spread 25 degrees wider on each side. This could have been a reason for the poor surround imaging the experiment participants rated. At the same time, this may not have been the reason for the low results, as the error in the conversion would have moved the location of the instruments in the song. Instruments in the rear corners would have moved more forward towards the sides of the listener, but that would have resulted in a greater density of instruments at the front half of the listening area. Therefore the listeners would have heard the same instruments but from a different location than the original Quad version. There would be a whole created in the rear image, but closer placed signals in al the remaining area. This would then mean that some of the respondents rated each audio sample according to preference of instrument and signal positioning inside the image.

More realistic and accurate results may have been collected if the same song used in all the different Quad systems contained more instruments that moved drastically, truly testing the phantom images of an Ambisonics system. The ideal music material to be used on the experiment would have been one where an instrument or other signal moved in a constant rate in a circle around the listening area. Unfortunately such a song would be far too difficult to locate in Quad format, especially at several different Quad formats.

A greater number of participants would provide more realistic and accurate results but due to the lack of availability in possible locations for setting up the loudspeaker array, it had to be set up at SAE College Sydney. This provided a short number of interested individuals from audio engineering classes, but limited the participants to just being SAE College students. An attempt to convince outsiders to come to the college quickly proved impossible.

Lastly the results could have been inaccurate by participants not taking the questioner seriously, filling out the questions just to complete the questioner and get over and done with it. Even if not intentional, there is always the possibility of participants not fully understanding the concept of the experiment, or unintentionally filling out the wrong answer due to lack of alertness, energy or focus.

With all this in mind, it can be said that based on the results and analysis of this experiment, Ambisonics cannot be implemented to restore Quad recordings. Quad recordings is an issue of the past and for those who wish to continue enjoying them with the facilities of the presently technologically advanced way of life, they can continue to have their records transferred onto four-channel DVDs. But, they will not have capability with their 5.1 loudspeaker array. Every occasion that they wish to playback Quad music off a DVD, they will need to move the 5.1 set up loudspeakers to suit the Quad original configuration.

4.3 Recommendations For Further Research and Study

Further study could continue with comparing other Quad formats with their converted version in Ambisonics. These formats could include the RM (Regular Matrix), 45j, Matrix H, Stereo 4, and Dynaquad. But most interesting would be to try this conversion with the UD-4 Quad system. UD-4 is said to be the only Quad system capable of accurately representing a sound moving around the listener at a constant speed. This made UD-4 the most accurate of Quad systems, but lacked the market success for reasons similar to the ones that cause the entire Quad technology to fail.

Further research could be carried out with a larger listening area, allowing for a greater number of listening positions to be tested. This project only tested one part of the outside perimeter of the loudspeaker array, and only tested one part of the area between the centre and the perimeter. With a larger number of positions, results could be obtained for several seats all around the loudspeaker array perimeter and in the area in between the perimeter and centre.

Finally, the study could select its participants to be audio experts, and having them write qualitative information regarding the different versions at different listening positions.

5. Glossary, Bibliography, References, Electronic References, Other Sources Used, Acknowledgements

5.1 Glossary

Aux/Auxiliary Send: An assignable split of a signal at line-level. Used to send a copy of a signal to another audio/visual device.

CD: (Compact Disc): Storage medium developed by Sony and Philips in the early 1980s. Allows for storage of audio, video, data and many more formats. Currently the most popular format of audio distribution.

Digital Performer: Audio and MIDI sequencing computer software developed by a company called MOTU (Mark Of The Unicorn).

DVD: (Digital Versatile Disc): A new media for the distribution of data, audio, film, images and many more formats. It allows for multi-channel audio transmission at high resolution and bit depth.

Loudspeaker: Device acting as a transducer, converting electric energy into acoustical energy. More commonly know as "speaker".

Pro Tools: Audio and MIDI sequencing computer software developed by a company called Digidesign.

Quad: Configuration and system of audio playback where the listener is surround by four loudspeakers at 90º from each other. Also know as Quadraphonics, Quadrophonics, Quadrisonics, and Quadrasonics.

SACD: (Super Audio Compact Disc) High quality media developed by Sony and Philips, initially intended for audio storage. Provides multi-channel capabilities and sampling rates up to 64 times of the earlier CD.

