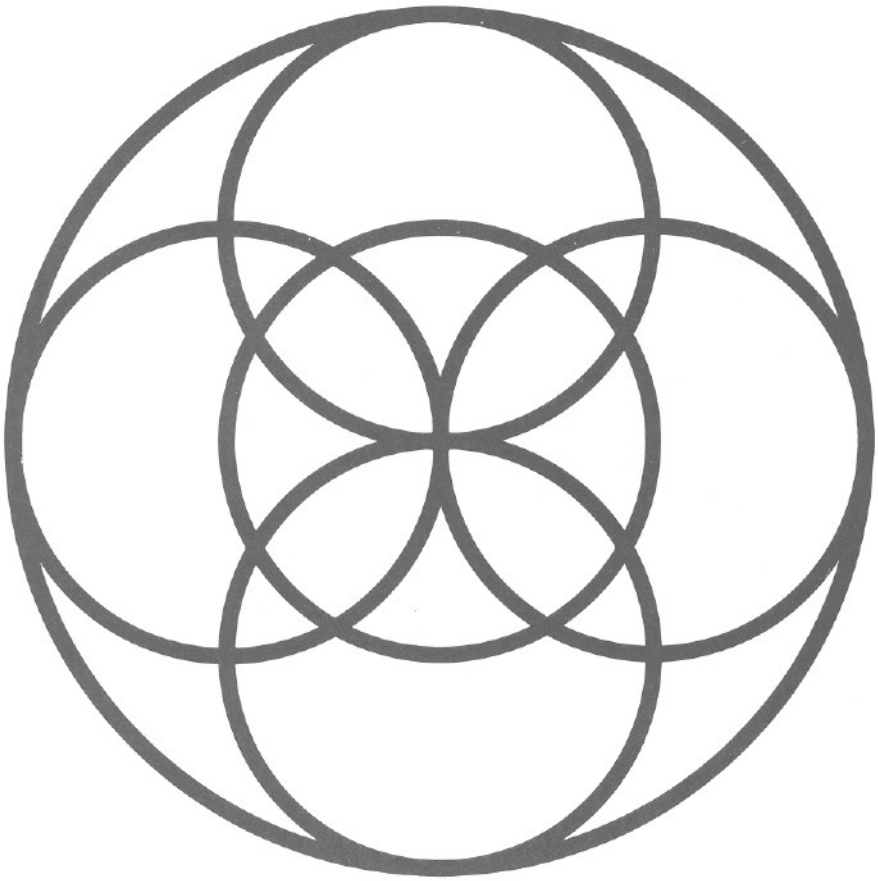
AMBISONIC SURROUND SOUND SYSTEM



NRDC

National Research Development Corporation

Stereo covers only a comparatively narrow front sector. The aural illusion works progressively less well as the speakers are placed further apart. If the speakers are behind, it is discovered that the stereo effect persists to some extent, but not as well as when the speakers are in the front. If the listener makes a half turn, so that the speakers are to one side, either directly to left or the right, it is discovered that the illusion works very poorly indeed.

Consider an attempt to reproduce sounds from any direction around the listener by extending ordinary stereo techniques from the front to all sides of the listening room, using four loudspeakers. This idea, which should properly be called 'surround-stereo', will perform poorly since four loudspeakers distributed around the listener must average 90^{o} between successive speakers. We know from experience that the illusion of phantom inter-speaker image is then rather poor. This is true even in the front sector; is worse for a pair of speakers behind, and is worse still from a pair at either side. Yet this arrangement was precisely the supposed ideal represented by "discrete quadraphony."

There is a further difficulty. If a sound source is circling the listener, corresponding electrical signals must be fed at each instant to only one pair of loudspeakers. No practicable directional microphone can perform this switching between pairs of speakers accurately. Thus it is impossible to realise 'discrete quadraphony' from any natural sound field, and the medium is confined to pan-potted multi-track material, which would restrict artistic possibilities.

