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(54) **Stereophonic sound reproduction in motor vehicles**

(57) To improve the stereophonic effect in motor vehicles a summation signal M may be fed to a central loudspeaker M' at the front of the passenger compartment of the vehicle, and/or a difference signal $S=L-AR$, $S=R-AL$, may be fed to one or more loudspeakers HL, HR at the rear of the passenger compartment.

The difference signals may be delayed. Also, a bass and mid-range summation signal may be fed to a central loudspeaker at the rear of the passenger compartment. In the latter case the difference signal is fed to a single rear speaker which has a figure-of-eight radiation characteristic, the primary emission direction being oriented horizontally and at right angles to the longitudinal axis of the vehicle.

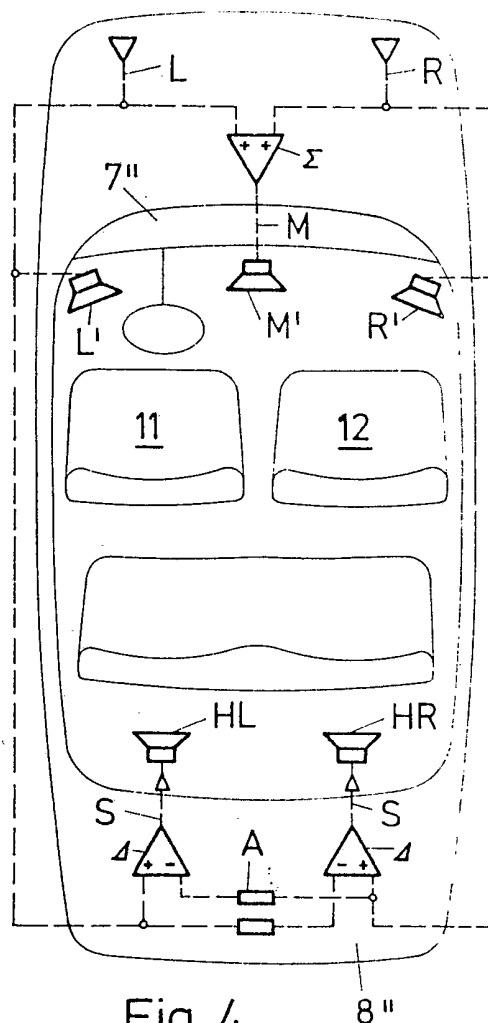


Fig. 4

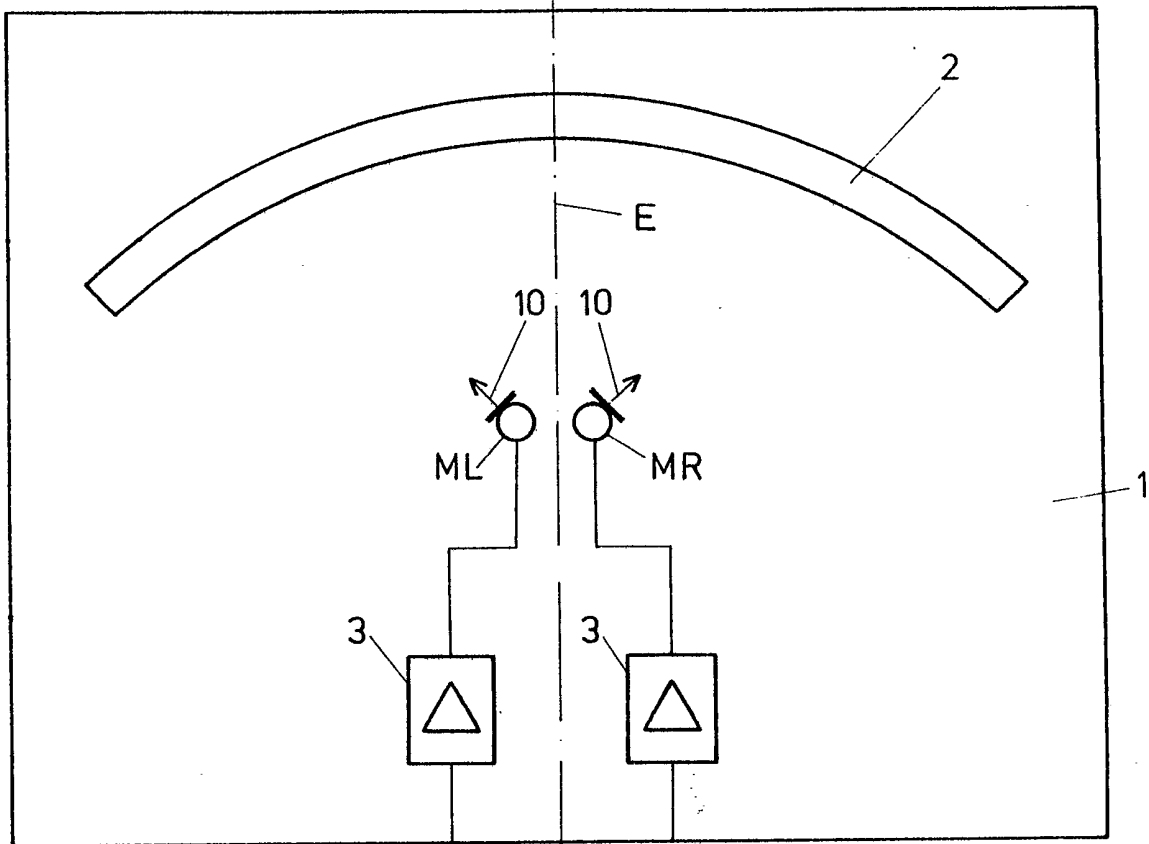
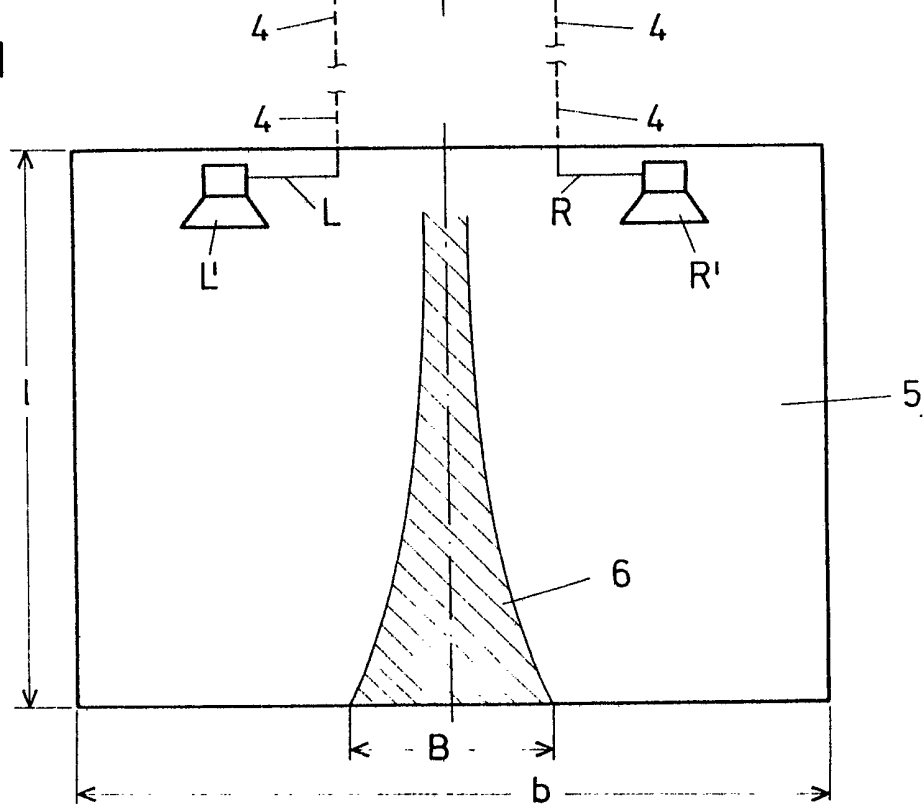


