(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 521 778 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
**12.03.2025 Bulletin 2025/11**

(21) Application number: **23196039.4**

(22) Date of filing: **07.09.2023**

(51) International Patent Classification (IPC):
***H04S 7/00*** *(2006.01)* *H04R 3/12* *(2006.01)*

(52) Cooperative Patent Classification (CPC):
**H04S 7/301;** H04R 3/12; H04R 2499/13; H04S 7/307

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR**
Designated Extension States:
**BA**
Designated Validation States:
**KH MA MD TN**

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# (54) SYSTEM AND METHOD FOR CREATING INDIVIDUAL LISTENING ZONES IN AN ENVIRONMENT, IN PARTICULAR INSIDE A MOTOR VEHICLE, AND MOTOR VEHICLE COMPRISING SUCH SYSTEM

(57) A system (100) for creating at least a first listening zone (A) and a second listening zone (B) in an environment (20) where audio contents have to be transmitted, comprising an electronic control unit (10), and a plurality of loudspeakers (1, 2, 3, 4, 5) suitable to be installed at predetermined positions inside the environment.

The electronic control unit is configured:
- to calculate, for each transmission frequency of a plurality of predetermined transmission frequencies, a reference matrix (G) wherein all elements of the reference matrix (G) are constituted each by a corresponding transfer function between each loudspeaker and one or more audio receiving target points (Mi) suitable to be located inside the first and second listening zones, wherein the reference matrix is calculated based on a predefined reference value assigned to a physical or geometric parameter influencing acoustic transmissions inside the environment;
- to calculate, for each transmission frequency, a plurality of additional matrices (Gi), wherein all elements of each additional matrix (Gi) are constituted by corresponding transfer functions between each loudspeaker and the audio receiving target points, and wherein each additional matrix (Gi) is calculated by assigning to the physical or geometric parameter a respective given value which is different from the predefined reference value and from the given value assigned to all other additional matrices (Gi);
- to calculate, for each given frequency, an overall matrix (GEXT) by concatenating the reference matrix (G) with all additional matrices (Gi) calculated for the given frequency;
- to elaborate, based on the overall matrix (GEXT) calculated, one or more sets of digital filters to be applied to the loudspeakers for transmitting audio content to be listened in one of the listening zones while being at least acoustically attenuated in the other listening zone.

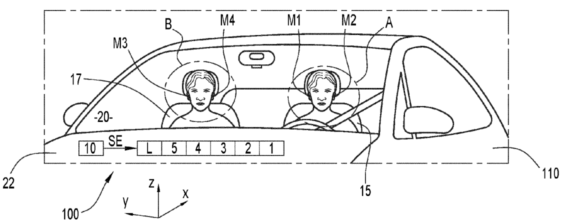


FIG.3

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## Description

**[0001]** The present invention relates to a system and a method for creating individual listening zones in an environment, in particular inside a motor vehicle, and to a motor vehicle comprising such a system.

**[0002]** The system and method according to the present invention are particularly suitable for creating individual listening zones within the passenger compartment of a car and will be described hereinafter by making more specific reference to such application without intending in any way to limit their possible application to other types of motor vehicles, such as buses, trucks etc., or in any other type of environment where audio contents can be transmitted, for example stations, banks, malls, schools, commercial centers, shops, theaters, music halls, auditoriums, convention centers, airports, etc.

**[0003]** The use of headphones for listening audio contents without disturbing or being disturbed or distracted by the surrounding environment is well known and widely used.

**[0004]** However, the use of headphones lead people not to interact properly with the surrounding environment, sometimes causing a deficit of attention that may lead to dangerous situations, and in any case it may pose also some hygiene problems.

**[0005]** Over the last decades, new technical systems have been developed that are capable to create individual listening zones ("ILZ") in order to avoid using headphones.

**[0006]** These systems reproduce a certain audio content at one specific area in space, i.e. the desired listening zone usually referred to also as the bright zone, while limiting audio leakage of the transmitted audio content into another distinct area, i.e. the non-listening zone, usually referred to as the dark zone.

**[0007]** For instance, in an international railway station, such systems allow to broadcast the same alert message in several languages to different zones in space, or for example in a bank, it is possible to convey a speech signal to an individual listener while ensuring that other people in the waiting room could not hear any confidential information.

**[0008]** In general, in order to provide effective results, such known systems make use of tracking systems or physical error microphones which take into account the movements of the head of user.

**[0009]** In this way, these systems adapt in real time the transmission of the audio content, thus trying to keep a proper acoustic contrast between the individual listening zone where the relevant audio content is meant to be listened, and the other area(s) where instead it should not be heard.

**[0010]** Although such known systems are quite effective, depending on the applications the use of sensors and/or tracking systems render such solutions overly sophisticated, sometimes cumbersome to be installed, and anyhow rather costly.

**[0011]** Hence, the present invention is aimed at facing and possibly mitigating at least some of such issues, and in particular at providing a solution that, while being functionally effective in terms of creating individual listening zones, at the same time is simpler and economically more convenient to be realized and used.

**[0012]** Accordingly, the present invention provides a system for creating at least a first listening zone and a second listening zone in an environment where audio contents have to be transmitted, the system being characterized in that it comprises at least:

- an electronic control unit;
- a plurality of loudspeakers suitable to be installed at predetermined positions inside said environment;

wherein the electronic control unit is configured:

- to calculate, for each transmission frequency of a plurality of predetermined transmission frequencies, a reference matrix wherein all elements of the reference matrix are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and one or more audio receiving target points suitable to be located inside the first listening zone and the second listening zone, wherein the reference matrix is calculated based on a predefined reference value assigned to at least one physical or geometric parameter influencing acoustic transmissions inside the environment from the plurality of loudspeakers towards said one or more audio receiving target points;
- to calculate, for each transmission frequency of said plurality of predetermined transmission frequencies, a plurality of additional matrices, wherein all elements of each additional matrix are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and said one or more audio receiving target points, and wherein each additional matrix is calculated by assigning to said at least one physical or geometric parameter a respective given value which is different from said predefined reference value and from the given value assigned to all other additional matrices;
- to calculate, for each given frequency, an overall matrix by concatenating the reference matrix with all additional matrices calculated for the given frequency;
- to elaborate, based on the overall matrix calculated, one or more sets of digital filters to be applied by the electronic

control unit to the plurality of loudspeakers for transmitting in the environment audio content to be listened in one of said first and second listening zones while being at least acoustically attenuated in the other one of said first and second listening zones.

**[0013]** The present invention also encompasses a motor vehicle, in particular a car, comprising a system as above indicated, and in particular as described hereinafter and defined in the appended claims.

**[0014]** The present invention also provides a method for creating at least a first listening zone and a second listening zone in an environment where audio contents have to be transmitted, the method being characterized in that it comprises at least:

(a): a first step of calculating, by means of an electronic control unit, for each transmission frequency of a plurality of predetermined transmission frequencies, a reference matrix, wherein all elements of the reference matrix are constituted each by a corresponding transfer function between each loudspeaker of a plurality of loudspeakers suitable to be installed at predetermined positions inside said environment and one or more audio receiving target points suitable to be located inside the first listening zone and the second listening zone, wherein said reference matrix is calculated based on a predefined reference value assigned to at least one physical or geometric parameter influencing acoustic transmissions inside the environment from the plurality of loudspeakers towards said one or more audio receiving target points;

(b): a second step of calculating, by means of said electronic control unit, for each transmission frequency of said plurality of predetermined transmission frequencies, a plurality of additional matrices wherein all elements of each additional matrix are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and said one or more audio receiving target points, wherein each additional matrix is calculated by assigning to said at least one physical or geometric parameter a respective given value which is different from said predefined reference value and from the given value assigned to all other additional matrices;

(c): a third step of calculating, for each given frequency, by means of said electronic control unit, an overall matrix by concatenating the reference matrix calculated with all additional matrices calculated for the given frequency;

(d): a fourth step of elaborating, by means of said electronic control unit, based on the overall matrix calculated, one or more sets of digital filters to be applied to the plurality of loudspeakers for transmitting in the environment audio content to be listened to in one of said first and second listening zones while being at least acoustically attenuated in the other one of said first and second listening zones.

**[0015]** In addition, the present invention provides also a computer product program comprising program code for performing, when executed by a processor device, the method above indicated, and in particular as described hereinafter and defined in the appended claims.

