Directional Information in Reproduced Sound

by P. B. Fellgett*

Directional information over a 360° sound-stage can be coded onto two channels, but encounters a difficulty involving the phase shift round the azimuth circle. Methods of coding this information onto ordinary two-channel media are necessarily of this kind, and are not four-channel as is often implied. Three channels enable the phase difficulty to be avoided. Existing techniques of f.m. stereo broadcasting use a modulation bandwidth of three times audio bandwidth, and could carry three-channel 'pantophonic' signals by exploiting both phase and amplitude modulation of the stereo sub-carrier. Tape cassettes can provide four channels, but the usually-assumed 'discrete' pair-wise blended coding is not ideal, and the phase difficulty recurs here, as it does for any even number of channels. The best possibilities for future development seem to lie in three-channel coding, with compromise towards two channels when required by the limitations of the medium. For serious musical applications, the coding must be consistent with a practicable microphone technique for picking up true reverberation and ambience. This condition ensures that 'pop' effects and existing four-channel pair-wise blended coding can be catered for within their respective implicit limitations; the converse is not necessarily true.

The earliest high-quality systems for the reproduction of sound aimed at giving the listener information about the waveform that would have been heard at the original performance, but no information about direction of arrival. Although such one-channel or monophonic systems could feed more than one loudspeaker at the listening position, the signals from all loudspeakers are, of course, equivalent.

The first development of sound reproduction to give directional information employed two channels of transmission, and the two stereophonic channels are implemented on a vinyl disc as two orthogonal directions of stylus motion. These may be regarded either as two orthogonal directions each at 45° to the surface of the disc, interpreted respectively as left and right stereo channels, or equivalently as lateral modulation representing the monophonic signal, and hill-and-dale modulation representing the stereo difference. Similarly in f.m. broadcasting, the mono signal is transmitted as base-band modulation, and the stereo-difference signal is modulated onto a subcarrier.

Stereophonic systems essentially provide directional information over a sound-stage subtending an angle of between about 30° and 90° centered on the direction in front of the listener. It seems certain that the directional information in reproduced sound of high quality, originally provided by the extension from mono to stereo, will be extended to full omni-directional information, or at least an approximation to this that is aesthetically satisfying. Systems which give this information over the full 360° of azimuth may be called 'pantophonic'. (Gerzon has used the term 'periphonic' for systems which give height information as well, but these are not considered here.) A system that is symmetrical throughout the 360°, both at source and in reproduction, may be called strictly pantophonic. This implies that a source at any azimuth will be dealt with equivalently, and similarly that in reproduction there are no preferred azimuths for the loudspeakers as seen by the listener. It cannot be assumed that strict pantophonic systems are necessarily best, but the onus to show an advantage lies with the proposer of any system not having this property.

Current thinking about pantophonic reproduction has followed a rather curious historical path resulting, unfortunately, in the perpetuation of a number of misconceptions. This historical approach derives from the practice of the recording industry of using four-channel master tapes. In so far as such tapes represent simply discrete sources there is of course no difficulty and any competent pantophonic system can accept these inputs as readily as any others, and can associate a chosen azimuth with each of the four channels.

A difficulty however arises from the convention, which appears to have grown without systematic thought being given to it, of associating the four channels with cardinal azimuths (usually 45°, 135°, 225° and 315°) and introducing cross-talk between channels associated with adjacent cardinal azimuths so as to associate particular sources with azimuths intermediate between these cardinal directions.

This pair-wise blending, in imitation of stereo blending between two channels, unfortunately has a number of disadvantages. To anticipate some of the argument which will follow, this method is non-optimal in the sense that it does not exploit the full capabilities of four channels in giving directional information. It has indeed been shown that its capability varies between that of three and of four channels according to the azimuth of the source. Secondly, there are discontinuities in the azimuth-weighting function resulting from the fact that signals are blended only into an adjacent pair of channels. To feed such a system correctly, it would be necessary to use microphones having a sinusoidal lobe of response over 180° of azimuth, and a zero response over the other 180°; such microphones do not exist. Evidently, no subsequent part of the reproduction chain can remove the degradation introduced by pair-wise stereo blending.

Systems of reproduction using four channels of information having audio bandwidth between the source and the listener could correctly be called 'quadrisonic'. To link with the accepted terms 'monophonic' and 'stereophonic', however, the term 'tetraphonic' should be used. The term 'quadraphonic', which has unfortunately gained some currency, is linguistically indefensible.

