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Surround sound from 2-channel stereo

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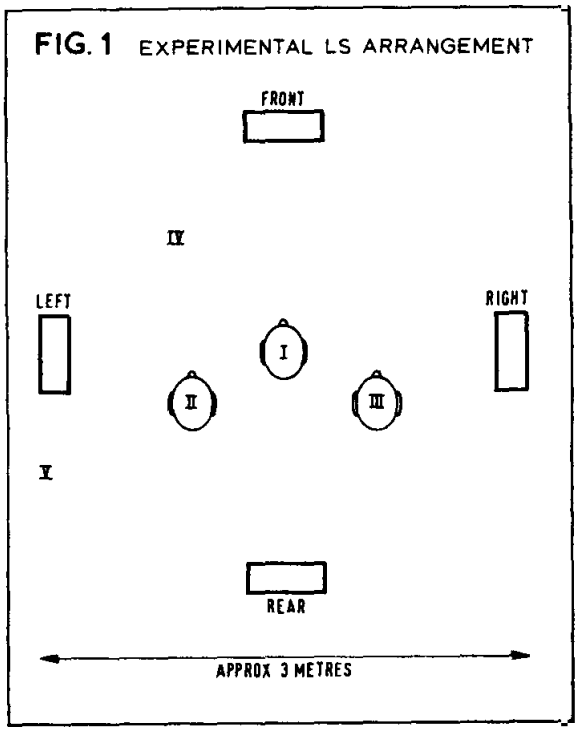
Recently there has been great interest in quadraphonic (4-channel) sound reproduction. It is generally believed that four channels are necessary adequately to reproduce true 'surround stereo', but this article describes a method of obtaining a genuine surround stereo effect from suitable conventional two-channel Pstereo recordings. To obtain quadraphonic sound from ordinary stereo recordings, two stereo systems will be required, and experiments can easily be carried out by people with friends who have a stereo system similar to their own. No special electronic or practical skills are required to set up the equipment for four speaker reproduction of stereo, and hi-fl enthusiasts throughout the country could make a valuable contribution to knowledge about quadraphony by reporting their own experiences with the sort of four-speaker arrangement described in the following.

A somewhat similar method of reproducing stereo via four speakers has been described recently by Peter Bouwer (in the April issue), but the method described in this article differs in that it is capable of genuinely reproducing sounds appearing to come from all around the listener, instead of merely producing an illusion of extra spaciousness.

At first sight, it may seem impossible to reproduce stereo tapes or disc so that sounds appear to come from all round the listener. However, there is enough surplus information contained in many ordinary stereo signals for it to be possible to reproduce sounds from behind the listener as well as from each side and to the front of him. The experimental set-up used by the author included four loudspeakers and two stereo amplifiers, with the loudspeakers arranged as in Fig 1. The sounds fed to the four speakers were as follows: the left-hand speaker was fed with the left stereo channel, the right-hand speaker was fed with the right stereo channel, the 'front' speaker was fed with the sum of the two stereo channels, and the rear speaker was fed with the difference 'between' the two stereo channels.

The intention is that a sound which is only recorded on the left stereo channel will be reproduced loudly from the left-hand speaker, rather more quietly from the front- and rear-speakers, and not at all from the right-hand speaker; thus the sound will appear to come from the left of the listener. Similarly, a sound which is only recorded on the right stereo channel will appear to come from the right of the listener. A sound which is recorded equally on both stereo channels will



be reproduced loudly from the front speaker, rather more quietly from each of the side speakers, and not at all from the rear speaker, and such a sound will appear to come from in front of the listener. A sound which is recorded *out-of-phase* on the two stereo channels, but equally loud on each, will be reproduced loudly from the rear speaker, less loudly from the side speakers, and not at all from the front speaker; such an out-of-phase sound will appear to come from behind the listener. (A stereo signal is said to be out-of-phase if the audio signal on the right stereo channel has the opposite polarity to the signal on the left stereo channel.) It is therefore possible to reproduce sounds from all around the listener.

Before going into the detailed method of wiring up such a 'sum-and-difference' four-speaker set-up, it is worth describing how this method of stereo reproduction works. Clearly, the performance of the set-up will depend on the loudspeakers used, the room in which they are placed, where the speakers are positioned, the nature and source of the stereo recording played, and where the listeners sit in relation to the loudspeakers. Here I can only describe the experiences of one set-up but this may help to guide others trying this system of reproduction.

