



Method and device for control of a unit for reproduction of an acoustic field

The present invention relates to a method and a device
5 for control of a reproduction unit for an acoustic field.

Sound is a wavelike acoustic phenomenon which evolves over time and in space. The existing techniques act
10 mainly on the temporal aspect of sounds, the processing of the spatial aspect being very incomplete.

Specifically, the existing high-quality reproduction systems actually necessitate a predetermined spatial
15 configuration of the reproduction unit.

For example, so-called multichannel systems address different and predetermined signals to several
20 loudspeakers whose distribution is fixed and known.

Likewise, so-called "ambisonic" systems, which consider the direction from which the sounds which reach a listener originate, require a reproduction unit whose configuration must comply with certain positioning
25 rules.

In these systems, the sound environment is regarded as an angular distribution of sound sources about a point, corresponding to the listening position. The signals
30 correspond to a decomposition of this distribution over a basis of directivity functions called spherical harmonics.

In the current state of development of these systems,
35 good-quality reproduction is possible only with a spherical distribution of loudspeakers and a substantially regular angular distribution.



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Thus, when the existing techniques are implemented with a reproduction unit whose spatial distribution is arbitrary, the quality of reproduction is greatly impaired, in particular on account of angular
5 distortions.

Recent technical developments make it possible to consider a modeling in time and in the three dimensions in space of an acoustic field rather than the angular
10 distribution of the sound environment.

In particular, the doctoral thesis "Représentation de champs acoustiques, application à la transmission et à la reproduction de scènes sonores complexes dans un
15 contexte multimédia" [Representation of acoustic fields, application to the transmission and to the reproduction of complex sound scenes in a multimedia context] Université Paris VI, Jérôme Daniel, of 11 July 2000, defines functions describing the wavelike
20 characteristics of an acoustic field and allowing decomposition over a basis of functions of space and time which completely describes a three-dimensional acoustic field.

25 However, in this document, the theoretical solutions are inspired by the so-called "Ambisonic" systems and high-quality reproduction can be obtained only for the 5 existing regular spherical distributions. No element makes it possible to ensure high-quality reproduction
30 with the help of an arbitrary spatial configuration of the reproduction unit.

It is therefore apparent that no system of the prior art makes it possible to perform quality reproduction
35 with the help of an arbitrary spatial configuration of the reproduction unit.

The aim of the invention is to remedy this problem by

providing a method and a device for determining signals for controlling a reproduction unit for restoring an acoustic field whose spatial configuration is arbitrary.

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A subject of the invention is a method of controlling a reproduction unit for restoring an acoustic field so as to obtain a reproduced acoustic field of specific characteristics substantially independent of the intrinsic characteristics of reproduction of said unit, said reproduction unit comprising a plurality of reproduction elements, characterized in that it comprises at least:

- 15 - a step of establishing a finite number of coefficients representative of the distribution in time and in the three dimensions in space of said acoustic field to be reproduced;
- a step of determining reconstruction filters representative of said reproduction unit, comprising a substep of taking into account at least spatial characteristics of said reproduction unit;
- 20 - a step of determining at least one control signal for said elements of said reproduction unit, said at least one signal being obtained by the application, to said coefficients, of said reconstruction filters; and
- 25 - a step of delivering said at least one control signal, with a view to an application to said reproduction elements so as to generate said acoustic field reproduced by said reproduction unit.

30

According to other characteristics:

- said step of establishing a finite number of coefficients representative of the distribution of said acoustic field to be reproduced comprises:
- 35 - a step consisting in providing an input signal comprising temporal and spatial information for a sound environment; and
- a step of shaping said input signal by decomposing

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- said information over a basis of spatio-temporal functions, this shaping step making it possible to deliver a representation of said acoustic field to be reproduced corresponding to said sound environment in the form of a linear combination of said functions;
- 5 - said step of establishing a finite number of coefficients representative of the distribution of said acoustic field to be reproduced comprises:
- 10 - a step consisting in providing an input signal comprising a finite number of coefficients representative of said acoustic field to be reproduced in the form of a linear combination of spatio-temporal functions;
- 15 - said spatio-temporal functions are so-called Fourier-Bessel functions and/or linear combinations of these functions;
- 20 - said substep of taking into account at least spatial characteristics of said reproduction unit is carried out at least with the help of parameters representative, for each element, of the three coordinates of its position with respect to the center placed in the listening zone, and/or of its spatio-temporal response;
- 25 - said substep of taking into account at least spatial characteristics of said reproduction unit is carried out moreover with the help:
- 30 - of parameters describing, in the form of weighting coefficients, a spatial window which specifies the distribution in space of reconstruction constraints for the acoustic field; and
- 35 - of a parameter describing an order of operation limiting the number of coefficients to be taken into account during said step of determining reconstruction filters;
- said substep of taking into account at least spatial characteristics of said reproduction unit is carried out moreover with the help:
- of parameters constituting a list of spatio-