**[0016]** Further, the present invention provides a non-transitory computer-readable storage medium comprising instructions which, when executed by a processor device, cause the processor device to perform the method above indicated, and in particular as described hereinafter and defined in the appended claims.

**[0017]** Preferred embodiments of the invention are specified in the dependent claims, the contents of which are to be understood as an integral part of this description.

**[0018]** Further characteristics and advantages will become apparent from the description of some preferred but not exclusive exemplary embodiments of a system, method and motor vehicle according to the present disclosure, illustrated only by way of non-limitative examples with the accompanying drawings, wherein:

Figure 1 schematically illustrates an exemplary embodiment of a system according to the invention for creating individual listening zones in an environment where audio contents are transmitted;

Figure 2 is a flow diagram schematically illustrating a method according to the present invention for creating individual listening zones in an environment where audio contents are transmitted;

Figures 3-5 schematically illustrate an exemplary embodiment where the system and method according to the invention are used for creating two individual listening zones inside the cabin of a car.

**[0019]** It should be noted that in the detailed description that follows, identical or similar components, either from a structural and/or functional point of view, may have the same or different reference numerals, regardless of whether they are shown in different embodiments of the present disclosure; it should also be noted that in order to clearly and concisely describe the present disclosure, the drawings may not necessarily be to scale and certain features of the disclosure may be shown in somewhat schematic form.

**[0020]** Further, when the term "configured" or "adapted" or "arranged" or "set" or "shaped", is used herein while referring to any component as a whole, or to any part of a component, or to a combination of components, it has to be understood that it means and encompasses correspondingly either the structure, and/or configuration, and/or form, and/or position of the related component or part thereof, such term refers to.

**[0021]** In particular, for electronic and/or software means, each of the above listed terms means and encompasses electronic circuits or parts thereof, as well as stored, embedded or running software codes and/or routines, algorithms, or complete programs, suitably designed for achieving the technical result and/or the functional performances for which such means are devised.

**[0022]** Figures 1 and 2 schematically illustrate a system and a method, indicated by the overall reference numbers 100 and 200, respectively, for creating at least a first listening zone A and a second listening zone B in an environment 20 where audio contents are transmitted.

**[0023]** In particular, and in the way that will result more in details from the following description, in the case of only two listening zones A and B, with respect for instance to a first audio content to be transmitted, a first listening zone A is treated by the system 100 and the method 200 and will be referred to in the following as the bright zone, i.e. the listening zone where the audio content should be correctly received and listened to, while the second listening zone B is considered and will be referred to in the following as the dark zone, i.e. the listening zone where such first audio content should be ideally not heard at all, or at least substantially mitigated from an acoustic point of view.

**[0024]** Clearly, if a second audio content is meant to be transmitted and listened to in the second listening zone B, then such zone is treated by the system 100 and the method 200 as the bright zone, while the first listening zone is treated and becomes the dark zone.

**[0025]** This approach is made possible by the fact that thanks to the devised system 100 and method 200 is possible to add the optimal signals obtained for each relevant zone by virtue of the principle of superposition relevant to any stationary linear system.

**[0026]** Consequently, in order to avoid unnecessary repetition, the system 100 and method 200 will be described hereinafter by making reference to the generation of just two individual listening zones A and B, out of which one becomes a bright zone and the other one the dark zone.

**[0027]** Clearly, the system 100 and the method 200 can be used for generating any desired number of individual listening zones inside the environment 20, and what described hereinafter can be applied likewise to the generation of any desired number of individual listening zones, in any suitable environment where the system 100 and/or the method 200 are used and are capable of reproducing several independent audio contents in several distinct listening zones of the environment 20.

**[0028]** As illustrated in figure 1, the system 100 comprises at least:

- an electronic control unit 10; and
- a plurality of loudspeakers 1, 2, 3, 4, 5,...L, suitable to be installed at predetermined positions inside the environment 20.

**[0029]** Clearly, depending on the applications, the number, type and positioning of loudspeakers inside the environment 20 where acoustic contents have to be transmitted, can be any suitable one.

**[0030]** Advantageously, in the system 100 according to the invention, the electronic control unit 10 is configured:

- to calculate, for each angular transmission frequency $\omega$ of a plurality of predetermined transmission frequencies, a reference matrix G wherein all elements of the reference matrix G (also referred to in the following as the plant matrix) are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers 1, 2, 3, 4, 5,...L, and one or more audio receiving target points Mi suitable to be located inside the first listening zone A and the second listening zone B, wherein the reference matrix G is calculated based on a predefined reference value assigned to at least one physical or geometric parameter influencing acoustic transmissions inside the environment from the plurality of loudspeakers towards the one or more audio receiving target points Mi;
- to calculate, for each transmission frequency of said plurality of predetermined transmission frequencies, a plurality of additional matrices Gi, wherein all elements of each additional matrix Gi are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers 1, 2, 3, 4, 5,...L, and said one or more audio receiving target points, and wherein each additional matrix Gi is calculated by assigning to said at least one physical or geometric parameter a respective given value which is different from said predefined reference value and from the given value assigned to all other additional matrices Gi;
- to calculate, for each given frequency, an overall matrix $G_{EXT}$ by concatenating, preferably by making a vertical concatenation, the reference matrix G with all additional matrices Gi calculated for that given frequency;
- to elaborate, based on the overall set of matrixes $G_{EXT}$ calculated at all frequencies, one or more sets of digital filters to be applied by the electronic control unit 10 to the plurality of loudspeakers 1, 2, 3, 4, 5,...L, for transmitting in the environment 20 audio content to be listened in one of the first and second listening zones, e.g. the bright zone A, while being at least acoustically attenuated, if not completely muted, in the other one of said first and second listening zones, e.g. the dark zone B.

**[0031]** In practice, once the one or more sets of digital filters have been elaborated, their application to the loudspeakers, via control signals $S_c$ imposed by the electronic control unit 10 to the loudspeakers, cause the emission of acoustic signals optimized in order to properly create the at least two listening zones A and B.

**[0032]** In particular, according to the invention, once the system 100 (or likewise the method 200) is put in operation, the one or more sets of digital filters elaborated are invariable, i.e. they are not changed or re-elaborated anymore.

**[0033]** The electronic control unit 10, which can be referred to also as a controller, can comprise or be constituted by any processor-based device, e.g. a microprocessor, microcontroller, a microcomputer, a programmable logic controller, an application specific integrated circuit, of a type commercially available, suitably programmed and provided to the extent necessary with circuitry, and/or software code, and/or firmware, in order to perform the functionalities devised within the frame of the present invention.

**[0034]** Depending on the applications, the electronic control unit 10 can be placed in any suitable position, e.g. directly in the environment 20 or outside it, close to or remotely there from, and it can comprise or being associated to any needed storage unit or repository, e.g. a memory for storing data, code instructions to be executed, etc., to a communication module for receiving/transmitting signals, etc.

**[0035]** In the example of figure 1 there are illustrated only four audio receiving target points (or audio control points) indicated by the references M1, M2, M3 and M4.

**[0036]** The audio target or control points Mi can be constituted, for example, by microphones installed at desired positions in the environment 20 within the desired first and second listening zones A and B, during the installation and calibration of the system 100 (and likewise of the method 200); such microphones can represent/simulate for instance the position of corresponding ears of individuals.

**[0037]** Alternatively, the audio receiving target points Mi can be constituted directly by the position of the ears of individuals present or supposed to be present inside the listening zones A and B, as it will be described in more details in the following description with reference to the exemplary embodiment of figures 3-5.

**[0038]** In particular, as above indicated the reference matrix G at each given frequency is calculated based on a predefined reference value assigned to at least one physical or geometric parameter whose variation influences/modifies acoustic transmissions inside the environment 20 from the plurality of loudspeakers towards the one or more audio receiving target points M.

**[0039]** In practice, the loudspeakers 1, 2, 3, 4, 5, ...L, the defined audio receiving target points Mi considered in a predefined initial position, the environment 20 with the respective at least one parameter having assigned initially its predefined reference value, form an acoustic reference or non-perturbed state.

**[0040]** Then, every time the at least one parameter considered is assigned with a value different than its reference value and the corresponding additional matrix Gi is calculated, there is virtually formed a new perturbed state of the overall acoustic system different from the acoustic reference state.

**[0041]** Hence, in the process of elaborating the optimum sets of digitals filters, the electronic unit 10 takes into consideration a reference state and a plurality of perturbed states different from the reference state.

