The author presents a new transmission system for space-related stereophony, in which the space information is transmitted by spatial modulation. This system is particularly suitable for compatible sound-broadcast transmission. At the studio end, the system is distinguished by an easy mixing technique : at the reproducing end, it has the advantage that it is possible to use any desired number of additional loudspeakers. The article reports on the acoustic results that have so far been obtained with the system.

A new process for space-related stereophony with improved transmission of spatial information *

P. Scherer **

ound incidence

1.1. The importance of the direction of incidence of the sound for realistic electro-acoustic transmission

The ability to distinguish different directions of sound incidence is an important prerequisite for the auditive perception of an acoustic scene ; unlike sight, hearing is not restricted to a given viewing angle, but comprises the entire space angle, it being borne in mind that, in addition to the conscious absorption of information, the auditive organ has also a watching function. Under these conditions, the auditive perception of the acoustic scene is largely subconscious and without any support by sight.

If a transmission is to be realistic, conscious and subconscious listening should be possible without any restriction. The ability consciously to distinguish the directions of discrete sources (for example, of actors on the stage, of musical instruments in the orchestra) certainly contributes greatly to the liveliness of a transmissi[illegible] Transparency is achieved by the fact that the l[illegible]ner is in a position to concentrate at will on a particular source and, in so doing, can subconsciously suppress other sources from other directions (the *cocktail-party* effect).

Thus, for the realistic transmission of a theatre scene, for example, it is necessary to reproduce the directions of incidence of the direct sound correctly, at least over the entire width of the stage ; that is to say, to all intents and purposes, in the frontal half-plane. Moreover, it is necessary for the reproduction to be space-related, so that any movements of the listener's head result in natural changes in the acoustic scene. This facilitates conscious location and increases the naturalness of the transmission.

The correct reproduction of the directions of sound incidence is even more critical in the case of diffuse sound components which are governed by the *acoutics* of the listening room, but which can be heard correctly only when their directions are reproduced. Indirect sound which arrives omnidirectionally and with correctly reproduced volume, will not disturb the listener to a wanted sound source only if, because of the possibility of omnidirectional location, he can subconsciously suppress the diffuse sound components. However, since these components contribute to the impression of space, they must not be attenuated, for example, by the use of directional microphones. It may be assumed, therefore, that the transparency and impression of space of a programme are in a balanced proportion only when the directions of sound incidence can be located over the entire space angle or, at least, over the entire auditive plane, and if, furthermore, the impression of distance is correctly rendered, even in the absence of diffuse sound. Under these conditions, intelligent listening is possible.

1.2. Conventional transmission of the direction of the sound incidence

The importance of the transmission of the direction of sound incidence has recently become increasingly apparent. This has been proved by the recent experimental work using the artificial-head technique, which without doubt gives the listener a certain feeling of space in the auditive impression. At this point, mention should be made of the experiments with various forms of quadraphony. A review of these two techniques within the framework of a general summary is given in reference [1].

The critical objections to both systems concern the acoustical aspect and the transmission technique. The most important of these are as follows.

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The main criticism of artificial-head stereophony is that location in the frontal horizontal plane is falsified ; in particular, with headphone listening, sound sources that are at a considerable distance in front of the artificial head, on the line of intersection of the horizontal and median planes, appear to be more or less elevated and too close to the listener. All auditive impressions are perceived as being in or near the head. In addition, the nature of the localisation depends on the characteristics of the headphone used. Movements of the head do not produce natural changes in the acoustic scene ; that is to say, it is not possible to take a bearing because a natural, space-related sound field does not exist.

As far as transmission is concerned, the most serious objection is that this method is not compatible with normal monophonic and stereophonic loudspeaker reproduction, because the artificial auditory meatus, whose linearity distortion is very considerable, is already included in the channel.

In the case of quadraphony, it is claimed that, despite the high outlay required for its transmission, the acoustic improvement, compared with two-channel stereophony under the usual conditions of recording and reproduction, is too small.

Quadraphony can be regarded as an attempt to transmit omnidirectional information by means of the same technique that is used for two-channel stereophony. In the conventional two-channel technique, the direction of sound incidence is represented by differences in amplitude and/or phase between audio-frequency voltages that are otherwise equal (*Fig. 1*). In theory, two equally-good channels are required for transmission. The difference in level fed to the two loudspeakers gives a listener on the centre line between the loudspeakers the impression of a virtual sound source somewhere between the loudspeakers. As long as their mutual spacing is not too great in relation to the distance from the listener, the virtual sound source moves along the line connecting the loudspeakers, approximately uniformly with the changes in level difference.

The technical implementation of this simple transmission principle has aggravating shortcomings when more than two loudspeaker channels are involved. In principle, all the channels must be of the same quality, and their number must be the same throughout the transmission path (FM link, sound-recording system) as the number of loudspeakers used at the reproduction end : in other words, the number of channels in the transmission path determines the maximum reproduction attainment possible. The channel separation achieved (and at great expense) on the transmission path is of no acoustic benefit because of crosstalk in the studio.

For a space-related reproduction system that makes possible the reproduction in the round of all directions of sound incidence, that is to say, in both the horizontal and vertical planes, the number of loudspeakers required is certainly more than four, most probably considerably more if one considers that an impression exceeding ± 30° in a listening plane between two loudspeakers is problematical. However, such a system is impractical in view of the number of channels that would be required in the transmission path (FM link, sound-recording system). In VHF/FM broadcasting, it is practically impossible to make more than two equally-good channels available, because VHF broadcasting was originally introduced for high-quality single-channel transmissions, and two-channel transmissions have already reduced the signal-to-noise ratio. Finally, from the production point of view, for mixing and for intermediate recording for example, the manipulation of a large number of channels would be too difficult without automation.

