Experimental Tetrahedral Recording: Part Two

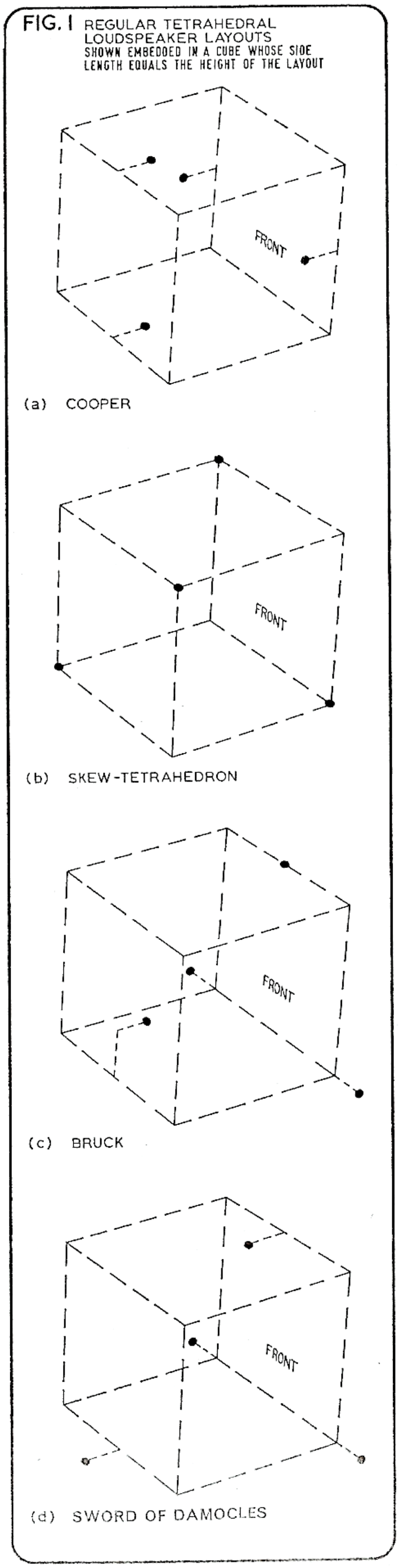
By Michael Gerzon

LAST month we described the actual set-up for a recent experimental tetrahedral recording and noted initial listener reactions. Perhaps more important than describing any one particular experiment is to indicate the problems facing anyone trying out similar experiments, and their solutions.

It is first necessary to choose the type of tetrahedral loudspeaker layout that it is intended to use for the playback. Four layouts have been proposed, and these are illustrated in **fig. 1**. The first such system was proposed by Granville Cooper (see ref. 1), and is shown in **fig. 1a**. A second system, using a skew tetrahedral layout, has been proposed by the author (ref. 2) and is shown in **fig. 1b**. A third playback system due to Jerry Bruck (ref. 3) is shown in **fig. 1c**, and a fourth 'sword of Damocles' tetrahedral layout has also been suggested.

A theoretical analysis indicates that the Cooper, Bruck and 'Damocles' layouts suffer from some important disadvantages resulting in an unsatisfactory distribution of stereo images around the listener. The most obvious disadvantage is that if the layouts lie on a regular tetrahedron, all these layouts require some loudspeakers to lie at large angles above or below the horizontal from the viewpoint of the listener (54.7° for the Cooper layout, 70.5° for the Bruck, and 90° for the 'Damocles'). Also, if room height is the smallest room dimension, then all these layouts include a much smaller volume than that of **fig. 1b** (35% for the Cooper layout, 54% for the Bruck, and 69% for the Damocles). These practical considerations make it necessary to 'squash' the tetrahedron vertically to obtain a reasonable listening area. Also, in order to prevent a hole-in-the middle at the front with these systems, it is necessary to narrow the angle between the front stereo pair of speakers from 109.5° to around 70°. The result of all these distortions of the loudspeaker layout is that is that sounds coming from directions not close to any loudspeaker (e.g. the sides) will not have an accurate stereo location. In the author's opinion, these practical compromises largely negate the whole reason for tetrahedral sound, i.e. to reproduce sounds from all horizontal and vertical directions from their original direction around the listener.

