After briefly recalling why a two-channel, matrixed system should be used for the broadcasting of quadraphony, the article then describes three series of experiments, the object of which was to study certain important properties of the subjective effect of monophonic, stereophonic and quadraphonic reproduction. The results of these experiments were used by the B.B.C. in the development of Matrix H, which is designed to provide a two-channel, compatible quadraphonic signal.

The matrixing characteristics were studied using a Scheiber sphere, a mathematical transformation that enables the matrixed signals to be studied more easily. Three impairment zones are then defined, corresponding to varying degrees of impairment of the stereophonic signal, and are plotted on a two-dimensional version of the Scheiber sphere. It is shown that a large proportion of the coding locus of commercial matrices lies in the zone of severe impairment. When the B.B.C. Matrix H is examined under the same conditions, it can be seen that it offers much-improved compatibility for the two types of recording techniques in current use (pan-pot or coincident-microphone).

Finally, several methods of decoding that may be used in conjunction with Matrix H are examined, and it is shown that the best results are given by " logic-enhanced " decoders, in which the decoding matrix varies as a function of the signal content.

The development of a compatible 4-2-4 quadraphonic matrix system, B.B.C. Matrix H

D.J. Meares and P.A. Ratliff *

1. Introduction

The broadcasting of quadraphony in Europe using four discrete channels is not readily feasible for many reasons. Firstly, the RF transmission problem is not solved as simply as might appear at first sight. Systems proposing the use of quadrature modulation of the stereophonic subcarrier (38 kHz) for the provision of a third audio signal [1 to 6] are unlikely to be satisfactory, even though the worsening in signal-to-noise and signal-to-interference ratios involved is only of the order of 5 dB relative to those of normal stereo. A considerable number of current European FM stereo receivers introduce crosstalk between the quadrature subcarrier signals at significantly high levels, and in addition, objectionable intermodulation distortions can be generated [7, 8]. Further problems are encountered if an additional audio signal is provided by modulation of a higher frequency subcarrier (e.g. 76 kHz), because of seriously worsening signal-to-noise and interference ratios [7, 9].

The problems are greatly simplified if the information can be compressed into fewer channels, and much attention has been paid to this aspect. Many proposals for the reduction of quadraphonic signals into two transmission channels have been made, involving linear matrixing of the source material [10 to 13]. These appear attractive from the broadcaster's point of view, as well as that of the record manufacturer, since the information is readily accommodated on current two-channel (stereo) systems. However, for broadcasting, signals would have to be transmitted over current VHF stereo networks, thus making compatibility with existing stereophonic and monophonic reception an essential requirement.

Stereo and mono receivers are likely to be in the great majority for many years to come and they must not be supplied with degraded signals merely to accommodate the needs of a small number of quadraphonic listeners. Since even discrete quadraphony fails to achieve the original intention of *completely uniform* " surround-sound " [14], the ability of matrix systems to reproduce quadraphonic sounds as intended required careful study, as did their compatibility in stereo and mono reproduction.

* Messrs Meares and Ratliff are with the B.B.C. Research Department.

Initial work at the B.B.C. Research Department therefore concentrated on investigating the subjective properties of human hearing, to find out to what extent quadraphonic signals produce the desired effect [14]. Also the effects produced by matrixed quadraphonic signals in stereophonic and monophonic reception had to be investigated [15, 16]. This information helped the B.B.C. team to develop a 4-2-4 * system giving a more compatible 4-2 encoder whilst also allowing sensible 2-4 decoding. This article discusses some of the findings on the properties of hearing and describes the subsequent development of the compatible 4-2-4 system, Matrix H.

2. Properties of hearing

2.1. Test techniques

A large number of subjective tests were carried out to examine some of the factors which affect the way listeners hear quadraphonic and stereophonic sounds. *Fig. 1* shows one of the experimental arrangements in a free-field room. The subject is seated inside a ring of curtains, with his head held still against a simple headrest. The experimenter, outside, moved a test sound-source until the subject was satisfied that the sound came from a pre-determined direction on a 16-point compass, or was co-located with a reference sound-source, as shown in the photograph. The subject always made a static assessment ; the test signals were switched off between assessments and were replaced by pink noise emanating from four fixed loudspeakers arranged around the listener (shown on the chairs in the photograph). This procedure masked any noise generated by the experimenter in moving the test sound-sources. In addition, illumination was provided only from within the curtains to prevent the listener from seeing the sound-sources. The test programme material was an excerpt from a news item read by a trained male announcer, which preliminary tests had proved to be the most sensitive material for localisation.

The experiments were, in fact, performed in both the free-field room, and in a listening room, which was designed to approximate acoustically to an average home living room (about 70 m^3 capacity and 0.35 sec. average reverberation time). The results obtained in the free-field room were always slightly more critical than those obtained in the listening room, and, in so far as deductive reasoning is concerned, prove more useful, because they do not suffer so much from peculiar ambiguities which seem to be a function of the asymmetries of particular listening rooms. In addition, such results are more readily verified by other workers.

2.2. Single sound-source perception [14]

Tests were carried out to establish three factors concerning the perception of a sound by the normal human hearing system.

First, at normal listening levels, that is well above the threshold of hearing, the human hearing system was found to be almost equally sensitive to the loudness of a single sound-source placed at any azimuth around the listener, although a drop of 1-2 dB in sensitivity was detectable, particularly at high frequencies, for azimuths behind the listener.