Accordingly, it is worth considering whether this technique is really suitable for the transmission of the directions of sound incidence and whether it might be possible to find another, more appropriate solution. When designing a new system, it must of course be borne in mind from the start that it must be technically compatible with the two-channel technique, which has already been universally adopted for broadcasting and disk-recording : the problem must be dealt with in such a way that the already-existing system could be considered to be a special case of the new technique. It should, of course, be possible to continue to use existing installations as before, without jeopardising the possible improvement in quality if they are adapted to the new system. In addition, the system should not implicitly determine the number of reproduction loudspeakers. It should be possible to design the reproduction installations to suit the particular standard of quality desired, without it then being necessary to modify the studio and transmission techniques as a consequence.

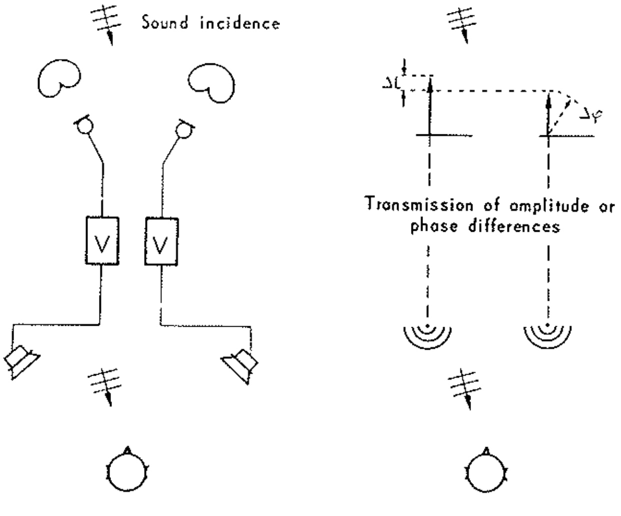


Fig. 1. — Principle of the conventional two-channel stereophonic technique for the transmission of the direction of sound incidence.

2. Transmission of the direction of sound incidence by spatial modulation (Eidophony)

2.1. Production and theoretical reproduction of a spatially-modulated signal

The new system proposed [2, 3] transmits correctly the direction of sound incidence in one plane or several planes and is thus capable of transmitting the entire sound scene in the round ; that is to say, pictorially (hence *eidophony*). Eidophony enables the number of channels required in the transmission path to be reduced by deliberately separating the information regarding the direction of sound incidence from the basic information regarding the acoustic wave itself.

The fundamental idea is depicted in *Fig. 2*. The incident sound wave is picked up by means of a cardioid microphone whose directional pattern rotates, in the plane of the incident wave, at 38 thousand revolutions per second. This rotary microphone produces an audio-frequency voltage which is amplitude-modulated at 38 kHz by the rapid rotation of the directional pattern. Because of the high speed of rotation, all the resulting sidebands fall outside the audible frequency range. They alone carry the information about the direction of sound incidence, that information being coded in the phase angle of the sidebands. It is easy to understand that a change in the angle of the sound incidence gives rise to a corresponding change of the phase angle with respect to the rotation of the directional pattern *(Fig. 2)*. Thus, if there is no predominant direction of sound incidence, the sidebands will disappear. In effect, if the sound arrives uniformly from all directions, the rotating directional pattern does not give rise to any modulation of the sound signal.

In *Fig. 2*, it is assumed that the rotating pattern is produced by means of first-order pressure-gradient microphones. With this assumption, the frequency requirement of the space signal corresponds exactly to that required by the amplitude-modulated second AF channel in VHF/FM transmission, because the rotation of a first-order pressure-gradient pattern gives rise to a sinusoidal modulation at the frequency of rotation (38 kHz). According to *Fig. 2*, therefore, the entire stereo signal (30 Hz to 53 kHz) consists of the normal audio-frequency signal (30 Hz to 15 kHz) and the space signal (23 kHz to 53 kHz). If, however, a higher-order pressure-gradient pattern were used at the same speed of rotation, the frequency requirement of the space signal, and thus the required bandwidth, would be greater, compared with the conventional two-channel transmission by VHF/FM transmitters.

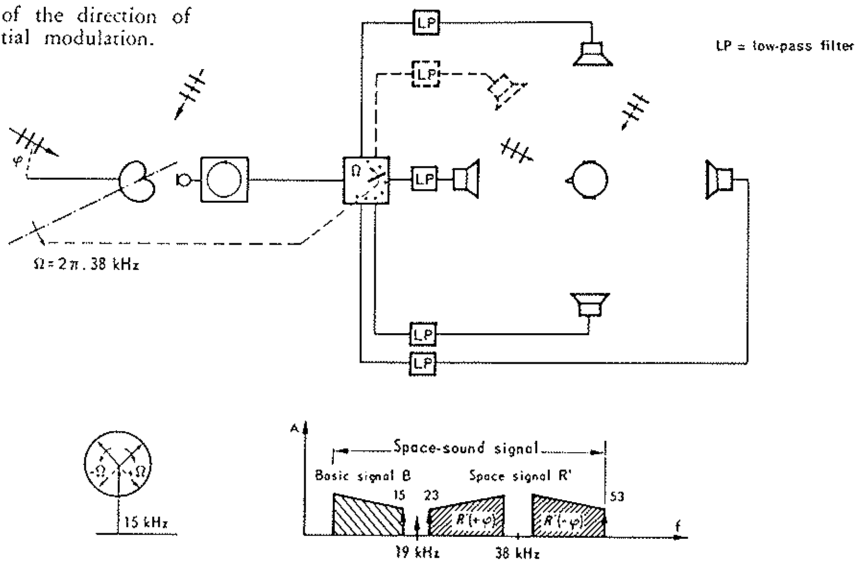
On reproduction, the direction of sound incidence is recovered by spatial demodulation. The demodulator could consist of a switch to which the various loudspeakers are connected. This switch would rotate in synchronism with the directional pattern and would distribute brief excerpts of the space-sound signal by way of low-pass filters to the loudspeaker channels (*Fig. 2*). In this way, the composite signal (= space-sound signal) can be broken down into appropriate audio signals for any given number of loudspeakers.