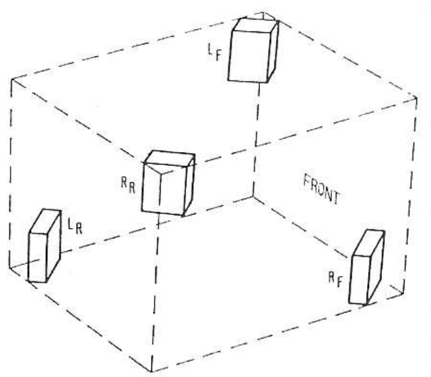
Perhaps even more serious is that in the Cooper, Bruck and Damocles systems, the loudspeakers



contributing the height information lie in the plane of symmetry of the listener's head, whereas the ordinary stereo speakers lie closer to the axis of the ears. As the ears are directional in the treble, this means that the height speakers contribute much less treble than the 'stereo' speakers, which must inevitably degrade the height effect and cause a poor stereo location of non-frontal images. On the other hand, the skew tetrahedral system of **fig. 1b** has all speakers lying at the same angle off the ears' axis, and would therefore stand a better chance of forming good non-frontal stereo images. Its large volume for a given room height makes 'squashing' much less necessary, no speaker lies more that 35.3^{o} from the horizontal, and location of sounds at the side should not be affected by any squashing. It can also be shown (ref. 4) that it is less liable to hole-in-the-middle, and provides more realistic information to human stereo location mechanisms using small head movements, as compared to other tetrahedral layouts.

It is for these reasons that the skew tetrahedral layout was adopted for experimental investigations, despite its rather odd appearance and its unsuitability for reproducing two-channel stereo. The skew tetrahedral layout of **fig.1b** may be thought of as a conventional square layout, with the left front (L_F) and rear right (R_R) speakers raised to the ceiling, and the right front (R_F) and left rear (L_R) ones lowered to the floor. The simplest way of visualising the layout is to imagine the speakers as lying on four alternate corners of a cube. Of course, there is no reason why the mirror-image tetrahedral layout should not work just as well but it is thought advisable to standardise on the L_F speaker being high up, to avoid needless incompatibility between recordings. When setting up the loudspeaker layout, care should be taken to ensure that their floor plan is accurately square, although it is a legitimate experimental aim to investigate the effects of distorting the tetrahedron. As explained last month, it is advisable to use four identical speakers of low coloration, and it would be a good idea to point them towards the listener, possibly as in **fig 2**.

FIG. 2 TYPICAL SKEW-TETRAHEDRAL LOUDSPEAKER ARRANGEMENT



The would-be experimenter should be warned against attempting to make A-B comparisons between tetrahedral and conventional four-channel sound by adding another two speakers at the other two floor-level corners of the cube to make a floor-level 'conventional' square layout. Such a comparison would be unfair to the conventional system, which sounds worse when its speakers are very low or very high than when they are at, or just a little above, ear level. A fair A-B comparison requires the four speakers for each system to be placed at the positions optimum for that system.

The one big disadvantage of the skew tetrahedron system is that speaker colorations emerge from directions quite different from those associated with direct sounds, whereas the Cooper, Bruck and Damocles systems have their coloration-producing speakers placed near the likely sources of direct sounds. A fruitful area of investigation is to determine ways of overcoming this coloration problem, and possibilities range from using cubic or octahedral loudspeaker layouts to placing four outwards-firing miniature loudspeakers pointing along the four tetrahedral axes round the head of the listener, so that the stereo image is reconstructed from the diffuse sounds reflected from the walls and ceiling.

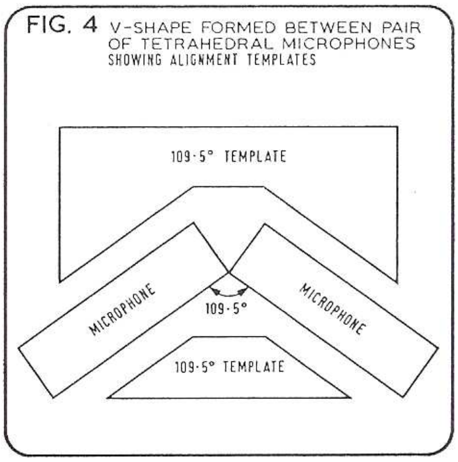
Now we must deal with the tricky problem of microphone technique. As explained in ref. 2, it is possible to make tetrahedral recordings with multimike pan-pot techniques, although this requires more elaborate matrix circuitry than is used currently. When only crude directional effects are required, as in much pop music, it is possible to use ordinary two-channel pan-pot techniques to make sounds come from straight above, straight below, from either side, from straight behind or directly in front (ref.2)

A profound philosophical problem with tetrahedral recording is where to put the microphones. If the tetrahedral system fulfils its aim of reproducing the live sound, then placing microphones several metres up is liable to make the poor listener seem to float high in the air; at least one listener has found Cooper's recording of the *Messiah* disconcerting just because the microphones had had to be placed 10m up. For experimental purposes, placing the microphones at a sensible listening height will allow the realism to be evaluated more effectively. If tetrahedral recording ever becomes commercial, one can be sure that this will be a perpetual source of controversy.

