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(54) **Device for the spatial codification of sounds.**

(57) Device for the spatial codification of sounds comprising a microphonic support shaped like a human head, equipped with auricles and internal cavities which faithfully reproduce the auditory meatus, the Eustachian tubes and the oral cavity, as well as with a wig which provides asymmetry for front and back discrimination and with two microphones arranged in the meatus cavity in the exact position and orientation as the eardrum and in communication in the back with the cavities acting as the Eustachian tubes. The oral cavity is in communication with the outside.

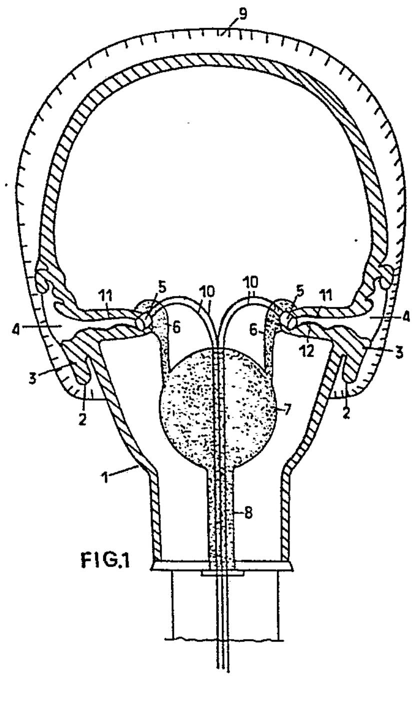

FIG.1

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Croydon Printing Company Ltd.

Device for the spatial codification of sounds

This invention concerns a device for spatial codification of sounds which may be defined as 'holophonic' in analogy with holography. In particular, the invention allows direct recording or transmission of stereophonic sounds, so as to give the listener effective spatial and true stereophonic dimension rather than a bidimensional one.

Up until now, stereophonic recording was done by placing two or more microphones in strategic points and recording on a record or tape two separate tracks which are then reproduced through two strategically placed speakers.

Other so-called 'binaural' systems place objects shaped like the human head between two panoramic microphones, so as to artificially create an acoustic shadow to separate the two stereo channels.

Another existing device consists of an artificial head equipped with internal microphones placed in the base of the neck so as to obtain a limited and imperfect sound prospective which may furthermore only be appreciated by using ear phones.

With the above systems, while there is a sensation that the recorded reproduction is spatial, in reality said systems only offer a bidimensional sensation of the sound, depending on the given timbre or instrument heard from the right or left speaker, each of which produces its own track.

This is explained by the fact that according to the physical laws of hearing, the human ear may be considered as a system in which a stimulus enters and a sensation exits, and the auricle of the ear acts as a collector of sound energy, concentrating it in the meatus and sending it to the eardrum in the form of resonant pressures.

The fruit of in depth research and study, the present invention gives another interpretation of the way in which sound energy is transmitted to the hearing organ and, starting from this interpretation, develops a recording system which is able to give a true stereophonic perception of the sound transmitted.

To introduce in a sufficiently clear way the holophonic recording mechanism of the device covered by this invention, a brief discussion of some fundamental concepts of the physics and anatomy of hearing is given below. The theory leading to the conception of the system according to this invention is also illustrated.

An examination of the hearing organ shows that it must analyze information from sound sources using its own mechanism. In animals in general, the hearing organ dynamically analyzes sound information by the sensorial effect of the entire body as well as by spatial codification through the auricles. On the other hand, in man, the most highly evolved animal with the most perfect hearing organs, this organ only performs an instantaneous statistical analysis of the sound information, which thus also instantaneously gives the position of the sound source with respect to the listener. According to this invention, this mechanism of analysis has been found to conform to laser holography, that is, to holography of sound.

As is known, laser holography consists of the formation and photographic impression of a diffraction figure formed by two laser rays (that is, by coherent light) coming from the same source. One of these is reflected in a mirror and impinges directly on the photographic plate, while the second directly illuminates an object and is then reflected by it. The two rays hit the plate with different angles and optical paths and so interfere with one another. This interference leads on the plate to a very complex pattern of light and shadow which however contains all the spatial information of the holographed object. Recomposition of the refraction pattern with an analogous technique gives rise to a spatial image of the object. Therefore, a person seeing this spatial image has the complete sensation of observing the original, not only its shape but also its volume.

To further clarify the inventive concept, a brief description of holography in water waves is in order. If a stone is dropped into a mirror of calm water, concentric circular waves are produced which expand until they finish. If these waves meet an obstacle, they are reflected to give rise to other waves which interfere with the original ones to form interference patterns.

