SOME PRODUCTION FACILITIES AVAILABLE IN AMBISONICS

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Contents

1. General Introduction

Ambisonics is a technology for surround-reproduction of sound belonging to the post-"quadraphonic" generation properly described as kernel psycho-acoustic systems. It provides an extensive set of studio and broadcasting production facilities some of which cannot be implemented, or even defined, in earlier systems. A selection only of the more basic of these are described in the present brief document.

The gamut of technical methods and devices comprising Ambisonics is backed by a well-structured body of theory validated by listening trials. Ambisonics is therefore not a fixed or arbitrary "system", but is a means of bringing surround-reproduction within the scope of engineering design. That is to say, a rational choice can be made of priorities among desirable system properties, and theoretical design calculations can then be made which enable the chosen balance of priorities to be implemented in a specified system. This is a process analogous to designing an audio amplifier by use of Ohm's law, semi-conductor data, etc. An essential outcome of these surround-sound design processes is a user coding specification for use in disseminating surround-sound signals to the public by broadcasting or in the form of recording. The 2-channel user specification recommended by the Ambisonics team, subject to discussion, is designated BHJ. This is the lowest member of a compatible series which includes 3-channel and 4-channel specifications designated respectively THJ and QHJ or HHJ.

Some of the reasons for the choice of BHJ and THJ user specifications are outlined in the remainder of this Introduction. It is to be understood of course that the facilities described in subsequent sections are independent of the exact choice of user encoding specification (so long as it is of the appropriate kernel type). It is however obviously necessary to define a precise and appropriate studio signal format; this is discussed in Section 2.1.

Specification BHJ defines a 2-channel encoding for surround reproduction free from the disadvantages of discontinuity of treatment that occurs at corner positions in the older so-called "quadraphonic" practice. BHJ encoding may be represented in the Poincaré-Stokes sphere by a near-circle locus. The difference in phase between the signals in the two channels is 35° for front-centre encoding and -115° for rear-centre. Azimuths are encoded on the locus in a smoothly non-uniform manner, having left-right symmetry, designed to increase stage-width in stereo playback and confer other advantages. The overall distribution of signal-gain (loudness) with azimuth is contrived having regard to the distribution of azimuth within the locus so as to optimise the forward-preference facility in 2-channel surround playback and to confer other advantages.

The BHJ specification has been chosen to give an optimised balance of compatibility downward to stereo and mono, having regard both to ambient and pan-potted material, and upward to 3-channel (and also 4-channel periphonic) systems. The 3-channel specification, designated THJ, contains a third channel contrived to combine in an optimised way with the two base-band channels to give improved properties in surround reproduction.

Special attention has been given to compatibility with the use of a third channel of reduced amplitude or bandwidth ("2½-channel systems") of particular interest respectively in broadcasting and in disc technology.

BHJ and THJ encode azimuth in a smooth manner accurately compatible with sound-field microphone techniques for the recording, transmission and reproduction of a natural sound including its reverberant and ambience content. Associated technology permits all the usual synthetic techniques (pan-potting, artificial reverberation, etc.) as well as new ones. UHJ encodings may be approximated from pairwise-blended signal sources in a continuum of ways giving optimum compromise performance according to circumstances.

2. Pan Pot and Sound Field Controls

2.1 Introduction

In order to design decoders capable of producing an optimum re-creation of the intended directional effect, it is necessary to design all studio equipment to follow a standard encoding specification. Such a studio "encoding specification" consists of assigning each position in space to a set of gains on the channels used on the master mixdown. While the encoded material may finally reach the consumer in a 2-channel, 3-channel or 4-channel form, the master encoding specification is 4 channel in most cases.

One method of correct encoding is to use a precisely coincident array of accurately defined directional microphones. Amother method of correct encoding is to pan-pot mono sources into the sound field encoding by means of pan-pots accurately following the chosen encoding specification. It is well known, and experimentally confirmed by many research groups, that the "pairwise" pan-pot (that assigns a sound in a "phantom image" position by activating only the 2 adjacent channels) is not capable of giving stable image localisation even in the front quadrant (due to the 90° angle subtended by the speakers), and the side images are hopelessly unstable. For this reason the following pages describe pan-pot circuits capable of following the <u>B-format</u> studio encoding specification, consisting of 4 signals W, X, Y, Z, where W is an omni-directional signal having gain 1 for all directions, X has the same gain as would a forward-facing figure-of-eight microphone with forward gain $\sqrt{2}$, Y has the same gain as would a leftward-facing figure-of-eight microphone with leftward gain $\sqrt{2}$, and Z has the same gain as would an upward-facing figure-of-eight microphone having upward gain $\sqrt{2}$.