In principle, the coincident microphone arrangement is simple, merely consisting of four cardioid or hypercardioid microphones pointing in the four directions of the cube corners in **fig. 2**, placed as coincidently as possible. The picture of the experimental microphone arrangement used for the Oxford recording last May shows that the reality looks a good deal more confusing (see **fig. 3**).

Fig. 3 Experimental tetraphonic array using Calrec capacitor microphones

The subsequent discussion assumes that the microphones used have a cylindrical shape with the capsules mounted at one end, as in the AKG *C451*, Calrec *652* and Calrec *1050* microphones. The simplest way of making such microphones 'coincident' is to make them face into one another, but this would cause a tetrahedral cavity to be formed between them which would cause coloration. To avoid this it was deemed necessary (perhaps wrongly!) to use the type of 'coincidence') shown in the photo, in which the V-shape formed by one pair of microphones (as in **fig. 4**) interlocks with the V formed by the other pair of microphones. In the view from the front, one of these V's is formed by the two leftward-pointing microphones and the other by the right-pointing microphones. This choice was made so that any microphone spacing that remains will tend to simulate the left-right spacing of the ears. There are also good arguments for the two



alternatives, i.e. using an upward-pointing V and a downward-pointing V, or a forward-pointing V and a backward-pointing V.

Whichever arrangement is chosen, there is some difficulty in setting up. It is possible to obtain adequate flexibility of adjustment by mounting the microphones in a fiendishly complex arrangement of laboratory clamps, but the design of a proper mounting jig is beyond my spatial visualisation. The actual setting up procedure is basically by trial-and error adjustment, although it helps to mount the left pair of microphones on a separate framework (e.g. of laboratory clamps) from the right microphones, and to arrange that each framework can be adjusted in height, direction and angle to the vertical. The actual setting up uses the following facts:

1. The angle between every pair of microphones should be 109.5°, which can be checked using 109.5° angle templates as illustrated in **fig.4**. The lower template in **fig. 4** has its angle vertex cut off to permit use when the other pair of microphones is in place.
2. The plane containing the left-pointing microphones is tilted 45° upwards towards the front, whereas the plane containing the right-pointing microphones is tilted 45° downwards towards the front.
3. When viewed with one eye precisely from the front, precisely from the side, or precisely from underneath, the bodies of the microphones should appear to form an X with arms at 90° to one another. It is very easy to find the position from which the X looks best, and the eye is very good at recognising even small deviations from 90°; this makes this test particularly useful in the final stages of adjustment.

With a bit of time and patience, all angles should be accurate within a degree or two. The procedure is easier for stereo microphones (such as the *C24*) in which one capsule is mounted above the other. One uses two such stereo microphones, and angles the capsules in each 109.5° apart. The bodies of the two stereo microphones are then crossed to form a vertical X with arms at 45° to the horizontal; one stereo microphone is made to point forward and the other backwards.

The choice of what microphones are to be used must be governed by their physical size and their directional characteristics. It is only possible to make the microphones very nearly coincident if they are small. A high degree of coincidence is desirable, as only then is it possible to obtain by a suitable matrixing of the four output signals *any* possible cardioid or hypercardioid output pointing in *any* possible direction. If the microphones are appreciably spaced, such matrixing will no longer have the desired effect, due to wavelength effects. It was by such matrixing that it was possible to convert cardioid microphone outputs to hypercardioid in the experiment described last month. The four capsules should certainly lie within a sphere of 5 cm diameter, and preferably less, in order to ensure that phase effects do not upset the matrixing. As will be described in detail next month, it is possible to rematrix a tetrahedral recording to be suitable for any four-channel playback system, and this flexibility depends on getting the microphones very coincident.

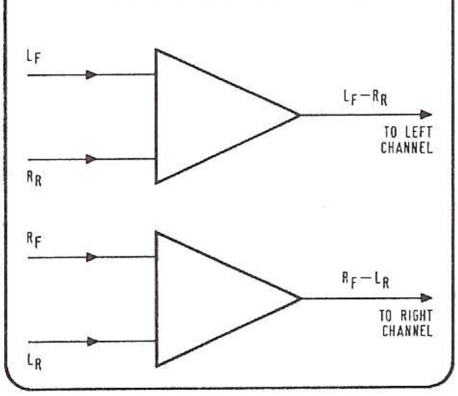
However, it is just as important that all the microphones should be as similar to one another as possible, and if possible, they should be identical. To give a correct reproduced directional effect, the directional characteristics of the microphones must be identical and should be either accurately cardioid (i.e. 2.5 dB down 60° off axis, 6 dB down 90° off axis, 12 dB down 120° off axis) or accurately hypercardioid. It does not matter if the microphones are not quite hypercardioid enough, as they can always be rendered more hypercardioid by the common mode reduction circuit described in Part 1. A polar response which is irregular or too directional in the treble should be avoided.

