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EXPERIENCE WITH LARGE AREA 3-D AMBISONIC SOUND SYSTEMS

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1. INTRODUCTION

In 1990, the Music Department at York University invested in 3-D concert sound projection system based on Ambisonic technology. The current author developed a software driven programmable multi-speaker decoder. This has subsequently been used for a number of concerts of electroacoustic music, culminating in its' use in this year's four week run of the York Mystery Plays. Details are given of the decoder hardware and software design. Aspects of the practical use of such systems are discussed, including procedures for optimising the performance of non-ideal speaker layouts. Information is provided on the production facilities used in the York Mystery Plays installation.

2. EARLIER RESEARCH

Ever since information about Ambisonic technology was first published, the author has been interested in the possibility of using the technology to meet the perceived need of composers of Electroacoustic Music for a fully controllable sound system. Composers working in the field, particularly in Europe, often make extensive use of spatial elements in their compositions. This has, however, always been limited by the difficulties inherent in controlling the way the sounds are diffused in the final concert situation. Whilst simple amplitude panned stereo images are usually handled quite well, if the composer needs to move sounds over wider sound stages or to include vertical movements, problems rapidly multiply. With conventional multi-speaker systems, transferring from the controlled studio environment to the concert hall whilst still retaining the intended spatial elements presents severe difficulties. This results in either the composer or a highly skilled sound diffusion performer (the word 'performer' is used here rather than 'engineer' to emphasise the dependence on performance skills akin to those required to play an instrument) having to be present at every performance, since the actual sound positions in a concert are determined by the diffusion mix s/he sets at the time.

Ambisonic systems presented a potentially very attractive alternative to this methodology. Because the studio (record) and concert (playback) processes are independent, it seemed likely that all that would be needed for correct directional reproduction in a concert was that a technically competent Ambisonic playback system be available in the concert hall. As well as this, the relative simplicity of the encoding equations held out the possibility of easy implementation on computers. Although these factors were very encouraging, there remained doubts about how well the system would perform over the sort of distances involved in concert work. The work done by the original developers of Ambisonics (Gerzon, Fellgett, Craven,Burton et al) had concentrated on the domestic playback situation and no published work existed on any thing larger. Having built a six speaker horizontal only decoder based on a design by Gerzon [1], a series of informal tests in the late seventies using arrays with a diameter of 14.5 metres convinced us that an Ambisonic system was useable over such areas (Fig 1). Although moving away from the central position distorted the sound positions it was very similar to the sort of thing that would happen in a 'natural' soundfield. Moreover, somewhat to our surprise, we found that it actually worked for listeners outside the array.

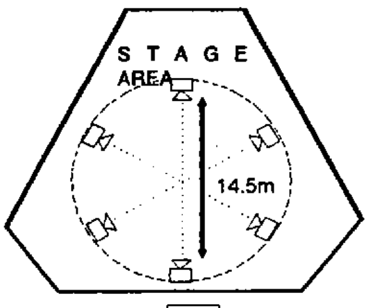

FIG 1

At this time insufficient information was available for us to look at fully three dimensional systems and although it became available in 1980 [2], it wasn't until the late 80's that we were in a position to start experimenting with 3 D reproduction systems. We hadn't been idle in the mean time, putting in a lot of work on the production facilities [3] [4] [5] [6].

3. EARLY 3D CONCERT SYSTEMS

Our first forray into 3D systems was the concerts held at York during the 'Mediamix 90' weekend in March 1990. We used an Audio Design Ambi 8, driving 8 speakers in a horizontal configuration and a vertical rectangle of speakers was added to this, driven by a four speaker decoder from a Calrec Soundfield control unit. This was fed the Z signal in place of the Y component. The B format signals used to feed the pair of decoders were modified by a so-called "HOFS BOX" to change the shelf filtering characteristics of the horizontal decoders to ones more suitable for full sphere operation [2]. This worked well enough to encourage us to complete work on our own fully programmable multispeaker decoder.