**[0042]** In particular, according to the invention, both in the system 100 and in the method 200, a finite number of states is considered, wherein each state is associated to one plant matrix containing the electro-acoustical transfer functions between each loudspeaker and each control point, estimated for that specific state.

**[0043]** According to possible embodiments, the signal processing parameters, i.e. the physical or geometric parameters taken into considerations and that influence acoustic transmissions inside the environment 20, are based on pre-measurements or on a numerical model of electro-acoustical transfer functions or impulse responses between the various loudspeakers and the various control points, for each possible state.

**[0044]** In one possible embodiment, the at least one physical or geometric parameter comprises or is constituted by the position of at least one ear of a first person suitable to be located inside the first listening zone A and of at least one ear a second person suitable to be located inside the second listening zone B.

**[0045]** In a further possible embodiment, the at least one physical or geometric parameter is selected among the group comprising the temperature of the environment 20 where audio contents are transmitted, the humidity of such environment 20, number of people in the environment 20, positions of people in the environment 20, such as number and positions of people in a car where audio contents are transmitted.

**[0046]** For example, in an environment 20 such as an office, the reference value of the temperature can be selected equal to 18°C or 20°C and the other values considered can vary by increments or decrements of five degrees.

**[0047]** In one possible embodiment, the electronic control unit 10 is configured to associate to the predefined reference value of and to each of the given values assigned to the selected parameter(s) for each additional matrix a corresponding numerical weight.

**[0048]** In particular, in one possible embodiment, each numerical weight associated to the predefined reference value and to each of the given values assigned to the selected parameter(s) for each additional matrix calculated, is defined based on an estimated probability that the parameter assumes the predefined reference value or a corresponding given value.

**[0049]** In this way, the electronic control unit 10, and in particular the parameter(s) of the signal processing algorithm associated therewith, is configured by suitably taking into account the relative importance of each state, expressed by a set of weights, namely one weight for each state of the acoustic system.

**[0050]** Conveniently, the higher the importance of a state, the more the electronic control unit 10 optimizes the acoustic performance in terms of creating the bright or dark zone(s) for that particular state of the system.

**[0051]** In one possible embodiment, the relative importance of each state considered is based on a Gaussian function.

**[0052]** In particular, the mathematical parameters that define the Gaussian function, mainly the variance or (standard deviation) of the Gaussian distribution, vary with frequency. Depending on the variance chosen, different performances might be obtained. Also, the values across the Gaussian distribution can be applied to each state of the system (with regard to values of the influencing parameter(s) considered, such as ear canals, humidity etc...), depending on their importance or probability of occurrence.

**[0053]** In one possible embodiment, the electronic control unit 10 is configured to elaborate the one or more sets of digital filters based on the solution of a multi-objective optimization problem, wherein, for each frequency, the calculated reference matrix and the additional matrices are associated to one or more objectives to be optimized.

**[0054]** In particular, one the objectives to be optimized comprises or is constituted by the energy associated to the one or more sets digital filters elaborated.

**[0055]** In particular, this energy is the sum of the magnitude squared of the filter coefficients for all loudspeakers, at each frequency.

**[0056]** In one possible embodiment, the electronic control unit 10 is configured to use/implement a Pressure Matching (PM) algorithm.

**[0057]** In particular, according to this embodiment, different sets of target pressure signals are reproduced at the audio targets points located in the respective listening zones where sound is to be controlled, wherein the plant matrix is constituted by a composition/combination of the plant matrices associated to the various states of the acoustic system and the target signals are the composition/combination of the target signals associated to each state of the system.

**[0058]** In another possible embodiment, the electronic control unit is configured to use/implement an Acoustic Contrast Control (ACC) algorithm.

**[0059]** In particular, according to this embodiment, the ratio of acoustic energy between the bright and dark zones is optimized, and the plant matrix is constituted by a composition/combination of the plant matrices associated to the various states of the system.

**[0060]** Figure 2 schematically illustrates a method 200 for creating at least a first listening zone A and a second listening zone B in an environment 20 where audio contents are transmitted.

**[0061]** The method 200, which can be implemented for example in connection with or by means of the components of the system 100 above described, comprises a first step 210 of calculating, by means of an electronic control unit, such as the electronic control unit 10, for each transmission frequency $\omega$ of a plurality of predetermined transmission frequencies, a reference matrix G, wherein all elements of the reference matrix G are constituted each by a corresponding transfer function between each loudspeaker of a plurality of loudspeakers 1, 2, 3, 4, 5, ... L, suitable to be installed at predetermined positions inside the environment 20 and one or more audio receiving target points Mi suitable to be located inside the first listening zone A and the second listening zone B.

**[0062]** In particular, each reference matrix G is calculated based on a predefined reference value assigned to at least one physical or geometric parameter, whose variation influences/modifies acoustic transmissions inside the environment 20 from the plurality of loudspeakers 1, 2, 3, 4, 5, ... L, towards the one or more audio receiving target points Mi.

**[0063]** The method 200 comprises also a second step 220 of calculating, for instance by means of the electronic control unit 10, for each transmission frequency $\omega$ of the plurality of predetermined transmission frequencies, a plurality of additional matrices Gi, wherein all elements of each additional matrix Gi are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers 1, 2, 3, 4, 5,...L, and the one or more audio receiving target points Mi.

**[0064]** As above indicated, usefully each additional matrix Gi is calculated by assigning to the at least one physical or geometric parameter a respective given value which is different from the predefined reference value and from the given value assigned to all other additional matrices Gi.

**[0065]** The method 200 comprises also:

- a third step 230 of calculating, for each give frequency, and for instance by means of the electronic control unit 10, an overall matrix $G_{EXT}$ by concatenating, in particular by making a vertical concatenation, the reference matrix G with all additional matrices Gi calculated for the given frequency; and
- a fourth step 240 of elaborating, by means of the electronic control unit 10, based on the overall matrix $G_{EXT}$ calculated, one or more sets of digital filters to be applied to the plurality of loudspeakers 1, 2, 3, 4, 5, L for transmitting in the environment audio content to be listened to in one of the first and second listening zones A, B, while being at least acoustically attenuated in the other one of the first and second listening zones A, B.

**[0066]** All considerations/assumptions and functionalities above described in connection with the system 100 are applicable to and implementable in terms of steps/phases/substeps/sub-phases by the method 200, only some of which are briefly recalled hereinafter for the sake of conciseness.

**[0067]** In particular, the fourth step 240 of elaborating comprises keeping the one or more sets of digital filters once elaborated invariable whatever is the current state of the acoustic system, i.e. in any perturbed state or in the non-perturbed state.

**[0068]** In one embodiment, the first step 210 comprises associating, to the predefined reference value and to each of the given values assigned to the parameter for each additional matrix calculated, a corresponding numerical weight.

**[0069]** In particular, also in the method 200, each numerical weight associated to the predefined reference value and to each of the given values assigned to the parameter for each additional matrix calculated, is defined based on an estimated probability that the parameter assumes the predefined reference value or a corresponding given value.

**[0070]** In one embodiment, the third step 240 comprises elaborating said one or more sets of digital filters (or at least parts thereof) based on the solution of a multi-objective optimization problem, wherein for each frequency, each matrix of the calculated reference matrices and additional matrices is associated to one objective to be optimized.

**[0071]** With reference to figures 3 to 5, it will be described now an exemplary embodiment, wherein the system 100 (and correspondingly also the method 200) is shown applied to the passengers cabin 20 of a car 110, the cabin 20 representing the environment inside which audio contents can be transmitted.

**[0072]** In this non-limiting example, the system 100 and the method 200 are used for generating a first listening zone A in correspondence of the driver seat 15, and a second listening zone B in correspondence of the front passenger seat 17.

**[0073]** For instance, in the exemplary embodiment of figure 1, the plurality of loudspeakers 1, 2, 3, 4, 5, ... L, are shown installed inside the passengers cabin 20 as a linear array of loudspeakers at the dashboard 22, e.g. substantially in front of the driver seat 15 and the front passenger seat. 17

**[0074]** In this exemplary embodiment, the audio receiving target points are represented by four points, namely the positions M1 and M2 of the ears of the driver and the position M3 and M4 of the passenger sitting on the front set 17.

**[0075]** According to this embodiment, preferably the position of the ears not only represents the target points but is also considered as the reference parameter whole values influence/modify the acoustic transmissions from the loudspeakers towards the target points themselves.