The B-format signal includes height information Z. It is expected that initially this would be used only to provide microphone information that would allow recordings to be electronically processed so as effectively to "tilt" the microphone array up or down for optimum effect. The Z information can also be used for full with-height encoding for eventual future use when this becomes commercially feasible. The reason for including the Z channel is that studies have shown that for 4-speaker reproduction, the 3 channels W, X, Y provide the optimum information for good directional localisation, and any other fourth channel of horizontal information can only degrade the stability of 4-speaker phantom images. Since the fourth channel is available in studio equipment, the best use that can be made of it is to store height information that would help to avoid obsolescence of recordings when height reproduction becomes commercial. Designs of with-height decoders for studio monitoring are available in a separate report.

The following is a selection of pan-pot and sound-field control devices, with a brief description of each.

2.2(a) Horizontal-only pan-pot, including full "interior" effect

This has continuously variable joystick action.

2.2(b) Constant gain version of (a), giving minimual gain variation for interior positions.

2.3 With-height pan-pot, including full interior effect, azimuth angle control and elevation and depression control. This covers the full sphere of directions. Azimuth and interior control are via a joystick action, and elevation is by a slider action.

2.4 Horizontal-only sound field control. This control operations on complete pre-mixed sound fields encoded in 3 or 4 channels, and provides the following control functions: (a) full rotation or "waltz" control operated by a joystick, permitting any desired rotation of the whole image, (b) interior mode control, operated by the same joystick, permitting the whole image to be varied from the normal "exterior" positions to full "interior" effect. This control allows such effects as pulsation of sound fields in and out from the listener, and the passage of whole sound fields through the listener's head over to the opposite side from which it started, (c) width control. This permits the relative widths of the front and back images to be varied (e.g. to modify the width of an orchestra or to emphasise rear reverberation). This is a linear control, and does not affect the correctness of the B-format encoding specification.

2.5 With-height Sound Field Control. This offers the same capabilities as the Horizontal SFC plus an up/down width control that, for example, allows a below-horizontal orchestra and audience (caused by high-up microphones) to be made horizontal by narrowing the upward width.

2.6 Hemisphere pan-pot. This has three operational modes, and uses a single joystick. In the first mode it produces horizontal panning, including "interior " effects, with minimal variation in the gain as the sound is panned. In the second "upper hemisphere" mode, it acts as a with-height pan pot for directions in the upper hemisphere, with the outmost joystick settings corresponding to to horizontal sounds. The "lower hemisphere" mode similarly covers below-horizontal positions.

When, as will be usual for the present, height information is not transmitted or decoded, any elevated or depressed sound-source will appear as the corresponding "interior" effect, the only difference from true "interior" positioning being that the overall loudness may not be treated quite correctly.

3. Artification Reverberation and Spreader Devices

3.1 Introduction

Besides the ability to handle sharply localised direct sounds, any well-designed system of surround sound must also be able to handle diffuse sounds, such as reverberation. The full advantages of reverberation can only be obtained by recording a sound along with its "live" reverberant field with a sound-field microphone, but there is often a requirement for artificial reverberation when undertaking recordings in the "creative" style. This section describes a method of optimizing the "surround reverberation" effect by spreading the reverberant sound from an artifical reverberation unit around the sound stage.

Also described are various types of device to "spread" direct sounds over part or the whole of the sound stage. Such "spreaders" may be used for a number of purposes: as a special effect on solo voices, to diffuse slightly the pin-point mono effect on mono chorus tracks, to "stereoize" mono sound effects, etc.

Just as it is an aim of well-designed surround sound systems to give stable and sharp localisation of direct sounds, so it is necessary to design spreaders to produce an accurately repeatable effect. Certain conventional attempts at producing spread (notably interchannel phase shifts and "overhead" or "interior" effects) have the defect that the listener often will not hear the intended effect if he is not correctly seated in the "quadraphonic" seat, and thus these effects are difficult to convey to the listener.

It must be noted that, in general, spreaders do not work well when fed with synthesized sound, and each such sound should be tested for goodness of spread before use.

3.2 Mono Spreader

This takes a single input channel and wraps it round and round the stage, differing frequencies being assigned to differing positions. A minor variant of the device (altering one resistor) may be used to wrap reverberation from a mono reverberation unit around the stage. As a spreader for direct sounds, this device has the advantage of being correctly heard as "surround spread" over most of a 4-speaker listening area, and of mixing-down to mono and 2-channel systems with relatively little quality degradation. It has the disadvantage of having little flexibility as one cannot adjust the degree of spread. For reverberation use, the fact that different frequencies come from different directions may render the reverberation quality unnatural. The mono spreader uses precision phase-shift networks.