Second, considering the *absolute* localisation of a sound, very accurate localisation was obtained in the front quadrant and at centre-back, but greater uncertainty arose in other directions, for example behind the right and left shoulders, where an expansion of the sound-stage was apparent.

* This code describes a system in which the *four* original discrete signals are transmitted (or recorded on disc) in *two* channels and are subsequently reconstituted for *four*-channel reproduction (Editor).

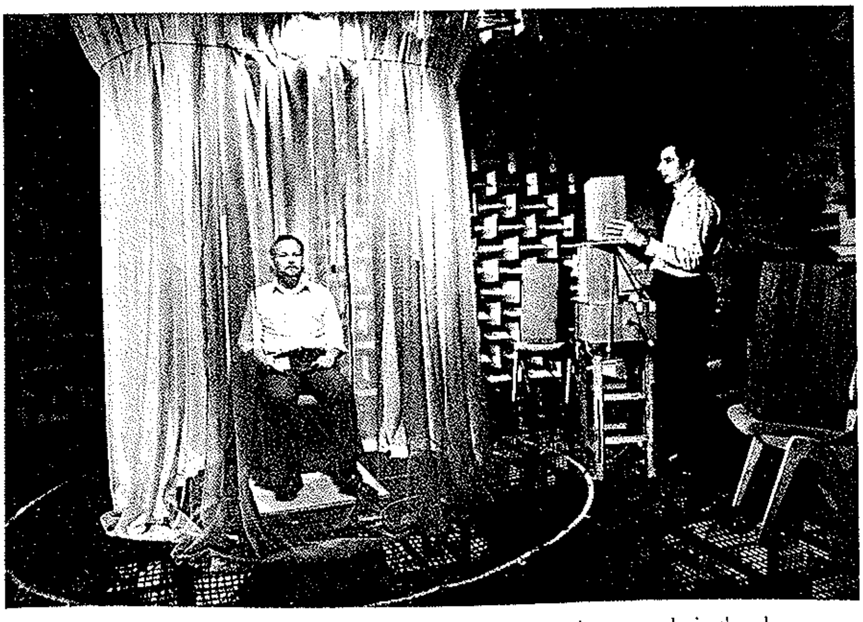

Fig. 1. — Experimental localisation of a sound source in an anechoic chamber.

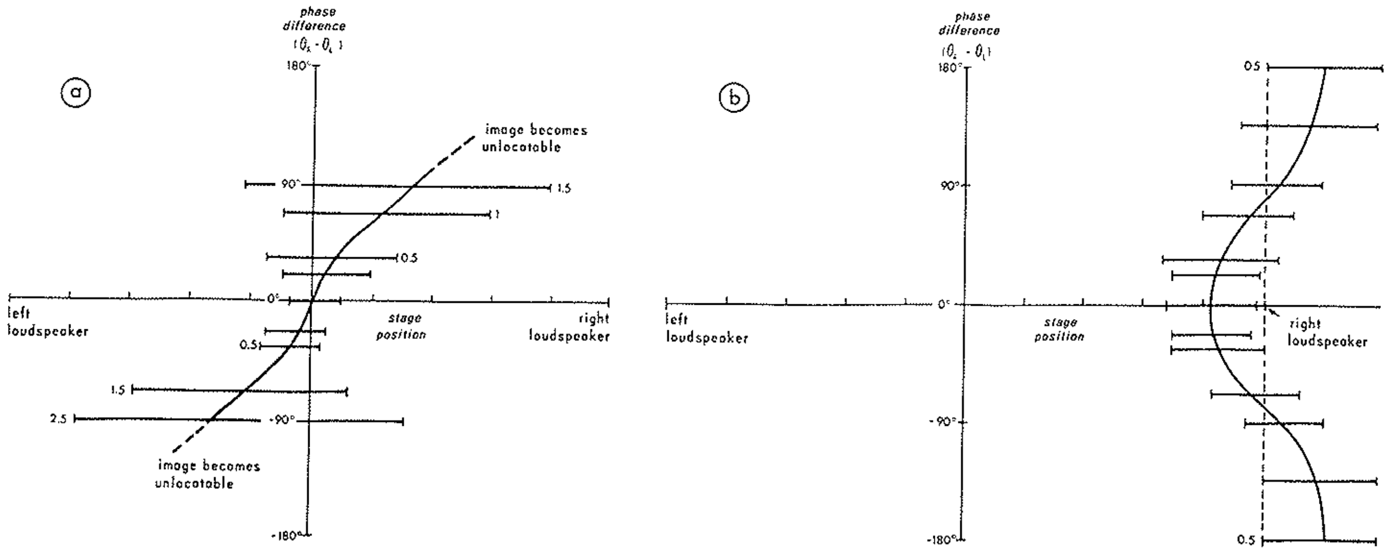

Fig. 2. — Effect of phase-shift on stereo-image localisation. The length of the line indicates the subjective image-spread and the number shows the disturbance factor (see *Table 1*). For simplicity, zero values of disturbance factor are not shown.

a) equal-level signal

b) signals differing in level by 14 dB (favouring the right-hand loudspeaker).

Third, comparing the location of a movable source against that of a reference source, *relative* localisation of a sound, it was found that the subjects could co-locate the two sounds to an accuracy of better than ± 3° for all directions.

From these results it is deduced that although in a real-life situation there is rear sound-stage expansion, comparison of sound-source azimuths is equally sensitive all around the listener. This is clearly an important factor in " surround-sound " reproduction since the listener may not be aware of the true positions of various sound-sources, but is likely to be much more critical of their relative positions.