- temporal functions whose reconstruction is imposed; and
- of a parameter describing an order of operation limiting the number of coefficients to be taken into account during said step of determining reconstruction filters;
 - said step of taking into account at least spatial characteristics of said reproduction unit is carried out moreover at least with the help of one of the parameters chosen from the group consisting:
 - of parameters representative of at least one of the three coordinates of the position of each or some of the elements, with respect to the center placed in the listening zone;
 - of parameters representative of the spatio-temporal responses of each or some of the elements;
 - of a parameter describing an order of operation limiting the number of coefficients to be taken into account during said step of determining reconstruction filters;
 - of parameters constituting a list of spatio-temporal functions whose reconstruction is imposed;
 - of parameters representative of the templates of said reproduction elements;
 - of a parameter representative of the desired local capacity of adaptation to the spatial irregularity of the configuration of said reproduction unit;
 - of a parameter defining the radiation model for said reproduction elements;
 - of parameters representative of the frequency response of said reproduction elements;
 - of a parameter representative of a spatial window;
 - of parameters representative of a spatial window in the form of weighting coefficients; and
 - of a parameter representative of the radius of a spatial window when the latter is a ball;
 - the method comprises a calibration step making it possible to deliver all or part of the parameters used in said step of determining reconstruction filters;

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- said calibration step comprises, for at least one of the reproduction elements:
 - a substep of acquiring signals representative of the radiation of said at least one element in the listening region; and
 - a substep of determining spatial and/or acoustic parameters of said at least one element;
- said calibration step comprises:
 - a substep of emitting a specific signal to said at least one element of said reproduction unit, said acquisition substep corresponding to the acquisition of the sound wave emitted in response by said at least one element; and
 - a substep of transforming said signals acquired into a finite number of coefficients representative of the sound wave emitted, so as to allow the carrying out of said substep of determining spatial and/or acoustic parameters;
- said acquisition substep corresponds to a substep of receiving a number of coefficients representative of the acoustic field generated by said at least one element in the form of a linear combination of spatio-temporal functions, which coefficients are used directly during said substep of determining spatial and/or acoustic parameters of said at least one element;
- said calibration substep furthermore comprises a substep of determining the position in at least one of the three dimensions in space of said at least one element of said reproduction unit;
- said calibration step furthermore comprises a substep of determining the spatio-temporal response of said at least one element of said reproduction unit;
- said calibration step furthermore comprises a substep of determining the frequency response of said at least one element of said reproduction unit;
- the method comprises a step of simulating all or part of the parameters necessary for carrying out said

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step of determining reconstruction filters;

- said simulation step comprises:

- a substep of determining missing parameters from among the parameters used during said step of
5 determining reconstruction filters;

- a plurality of calculation substeps making it possible to determine the value or values of the missing parameter or parameters as defined previously as a function of the parameters received, of the
10 frequency, and of predetermined default parameters;

- said simulation step comprises a substep of determining a list of elements of the reproduction unit that are active as a function of the frequency, and said calculation substeps are carried out just for the
15 elements of said list;

- said simulation step comprises a substep of calculating a parameter representative of the order of operation limiting the number of coefficients to be taken into account during said step of determining
20 reconstruction filters with the help of at least the position in space of all or part of the elements of the reproduction unit;

- said simulation step comprises a step of determining parameters representative of a spatial
25 window in the form of weighting coefficients with the help of a parameter representative of the spatial window in the spherical reference frame and/or of a parameter representative of the radius of said spatial window when the latter is a ball;

- said simulation step comprises a substep of determining a list of spatio-temporal functions whose reconstruction is imposed with the help of the position of all or part of the elements of the reproduction
30 unit;

- the method comprises a step of input making it possible to determine all or part of the parameters used during said step of determining reconstruction
35 filters;

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- said step of determining reconstruction filters comprises:

- a plurality of calculation substeps carried out for a finite number of frequencies of operation and making it possible to deliver a matrix for weighting the acoustic field, a matrix representative of the radiation of the reproduction unit, and a matrix representative of the spatio-temporal functions whose reconstruction is imposed; and