Linguistics apart, it is bad physics to call any system using the conventional vinyl disc, for example, four-channel. In its present state of development the vinyl disc provides, as we have seen, two channels of information of audio bandwidth. It is not converted into a system having any other number of channels simply by having four, eight, or a thousand inputs, nor by connecting four or any other number of loudspeakers to its output.

The true position is that the vinyl disc in conventional form provides a two-channel system, as does conventional stereo broadcasting. As the stereo sub-carrier has double sidebands, sufficient bandwidth is available to provide a three-channel system. This possibility could be realised compatibly by incorporating the third channel as phase-modulation of the stereo sub-carrier. The limited extension of the bandwidth of the vinyl disc in the TMX system of Cooper and Shiga[1] provides a third channel of restricted

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bandwidth. (This could be called 'sesquisonic'.) Tape cassettes are of course in principle capable of providing four or more channels; the maximum number is limited by signal/noise ratio considerations, and pair-wise stereo blending is at a marked disadvantage in this respect in comparison with optimal coding.

Perhaps the most serious misconception is that it is possible to encode four (or three, or more) channels onto the two channels of a vinyl disc, and subsequently recover the information. This however could be done only by magic—it is clearly physically and informationally impossible. An associated fallacy is to suppose that the objective in pantophonic reproduction is to imitate a blended four-channel master tape. If indeed such a tape is the primary source, then an ideal system will evidently sound very similar to this master; some of the defects of the sub-optimal coding may be mitigated but they cannot be overcome. Nevertheless this is not a true statement of the problem. Monophonic reproduction has been referred to as "listening through a hole in the wall". Analogously, stereo provides two oles, and a four-channel master four holes. What is wanted is something different, namely the best directional information that is possible with the available capacity.

For serious aesthetic use, the problem is accordingly to reproduce in the neighbourhood of the listener's head the sound-field he would have experienced at the actual performance. If this is possible, then it is equally possible to associate the signal from each separate microphone in a multi-microphone recording with a prescribed azimuth by an extension of the conventional method of pan-potting so as to imitate sound coming from this direction. Unless a microphone technique is available which enables the true ambience and direction of arrival to be recorded the system is not a candidate for recording serious music, for example church music in which a full 360° sound-stage is traditionally used. Failure to recognize this distinction, or to implement it, in some of the current commercial proposals may account for a large part of the doubt that is still felt by some critical listeners as to the value of extending stereo to pantophonic reproduction.

Consider a microphone at point O in a sound field (Fig. 1). If the microphone is responsive only to pressure, it can record the intensity of the sound at O but nothing about its direction. Sound is however propagated as a longitudinal wave, so that a source at A gives rise to particle-motion along the line AO. The sum of the particle motions due to any number of sources can be resolved along convenient orthogonal directions, say Ox and Oy, and these two signals then carry complete information about the directional properties of the sound-field at O. Unfortunately a source at A′, 180° from A, produces particle motion which also lies in the direction OA, and consequently a 180° ambiguity exists in the absence of a reference of phase. This reference, as may be verified formally from the wave equation, is properly provided by measurement of the pressure at O due to the sound-field.

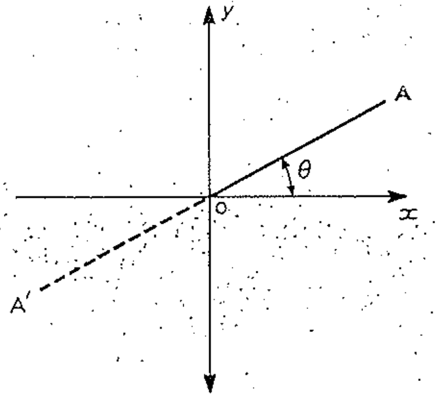

Fig. 1. Particle motions in a sound-field.

It follows that complete and unambiguous information about the sound field at a point can be provided using two velocity-sensitive microphones oriented at right angles, in combination with a pressure microphone, and feeding only three independent channels of audio bandwidth. Any theoretical analysis however represents an abstraction from the real complexities of nature, and the principal approximation in the present case lies in the fact that the human head is not a point. The argument is probably valid for frequencies below about 1kHz but may need modification at high frequencies. Both theoretically and empirically an optimal three-channel system seems to be inferior to four-channel pair-wise stereo blended arrangements by at most an insignificant amount. The argument for three-channel pantophonic f.m. broadcasting appears very strong, especially as full mono and stereo compatibility presents few problems.