While these interference patterns seem disordered, they contain a series of information like a hologram. Thus, this series of information can give the shape of the reflecting surface of the obstacle. If an obstacle is shaped symmetrically, it will give a symmetric interference pattern. However, this pattern gives incomplete information since there are two images possible, one re real one and one completely analogous but rotated 180°. Therefore, the real position of the wave source cannot be part of this information. For an asymmetric reflecting surface, however, there is one and only one possibility of spatial reconstruction. Of course, the interference pattern will also be asymmetric and will be unequivocal in that the exact position of the wave source may be determined. Note that as in laser holography, the interference pattern is a formation of points, each one of which contains the information of the entire hologram. That is , a suitably programmed computer could reconstruct the entire hologram with the information contained in only one of its points.

The above is the theory on which the present invention is based; it shows the functional ineffectiveness of classic stereophony, that is, the lack of 'depth' in conventional two track recordings. In fact, when a classic recording of this type is made, one notices that it cannot discriminate sound coming from two different points, given that the microphone does not have enough asymmetry to produce an unequivocal interference pattern. Therefore, the listener of a classic stereo recording only gets the sensation of right-left discrimination and not, for example, up-down.

Thus an asymmetric reflecting surface is required for there to be spatial discrimination of sound. According to the invention, it may be shown that the auricle of the human ear is such a surface. The ear is in itself the synthesis of perfection never before developed, a sublime and extremely precise work of engineering. Its morphological dimensions are such that it forms almost a complete spiral, up to half of the third quadrant before starting to decrease. Therefore, in light of the above discussion, the auricle of the ear shows total asymmetry; in front of a wave source of a given frequency both the ears and the head of the listener give rise to the interference patterns necessary for spatial analysis, but it is the auricle itself which gives the most valuable information. In fact, the longer vertical dimension allows the auricle to spatially perceive low frequency waves (on the order of 1400 Hz), while the shorter horizontal dimension allows the perception of high frequencies up to 3400 Hz.

The research performed for this invention also showed that hair is of considerable importance in spatial discrimination, allowing a precise perception of sound coming from the front or the back by giving rise itself to an asymmetric hologram. In fact, bald persons have been observed to have somewhat reduced front-back discrimination along the axis of symmetry of the head.

On the basis of these considerations, a holophonic recording system was developed characterized by the fact that it involves a microphonic device shaped like a human head, equipped with auricles and internal cavities which faithfully reproduce the shape of the auricle, the auditory meatus, the Eustachian tubes and the oral cavity, as well as a wig which serves to generate asymmetry for front-back discrimination and two microphones placed in cavity acting as auditory meatus, in the exact position and orientation as the eardrum and in communication in back with the cavities acting as Eustachian tubes. The oral cavity is in communication with the outside.

In particular, the microphones have a cardioid-shaped membrane no smaller than 7mm.

The cavity acting as auditory meatus is in the shape of an elliptical section cylinder twisted on its axis so that the wall (which is behind the internal orefice) inclines gradually so as to become lower-back, while the upper part becomes upper-back.

The cavity acting as auditory meatus preferably has an average length along its axis of 24mm, the first eight of which are made of the same material as the auricle. The other 16 have a covering layer of more rigid material, so as to simulate the fibro-cartilaginous (8mm) and the bony portions (16mm).

Obviously, the cords for the two microphones pass through the oral cavity and come out through the outside opening.

Furthermore, in the process of recording and reproducing sound, one always tries to use transducers (microphone and speaker) as linear as possible through the frequency range audible to the human ear. Even though the microphone - amplifier - speaker chain is almost perfect today, when the sound of a single sound source (for example, a violin) is to be reproduced, the reproduced sound is always much different from the original. Most of this difference is not due to the microphone, amplifier or speaker, but rather to our ear. In fact, even though the microphone faithfully recorded the acoustic signal and the speaker faithfully reproduced it, the result is quite different from what oru ear hears when we listen to the live performance. This is because the microphone does not pick up the acoustic signal the same way our hearing system does.

The two ears that are the basis of our auditory system enable us to distinguish the source of the sound. But the sound itself (for example, the violin) does not come from one point but rather a collection of points. Moreover, the room where we are, which reflects the sound generated by the violin, in turn generates a collection of sounds which are perceived by our hearing system to arise from a space outside the area of the primary sound source (in this case the violin).

While the ear distinguishes without difficulty the innumerable, different sound sources, the microphone sums them up. It is precisely this sum which we hear from the speaker, which in turn becomes a single sound source.

