

SURROUNDED!

Though Ambisonics offers the potential for true three-dimensional sound, it remains a commercial non-starter in danger of being swamped by inferior 'surround' systems. Trevor Butler explains. . .

OFTEN TALKED ABOUT, rarely sampled, Ambisonic surround-sound is well-established in theory, though it has but yet to see its heyday in practice. The technology has been more readily accepted in professional applications than in the world of hi-fi. But what is Ambisonics and what can it do for the music lover?

While it is true that the audio industry has spent millions of pounds developing hi-fi, often with the main goal of trying to make the reproduction as near the original as possible.

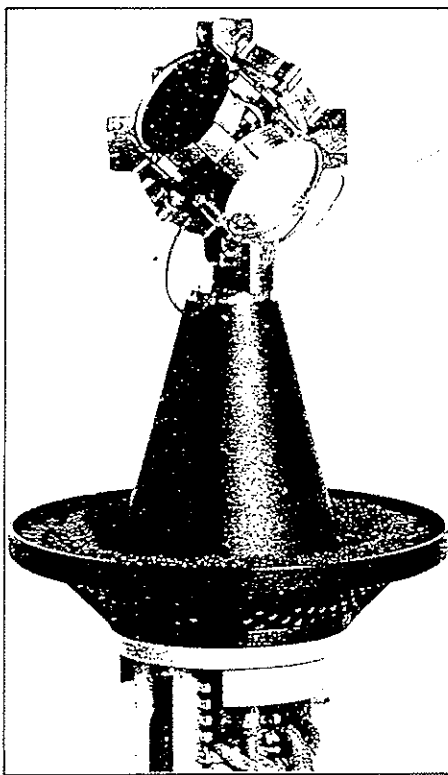
In the 1960s the work has centred around stereo. In real life, though, we hear from all around, not just left and right. There is detailed information from the front, back, above and below for the brain to process. Yet, in the majority of hi-fi installations, this information is split for just two separate frontal signals. It can be argued, therefore, that a system incapable of accurately reproducing front-back and up/down information is imposing a serious kind of distortion: 'directional distortion'. This was in the minds of the inventors of Ambisonics - the surround sound system based on encoding the structure of the sound fields at the original recording or simulating it synthetically.

Quadraphonics was aimed broadly at the same concept. It used separate microphones to capture the sounds at the rear of the concert hall to improve the ambience. This effort was largely empirical in its assumptions: the effect was lost once one's head was turned or the speakers moved. The techniques could not capture any height information and it is in this way that Ambisonics has gone a stage further towards realism. Because it was not constrained by precise physical theory quadraphonics suffered from standardization problems and its life span was short.

An important contrast is that Ambisonic's technology is based on a precise and unambiguous technical specification of how the encoding method should handle every direction of sound in space. This can be contrasted with the quadraphonic approach in which the handling of only four speaker directions was explicitly specified, with other directions being left largely to chance.

History

It was as long ago as the 1930s that Blumlein patented the concept of stereo, something which later came to dominate the hi-fi scene and has done so to the present day. But Blumlein's work also laid the very foundations for Ambisonics. He said that you perceive direction between loudspeakers if you capture a sound's relative intensity in each channel (loudness) and if you can capture the relative difference in time it took for the sound to first appear from one channel and then the other (phase). One of the 70 claims described in the original patent was a 'parity' of speakers in suitably spaced relationship to the listener. Thus stereo was only a convenient reduction of a more



The Calrec Soundfield microphone, cover removed to reveal one capsule.

general concept which made it practicable with the technology of the day.

By extending the concept of Blumlein stereo miking to three dimensions and by capturing the relative magnitude and phases of all signals in the room as they arrived at the microphone, it became possible to record all the sonic direction clues needed for a listener to get a realistic impression of actually 'being there'. Figure 1.

The work on Ambisonics was carried out almost 20 years ago by Professor Peter Felgett of Reading University and Michael Gerzon of Oxford, making it a uniquely British contribution to the world of surround sound.

Ambisonic technology embraces several aspects of the origination of signals carrying directional information, their processing, recording and the way in which the listener is able to make use of these signals. This encoding of directional information is always in terms of the relationship of the signal format to the direction that is to be represented, and not by reference to an arbitrary concept such as 'corner directions'. A necessity is that the signal formats should vary smoothly with direction, without any sudden jumps in value or gradient.