3.3 2-channel Spreader

This takes two independent channels and wraps both of them around the sound stage, differing frequencies being assigned to different directions. At each frequency, one of the two input channels is assigned to the direction opposite to that of the other. This means that when two direct sounds (one at each input) are spread, a greater diversity of sound reaches the ear than if they were mixed and fed to a mono spreader. A minor variant permits the device to be used with two mono reverberation units having similar (but not precisely the same) behaviour or with so-called "stereo" reverberation units that are actually independent mono units (e.g. AKG BX20). It is not suitable for use with stereo reverberation units with highly correlated outputs. The two reverberation outputs of the reverberation unit are wrapped round and round the listener with one unit exciting the direction opposite to the other at each frequency. The 2-channel spreader uses a circuit only slightly more complex than the mono spreader.

3.4 Spread Pan-pot

This device, intended for direct sounds only, allows adjustment of both the position and the degree of spread of a mono input. The character of the "spread" is quite different from the "surround spread" effect of the above-described devices, and spreads the frequencies of a sound to-and-fro across a restricted and sharply defined region. The spread can be adjusted from 0° to 180°, and the position of the sound can be adjusted to any azimuth, and also to "interior" (in-the-head) positions should these be required. In direct reproduction or mono reproduction, the device does not affect sound quality, but in 2-channel matrix reproduction some degree of "comb filter"coloration is obtained. This should not be serious for smallish spreads, and is worst for a spread of around 90°. The device is less complex than the earlier spreaders in that it uses only one non-precision phase shifting network.

3.5 With-height Reverberation Spreader

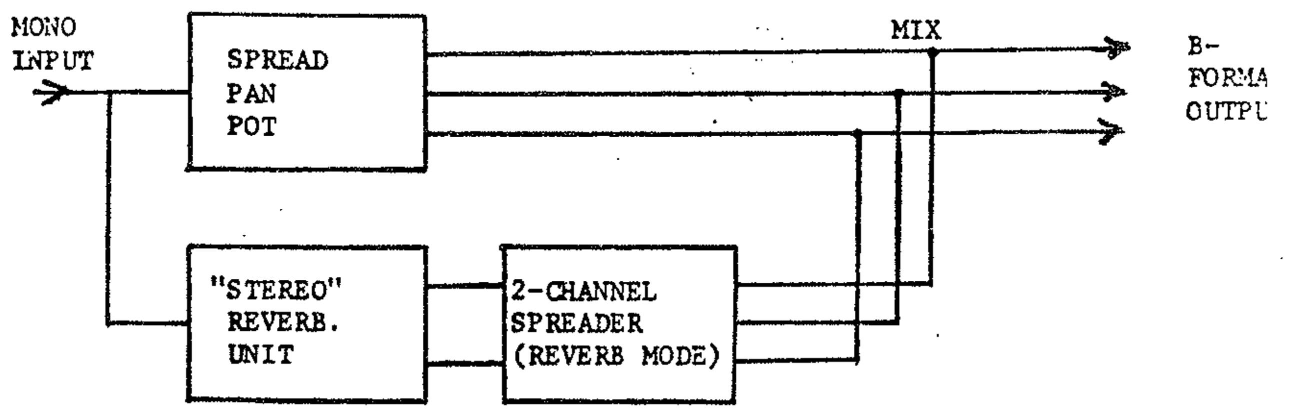
This is a with-height modification of device (3.3), and spreads one input around a circle 35.3° above the listener's head and another 35.3° below in the opposite direction at each frequency. This mode of use is suitable either for uncorrelated artificial reverberation inputs or for direct sounds when this periphonic effect is required. Switching also permits the with-height spreader to perform the same horizontal spreading functions as the 2-channel spreader (3.3). The periphonic (with-height) effect will, of course only be evident over suitably designed with-height playback equipment. Essentially, the circuit differs from the ordinary 2-channel spreader only in requiring an additional switch pole and phase shift network.

4. Typical Uses of Spreaders

Here we indicate some typical uses of the two types of spread device.

4.1 Re-channelling Mono

For old mono recordings, a re-channelling for "surround" effect may be obtained by the following arrangement.