Anyone who has recorded an acoustic signal in a non-acoustically correct room has noted that the effect of the room, including outside noise, is much more apparent heard through the microphone than upon direct listening. Therefore, for a recording to be as close as possible to reality, it is very important to have this spatial sound discrimination through the microphone as well. Furthermore, the acoustic signal picked up by the microphone is different from the original also because the waves reflected by the walls are added to the direct signal from the sound source, sometimes in phase and sometimes not, depending on the distance travelled and the wavelength of the signal itself. The same phenomenon is even more accentuated where there are several sound sources, as in an orchestra.

In stereophonic recordings on two separate channels, the quality of the sound reproduced is much higher than that of monophonic sound. This is because the signals picked up by the left and right microphones are different from one another. By listening to the two signals with the right and left ears, using two suitably positioned speakers, we have a spatial auditory sensation. This however is limited to the frontal face that combines the two speakers in front. Even this procedure lacks high-low and rear information, however.

Lengthy study and experimentation has shown that the human auditory system must be reconstructed in order to obtain holophonic sound reproduction. In fact, before arriving at the eardrum membranes, sound undergoes different delays and deflections from one ear to the other, depending on the source of the sound itself. Especially for frequencies above 1000Hz, these lead to different response curves for different positions of the sound source and to phase displacements which make a code of a sort through which the brain can determine the source of the sound. The particular shape of the human auditory duct must be remembered - there are various curves and two resonance frequencies around 2500Hz and 7500Hz. These resonances must be eliminated in recording sound, since they are already present in the ear and would be reinforced by an ear-shaped microphone as well. To this end suitable filters have been made (which may be either electronic or acoustic, in the latter case they are placed near the microphone membrane) to remove these damaging resonances.

The invention is described below in one preferred form, given only as a non-limiting and illustrative example, referring to the attached drawing in which:
figure 1 is a longitudinal section made in correspondence with the auditory meatus cavity, of the recording system according to this invention;
figure 2 is a transverse section of the portion acting as auricle and auditory meatus.

As shown in the drawing, the holophonic recording system involves a microphonic support 1 shaped like a human head. This support is preferably made of plastic material like polystyrene and has two ears 2 with an auricle 3 which faithfully copies the auricle of a human ear. Each auricle 3 has a cavity 4 shaped exactly like the auditory meatus, at the bottom of which a microphone 5 is placed in the same position and orientation as the eardrum of the ear. The rear face of each microphone 5 is in free communication with a tubular cavity 6 which faithfully reproduces the shape of the Eustachian tubes. These cavities 6 are in communication with a central cavity 7 which faithfully reproduces the shape of the oral cavity and which is in communication with the outside through a tubular cavity 8. Auricles 5 and the first 8mm of the auditory meatus (24mm long) are preferably made of rubber, while the remaining 16mm has an interior layer of plaster or the like 11, to simulate respectively the fibro-cartilagenous and bony portions of the middle ear. The top is covered with a wig 9 to generate the desired asymmetry front to back. Wires 10 of the microphones come out of tubular cavity 6, enter central cavity 7 and go outside through tubular cavity 8. To eliminate the so-called 'pop' effect found with usual microphones (usually covered for this purpose with a porous material, generally stretched polyurethane), the human ear and therefore the system according to this invention have in the meatus a sharp dilation 12 which acts like the muffler of an internal combustion engine. Therefore, the microphones may be exposed to the external area without showing this effect. Microphones 5 have a cardioid membrane no smaller than 7mm, preferably delineated by the external covering of the microphone which has an opening this shape. Cavity 4 acting as the meatus has a section of an elliptical section cylinder with a torsion on its axis such that the wall in correspondence with the external orefice is anterior, inclining gradually so as to become lower front, while the posterior wall becomes upper rear. The flatter the former, the more highly convex is the latter.

While in laser holography two different rays are made to interfere, one known and the other reflected by the object, in holophony the known sound is that created in the reflection of the signal in the personal anatomical configuration.

With the present system, reproduction of a magnetic tape recroding on a conventional stereo system allows the listener to mentally reproduce how the recording was made in a studio, independently of the hearing sense. In this way, even if two listeners are facing one another, they will have the front-back sensation in the exact sense in which they are arranged. It is interesting to observe that it is not necessary to put the acoustic boxes in a pre-fixed position, since their sound has already been codified and this information cannot be altered.

With regard to the sensation of the height of the sound, starting from the studies of Stevens and Wolkmann and from their diagram which shows that frequencies below 500Hz are linearly dependent on the height of the sound and then show curvature, the theory developed for this invention can interpret these studies. In fact, since it is known that a wave of a certain frequency will be reflected only by an obstacle whose physical size is on the order of 1/4 of the wavelength, there are frequencies to which the auditory system (ears and head) is indifferent. These sounds are thus not altered or codified, that is, they cannot be spatially identified and so have a completely linear frequency-height relationship.