Ambisonics does not mean that an existing stereo system has to be replaced - the two are compatible, and stereo can still be received with just two of the Ambisonic channels, with no extra hardware. To enjoy the benefits of full 'surround sound' of varying qualities, up

to the full 3-D, a decoder is added together with more speakers and further amplification. In the demonstration I saw the decoder was placed between the pre-amp and the main power amps, and with an extra amp attached to the decoder's additional terminals to drive successfully the fill-in speakers. A full review of a domestic decoder will follow in a future edition of *HFNR* as the equipment is currently undergoing some enhancements.

The National Research Development Corporation were early financiers of the Ambisonic project and NRDC signed an agreement with the Ambisonics team to produce some financial backing. The NRDC was replaced by new sponsors in the form of British Technical Group (BTG) who started in fine fettle by having a Seminar in London and organizing other Workshops. Then followed Ambisonic Limited, a licensing company set up to promote the idea worldwide. All Ambisonic rights previously held by BTG are now owned by this new company who is actively pursuing a policy of developing technology markets and also of stimulating the development of the hardware and software. Ambisonic Limited is part of the Avesco plc Group which is already active in the professional video industry.

Perhaps one reason Ambisonics has not been a raging success so far is that people still remember the frustrating mistakes made by nearly everyone in promoting the three ill-fated quadraphonic systems: SQ, QS and CD4.

These attempts and others to improve stereo imagery have resulted in the use of either complex multi-way speaker systems or the simplistic 'doubling up' of a stereo output to duplicate the original sound through a second pair of speakers, often with the use of a delay line.

It is generally accepted that these early efforts to produce surround sound under the guise of quadraphony were a failure. Possibly a preconception arose that because stereo employs two channels feeding two loudspeakers, therefore four loudspeakers required four channels. Additionally, because the two channels of conventional stereo have a high degree of separation, this was deemed a necessary function of 'quad'.

Futile attempts were made to mix the four channels down into two, with some hope of recovering them on playback. But no matter how sophisticated or expensive the playback equipment, the reproduction is unnatural when compared to a live concert hall performance, leaving much to be desired. 'Poor imagery', albeit an esoteric term, cannot elude a discerning ear and would usually leave the listener dissatisfied. The Ambisonic concept with its UHJ encoding attempts to address this problem by providing more information, and it is in this area that Ambisonics differs fundamentally from other attempts to produce a 'surround sound'.

Nowadays, with the development of digital reverberation devices replacing echo springs,

it has become common practice to add, often in exaggerated quantities, artificial reverb to compensate for losses in the recording. Whilst partly successful, it can be argued that this does not give the true impression of hearing reverberant information from behind, above, and below — at best it tends to make frontal images deeper, rather like standing at the back of the concert hall. Ambisonics is concerned with rectifying this.

The structure of the sound fields in the original concert hall must be considered an integral part of Ambisonic technology. Sound waves travel in straight lines and would be emitted as a 'direct sound' from a stage but, as with any normal acoustic environment, a certain amount of the sound is eventually reflected, giving 'primary reflections'. Furthermore, the sound waves could continue to bounce off walls and other surfaces to give 'secondary reflections' which will continue until the sound pressure finally dissipates.

Unfortunately, because one does not have a listening environment the size of the Royal Albert Hall or the finances necessary for acoustic design, it may seem impossible to create the reverberant field which existed in that original hall. Also, and perhaps more importantly, the creators of the work have no control over the area in which the recording will be replayed, thereby sacrificing an important aspect of the artistic work and leaving things mainly to chance. This is where Ambisonics comes especially into its own.

Encoding

The ability to send directional information to the listener is dependent upon the number of audio channels. But, instead of dictating the number of channels, Ambisonics leaves this to the recording studio — and the number is governed only by fundamental limitations. The UHJ Ambisonic specifications include signal formats using two audio channels, as in stereo; two and a half channels, that is with an extra channel of restructured bandwidth or amplitude; three channels, or four channels, for the realization of full spherical surround sound.

In essence, Ambisonics is capable of capturing acoustic pressure and the directional acoustic velocities of a sound. Wherever you are, you experience only one air pressure at a time, and since there are only three possible dimensions for sound to travel in (left/right, front/back, and up/down) you need only 4 baseband audio-bandwidth channels to transmit all the available first-order information. Hence, within this sort of system, sounds of any intensity and direction in space can be represented in a manner which is non-ambiguous and non-redundant.

The encoding specification used with Ambisonics is classed Universal HJ ('UHJ') and incorporates the former HJ system, from the BBC, used in radio experiments.