10 - a substep of calculating a decoding matrix, carried out for a finite number of operating frequencies, with the help of the matrix for weighting the acoustic field, of the matrix representative of the radiation of the reproduction unit, of the matrix
15 representative of the spatio-temporal functions whose reconstruction is imposed, and of a parameter representative of the desired local capacity of adaptation to the spatial irregularity of the reproduction unit, representative of the reconstruction
20 filters;

- said calculation substep making it possible to deliver a matrix representative of the radiation of the reproduction unit is carried out with the help of parameters representative for each element:

25 - of the three coordinates of its position with respect to the center placed in the listening zone; and/or

- of its spatio-temporal response; and

- said calculation substep making it possible to deliver a matrix representative of the radiation of the reproduction unit is carried out moreover with the help of parameters representative for each element of its frequency response.

35 A subject of the invention is also a computer program comprising program code instructions for the execution of the steps of the method when said program is executed on a computer.

A subject of the invention is also a removable medium of the type comprising at least one processor and a nonvolatile memory element, characterized in that said
5 memory comprises a program comprising instructions for the execution of the steps of the method when said processor executes said program.

The subject of the invention is also a device for
10 controlling a reproduction unit for restoring an acoustic field, comprising a plurality of reproduction elements, characterized in that it comprises at least:
- means of determining reconstruction filters representative of said reproduction unit, adapted so as
15 to make it possible to take into account at least spatial characteristics of said reproduction unit; and
- means for determining at least one control signal for said elements of said reproduction unit, said at least one signal being obtained by application of said
20 reconstruction filters to a finite number of coefficients representative of the distribution in time and in the three dimensions in space of said acoustic field to be reproduced.

25 According to other characteristics of the invention:
- the device is associated with means for shaping an input signal comprising temporal and spatial information for a sound environment to be reproduced, which means are adapted for decomposing said
30 information over a basis of spatio-temporal functions so as to deliver a signal comprising said finite number of coefficients representative of the distribution in time and in the three dimensions in space of said acoustic field to be reproduced, corresponding to said
35 sound environment, in the form of a linear combination of said spatio-temporal functions;
- said spatio-temporal functions are so-called Fourier-Bessel functions and/or linear combinations of

these functions;

- said means for determining reconstruction filters receive as input at least one of the parameters from the following parameters:

- 5 - parameters representative of at least one of the three coordinates of the position of each or some of the elements, with respect to the center placed in the listening zone;
- parameters representative of the spatio-temporal responses of each of some of the elements;
- 10 - a parameter describing an order of operation limiting the number of coefficients to be taken into account in the means of determining reconstruction filters;
- 15 - parameters representative of the templates of said reproduction elements;
- a parameter representative of the desired local capacity of adaptation to the spatial irregularity of the configuration of said reproduction unit;
- 20 - a parameter defining the radiation model for said reproduction elements;
- parameters representative of the frequency response of said reproduction elements;
- a parameter representative of a spatial window;
- 25 - parameters representative of a spatial window in the form of weighting coefficients;
- parameters representative of the radius of a spatial window when the latter is a ball; and
- parameters constituting a list of spatio-temporal functions whose reconstruction is imposed;
- 30 - each of said parameters received by said means of determining reconstruction filters is conveyed by one of the signals from the group of the following signals:
- a definition signal comprising information representative of the spatial characteristics of the reproduction unit;
- 35 - a supplementary signal comprising information representative of the acoustic characteristics

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associated with the elements of the reproduction unit;
and

an optimization signal comprising information
relating to an optimization strategy,

5 - so as to deliver, with the aid of the parameters
contained in these signals, a signal representative of
said reconstruction filters representative of said
reproduction unit;

- the device is associated with means for
10 determining all or part of the parameters received by
said means for determining reconstruction filters, said
means comprising at least one of the following
elements:

- simulation means;

15 - calibration means;

- parameters input means;

- said means for determining reconstruction filters
are adapted for determining a set of filters
representative of the position in space of the elements

20 of the reproduction unit; and

- said means of determining reconstruction filters
are adapted for determining a set of filters
representative of the room effect induced by the
listening zone.