**[0076]** In particular, for each individual considered, namely the driver or the side passenger, the reference position of their ears, indicated in figure 4 by the reference PREF, i.e. the central positon, is the one representing the reference or non-perturbed acoustic state, while the other side positions indicated by the references PER1, PER2, PER3, PER4, are positions corresponding each to a respective acoustic perturbed state.

**[0077]** Hence, in this example, a total of five possible acoustic states are considered.

**[0078]** Thus, considering that the system 100 comprises L loudspeakers and that there are M audio receiving target points, e.g. four, distributed over the bright and dark zones A and B, a set of transfer functions are defined for each angular frequency $\omega$ between the L loudspeakers and the M audio receiving target points and are arranged as the elements of the reference or plant matrix $\mathbf{G}(\omega)$.

**[0079]** Thus, for a given frequency $\omega$ (in order to lighten the notations, any reference to the frequency index will be hereby omitted) the reference matrix $\mathbf{G} \in C^{M \times L}$ is defined as:

$$G = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1L} \\ \vdots & \vdots & \ddots & \vdots \\ g_{M1} & g_{M2} & \cdots & g_{ML} \end{bmatrix} \quad (1)$$

wherein $g_{m\ell}$ is the transfer function between the $\ell^{th}$ loudspeaker and the $m^{th}$ control point.

**[0080]** Then, the following relationships can be easily deduced:

$$\mathbf{p} = \mathbf{Gq} = \begin{bmatrix} \mathbf{G}_b \\ \mathbf{G}_d \end{bmatrix} \cdot \begin{bmatrix} q_1 \\ q_2 \\ \vdots \\ q_L \end{bmatrix} = \begin{bmatrix} \mathbf{P}_b \\ \mathbf{P}_d \end{bmatrix} \quad (2)$$

where $\mathbf{q} \in C^{L\times 1}$ is the column vector of complex source strengths, corresponding to the loudspeaker signals in the frequency domain, $\mathbf{p} \in C^{M\times 1}$ is the column vector of the pressure signals reproduced at all control points, and subscripts d and b indicate the quantities related to the dark Zone and the bright zone, respectively.

**[0081]** Finally, for instance an acoustic contrast metric called $AC_{dB}$ is defined as the ratio of the spatially averaged energies between the bright and dark zones and is expressed as:

$$AC_{dB} = 10\log_{10}\left(\frac{\mathbf{p}_b^H\mathbf{p}_b}{\mathbf{p}_d^H\mathbf{p}_d}\right) \qquad (3)$$

where the superscript H is the conjugate transpose operator, and the acoustic contrast metric $AC_{dB}$ is defined based on the following:

$$G_{ext} = \begin{bmatrix} \mathbf{G}_1 \\ \mathbf{G}_2 \\ \vdots \\ \mathbf{G}_C \end{bmatrix} \qquad (4)$$

**[0082]** In particular, as above described, the acoustic system comprises or is substantially formed by the plurality of loudspeakers, the audio receiving target points Mi, the environment 20 and related conformation and materials therein used. The acoustic system is assumed to change from one state $E_i$ to another state $E_j$, both determined by a variety of physical and or geometrical quantities such as the temperature, humidity, the positions of the target points Mi, at least some of these parameters might vary over time.

**[0083]** Hence, in the system 100 and method 200 according to the invention, a distinct plant matrix $\mathbf{G}_i$ can be associated to each of these states $E_i$.

**[0084]** Preferably, the number of possible states $C$ is assumed to be finite.

**[0085]** In the example illustrated in figures 3 to 5, as above indicated, the only parameter considered which influences/modifies the current state of the acoustic system is the position of the ears of two individuals inside the listening zones A and B.

**[0086]** Further, as illustrated in figure 4, only five possible states are considered, namely those corresponding to the position of the ears indicated by the references PREF, PER1, PER2, PER3, PER4.

**[0087]** As a consequence, the extended plant matrix $G_{ext}$ is constructed by vertical concatenation of all $G_i$ matrices, where the number of rows is naturally equal to $M_C = M \times C$, such that $G_{ext} \in C^{MC\times L}$.

**[0088]** In the particular case of only two zones described by two control points M1 and M2, and M3 and M4, respectively, which represent the entrance to the ear canals of two passengers in the car cabin, the total number of audio receiving target points is $M = 4$.

**[0089]** In addition, since in this exemplary embodiment the only degree of freedom of the acoustic system is selected to be the position of the ears (and hence of the head) of the two passengers, each of which can take $P$ different spatial positions, then the number of combinations is $P^2$ and the matrix $G_{ext}$ will belong to $C^{4P2\times L}$.

**[0090]** It has to be noted that, since the solution according to the invention is not adaptive, the vector $\mathbf{q}$ does not depend on the specific state $E_i$.

**[0091]** With this approach, the reproduced sound field can be usefully predicted at multiple control points for all considered system states and for a fixed set of loudspeaker signals.

**[0092]** In this way, the design of the vector q can be optimized by taking multiple states into consideration.

**[0093]** For instance, by applying the Pressure Matching (PM) technique, i.e. where different sets of target pressure signals are reproduced at the audio targets points located in the respective listening zones where sound is to be controlled, these target pressure signals for a particular state of the acoustic system can be compiled in a vector called $\mathbf{d}_i \in C^{M\times 1}$. Note that there is no requirement that the number of control points M be the same for every state of the system. However, for the sake of convenience, it is hereby assumed that this is always the case. It is also likely that the target pressure signals will be different for different states, i.e. $d_i \neq d_j$ if $i \neq j$.

**[0094]** Once the choice of audio targets points is made, the unique set of signals, and thus the associated one or more set of digital filters, to be fed to the loudspeakers in order to best reproduce the targets at each control point have to be defined.

**[0095]** Hence, for each state $E_i$ of the acoustic system, this is equivalent to solving the conventional minimisation problem:

$$\mathbf{G}_i\mathbf{q} = \mathbf{d}_i \quad (6)$$

**[0096]** The solution of this linear problem depends in theory on the dimensions of the plant matrix. Indeed, if $\mathbf{G}_i$ is fat ($M \leq L$) the system is underdetermined, i.e. more than one solution **q** may exists to the above problem. Consequently, it is necessary to chose one of the possible solutions by using a given criterion, for example by selecting the solution with minimum $\ell^2$-norm, hereafter referred to as minimum norm (MN) solution. The problem thus becomes:

$$\min_{\mathbf{q}} \|\mathbf{q}\|_2^2 \quad s.t \quad \mathbf{G}_i\mathbf{q} = \mathbf{d}_i \quad (6)$$

where $\|.\|_2$ is the Euclidean norm. This gives the following least-norm (LN) optimal solution:

$$\mathbf{q}(iLN) = \mathbf{G}Hi\,(\mathbf{G}i\mathbf{G}Hi\,)-1\mathbf{d}i \quad (7)$$

The numerical inversion in the above expression can lead to large amplification of errors at frequencies where the system is ill-conditioned and where the norm of the solution may be large, impossible to reproduce in practice. The Tikhonov regularization scheme is therefore often applied before the inversion, by adding a small term to the elements on the diagonal of the grammian $\mathbf{GG}^H$, called the regularization parameter and here noted by the symbol $\beta$. Thus

$$\mathbf{q}^{RLNi} = \mathbf{G}H_i(\mathbf{G}_i\mathbf{G}H_i + \beta\mathbf{I})-1\mathbf{d}_i \quad (8)$$

which can no longer be considered strictly speaking as an LN solution. This explains the new superscript RLN, i.e. *regularized least-norm.* Conversely, in the case where $\mathbf{G}_i$ is skinny ($M \geq L$), the above linear problem is overdetermined and an exact solution will not exist in general. Thus, one of the methods used to obtain an approximate solution is to consider the following least-squares problem:

$$\min_{\mathbf{q}} \|\mathbf{G}_i\mathbf{q} - \mathbf{d}_i\|_2^2 + \beta\|\mathbf{q}\|_2^2 \quad (9)$$

where $\beta$ is balancing in the relative importance of the norm of the solution against the least-squares error $\|\mathbf{G}_i\mathbf{q} - \mathbf{d}_i\|_2^2$. This gives the following least-squares (LS) solution:

$$\mathbf{q}_i^{(LS)} = (\mathbf{G}_i^H\mathbf{G}_i + \beta\mathbf{I})^{-1}\mathbf{G}_i^H\mathbf{d}_i = \mathbf{G}_i^\dagger\mathbf{d}_i \quad (10)$$

where $\mathbf{G}^\dagger_i$ is the regularised pseudo-inverse of $\mathbf{G}_i$. However, a singular value decomposition (SVD) analysis as presented of the two solutions leads to the conclusion that if $\beta > 0$ then $\mathbf{q}_i^{(LS)} = \mathbf{q}_i^{(RLN)}$. Therefore, only the least-squares formulation is employed hereinafter.