As mentioned, the full UHJ encoding set is able to use up to three audio channels for horizontal surround, and a fourth channel for full spherical surround: L and R for the basic pair as in conventional stereo; T for enhanced directional resolution for horizontal sounds; and P for additional elevation information. The fourth channel, then designated Q, can alternatively be used to convey the 'speaker emphasis' effect in case anyone likes this.

The initials UHJ on a record or CD indicate that it is in the prescribed Ambisonic format. It is a major factor too in the existence and use of UHJ recordings that

they are all stereo-compatible; indeed some have received awards judged just on their stereo qualities, including a Grand Prix du Disc. Moreover the listener possessing a UHJ decoder can use it not only for UHJ-encoded software but also for ordinary stereo releases, using the 'stereo decode' mode of the decoder to give enhanced enjoyment.

As part of the technology associated with Ambisonics, a special 'Soundfield' microphone has been developed. This was invented by Dr Peter Craven and Michael Gerzon in Oxford in the early 1970s. After practical development with Calrec Audio, Ken Farrar the Managing Director of Calrec, set about the task of putting it into commercial practice. Almost two decades ago the Soundfield microphone was thus invented, and today is manufactured solely by Calrec Limited, although is now in its Mk IV form: a remarkable achievement for which Mr Farrar deserves much credit.

In its simplest form, the Soundfield consists of a geometrical array of four very closely spaced capsules instead of the customary one or two. The signals from the individual capsules are combined by addition and subtraction, together with equalization, filtering

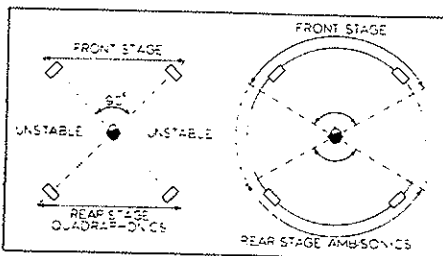


Figure 1: Quadraphonics is restricted to a 90° usable front stage and rear stage. Ambisonics can give much wider front and rear stages, even with just 4 speakers

and phase-correction, to provide a full set of signals giving the required information regarding direction of sounds from all around.

The Soundfield provides by far the easiest way to record for Ambisonic applications but is not the only possible way. Systems employing more conventional microphone techniques may also be employed.

Unlike Ambisonics, the Dolby Surround system is intended to be accompanied by pictures. It is not surprising therefore that it is, unlike Ambisonics, frontally originated.

With Dolby, the predominant sound originates from, and is associated with, the on-screen sources. The surround channel serves to convey spatial information, adding depth to the audience's perception of the sound by mimicking the ambience and directional signals familiar in real life.

All the Dolby Surround decoders contain circuits to reduce the audibility of front-channel leakage into the surround channel thereby preserving the necessary degree of realism. These feature a time delay, limited surround channel bandwidth and a modified form of Dolby-B noise reduction.

Like the psychoacoustical phenomenon known as Haas effect, the Dolby principle is based on the fact that the mind identifies the first place from which a sound is heard as its origin and mentally ignores other sources of the same sound arriving later. Making use of this, Dolby Surround provides a time delay to ensure that any front channel leakage from the surround speakers will not cause distraction. The signal from the front speakers reaches the ear first, so the mind will ignore

the same signal coming from the surround speakers several milliseconds later.

Dolby Surround decoding systems are categorized as either passive or active, depending upon the matrix circuitry employed. A fixed L-R matrix is used in the passive units, while a variable matrix with logic circuitry is used in the active Pro-Logic Surround units.

Decoding

In order to convince the ear that it is hearing a smooth soundfield from just a few speakers, it is essential to have a knowledge of the way sound is received, with particular regard to the direction; a multiplicity of mechanisms of localization used by the human ear and the relative importance of these changes according to frequency range. The Ambisonic decoders are tailored to fit these psychoacoustic mechanisms, the decoding equations being frequency-dependent in such a way that the total perceived sound-energy is uniform with frequency, while at the same time each mechanism is favoured in its own frequency range.

The more characteristic features of Ambisonics are displayed in the use which the listener makes of the signals received. It is here that the final step is taken in disguising from the ear the limited number of radiating loud speakers. The task falls to the Ambisonic decoder which has the function of using the received signals to generate a set of loudspeaker-feed signals. These must cause the speakers to radiate sound which combine in the room to convince the brain that it is perceiving a smooth, all-round distribution of possible sound directions. Ambisonics recognizes that valid speaker feeds cannot exist at any earlier point than this in the transmission chain and, as such, is contrary to the presumptions made by other, cruder systems. This comes about because the necessary feeds depend on the size and shape of the speaker layout, and this will differ from one listener to another. It is for the same fundamental reason that, with Ambisonics, the number of speakers used is not prescribed, and the choice is left to each individual. Four speakers used for horizontal surround do not need to be in a square format either — indeed this is often impractical in a domestic environment. Instead, the decoder has a layout control and an adjustment enabling the outputs to be optimized for the room size.