Group/Grouping: Method of linking separate audio channels in a console, or computer audio software, enabling the actions on one channel to be repeated for all the channels in the same group.

Normalize/Normalizing: Process of boosting a digital signal to the maximum possible level before causing the signal to distort.

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5.6 Acknowledgments

Many 'Thanx' to Dad (S. Digenis), Mom (O. Digenis), and Sister (P. Digenis).

An extra big "Thank You" to Alexandra Stephanou.

Dedicated to Teli Ladakakou.

6. Appendices

6.1 Pilot Questioner

Thank you for taking the time to participate in this experiment. All the information you will provide will be strictly used for this experiment only and not shared with any third party.

The experiment aims to test the effectiveness of different surround sound systems. You will be seated in a chair within an area surrounded by speakers. Three pairs of music tracks will be played back over the speakers. After each pair of tracks is played, you will need to rank each track in terms of surround image accuracy and ease of localization.

Circle number 1 if you feel there is a poor sense of surround imaging and inaccurate localization. Circle 5 if you feel the imaging and localization is great. Circle the any of the numbers in between 1 and 5 according to your perception of the sound. Please note that you are not judging the tracks according to the musical performance, quality, or music style preference.

On the desk that you will be seating there will be a sticker with either a letter "A", "B", or "C". Fill out the section of the form according to the desk you are sitting on. When you have completed the questions for the three pairs of tracks, you will do the same procedure while seating at each of the remaining desks.

If you have any questions, do not hesitate to ask for assistance. Thank you

1) Name:

2) Email address:

3) Contact Number:

4) Are you an audio enthusiast/engineer/expert/audio engineer student?

Yes No (Circle your choice)

5) Have you had any previous experience with surround sound systems/technologies?

Yes No (Circle your choice)

(If yes then please give a brief description in the space below).

Seat A						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Seat B						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Seat C						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5

The results of this research project will be available by July 2002. Would you be interested in receiving a copy of the final thesis via email?

Yes No (Circle your choice)

6.2 Final Questioner

Thank you for taking the time to participate in this experiment. All the information you will provide will be strictly used for this experiment only and not shared with any third party.

The experiment aims to test the effectiveness of different surround sound systems. You will be seated in a chair within an area surrounded by speakers. Three pairs of music tracks will be played back over the speakers. After each pair of tracks is played, you will need to rank each track in terms of instrument balance and location. This means you will be judging whether the instruments seem to be coming from an accurate and realistic distance and direction from where you are sitting.

Circle number 1 if you feel the surround sound is poor in sense of direction and realism, circle 5 if you think it is great. Please note that you are not judging the tracks according to the musical performance, quality, or music style preference.

On the desk that you will be seating there will be a sticker with either a letter “A”, “B”, or “C”. Fill out the section of the form according to the desk you are sitting on. When you have completed the questions for the three pairs of tracks, you will do the same procedure while seating at each of the remaining desks.

If you have any questions, do not hesitate to ask for assistance. Thank you

1) Name:

2) Email address:

3) Contact Number:

4) Are you an audio enthusiast/engineer/expert/audio engineer student?

Yes No (Circle your choice)

5) Have you had any previous experience with surround sound systems/technologies?

Yes No (Circle your choice)

(If yes then please give a brief description in the space below).

Seat A						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Seat B						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Seat C						
Pair 1)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 2)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5
Pair 3)	Track A	1	2	3	4	5
	Track B	1	2	3	4	5

The results of this research project will be available by July 2002. Would you be interested in receiving a copy of the final thesis via email?

Yes No (Circle your choice)

6.3 Correspondence With Tab Patterson

Hello there,

My name is Aristotel Digenis, and near to completing my BA Honours in Recording Arts in Sydney. For my final thesis I need to carry out an experiment with Quadraphonic recordings. I looked and found some Quad Vinyl here in Sydney, but I do not have the appropriate needle or decoder to retrieve the four channels. I then started to look for Quad reels, so that I can book out a studio that has a reel player and import them into Pro Tools. Unfortunately I have had no luck!

Since you are involved in this field, would it be possible for you to extract the four discreet channels, capture them into the computer(44.1, 16-bit), and then burn a data CD with the four channels as AIFF of WAVE files?