The rotating cardioid pattern assumed in *Fig. 2* could be simulated by an omnidirectional pattern which picks up the basic signal, and a figure-of-eight pattern which produces the space signal. The rotating effect could be produced by means of the modulation system shown in *Fig. 3*.

Each of the output signals from the two coincident figure-of-eight microphones mounted with their axes at 90° is modulated with a 38-kHz sinusoidal signal in quadrature to the other. When sound is picked up, this arrangement produces the same signal as that which would be given by a figure-of-eight pattern rotating at 38 kHz. By adding the output of an omnidirectional microphone, one finally obtains a cardioid pattern rotating in the sensitivity plane. A 19-kHz pilot tone provides for the synchronisation of the space modulator (38-kHz oscillation) and of the space demodulator at the receiver, and it is, therefore, added to the stereo signal at an appropriate level (some 30 dB below full modulation) (*Fig. 2*).

The complete reproduction of the direction of sound incidence requires more than one scanning and repro-

Fig. 2. — Transmission of the direction of sound incidence by spatial modulation.



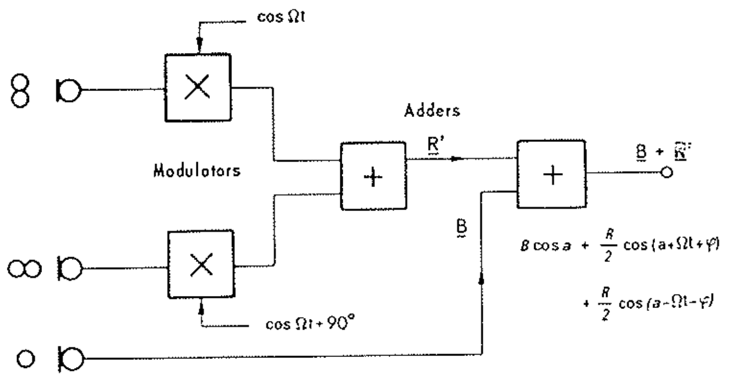


Fig. 3. — Rotating modulator for the production of the space-sound signal.

duction plane ; that is to say, more than one rotary microphone. When scanning is effected by means of rotating first-order cardioid microphones, a total of two scanning planes placed at right angles to one another is sufficient. The simplest way of transmitting the two stereo signals is over two separate circuits. In theory, however, it is also possible to transmit the two stereo signals in time-division multiplex, provided that the switching occurs sufficiently rapidly and always at the instant when the scanning directions of the two microphones coincide : at the reproduction end, a short-term store receives the information of one microphone rotation and is so arranged that no gaps occur when switching between the reproduction planes. Because of the high switching speed, such a technique requires either that the microphones rotate at a higher speed or that the reproduction of the direction of sound incidence be limited to about 9 kHz.

2.2. Processing of the stereo signal in the control room : compatibility

The stereo signal contains basic and space information in frequency-division multiplex. A channel having a bandwidth of 30 Hz to 53 kHz suffices for its transmission if the rotating pattern is a first-order cardioid and scans only one plane. Because the directions of sound incidence are represented by the phases of the sidebands, strict demands must be made of the linearity of the phase response of the transmission path, particularly over the space-signal band. Frequency-dependent phase changes generally interfere with the perception of the direction of sound incidence.

On the other hand, the space-sound signal requires only one channel ; the channel amplification affects the basic and space signals simultaneously, and thus only the level of the reproduced sound. A change in the sound-incidence direction requires a change of the

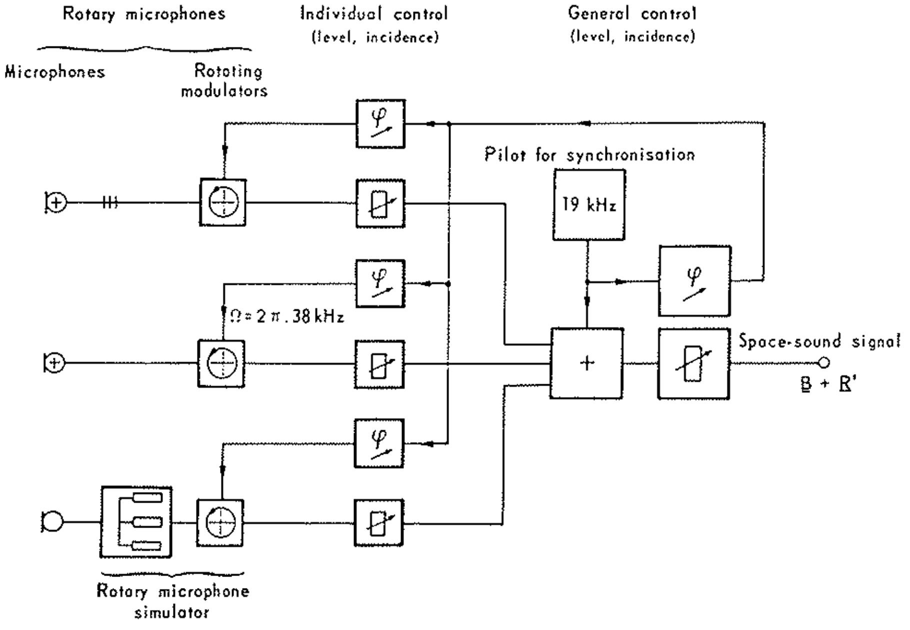


Fig. 4. — Block diagram of a control desk for space-sound signals.