In relation to the vinyl disc, the question remains how the three channels can be compressed into the two that are available on the disc. Around 1970 it was noticed by several people independently that the velocity components along Ox and Oy of Fig. 1 could be transmitted as the in-phase and quadrature components of an ambience channel, with the reference of phase being provided by a monophonic channel deriving its signal from the pressure microphone; or equivalently in the simulation by pan-potting. It has been confirmed that this phasor arrangement is capable of giving directional information acceptable in many circumstances. The introduction of phase shifts carries, however, a disadvantage that may be best seen by developing the argument from a different point of view.

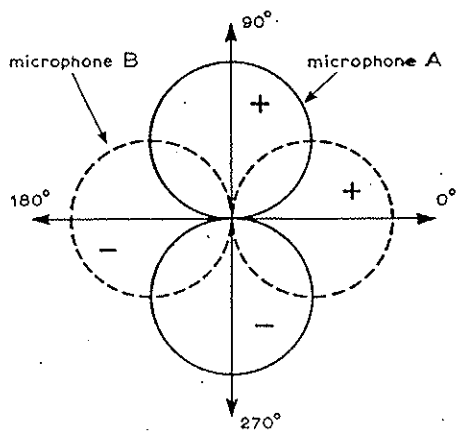

Fig. 2. Responses of microphones in a Blumlein configuration.

Consider two Blumlein microphones for stereo recording having figure-of-eight responses oriented for convenience as shown in Fig. 2. The respective signals from the two microphones from a source at azimuth θ are given by

$$A = a \sin \theta$$

$$B = a \cos \theta$$

The monophonic intensity information is evidently provided by the sum of squares of these two signals, while azimuth information is provided by their ratio in the form

$$\tan \theta = A/B$$

This azimuth information is complete apart from the 180° ambiguity corresponding to this last function being two-valued in the interval 0 to 360°. Provided therefore the sound-stage is confined to the front 180° semi-circle (strictly impossible for reverberation, of course) the original Blumlein microphone arrangement already provides the basis of a fully pantophonic two-channel system, and in this limited sense no further invention was necessary. It is this property that was exploited in the original Hafler surround-sound arrangement.

The 180° ambiguity may be removed, in principle, by mapping the azimuth range 0 to 180° (Fig. 2) onto a 360° circle. This transformation would result in the Blumlein microphone responses of Fig. 3. The amplitudes present no problem, but one microphone is required to change polarity suddenly at azimuth 270° onto which both the old 0° and 180° azimuth have been mapped. More sophisticated arguments show that this unwanted phase reversal is a general property of two-channel systems which cannot be avoided. It appears in various guises in the theory of such systems, and in particular requires a 180° phase shift to be distributed around the circle of loudspeakers used to reproduce the pantophonic sound. The only available choice is how this 180° of relative shift is distributed; the UMX[1] (both BMX and TMX) system distributes it uniformly, Sansui QS with rather less regularity, and CBS SQ with still greater irregularity.

The coding of directional information onto n channels has been analysed by two principal methods; the circular harmonic method of Cooper and Shiga[1], and the representative sphere or energy sphere of Scheiber[2] and Gerzon[3]. Both methods are applicable to any number of channels, but the energy sphere is particularly useful for two-channel systems because the sphere is then an ordinary three-dimensional one which can be more readily visualized than the hyperspheres needed in general.

According to this method, the two channels A and B are taken as normalized so that a source of unit strength gives rise to the same energy $A^2+B^2 = 1$ irrespective of azimuth. As only relative phase between the two channels is of interest, absolute phase

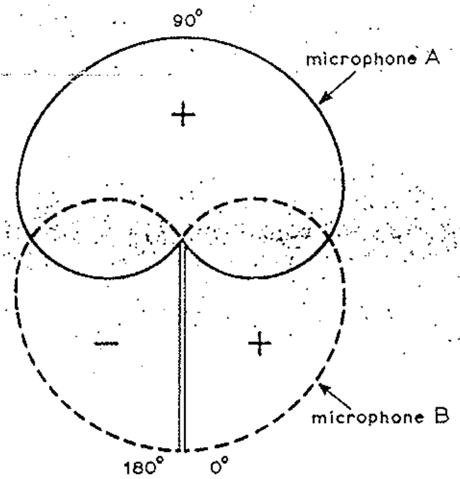

Fig. 3. Responses which result when the front 180° region (top part in the diagram) of Fig. 2 is mapped into 360°.

being irrelevant, the amplitudes in the two channels may be written without loss of generality as

$$A = \sin(\alpha/2)\exp(i\beta/2)$$

$$B = \cos(\alpha/2)\exp(-i\beta/2)$$

in which the angles α, β are defined as spherical co-ordinates on the representative sphere. Each azimuth θ corresponds to a point on the sphere according to the relations $\alpha = \alpha(\theta)$, $\beta = \beta(\theta)$ and the problem of encoding is to choose the function α and β which define the locus described on the sphere as θ explores the 360° of azimuth.