25

The invention will be better understood on reading the
description which follows, given merely by way of
example and while referring to the appended drawings,
in which:

30 - fig. 1 is a representation of a spherical
reference frame;

- fig. 2 is a diagram of a reproduction system
according to the invention;

- fig. 3 is a schematic diagram of the method of the
35 invention;

- fig. 4 is a diagram detailing the calibration
means;

- fig. 5 is a diagram detailing the calibration

step;

- fig. 6 is a diagram of the simulation step;
- fig. 7 is a diagram of the means of determining reconstruction filters;
- 5 - fig. 8 is a diagram of the step of determining reconstruction filters;
- fig. 9 is a mode of embodiment of the step of shaping the input signal; and
- fig. 10 is a mode of embodiment of the step of
10 determining control signals.

Represented in figure 1 in such a way as to specify the system of coordinates to which reference is made in the text is a conventional spherical reference frame.

15

This reference frame is an orthonormal reference frame, with origin O and comprising three axes (OX) , (OY) and (OZ) .

- 20 In this reference frame, a position denoted $\bar{x}$ is described by means of its spherical coordinates (r, θ, ϕ) , where r designates the distance with respect to the origin O and θ the orientation in the vertical plane and ϕ the orientation in the horizontal plane.

25

- In such a reference frame, an acoustic field is known if at each instant t the acoustic pressure denoted $p(r, \theta, \phi, t)$, whose temporal Fourier transform is denoted $P(r, \theta, \phi, f)$ where f designates the frequency, is defined
30 at every point.

Figure 2 is a representation of a reproduction system according to the invention.

- 35 This system comprises a decoder 1 controlling a reproduction unit 2 which comprises a plurality of elements 3_1 to 3_N , such as loudspeakers, acoustic enclosures or any other sound source, arranged in an

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arbitrary manner in a listening region 4. The origin 0 of the reference frame, referred to as the center 5 of the reproduction unit, is placed arbitrarily in the listening region 4.

5

Together, the set of spatial, acoustic and electrodynamic characteristics is considered to be the intrinsic characteristics of reproduction.

10 The system also comprises means 6 for shaping an input signal SI and means 7 for generating parameters comprising means 8 of simulation, means 9 of calibration and means 10 of inputting parameters.

15 The decoder 1 comprises means 11 for determining control signals and means 12 for determining reconstruction filters.

The decoder 1 receives as input a signal SI_{FB} comprising
20 information representative of the three-dimensional acoustic field to be reproduced, a definition signal SL comprising information representative of the spatial characteristics of the reproduction unit 2, a supplementary signal RP comprising information
25 representative of the acoustic characteristics associated with the elements 3_1 to 3_N and an optimization signal OS comprising information relating to an optimization strategy.

30 The decoder emits a specific control signal sc_1 to sc_N destined for each of the elements 3_1 to 3_N of the reproduction unit 2.

Represented diagrammatically in figure 3 are the main
35 steps of the method implemented in a system according to the invention as described with reference to figure 2.

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The method comprises a step 20 of inputting optimization parameters, a step 30 of calibration making it possible to measure certain characteristics of the reproduction unit 2 and a simulation step 40.

5

During the parameters input step 20 implemented by the interface means 10, certain parameters of the operation of the system may be defined manually by an operator or be delivered by a suitable device.

10

During the calibration step 30, described in greater detail with reference to figures 4 and 5, the calibration means 9 are linked in turn one by one with each of the elements 3_1 to 3_N of the reproduction unit 2 so as to measure parameters associated with these elements.

15

The simulation step 40, implemented by the means 8, makes it possible to simulate the signals of parameters necessary for the operation of the system which are neither input during step 20 nor measured during step 30.

20

The means 7 for generating parameters then deliver as output the definition signal SL, the supplementary signal RP and the optimization signal OS.

25

Thus, steps 20, 30 and 40 make it possible to determine the set of parameters necessary for the implementation of step 50.

30

Following these steps, the method comprises a step 50 of determining reconstruction filters that is implemented by the means 12 of the decoder 1 and makes it possible to deliver a signal FD representative of the reconstruction filters.

35

This step 50 of determining reconstruction filters

makes it possible to take into account the at least spatial characteristics of the reproduction unit 2 that are defined during the steps 20 of input, 30 of calibration or 40 of simulation. Step 50 also makes it possible to take into account the acoustic characteristics associated with the elements 3_1 to 3_N of the reproduction unit 2 and the information relating to an optimization strategy.

10 The reconstruction filters obtained on completion of step 50 are subsequently stored in the decoder 1 so that steps 20, 30, 40 and 50 are repeated only in case of modification of the reproduction unit 2 or of the optimization strategies.