phase angle of the sidebands, which is brought about, for example, by a phase-shift of the synchronisation of the modulator and demodulator. This makes the mixing of the signals from several rotary microphones and their processing in the control room particularly simple. The sound volume and the direction of sound incidence can be controlled independently.

The block diagram of a space-sound installation (*Fig. 4*) is very similar to that of a corresponding monophonic installation. In addition to the level controls, there are controls for varying the direction of sound incidence. By altering the phase of the rotations of the individual rotary microphones (that is to say, of the pilot frequency fed to them), their contributions can be easily modified relative to the " mixed scene " as regards direction and sound level. Similarly, the sound level, and position in space of the mixed scene, can be modified by means of a group attenuator before the output of the control room (*Fig. 4*).

It is not necessary for all the individual space-sound signals, of which the total signal is composed, actually to be picked up by rotary microphones, each of which has three, spatially-separated microphone capsules. When the sound of a soloist is to be inserted at a particular point in the acoustic scene, this may be done by using a single microphone and a rotary-microphone simulator (*Fig. 4*). Such a sound source can be picked up, for example, by means of a closely-positioned directional microphone. The microphone output is fed, by way of three special attenuators, to the input of the rotating modulator in such a way that it is indistinguishable from those that the three capsules would supply at certain angles of sound incidence. By adjusting the attenuators or by shifting the phase of the associated pilot tone, it is possible to simulate any desired direction of sound incidence. This demands a smaller outlay on microphones and has, moreover, the advantage that the angle of sound incidence is completely independent of frequency, which is difficult to obtain with a coincident arrangement of three microphones, at least at higher frequencies.

It has already been shown in *Fig. 2* that the frequency spectrum of a space-sound signal with added 19-kHz pilot-tone corresponds exactly to the two-channel-stereo signal with which VHF/FM transmitters are at present modulated. Thus, at the output from the control room, the space-sound signal already meets the existing standards. It is, however, essential that standard demodulation followed by linear combination ($A + B$; $A - B$), when applied to the space-sound signal, results in the formation of two intensity-stereophony signals : the demodulation of the space signal supplies an AF voltage, which would also be produced by a pressure-gradient microphone and which is subsequently either added to, or subtracted from, the basic information from an omnidirectional pattern. This gives two signals, similar to those that could be produced by two cardioid microphones placed at an angle of 180° to each other.

This compatible demodulation is represented in *Fig. 5*. With monophonic reception of the space-sound signal, only the basic signal is received. Thus, when the space-sound signal is radiated by a VHF/FM transmitter, eidophony is technically compatible with both monophony and stereophony.

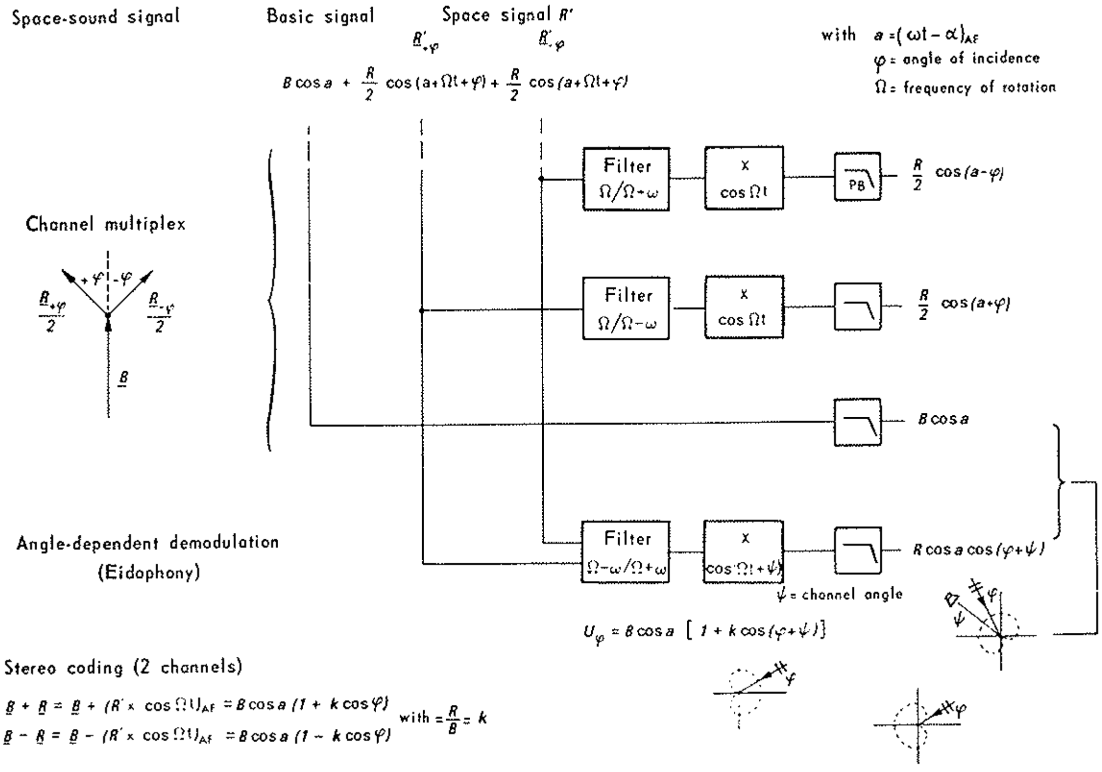


Fig. 5. — Demodulation of the space-sound signal. Compatibility.