The experimental set-up (in the common room of Pusey House, Oxford) was as in Fig 1, and depicted with the speakers placed in a square whose diagonal was just over three metres. The speakers used were Quad electrostatics, fed by four Quad II valve amplifiers via two Quad 22 stereo control units. One control unit controlled the front and rear speakers, the other controlled the side speakers. It was thus possible to control independently the left-to-right balance and volume, and the front-to-rear balance and volume.

The programme source was a Revox F36HS tape recorder.

Most of the recordings played over this set up were stereo master-tapes of live concerts recorded by Oxford University Tape Recording Society. These master-tapes were all recorded using a coincident pair of ribbon microphones, one mounted immediately above the other, either Reslo VRTs or STC 4038s. All the listeners in this experiment were familiar with these tapes reproduced via Quad electrostatics in ordinary stereo, and were familiar with the live sound of the various performers. For this reason, it was possible to judge how realistic the four speaker reproduction was, without being misled by unknown defects or gimmickry in the recordings.

Once the relative levels of the four speakers had been correctly adjusted, all listeners were impressed by the generally realistic and spacious quality of reproduction. The acoustic and ambience of the buildings in which the tapes had been recorded was accurately captured, but a number of unwanted side-effects were noticed. Listeners seated in the middle of the four speakers (position I in Fig 1) found that the stereo image moved rapidly if the listener's head moved. Also, on just a few of the tapes, some listeners (not all) found that some instruments and performers appeared (incorrectly) to be playing just behind the listener's head. However, on most tapes this effect was not noticed. One listener observed that on one tape he had the sensation that there were four orchestras playing simultaneously.

This sort of reaction from listeners dead in the middle of the four speakers was expected in advance. What was not predicted in advance was how well the four-speaker reproduction of stereo tapes works for listeners not in the middle. It was found to be important that each listener should not have any other listener in the path of the sound from any of the four speakers. By seating listeners in positions I, II and III in Fig 1, it was possible for three listeners to hear all four loudspeakers simultaneously. To everyone's surprise, it was found that listeners in positions II and III got a very good sound, with the orchestra or chorus appearing to come definitely from in front of the listener. In some recordings, the sound obtained at positions II and III was actually preferred to the sound at position I.

Listeners in positions II and III of Fig 1 found that the ambience and acoustic of the concert halls in which the recordings were made was reproduced with great realism and presence. One psychological difficulty was that it was impossible to convince oneself that this spacious sound, full of depth, originated from the rather close loudspeakers, with the result that the image tended to seem unnatural unless one ignored the loudspeakers or shut one's eyes.

It was found that the rear loudspeaker contributed very little, and switching it off hardly affected the stereo position of instruments: however, a loss of 'depth' was noted when the rear speaker was not operating. Readers who possess only a mono amplifier and a single loudspeaker in addition to their stereo system could try reproducing stereo via three loudspeakers by omitting the rear channel. The reproduction is still quite spacious, and such a three-speaker set-up bears a distinct similarity to Peter Bouwer's 'bi-amplification' set-up.

One surprising effect of four-speaker reproduction was the sheer volume that could be reproduced. Due to the fact that live master-tapes contain a good deal of treble that has not been limited or removed by technical processing, many of these recordings tend to overload the Quad II/electrostatic set-up in ordinary stereo reproduction at well below life-like levels. It was found that four-speaker reproduction produced very much higher subjective levels before distortion set in. Despite the fact that the volume of musical climaxes seemed very loud (as it did live), there was no sense of strain or discomfort, but just a thrill at the rousing 'electric' quality of the music, which the writer has only previously experienced at live concerts.

In other words, four-channel reproduction tends to increase the apparent volume of *fortissimo* passages in a manner that reproduces the tremendous power and effect of live music. The quieter passages, however, retained their quietness, and four-speaker reproduction seems to preserve the dynamics better than ordinary stereo. The different acoustic qualities of the various recording locations were immediately apparent via four speakers. One defect of this four-speaker playback system was that listeners in the middle heard too much acoustic, although listeners in positions II and III of Fig 1 found the acoustic quite realistic.

Many of the live tapes included such non-musical sounds as clapping, the choir walking on to the stage, the audience chatting while leaving, conversations near the microphones, and the various noises and whisperings associated with rehearsals. Such sounds were reproduced most impressively, with the clapping, footsteps, chatting, etc, coming from all around one. Particularly impressive were recordings of the choir walking on to the stage past the microphones, in which the footsteps of the performers passed from behind the listener, to his right, and then in front of him. These effects were observed by listeners in positions I, II and III of Fig 1. There seems to be no doubt that the 'sum-and-difference' four-speaker reproduction technique for stereo gives a genuine all-round sound.