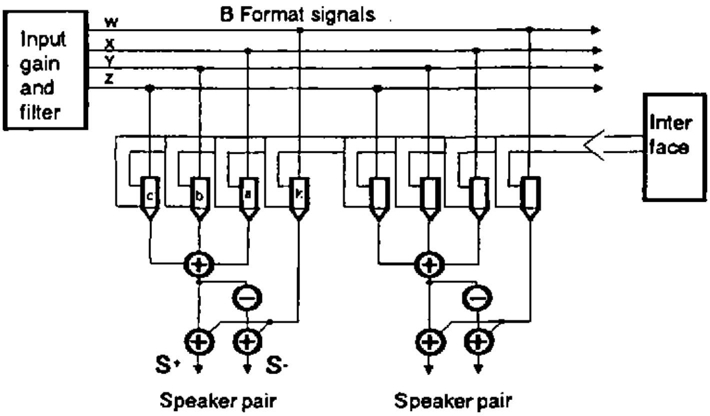

FIG 2

4. PROGRAMMABLE DECODER DESIGN

The decoder is designed to drive up 16 speakers in the 'diametrically opposed pair' format as described by Gerzon [2]. B format Ambisonic signals come in via a gain control, are subject to psychoacoustic filtering and are fed to digital controlled gain elements which set the coefficients for the loudspeaker drive signals thus:-

$$S^{\pm} = kW \pm (aX + bY + cZ)$$

The coefficients are calculated in software using data on speaker position entered by hand . They are then sent to the control elements (multiplying DAC's) via a suitable interface. Originally, an 8 bit computer was used, with software written in Basic but this has recently been upgraded to an Atari ST and the software completely re written in 'C'.

5. IN USE EXPERIENCE

5.1 Early work.

The first trials were done with a relatively small cuboid of speakers (6.2 x 9.3 x 4 metres) set up on stage in the Sir Jack Lyons Concert Hall, with the audience standing on a slightly rased platform in the centre. At first, this produced very poor vertical imaging, even for an exactly central listener. This was traced to an upward tilt of the bottom speakers. Once they were repositioned to fire horizontally, as the upper units, constrained by their stands, were forced to, a very good image, with excellent sound movement, appeared. At this stage we were working without an audience.

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The experience was one of entering and walking around in 'sound sculpture' with good to excellent imagery in approximately the central two thirds of the cuboid. Outside that, proximity to individual speakers began to dominate. Things deteriorated when an audience was introduced with a considerable degree of screening taking place. Individual listeners found it very difficult to be in a position to get an even balance from all speakers with consequent disruption of the perceived soundfield. This is not, of course, a problem limited to Ambisonic systems, but will occur with any 3D sound system for larger audiences. There is a way round this, give all the audience headphones and feed them with binaurally synthesised images, using individually sensed head position steering of the images so that they stay stable with respect to the visual environment. Although this is certainly feasible, the costs are currently likely to rule it out, especially considering the difficulty we had in getting funding to buy the few extra speakers we need for our Ambisonic work.

5.2 International Computer Music Conference, Glasgow 1990.

This set up was also used, with somewhat larger dimensions, at ICMC90 [7]. The space it was set up in there had a very strange acoustic. Angled reflectors in the ceiling space, designed to reflect light down from the high level windows, did very odd things to the sound images. This greatly reinforced one of the conclusions that we had arrived at earlier, which is that when attempting to set up a new system it is important to provide some means of distinguishing between imaging problems caused by system faults and those resulting from systemic errors caused by the acoustics of the projection space or the nature of the sound being projected.

5.3 Larger Rigs.

Shortly after ICMC 1990, a larger rig with six diametrically opposed pairs of speakers was set up in the Sir Jack Lyons Concert Hall for the Music Department's 1990 Practical Project Electric Zodiac (figs 4,5). This Multi Media event made extensive use of Ambisonics manipulation of sound.

Fig. 3 View from front of concert hall, showing speaker positions. Planes are audience ear level.

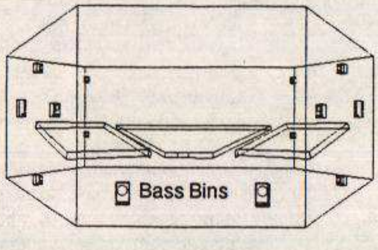
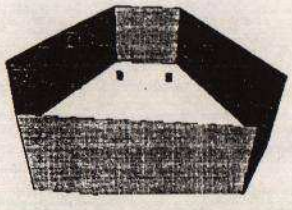