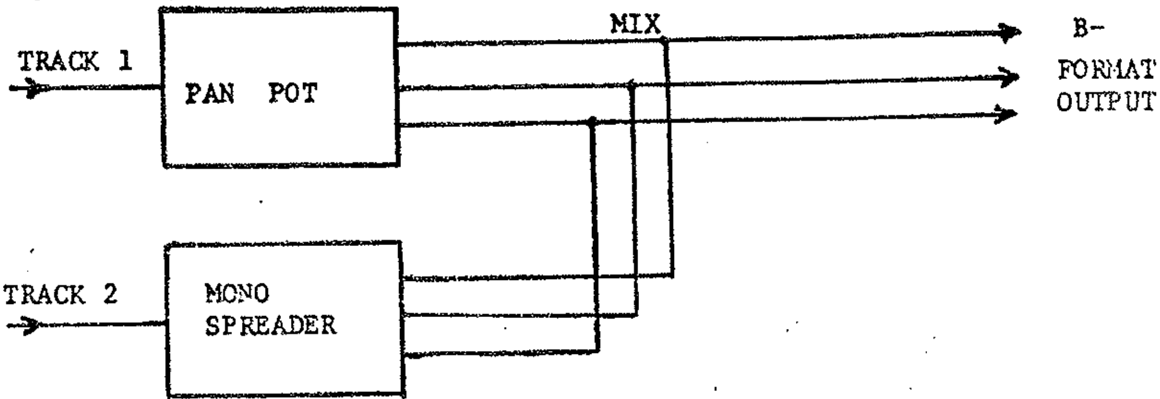


Typically, the spread pan pot would be adjusted for a front-centre position with enough spread (say 45°) to convey some feeling of width without an unduly artificial effect.

4.2 Re-channelling "Discrete" Stereo

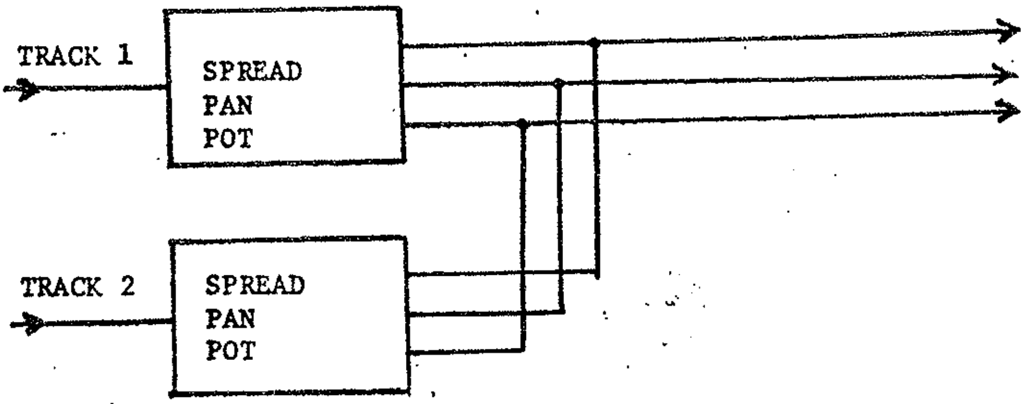
Many early "stereo" pop recordings have masters which are actually just two tracks, each containing half of the musical lines, without any intermediate panning. Three possible ways of re-channelling for "surround" are shown. We assume that track 1 of the original recording contains the main vocal, and that track 2 is primarily backing.

(a)

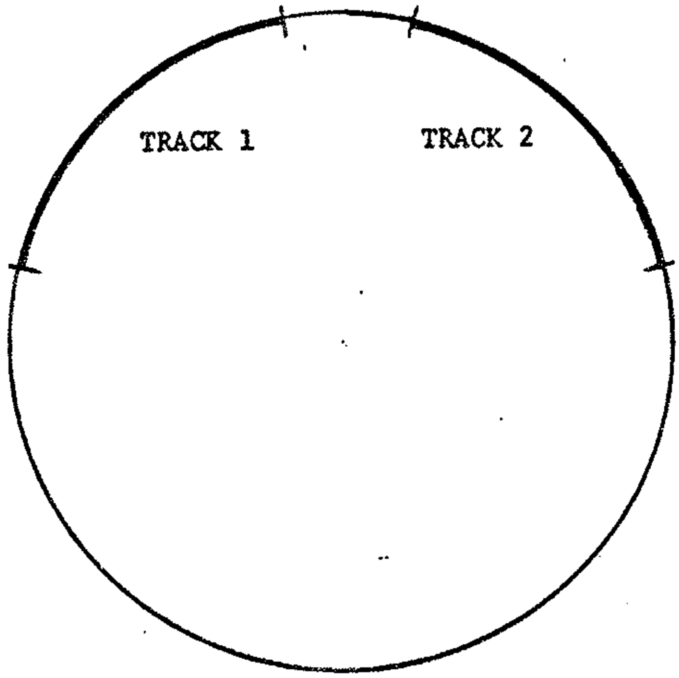


Normally, the track 1 would be panned without spread to front centre.