I would need to have a song in SQ, a song in QS, and one in CD-4 if possible. I would only need 1 minute of each song, and it is for educational purposes so I don't think there would be any problem with copyright matters.

One additional question, Quad reels are 1/2 inch or 1/4 inch?

Please let me know if you could help me, and then the details can be arranged.

Regards,

Aristotel Digenis

Does it have to be the same song? I might have 1 or 2 in all three formats,
but I'm not sure...

Tab

If they can be the same song in different formats (like SQ, QS CD4) then that would be even better.

Aristotel

So you just want wav files then?? No encoding? 1 minute of each song, right?

Yes...Wave or AIFF..either will be fine.AIFF is slightly preferable but I can still work around Wave.

Basically it should be like this:
-A folder titled SQ having 4 files inside labeled frontleft.aif, frontright.aif, rearleft.aif, and rearright.aif
-Another folder titled QS with the similar files
-and one last folder called CD-4 with the similar files

I only need about a minute of each song, lets say starting at after 1 minute into the song. Preferably if all the SQ QS CD4 can be of the same song.

Then just a little .txt file with information on the artist name, song title etc..just for the Bibliography section of the thesis.

Let me know if it's all possible. I will of course pay for costs of the CD, and postage etc.

Thanking you

Aristotel Digenis

OK...I found 1 song on all 3 formats. It is Enoch Light's Big Band Hits of the 30s and 40s. The song is "Cherokee." I never compared the three back to back. The song is very discrete in nature. What is interesting is how well the SQ and QS versions sound, yet the CD-4 doesn't sound as discrete at times. The sax solos leak a little in the front right channel even after tight calibration. Most of the time, the CD-4 will sound better....I think. Saxes are hard to isolate with CD-4 because they distort. I used some high end equipment and an aligned turntable. I used a Fosgate Tate 101a for SQ, a Sansui QSD-1 for QS and a Marantz CD-400 demodulator for CD-4.

Use the above for your "liner notes." The files are marked SQ_FrL, SQ_FrR, SQ_RrL and so on....

Where do I send this?

Thank you very much,

Apart from comparing the SQ, QS, and CD-A systems, they will be compared with processed versions. The specific processing is said to dramatically increase the sweet spot, as well as in some cases add accuracy to the image. All versions will be compared with various people, and data collected to determine wether there truly are improvements.

The data CD that you have prepared will now need to be sent to a professor in California, where he will add the processing as I don not have the appropriate hardware/software.

He then will send me the data CD you prepared and the data CD with the processes files that he will make. At that point I will carry out the tests and continue to complete the thesis.

The thesis will be handed in by July 4th (your independence day if I am not mistaken), and a copy of the final thesis will be emailed to you. the steps and procedures for the processing will be explained, so if the data collected show improved results, you can include it as part of your services.

The thesis will also be posted on my website, which will include links to Spatial and surround sound related sites. If you have no objection, I would like to add a link to your web site as well, and to add your name in the "credits" section of the thesis.

Please let me know of your full name and postal address in order to prepare an international money order to cover the expenses of the CD, postage, and your services.

I will let you know of the postal address where the CD needs to be sent to, as soon as the professor replies to my email confirming the correct address. Unfortunately that may take a day or two, due to the nearly 20 hour difference between Sydney and California.

Thanking you,

Aristotel Digenis

My address is....

Tab Patterson
XXX XXXX XXXX XXXXX
XXXXX, XX XXXXX USA

I'll only charge $10.00 to do it..

Hello again Tab,

I got the address that the CD needs to be sent to:

Thomas Chen, M.D.
Custom Recording/Studio C
XXXX XXXXXXXXX XXX
XXXXXX, XX XXXXX
USA

I will send the money order on Monday morning (Its already the weekend here in Sydney). Please let me know when the CD is on its way to CA.

Have a nice weekend.

Aristotel Digenis

Dear Tab,

I have received your disk and the additional conversions from California. Everything is great. I will keep you informed with the results of the thesis.

Thank you

Aristotel

6.4 Correspondence With Richard Elen

Dear Richard

Having read your article "Transcoding "Quad" Recordings to Ambisonics" I am interested in carrying out tests to see the type of results achieved by this process. The general idea is to set up a Quadraphonic speaker set up, and playback original Quadraphonic material, followed by the same material converted into UHJ. I will get several individuals to sit within the speaker array, and have them fill out surveys regarding which version sounded better to them.