The possibilities of demodulation of the frequency-division multiplexed space-sound signal are summarised in *Fig. 5*. It is assumed that filtering and subsequent multiplication with a 38-kHz oscillation takes place on demodulation. The decomposition of the space-sound signal into the audio-frequency channel multiplex results in three audio-frequency sound signals. Two audio-frequency signals may be derived from the space signal, their phase relations relative to that of the basic information being shifted by the positive and the negative angles respectively of sound incidence. With a given direction of incidence, the relative positions of the three voltage vectors are independent of the frequency and of the audio-frequency phase as shown in *Fig. 5*. Moreover, it does not change as long as the phase and amplitude responses of the three channels are the same. For this reason, this signal configuration has advantages in certain cases such as tape-recording or the use of companders. At the output of the control position, the processed space-sound signal would then have to be transposed into a channel multiplex and be recorded, as three channels, on a studio-type, three-channel audio tape-machine. Distribution to the transmitters could also be effected in the form of a three-channel multiplex. The transposition back into the frequency-division multiplex would then be performed at the input to the transmitter.

2.3. Conversion of the space-sound signal into the two-channel multiplex

The radiation of the space-sound signal by VHF/FM transmitters presents no difficulty, but other transmission paths, sound recording, for example, cannot cope with the frequency multiplex without special precautions. In the case of disks, the number of transmission channels is limited to two, so that the equivalent three-channel transmission of the space-sound signal mentioned in Section 2.2 is not possible, at any rate not when one foregoes the recording of the higher frequencies, as with the four-channel disk.

The conversion of the space-sound signal into a two-channel multiplex is in fact possible, subject to the reservation that the sound-incidence directions are, as explained in the preceding section, no longer reproduced faithfully.

It is outside the scope of this article, which is devoted to broadcasting transmission, to deal in detail with the two-channel transmission of the space-sound signal (type B). Thus, *Fig. 6* merely outlines the principle.

The basic signal is combined with each of the two audio-frequency voltages derived from the sidebands of the space signal, to produce audio-frequency channel voltages, as depicted in the vector diagram in *Fig. 6*. The resultant two audio-frequency channel voltages are modulated by a 38-kHz signal and, after filtering, it is possible to reconstitute the space signal or ultimately the space-sound signal. The latter can then be demodulated in the usual manner by means of switching demodulators. It is necessary to ensure that the transmission of the two channel voltages and of the 19-kHz pilot tone is not subject to any phase-shift. At this point, mention should be made of the fact that, by selecting the polarity of the channel voltages and the operational parameters, full compatibility with conventional two-channel stereophony can be obtained and the audio-frequency channel signals can be reproduced stereophonically (*Fig. 7*).

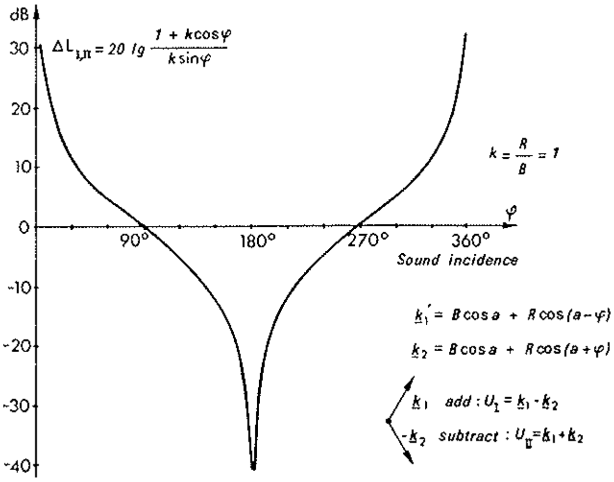
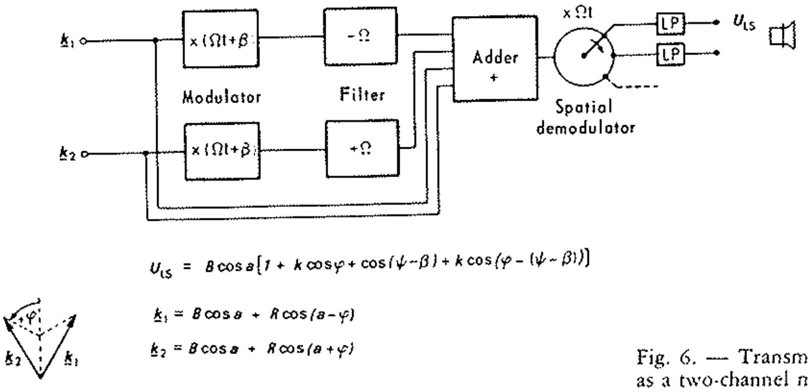


Fig. 7. — Compatible reproduction of the two-channel signals when the conventional technique is used.