2.3. Stereophonic sound-source perception [15, 16]

The compatibility of quad transmissions using a two-channel matrix is, as already stated, extremely important. All the currently proposed 4-2-4 systems use the relative phases of the two transmitted signals as well as their amplitudes to carry directional information, and it was therefore essential to examine the possible effects of this phase information on the stereophonic listener *. A comprehensive series of tests was carried out to examine the effects of interchannel phase-differences for specified ratios of sound intensity from the loudspeakers. *Fig. 2* shows two typical results.

Fig. 2a shows the effects of interchannel broadband phase-shift on a nominally central image, with equal-level signals applied to the loudspeakers. The image is seen to shift towards the phase-leading loudspeaker, which is in support of the well-known Haas time-precedence effect. (Since a frequency-independent phase-difference represents a linear frequency-dependent time-difference.) The horizontal bars indicate subjective assessments of the width of the image, and the numerical values indicate the subjective degree of " phaseyness " or disturbance of image quality as defined in *Table 1*.

Table 1 — Image quality scale

Value	« phaseyness » or degree of disturbance
0	not phasey/not disturbing
1	just detectably phasey/slightly disturbing
2	distinctly phasey/disturbing
3	objectionably phasey/extremely disturbing

The image width is seen to increase as the magnitude of the phase-difference increases, and the image also takes on an increasingly " phasey " quality. Beyond about 90° phase-difference the image is no longer locatable and becomes totally diffuse. In the limit, under high-quality monitoring conditions using closely matched loudspeakers, anti-phased signals produce a most uncomfortable, even nauseating feeling, where the image may appear to be located within the listener's head, often giving the sensation of pressure on the ears.

* Previous work has been confined to setting tolerances for stereo distribution systems, and is limited to a worst-case, phase-error criterion [17].

However, when the signal to one loudspeaker is much larger than the other, a different phenomenon occurs. As *Fig. 2b* shows, with the right-hand loudspeaker 14 dB louder than the left-hand one, introduction of interchannel phase-shift causes the image to shift towards the dominant, right-hand loudspeaker, irrespective of the polarity of the phase-difference (" dominant loudspeaker precedence effect "). At large phase-differences, the image does not become diffuse, objectionable in quality, or unlocatable, but merely shifts beyond the right-hand loudspeaker. This implies that, by careful control of phase and amplitude parameters, it is possible to generate a " super stereo " that gives a wider stage than conventional stereo, but does not introduce any unpleasant quality changes.

It can be seen that two effects occur which cause the sound-image to shift when a phase-difference is introduced between the left and right stereo signals. When the louder loudspeaker leads in phase, both effects (Haas precedence and dominant loudspeaker precedence) cause the image to shift towards the louder loudspeaker. However, when the louder loudspeaker lags in phase, the two effects occur in mutual opposition. It was found that for level-differences of less than 5 dB, the introduction of a phase-difference moves the image towards the phase-leading loudspeaker (Haas precedence). On the other hand, for level-differences greater than 5 dB, the image always moves towards the louder loudspeaker (dominant loudspeaker precedence).

2.4. Quadraphonic sound-source perception [14]

As in the case of stereo, one of the more usual ways of mixing quad programmes is to " pan " the sounds into the required part of the sound-stage. It was therefore necessary to determine the interchannel intensity/subjective localisation law for each of the quadrants of a quadraphonic array of loudspeakers. The tests in this case were carried out in the free-field room only, but with a single reflecting surface (floor) included to aid sound-image formation.

Fig. 3 shows the results plotted in polar form for the conventional " square " loudspeaker array. The curves show fairly conventional localisation for front and back quadrants, similar to that of normal stereo, giving a centre-quadrant image for equal-level signals, and an image located at one loudspeaker for a signal level-difference greater than about 25 dB. However, a very different phenomenon occurs in the side quadrants. Image localisation is very difficult near the centres of these quadrants, as is shown by the large standard deviations of the results, and subjects gave answers of great image diffuseness or instability, jumping from front to back of the quadrant, and vice versa, caused by the slightest of head movements. Equal-level signals tend to give an image located well forward, and about 10 dB more signal is required on the rear loudspeaker to give any impression of centre-side. However, the exact level-difference varies from person to person, and slight variations about the

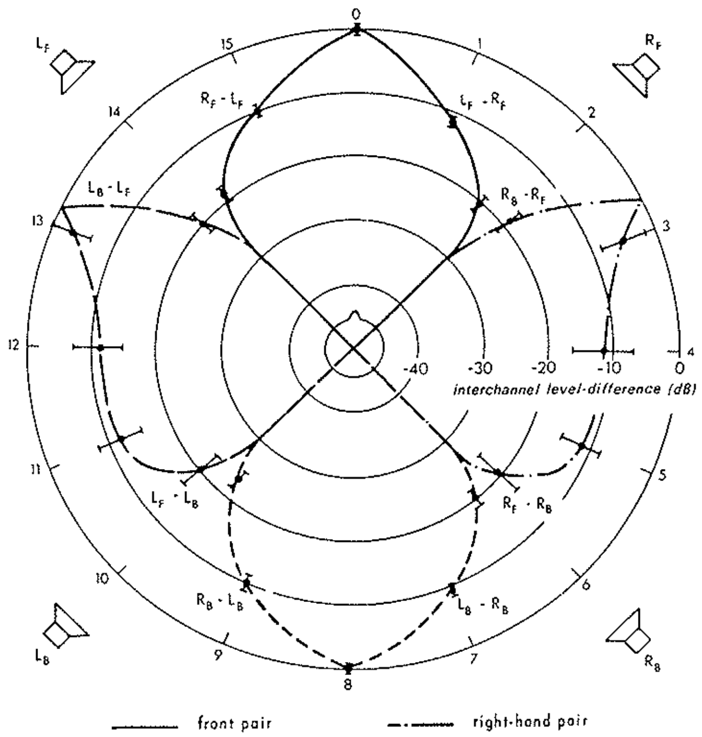

Fig. 3. Interchannel level-difference localisation law for pan-pot quadraphony.