My main concern at the moment is that I do not have any of the necessary hardware for making the conversion. There are software solutions for conversion to UHJ from B-Format and vice versa such as the ones written by Angelo Farina, but can this be used instead of a UHJ transcoder? Perhaps there are some controls on the hardware which are not available on any software? My question simply is, can I convert Quadraphonic recordings into UHJ with software? If so then which software would do the job?

Thanking you in advance

Aristotel Digenis

Hi, and thanks for your question.

Bearing in mind the present availability of multi-channel digital audio distributions systems, I do not believe that transcoding quad recordings to 2-channel UHJ would serve a purpose today. You could simply play the recordings back as they were originally made, and recover their original intent. This is already common practice with DVD and DTS-CD material. The only purpose of processing quad recordings to UHJ was to make them available to people who did not have "discrete" quad equipment, and do it better than previous matrixing systems.

You could transfer a quad recording direct into B-Format using either hardware (eg the original Pan-Rotate unit) or the increasing number of software solutions out there such as those from Thomas Chen. In this case you would place the four sources in the corners of a square at maximum radius. What you would then do would be to decode the B-Format to ITU 5.1 speaker feeds ("G-Format") using a Vienna decoder (preferably, or a regular one if not available). Again this can be done with Thomas's software or that from other people. The result would be able to be mastered to any of the current 5.1 digital disc formats.

The benefit of this would be that the B-format panning would create a "virtual quad array" that could be reproduced over a standard 5.1 system, thereby replaying the discrete quad original in a standard 5.1 replay system more accurately than simply playing the quad source through the LF, RF, LS and RS speakers in the 5.1 array, these not being in the right places in an ITU configuration.

Please bear in mind that while it is possible to generate a "B-Format" signal from UHJ, this is only truly possible if you have a 4-channel UHJ original. In the case of a 3-channel UHJ original there is no vertical information, so you can do planar conversion (fine for quad). But if you only have 2-channel UHJ as a source you CANNOT recover true B-Format from it, even planar only, as there is a significant amount of information missing due to the compromises inherent in encoding B-format down to 2-ch UHJ.

As 2-channel UHJ in particular is no longer necessary, and the compromises involved were far greater than in systems we are now able to work with, I do not think anything would be achieved by attempting what you propose. Quad-to-G-Format, however, as described above, could be quite useful. I hope this helps...

--Richard Elen

Dear Richard,

Thanks a lot for the information. Having read your reply, I have decide to go ahead with carrying out the experiment with Quad-G-Format rather than Quad-UHJ. I have contacted Mr. Thomas Chen regarding his software. Unfortunately, this experiment is for educational purposes and the cost of the software is quite high. Luckily, he offered to convert the material for me. This would work, but would require the sending of Quad material back and forth from Australia to America.

I am intending on carrying on with that plan, but in your email you mentioned that there are several software solutions to the conversion. Perhaps you could tell me of some additional ones. I would rather not have to put Mr. Thomas Chen through the trouble of making the conversions, but if its the only option then I will take him up on his offer.

In your website, you mention that it is also possible to convert a binaural recording into Ambisonics. How would I go about this in a software scenario? In a Quad setup, I would pan the individual channels to the four corners of the sound field, but with binaural? Would I set them in closely in the center of the sound field (replicating the human ear position)? A student in my class is carrying out experiments with binaural recordings, and it would be very interesting to try converting some binaural material to G-Format.

On an additional note, your website is a great help to my project. I visit the site at least twice daily to check information I am not clear on. Keep up the great work.

Regards,

Aristotel Digenis

6.5 Correspondence With Thomas Chen

Dear Thomas Chen

My name is Aristotel Digenis and I am in my the last year of my BA(Hons) in Recording Arts in Sydney. For my final project I need to convert a Quadraphonic recording into G format, and I was told by Mr. Richard Elen that you have a software for Creamware, which will allow me to do this. Could you please let me know how I would go about to using this plug in for my project?