Fig 4 View from rear of concert hall



During the initial set up, several problems became apparent. These centred around the unevenness of the reproduced soundfield. Two main areas gave cause for concern. The first was the upper and lower central areas. Sounds moving overhead or underneath became louder as they moved away from the horizontal plane. Analysis of the decoder equations showed that when the distribution of loudspeakers on the notional sphere is uneven, speakers around the edges of any 'holes' in the distribution are driven harder in an attempt to compensate. The two to one rule which applies to horizontal decoders, where the ratio of front/back to left/right dimensions may not be more than two to one, may be extended to the periphonic case, requiring a spread of no more than two between the maximum and minimum side of any of the three orthogonal planes through the centre point. In the Electric Zodiac rig, the maximum vertical (Z) dimension was significantly less than that of either of the horizontal dimensions (X,Y). The problems caused by the lack of the height component in the Electric Zodiac rig were accommodated by reducing the Z component fed to the decoder until the loudness bulges for upper and lower sound positions were at an acceptable level. Although sounds placed away from the horizontal became more diffuse than before, this was judged to be better than having uneven loudness.

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The other major problem found was a 'hole' in the frontal sound stage which rendered due front images unstable. This was associated with the fact that front pair of speakers were the only ones not adjacent to one (or more) flat surfaces, making for significant differences in frequency response and power output. Increasing the drive to the front pair resulted in another loudness bulge without stabilising the image. The drive was reduced to normal levels and an additional due front 'fill in' speaker was added. This was actually made up of a pair of speakers, slightly separated, since the centre front position was occupied by a projection screen. These speakers were fed with the X (front-back) component at a relatively low level. This was adjusted by ear, until stable centre front images were obtained without having any apparent undue effect on centre rear images as might have been expected from the use of raw X component as the fill-in drive.

5.4 York Mystery Plays.

The next major step forward came in 1992 when we were invited to provide Ambisonic sound facilities for the forthcoming production of the York Mystery Plays. This mystery play cycle is normally staged outside but on this occasion it was be performed in the Theatre Royal, York. The Ambisonic rig had to run in parallel with the standard stereo diffusion system used for the main stage sound system. The Ambisonic rig was brought into play as dictated by the needs of John Jansen, the Musical Director for the Mystery Plays. A reasonable, but not over generous sound budget meant that, with the help of Wharfedale Loudspeakers Ltd. the theatre was able to acquire 16 channels of speakers and amps of sufficient quality to set up what was potentially our best rig so far.

5.4.1 Speaker placement. Originally it was hoped to place the audience within the soundfield but the nature and positioning of the balconies in the theatre rendered this impractical. We then pursued the alternative option of having the audience looking into the sphere of the soundfield. An extensive, manual, search for optimum speaker positions resulted in the layout shown in fig 5. The layout found was surprisingly good, given the limited opportunities we had for providing new mounting points for the speakers. Most of the speakers sit fairly close to the surface of a notional sphere occupying virtually the whole of the open space between the audience and the stage. The only exception was the topmost one which, for structural reasons, were displaced upwards by around 15% from the sphere's centre. In practise, this caused less of a problem than the tonal differences caused by it being placed behind a ventilation grill. The pair of subwoofers were fed with pure omnidriectional (W) signal at low frequencies only.

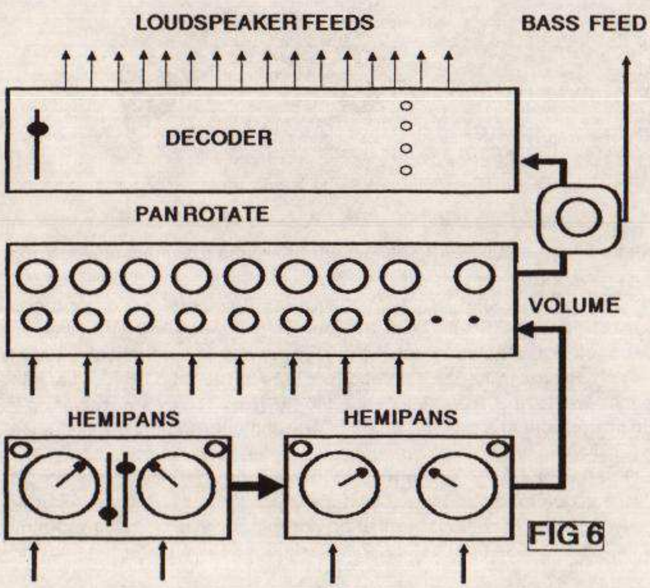

FIG 6

5.4.2 Production facilities. Sounds were placed in the soundfield using manually operated controls (fig 6). For sounds which need to have vertical movement capability four hemipans were employed. These are based on the designs in [8] and have joysticks which can set the