The length of the bar corresponds to the standard deviation in the experimental result.

critical value rapidly send the image to the front or back of the quadrant.

In addition to the azimuth localisation obtained by " panning ", it is also of interest to note that a variation in perceived image-height occurs. Centre-front images are typically elevated by about 40°, whereas side and rear corner images are similarly depressed.

When two-channel matrices or coincident-microphone techniques are employed, more than two signals may be present to define a sound-source in quadraphonic reproduction. Also there may be broad-band, constant phase-differences between these signals. A series of experiments was carried out to give an indication of the effects one might expect with such sound reproductions. The minimum perceptible phase-difference on images formed by " pan-potting " were determined, and the minimum perceptible levels of unwanted (crosstalk) signals from the other loudspeakers that could be added without disturbing the image, were also determined.

Phase differences of about 10° were detectable for centre-front and back images, but only those of about 60° for the centre-sides. In the case of reproduction of corner and centre-quadrant images, the minimum perceptible level of the crosstalk signals is about — 20 dB relative to the level of the wanted signal, with the notable exceptions of centre-front and centre-back images, where it was found to be approximately — 12 dB. The main effect of increasing the level of crosstalk signals beyond the level of perception is to make the sound-image move in towards the listener, and become bass-heavy in quality.

However, if these crosstalk signals are applied in anti-phase, the closing-in effect is not nearly so apparent, and the image becomes somewhat nasal or " phasey " in quality, and is diffuse or unpleasant. In addition, crosstalk signal phase-shifts can affect the extent or direction of image-shift, and in general, crosstalk signals phase-shifted by about 45° from the wanted signals produce the least disturbing subjective effects. Where two crosstalk signals are present, it is preferable to arrange for one to phase-lead and the other to phase-lag the wanted signals. However, in order to improve side-quadrant image localisation, crosstalk signals arranged to have plus and minus 90° phase-shift are preferred. This arrangement can, in fact, substantially improve image-stability and localisation within the side-quadrant.

3. Specification of matrix H

The brief presentation above of the investigations into single, stereophonic, and quadraphonic sound-source perceptions, provides an insight into the subjective results that have been obtained from various quadraphonic matrices. It is these investigations that have aided the B.B.C. Research Department in the design and optimisation of a compatible broadcast quadraphonic system, Matrix H.

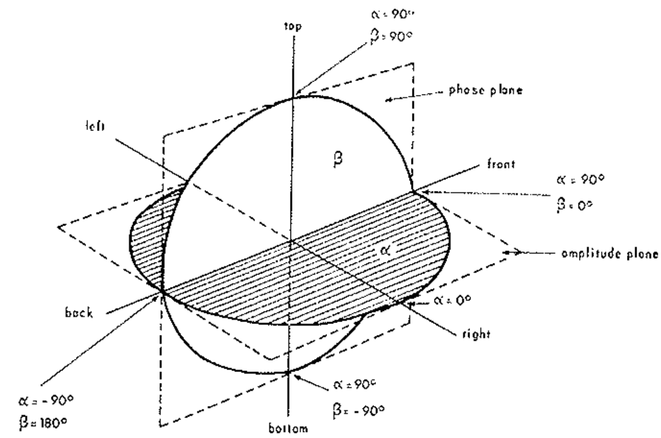

Fig. 4. — Derivation of the Scheiber sphere.

3.1. The Scheiber Sphere representation of matrix signals

In order to gain an understanding of the salient parameters involved in two-channel matrixing, a special graphical presentation of the signals is introduced, known as the Scheiber Sphere [11]. This is a mathematical transformation which maps the matrixed stereo signals onto the surface of a sphere and it is derived in the following way. When audio signals are mixed into the two stereo channels of a 4-2-4 matrix system, there are two parameters which define the way the signals are combined. For each input signal these are the ratio of the amplitudes panned into each channel, and the relative phase of that signal's contributions to the left and right channels.

The amplitude ratio, α, of the left and right signals and the phase difference, β, between the left and right signals are both expressed as angles * thus :-

$$|\alpha| = 2 \tan^{-1} \left|\frac{L}{R}\right|$$

$$\beta = \theta_L - \theta_R$$

α is also given a sign according to the following convention :-

$$\text{when } |\beta| \leqslant 90^\circ, \ \alpha \geqslant 0^\circ$$
$$\text{when } |\beta| > 90^\circ, \ \alpha < 0^\circ$$

As α and β are independent continuous variables they may be represented diagrammatically as two orthogonal circles, which, in combination, form the surface of a sphere (see *Fig. 4*). Thus any amplitude and phase combination of the left and right signals may be represented by a point on the sphere.