Just as the accurate reproduction of performed music is the crucial test of high fidelity, so the ability to reproduce correctly the directionality of natural sounds is the crucial test of a surround sound system. Unless it can do this, there will not be the correct disposition of indirect sound which provides the acoustic ambience of the performance and gives the position-dependent labelling of direct sounds by their wall reflections, which is an important aspect of the appreciation of music. If a system can cope with this difficult task, it should go without saying that it can easily deal with the relatively simple problems of synthetic source material. A system of surround sound which is able to reproduce the directionality of indirect reverberent sounds, as well as of direct sources, is termed "Ambisonic."

Ambisonics is based upon encoding a directional pattern of sound, and decoding in the listening room an illusion of the intended directional effect. The process of encoding direction may be performed by suitably designed ambisonic equipment in the recording or broadcasting studio, disc cutting or transmitting apparatus. In studio use the directional effect is encoded into three or more related channels of information, analogous to sum-and-difference techniques in stereo and designated 'B Format,' which is re-encoded using a phase-amplitude matrix to a consumer form: 'C Format.' The broadcast or transmitted C-format signal is used by the equipment in the listener's home to re-create the directional illusion.

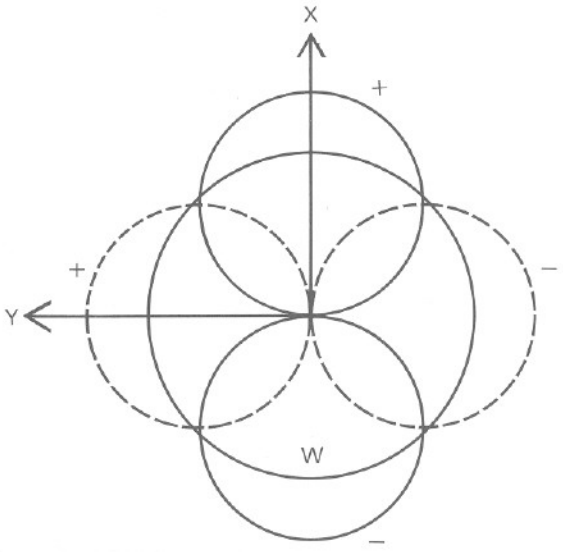


FIG. 2 B - Format, Z Points up.

The studio signals are capable of accomodating a full 360^{o} of directional sound in three channels, or even a full sphere of directions (including all angles of elevation and depression) in four B-format channels. The gain with which each of the three horizontal channels (denoted by W, X and Y) encode each direction has a polar pattern shown in Figure Two where the W signal incorporates all sounds with identical gain. The X pattern is a forward-facing figure-of-eight with gain of $+\sqrt{2}$ for sound straight in front, zero at the sides and gain of $-\sqrt{2}$ behind. The Y signal has a similar leftward-facing figure-of-eight pattern. For height information a similar upward-pointing Z signal is used.