Similarly in decoding a representative point on the energy sphere is defined in spherical co-ordinates by

$$\text{output} = A\cos(\alpha'/2)\exp(-i\beta'/2) + B\sin(\alpha'/2)\exp(i\beta'/2)$$

in which α' and β' represent the amplitudes and relative phases of the respective contributions from the A and B channels to a given output of the decoder.

The energy sphere provides a geometrical picture from which many relations can be clarified. In the first place, fallacious 'four-channel' thinking has concentrated the attention of some designers only onto four points corresponding to cardinal azimuths. In fact of course the representative point of the encoder will explore the full 360° of azimuth, whether this was intended consciously or not, either in a system using a microphone technique to record the true ambience and direction of arrival of the sound, or in one in which separate microphones are pan-potted. If four (or indeed any other number) of points in a pair-wise blended system are fixed, the locus between these points is dependent on the phase-shifts between adjacent channels. Phase shifts of 90° between four cardinal channels have been used, for example, in the Sansui system to control the intermediate locus. (Reference to the block diagram shows that these 90° phase shifts may properly be regarded as outside the encoding matrix itself.)

A systematic approach is evidently desirable, and two forms of locus deserve initial consideration, the great circle and a locus passing through tetrahedral points. The 'modified Blumlein' amplitude coding described in connection with Fig. 3, and phasor systems such as BMX[1], give great circle loci. Indeed these two methods of encoding are informationally equivalent in the sense that one can be converted into the other, or *vice versa* at the decoder by means of the linear operations of 90° phase shift combined with addition and subtraction. For example the amplitude-coded signal can be converted into a phasor-coded one according to the following relationships

$$A = \sin(\alpha/2) \qquad B = \cos(\alpha/2)$$

$$B + iA = \cos(\alpha/2) + i\sin(\alpha/2) = \exp(i\alpha/2)$$

$$B - iA = \cos(\alpha/2) - i\sin(\alpha/2) = \exp(-i\alpha/2)$$

Although tetrahedral arrangements of cardinal azimuths have been considered, there seems to have been little or no discussion of the locus between these points. A desirable locus would be roughly in the shape of the seam on a tennis ball, crossing a great circle at four points half-way between the cardinal azimuths.

It can be shown that the cross-talk between decoder outputs is given by

$$-20\log_{10}\{\cos(\Omega/2)\}$$

in which Ω is the angle subtended at the centre of the sphere by the points representing the decoding of the two channels. In terms of energy, this formula represents a cardioid of revolution—rather like the top bun of a cottage loaf—with maximum at the representative point and zero 180° away from it on the sphere. It is important to note that separation is purely a property of the decoder, irrespective of the encoding which feeds it.

Separation has been an obsession in the discussion of pantophonic proposals, probably by false analogy with stereo in which cross-talk between channels represents a degradation of the intended system. In pantophonic reproduction however the objective is not to provide high separation between an irrelevant and in general mythical four-channel source, but to reproduce at the listener an approximation to the directional properties of the sound-field that would have been heard at source. Imitation of stereo operation is not the ideal way of achieving this, as stereo blending is itself non-ideal.

Consider a listener at the centre in Fig. 4 listening to a front-centre signal presented, as some authors have supposed to be desirable, as equal signals from loudspeakers a and b, while c and d remain silent. It is easy to see that in fact the particle velocity is along the desired centre line, but the pressure due to the sound-field is 3dB too high. This phenomenon may be the explanation of the slightly oppressive 'overhead' quality experienced by some listeners to normal stereo. Even with loudspeakers oriented so that one is in the front-centre direction as in Fig. 5, feeding a signal to this speaker alone is not the only way of establishing particle velocity along the centre line, accompanied by a correctly related pressure field. Fig. 5(a) illustrates another out of the infinity of ways in which this

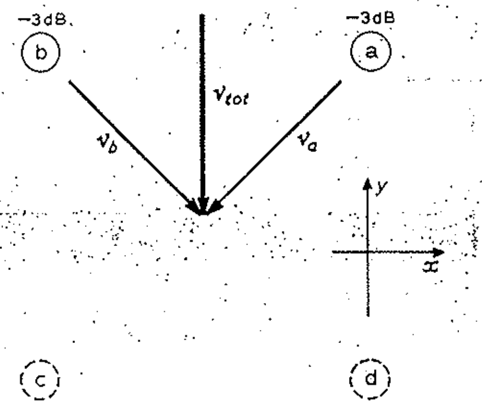

Fig. 4. Stereo speakers do not give exactly correct relationship between air pressure and velocity for a front centre source. For $a = b = 0.707$, $v_x = 0$, $v_y = 1.00$ and $p = 1.414$.