It should be stressed that, unlike more conventional systems, with Ambisonic sound it is not necessary to sit in the centre of the listening room to fully appreciate the effect. It can be set up for a normal seating position. After all, no one wants to sit in the middle of a room — it can look very odd.

Obviously the more speakers that are employed, and the better their quality, the better the re-creation of the acoustic pressures and velocities which are necessary to produce a convincing soundfield. The aim of Ambisonics is that the sound reproduced should be virtually indistinguishable from the original.

It is clear though that an infinite quantity of speakers (or 'handles') would be required to reproduce exactly the information present at the recording. Stereo has only two such 'handles' acting on the air and they usually 'grab' it from just one end of the room. With more 'handles' working together along more edges, it is much easier to establish regular patterns. It follows that the greater the number of 'handles' the finer the resolution

of the patterns re-created, so the greater the number of speakers the more convincing the rendering of the original acoustic space.

A minimum of six speakers is required for full spherical surround sound including both horizontal directions and height; these must be suitably positioned and can be considered to be the finest way of reducing 'directional distortion'.

Many domestic environments can accommodate only two pairs of speakers though, but this will still allow for the benefits of an Ambisonic decoder. Some rooms, by contrast, can more easily accommodate six speakers (which can be smaller and cheaper individually) and Ambisonic decoders can accommodate such layouts also. It is important to understand that all the speakers are involved with the sounds from any direction. If a speaker obtrudes as a separate source of sound it may be that it is receiving either too much or too little signal, or the phase may be wrong.

It is a fortunate coincidence that it is the lower frequencies, below around 700Hz, which take the lion's share of the available electrical power to reproduce an equivalent low frequency acoustic power. A single subwoofer in a convenient location, combined with the miniature satellite speakers of an Ambisonic array, can produce a directional acoustic field, but with sacrifices of low frequency directional rendering.

Because Ambisonics captures four types of information (sound pressure, and three dimensions of sound velocity) about an acoustic environment, four channels are thus needed to transmit the complete information. They do this directly in the professional Ambisonic 'B' format, but, to ensure mono and stereo compatibility in the consumer UHJ set of formats, the individual channels contain a mixture of the information, which of course can be recovered explicitly provided that all four PHJ signals are retrieved. (Figure 2). However, the results must be both pleasing and meaningful if one or more of the channels is, for whatever reason, lost.

If three of the four are decoded, the result will be horizontal 'surround sound', lacking only height information. Losing a further channel, leaving just two to decode, results in reduced sharpness or focus. If these two remaining channels are fed to a left/right stereo system, good stereo imaging will result.

Further, if one can receive two of the Ambisonic channels and they are simply summed to get mono, the result is still 'pleasing' and by design is an improvement over simply summing stereo. In some other surround systems, summing left and right results in complete cancellation of surround information.

Because Ambisonic technology defines a signal format directly in terms of the desired directional illusion, it is able to cope with the problems of creative production.

Systems

The various surround sound systems in use are based on different principles and standards. Both the Japanese Regular Matrix and the Nippon-Columbia BMX coding specifications are completely compatible with Ambisonic's surround reproduction. They differ mainly in that Regular Matrix is biased completely in the direction of stereo compatibility and, in mono, back-centre signals do not come through; whereas BMX gives a true mono signal at the expense of 'phasiness' in

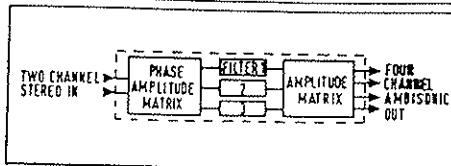


Figure 2: Block diagram of an Ambisonics decoder

stereo playback. The preferred Ambisonic coding lies essentially between RM and BMX, thus giving a better overall compromise.

In view of all the obvious attractions it has to offer, why is Ambisonics not already a raging commercial success? It is not after all a 1989 creation. For a start, it would be far easier to use if the facility were built into the pre-amplifier or control unit, rather than necessitating another add-on box. Attempts have been made to try and interest amplifier designers to incorporate the necessary electronics but, to date, without success, leaving the separate decoding units as the only available option.