15

During operation, the signal SI comprising temporal and spatial information of a sound environment to be reproduced, is provided to the shaping means 6, for example by direct acquisition or by reading a recording or by synthesis with the aid of computer software. This signal SI is shaped during a shaping step 60. On completion of this step, the means 6 deliver to the decoder 1 a signal SI_{FB} comprising a finite number of coefficients representative, over a basis of spatio-temporal functions, of the distribution in time and in the three dimensions in space, of an acoustic field to be reproduced corresponding to the sound environment to be reproduced.

30 As a variant, the signal SI_{FB} is provided by exterior means, for example a microcomputer comprising synthesis means.

The invention is based on the use of a family of spatio-temporal functions making it possible to describe the characteristics of any acoustic field.

In the embodiment described, these functions are so-

called spherical Fourier-Bessel functions of the first kind subsequently referred to as Fourier-Bessel functions.

5 In a zone devoid of sound sources and devoid of obstacles, the Fourier-Bessel functions are solutions of the wave equation and constitute a basis which spans all the acoustic fields produced by sound sources situated outside this zone.

10

Any three-dimensional acoustic field is therefore expressed as a linear combination of Fourier-Bessel functions, according to the expression for the inverse Fourier-Bessel transform which is expressed as:

15

$$P(r, \theta, \phi, f) = 4\pi \sum_{l=0}^{\infty} \sum_{m=-l}^l P_{l,m}(f) j_l(kr) y_l^m(\theta, \phi)$$

In this equation, the terms $P_{l,m}(f)$ are, by definition, the Fourier-Bessel coefficients of the field
 20 $p(r, \theta, \phi, t)$, $k = \frac{2\pi f}{c}$, c is the speed of sound in air (340 ms^{-1}), $j_l(kr)$ is the spherical Bessel function of the first kind of order l defined by $j_l(x) = \sqrt{\frac{\pi}{2x}} J_{l+1/2}(x)$

where $J_v(x)$ is the Bessel function of the first kind of order v , and $y_l^m(\theta, \phi)$ is the real spherical harmonic of
 25 order l and of term m , with m ranging from $-l$ to l , defined by:

$$y_l^m(\theta, \phi) = \begin{cases} \frac{1}{\sqrt{\pi}} P_l^{|m|}(\cos \theta) \cos(m\phi) & \text{for } m > 0 \\ \frac{1}{\sqrt{2\pi}} P_l^0(\cos \theta) & \text{for } m = 0 \\ \frac{1}{\sqrt{\pi}} P_l^{|m|}(\cos \theta) \sin(m\phi) & \text{for } m < 0 \end{cases}$$

In this equation, the $P_l^m(x)$ are the associated Legendre

functions defined by:

$$P_l^m(x) = \sqrt{\frac{2l+1}{2}} \sqrt{\frac{(l-m)!}{(l+m)!}} (1-x^2)^{m/2} \frac{d^m}{dx^m} P_l(x)$$

with $P_l(x)$ the Legendre polynomials, defined by:

$$P_l(x) = \frac{1}{2^l l!} \frac{d^l}{dx^l} (x^2 - 1)^l$$

5

The Fourier-Bessel coefficients are also expressed in the temporal domain by the coefficients $p_{l,m}(t)$ corresponding to the inverse temporal Fourier transform of the coefficients $P_{l,m}(f)$.

10

As a variant, the method of the invention uses function bases expressed as linear combinations, possibly infinite, of Fourier-Bessel functions.

15 During the shaping step 60, carried out by the means 6, the input signal SI is decomposed into Fourier-Bessel coefficients $p_{l,m}(t)$ in such a way as to establish the coefficients forming the signal SI_{FB} .

20 The decomposition into Fourier-Bessel coefficients is conducted up to a limit order L defined previously to this shaping step 60 during the input step 20.

On completion of step 60, the signal SI_{FB} delivered by
 25 the shaping means 6 is introduced into the means 11 for determining the control signals. These means 11 also receive the signal FD representative of the reconstruction filters defined by taking account in particular of the spatial configuration of the
 30 reproduction unit 2.

The coefficients of the signal SI_{FB} , delivered on completion of step 60, are used by the means 11 during a step 70 of determining the control signals sc_1 to sc_N
 35 for the elements of the reproduction unit 2 with the

help of the application of the reconstruction filters determined during step 50 to these coefficients.

5 The signals sc_1 to sc_N are then delivered so as to be applied to the elements 3_1 to 3_N of the reproduction unit 2 which reproduce the acoustic field whose characteristics are substantially independent of the intrinsic characteristics of reproduction of the reproduction unit 2.