Matrixing the outputs of the microphones can only give good results if they also have a good polar phase response, i.e. do not introduce spurious phase shifts into off-axis sounds. Unfortunately, it is difficult to measure polar phase response and one can only make intelligent guesses as to how good this will be. As a guide, a microphone is likely to have a poor polar phase response if it is a dynamic type, has two units, uses reflection plates, or has an irregular frequency or polar response at high frequencies. The closer frequency and polar response measurements conform to the ideal theory, the more suitable the microphone is likely to be for use with matrixing circuits. On this basis, the AKG *C451* and Calrec *CM652* or *CM1050* cardioids seem particularly suitable.

Because of the stringent requirements on the technical specifications, it is unwise to choose microphones on the basis that they give a good sound when used for ordinary stereo.

One can make a simultaneous two-channel Blumlein (i.e. 90°–angled crossed figure-of eight) recording by feeding the L_F and R_R signals into a differential amplifier for the left output, and the R_F and L_R signals into a second differential amplifier for the right output, as in **fig. 5**. Such differential amplifiers

FIG. 5 DERIVATION OF 2-CHANNEL BLUMLEIN OUTPUT USING DIFFERENTIAL AMPLIFIERS



are also invaluable for matching the sensitivities of the four microphones. If the differential amplifiers are constructed with high tolerance components, then the following 'nulling' method is used: place two of the microphones right next to one another, pointing them in the same direction. Feed them into the line amplifiers with which they will be used during the recording, and take the line amp outputs into a differential amplifier. Monitor the output of the differential amplifier on a speaker, and talk in front of the two microphones. Adjust the gain presets on the line amplifiers until the sound from the speaker is minimised. The two microphones are then matched. This procedure should be repeated retaining one of the microphones as a reference standard and nulling it against the other two microphones in turn, each fed into its own line amplifier. One thereby ensures that the four tetrahedral microphones are accurately matched. If there is some doubt about the accuracy of the differential amplifier used, each nulling should be performed twice, interchanging the two inputs to the differential amplifier between the two nullings. The correct gain preset is half-way between the settings thus obtained.

The four microphones should be fed to the following four tape tracks: L_F (pointing left front upwards) to track 1, L_R (pointing left rear downwards) to track 2, R_F (pointing right front downwards) to track 3, and R_R (pointing right rear upwards) to track 4. This agrees with the usual quadraphonic convention.

It is relatively unimportant whether the microphones are cardioid or hypercardioid as matrixing can manufacture the optimum polar diagram. As yet, the optimum characteristic is not known, although the initial tests reported last month suggest something near 135° null hypercardioids. One problem is that if four cardioids are recorded on tape, and the matrixing to hypercardioids is performed during playback, then there will be a loss of 2 dB in signal-to-noise

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ratio, because of the loss of common-mode signal energy. In the Oxford experiment, it was considered advisable to record the original cardioids rather than matrixed hypercardioids despite the extra noise, so that the nature of the signal on the tape was known precisely. One would thus be able to calculate exactly what microphone characteristics and technique is produced by any matrixing on playback. Any pre-record matrix used in tetrahedral experiments should be built with high tolerance components, so that the matrix is accurately known.

For the same reasons, all four tape channels were recorded with precisely the same gain. It is helpful to record test tones at the start of all four tracks, so that any difference in channel gains can be corrected during playback. If the microphones are placed at a normal audience distance from the orchestra, then it is likely that the peak energies on all four tracks, front and rear, will be similar, although the rear tracks will sound quieter. If a higher gain is considered necessary on tracks two and four, then test tones are vital. Because of the need to match the four channels accurately, the gain of the rear channels should *never* be varied independently of the front. Remember that the rear channels provide not only ambience, but also stereo information to make the front sound horizontal. The recording engineer for the *Messiah* tetrahedral recording had altered the front-rear balance at several points, and at the playback last November at the University of Surrey it was fascinating to see listeners not knowing this become restless and perturbed at 'something wrong' at those points where the balance had been altered.

The final test for tetrahedral sound is whether it reproduces the overall musical impact of the live sound when technicalities are ignored. For this reason, no compression of dynamics was applied during the Oxford recording. Otherwise, a true comparison with the live sound would have been impossible. Any departure from reality will be far more obvious with tetrahedral sound than with two-channel stereo. The last part of this article next month will deal with methods of matrixing tetrahedral recordings

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1. Granville Cooper, Tetrahedral Ambiophony, *Studio Sound*, June 1970
2. Michael Gerzon, Principles of quadraphonic recording, Part 2, Studio Sound, September 1970
3. Jerry Bruck, Interview, *Studio Sound*, December, 1970
4. M.A. Gerzon, Recording techniques for multi-channel stereo, *B.K.S. & T. Journal*, June 1971