It was found that four-speaker reproduction gives a much wider stereo image than conventional stereo, and that the separation between instruments was very marked. It was possible to distinguish between singers

in a part of the choir, or violins within the orchestra, far more easily than with two-speaker stereo. However, it was found that even very small amounts of distortion badly blurred the stereo image. Indeed, it was a general observation that small defects of technical quality were much more noticeable with four-speaker reproduction than with ordinary stereo. Small amounts of distortion, which are almost imperceptible in ordinary stereo, are clearly audible as 'clogging' and 'blurring' with four-speaker reproduction, and even 38cm/sec master-tapes, recorded at reasonable levels, were found to be subtly distorted when played through four speakers. The result was that the stereo definition tended to blur during climaxes in the music.

A general loss of realism was also noted due to the frequency response of the recordings. By most standards, the Quad speakers and STC 4038 microphones are regarded as really excellent, but it is known that the STCs gradually roll off above 7kHz, and the Quad speakers above 12kHz. The result is that stereo tapes played via four speakers sounded rather dull compared to the live sound; this dullness is less objectionable in ordinary stereo, as ordinary stereo sounds pretty dull and lifeless in comparison to reality anyway.

Listeners in position IV of Fig 1 found that most of the sound appeared to come from behind, which was very disconcerting. On the other hand, listeners outside the square of loudspeakers, such as at position V of Fig 1, found that they heard spacious and pleasant stereo sound, although this sound no longer fully surrounded the listener.

Besides master-tapes of live music, the reproduction of BBC stereo broadcasts was tried. While BBC stereo is often based on a coincident pair of microphones, additional microphones are frequently used to 'highlight' soloists or to add reverberation. Generally, recent BBC broadcasts have conveyed relatively little of the acoustic, and have sounded extremely dry over the Quad speakers. BBC stereo, reproduced via four speakers, was found to sound richer and more spacious than when played over two speakers. However, the dry acoustic resulted in the four-speaker reproduction giving virtually no sensation of actually being in the concert hall, and it was felt that BBC stereo did not fully realise the advantages of four-speaker reproduction. The stereo definition of BBC stereo over four speakers was found to be rather worse than that of the master-tapes.

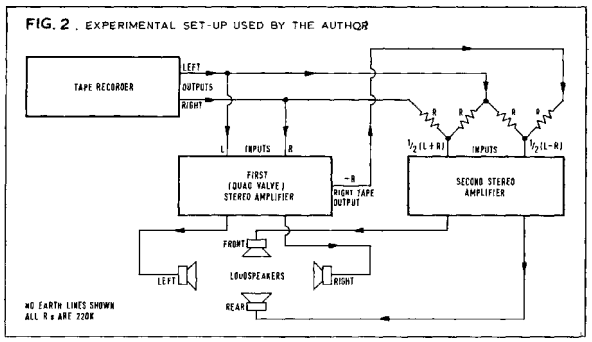
As a final experiment, some Beatles stereo recordings were played via four speakers, but the results were rather disappointing for two reasons. Firstly, the stereo was from gramophone records, and the subtle distortions inevitable with disc tended to be far more noticeable, as explained earlier. Secondly, recent Beatles stereo is recorded by a 'pan-pot' technique, in which each instrument or singer is recorded on a separate mono track and put in the stereo image by feeding the tracks with different volumes into the two stereo channels. When reproduced via four speakers, this resulted in a rather poor stereo effect, and it was not always easy to say where a sound was coming from. Numbers with a very simple musical arrangement seemed to work best.

To summarise, the four-speaker sum-and-difference technique of reproducing stereo recordings can tremendously increase the realism of coincident 'figure-of-eight' microphone recordings, but is less successful with the more artificial stereo recording techniques. The fact that only two channels are used to supply the sound for four loudspeakers inevitably means that reproduction is not perfect in every way, but it is none-the-less surprisingly good. Clearly, suitable three or four-channel recording techniques should be able to do even better.

Now we can return to the technicalities when there are clearly problems in finding a way of wiring up the four loudspeakers. The signals fed to the right-hand and left-hand loudspeakers may be obtained by feeding the programme source (stereo tape, disc or radio) into a stereo amplifier in the usual manner. The main problem is to derive the signals for the front and rear speakers, which are to be fed by a second two-channel amplifier.

