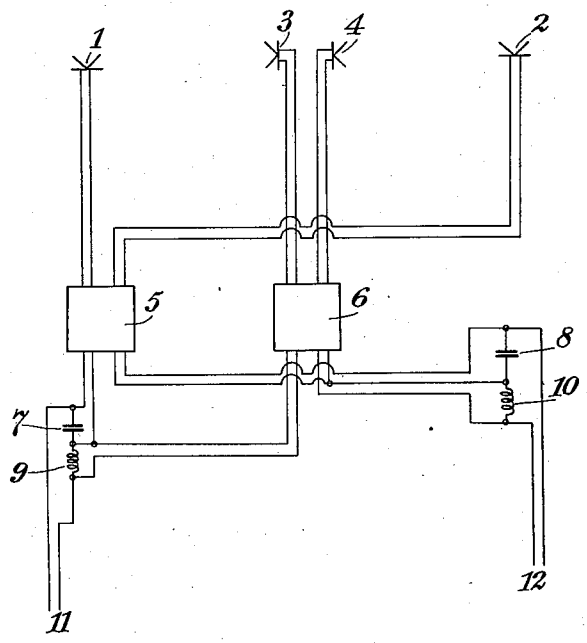
Nov. 9, 1937. A. D. BLUMLEIN 2,098,372

SOUND TRANSMISSION, SOUND RECORDING, AND SOUND REPRODUCING SYSTEM

Filed Oct. 31, 1934 2 Sheets-Sheet 1

Fig. 1.



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Fig. 2.

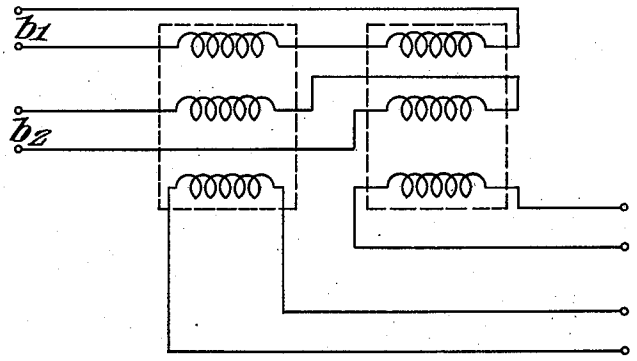


Fig. 3.

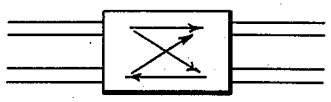


Fig. 5.

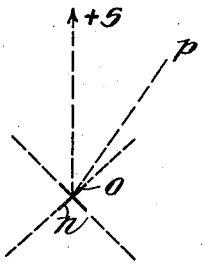


Fig. 4.

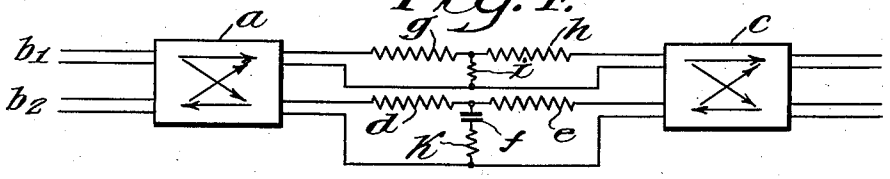
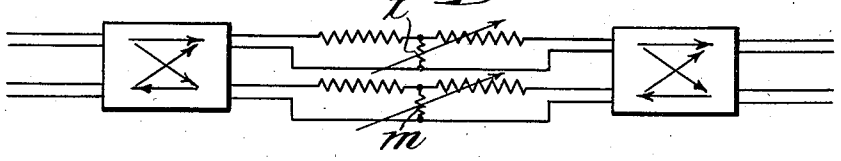


Fig. 6.