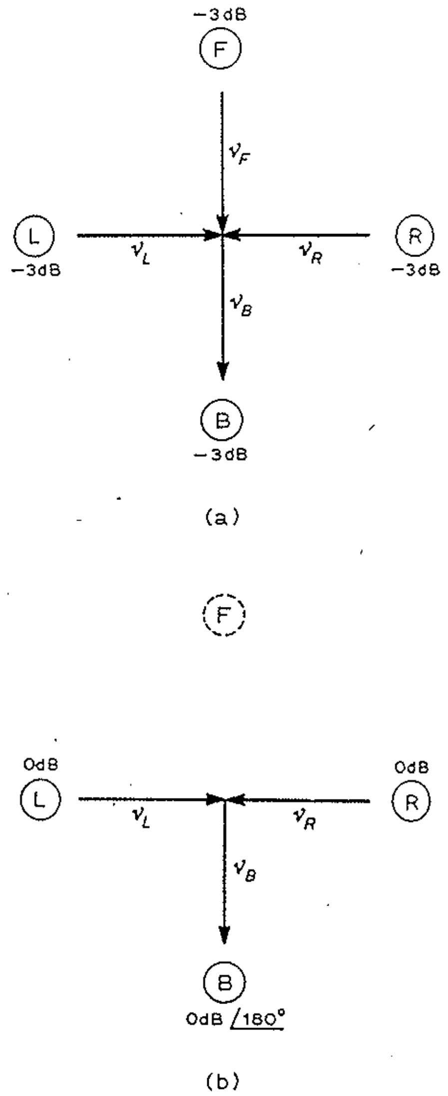

Fig. 5. Examples, one pathological, of configurations which give correct relationship between pressure and velocity for front centre source. $v_x = 0$, $v_y = 1$ and $p = 1$ not only when $F = 1, L = R = B = 0$, but in general when $F - B = 1$, $F + L = 1$ and $L = R$. Cases illustrated are for $F = L = R = \frac{1}{2}$, $B = -\frac{1}{2}$, and $F = 0$, $L = R = 1$, $B = -1$.

..n be done, and Fig. 5(b) illustrates a particularly pathological example. It may rightly be objected that an extended listening area must be considered, and that the sound-field in the neighbourhood of the listener's head cannot be taken as equivalent to the behaviour at a point, particularly for frequencies above 1kHz. For these reasons it is certainly not recommended that the arrangement shown in Fig. 5(b) should be deliberately used.

The arrangement shown in Fig. 6, in which the speakers are once again placed in the 45° cardinal position, may however be preferable to 'infinite separation' between front and rear speakers, particularly below 1kHz.

The last equation shows that the false goal of infinite separation can be attained between any two decoder outputs by simply placing the representative point of each at the zero response of the other. There is however then a limit to the separation that can be achieved between both of these channels and any third channel. Table 1 shows that if

Table 1

Separation X to Y and X to Z (dB)	Maximum separation Y to Z (dB)
3	∞
4.5	10.7
10	6
∞	1.95

the separation between output X and both of outputs Y and Z is to be at least as great as that shown in the first column, then the separation between Y and Z is limited to the value shown in the second column. These relationships are further illustrated in Fig. 7, which shows as a function of azimuth the separation between adjacent pairs and across diagonals of the 'high-separation' tetraphonic coding proposed by Scheiber when the full pantophonic locus is considered. It may be doubted whether the extra complication and asymmetry of tetrahedral encoding, which in any case increases adjacent-speaker separation at the expense of the diagonals, is worthwhile over the whole locus. (Claims for separations exceeding those implied by the crosstalk equation can be true only in the sense of being achieved by non-linear or gain-riding techniques, the limitations of which appear as unacceptable for serious music as were those of processed stereo.)

The implication of this last equation for great-circle encoding is that each output of the decoder, which may be connected to its own loudspeaker, behaves as if it were effectively connected to a source microphone having a cardioid directional characteristic. It would be at most pointless, and probably undesirable, if it were possible to increase the directivity of this polar so that it exceeded the directional discrimination of practicable studio microphones. A three-channel pantophonic system can give 6dB between decoder output associated with azimuths 90° apart and complete separation across diagonals, or alternatively this polar can be slightly sharpened at the expense of a small secondary lobe in the rear direction.