10

By virtue of the method of the invention, the control signals sc_1 to sc_N are adapted to allow optimal reproduction of the acoustic field which best utilizes the spatial and/or acoustic characteristics of the reproduction unit 2, in particular the room effect, and which integrates the chosen optimization strategy.

15

Thus, on account of the quasi-independence between the intrinsic characteristics of reproduction of the reproduction unit 2 and of the acoustic field reproduced, it is possible to render the latter substantially identical to the acoustic field corresponding to the sound environment represented by the temporal and spatial information received as input.

25

The main steps of the method of the invention will now be described in greater detail.

During step 20 of inputting parameters an operator or a suitable memory system can specify all or part of the calculation parameters and in particular:

30

- x_n , representative of the position of element 3_n with respect to the listening center 5; x_n being expressed in the spherical reference frame by means of the coordinates r_n , θ_n , and ϕ_n ;

35

- $G_n(f)$, representative of the template of element 3_n of the reproduction unit specifying the frequency band of operation of this element;

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- $N_{l,m,n}(f)$, representative of the spatio-temporal response of the element 3_n corresponding to the acoustic field produced in the listening region 4 by the element 3_n , when the latter receives an impulse signal as input;
- $W(r,f)$, describing for each frequency f considered a spatial window representative of the distribution in space of constraints of reconstruction of the acoustic field, these constraints making it possible to specify the distribution in space of the effort of reconstruction of the acoustic field;
- $W_1(f)$, describing directly in the form of weighting of the Fourier-Bessel coefficients and for each frequency f considered, a spatial window representative of the distribution in space of constraints of reconstruction of the acoustic field;
- $R(f)$, representative, for each frequency f considered, of the radius of the spatial window when the latter is a ball;
- $H_n(f)$, representative, for each frequency f considered, of the frequency response of element 3_n ;
- $\mu(f)$, representative for each frequency f considered, of the desired local capacity of adaptation to the spatial irregularity of the configuration of the reproduction unit;
- $\{(l_k, m_k)\}(f)$, constituting for each frequency f considered, a list of spatio-temporal functions whose reconstruction is imposed;
- $L(f)$, imposing, for each frequency f considered, the limit order of operation of the means of determining reconstruction filters;
- $RM(f)$, defining, for each frequency f considered, the radiation model for the elements 3_1 to 3_N of the reproduction unit 2.

35

The definition signal SL conveys the parameters x_n , the supplementary signal RP, the parameters $H_n(f)$ and $N_{l,m,n}(f)$ and the optimization signal OS, the parameters

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$G_n(f)$, $\mu(f)$, $\{(l_k, m_k)\}(f)$, $L(f)$, $W(r, f)$, $W_1(f)$, $R(f)$ and $RM(f)$.

5 The interface means 10 implementing this step 20 are conventional type means such as a microcomputer or any other appropriate means.

10 Step 30 of calibration and the means 9 which implement it will now be described in greater detail.

Represented in figure 4 are the details of the calibration means 9. They comprise a decomposition module 91, a module 92 for determining impulse response and a module 93 for determining calibration parameters.

15 The calibration means 9 are adapted to be connected to a sound acquisition device 100 such as a microphone or any other suitable device, and to be connected in turn one by one to each element 3_n of the reproduction unit
20 2 so as to tap information off from this element.

Represented in figure 5 are the details of a mode of embodiment of the calibration step 30 implemented by the calibration means 9 and making it possible to
25 measure characteristics of the reproduction unit 2.

During a substep 32, the calibration means 9 emit a specific signal $u_n(t)$ such as a pseudo-random sequence MLS (Maximum Length Sequence) destined for an element
30 3_n . The acquisition device 100 receives, during a substep 34, the sound wave emitted by the element 3_n in response to the receipt of the signal $u_n(t)$ and transmits signals $c_{l,m}(t)$ representative of the wave received to the decomposition module 91.

35 During a substep 36, the decomposition module 91 decomposes the signals picked up by the acquisition device 100 into a finite number of Fourier-Bessel

coefficients $q_{l,m}(t)$.