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UNITED STATES PATENT OFFICE

2,098,372

SOUND-TRANSMISSION, SOUND-RECORDING, AND SOUND-REPRODUCING SYSTEM

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Application October 31, 1934, Serial No. 750,898
In Great Britain October 23, 1933

2 Claims. (Cl. 179—1.2)

This invention relates to systems for the electrical transmission of sound, and is an improvement in or modification of the invention described in the specification of application No. 647,057 filed the 13th day of December, 1932. This prior specification describes transmission systems (including also, if desired, recording and/or reproducing stages) wherein impulses are picked up by a plurality of microphone elements and reproduced by a plurality of loudspeakers; and there are described therein means for controlling or modifying the impulses so that the sounds heard from the loudspeakers will convey to a listener a locational impression of the sound source.

One of the arrangements set forth in the above-mentioned specification for obtaining this effect and described in part more fully below comprises the use of two pressure microphones, in spaced relationship, for picking up the sounds, and network arrangements of electrical elements in the transmission circuits from these microphones, whereby phase differences between the microphone outputs are converted into differences of loudness between the loudspeaker outputs. The step of modifying the impulses to obtain the desired effect will be referred to in this specification as "shuffling", and the networks employed for this purpose as "shuffling" networks.

In connection with the arrangement referred to difficulties have been encountered in dealing with sound waves of low and very low frequencies in order to provide the effect at which the invention aims. As explained in the earlier specification the apparent direction from which the sounds reach the microphones (as determined by the relations between the impulses in the microphones) becomes ambiguous if the distance between the microphones exceeds half the wave length of the sound waves in question, and in order therefore that they may deal satisfactorily with an adequate range of frequencies (and in particular receive unambiguously the middle and high frequencies of the range) it is desirable to place the microphones close together. If this is done, however, the phase difference between the microphone outputs at low and very low frequencies (from an obliquely situated sound source) becomes very small. Theoretically this state of affairs is not unsatisfactory, but in practice it renders it necessary to make the microphones and associated circuits correctly sensitive to very small phase variations and differences, and this involves the use of large amplification (with the attendant risk of parasitic noises), and of transformers and similar apparatus designed to introduce negligible, or accurately controlled, phase changes at low frequencies. The usual types of speech range transformers employing a laminated magnetic core produce large phase shifts at low frequencies and these phase shifts are difficult to control owing to the variable nature of the transformer cores.

To overcome these difficulties it is proposed in this invention to use two pairs of microphones, one pair dealing with the lower frequencies and the other with the higher frequencies. The separation of the microphones can then be suitable for the range of frequencies dealt with by the microphones, and is not the compromise necessary when one pair of microphones deals with the whole frequency gamut.

The outputs of a pair of microphones are dealt with separately and shuffled so that a binaural effect is obtained from this pair; and similarly with the other pair. The four channels are then combined so that two loudspeakers each reproducing the whole frequency range may be used.

The invention will be more readily understood from the following description of a few forms thereof, but it must be understood that these are described only by way of example. The understanding of this description will be facilitated by reference to the accompanying drawings wherein

Figure 1 represents in usual symbols an electrical circuit forming one embodiment of the invention, and

Figures 2 to 6 represent details of arrangements suitable for the embodiment shown in Figure 1 or for various other embodiments of the invention.

Figure 1 shows two pairs of pressure microphones 1, 2, 3 and 4, arranged symmetrically about the center line or axis of the sound field, one pair 1 and 2 being widely spaced from one another and the other pair 3 and 4 being closely spaced. Separate shuffling networks 5 and 6 are provided, one for each pair of microphones, and these operate to combine the outputs of the microphones in such a way that phase differences in the outputs of the microphones over part or all of their frequency range are converted into amplitude differences.

It will now be explained how this is obtained. In Figure 2, two channels b_1 b_2, one from one microphone of a pair, the other from the other, are connected to transformer windings as shown whereby the output passed therefrom into one channel corresponds to half the sum of the initial impulses, whereas the output into the other channel corresponds to half their difference. This process is symbolized in Figure 3. As shown in Figure 4, the impulses in the sum channel are modified in amplitude only by the resistive T-network comprising series resistances g and h and shunt resistance i. The impulses in the difference channel are modified in amplitude and changed in phase by 90° by means of the network comprising series resistances d, e and a shunt condenser f. The resistance k in series

with the condenser f is inserted if it is not desired to change phase differences into amplitude differences over the whole of the frequency range of the pair of microphones. Above a certain frequency in the range, therefore, at which the impedance of the condenser is comparable with that of the resistance, the phase change is obtained to a smaller degree. The voltages at the output of the two networks are now substantially in phase and of different amplitude. A further sum and difference operation is performed by a second transformer represented in Figure 4 by the symbol of Figure 3. The final channel voltages are now in phase, but differ considerably in amplitude, and are fed to two spaced loudspeakers to give a binaural effect.