$L_{I,II}$ represents the difference in level between voltages U_I and U_{II}.



$$U_{LS} = B\cos a[1 + k\cos\varphi + \cos(\psi-\beta) + k\cos(\varphi - (\psi - \beta))]$$

$$\underline{k}_1 = B\cos a + R\cos(a-\varphi)$$

$$\underline{k}_2 = B\cos a + R\cos(a+\varphi)$$

Fig. 6. — Transmission of the space-sound signal as a two-channel multiplex.

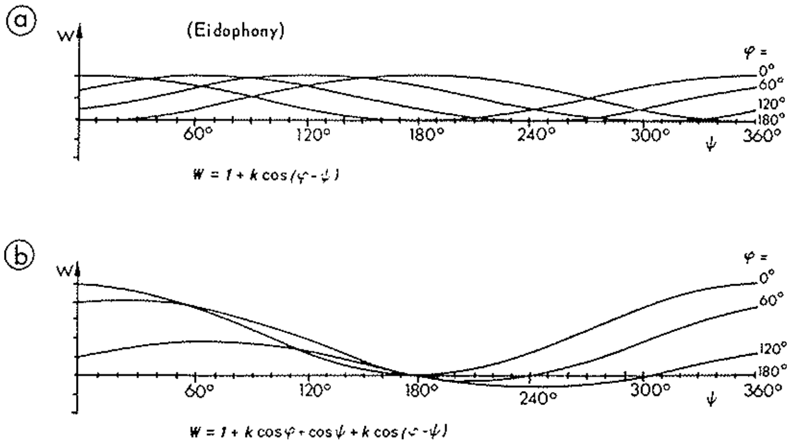


Fig. 8. — Loudspeaker charge functions W.

a) type A eidophonic reproduction

b) type B eidophonic reproduction (two-channel transmission)

φ is the angle of incidence of the sound ; ψ is the angular separation of the loudspeakers in the listening room.

2.4. Reproduction of spatially-directed sound fields

The eidophonic reproduction of a plane by means of space demodulation has already been outlined in *Fig. 2.* The loudspeakers are placed in a closed configuration, for preference in a square, and fed through low-pass filters from switching demodulators to which the space-sound signal is applied. The latter contains the direction-dependent sound information at a point, or in a small area around it. As long as the rotation of the directional patterns is rapid compared with the audio-frequency, the latter is radiated in phase by the loudspeakers, but at direction-dependent, differing volumes. The charge function of the loudspeakers — that is to say, their maximum amplitude for a given direction of incidence as a function of the angle of incidence — is determined by the shape of the rotating directional pattern. *Fig. 8a* demonstrates that the charge functions are independent of the sound-incidence direction and correspond to the rotating directional pattern used. On the contrary, however, the charge functions of the systems as described in Section 2.3. (eidophony, type B) clearly show their dependence on the direction of sound incidence (*Fig. 8b*).

The purpose of the investigations with models was to obtain a criterion for the acoustic field produced in the area between the loudspeakers, when these are fed in phase at a single frequency, with a charge function as depicted in *Fig. 8a.* Several loudspeaker configurations (circles, squares, rectangles) were examined with different wavelengths, it being assumed that the waves extend omnidirectionally from all loudspeakers and are not reflected from walls. The amplitude and phase of the resulting sound pressures were calculated, and finally the lines of constant phase and constant amplitude were determined. A typical example for a square arrangement (6 × 6 m, 100 Hz, 16 loudspeakers) is shown in *Fig. 9.* In the wide area around the centre, the directions of incidence of the sound wave-fronts correspond largely to the original directions of incidence ; towards the edge, the shapes and curvatures of

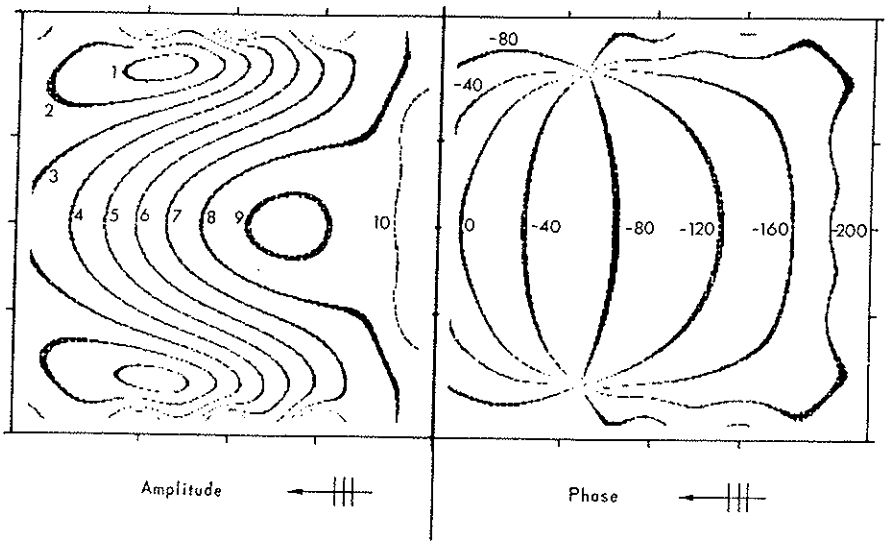


Fig. 9. — Eidophonic reproduction of the sound field.
Lines of equal phase and amplitude in the two-dimensional computer model.

the wave fronts depend on the configuration. In the rear half of the square, the amplitude of the sound waves decreases (space limitation) by about 10 dB, so that reflections from the back wall (taking account of reflection losses) have virtually no disturbing effect.

To summarise, it may be said that, theoretically, at least three loudspeakers are required for eidophonic reproduction. The number of loudspeakers can be increased as desired, which has the advantage that the auditive impression then is less dependent on the position of the listener.