The critical measurements of the entire external auditory system are 20cm for the head (equal to a frequency of 450Hz) and 6cm for the ear (equal to a frequency of 1400Hz). Above these frequencies, anomalies are to be expected arising from the cancellation, due to the interference patterns created near the ear.

Furthermore, as mentioned above, the existence of a spatial code allows the brain to interpret the source of the sounds reaching it. Thus, once the device according to this invention is built, in complete analogy with the human auditory system, all the details of this code may be studied.

In this way, it may be shown on an oscillograph that independently of the presence of two ears, for each spatial position there is a striking variation of the response curve of the auditory system, in addition to a phase displacement of the harmonics with respect to the fundamental sound.

In fact, if the frequency response curve of the human head is measured, it will correspond to that of the device according to this invention, as precisely as the anatomical characteristics are respected in its construction. Experiments have shown that the curves traced with sounds coming from the sides of the device resemble the mean normal audiogram known to all who study physiological acoustics. Furthermore, said curves show a striking drop corresponding to low and high frequencies and two resonance peaks at 2500Hz and 7500Hz, corresponding to the 1st and 3rd resonance frequency of the auditory system.

Measuring the other characteristic curves corresponding to the front, rear, top and other positions shows that siad curves differ considerably from those obtained laterally, especially at the ends - from the front high sounds are richer, from the rear low sounds. Therefore it is to be expected that in listening to spatial information some parameters are modified, thus marring the recording.

This negative aspect may be eliminated by cancelling the resonances in a known fashion with suitable filters and by using octave amplifiers for the missing low and high frequencies.

The use of an equalizer will thus create optimal conditions for the listener.

With regard to the phase displacement of the harmonics with respect to the fundamental, a dynamic analysis of a sound composed using this invention reveals a delay of some upper frequencies while the low frequencies remain stable on the oscillograph.

The phenomenological interpretation is simple, arising from consideration of the various paths taken by sounds of different frequencies making up the sound:

- for low frequencies, it is as if the auditory membrane were exposed to a free field, given that after a determined wavelength, the information passes over the body as if it weren't there, with the exception of any quenching or contributions of the cranial cavity or the internal echo chambers;
- rather than following the direct path, the upper frequencies bounce several times in the auditory meatus reproduced in the device, so that arrival at the microphone placed in the eardrum does not occur at the same time for all frequencies. Moreover, the two different spatial positions do not have the same delay. Obviously this enriches the complete spatial code.

Consequently, the speakers must be placed in strategic points so as to avoid sizeable modifications of the original phase displacement.

Also, all pertinent technical expedients should be used to respect all the phase codes during electro-acoustic transduction, that is, to use acoustic boxes with phase correction or a single speaker of the extended range type.

Obviously, the device according to this invention, with spatial codification of sounds, may be used in the same way in direct transmissions in addition to recordings.

Claims:

1. Device for the spatial codification of sounds, called holophonic by analogy with holography, able to record or directly transmit stereophonic sounds with an effective spatial dimension.

2. Device for the spatial codification of sounds, with a microphonic support 1 shaped like a human head equipped with auricles 3 and internal cavities 4, 6 and 7 which faithfully reproduce the shape of the auditory meatus, the Eustachian tubes and the oral cavity, respectively, as well as a wig 9 to generate asymmetry for front-back discrimination, plus two microphones 5 placed in cavity 4 (auditory meatus) in the exact position and orientation as the eardrum in communication at the back with cavities 6 (Eustachian tubes); oral cavity 7 is in communication with the outside.

3. Device for the spatial codification of sounds wherein cavity 4 (auditory meatus) is in the shape of an elliptical section cylinder twisted on its axis so that the wall which is behind the internal orefice inclines gradually so as to become lower-back, while the upper part becomes upper-back.

4. Device as claimed in the preceding claims, wherein the cavity 4 acting as auditory meatus has an average length along its axis of 24mm, the first eight of which

are made of the same material as the auricle and the other 16 of which have a covering layer of more rigid material, so as to simulate the fibro-cartilaginous and the bony portions, respectively.

5. Device as claimed in claim 1, wherein haed-shaped support 1 is made of rubber or plastic materials.

6. Device as claimed in the preceding claims, wherein cavity 4 acting as auditory meatus has a brusque dilation 12 to eliminate the so-called 'pop' effect, as in a real auditory meatus.

7. Device as claimed in the preceding claims, wherein the phase displacement of the harmonics with respect to the fundamental is corrected using acoustic boxes with phase correction or speakers of the extended range type.