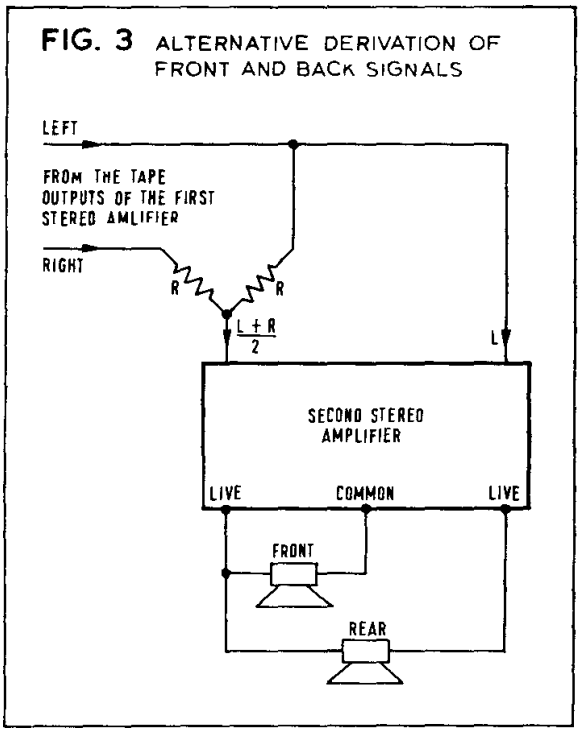
Recall that the signal to be fed to the front loudspeaker is the sum of the two stereo channels. In our experimental set-up, this signal was obtained by feeding both the right and the left channel outputs of the tape recorder into 220K attenuator plugs which were fed, via a Y-adaptor (*ie* a device that allows two leads to be connected to one socket), into (say) the left input of a second Quad stereo unit; the corresponding amplifier fed the front loudspeaker (see Fig 2). The rear speaker needs to be fed with the 'difference' between the right- and left-channel signals. One can derive the difference of the two channels by combining the left-hand tape recorder output with a reversed polarity right-hand signal via attenuator plugs and a Y-adaptor fed to the right input of the second stereo amplifier. Unfortunately, one needs a phase-inverter circuit, with a gain of minus one, to reverse the polarity of the right-hand signal. While those experienced with electronics can construct a phase-inverter easily enough, those with Quad valve amplifiers don't need to. In the Quad 22 control unit, the path between the high-level tape input and the tape 1 output sockets has a gain of −1; in other words, for a high level signal fed into the tape input, Quad preamplifiers contain a built-in phase inverter. Thus, if the first amplifier (which feeds the side speakers) is a Quad, then one obtains the difference signal to be fed to the second amplifier by combining the left hand output of the tape recorder with the right hand tape output of the first Quad control unit via two attenuator

plugs and a Y-adaptor. This difference signal is fed to the right input of the second amplifier, which feeds the rear speaker (see Fig 2). I would like to thank Peter Craven for suggesting using the Quad as a phase inverter in this manner – a technique that will not work with the Quad 33, although other designs may well be suitable.



The above arrangement has the disadvantage that it can only be used with high level unequalised programme sources such as tape or radio. Those who are capable of constructing phase inverters (or have transformers which can be used as phase inverters) can also use low-level and equalised sources (such as disc) by deriving the signals for the second amplifier from the tape outputs of the first amplifier, which need not then be a Quad. The advantage of the above methods of deriving the front- and rear-speaker signals is that the levels fed to all four speakers can be adjusted independently of one another. Also, if the front and rear speakers differ from the side speakers, then the 'tone' of the front and rear speakers can be adjusted to match that of the side speakers.

If the reader does not have an amplifier with built-in phase inverter, or if he lacks the time or knowledge to build one, there is another method of obtaining the 'sum-and-difference' signals, which also has the advantage that it can be used with low level equalised inputs such as disc. Feed the left- and right-signals from disc, tape or radio to the first stereo amplifier in the usual manner; this amplifier feeds the side speakers. Take the left- and right-signals from the tape output of the first amplifier, and feed the left-hand tape output signal into the left high level input of the second amplifier (see Fig 3), and feed the left- and right-tape output signal of the first amplifier via attenuator plugs (*eg* 220K) and a Y-adaptor to the right high level input of the second amplifier. The front loudspeaker is then driven from the right speaker output of the second amplifier, as it must reproduce the sum of the original stereo channels. The two common or earth speaker connections of the second stereo amplifier are joined together, and the rear speaker is connected between the live terminal of the left speaker output and the live terminal of the right speaker output. (This could cause damage at high levels with some cheap transistor amplifiers, but should be safe with good equipment at normal volumes).