**[0097]** Thus, the objective is to determine a unique solution **q** that can lead to a combined minimum least-squares error for all stated of the acoustic system $E_i$, $i = 1,...,C$.

**[0098]** This multi-objective optimization problem (MOOP) is formulated as:

$$\mathbf{P} : \min \{J_1(\mathbf{q}), J_2(\mathbf{q}),...,J_C(\mathbf{q}), N_{L2}(\mathbf{q}) : \mathbf{q} \in C^{Lx1}\} \quad (11)$$

where the individual cost function $J_i(\mathbf{q})$ is the least-squares reproduction error associated to the state $E_i$, expressed as:

$$J_i(\mathbf{q}) = \|\mathbf{G}_i\mathbf{q} - \mathbf{d}_i\|_2^2 \quad (12)$$

In addition, the last objective function $N_{L2}(\mathbf{q})$, allowing the solution to be regularized, is expressed as:

$$N_{L_2}(\mathbf{q}) = \|\mathbf{q}\|_2^2 \quad (13)$$

This MOOP problem can be solved for instance by using any known linear scalarization technique in order to formulate a new single-objective optimization problem whose optimal solution will also be part of the Pareto-optimal solutions of the MOOP. After scalarisation, **P** becomes a scalarised problem $\mathbf{P}_s$ such that:

$$\mathbf{P}_s : \min \left\{ \hat{J} = \beta N_{L_2}(\mathbf{q}) + \sum_{i=1}^{C} w_i J_i(\mathbf{q}) \ : \ \mathbf{q} \in \mathbb{C}^{L\times 1} \right\} \quad (14)$$

where the weights $w_i \in R^+$ are chosen to represent the relative importance of each state $E_i$. These weight $w_i$ can be chosen, for example, as the occurrence probability of the corresponding state $E_i$.

**[0099]** For example, figure 4 illustrates graphically the case of weights $w_i$ following a truncated Gaussian probability distribution, with C = 5. If each state corresponds to a given position of the head, and thus of the ears, then the central state on the graph corresponds to the most frequent one. It is therefore sensible to assign the greatest importance to the cost function $J_3$ corresponding to that state, and hence to chose a large weight $w_3$. On the other hand, the positions at the extremes (PER3 and PER4 in Figure 4) are considered rather rare and it is therefore unnecessary to give them great importance.

**[0100]** In addition, $\beta \in [0, 1]$ also known as the Tikhonov parameter, adjusts the regularisation level. $\hat{J}$ can then be factorised, by replacing the expression of the individual cost functions $J_i$ and $N_{L2}$, as:

$$\hat{J} = \beta\|\mathbf{q}\|_2^2 + \sum_{i=1}^{C} w_i \|\mathbf{G}_i\mathbf{q} - \mathbf{d}_i\|_2^2 = (\hat{\mathbf{G}}\mathbf{q} - \hat{\mathbf{d}})^H \mathbf{W}(\hat{\mathbf{G}}\mathbf{q} - \hat{\mathbf{d}}) + \beta\|\mathbf{q}\|_2^2 \quad (15)$$

where Ĝ in the above formula (15) corresponds to Gext been defined in (4) above, and $\hat{d} \in R^{MC\times 1}$ is obtained by concatenating all the target vectors $\mathbf{d}_i$ such that

$$\hat{\mathbf{d}} = [\mathbf{d}_1^T, \mathbf{d}_2^T, \ldots, \mathbf{d}_C^T]^T \quad (16)$$

In addition, $\mathbf{W} \in R^{MC\times MC}$ is a diagonal matrix with the weights $w_i$ associated to each state such that:

$$\mathbf{W} = \begin{bmatrix} w_1\mathbf{I}_M & & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & & w_C\mathbf{I}_M \end{bmatrix} \quad (17)$$

**[0101]** This matrix consists of C identity blocks $\mathbf{I}_M \in R^{M\times M}$ multiplied by their specific weights $W_i$.

**[0102]** Finally, since $\hat{J}$ is convex and differentiable, the search for the roots of its gradient allows to find the unique optimal solution, which is given by

$$\mathbf{q}_{opt} = \left(\hat{\mathbf{G}}^H\mathbf{W}\hat{\mathbf{G}} + \beta\mathbf{I}\right)^{-1}\hat{\mathbf{G}}^H\mathbf{W}\hat{\mathbf{d}} \quad (18)$$

for a given set of weights $\{w_1, w_2, \ldots, w_C, \beta\}$.

**[0103]** In practice, according to the invention, the frequency response of one of the array's loudspeakers at that particular point is used as a desired target for each control point located in the bright zone, This approach has the merit of not requiring additional measurements, as the so-called *natural* target associated to each control point is found directly in the plant matrix $\mathbf{G}_i$, for a given system state $E_i$.

**[0104]** Furthermore, the same reasoning applies when considering multiple states, for it can be seen as the addition of new control points to the system. There is indeed no reason to impose the same set of targets to all states since it would add unnecessary constraints to an already over-determined system.

**[0105]** As a consequence, if the system has $M_B$ control points in its bright area and C states, the number of distinct targets to be determined will be $M_B \times C$, in the general case. For instance, if only one state $E_i$ is considered, $M_B$ control points in the bright zone and the response of the $\ell^{th}$ loudspeaker as a reference, the vector of *natural* target pressures $\mathbf{d}_i$ is expressed as:

$$\mathbf{d}_i = \left[g_{1\ell}, g_{2\ell}, \ldots, g_{M_B\ell}, 0, 0 \ldots, 0\right] \quad (19)$$

where the terms $g_{i\ell}$ ate those already defined in (1). Figure 5 illustrates the vector $\mathbf{d}_i$ in the particular case where M = 4 and $\ell$ = 5.

**[0106]** As for the PM method, the multi-state framework used by the system 100 and method 200 can be applied also to the acoustic contrast control (ACC) technique, which substantially aims to maximize the ratio of acoustic energy between the bright and dark zones, in particular without any consideration of the phase of the reproduced sound field.

**[0107]** In order to avoid the inversion problems related to ill-conditioned linear systems, the problem to be solved can be formulated as a minimization of the average acoustic energy $\mathbf{p}^H{}_d\mathbf{p}_d$ in the dark zone while keeping the energy level in the bright zone $\mathbf{p}^H{}_b\mathbf{p}_b$ at a constant value $E_b$.

**[0108]** In one possible embodiment, a limit is conveniently imposed to the energy of the optimal solution $\mathbf{q}_{opt}$, thus a new term is introduced that takes into account the $L_2$ norm of the q solution. The Lagrangian function to be minimized is then expressed as:

$$L = \mathbf{p}_d^H \mathbf{p}_d + \lambda_1(\mathbf{p}_b^H \mathbf{p}_b - E_B) + \lambda_2(\mathbf{q}^H \mathbf{q} - E) \quad (20)$$

**[0109]** After nullifying the partial q-derivative of the equation (20) above, the following eigenvalue problem arises:

$$(\mathbf{G}_d^H \mathbf{G}_d + \lambda_2)^{-1} \mathbf{G}_b^H \mathbf{G}_b \mathbf{q} = -\frac{1}{\lambda_1 \mathbf{q}} \quad (21)$$

**[0110]** Finally, the optimal solution $\mathbf{q}_{opt}$ is the eigenvector associated to the largest eigenvalue of (21), which has to be then scaled in order to match the energy constraint $\mathbf{p}^H{}_b\mathbf{p}_b = E_B$ on the bright zone, while fulfilling the energy limit E.

**[0111]** Accordingly, first, for each state $E_i$ and according to the above formula (2):

$$\mathbf{p}^{(i)} = \mathbf{G}_i \mathbf{q} = \begin{bmatrix} \mathbf{p}_b^{(i)} \\ \mathbf{p}_d^{(i)} \end{bmatrix} \quad (22)$$

where $\mathbf{p}^{(i)}_b$ and $\mathbf{p}^{(i)}_d$ contain respectively the pressure signals associated to $E_i$ at all control points in the bright and dark zones.