Thanking you in advance,

Aristotel Digenis

Creamware is a DSP board that has I/O for your computer. You would need a Pulsar board. It has 16 channels of ADAT Optical in and out as well as 2 channels of analog and one SP/Dif or AES/EBU in and out. My sorftware runs on the Pulsar card. The Pulsar card can also connect with your computer either via ASIO or MicrosoftMedia hooks. You can run recording sorftware with the Pulsar board. You can then work in B format, B+ format, decode to G Format(5.1) or decode to 6, 8, 10, 12 or 16 channels. The Pulsar board is compatible with both PC and Mac computers. I am running Vegas on a PC with a Pulsar card and Deck on a Mac Powerbood with a cardbus expansion chassis.

I am selling the software for $495 USD. There is a manipulator to change the B format field which gives you azimuth, tumble, dominence, and gain of X, Y, Z channels. The decoder itself has an output volume control, a mix control to adjust the balance in B+ of the stereo signal and the B format signal. The is a center fill control to fill the center so there is no hole in the middle. There is also a B format mixer with 8 inputs. There are 2 B format inputs and 6 mono or stereo inputs with to output in B format. There are controls over the position in the soundfield, ie azimuth, tumble, delay, eq, x&y&z gain.

I was just in Sydney over the New Year and could have visited.

ThomasChen

If you want I could convert it for you.

ThomasChen

Dear Thomas,

thank you for your reply. I am aware about the Creamware software, and luckily my friend has the Pulsar card running on a PC (I myself have a G4). Unfortunately even though your software seems to be perfect for the experiment, $500 is quite a bit out of my affordability, as this is just for educational use.

Since we are on the topic, I will explain a bit more about the experiment. In Mr. Richard Elen's article "Transcoding Quad Recordings to Ambisonics" (http://www.ambisonic.net/quaduhj.html) it says:

"In general, transcoding (or "re-encoding") quad recordings will give you a result in which the experience anywhere within the Ambisonic speaker array is at least similar to the experience in the quad "sweet spot", ie the acceptable listening area is significantly enlarged. In addition you may get a better feeling of the acoustic environment if the techniques used on the original recording captured them. In certain cases you may experience better localization and find individual musical components easier to discern. "

In short, my experiment will be to convert Quadraphonic recordings into G-Format and set up the appropriate speaker arrangement for both formats. I will then collect data from listeners regarding any changes noticed between the two formats and preferences between the two. In the final thesis I will then be able to come to a conclusion wether the conversion can in cases improves localization and increases the sweet spot area.

Thank you for your offer to do the conversions for me, but in order to avoid taking up your time, perhaps you know of another software that will do the job? If not, I might have to take you up on the offer to do the conversions.

I am currently looking in Australia for a Quadraphonic recording on a 4 track open reel tape, because I do not have the necessary turntable cartridge and decoder for quadraphonic LPs. Once I have some reels, I can locate a studio with the 1/4" 4 track machine, and have the tracks imported into Pro Tools. At that point I will have to burn the aiff files on a CD-ROm and send it to you.

My priority is to avoid putting you through the trouble. Please let me know of any other budget software solutions available that will allow me to carry put the conversion.

Regarding your visit in Sydney over New Years, how did you find it? Did you come with family and friends or was it work related?

I myself am not from Australia. I was actually born in the Netherlands, lived there 2 years, then moved to Greece for 8 years, then moved to India for 3 years, then United Arab Emirates for 5 years, then UK for 1 year, and now I am in Sydney for 1.5 years. My background is Greek and nearly 21. I will be completing my BA Hounors in Recording Arts in July, which I get from Middlesex University London, even though I get to do the course in Sydney.

I am also attempting to write an Ambisonic software decoder in Cocoa for the Mac OS X. So far the graphic Interface is nearly done, but the scripting side of things will take a long time. I don't think it will be done before the end of next year. I have applied for a MSc in Software Engineering (conversion) in the UK but will not hear from university regarding the decision for a few more weeks. Hopefully I will get accepted, and get enough required programming knowledge to complete the program.

Anyway, thank you once again for your response and help so far and hope to hear from you soon again.

Regards,

Aristotel Digenis

My address:

Thomas Chen, M.D.
Custom Recording/Studio C
XXXX XXXXXXXXXX XXX
XXXXXX, XX XXXXX
USA

I don't know if I can decode the SQ files but will be happy to do the Quad files.