Fig. 1



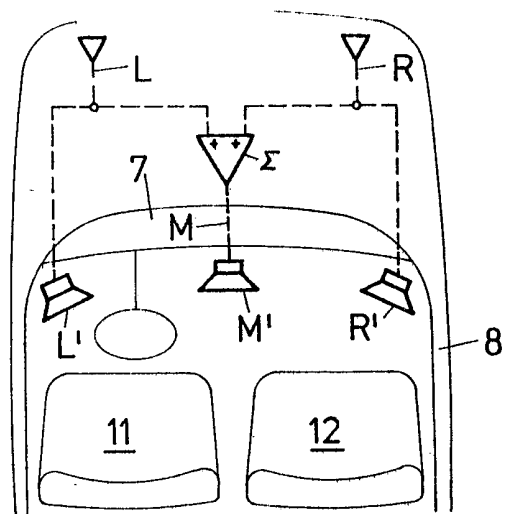


Fig. 2

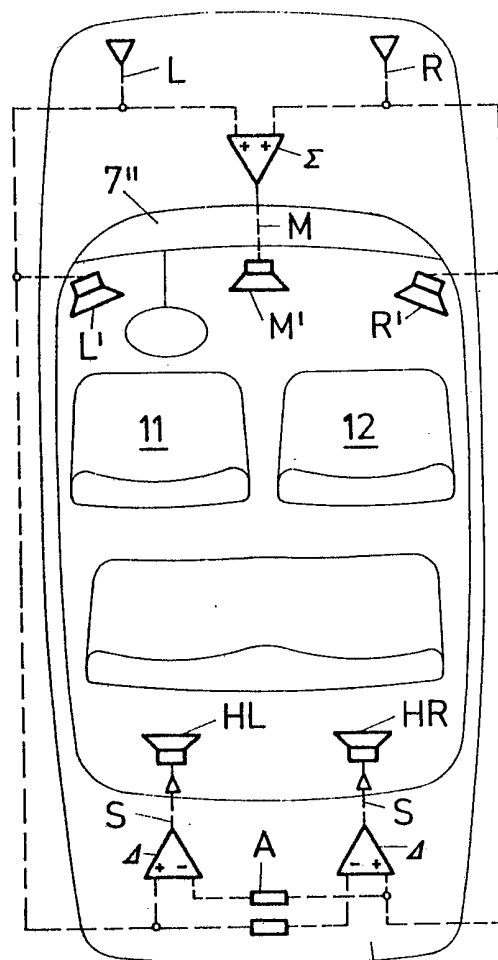


Fig. 4

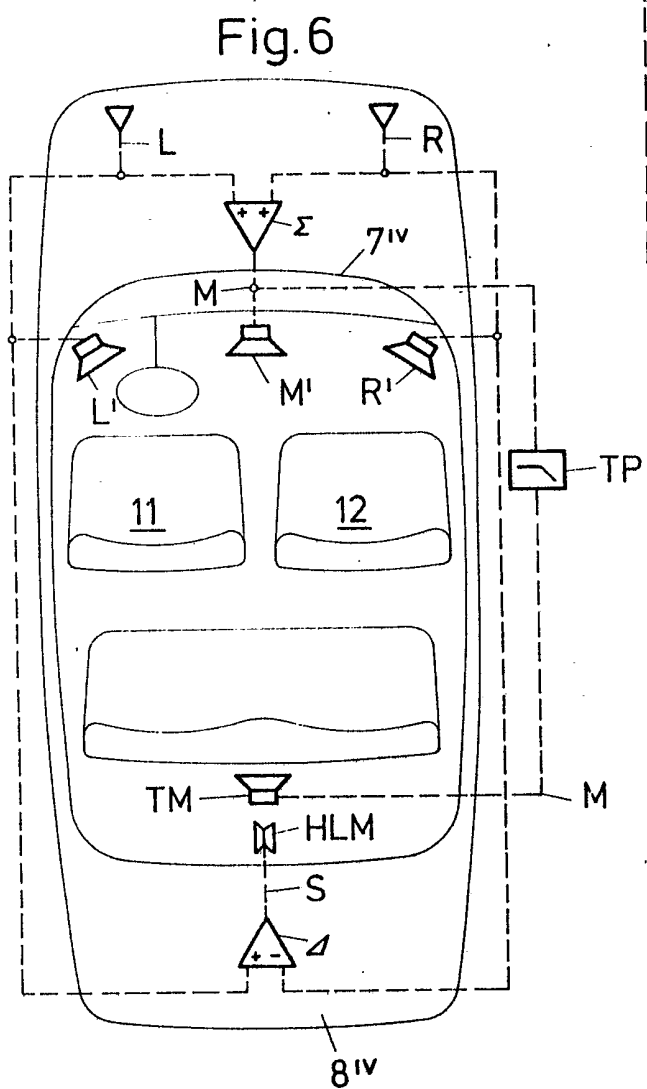


Fig. 6

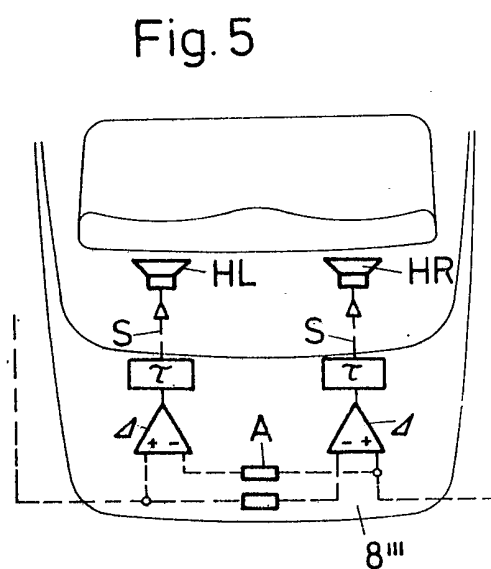


Fig. 5

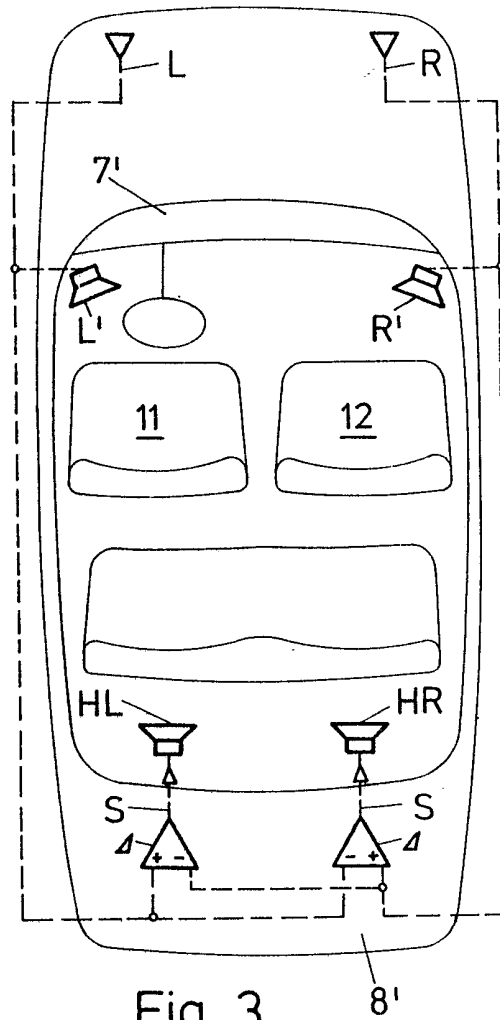


Fig. 3

SPECIFICATION

Stereophonic sound reproduction in motor vehicles

The invention relates to a method for the
 5 stereophonic reproduction of acoustic phenomena
 in the passenger compartments of motor vehicles,
 especially of motorcars, and to a stereophonic
 reproduction installation with at least one
 10 receiving unit and/or reproducing unit and several
 loudspeakers, at least two loudspeakers spaced
 apart from one another being provided in the
 close vicinity of the driver's and/or passenger's
 seat, one of which loudspeakers serves for the
 reproduction of the left-hand signal and the other
 15 loudspeaker serves for the reproduction of the
 right-hand signal.