Although in practice the sphere is extremely easy to use, it is also useful to have a two-dimensional representation. This is shown in *Fig. 5*, where the sphere is viewed looking towards its right-hand pole (seen in the centre), with the front of the sphere at the right of the diagram. In general most quadraphonic matrices show left/right symmetry and so only the right-hand view of the sphere need be considered.

* This definition is slightly different from that in Scheiber's original paper in that it avoids the possibility of certain ambiguities of sign.

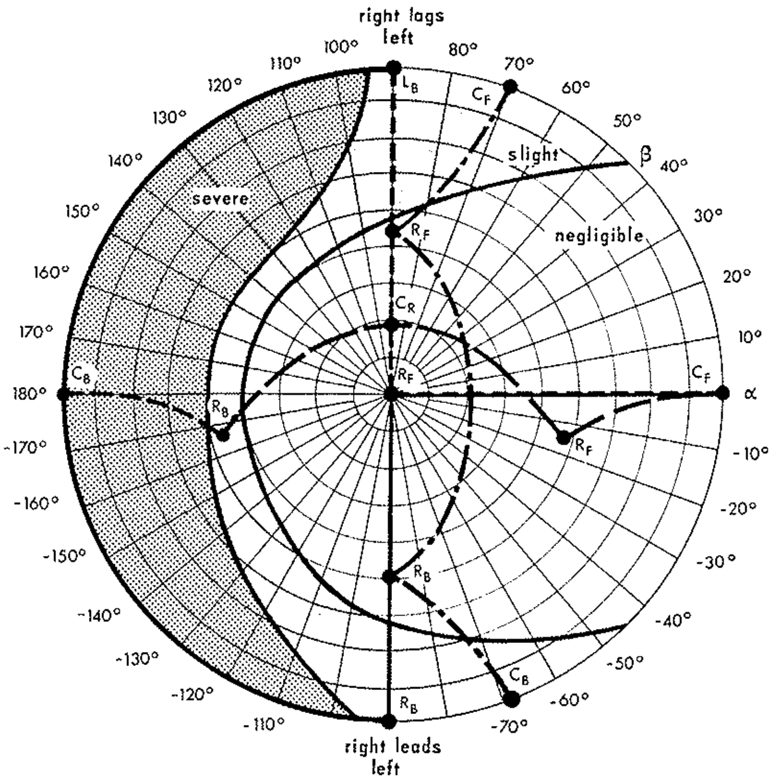

Fig. 5. — Scheiber-sphere diagram with stereo-image impairment zones showing pan-pot loci of various matrices.

For the analysis of the stereo compatiblity of matrix systems, the results described in Section 2.3 have been mapped on to the sphere diagram [18] in what have been called *stereo impairment zones.* These zones, which indicate the reduction in quality of a stereophonic image due to the presence of a phase-difference between the left and right channels, are defined as :-

negligible impairment : imperceptible impairment of the tonal quality of the sound image but allowing a just perceptible broadening of that image;

slight impairment : perceptible impairment of the tonal quality and/or a significant broadening of the image;

severe impairment : severe impairment of the tonal quality and/or extreme broadening of the image, often deemed to be unlocatable.

It can be seen that where the signals are of nearly equal amplitude, the phase-difference between the left and right channels can have a very marked effect. For example, for $\alpha = 90°$, β has only to exceed $\pm 45°$ before the image is considered to be slightly impaired. On the other hand, when one of the stereo signals is louder than the other, for example $\alpha = 60°$, which corresponds to a level-difference of approximately 5 dB, β has to exceed either $+65°$ or $-95°$ before a similar impairment applies. It should be noted that the asymmetry between positive and negative values of β is genuine : in one case the louder sound is phase-leading, in the other it is phase-lagging.

In a similar way it is possible to categorise impairment zones for mono reproduction [18]. However, the effect of the phase-difference between the left and right matrix signals is less severe, resulting only in a reduction of level for large values of β, and thereby affecting the balance of sounds in the reproduced mono.

Having thus " calibrated " the surface of the sphere it becomes very easy to assess the stereo and mono performance of two-channel matrices. The final additions to *Fig. 5* show examples of some of the commercially proposed matrices mapped on to the sphere diagram. (Each matrix locus is a line joining, in rotational order, the encoding points for the different quadraphonic stage locations.)

This is not the place to go into a detailed analysis of why these matrices seem unable to provide sufficiently compatible stereo and mono results; suffice it to say that tests have shown that these matrices make too much use of the slight and severe impairment zones and/or not enough use of the negligible impairment zones [19, 20]. Certainly the area at the back of the sphere is particularly hazardous as far as compatibility with stereo and mono is concerned.

3.2. Matrix H

Because of the apparent inability of commercial 4-2-4 matrix quadraphonic systems to provide adequate stereo and mono performance, the B.B.C. Research Department has examined other ways of matrixing directional information into two channels. The first priority was placed on developing an encoder which would give sufficiently good stereo and mono. In fact, in many ways it is the encoder which defines the system. In the case of stereo radio transmission, it was the choice of the Zenith/GE pilot-tone form of encoding that fixed the characteristics of the system, and several forms of receiver have been devised. In a similar way, it is the encoding equations for Matrix H that define the system, and different forms of decoder are envisaged.