ThomasChen

Dear Thomas,

I will have to take you up on that offer to convert the Quadraphonic signals for me into G-Format if the offer is still open. I have found somebody in America who has the same song in SQ, QS, and CD-4 Quadraphonic format. He recorded a minute of each into the computer, saving the files as SQ_FrL, SQ_FrR, SQ_RrL and so on. He then burned a data CD with all 12 tracks, 4 of each system (SQ, QS, CD-4).

I would like to have him send the CD ROM to you by post for the conversion into G-Format. You would need to position each channel to corresponding corner of the Quadraphonic speaker array. Then the 5.1 channels would be saved as SQ_FrL, SQ_C, SQ_FrR, SQ_RrL, and SQ_RrR. The same process would be done for the QS and CD-4. I am assuming the Sub channel would not be used. All the files would then be burned onto a CD-ROM as AIFF or Wav at 44.1 16-bit. The CD-ROM containing the original Quadraphonic channels, along with the CD-ROM containing the G-Format signals would both be sent to me in Sydney, Australia. to carry on with the experiment.

I will cover the charges for the CDR, posting to Sydney, and any other related costs by money order. If you are still willing to assist me with the project and the mentioned process, then please let me know of you postal address in order to have the CD-ROM sent to you.

Thanking you in advance,

Aristotel Digenis

I have received the CD and will need your address in Sydney to send it to you.

ThomasChen

Dear Thomas,

The CD rom which you will be sent, has the files already decoded into four channels. There will be 4 channels of the SQ, 4 channels of the QS, and 4 channels of CD-4. The CD will only contain individual channels. The decoding of the Quadraphonic format has been done already. All that is needed, is for the individual channels to be panned at the four corners of a square and saved as G-Format.

The results should be a CD Rom with three folders titled: Gformat SQ, Gformat QS, and GformatCD4. In each folder there should be five mono files of the gformat conversion. I will then need both CDs sent back to me in Sydney.

So as you can you, there is no Quadraphonic decoding necessary for you to do. the CD-rom with the files should be on its way to you this week from Texas.

Please let me know when it reaches, and what the progress is.

Thanking you,

Aristotel Digenis

On Monday, April 22, 2002, at 12:35 AM, ThomasChen@aol.com wrote:

I have received the CD and will need your address in Sydney to send it to you.

ThomasChen

Hello,

My address is:

Aristotel Digenis
XXX XXXXX
XXX XXXXXXXXX XXXXX
Sydney
NSW 2000
Australia

That was fairly quick, I didn't expect it to reach yet. Please send both the CD you received, and the CD you made and let me know what the expenses have been (blank discs, postage, etc) and I can prepare an international money order. Let me know when its on its way.

Thanking you,

Aristotel Digenis

Your disks will be in the mail tomorrow.

ThomasChen

Dear Thomas,

Thank you for your help. I will let you know when I receive the disks.

Regards

Aristotel Digenis

Dear Thomas,

the disks have arrived. Everything is great. Thank you

Aristotel

6.6 Tabulated Data From Completed Questioners

Name	Email	Contact	Audio Background	Previous Experience	Experience from
Lap	lap@localbar.com	88167629	Yes	No	
Marc Lennon	marc.lennon@bigpond.com	0418935725	Yes	Yes	At Home
Sally Morgan	sallcm@hotmail.com	n/a	Yes	No	n/a
Adrian	anewbizz@hotmail.com	n/a	Yes	No	n/a
Ross Douglas	rossellini76@hotmail.com	0405289754	Yes	No	n/a
Jarrod henderson	jarrod_william@hotmail.com	0414697183	Yes	Yes	At Home
Sean Mangan	flytrap7@aol.com	92030065	Yes	Yes	At Home/Pro Logic
Johennes Huber-Pock	jupo@3downunder.com	93693726	No	No	n/a
Felix Heinrich	felix@felixelgatofutbedl.com	0431212196	No	No	n/a
Richard Lambert	tuhivatahiti@hotmail.com	92836639	Yes	Yes	At Home
Ernesto Estivill	ernestoestivill@hotmail.com	0421152060	Yes	Yes	At Home
Virasai Sacopraseuth	n/a	97533997	Yes	No	n/a
Pieter Van Hooff	pedrobango@hotmail.com	0415968180	Yes	Yes	At Home & Studio
David Do-Nguyen	sepulerao1@hotmail.com	97340586	Yes	No	n/a
Kirsten Rose	thebrain@spin.net.au	95654732	Yes	Yes	Studio/Cinema
Andy Hale	andyhale@bigpond.com	0418297926	Yes	Yes	n/a
Tim Chang	moebious@sweet.as	95189047	Yes	No	n/a
Kurt Olsen	chiolsen@hotmail.com	96972881	Yes	No	n/a
Marco Cailao	death_trapph@yahoo.com	0415780255	Yes	No	n/a
Sashikharan Nair	sashi@xsmusic.com	95911703	Yes	Yes	"heard it"
Terence Lau	purpleslob@yahoo.com	0410450169	Yes	No	n/a
Dave Burman	djburman@hotmail.com	93323658	Yes	Yes	Studio