For example, the device 100 delivers pressure information $p(t)$ and velocity information $\vec{v}(t)$ at the center 5 of the reproduction unit. In this case, the coefficients $q_{0,0}(t)$ to $q_{1,1}(t)$ representative of the acoustic field are deduced from the signals $c_{0,0}(t)$ to $c_{1,1}(t)$ according to the following relations:

$$\begin{aligned} q_{0,0}(t) &= \frac{1}{\sqrt{4\pi}} c_{0,0}(t) & \text{with} & & c_{0,0}(t) &= p(t) \\ q_{1,-1}(t) &= \rho c \sqrt{\frac{3}{4\pi}} c_{1,-1}(t) & \text{with} & & c_{1,-1}(t) &= v_Y(t) \\ q_{1,0}(t) &= -\rho c \sqrt{\frac{3}{4\pi}} c_{1,0}(t) & \text{with} & & c_{1,0}(t) &= v_Z(t) \\ q_{1,1}(t) &= -\rho c \sqrt{\frac{3}{4\pi}} c_{1,1}(t) & \text{with} & & c_{1,1}(t) &= v_X(t) \end{aligned}$$

10

In these equations, $v_X(t)$, $v_Y(t)$ and $v_Z(t)$ designate the components of the velocity vector $\vec{v}(t)$ in the orthonormal reference frame considered and ρ designates the density of the air.

15

When these coefficients are defined by the module 91, they are addressed to the response determination module 92.

20 During a substep 38, the response determination module 92 determines the impulse responses $hp_{l,m}(t)$ which link the Fourier-Bessel coefficients $q_{l,m}(t)$ and the signal emitted $u_n(t)$.

25 The impulse response delivered by the response determination module 92 is addressed to the parameters determination module 93.

During a substep 39, the module 93 deduces information on elements of the reproduction unit.

30

In the embodiment described, the parameters determination module 93 determines the distance r_n between the element 3_n and the center 5 with the help of its response $hp_{0,0}(t)$ and of the measurement of the time taken by the sound to propagate from the element 3_n to the acquisition device 100, by virtue of delay estimation procedures with regard to the response $hp_{0,0}(t)$.

10

In the embodiment described, the acquisition device 100 is able to unambiguously encode the orientation of a source in space. Thus, trigonometric relations between the 3 responses $hp_{1,-1}(t)$, $hp_{1,0}(t)$ and $hp_{1,1}(t)$ involving the coordinates θ_n , and ϕ_n are apparent for each instant t .

The module 93 determines the values $hp_{1,-1}$, $hp_{1,0}$ and $hp_{1,1}$ corresponding to the values taken by the responses $hp_{1,-1}(t)$, $hp_{1,0}(t)$ and $hp_{1,1}(t)$ at an arbitrarily chosen instant t such as for example the instant for which $hp_{0,0}(t)$ attains its maximum.

Subsequently, the module 93 estimates coordinates θ_n and ϕ_n with the help of the values $hp_{1,-1}$, $hp_{1,0}$ and $hp_{1,1}$ by means of the following trigonometric relations:

$$\begin{aligned}
 & \text{- for } hp_{1,0} > 0 : \quad \theta_n = \arctan \left(\frac{\sqrt{hp_{1,-1}^2 + hp_{1,1}^2}}{|hp_{1,0}|} \right) \\
 & \text{- for } hp_{1,0} < 0 : \quad \theta_n = \pi - \arctan \left(\frac{\sqrt{hp_{1,-1}^2 + hp_{1,1}^2}}{|hp_{1,0}|} \right) \\
 & \text{- for } hp_{1,1} > 0 : \quad \phi_n = -\arctan \left(\frac{hp_{1,-1}}{hp_{1,1}} \right) \\
 & \text{- for } hp_{1,1} < 0 : \quad \phi_n = \pi - \arctan \left(\frac{hp_{1,-1}}{hp_{1,1}} \right)
 \end{aligned}$$

These relations admit the following particular cases:

- for $hp_{1,0}=0$ and $hp_{1,1}\neq 0$: $\theta_n = \frac{\pi}{2}$
- for $hp_{1,1}=0$ and $hp_{1,-1}=0$ and $hp_{1,0}=0$: θ_n and ϕ_n are undefined
- for $hp_{1,1}=0$ and $hp_{1,-1}\neq 0$ and $hp_{1,0}=0$: $\theta_n = \frac{\pi}{2}$
- for $hp_{1,1}=0$ and $hp_{1,-1}\neq 0$ and $hp_{1,0}\neq 0$: $\phi_n = -\text{signe}(hp_{1,-1})\frac{\pi}{2}$

- 5 Advantageously, the coordinates θ_n , and ϕ_n are estimated over several instants. The final determination of the coordinates θ_n , and ϕ_n is obtained by means of techniques of averaging between the various estimates.
- 10 As a variant, the coordinates θ_n , and ϕ_n are estimated with the help of other responses from among the available $hp_{1,m}(t)$ or are estimated in the frequency domain with the help of the responses $hp_{1,m}(f)$.
- 15 Thus defined, the parameters r_n , θ_n , and ϕ_n are transmitted to the decoder 1 by the definition signal SL.