In fact, the encoding specification for Matrix H can be defined as [21] :

$$\begin{bmatrix} L \\ R \end{bmatrix} = \begin{bmatrix} 0.634 \angle{-7.5^\circ}, & 0.437 \angle{+72.9^\circ}, & -0.634 \angle{-7.5^\circ} \\ 0.634 \angle{+7.5^\circ}, & 0.437 \angle{-72.9^\circ}, & 0.634 \angle{+7.5^\circ} \end{bmatrix} \begin{bmatrix} 1 \\ \cos\theta \\ \sin\theta \end{bmatrix}$$

where θ is the azimuth angle of the sound source, measured from the centre-front direction in a clockwise sense. However, for normal studio applications, using pairwise-panpot signal-mixing, where the mixing-desk produces a 4-channel output, the Matrix H encoding equations become :-

$$\begin{bmatrix} L \\ R \end{bmatrix} = \begin{bmatrix} 0.926 + j\,0.163, & 0.145 + j\,0.310, & 0.852 - j\,0.397, & -0.145 - j\,0.310 \\ 0.145 - j\,0.310, & 0.926 - j\,0.163, & -0.145 + j\,0.310, & 0.852 + j\,0.397 \end{bmatrix} \begin{bmatrix} L_F \\ R_F \\ L_B \\ R_B \end{bmatrix}$$

These map on to the sphere diagram as shown by the solid curve in *Fig. 6*. As can be seen, 80% of the locus is designed to lie in the negligible impairment zone, particularly the all important front quadrant of the quadraphonic sound-stage. It is only the back quadrant which is allowed to go into the slight impairment zone; this is necessary if the encoded signals are to be decoded to give a sensible form of quadraphony. Putting it simply, the closer together C_F and C_B are on the Scheiber sphere, the more difficult will it be to decode them, and the higher will be the risk of unwanted crosstalk from one to the other. Full-width stereo is ensured by arranging that the locus passes through the right (and left) poles of the diagram and in fact slight over-width stereo is obtained because of the phase-encoding of the rear corners. However, the encoding of these points does not produce unpleasant phase effects in stereo, even if a principal source is located there.

Mono compatibility is obtained by keeping the locus well away from the $\beta = 180^\circ$ points, particularly when the level-difference between the stereo signals is small. However, a significant reduction in mono level is obtained at the rear corner positions (— 3.6 dB relative to front corners) which can be highly desirable in order that, for example, a reduction of ambience level can be achieved in mono to retain the correct sound balance with principal sources. In a quad surround presentation, where such a level reduction in mono is not desired, sources at the rear corners are panned slightly inwards towards the centre-stage position or slightly to one side of the corner position.

Conventional recording techniques for stereophonic broadcasting in the B.B.C. are not restricted only to the use of multi-microphone pairwise-panpot working; on many occasions coincident stereo-pairs of microphones are also employed. It is to be hoped that this degree of flexibility can be maintained in quadraphonic working [22], so that a producer can use, at will, any combination of coincident and spot microphones. To this end, B.B.C. Matrix H has been designed for both spot microphone/panpot working and for coincident-group microphone working.

Fig. 6 also shows the encode locus for signals derived from a group of four coincident hypercardioid-response microphones (the dotted curve). As can be seen, the two loci are close to each other and very similar results are obtained from either type of signal origination.

3.3. Decoding Matrix H

It has been shown that the encoding format defines completely the stereo and mono compatibilities of a 4-2-4 system, as well as partially defining the quad performance. The latter is obviously also dependent on the type of decoding that is employed. To date, three forms of decoding have been investigated.

Initially tests were carried out on linear decoding of Matrix H, i.e. the decoding was time and frequency invariant. The basis of a suitable linear decoder is the complex conjugate * of the encoder. With this form of decoding the overall transfer characteristic is :

* The name is derived from the fact that the mathematical elements in the decode equations are the complex conjugates of the corresponding elements in the encode equations.

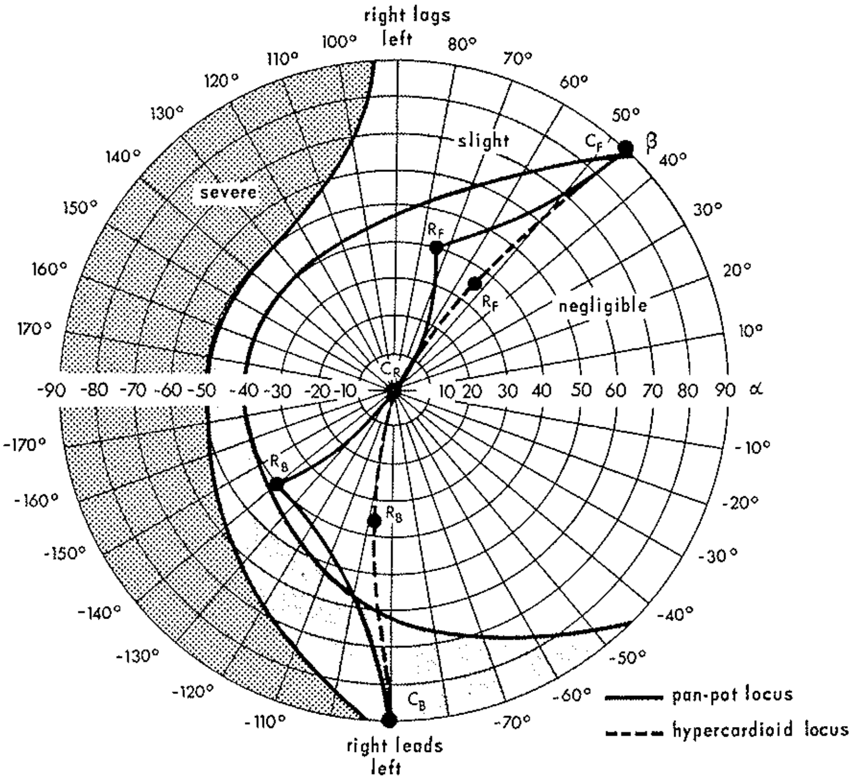

Fig. 6. — Scheiber-sphere diagram with stereo-image impairment zones showing pan-pot (thick curve) hypercardioid microphone (dotted curve) loci of Matrix H.