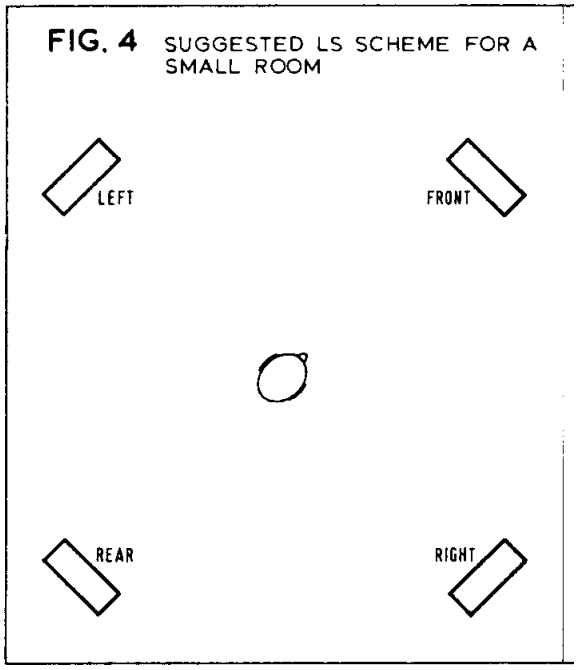
A central mono sound (*eg* a mono disc played with the equipment switched to stereo) should then be played over the system, and the balance control of the second amplifier should be carefully adjusted to minimise the output of the rear speaker. Once this is done, the rear speaker should reproduce the difference of the two stereo channels, and the balance control of the second amplifier should thereafter be left untouched.

One disadvantage of this method of obtaining the sum-and-difference signals is that it is not possible to separately control the levels of the front speaker and the rear speaker. A second disadvantage is that the method of connecting the front and rear speakers places extra demands on the amplifier. This disadvantage can be minimised by using 15 ohm rather than 8 ohm speakers.

Whichever method is used, care should be taken to phase the front three speakers. It is no good to rely only on which way round the wires are connected at the amplifier and speaker terminals, as if the front speaker has a signal derived from the tape outputs of the first amplifier, it is possible that the tape outputs *might* have altered the phase. The phasing of the front speaker should be achieved, for example, by temporarily placing the front speaker next to, say, the left speaker, and determining which phase for the front speaker gives most bass on bass-heavy mono sounds. There is no 'correct' phase for the rear

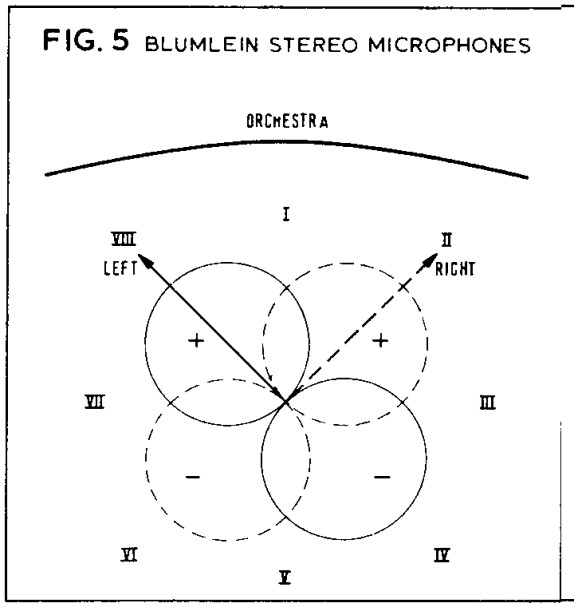
speaker, and its phase should be adjusted for what the listener feels is the best four-speaker reproduction. But the phase of the rear speaker does not make much difference.

The signals fed to the second amplifier *can* be from the preamplifier output of the first amplifier, so that volume and tone adjustments on the first amplifier will affect all four speakers. However, in that case the balance control of the first preamplifier must be left central, otherwise it will affect the blending of sound fed to the front and rear speakers. To minimise treble loss, it is advisable to place all attenuators as close to the second amplifier as possible. It is possible to position four speakers for 'sum-and-difference' reproduction in quite small rooms by placing them as in Fig 4; however, many people might feel that staring into the corner of the room rather spoils musical enjoyment.