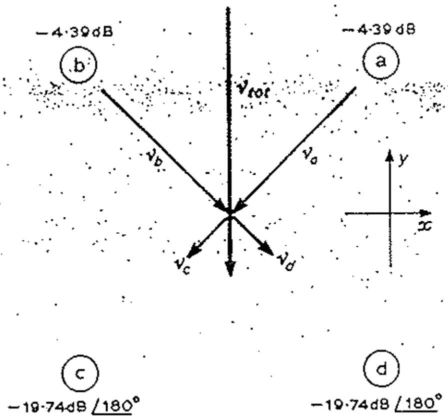

Fig. 6. Theoretically desirable configuration giving correct relationship between pressure and velocity. $v_x = 0.707 (v_a - v_b - v_c + v_d)$, $v_y = 0.707 (v_a + v_b - v_c - v_d)$. *For* $a = b = 0.603$, $c = d = -0.103$, $v_x = 0$, $v_y = 1.00$.

Table 2 shows the number of zeros on the effective polar of a decoder output that can be achieved with different numbers of channels. The phase shift problem, discussed in connection with Fig. 3, applies not only to two-channel systems but to all systems having an even number of channels, as stated in the third column of Table 2. This table suggests that three-channel pantophonic systems have a special claim to consideration, and underlines again the desirability of developing f.m. broadcasting in this mode.

In the original development of stereo reproduction, it was taken for granted that no adequate test of the new system could be made without adapting the studio technique to exploit the directional information that was then being provided for the first time. Pantophonic sound has unfortunately often been denied the courtesy of this logical necessity, and attempts have been made to express compatibility with existing systems in terms of the use of a sound-stage restricted by the limitations of conventional stereo. At the present stage of development, the source material is largely under the control of the proponents of any given

Table 2

No. of channels	No. of zeros in the output polar	Phase shift present
1	0	—
2	1	yes
3	2	no
4	3	yes

system, and may be chosen to illustrate the good points of the latter while concealing its defects. A compatible pantophonic system should fulfil the following requirements with good approximation:

- It should be capable of exploiting a full 360° sound-stage. In a demonstration, the material should be such as to exploit this capability artistically, for example church organ music with detached choir and echo organs.
- It must be capable of reproducing correctly the direction of arrival of sound at the original performance, including reverberant sound. The ability to pan-pot separate microphones may be taken for granted if this condition is fulfilled.
- A good monophonic signal should be available without the use of a special decoder. This signal should give equal weight to all azimuths, or nearly so.
- Played in stereo mode without decoder,

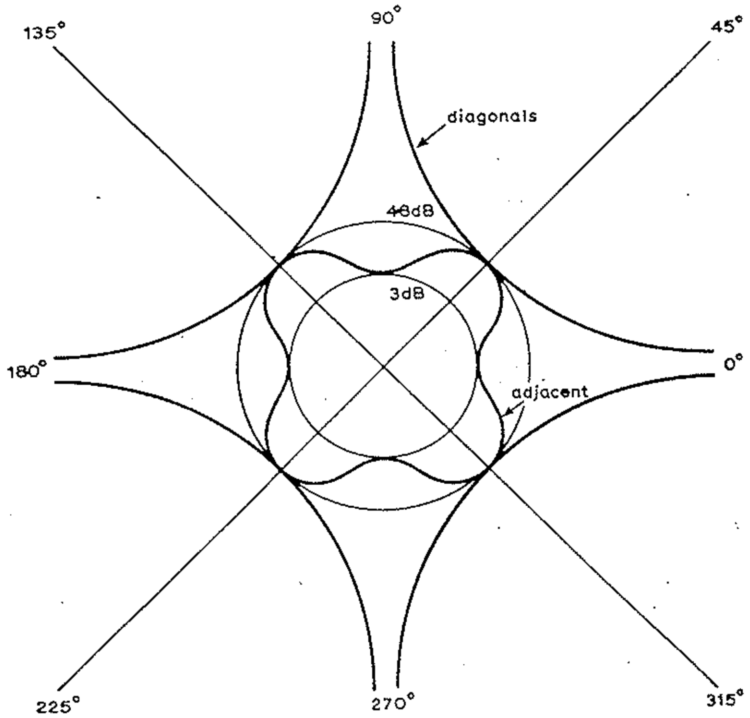

Fig. 7. Characteristics of Scheiber 'high separation' tetraphonic coding used pantophonically. Extra 1.4-dB separation between adjacent speakers is realizable only in the four cardinal directions, and is at the expense of separation across diagonals.