According to the invention, there is determined a unique solution $\mathbf{q}_{opt}$ that can lead to a combined maximum acoustic contrast for all system states $E_i$, $i$ = 1,...,$C$.

Such multi-objective optimization problem **P** can be expressed as:

$$\mathbf{P}: \max \{J_1(\mathbf{q}), J_2(\mathbf{q}), \ldots J_C(\mathbf{q}) : \mathbf{q} \in C^{L\times 1}\} \quad (23)$$

where

$$J_i(\mathbf{q}) = \frac{\mathbf{p}_b^{(i)H} \mathbf{p}_b^{(i)}}{\mathbf{p}_d^{(i)H} \mathbf{p}_d^{(i)}} > 0 \quad (24)$$

Then, according to methods well known in the art or readily available to those skilled in the art, this MOOP can be solved by apply a linear scalarisation, resulting in a new single-objective problem $\mathbf{P}_s$ as follows:

$$\mathbf{P}_s : \max \left\{ \hat{J}(w_i) = \sum_{i=1}^{C} w_i J_i(\mathbf{q}) \ : \ \mathbf{q} \in \mathbb{C}^{L\times 1} \right\} \quad (25)$$

where the $w_i \in R^+$ are weights given to each objective function $J_i$ and can be associated to the probability of occurrence of each state, as above mentioned.

**[0112]** In particular, in one possible embodiment of the system 100 and method 200 according to the invention, there is considered the maximisation of a new condensed objective function expressed as:

$$\breve{J} = \frac{\sum_{i=1}^{C} \alpha_i \mathbf{p}_b^{(i)H} \mathbf{p}_b^{(i)}}{\sum_{i=1}^{C} \alpha_i \mathbf{p}_d^{(i)H} \mathbf{p}_d^{(i)}} \quad (26)$$

where the numerator and denominator are the weighted sum, over all states, of the average acoustic energy in the bright and dark zones, respectively. The weights $\alpha_i$ have the same function as the weights $w_i$, without any loss of generality. The following mathematical identity can be deduced:

$$\breve{J} = \frac{\sum_{i=1}^{C} \alpha_i \mathbf{p}_b^{(i)H} \mathbf{p}_b^{(i)}}{\sum_{i=1}^{C} \alpha_i \mathbf{p}_d^{(i)H} \mathbf{p}_d^{(i)}} = \sum_{i=1}^{C} \breve{w}_i \left( \frac{\mathbf{p}_b^{(i)H} \mathbf{p}_b^{(i)}}{\mathbf{p}_d^{(i)H} \mathbf{p}_d^{(i)}} \right) = \hat{J}(\breve{w}_i) \quad (27)$$

where

$$\breve{w}_i = \frac{\alpha_i \mathbf{p}_d^{(i)H} \mathbf{p}_d^{(i)}}{\sum_{j=1}^{C} \alpha_i \mathbf{p}_d^{(j)H} \mathbf{p}_d^{(j)}} \quad (28)$$

Then, for any set of positive weights $w_i$ in the single-objective problem $\mathbf{P}_s$ as defined in the above definition (25), the optimal solution obtained is necessarily maximizing the original MOOP **P**. Consequently, the optimization of $\breve{J}$ is adequate to find a Pareto optimal solution for **P**, for any set of weights $\alpha_i$.

**[0113]** Finally, the term $\breve{J}$ as defined in the above formula (26) can be factorised as:

$$\breve{J} = \frac{\hat{\mathbf{p}}_b^H \mathbf{W} \hat{\mathbf{p}}_b}{\hat{\mathbf{p}}_d^H \mathbf{W} \hat{\mathbf{p}}_d} \quad (29)$$

where

$$\hat{\mathbf{p}}_b = \left[ \mathbf{p}_b^{(1)} \ \mathbf{p}_b^{(2)} \ \ldots \ \mathbf{p}_b^{(C)} \right]^T \quad \text{and} \quad \hat{\mathbf{p}}_d = \left[ \mathbf{p}_d^{(1)} \ \mathbf{p}_d^{(2)} \ \ldots \ \mathbf{p}_d^{(C)} \right]^T \quad (30)$$

are the concatenated vectors of reproduced pressures and

$$\mathbf{W} = \begin{bmatrix} \alpha_1 \mathbf{I}_M & & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & & \alpha_C \mathbf{I}_M \end{bmatrix} \quad (31)$$

The Lagrangian formulation above introduced gives the following equation:

$$\hat{L} = \hat{\mathbf{p}}_d^H \mathbf{R} \hat{\mathbf{p}}_d + \lambda_1 (\hat{\mathbf{p}}_b^H \mathbf{R} \hat{\mathbf{p}}_b - E_B) + \lambda_2 (\mathbf{q}^H \mathbf{q} - E) \quad (32)$$

where $q_{opt}$ is a solution of the following eigenvalue problem:

$$(\hat{\mathbf{G}}_d^H \mathbf{R}\hat{\mathbf{G}}_d + \lambda_2)^{-1}\hat{\mathbf{G}}_b^H \mathbf{R}\hat{\mathbf{G}}_b\mathbf{q} = -\frac{1}{\lambda_1 \mathbf{q}} \quad (33)$$

where $\hat{G}_b$ and $\hat{G}_d$ are obtained by collating the rows of $\hat{G}$ that are related to the bright and dark zones, respectively, for all states.

**[0114]** Hence, it is evident from the foregoing description that the system 100 and method 200 according to the present invention allow creating different listening zones in an environment, according to a solution that is functionally effective and robust, and is easy to be implemented in practice since it does not require the use of sensors and/or sophisticated tracking systems.

**[0115]** In particular, the present invention can be implemented also as computer product program comprising program code for performing, when executed by a processor device, e.g. the processor of the electronic control unit 10, the method 200 as above described and in particular as claimed, and also as a non-transitory computer-readable storage medium comprising instructions which, when executed by a processor device, .g. the processor of the electronic control unit 10, cause the processor device to perform the method 200 as above described and in particular as claimed.

**[0116]** The system 100 and method 200 thus conceived are susceptible of modifications and variations, all of which are within the scope of the inventive concept as defined in particular by the appended claims; for example, in relation to the specific application, it is possible to consider at the same time a plurality of geometrical or physical parameters that influence/modify the acoustic transmissions inside the environment 20.

**[0117]** All the details may furthermore be replaced with technically equivalent elements.

## Claims

1. A system (100) for creating at least a first listening zone (A) and a second listening zone (B) in an environment (20) where audio contents have to be transmitted, the system (100) being **characterized in that** it comprises at least:

   - an electronic control unit (10);
   - a plurality of loudspeakers (1, 2, 3, 4, 5) suitable to be installed at predetermined positions inside said environment (20);

   wherein the electronic control unit (10) is configured:

   - to calculate, for each transmission frequency of a plurality of predetermined transmission frequencies, a reference matrix (G) wherein all elements of the reference matrix (G) are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and one or more audio receiving target points (Mi) suitable to be located inside the first listening zone (A) and the second listening zone (B), wherein the reference matrix is calculated based on a predefined reference value assigned to at least one physical or geometric parameter influencing acoustic transmissions inside the environment (20) from the plurality of loudspeakers towards said one or more audio receiving target points;
   - to calculate, for each transmission frequency of said plurality of predetermined transmission frequencies, a plurality of additional matrices (Gi), wherein all elements of each additional matrix (Gi) are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and said one or more audio receiving target points, and wherein each additional matrix (Gi) is calculated by assigning to said at least one physical or geometric parameter a respective given value which is different from said predefined reference value and from the given value assigned to all other additional matrices (Gi);
   - to calculate, for each given frequency, an overall matrix ($G_{EXT}$) by concatenating the reference matrix (G) with all additional matrices (Gi) calculated for the given frequency;
   - to elaborate, based on the overall matrix ($G_{EXT}$) calculated, one or more sets of digital filters to be applied by the electronic control unit (10) to the plurality of loudspeakers for transmitting in the environment (20) audio content to be listened in one of said first and second listening zones (A, B) while being at least acoustically attenuated in the other one of said first and second listening zones (A, B).

2. The system (100) of claim 1, wherein the one or more sets of digital filters elaborated are invariable.

3. The system (100) of claim 1 or 2, wherein the electronic control unit (10) is configured to associate to said predefined

reference value and to each of the given values assigned to the parameter for each additional matrix a corresponding numerical weight.

**4.** The system (100) of claim 3, wherein each numerical weight associated to said predefined reference value and to each of the given values assigned to the parameter for each additional matrix calculated, is defined based on an estimated probability that the parameter assumes the predefined reference value or a corresponding given value.