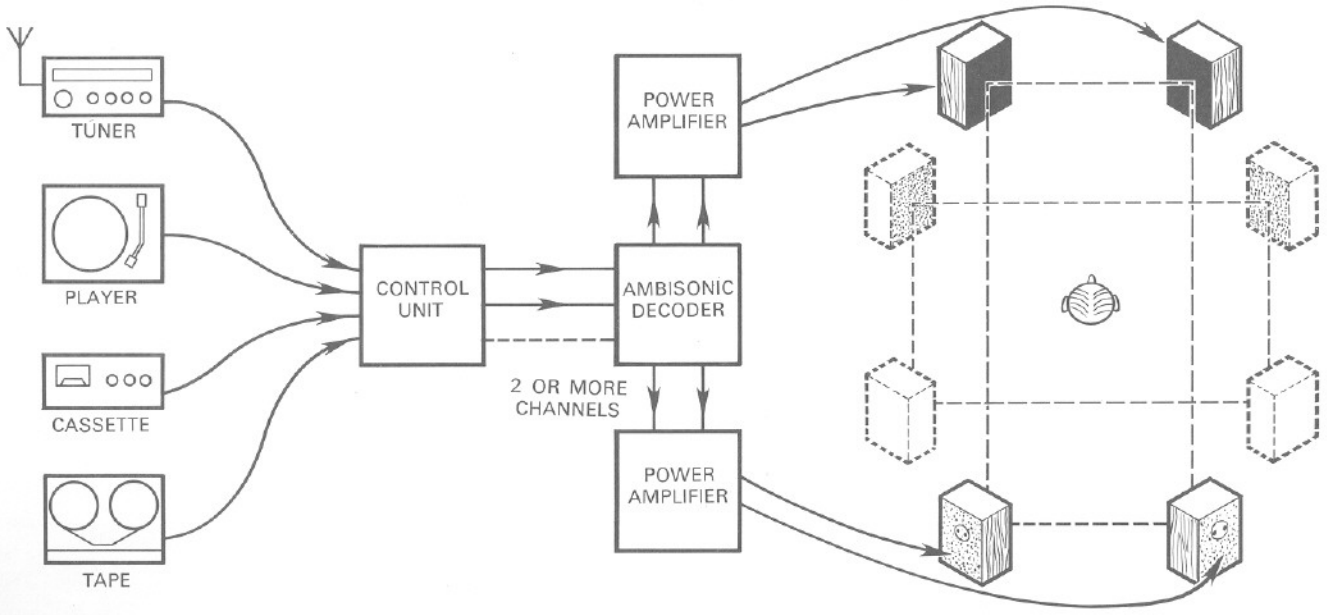


FIG. 1 Playback arrangements for Ambisonic encoded programme material.

FIG. 3 A 'Soundfield' microphone produced under licence by Calrec Audio Limited of Hebden Bridge, Yorkshire, England.

These signals can be produced by a number of different techniques; an ambisonic 'Soundfield' microphone which converts live sounds straight to B-format; a large number of conventional microphones close to each instrument, positioned in the 360° sound stage by an ambisonic pan-pot; or even spaced microphone techniques if the producer so prefers.

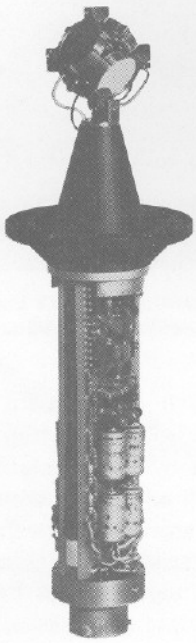


FIG. 4 Calrec 'Soundfield' microphone with cover removed to show tetrahedral capsule array.

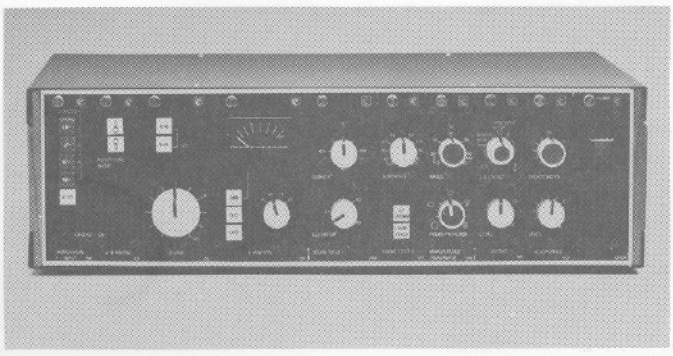


FIG. 5 Control unit accompanying the Calrec 'Soundfield' microphone.

The Soundfield microphone consists of four capsules in a tetrahedral array with electronic compensation to remove the effects of capsule spacing, designed to capture accurately the sounds that exist at a point in space. It may equally well be used for mono or stereo, and its directional characteristics may be altered by remote control. The 'true coincidence' of the outputs also improves performance over that available from previous microphones. By storing its signals in B-format, optimum recordings may be issued not only in mono and stereo, but in surround sound, or later even periphonically (with height).