$$\begin{bmatrix} L'_F \\ R'_F \\ L'_B \\ R'_B \end{bmatrix} = \begin{bmatrix} 1.000 + j\,0.000, & 0.370 + j\,0.527, & 0.607 - j\,0.507, & -0.184 + j\,0.058 \\ 0.370 - j\,0.527, & 1.000 + j\,0.000, & -0.184 - j\,0.058, & 0.607 + j\,0.507 \\ 0.607 + j\,0.507, & -0.184 + j\,0.058, & 1.000 + j\,0.000, & -0.001 - j\,0.643 \\ -0.184 - j\,0.058, & 0.607 - j\,0.507, & -0.001 + j\,0.643, & 1.000 + j\,0.000 \end{bmatrix} \begin{bmatrix} L_F \\ R_F \\ L_B \\ R_B \end{bmatrix}$$

Low separation figures are a characteristic of linear 4-2-4 matrix systems, but in this case they are not symmetric; more left/right than front/back separation is employed to give subjectively satisfactory results. In addition, earlier work on the effects of crosstalk signals showed that some departure from the phase-shifts of the crosstalk signals provided by the complex conjugate decoder were also beneficial.

In analytical, single-source localisation tests this form of decoding was found to give very accurate directional information for a central stationary listener. However, whenever the listener moved away from the central seat the directional information was diluted. Furthermore, when listening to normal programme material through this decoder, the sound sensation, although extremely pleasant, was very close to the listener, i.e. sound images seemed to be much closer than the loudspeakers. Both of these effects are explained by examining the transfer characteristic, which shows, for example, that for a single corner input, the adjacent corner output signals are on average only about 3 dB lower than the wanted signal. This is a fundamental limitation of linear 4-2-4 matrixing.

For this and other reasons, many of the commercial proposals have included " logic-enhanced " decoders; the decoding matrix varies with time according to the composition of the incoming encoded stereo signals such that the amplitudes of the crosstalk signals are reduced. This was the second line of investigation : could the known logic-enhanced decoding techniques be adapted to work on Matrix H encoded signals, and if so how good were the results. The investigation was initially based upon a good commercial logic-enhanced decoder, modified in a simple manner. It was then compared in a wide range of tests with the performance of the original commercial system, and discrete (4-4-4) quad. The results [20, 23, 24] showed first of all that the compatibility of Matrix H was markedly superior to that provided by the commercial system. Matrix H also gave slightly better quadraphonic reproduction but this was not due to a fundamental technical change. Generally it has been found that simple modifications to commercial logic-enhanced decoders enable them to decode Matrix H signals. However, both Matrix H and the best commercial system gave quad results somewhat inferior to the discrete system.

The third line of investigation was concentrated on developing a specific logic-enhanced decoder for Matrix H, using the information outlined in Section 2.4. This work is still proceeding and already it is becoming clear that the decoded quad given by Matrix H can be made to match more closely that from a four-channel discrete system than is possible with any current commercial system, even those using logic-enhanced decoders.

4. Conclusions

If quadraphonic broadcasting is to be viable in the United Kingdom, it is almost certain that a two-channel matrix system will have to be adopted. However, tests have shown that the current commercial matrix systems are all lacking, in one aspect or another, when received on stereophonic or monophonic receivers.

Design criteria for the stereo and mono compatibility of two-channel matrix systems have been established from the results of extensive subjective testing, and an insight into the expected quadraphonic performance of matrix systems has also been obtained.

Inasmuch as this type of system is defined by the characteristics of the transmitted signal, the specification of the B.B.C. Matrix H is that given in Section 3.2. Extensive subjective tests have shown that the stereo and mono signals generated by Matrix H are as good as conventional stereo and mono sound mixes. At the same time, Matrix H allows sensible decoding in several forms. For the cheapest decoder, a linear decoding matrix gives very pleasing results for a centrally-seated listener. If more freedom of movement is required whilst listening to quad, it will be necessary to employ some form of logic-enhancement in the decoder. Tests have shown that simple modifications to commercial decoders enable Matrix H to be decoded to give quadraphony as good as that obtained with the commercial 4-2-4 systems. Current work is also showing that direct decoding of Matrix H can give even better quadraphonic results than the best of the available commercial systems.

* * *

The authors are grateful to the many people who have helped during the development of Matrix H ; in particular Messrs. Crompton, Gaskell, Harrison and Wright, and those who took part in the numerous subjective tests.

The authors also wish to thank the Director of Engineering of the B.B.C. for permission to publish this paper.

BIBLIOGRAPHICAL REFERENCES

[1] Dorren, L. and Torczyner, J. : *An optimum quadraphonic f.m. broadcast system.* I.E.E.E. Transactions on Broadcast and Television Receivers, BTR-19(4), November 1973, pp. 227-285.

[2] Gibson, J.J., Christensen, R.M. and Limberg, A.L.R. : *Compatible f.m. broadcasting of panoramic sound.* I.E.E.E. Transactions on Broadcast and Television Receivers, BTR-19(4), November 1973, pp. 286-292.