At present only one company Minim (of Slough) is licensed to manufacture the Ambisonic decoders for the domestic market. They have been actively involved in this field since 1980 and currently have two decoder models: the AD7 and the AD10. Although a lull in production occurred last year, the company hopes to be meeting all order demands soon and has also promised some exciting new developments by way of expanding the model range. This interest is stimulated by growth areas in the United States and the UK, says Minim. Troy Ambisonics, based in Sunningdale, Berkshire, manufactures decoders intended primarily for in-car use. These have been successfully used in domestic environments using a 12V transformer.

Minim's Decoders have several modes of operation. The first is Enhance in which any regular stereo input is widened into Ambisonic stereo surround sound enhancement. This can be considered the primary mode for conventional stereo material. Second is UHJ which is selected when listening to known UHJ-encoded material. This setting can also produce interesting and often very pleasing results on ordinary stereo material. A Bypass mode negates any effect of the processor on the original audio system, offering regular stereo listening. There is a Width control which provides a variable setting for personal preference when in the Enhance mode. This has the effect of moving the listener towards the stage or conversely towards the back of the auditorium where the stereo image is narrower and left and right channels seem less well defined.

So good can the '3D' effects of enhanced stereo through a UHJ decoder be that it is often only a very good ear which can detect that the surprisingly vivid results are not full UHJ. The stereo enhance facility, or Ambistereo, is a worthy addition and could become a major selling point. Many of the other surround systems marketed are only enhanced stereo, and yet they have been successful. With Ambisonics, there is the full UHJ-decode mode as well, giving surround information not just a surround effect.

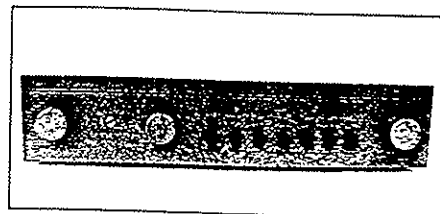
A reversion to straight stereo Bypass mode will nearly always produce a disappointing effect since conventional stereo is, by comparison, 'small' and 'flat'. Adding Ambisonics will probably add greater pleasure than a stereo-only system even without UHJ-encoded material, but the listening pleasure

will inevitably be greatly increased when UHJ recordings are obtained. It is interesting to note that Nimbus CDs are UHJ encoded and stereo compatible. The UHJ symbol is not, though, emblazoned across Nimbus' covers but instead a small logo is printed on the face of the disc itself.

Conclusion

Ambisonics represents a technology that defines directional sound waves and conveys them around its listener - making the listener the most important feature of the exercise. To the uninitiated, the Ambisonic surround sound experience is not one likely to be forgotten. It is under Ambisonics that height information is given to provide what can only really be described as virtually '3D'. The overall effect creates a high degree of ambience which totally surrounds the listener. The experience really has to be heard to be believed, although that is easier said than done because of the limited availability of suitable decoders.

The 3D effects from enhanced stereo and the even greater benefits of full decoded UHJ are likely to have strong appeal. Ambisonics has been used at amplified pop concerts to



Minim AD10 Ambisonic domestic decoder unit

provide a sense of space. The Cure was one group to use it on their 1987 World Tour. The concept has also found outlets in theme parks, audio/visual presentations and some cinemas.

Opponents of Ambisonics have argued against it because, for the purist, it involved extra steps in the replay chain which are thought to be degrading, literally. But having decided that audio is about creating an image of reality, Ambisonics is much closer to the way the human ear hears than a stereo system is ever capable of being. If it is nearer it is arguably more accurate, and therefore pure. Unfortunately the human ear is not 'pure' in the way it works. Our listening, in fact, modifies the sound spectrum and the range is divided with different parts of the spectrum handled separately. We are, apparently, more sensitive to sounds at the back at lower frequencies than we are to the position of sounds at the front at the same frequencies. High frequencies are needed to give direction at the front.

Historically, surround reproduction made a bad start. Systems were formulated and promulgated commercially before there had been sufficient critical thought about the real aims and objects of surround reproduction. Unlike attempts to apply stereo techniques to four speakers, Ambisonics represents a departure in the development of high fidelity sound comparable to the jump from mono to stereo. As such, it has its own language and techniques.

Just as in the early days of stereo, when crude 'ping-pong' attempts were made to treat it as double mono and the quadraphonic attempt to treat surround-sound as mere 'double-stereo' was recognized as misguided so the full potential of Ambisonics will one day be realized.