The mathematical analysis of the above exposition is as follows:—

(This analysis refers to the arrangement of two michrophones, one being referred to as the left-hand microphone and the other as the right-hand microphone, relatively to the line perpendicular to and bisecting the line joining the microphones.)

Current from left-hand microphone is defined by $A \cos (\omega t+\phi)$

Current from right-hand microphone is defined by $A \cos (\omega t-\phi)$

Where A=amplitude of an impulse from either microphone:

ω=the angular frequency of the transmitted impulses:

t=the time, measured from the commencement of the impulses:

and ϕ=half the phase difference between impulses from the two microphones.

The above expressions represent instantaneous conditions at any time during transmission.

Semi-sum of above=

$$\frac{A}{2}\cos(\omega t+\phi)+\frac{A}{2}\cos(\omega t-\phi)=A\cos\omega t\cos\phi$$

Semi-difference=

$$\frac{A}{2}\cos(\omega t+\phi)-\frac{A}{2}\cos(\omega t-\phi)=-A\sin\omega t\sin\phi$$

The electrical phase of the above two depend on the terms in ωt only and it will be seen that the two waves are 90° out of phase.

The sum channel is now modified by a multiplier "a", and the difference by a multiplier

$$\frac{\text{"}b\text{"}}{j\omega}$$

(integration).

These factors are introduced by the modifying networks shown in the two channels, and j is the usual symbol representing the imaginary quantity $\sqrt{-1}$, well known in this art.

The resultant waves will be:—

Modified sum=$aA \cos \omega t \cos \phi$

Modified difference=$-\frac{b}{j\omega}A \sin \omega t \sin \phi$

$$\frac{b}{\omega}A\cos\omega t\sin\phi$$

The final summing and differencing will give:—

Left hand channel

$$\left(aA\cos\phi+\frac{b}{\omega}A\sin\phi\right)\cos\omega t$$

Right hand channel

$$\left(aA\cos\phi-\frac{b}{\omega}A\sin\phi\right)\cos\omega t$$

These two waves are electrically in phase but differ in amplitude in dependence on ϕ, i. e. depending only upon the initial phase difference of impulses from the microphone.

Suppose now that the distance apart from the microphones be y which is assumed small compared with the wave length. If the sound be incident at an angle θ to the line joining the microphones, the outputs of the two microphones will have the time difference

$$\frac{y\sin\theta}{c}$$

where c is the velocity of sound. This is equivalent to an electrical phase difference of the two microphone outputs of

$$\frac{\omega y\sin\theta}{c}$$

This phase difference is equal to 2ϕ. Now if the wave length is long compared with y, this phase angle will be small, so that $\cos \phi$ will equal unity and $\sin \phi$ will equal

$$\phi=\frac{\omega y\sin\theta}{2c}$$

The expression for the left hand channel output now becomes:—

$$\left(aA+\frac{b}{\omega}A\cdot\frac{\omega y\sin\theta}{2c}\right)\cos\omega t=A\left(a+\frac{by}{2c}\sin\theta\right)\cos\omega t$$

and similarly the expression for the right hand channel is the same with the sign reversed.

From the above it will be seen that the ratio of the amplitudes of the two channels is independent of ω, but depends only on θ, the direction of arrival of the incident sound.