On the basis of the investigations made with models, we may expect that localisation is more or less accurate, as far as direction is concerned, within a relatively wide area around the centre and that, above all, the acoustics of the listening room have very little effect on the sound reproduction, provided that the number of reproducing loudspeakers is not too small.

3. Acoustic testing

3.1. Perception of the sound-incidence direction

The method described in Section 2.1. (eidophony, type A) was tested acoustically by scanning a microphone plane and reproducing by way of sixteen loudspeakers, which were arranged either in a circle (6-m diameter) or in a square (6-m sides). The studio and the listening room used were alternately echo-free rooms and rooms with average reverberation. In addition, a few experimental trials were made in a hall with greater reverberation.

Initial listening tests in a normal room ($T = 1.6$ s ; $r_H = 0.6$ m) had shown that, although the angular fidelity was a little worse with the square arrangement, the auditive impression with frontal sound incidence nevertheless appeared to be a little better. The sixteen small loudspeakers were mounted on stands at approximately head-height and spaced at equal angles. It was noted that the height of the listening position could be made less critical by using two loudspeakers, fed in parallel, one placed about 0.8 m above the other. Here, it should be mentioned that, in spite of the low power fed to each individual loudspeaker in the overall configuration, it was to be expected that the resultant sound volume would be high ; the arrangement that was chosen gave a considerable improvement in bass response.

The test signal used was relatively " dry " speech which was reproduced eidophonically by way of a rotary-microphone simulator. When the same system was tested in the acoustically-treated room, it was found that the difference between the two configurations was greater, the circular arrangement remaining inferior. The latter configuration had to be modified by displacing the loudspeakers alternately by about ± 20 cm from the circumference of the circle and the observers were placed some 0.3 m behind the centre. This version of the circular configuration gave acceptable results and eliminated the elevation of the virtual sound source.

In order to investigate the validity and accuracy of localisation with eidophonic transmission in the acoustically-treated room, the observers were at first offered a reference sound from one of three separate loudspeakers. The reference and eidophonic test items were presented alternately from the same audio signal (speech) and the apparent direction of sound incidence was noted. By changing the phase of the 38-kHz oscillation, it was possible to adjust incidence of the eidophonic signal to coincide with that of the reference. The angle of deviation from the reference was measured electronically.

Fig. 10a shows the localisation deviation as a function of the direction of sound incidence, for the eidophonic system. Even with the square arrangement, the angular localisation is surprisingly accurate and, according to Gottlob's measurements [5], it is surpassed only by natural listening. The results obtained by Damaske [6]

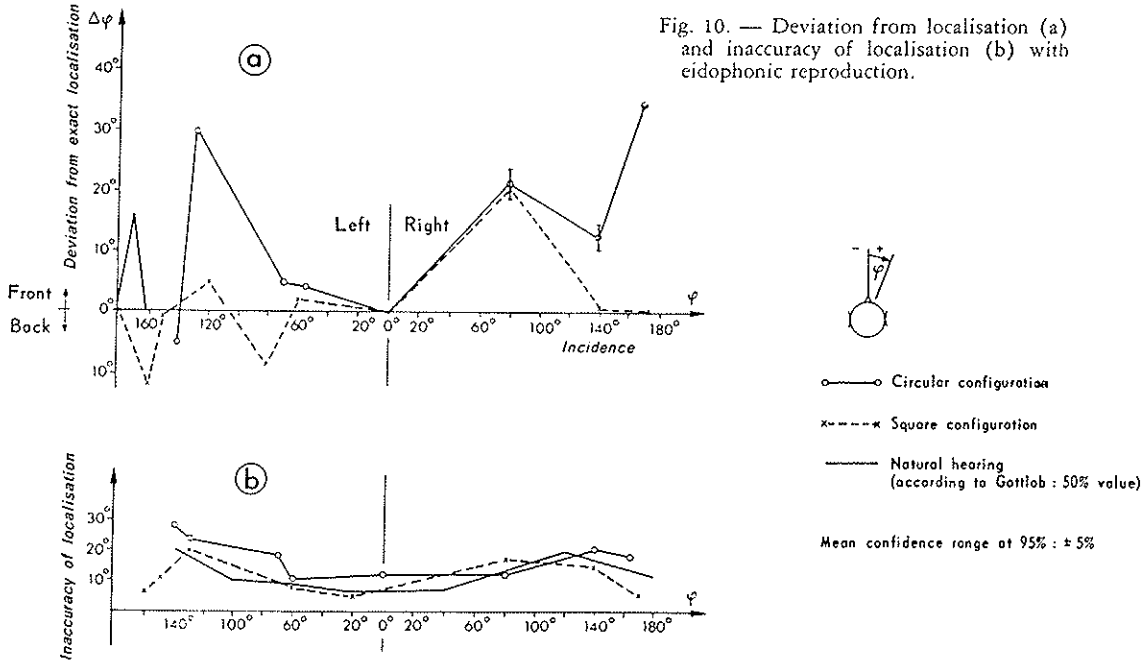


Fig. 10. — Deviation from localisation (a) and inaccuracy of localisation (b) with eidophonic reproduction.

using artificial-head stereophony, which were published in the same article [5], show much greater deviations. Eidophonic localisation errors are generally due to the fact that sound sources are displaced by up to 20° towards the front which, with the circular arrangement, is explained by the off-centre listening position.