By the electro-acoustic recording, transmission
 and reproduction of an acoustic phenomenon
 from a recording room into a reproduction room
 20 *via* two channels, it is well known that it is
 possible to convey directional impressions and to
 produce, on the reproduction side, a spatial
 sound impression, corresponding to the ability of
 man to hear spatially with both ears.

By means of this so-called stereophony, it is
 possible for example to locate sound sources
 according to direction and distance in the
 reproduction room or to sense a sound-emitting
 body in its spatial disposition. The simplest
 30 transmission device for such a stereophonic
 system comprises two directional microphones,
 the primary sensitivity directions of which form an
 angle of about 90 to 120°, in which case the
 plane of symmetry of this microphone
 35 arrangement and of the sound-emitting body to
 be recorded approximately coincide, and a
 transmission device with corresponding stores,
 multiplex parts, amplifiers, decoders etc., and also
 two loudspeakers disposed at a distance from one
 40 another. The stereophonic effect is thus based on
 the fact that for each sound incidence direction
 each frequency group of the original sound source
 between the two channels there is a particular
 level difference and, accordingly, at the listener's
 45 location there is a particular acoustic-pressure
 difference for the sound originating from the
 right-hand and left-hand speaker respectively. The
 ear then associates this pressure difference with a
 particular direction, according to which it localises
 50 this so-called phantom sound source. In addition,
 however, in an objective case of less importance
 the ear also makes use of time-lag differences for
 the purpose of localisation, in which case it is
 necessary, however, for the recording
 55 microphones to be spaced from one another.

It is evident from this that satisfactory
 stereophonic reproduction can only be
 accomplished within a particular area zone
 between the two loudspeakers, i.e. the so-called
 60 stereophonic auditory area, which is determined
inter alia by the fact that the pressure differences,
 which are produced *a priori* because of the
 difference in distance of the listener from the two
 loudspeakers by the natural acoustic-pressure

65 drop in emission, do not exceed a certain
 minimum and thus mask the necessary
 differences present for the spatial auditory
 impression.

If the situation in a motor vehicle is now
 70 visualised, in which the loudspeakers, dependent
 upon the structure, are necessarily mounted near
 to the driver or to the passenger, it readily
 happens that both of these listening sites, as well
 as generally the sites at the rear seats, lie outside
 75 the aforementioned stereophonic auditory area
 and, therefore, a satisfactory stereophonic
 reproduction is excluded from the outset, because
 of the prevailing asymmetry.

Another difficulty is the fact that the interior of
 80 a motor vehicle is generally very small and is very
 heavily damped. Therefore, initially it is not
 possible to develop in a motor vehicle a
 reproduction acoustic field which comes fairly
 close spatially and temporarily to the original
 85 acoustic field. The development of such an
 acoustic field is at once more readily possible in a
 room of a building. Above all, after the direct
 sound in time sequence it has a greater number of
 reflections which originate from the boundary
 90 surfaces of the room, which give information on
 the size of the room and then, becoming
 increasingly close, merge into diffuse
 reverberation.

In order to improve the stereo listening
 95 conditions in a motor vehicle, separate stereo
 reproduction systems could be provided in the
 passenger compartment for the driver's and
 passengers seats respectively. Therefore, the
 stereo reproduction system would, as it were,
 100 have to be provided twice in the car, firstly for the
 driver and secondly for the passenger. This
 arrangement is of course extremely expensive and
 impractical.

The invention now indicates a way of bringing
 105 about quite substantial improvement for the two
 problems outlined above. The invention is
 characterised in that, viewed spatially, between
 the two loudspeakers a summation signal formed
 from the right-hand signal and left-hand signal is
 110 emitted, and/or in that from the rear of the
 passenger compartments at least one differential
 signal formed from the right-hand signal and the
 left-hand signal is emitted.

A stereophonic reproduction installation for
 115 carrying out this method is thus characterised in
 that between the two loudspeakers, and
 additionally thereto, a further loudspeaker is
 arranged approximately on the centre axis of the
 motor vehicle ahead of the front seats, for
 120 example in the middle of the dashboard, and the
 electrical summation signal from the right and
 left-hand channels is fed to this loudspeaker,
 and/or in that at least one rear loudspeaker is
 provided which is arranged in the rear zone of the
 125 passenger compartment and to which the
 electrical differential signal from the right and left-
 hand channels is fed.