Referring again to Figure 1, it will be seen that impulses from a pair of microphones (say microphones **3** and **4**) pass to a shuffling network (**6**) which may comprise, for example, an arrangement identical with that shown in Figure 4 described above, and from the above analyses it will also be seen that, on account of the two summing-and-differencing operations with the intervening modifying networks in the shuffler, the impulses further transmitted to the loudspeaker channels, **11** and **12**, are in phase and differ in amplitude by an amount depending solely on the orientation of the sound source with respect to the line joining the microphones. Similarly the impulses from shuffler **5** originating from microphones **1** and **2** are in phase, and differ in amplitude by an amount depending upon the position of the sound source relative to the microphones. This is a condition required in the case of each pair of microphones, according to the invention in order to provide a binaural sensation to a person listening to the loudspeakers.

It will be clear from the above analysis that by choosing the value of the shunt resistance i in the summation channel and the shunt condenser f in the difference channel for a given frequency, any degree of amplitude difference in the final channels can be obtained for a given phase difference in the original channels. For the low frequencies it can be shown that the phase difference between the waves will, for a given obliquity of the sound source, vary proportionately with frequency, being very small for a very low frequency. Thus, for a given obliquity of the sound the current in the difference channel after the first sum and difference operation will be increasingly great compared with that in the summation channel the higher the frequency. Hence the use of a shunt condenser f where impedance decreases

with frequency in the difference circuit will have the desirable effect of producing a fixed intensity difference in the final channels for a given obliquity at all low frequencies, as well as the effect of changing the phase by 90°.

It will of course be understood that the arrangement described above is not the only possible arrangement for achieving the desired effect, and various other networks may be employed as desired to attain the desired result.

Referring again to Figure 1, 5 and 6 represent each a complete shuffling network such as illustrated for example in Figure 4, and while 5 converts phase differences between microphones 1 and 2 into amplitude differences in the output channels, 6 operates in the same way upon impulses from microphones 3 and 4.

From the explanation given above it will be clear that the closely spaced microphones 3 and 4 while being suitable for dealing with middle and high frequencies are not entirely satisfactory as regards low frequencies on account of their closeness to one another, while the widely spaced microphones 1 and 2 although convenient for low frequencies introduce ambiguity in the directional impression which they provide as regards medium and high frequencies. For this reason the closely spaced microphones 3 and 4 and their associated shuffling network 6 are arranged to deal mainly or entirely with medium and high frequencies and no attempt is made to obtain separation of the low frequencies. The widely spaced microphones 1 and 2 and their associated shuffling network 5 on the other hand are arranged to deal mainly or entirely with low and very low frequencies, but no separation of the higher frequencies is obtained. The arrangements employed for rendering the microphones operative over portions of the frequency range may be of any convenient kind such, for example, as those which have been used for a similar purpose in connection with loudspeakers, and may comprise adaptation of the mechanical characteristics of the microphone, and/or of the electrical characteristics of the microphones or their circuits (e. g. by adding filter networks).

The voltages from the shuffling networks transformed or assumed transformed to a common impedance (of value R) are fed (after further amplification if necessary) to two loudspeakers which are common to the two networks. Two pairs of leads, as shown, connect each shuffling network one to each loudspeaker and the pairs of leads from the high frequency shuffling network 6 (i. e. the network associated with the closely spaced microphones) are, in each case, shunted by an inductance 9 and 10, while the pairs of leads from the low frequency shuffling network 5 are in each case shunted by a condenser 7 and 8. The leads to each loudspeaker are connected to the outer terminals of the appropriate inductance and condenser, which thus remain in series as a shunt across the loudspeaker. Thus condenser 7 and inductance 9 are in series with one another as a shunt across the leads 11 going to one loudspeaker while condenser 8 and inductance 10 in series form another shunt across the leads 12 to the other loudspeaker. The relative values of the inductances and capacities to be employed are determined by the equation

$$\sqrt{\frac{L}{C}} = R$$

where L represents the value of the inductance, C the value of the capacity and R the value of the impedance (referred to above) in any consistent system of units.

It is to be understood that frequency discriminating networks may be employed having any convenient form, and may be quite different from those shown. For example, sharp selective high-pass and low-pass filters may be used, or any other electrical change-over circuit. Such frequency discrimination elements may be inserted within the "shufflers" and the channels may be mixed if desired before the final summing and differencing operation. It is, however, preferable that the discriminating networks which apply to the two channels be similar to one another.