Ambisonic signals are conveyed to the listener after being encoded with phases and amplitudes which conform to the Universal HJ system of consumer (C-format) signal encoding. The UHJ system is based on two signals, left and right, which are manipulated like stereo signals and provide conventional mono and stereo sound for listeners using only mono or stereo apparatus. Thus these two channels are mono and stereo compatible, and additionally contain the information from which a full 360° directional effect can be recovered by the listener with ambisonic decoding equipment.

The precise form of signals in the two basic UHJ channels is carefully chosen not only to allow good surround sound reproduction by themselves, but also to allow a further improved illusion with sharper images if these channels are supplemented with a third channel, so that the full horizontal information from the studio can be recovered. In practice, because the basic two-channel version of UHJ already gives good results, it is possible to obtain this further improvement if the third channel is provided only with a limited audio bandwidth. Therefore the consumer decoder may work with three channels at low frequencies but only two at high frequencies. Such '2½' channel signals can also be received by equipment designed only for two-channel UHJ, since the extra 'half' channel is then ignored. In broadcasting, this extra information can be transmitted in a stereo multiplex signal by an additional modulation of the 38kHz sub-carrier, and on disc can be cut according to UD-4 standards.

Whether the UHJ programme is available with 2, 2½, 3 or even 4 channels, the method of re-creating the directional effect is similar. Since real sounds occur from any direction and distance, the reproduction of this directional effect from only a few loudspeakers must still be an illusion. However, ambisonics has more control over the sound field in the listening room than stereo, owing to this larger number of speakers, and so is capable of a convincing re-creation of actual sounds.

This illusion is governed by the way the human brain interprets the sounds arriving at the ears, and the detailed design of decoders involved extensive study of human hearing. The ears have a number of different ways of locating sounds, and the decoder must not only stimulate several of these at the same time but do so accurately for all possible direction of sounds! The brain uses different ways of locating sounds at low and at high frequencies, so that the loudspeaker-feeds required to create the directional pattern must similarly vary their nature with frequency.