In order to improve the spatial sound
 impression, provision is further made, in the case

where two rear loudspeakers are provided, that, in the differential signal for the left-hand rear loudspeaker, the component of the signal of the left-hand channel is stronger in relation to that of the right-hand channel and, in the differential signal for the right-hand rear loudspeaker, the component of the signal of the right-hand channel is stronger in relation to that of the left-hand signal.

Another advantageous design feature of the invention also lies in the fact that a rear loudspeaker may be provided, to which the differential signal is fed, which has an approximately figure-of-eight radiation characteristic (radiator of the 1st order) and is arranged approximately in the meridian plane of the motor vehicle and the primary emission direction is oriented approximately at right-angles and horizontally to the longitudinal axis of the motor vehicle, and, moreover, a non-directional further rear loudspeaker is provided which is arranged in the vicinity of the first-mentioned rear loudspeaker and to which the electrical summation signal is fed which, preferably, is formed from the signal components of the medium and, above all, low frequency ranges.

Specific embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a basic diagram;

Figures 2 to 6 show different circuit diagrams of installations in passenger cars.

In Figure 1 it is illustrated diagrammatically and in plan view that a sound-emitting body 2, for example an orchestra, is set up in a recording room 1. Two microphones ML and MR, whose primary sensitivity directions form an angle of about 90° , are arranged in front of this sound-emitting body and are situated close to one another. The arrows 10 in Figure 1 indicate the primary sensitivity directions. The plane of symmetry E of the two microphones ML and MR coincides approximately with the plane of symmetry of the sound-emitting body 2. An amplifier and a transmission device 3 is assigned to each microphone ML and MR. Leads 4 pass into a reproduction room 5 and are connected to loudspeakers L' and R'. The microphone ML and the loudspeaker L' serve for the recording and emission of the left-hand signal L, the microphone MR and the loudspeaker R' serve for that of the right-hand signal R. The hatched area 6 drawn centrally in the reproduction room 5 represents the stereophonic auditory area. A listener positioned in this area zone 6 can hear stereophonic sound. Stereophonic sound is reproduced satisfactorily only within this area. With a room length l and a room width b each of about 5 metres, the maximum width B of this area amounts to about 0.5m.

Figure 2 now shows diagrammatically a plan view of an open passenger compartment of a motor vehicle 8. In the vicinity of the windscreen or dashboard 7, three loudspeakers L', R' and M'

are arranged ahead of the front seats 11 and 12; the loudspeakers L' and R' are situated at the sides and, possibly, may be installed in the motor-vehicle doors; the loudspeaker M' is situated in the middle. The signal L of the left-hand channel is fed to the loudspeaker L', the signal R of the right-hand channel is fed to the loudspeaker R' but the middle loudspeaker M' is supplied with an electrical summation signal $M=L+R$ which results from the electrical addition of the signals L, R of the right and left-hand channels and such as is used to produce a monophonic, i.e. single-channel, signal from the two stereo units. There is indeed the well-known requirement that stereo recordings have to be mono-compatible, namely that from the addition of the two stereo signals it is possible to produce monophonic signals which are free from disturbing sound distortion, for example interference. This mixing together could also be achieved, on the acoustic side, by means of corresponding outlay in respect of equipment. According to the invention, however, on the electrical side the signals L, R of the two channels are added in a suitable amplifier Σ and the summation signal M is emitted through a single loudspeaker M', as shown in Figure 2. In this case, additional use can be made of the fact that essential directional information is contained only in the medium and upper frequency ranges, approximately from 250 Hertz, and in that therefore only these frequency ranges would have to be emitted from all three loudspeakers L', M', R', whereas the bass range can be emitted only *via* the middle loudspeaker M' or *via* the two lateral loudspeakers L' and R'.