**5.** The system (100) as in any one of the previous claims, wherein the electronic control unit (10) is configured to elaborate said one or more sets of digital filters based on the solution of a multi-objective optimization problem, wherein for each frequency, each matrix of the calculated reference matrices and additional matrices is associated to one objective to be optimized.

**6.** The system (100) as in claim 5, wherein one the objectives to be optimized comprises or is constituted by the energy associated to the one or more set of digital filters elaborated.

**7.** The system (100) as in any one of the previous claims, wherein said at least one physical or geometric parameter comprises or is constituted by the position of at least one ear of a first person suitable to be located inside the first listening zone (A) and of at least one ear of a second person suitable to be located inside the second listening zone (B).

**8.** The system (100) as in any one of the previous claims, wherein said at least one physical or geometric parameter is selected among the group comprising the temperature, the humidity, number of people, positions of people of/in the environment where audio contents are transmitted.

**9.** A motor vehicle (110), comprising a system (100) according to one or more of the previous claims.

**10.** A method (200) for creating at least a first listening zone (A) and a second listening zone (B) in an environment (20) where audio contents have to be transmitted, the method (200) being **characterized in that** it comprises at least:

- (210): a first step of calculating, by means of an electronic control unit (10), for each transmission frequency of a plurality of predetermined transmission frequencies, a reference matrix (G) wherein all elements of the reference matrix (G) are constituted each by a corresponding transfer function between each loudspeaker of a plurality of loudspeakers (1, 2, 3, 4, 5, ... L) suitable to be installed at predetermined positions inside said environment (20) and one or more audio receiving target points (Mi) suitable to be located inside the first listening zone (A) and the second listening zone (B), wherein said reference matrix is calculated based on a predefined reference value assigned to at least one physical or geometric parameter influencing acoustic transmissions inside the environment (20) from the plurality of loudspeakers towards said one or more audio receiving target points;
- (220): a second step of calculating, by means of said electronic control unit (10), for each transmission frequency of said plurality of predetermined transmission frequencies, a plurality of additional matrices (Gi) wherein all elements of each additional matrix (Gi) are constituted each by a corresponding transfer function between each loudspeaker of the plurality of loudspeakers and said one or more audio receiving target points, wherein each additional matrix (Gi) is calculated by assigning to said at least one physical or geometric parameter a respective given value which is different from said predefined reference value and from the given value assigned to all other additional matrices (Gi);
- (230): a third step of calculating, for each given frequency, by means of said electronic control unit (10), an overall matrix ($G_{EXT}$) by concatenating the reference matrix (G) calculated with all additional matrices (Gi) calculated for the given frequency;
- (240): a fourth step of elaborating, by means of said electronic control unit (10), based on the overall matrix ($G_{EXT}$) calculated, one or more sets of digital filters to be applied to the plurality of loudspeakers for transmitting in the environment audio content to be listened to in one of said first and second listening zones (A, B) while being at least acoustically attenuated in the other one of said first and second listening zones (A, B).

**11.** The method (200) according to claim 10, wherein said step (240) of elaborating comprises keeping the one or more sets of digital filters once elaborated invariable.

**12.** The method (200) according to claim 10 or 11, wherein said first step (210) of calculating, comprises associating to said predefined reference value and to each of the given values assigned to the parameter for each additional matrix calculated a corresponding numerical weight.

**13.** The method (200) of claim 12, wherein each numerical weight associated to said predefined reference value and to each of the given values assigned to the parameter for each additional matrix calculated, is defined based on an estimated probability that the parameter assumes the predefined reference value or a corresponding given value.

**14.** A computer product program comprising program code for performing, when executed by a processor device, the method of any of claims 10 to 13.

**15.** A non-transitory computer-readable storage medium comprising instructions which, when executed by a processor device, cause the processor device to perform the method of any of claims 10 to 13.