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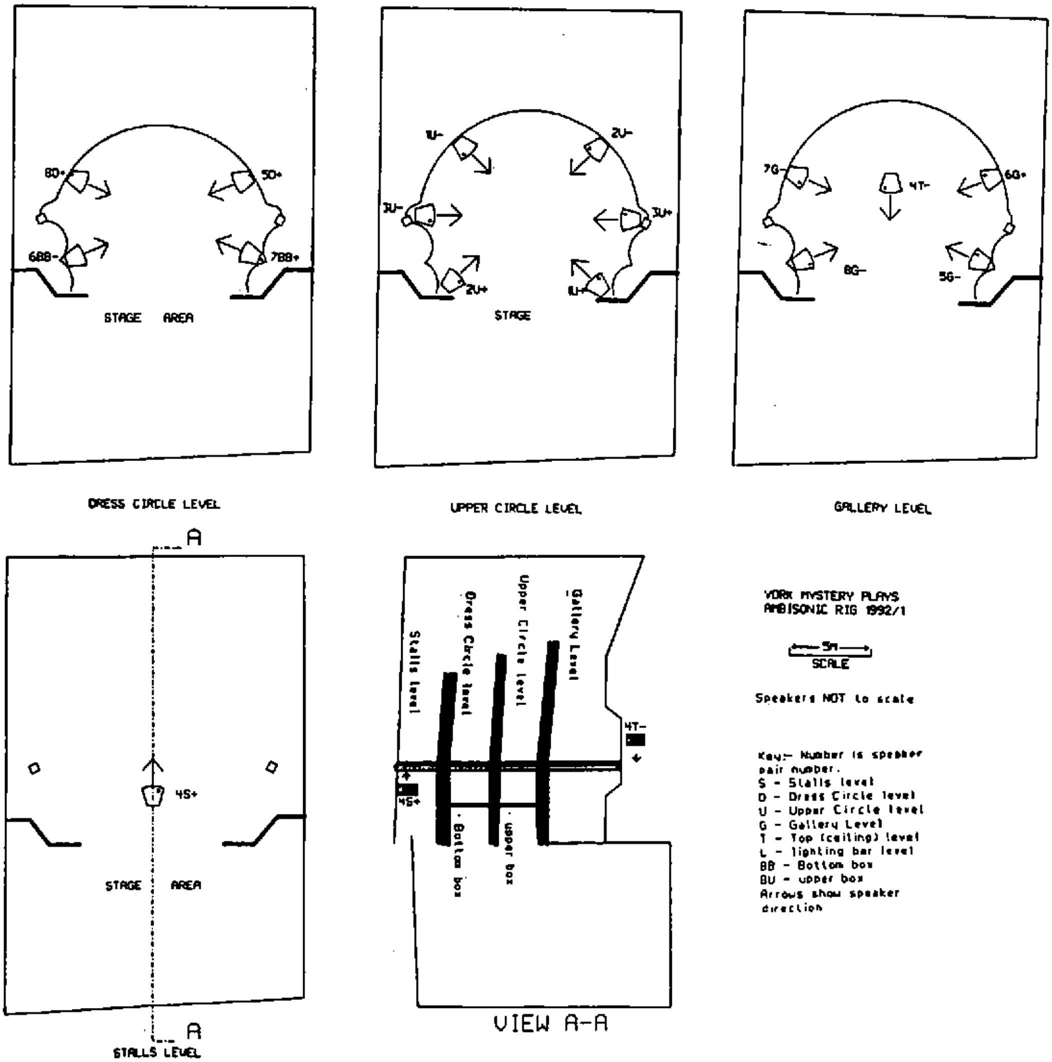
FIG 5



sound anywhere on the surface of either the upper or lower hemisphere of the reproduced soundfield, with the vertical component on one pair being controlled with linear fader. For sounds requiring only horizontal movements, an Audio Design Pan Rotate unit was used. As this was placed last in the B Format signal path, its overall rotate control could be used to simultaneously rotate all the signals in the horizontal plane, including those generated by the hemipans.

5.4.3 System set up. First tests with the system were very discouraging, with poor localisation and sounds which were meant to move along diameters tending to bounce back before completing the traverse. Suspicion fell on two possibilities - the software, which had only just been converted from Basic on an 8 bit machine to 'C', on a 16 bit one, or the removal, on the advice of Michael Gerzon, of the psychoacoustic shelf filtering, normally used in Ambisonic decoders intended for small area use. Extensive checking of the software revealed no apparent problem as it gave essentially the same coefficients as the Basic program did when fed identical data sets. The shelf filtering was switched back in with no improvement. In fact, if anything, the performance was worse.