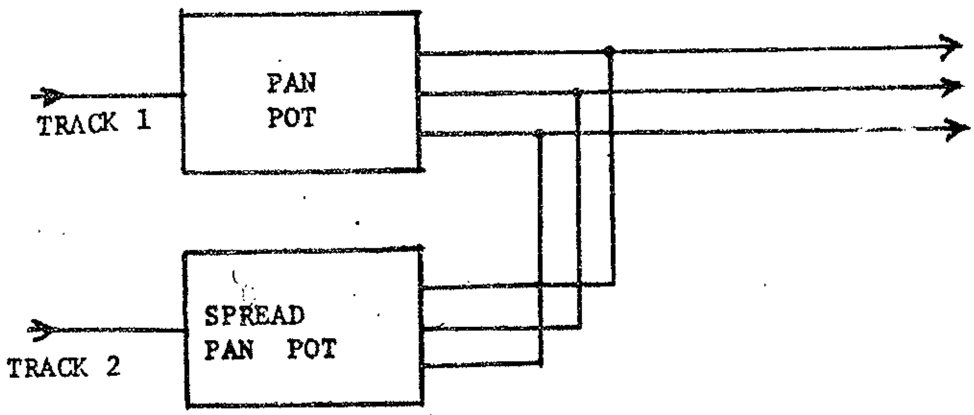
(b)



In this case, the tracks would be panned say 45° to the left and right of front respectively, with spread controls set to (say) 60° spread, giving a sound stage as illustrated



(c)



Here, track 1 would be panned to front centre (with no spread) and track 2 would also be panned to front centre, but with quite a large spread (e.g. 120°).

Clearly, when re-channelling old pop material, the rechannelling technique should be varied from track to track to avoid monotony of effect. Also, variety can be attained by varying the degree of spread from moment to moment according to the musical content.

4.3 Multitracking and Halo Reverberation

When a solo line is double-tracked, or when reverberation is added to it, it is often desirable to spread the accompanying sound diffusely around the original. Thus one might pan a voice sharply, and pan its reverberation or double tracking to the same position, but with say 20° of spread around it. This effect may be termed "halo reverberation" or "halo double tracking". The same halo-effect might also be used with repeat echo, or for the accompaniment of the predominent instrument in a distinctive sub-group of instruments.

As explained in the description of the spread pan pot, halo effects may easily be obtained from a single spread pan pot equipped with several "spread control" inputs.

4.4 Sound Effects

Certain sound effects lend themselves particularly well to spreading. Broadband noises (rain, crowd noises) may often be spread from a mono original.

4.5 Special Effects

The effect of spreading a direct sound right round the image is for its various frequency components to seem to come from different directions around the listener. This effect may be appealing for certain types of sound (e.g. the human voice) having components at many frequencies, but will merely cause the sound to jump around randomly if it is "pure" in quality (e.g. flute, certain organ stops, some synthesised tones).

5. Sound Field Microphone

In cooperation with Calrec Audio, a sound field microphone has been developed producing four outputs W, X, Y, Z conforming to the B-format specification. A unique feature of this microphone is that these outputs are precisely coincident in space (to the order of 1mm), so that no coloration or gross mislocation of the treble occurs when subsequent matrix processing or encoding is used. Recording the four B-format outputs on tape permits the use of the sound field controls described in section 2 to rotate the microphone array either in the horizontal plane or vertically to obtain optimum orientation and balance of direct to reverberant sound. The B-format signal may also be processed after recording to provide an arbitrary coincident stereo microphone technique, since the information is available on tape to provide any first-order microphone directional characteristic (e.g. cardioid or hypercardioid) pointing in any spatial direction. A mixdown unit for this purpose has been designed.

Hitherto, so-called "coincident" microphone arrays involving intercapsule spacings of the order of 5 cm have been found to give poor results when matrixed for surround-sound reproduction, partly because of the spacing (which is several wavelengths of the highest audio frequency), but also because the individual microphones have had frequency-dependent polar characteristics. The sound field microphone has been designed with particular attention paid to the accuracy of the polar diagrams up to about 10 kHz.

The sound field microphone may be used on its own for accurate recording of a live sound field, or in conjunction with 'spot' microphones if a less natural 'highlighted' effect is desired. In multitracking work, several groups of tracks may be laid down and mixed, with each B-format group recorded via a sound field microphone. The full advantages of the sound field microphone will be obtained in room acoustics suitable for live listening, rather than in "studio" acoustics optimised for separation between multi-microphones.