An installation, which is shown in Figure 3, gives a stereophonic audio impression which, perhaps, is slightly less satisfactory. Here exclusively the two loudspeakers L' and R' for the right and left-hand signals are mounted on the dashboard 7'. The two rear loudspeakers HL and HR emit respectively the differential signals $S=L-R$ and $S=R-L$. Differential amplifiers Δ are provided for the formation of these differential signals.

A further additional critical improvement possibility for stereophonic reproduction in a motor vehicle can be achieved if it is possible to improve the spatial effect of the sound impression, namely in addition to the direct sound also to emit time-shifted reflections and diffuse sound, such as is the case, for example, in auditoria and also in living rooms, the reflecting boundary surfaces of the room constituting such a sound field. This is at once not possible inside a motor vehicle because of the much smaller volume and the generally excessive damping of the boundary surfaces and is additionally worsened by the known arrangement of so-called rear loudspeakers which, most unnaturally, emit the signals of the right and left-hand channels directly from the rear.

In the arrangement according to Figure 4, two rear loudspeakers HL and HR are provided additionally to the three front loudspeakers L', M',

and R' in the motor vehicle 8" and moreover, differential amplifiers Δ and also, in a further development, attenuators A which enable the level of the respective other channel to be reduced by an adjustable or a desired amount (about 3 to 6 dB).

The two rear loudspeakers HL, HR are then supplied with signals which result from the difference of the left and right-hand signal (L—R) and of the right and left-hand signals (R—L) respectively. As a result of this measure, all correlated signals L, R of the right and left-hand channel, which correspond to direct sound, are rejected and only uncorrelated signals are emitted, which correspond to the diffuse sound field. This signal is also designated "lateral signals". Tests have shown that this sound signal does in fact bring a considerable improvement in the spatial impression, however, particularly because it is emitted close to the ears of the rearseat passengers, it sounds slightly unnatural and thin.

It has been found to be an advantageous further improvement to emit the differential signal S in fact *via* a left-hand rear loudspeaker HL and a right-hand rear loudspeaker HR, however, slightly more of the left-hand signal (3 to 6 dB) being fed to the left-hand loudspeaker HL and slightly more of the right hand signal being fed to the right-hand one HR. The attenuators A, which are shown in Figure 4, serve for this purpose, so that the signals fed to the rear loudspeakers HL and HR may be represented as follows:

$$S=nL-R \text{ and } S=nR-L,$$

respectively where n is greater than 1.

Another solution according to the invention lies in that, in addition to the indicated differential signal S for the medium and low frequencies which in fact contain little directional information, the mid-range signal M is emitted from an individual medium-frequency loudspeaker TM, *via* a low-pass filter TP, non-directionally from the middle of the rear-end zone of the motor vehicle 8^{iv} (Figure 6), whereas the differential signal S is emitted turned spatially through 90° on either side of the rear part of the motor vehicle 8^{iv}, which can be effected by a so-called radiator of the 1st order, i.e. a loudspeaker HLM in an open cabinet, in which the front side and rear side of the diaphragm are in contact with the air (Figure 6). The two rear loudspeakers TM and HLM lie substantially on the centre longitudinal axis of the motor vehicle and are arranged one behind the other in relation to its longitudinal direction.

A further improvement in the impression of spatial effect may be achieved if the differential signal S is delayed by about 5—20 millisecc. using a suitable electronic delay device τ , for example a so-called bucket-brigade circuit, and then emitted. As a result of this measure, the localisation of the rear-end loudspeakers is apparently displaced in depth (Figure 5).

Fundamentally, it should again be pointed out that it is essentially sufficient for the described measures according to the invention to be limited to the medium and high frequencies, while it is adequate for the low frequencies to be emitted only either by the front lateral loudspeakers or by the front middle loudspeaker or by a middle rear loudspeaker. The emission of the low frequencies by the two rear lateral loudspeakers has proven to be less advantageous. The practical embodiment of the invention can, of course, be effected in many ways. It is readily possible to employ the current already conventional installation methods for automobile loudspeakers and to interconnect them, in accordance with the invention, merely by interposing suitable and known summation and differential amplifiers.