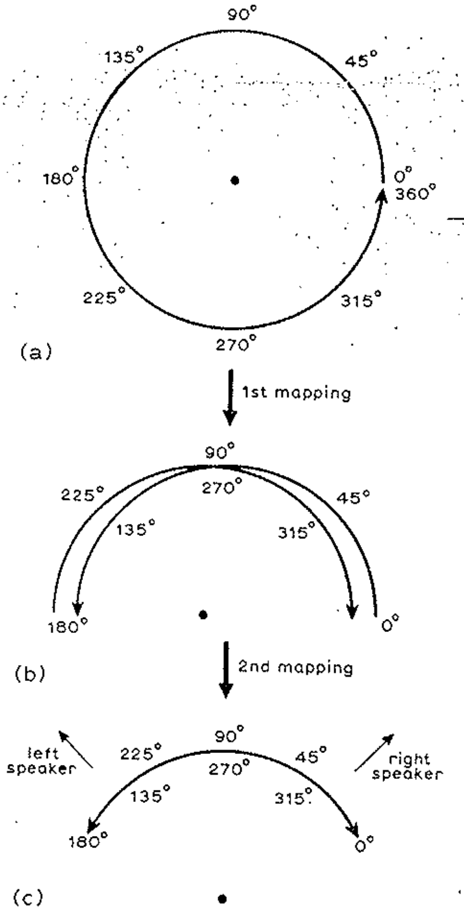

Fig. 8. Way in which a system for reproducing 360° sound stage (a) can be made stereo compatible by first mapping rear semicircle onto front (b) and then compressing to range encompassed by stereo speaker positions (c).

the front 180° of sound-stage should appear between the two stereo speakers (with perhaps some further additional spread from 'stereo enhancement' if used). The rear 180° should be superposed on the front hemisphere by mirror imaging in the diameter joining these hemispheres.

- The system should be capable of being played pantophonically with the, logically, minimum of three decoder outputs feeding three loudspeakers, and there should be progressive subjective improvement as the number of decoded signals is increased to four or more. This requirement follows on from the practice of using an intermediate speaker in conventional stereo; four loudspeakers fed from either three or four decoder outputs may be a convenient compromise between aesthetics and cost, but there is nothing magical about the number four in this connection and the use of six to eight speakers (not all covering the full bass range) may be required.

The fourth requirement is illustrated in Fig. 8. The true 360° sound-stage, illustrated in Fig. 8(a), should be reproduced in pantophonic play-back. In stereo mode, it is inevitable that front-to-back information is lost, and the only practicable mapping seems to be to that shown in Fig. 8(b) in which corresponding front and rear azimuths are superposed. If the loudspeakers are placed in the conventional stereo positions, the hemisphere of Fig. 8(b) is necessarily compressed to the region shown in Fig. 8(c) lying approximately between the left and right speakers. This compression would of course give an undesirably narrow stereo image if a studio technique had been used which confined the sound-stage to the stereo limitation of the front quadrant only. If however a correct pantophonic studio technique has been used, in which instrumentalists may occupy at least the front semi-circle, then this compression will be harmless and will give the stereo listener a good approximation of what he is used to. The inevitability of mapping operations closely approximating those shown in Fig. 8 has been missed by those who have concentrated attention on cardinal directions only, with the possible addition of stereo blending over the front quadrant, instead of considering the whole of the pantophonic locus.

Most, or all, of the theory on which the above discussion is based was afterwards found to have been anticipated in the more general and elegant theoretical analysis developed by Michael Gerzon[3] and incorporated in a series of circulated reports. The author has benefited from these reports, and from helpful discussions with Mr. Gerzon for which acknowledgement is gratefully made. Any errors in this article are however the author's own.

REFERENCES

1. Cooper, D. H. and Shiga, T. 'Discrete Matrix Multichannel Stereo'. Audio Engineering Society, Inc. Munich Convention, 1972, also Los Angeles Convention, 1972.
2. Scheiber, P. 'Analysing Phase-Amplitude Matrices'. *J. Audio Eng. Soc.*, vol. 19, 1971, p. 835.
3. Gerzon, M. 'Matrix Systems for Four-Speaker Stereo I'. Privately circulated report, 1971.

Announcements

The Institution of Electrical Engineers has organized a residential vacation school on *"Lasers and Optical Electronics"* to be held at the University of Southampton from 10th-22nd September. Information from the Divisional Secretary LS(S), I.E.E., Savoy Place, London WC2R OBL.