[3] Csicsatka, A., Foster, J.F. and Metro, J.G. : *An experimental quadraphonic f.m. broadcast system.* I.E.E.E. Transactions on Broadcast and Television Receivers, BTR-19(4), November 1973, pp. 294-297.

[4] De Weger, D., Eilers, C., Fockens, P. and Prosser, H. : *Two proposed quadraphonic f.m. broadcasting systems.* I.E.E.E. Transactions on Broadcast and Television Receivers, BTR-19(4), November 1973, pp. 298-310.

[5] Cooper, D.H. : *Proposal QFMX for use of 4-4-4 QMX matrix in quadraphonic encoding of f.m. transmission.* I.E.E.E. Transactions on Broadcast and Television Receivers, BTR-19(4), November 1973, pp. 311-319.

[6] Carey, M.J. and Sager, J.C. : *Quadraphonic Broadcasting — Current proposals and the way ahead.* Wireless World, No. 1466, November 1974, pp. 422-425.

[7] Netzband, R. : *Multiplex systems for v.h.f./f.m. sound broadcasting.* E.B.U. Review — Technical, No. 147, October 1974, pp. 225-229.

[8] Whythe, D.J. : *How quadrature subcarrier modulation used for tetraphony could affect stereophonic reception with existing receivers.* E.B.U. Review — Technical, No. 154, December 1975, pp. 286-292.

[9] Meares, D.J. : *Quad broadcasting — an alternative view.* Letter to the editor, Wireless World, No. 1470, February 1975, pp. 65-66.

[10] Bauer, B.B. and Gravereaux, D.W. : *A compatible stereo-quadraphonic (SQ) record system.* Journal of the Audio Engineering Society, No. 8, September 1971, pp. 638-646.

[11] Scheiber, P. : *Analysing phase-amplitude matrices.* Journal of the Audio Engineering Society, No. 10, November 1971, pp. 835-839.

[12] Ito, R. : *Proposed universal encoding standards for compatible four-channel matrixing.* Journal of the Audio Engineering Society, No. 3, April 1972, pp. 167-173.

[13] Cooper, D.H. and Shiga, T. : *Discrete-matrix multichannel stereo.* Journal of the Audio Engineering Society, No. 5, June 1972, pp. 346-360.

[14] Ratliff, P.A. : *Properties of hearing related to quadraphonic reproduction.*
B.B.C. Research Department Report, RD 1974/38, November 1974.

[15] Bower, J.S. : *The subjective effects of interchannel phase-shifts on the stereophonic image localisation of wide-band audio signals.*
B.B.C. Research Department Report, RD 1975/27, September 1975.

[16] Bower, J.S. : *The subjective effects of interchannel phase-shifts on the stereophonic image localisation of narrow-band audio signals.*
B.B.C. Research Department Report, RD 1975/28, September 1975.

[17] Shorter, D.E.L., Harwood, H.D. and Manson, W.I. : *Stereophony : the effect of interchannel differences in the phase/frequency and amplitude/frequency characteristics.*
B.B.C. Engineering Monograph, No. 56, December 1964.

[18] Ratliff, P.A. and Meares, D.J. : *The design and evaluation of a linear 4-2-4 matrix system.*
B.B.C. Research Department Report, in preparation.

[19] Crompton, T.W.J. : *The subjective performance of various quadraphonic matrix systems.*
B.B.C. Research Department Report, RD 1974/29, November 1974.

[20] Gaskell, P.S. and Price, H.M. : *Quadraphony : subjective assessment of the stereo and mono compatibility of two-channel matrix systems.*
B.B.C. Research Department Report, in preparation.

[21] Crompton, T.W.J. and Ratliff, P.A. : *British patent application No. 34839/74.*

[22] Meares, D.J. : *Quadraphony : techniques involved in four channel recording and reproduction.*
B.B.C. Research Department Report, RD 1974/26, July 1974.

[23] Ratliff, P.A., Wright, K.J. and Mudd, G.N. : *Quadraphony : the subjective performance of two channel matrix systems (a second appraisal).*
B.B.C. Research Department Report, in preparation.

[24] Meares, D.J., Ratliff, P.A. and Wright, K.J. : *Quadraphonic system assessments by means of programme production tests.*
B.B.C. Research Department Report, in preparation.

Guiding principles for the design of electronic equipment

When using electronic equipment, problems may be encountered at various stages, such as during installation, alignment, operation, fault location and repair, or in the supply of spare parts. As the member organisations of the E.B.U. use a variety of types of equipment and as they employ differing methods of maintenance, it was felt that it would be useful to establish a synthesis of the opinion of specialists who are concerned with the design and acceptance-testing of electronic equipment used in broadcasting. This document, entitled **Guiding principles for the design of electronic equipment**, has been drawn up by E.B.U. Sub-group T3 (Video development) and it was published at the end of 1975. It specifies the information that should be contained in handbooks and indicates the rules that should be followed in the choice of components, the mechanical construction, the design of printed-circuit boards and, finally, the circuit design itself. These specifications are to be followed in the design and manufacture of equipment that is to satisfy E.B.U. requirements.

This 10-page document bears the reference **Tech. 3215** and can be obtained from the E.B.U. Technical Centre, avenue Albert Lancaster 32, 1180-Bruxelles, at a cost of 80 Belgian francs, including postage.