8. Device as claimed in the preceding claims, wherein an equalizer is used to cancel all possible variations of the frequency response curve.

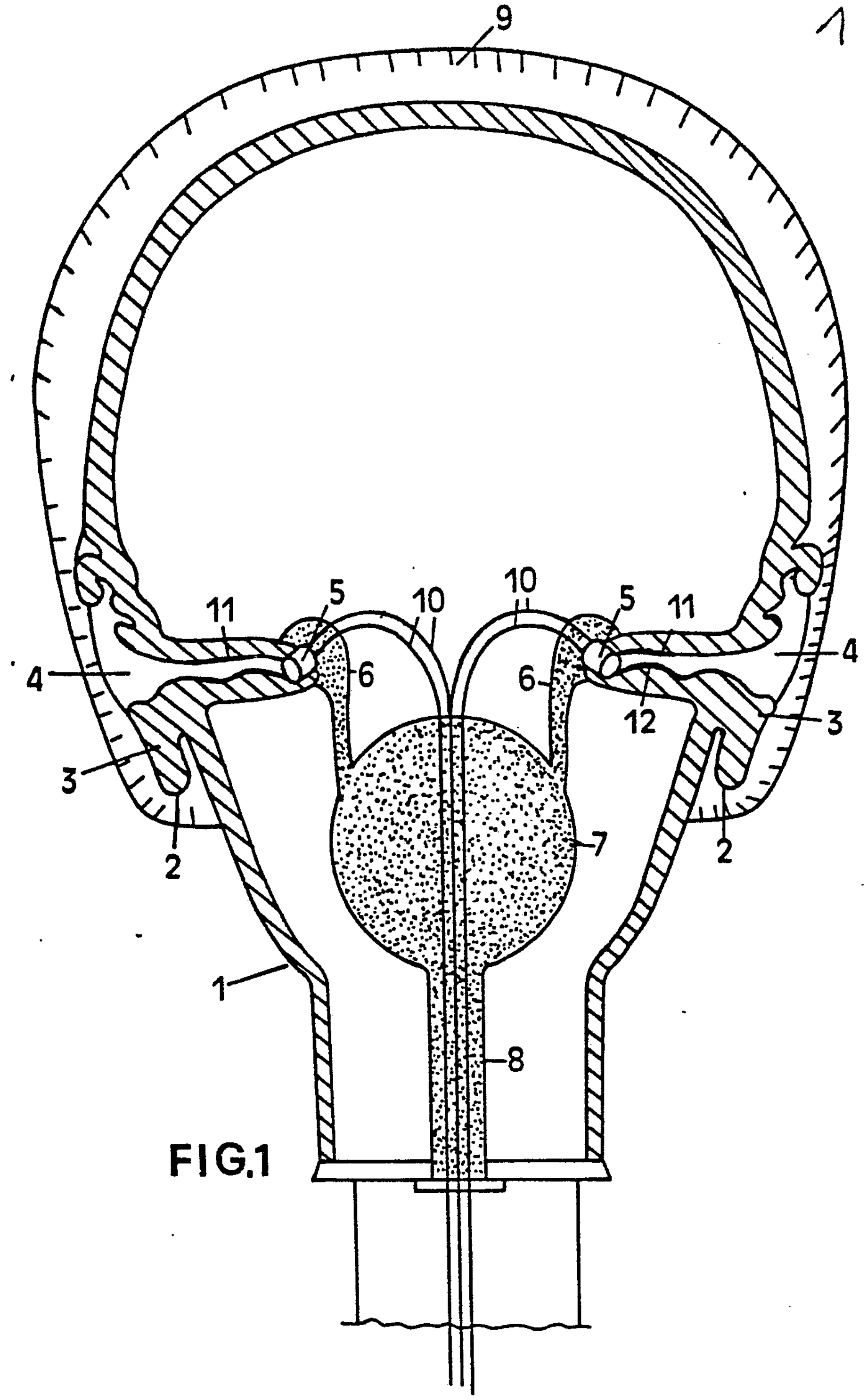

FIG.1

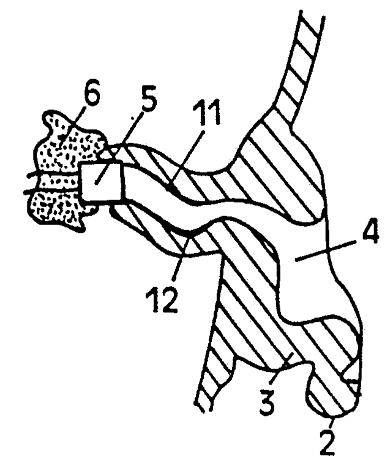

FIG.2