In practice, therefore, an arrangement has proven to be successful, for example, in which the left-hand signal L and the right-hand signal R are emitted in a wide-band *via* commercial door loudspeakers, whereas the mid-band signal $M=R-L$ is emitted, according to the invention, *via* a small auxiliary loudspeaker (only for high and medium frequencies) which may be simply mounted on the dashboard and may also contain the associated electronic components, and in addition the two rear loudspeakers, which are usually provided in any case in a sophisticated stereo installation, are acted upon by the differential signals, in accordance with the proposal.

The improvement, achieved with this arrangement, in stereo reproduction and also in natural spatial effect is extraordinarily brilliant, in which case its subsequent application to an existing installation can be effected without great expense.

Claims

1. A method for the stereophonic reproduction of sound in the passenger compartments of motor vehicles, especially motorcars, with at least one receiving unit and/or reproducing unit and several loudspeakers, at least two mutually spaced loudspeakers being provided in the close vicinity of the driver's and/or passenger's seat, one of which loudspeakers serves for the reproduction of the left-hand channel signal and the other loudspeaker serves for the reproduction of the right-hand channel signal, the method including the emission between the two loudspeakers of a summation signal formed from summing the right-hand channel signal and left-hand channel signal or portions thereof and/or the method including the emission from the rear end of the passenger compartment of at least one differential signal formed from subtracting the right-hand channel signal and the left-hand channel signal or portions thereof.

2. A stereophonic sound reproduction installation in a passenger compartment or a motor vehicle, especially a motorcar, comprising at least one receiving unit and/or reproducing unit and several loudspeakers including at least two

mutually spaced loudspeakers provided in the close vicinity of the driver's and/or passenger's seat, one of which loudspeakers serves for the reproduction of the left-hand channel signal and

5 the other loudspeaker serves for the reproduction of the right-hand channel signal; the installation further comprising, between the two loudspeakers and additionally thereto, a further loudspeaker which is arranged approximately on
10 the centre axis of the motor vehicle ahead of the front seats thereof, for example in the middle of the dashboard, and also means for producing an electrical summation signal from the right and left-hand channel signals which is fed to the
15 further loudspeaker; and/or the installation further comprising at least one rear loudspeaker which is arranged in the rear zone of the passenger compartment and also means for producing an electrical differential signal from the right and left-
20 hand channel signals which is fed to the rear loudspeaker.

3. An installation according to Claim 2, wherein two such rear loudspeakers are provided arranged as a left-hand rear loudspeaker and a
25 right-hand rear loudspeaker, the differential signal producing means providing a differential signal to the left-hand rear loudspeaker in which the left-hand channel signal is stronger than the right-hand channel signal, and differential signal to the
30 right-hand rear loudspeaker in which the right-hand channel signal is stronger than the left-hand channel signal.

4. An installation according to Claim 2 or 3, further comprising a further rear loudspeaker
35 arranged in the rear zone of the motor vehicle.

5. An installation according to Claim 4, wherein the or one of the rear loudspeakers to which a differential signal is fed has an approximately figure-of-eight radiation
40 characteristic (i.e. radiator of the 1st order) and the primary emission direction is oriented approximately at right-angles and horizontally to the longitudinal axis of the motor vehicle, the further rear loudspeaker being non-directional and
45 arranged in the vicinity of the first-mentioned rear loudspeaker and to means being provided to produce a summation signal formed by summing the left and right-hand channel signals which is fed to the further rear loudspeaker, the
50 summation signal preferably being formed from the medium and, above all, low frequencies.

6. An installation according to Claim 5, wherein the two rear loudspeakers are arranged one behind the other, viewed in the longitudinal direction of the passenger compartment (Figure 6).

7. An installation according to any of Claims 2 to 6, wherein the or each rear loudspeaker is fed *via* delay unit e.g. a so-called bucket-brigade circuit.

8. A method of reproducing stereophonic sound in a motor vehicle, substantially as hereinbefore described with reference to any of Figures 2 to 6 of the accompanying drawings.

9. An installation for reproducing stereophonic sound in a motor vehicle, substantially as hereinbefore described with reference to and as illustrated in any of Figures 2 to 6 of the accompanying drawings.