The sense of poling of the connections is such that in a uniform "face on" sound field the contribution from the widely spaced microphones 1 and 2 is added to that from the closely spaced microphones 3 and 4 in the correct phase at the points of junction so that a uniform response to such a wave is obtained throughout the full frequency range. In order to achieve this, it is necessary to arrange that the relative efficiencies of the portions of the system between a microphone and the output terminals of its shuffling network shall be of the same value in each case. The values of the inductances and condensers are chosen so that low frequency impulses are received from the widely spaced microphones, and the medium or high frequency impulses from the closely spaced microphones.

It will be clear that a number of modifications may be introduced into a system of the character described above. For example, in place of two pairs of microphones three pairs may be employed, the third pair being of very small size and placed very near together (between the pair 3 and 4 previously referred to as closely spaced). These additional microphones operate, and are connected to a shuffling network operating, mainly or entirely in respect of very high frequencies, and their outputs would be "mixed" with the outputs from the other microphones in the manner described above. For example, in the above described system the "loudspeaker" leads 11 and 12 (carrying the combined impulses from the low, medium and high frequency microphones) may be shunted by condensers (smaller in value than the shunt condensers used on the low frequency leads alone), while the leads carrying the shuffled outputs from these additional, very high frequency microphones may be shunted by small inductances, these added condensers and inductances being in series as before and acting as a shunt across the final loudspeaker leads which are connected to their outer terminals.

In any of the systems described above any pair or pairs of microphones may be replaced by directionally sensitive microphones or microphone elements (e. g. velocity microphones), the outputs of which will not generally be shuffled to convert phase differences to amplitude differences (although this may be effected if desirable), but modifications may be effected to increase or decrease the amplitude differences. Such arrangements for using directionally sensitive microphones are described in the abovementioned specification No. 647,057 filed the 13th day of December, 1932. If a pair of pressure microphones be replaced by velocity microphones the spacing between them need not be maintained, and the velocity microphones may be brought close together. For example in the systems described above the low and middle frequency

sounds may be picked up by one or two pairs of pressure microphones provided with suitable shuffling networks, and the high frequencies by two velocity microphones or microphone elements arranged close together, or (e. g. in the case of strip microphones) in line one with the other, their axes of maximum sensitivity being suitably inclined to one another in the manner described in the abovementioned specification.

An arrangement of this kind is illustrated in Figures 5 and 6 extracted from said prior specification. In Figure 5 *n* and *o* represent in plan the strip elements of two velocity microphones placed one above the other in line perpendicular to the paper. Since these strips are colinear with one another no phase differences between their outputs occur, but as a sound source moves from the centre of the sound field *s* to a position *p* the difference between the amplitudes of their outputs varies with direction of the sound source. When these amplitude differences are to be augmented, as explained in the earlier specification a shuffling network of the kind shown in Figure 6 is appropriate. This is substantially identical with that shown in Figure 4 except that the shunt condenser *j* and resistance *k* in series, and the shunt resistance *i* are replaced by shunt resistances *l m* which are preferably variable as shown. These lines therefore form artificial attenuators and by altering their relative attenuation the intensity differences in the two lines corresponding to a given obliquity of sound are controlled.

The invention is not limited solely to the arrangements described above since various modifications may be introduced as they become necessary or desirable in order to carry the invention into effect under different conditions or requirements which have to be fulfilled without departing in any way from the scope of the invention.

Having now described my invention, what I claim as new and desire to secure by Letters Patent is:—

1. In a system of sound transmission comprising a plurality of microphones connected to a plurality of loud speakers, two comparatively closely spaced microphones adapted to pick up high frequency sounds, two more widely spaced microphones adapted to pick up sounds of lower frequencies, and means in the circuits from each pair of microphones adapted to transmit differences of phase between the impulses received from the microphones, over at least part of the frequency range being dealt with, as differences of loudness in the loud speakers.

2. In a system as claimed in claim 1 a plurality of loud speakers each connected to receive impulses from the circuits of the high frequency and also of the lower frequency microphones.

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