The Royal Television Society is introducing a series of short training courses the first of which will cover *digital techniques in television engineering*. The nine lectures will be given on consecutive Wednesday evenings beginning on October 25th at University College, Gower Street, London WC1. The fee for non-members is £7.50. Application forms from Mrs. Jill Cousins, R.T.S., 166 Shaftesbury Avenue, London WC2H 8JH.

Three courses to be held at the Polytechnic of North London are: *"High Quality Sound Reproduction"* commencing October 26th at 18.30, fee £6.30; *"Sound Studios and Recording"*, October 26th at 14.30, fee £10.50; *"Television Engineering"*, a post-graduate course, October 3rd at 17.30, fee £6. Further details from the Head of Department of Electronic and Communications Engineering, Polytechnic of North London, Holloway Road, London N7 8DB.

An advanced *course in noise and vibration* is being conducted by the Institute of Sound and Vibration Research at the University of Southampton from 18th-22nd September, the fee, including accommodation, is £50. Registration forms etc. from Mrs. O. G. Hyde, I.S.V.R., University of Southampton, Southampton SO9 5NH.

A post-graduate *evening course on integrated circuit electronics* will be held at North East London Polytechnic commencing November 2nd. Fee £6. Details from The Engineering Faculty Registrar, North East London Polytechnic, Barking Precinct, Longbridge Road, Dagenham, Essex, RM8 2AS.

A 32-week evening course entitled *"Non-destructive Testing"* is to be held at Croydon Technical College starting in the Autumn. Fee £3. further details from Head of Science Department, Croydon Technical College, Fairfield, Croydon, Surrey, CR9 1DX.

A course of ten *lectures on audio techniques* will be held at Norwood Technical College at 18.30 each Tuesday commencing October 3rd. Fee £3. Further information from the Senior Administrative Officer, Norwood Technical College, Knight's Hill, London SE27 OTX.

"Confidence in Measurement" is the title of a 16mm colour film which describes the work and facilities of the British Calibration Service and is available for hire or purchase from the Central Film Library, Government Building, Bromyard Avenue, Acton, London W3 7JB.

A ten-week evening course on *modern electronic techniques* will be held at Portsmouth Polytechnic commencing October 12th. Fee £5. Details from D. Meek, Administrative Assistant, Portsmouth Polytechnic, Department of Electrical and Electronic Engineering, Burnaby Road, Portsmouth PO1 3QL.

Mr. M. R. Lord, 7 Dordells, Basildon, Essex, would be pleased to hear from anyone interested in the formation of an *Amateur Computer Constructors' Society*.

Acoustic Research are to open a new assembly plant in London for their range of audio products on October 2nd. It will supply products for the U.K. market and be the base for service operations. The significant feature of this move is that the price of their range of products will be cut by 17% to 25%. The AR tuner, not previously available in the U.K. will be introduced at £110 together with a new loudspeaker unit designated the AR7 and priced at £26.

The signing of an agreement appointing Celdis as Hewlett-Packard's sole U.K. distributor for their range of *opto-electronic components* has been announced. The existing H-P marketing organization will continue but will concentrate on "the big-order end of the business." The products Celdis will be stocking are light-emitting diode numeric and alpha-numeric displays, solid-state lamps, emitters of visible light, and isolators made up of emitter-detector pairs.

Available in the U.K. from Tranchant Electronics (U.K.) Ltd, Tranchant House, 100a High Street, Hampton, Middlesex, TW12 2ST, is the Intersil series of high slew-rate *operational amplifiers*, electrically and pin-for-pin compatible with the Harris HA2500 Series.

The Plessey Company, Poole, Dorset, has signed a marketing agreement with the Frederick Electronics Corporation, of Maryland, U.S.A., covering the sale and service of *data and telegraph equipment* in the U.K. and a large number of countries overseas.

Burndept Electronics (ER) Ltd, have acquired the *mobile radio-telephone* business previously carried on by Ultra Electronics Ltd, for the sum of £350,000.

The electronic component distributors SDS-WEL Components Ltd, of Gunstore Road, Hilsea Trading Estate, Portsmouth, Hants, have changed the name of the company to *SDS Components Ltd.*

B & W Electronics have moved from Littlehampton Road to a factory at Meadow Road, Worthing, Sussex, BN11 2RX.

From 1st. September, *Aveley Electric Ltd*, of South Ockendon, will operate from premises at Roebuck Road, Chessington, Surrey. (Tel: 01-397 8771)