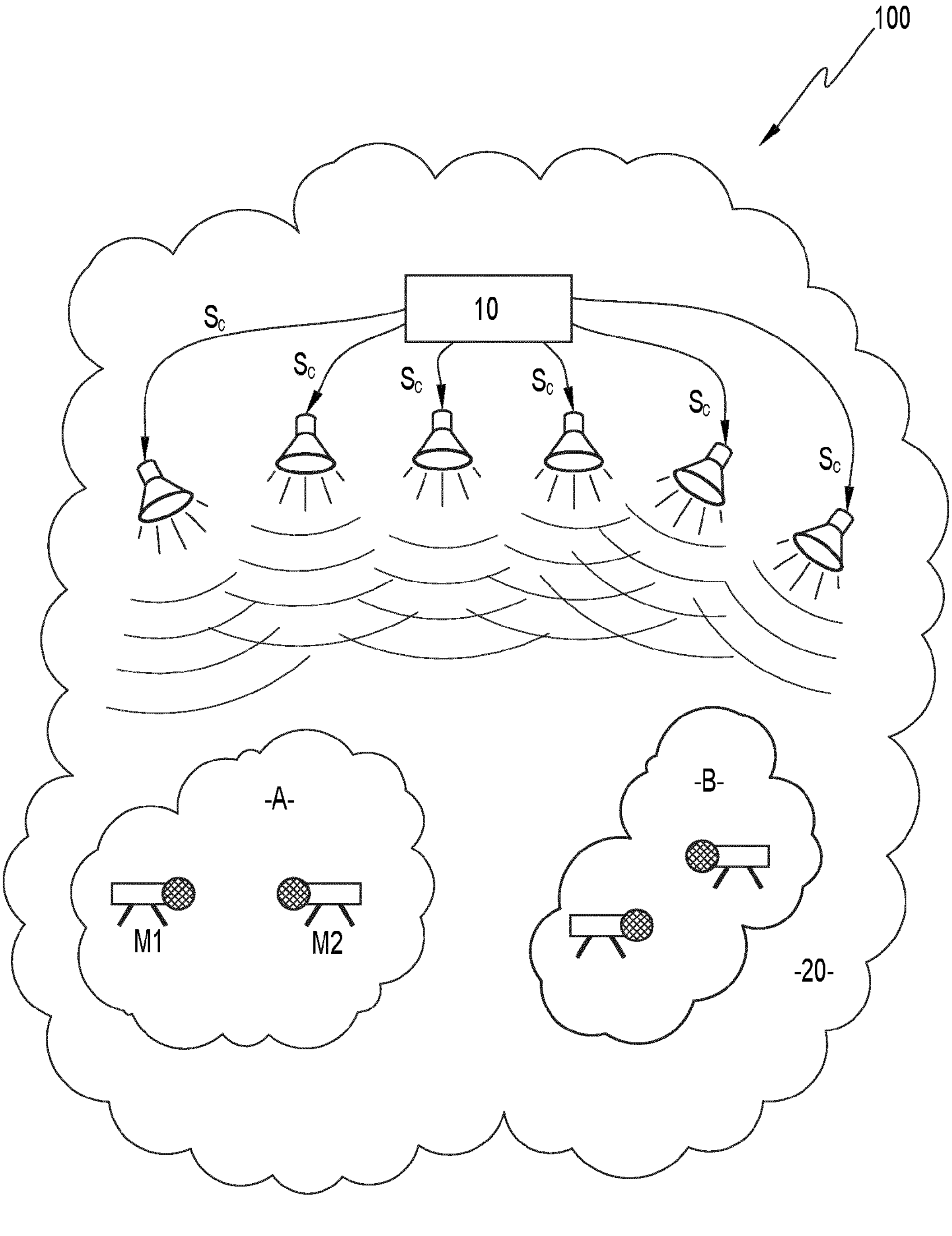


FIG.1

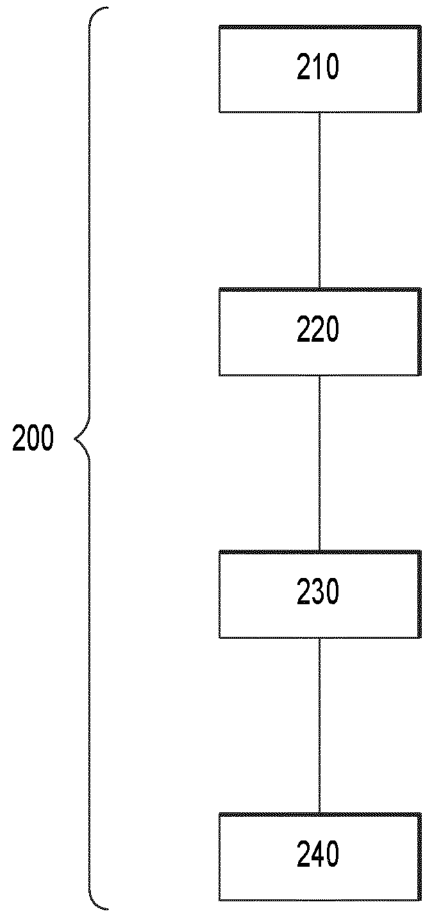


FIG.2

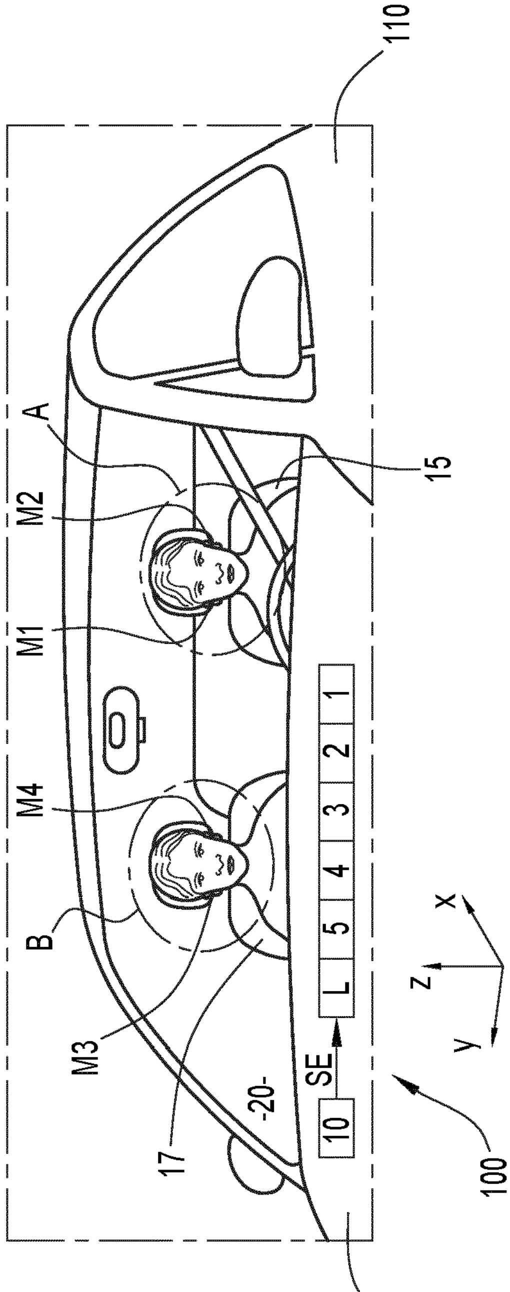


FIG.3

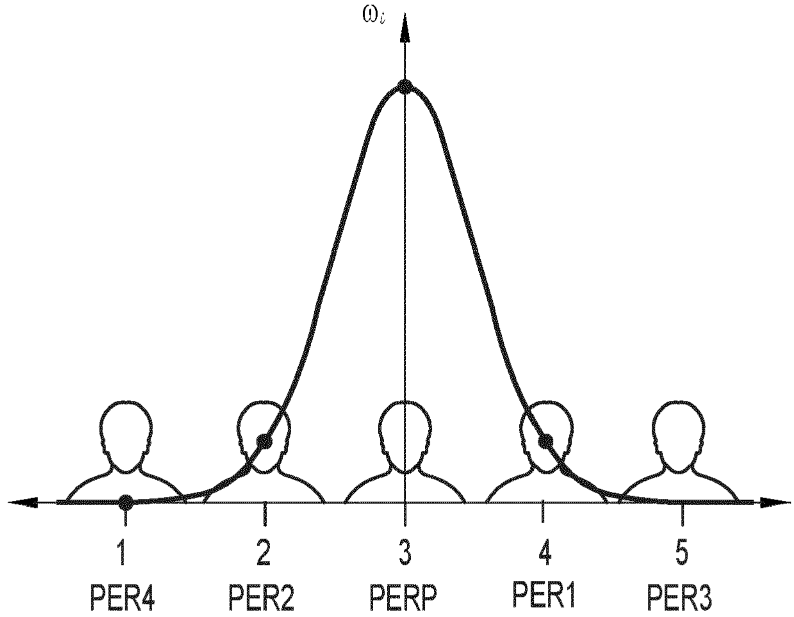


FIG.4

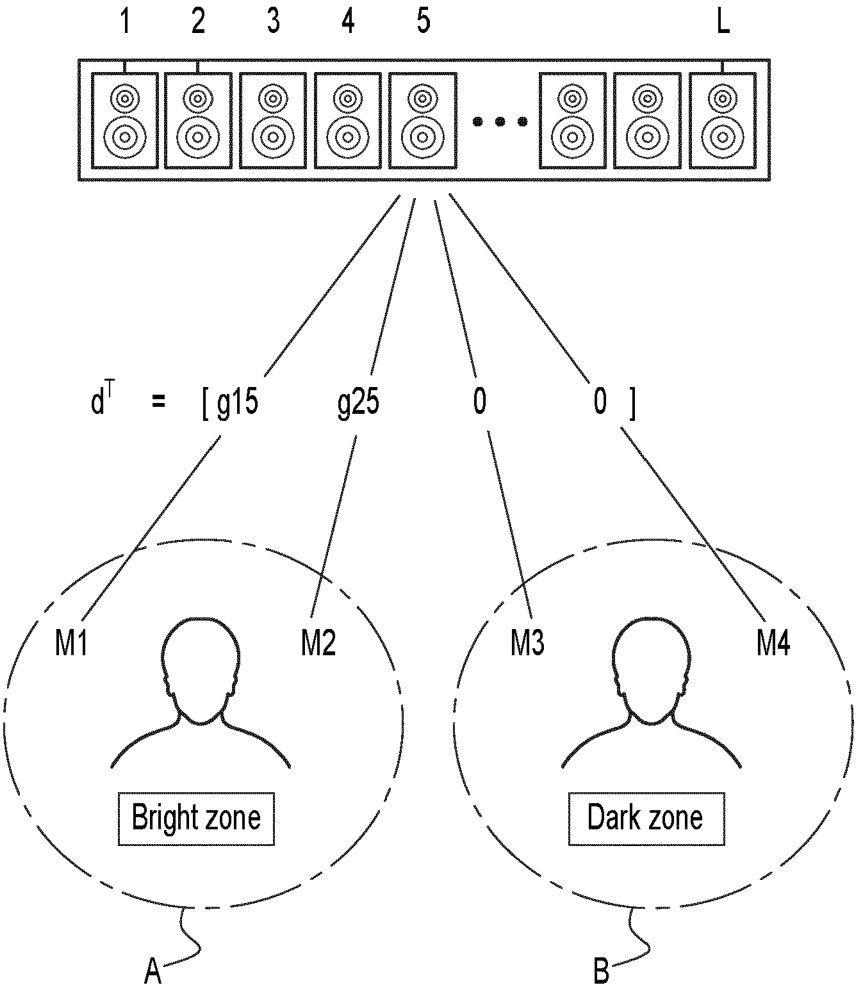


FIG.5

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# EUROPEAN SEARCH REPORT

Application Number
EP 23 19 6039

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X | WO 2018/001490 A1 (HUAWEI TECH CO LTD [CN]; UNIV SOUTHAMPTON [GB]) 4 January 2018 (2018-01-04) | 1-6,9-15 | INV. H04S7/00 |
| Y | * page 9 - page 23; figures 1-7 * | 7,8 | ADD. H04R3/12 |
| X | EP 3 451 696 A1 (SQAND CO LTD [KR]) 6 March 2019 (2019-03-06) | 1-6,9-15 | |
| Y | * paragraphs [0030] - [0065]; figures 1,2 * | 7,8 | |
| X | US 2021/360363 A1 (ROUSSEL GEORGES [FR] ET AL) 18 November 2021 (2021-11-18) | 1-15 | |
| Y | * paragraphs [0047] - [0086]; figures 1,2 * | 7,8 | |

TECHNICAL FIELDS SEARCHED (IPC)

H04S
H04R

The present search report has been drawn up for all claims

1

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 21 February 2024 | Navarri, Massimo |

CATEGORY OF CITED DOCUMENTS

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