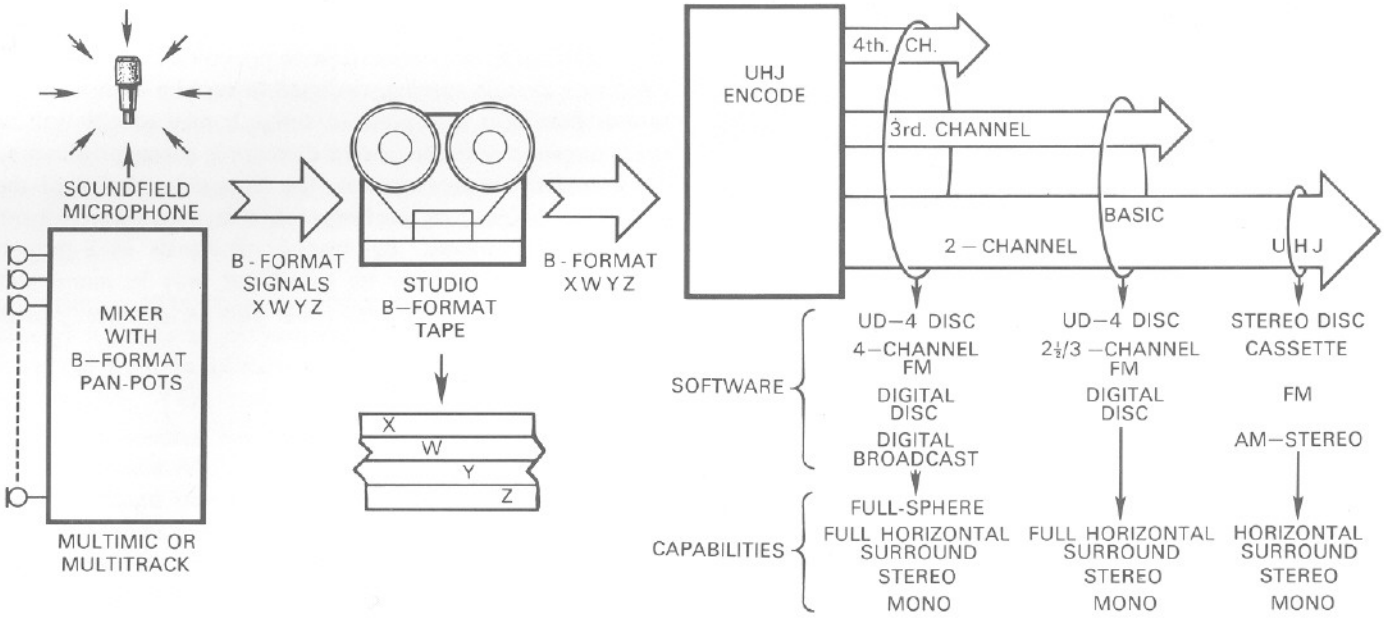


FIG. 6 UHJ is a unique hierarchical system of encoding and decoding directional sound information within the Ambisonics technology.

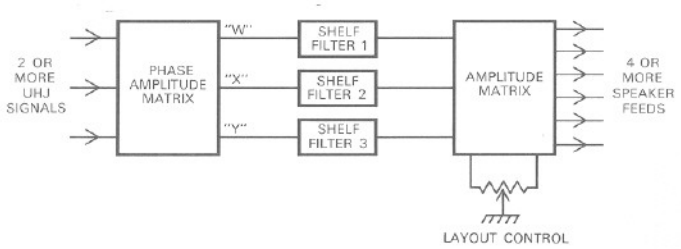


FIG. 7 Ambisonic decoder.

The way in which this is achieved is illustrated in Figure Seven. Here the available number of UHJ signals for decoding are fed to a phase-amplitude matrix to recover a suitable approximation to the original W, X and Y signals; this matrix being chosen especially carefully where only the minimum number of channels are available. These signals are then passed through 'shelf-filters' treating them differently at different frequency ranges, but ensuring that the total information in all signal paths has a flat perceived frequency response for every encoded direction of sound. Ultimately these signals (representing the sound-pressure and the components of acoustic velocity in the listening area) are passed through a further matrix to derive the required number of loudspeaker feeds. The minimum number of speakers is four, but any higher number may be employed for improved results. Indeed, it can be said that it is more the number of available loudspeakers than the number of permissible transmission channels that provides a limitation for surround sound. An ambisonic decoder incorporates a 'layout' control for the particular shape in which the speakers are used in the listener's room. This is necessary since speaker signals giving an ideal illusion of the intended directional effect would no longer do so if the speakers are moved in position. Additional refinements compensate for the size of loudspeaker layout whilst a 'directional preference' technique optimises the sharpness and sound quality of the most important directions.

All the technology mentioned already exists and development of new facilities continues. Ambisonics provides the creative producer and the receptive listener with new possibilities in sound.

FIG. 8 Part of the inside of the IBA's mobile control room which was specially equipped for surround sound broadcasts. Courtesy IBA.

The National Research Development Corporation of Great Britain has been actively supporting the years of intensive research upon which the Ambisonic Sound System is based. Practical work as well as theoretical studies have been carried out in England by a team headed by Prof. Peter Fellgett of the University of Reading and Michael Gerzon of the Mathematical Institute of Oxford, together with IMF Electronics Limited. The British Broadcasting Corporation is already transmitting music and drama programmes encoded in accordance with Ambisonic specifications and the Independent Broadcasting Authority of the U.K. has also broadcast 2½ channel material similarly originated. The first phonograph disc records are becoming available and manufacturing licences have already been granted to a number of companies in respect of Ambisonic equipment. NRDC's collaboration incorporates agreements with Prof. Duane Cooper of the University of Illinois and with the Japanese audio manufacturers Nippon Columbia, both of whom have made significant contributions to the development of surround sound.

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