Seat A						Seat B					
Pair 1		Pair 2		Paid 3		Pair 1		Pair 2		Paid 3	
CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original	CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original
4	4	5	4	5	4	4	4	5	4	4	3
4	2	4	3	2	5	3	5	4	2	5	3
3	2	4	3	5	3	3	3	4	3	5	3
1	5	4	4	2	2	4	4	3	2	2	3
2	5	1	3	2	4	3	5	4	2	1	4
5	3	2	3	2	4	4	2	1	1	3	3
2	4	5	3	4	3	4	2	4	3	3	2
2	4	4	4	3	4	2	4	2	3	3	3
2	4	2	4	3	4	3	4	3	2	4	4
3	4	3	3	2	4	2	4	2	3	4	5
3	4	2	3	4	5	3	4	4	5	2	5
2	4	3	4	4	5	3	5	2	3	2	4
3	5	2	3	3	3	2	4	2	3	1	3
3	4	4	5	3	4	3	4	2	4	5	3
3	4	2	3	4	5	3	5	2	5	3	5
3	2	4	1	2	4	5	2	4	3	3	2
2	3	1	2	1	3	3	4	3	4	5	4
4	5	3	5	3	4	3	4	3	3	4	5
3	3	2	4	4	5	4	5	3	3	4	3
4	5	3	4	5	5	2	3	2	2	2	3
3	3	2	3	3	3	4	2	2	3	3	4
2	5	2	3	3	5	3	4	2	3	4	5

Seat C						
Pair 1		Pair 2		Paid 3		**Interested in results**
CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original	
3	3	3	3	4	3	Yes
4	5	5	3	2	4	yes
2	2	3	2	3	2	Yes
4	4	4	4	2	5	Yes
1	5	2	4	1	3	Yes
2	4	4	2	1	5	Yes
3	2	2	2	1	2	No
4	4	3	3	4	5	Yes
1	1	2	2	1	2	No
2	2	2	4	2	4	Yes
2	2	3	3	4	5	Yes
4	5	3	4	4	5	No
2	3	1	3	3	2	Yes
2	4	2	2	2	3	No
1	2	3	5	4	4	Yes
2	1	4	3	5	1	Yes
3	5	3	4	5	4	Yes
1	2	1	3	2	3	Yes
2	3	3	4	4	3	yes
4	5	5	5	3	2	Yes
4	4	4	4	3	4	Yes
3	2	4	3	5	3	Yes

	Seat A						Seat B						Seat C					
	Pair 1		Pair 2		Paid 3		Pair 1		Pair 2		Paid 3		Pair 1		Pair 2		Paid 3	
	CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original	CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original	CD-4 G-Format	CD-4 Original	QS G-Format	QS Original	SQ G-Format	SQ Original
Total	63	84	64	74	69	88	70	83	63	66	72	79	56	70	66	72	65	74
Percentage(%)	46.6	70.5	47.7	59.1	53.4	75	54.4	69.3	46.6	50	56.8	64.8	38.6	54.5	50	56.8	48.9	59.1
Mode	3	4	2	3	3	4	3	4	2	3	4	3	2	2	3	3	4	3
Mean	3	4	3	3	3	4	3	4	3	3	3	4	3	3	3	3	3	3

6.7 Completed Questioners