5.4.4 Initial Decoder Algorithm Modification.An analysis of the signals which would be fed to a single speaker in array driven according the 'Diametrically Opposed Pair' theorem [2] was then carried out. This showed that as a sound moved away from the speaker along the diameter towards the other member of the pair, the output from the near speaker drops to zero but then reappears but with reversed polarity. This analogous to a hypercardiod directivity characteristic (fig 6). Whilst this contributes significantly to the performance of small area Ambisonic decoding, it was obvious that this was the cause of the 'bounce back' effect. This problem had not been obtrusive enough to be noticed in earlier performances because with the audience being inside the array there was less difference between the distance related amplitude loss of a speaker pair (fig 7). The

Fig. 6

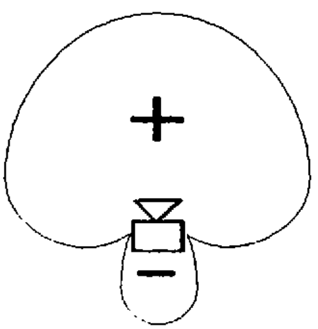
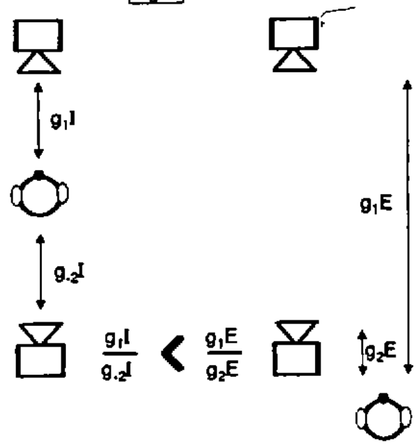


Fig. 7



hypercardiod response was modified to cardiod by reducing the ratio of directional (X,Y,Z) to omnidirectional (W) components which removed the 'bounce back' but left only a very confused image. It should be noted here that the physical polar diagram of the speaker does not necessarily varies in this manner. What is referred to here is the Source Directional Response (SDR) which is the the curve the output of the speaker is constrained to make as a sound source traverses around the perimeter of the soundfield.

5.4.5 Revised Decoder Software. At this stage we began to doubt the validity of the numerical solution of the diametrically opposed pairs theorem which we had implemented in software. Although it produced sensible figures for simple arrays, such as are detailed in the patent covering this subject (British Patent No 2073556), for the more complex array that we were using the numbers made little sense. With time running short, it was decided to try an idea for a decoder algorithm based on position related power distribution that the author had been considering for some time. After an intensive software writing session, code was produced which would implement the new algorithm. Initial trials proved very promising. Options were added to allow gain trimming of individual pairs, to allow for the inevitable variations in actual diameters - there was a spread of around 10%, ignoring the up-down pair mentioned earlier - and variation of directional/omnidirectional component ratios so that the SDR's of the speakers could be modified. A test function was also added which allowed individual speakers to be turned on for testing.

After a certain amount of experimentation, a very good image was achieved. In the course of this experimentation it was noticed that listening inside or outside the notional sphere the speakers sit on provided good imagery, but listeners positioned actually on the surface of the sphere, even if they were not adjacent to a speaker, lost most of the image. As had been observed previously, faster moving sounds tended to be more easily localised. It is felt that this is due to the averaging of anomalies in the response of individual loudspeaker locations resulting from room responses. It was interesting that these fast movements resulted in a 'phasey' sound for the fastest movements which not unlike that which occurs with a fast moving natural sound source - a rather unexpected bonus.

We had hoped to make use of the opportunity of having a large rig set up for four weeks to do extensive system tests, but unfortunately pressure of work,both on the authors part and in the theatre curtailed this. We were, however, able to set up a lunch time electroacoustic concert, after which we were able to press gang a number of our Music Technology post graduates and other members of the audience into staying behind to take part in a series of listening tests. We hope to repeat this experiment at a further concert at the Theatre in the next few months and will be presenting a paper on the results at a later date.

6. CONCLUSION

Ambisonics has been shown to be a viable technology for projection of sounds in three dimensions to concert size audiences. As with all technologies, there are problems to overcome, but they are no more significant than in any other systems and the underlying simplicity of the system conveys advantages which more than outweigh them.

7. REFERENCES

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