A fuller understanding of how the 'sum-and-difference' four speaker reproduction of stereo works can be gained by considering the reproduction of sounds picked up by a Blumlein pair of stereo microphones. It will then become apparent that, despite the good results, there are certain inherent imperfections in this method of playing stereo. The most basic method of recording stereo sound is the Blumlein technique, in which two almost coincident microphones with 'figure of eight' directional characteristics is used. The left-channel microphone is pointed 45° towards the left, and the right-channel microphone is pointed 45° towards the right, as illustrated in Fig 5.

A live sound at position I of Fig 5 (straight in front of the microphones) will be reproduced from the front of a listener listening via the sum-and-difference four



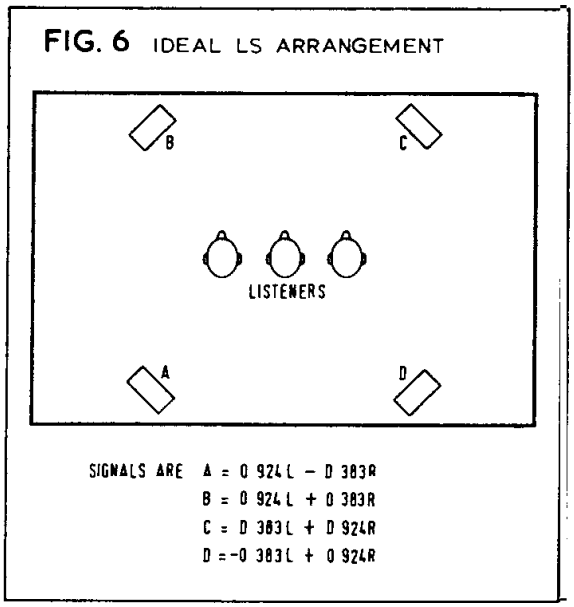
speaker set-up. A sound from position II of Fig 5 will only be picked up on the right-channel, so will be reproduced to the right of the listener. A sound from position III of Fig 5 will be picked up as an out-of-phase stereo signal, so will be reproduced from behind the listener. Similarly, sounds from positions IV, V, VI, VII and VIII of Fig 5 will be reproduced, respectively, to the left, front, right, rear and left of the listener.

The result is that a speaker or musician walking once round the stereo microphones will be reproduced as if he were going round the four loudspeakers *twice.* The four-speaker reproduction of stereo does not reproduce the original direction of sound, and causes the reproduced width of stereo images to be twice their original live width. An indirect mathematical consequence of this is that not all four speakers can be correctly phased, and this is why the rear speaker has no correct phase, inevitably weakening the solidity and impact of images to the rear of the listener.

If spaced or coincident cardioid microphones are used to make a stereo recording, then no sounds will be recorded out-of-phase, and such recordings will be reproduced over four speakers with no sounds coming from behind the listener. They will lack much of the 'depth' and spaciousness of Blumlein recordings reproduced via four speakers, and will probably sound just as well if the rear speaker is disconnected. However, many BBC recordings are made with 'crossed cottage-loaves' (BBC jargon for crossed coincident hypercardioid microphones) and these recordings should reproduce a fair amount of ambience from behind the listener.

Another, more obvious, defect of 'sum-and-difference' four-speaker reproduction is the highly inconvenient seating arrangements, which are hardly suitable for the cosy domestic enjoyment of music. Domestically one would wish to use a speaker layout as in Fig 6, with speakers to the rear left, front left,

front right and rear right. Clearly, with this speaker layout, the proportions of the left stereo signal L and the right stereo signal R which must be fed to the four speakers is different from the proportions in the 'sum-and-difference' layout.



A = 0.924 L – 0.383R
B = 0.924 L + 0.383 R
C = 0.383 L + 0.924 R
D = -0.383 L + 0.924 R

Labelling the signals fed to the four speakers A, B, C and D as in Fig 6, the signals are derived from L and R as given there. These coefficients are chosen so that stereo sounds are reproduced by the four speakers from the same apparent direction, with respect to the listener, as with the sum-and-difference layout. While the author has not tried out the reproduction system of Fig 6 it will most probably suffer from defects similar to those of the 'sum-and-difference' layout. In particular, the rear speakers are out-of-phase with respect to one another.

The general success, on musical and natural recordings, of four-speaker reproduction of stereo indicates that properly recorded quadraphonic recordings should be something to really look forward to. Meanwhile, many thanks are due to Peter Craven and Stephen Thornton for their constructive comments and help, and to Philip Allen for his infinite patience.