The accuracy of localisation, which is in itself more important, can be said to be very good, even in comparison with the measurements made with a natural head by Gottlob (*Fig. 10b*). In comparing the numerical values of the figure, it should be noted that when determining the inaccuracy of localisation, Gottlob made use of the 50 % interval which is narrower by the factor 0.75, so that, with equal localisation inaccuracy, his values are a little lower. The comparison of the numerical values is, however, not as important as the fact that the curves of the localisation inaccuracy, as a function of the angle of incidence, correspond.

In comparison with the location by way of an artificial-head system with loudspeaker reproduction, according to Damaske, the inaccuracy of localisation with eidophonic transmission is no greater. Towards the sides, it is even less. This is probably due to slight direction-seeking movements on the part of the observers. Although they had not actually been asked deliberately to make such movements of the head, nevertheless they had not been prohibited, because such movements must be regarded as necessary for natural listening.

Listening tests in the normal listening room ($T = 1.6$ s ; $r_h = 0.6$ m) using speech as the test signal, proved to be even more convincing. A number of blind listeners experienced no difficulty in localisation even with a strictly-circular arrangement of the loudspeakers. The virtual sound source was precise and its movements were regular. According to the test experience available so far, it would appear to be of advantage if certain disturbances of the phase-planes are produced, either by reflection or by displacement of the loudspeakers.

Eidophonic transmission from a large, reverberant studio to the anechoic listening room showed a surprising transparency of the indirect sound. Even at large source-to-microphone distances, the volume of the wanted source, compared with that of the indirect sound, appeared to be only slightly less than that of the original. To obtain the same impression of reverberation, it was necessary to reduce the distances by a factor of 0.7. Since only one plane has been scanned in the tests that have been undertaken so far, part of the indirect sound is reproduced without indication of direction so that one would expect the reproduction to be too reverberant.

The transmission of firearm shots in an anechoic environment into the normal room ($T = 1.6$ s) was convincingly realistic.

The anechoic ambience was reproduced surprisingly well within the circle of the loudspeakers ; outside this, the impression of reverberation increased appreciably. These observations are in agreement with the results of the model investigation (*Fig. 9*), as well as with those of a simple experiment in a circular tank of water. The waves emanating from a drop falling on the surface of the water near the centre, rejoin, after reflection at the wall of the tank, at the point of departure in such a manner that hardly any subsequent wave motion can be detected. The second phase — from the reflection onwards — corresponds to eidophonic reproduction with omnidirectional sound incidence.

3.2. Acoustic susceptibility of space-sound reproduction to interference

An investigation was made of the acoustic susceptibility to interference of eidophonic transmission, in particular in the space-signal spectrum (23 to 53 kHz), because the VHF/FM transmission is particularly subject to strong interference signals in that region. Logically, it was anticipated that with directional demodulation, unwanted signals would be transposed into the audio-frequency band, as occurs with the demodulation of the second channel after VHF/FM transmission, but that the effect of this interference would be different, because the noise is reproduced in the round over the entire scene.

Preliminary measurements with white noise over a range of 20 to 55 kHz (30 dB below full modulation, peak-value indication) gave an AF signal-to-noise ratio at each demodulator output of about 30 dB (filtered psophometrically). In the listening test, however, the disturbing effect of the noise seemed to be less. It dropped still further when the spectrum of the interference, with the same overall level, was restricted to the higher frequencies (40 to 55 kHz).

In order to be able to measure the reduced acoustic interference effect of the space-signal noise, it was compared with that of noise in the case of single-channel transmission. A separate single-channel installation provided an audio-frequency noise whose spectrum ressembled that which was given acoustically by the eidophony installation (by injection of noise in the space-signal range). To begin with, a point source of noise was compared with noise spread over a very wide space.

For an equal sensation of volume with eidophonic reproduction, the sound level had to be reduced on an average by 7.5 dB. On the other hand, the reproduction of equally-loud point sources of wanted modulation (speech) required the same sound level for both systems. In other words, point sources seem to be equally loud, whereas widely-distributed sources seem louder than point sources of equal intensity.

When in another test, the noise and wanted signals were compared to evaluate the disturbance of the wanted signal, it was necessary, for the same disturbing effect in the case of single-channel reproduction, to reduce the noise level by about 2 dB. In that experiment, with concentration on the equally-strong wanted signals, therefore, the point-source monophonic noise seemed louder by 2 dB than the distributed eidophonic noise. At the same time, the observers indicated that the eidophonic noise was heard only from " somewhere at the back ". Obviously, in this case the observers could concentrate better on the wanted signal. It should be borne in mind, however, that this subjective reduction in noise assumes the will for concentration, for which reason the observers considered this last experiment to be very difficult.

Even at very high levels of noise, no impairment of the direction of sound incidence of the wanted modulation could be observed. It was only when the noise was very much stronger than the wanted signal that it seemed to a few observers that the sound sources were raised in the centre.

4. Conclusion

It was stated at the beginning how important the space-related, omnidirectional reproduction of the directions of incidence of the sound is for realistic sound transmission. A new method of space-related stereophony has been described, which makes it possible, with the same transmission facilities, to broadcast the complete horizontal listening plane via VHF/FM transmitters while retaining compatibility with the existing system. The technical advantages of the new system have been described in detail.

The listening tests showed that the reproduced space sound had a satisfactory transparency which is certainly due to good omnidirectional localisation. Unwanted voltages in the space-signal spectrum produce a spatially-distributed noise signal : the subjective effect of this noise can be reduced if the listener concentrates on the wanted signal. A remarkable result of the listening tests is that spatially-wide wanted sources are heard more loudly. This may be regarded as a further important advantage of the system, in view of the limited sound isolation between adjoining dwellings.

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