In the embodiment described, the module 93 also
 20 delivers the transfer function $H_n(f)$ of each element 3_n, with the help of the responses $hp_{1,m}(t)$ arising from the response determination module 92.

A solution consists in constructing the response
 25 $hp'_{0,0}(t)$ corresponding to the selection of the part of the response $hp_{0,0}(t)$ which comprises a non zero signal stripped of its reflections introduced by the listening region 4. The frequency response $H_n(f)$ is deduced by Fourier transform from the response $hp'_{0,0}(t)$ previously
 30 windowed. The window may be chosen from the conventional smoothing windows, such as for example

rectangular, Hamming, Hanning, and Blackman.

The parameters $H_n(f)$ thus defined are transmitted to the decoder 1 by the supplementary signal RP.

5

In the embodiment described, the module 93 also delivers the spatio-temporal response $N_{l,m,n}(f)$ of each element 3_n of the reproduction unit 2, deduced by applying a gain adjustment and a temporal alignment of
10 the impulse responses $hp_{l,m}(t)$ with the help of the measurement of the distance r_n of the element 3_n in the following manner:

$$\eta_{l,m,n}(t) = r_n hp_{l,m}(t + r_n/c)$$

15 The spatio-temporal response $\eta_{l,m,n}(t)$ contains a large amount of information characterizing the element 3_n , in particular its position and its frequency response. It is also representative of the directivity of the element 3_n , of its spread, and of the room effect
20 resulting from the radiation of the element 3_n in the listening region 4.

The module 93 applies a time windowing to the response $\eta_{l,m,n}(t)$ to adjust the duration for which the room
25 effect is taken into account. The spatio-temporal response expressed in the frequency domain $N_{l,m,n}(f)$ is obtained by Fourier transform of the response $\eta_{l,m,n}(t)$. The spatio-temporal response $N_{l,m,n}(f)$ is then frequency-windowed so as to adjust the frequency band over which
30 the room effect is taken into account. The module 93 then delivers the parameters $N_{l,m,n}(f)$ thus shaped which are provided to the decoder 1 by the supplementary signal RP.

35 Substeps 32 to 39 are repeated for all the elements 3_1 to 3_N of the reproduction unit 2.

As a variant, the calibration means 9 are adapted to

receive other types of information pertaining to the element 3_n . For example, this information is introduced in the form of a finite number of Fourier-Bessel coefficients representative of the acoustic field produced by the element 3_n in the listening region 4.

Such coefficients may in particular be delivered by means of acoustic simulation implementing a geometrical modeling of the listening region 4 so as to determine the position of the image sources induced by the reflections due to the position of the element 3_n and to the geometry of the listening region 4.

The means of acoustic simulation receive as input the signal $u_n(t)$ emitted by the module 92 and delivered, with the aid of the signal $c_{1,m}(t)$, the Fourier-Bessel coefficients determined by superposition of the acoustic field emitted by the element 3_n and of the acoustic fields emitted by the image sources when the element 3_n receives the signal $u_n(t)$. In this case the decomposition module 91 performs only a transmission of the signal $c_{1,m}(t)$ to the module 92.

As a variant, the calibration means 9 comprise other means of acquisition of information pertaining to the elements 3_1 to 3_N , such as laser-based position measuring means, signal processing means implementing beam forming techniques or any other appropriate means.

The means 9 implementing the calibration step consist for example of an electronic card or of a computer program or of any other appropriate means.

The details of the parameters simulation step and the means 8 which implement it will now be described. This step is carried out for each frequency f of operation.

The embodiments described require the knowledge for each element 3_n of its complete position described by the parameters r_n , θ_n , ϕ_n and/or of its spatio-temporal response described by the parameters $N_{l,m,n}(f)$.

5

In a first embodiment, described with reference to figure 6, the parameters which are neither input, by an operator or by external means, nor measured, are simulated.

10

Step 40 begins with a substep 41 of determining parameters missing from the signals RP, SL and OS received.

15 During a substep 42, the parameter $H_n(f)$ representative of the response of the elements of the reproduction unit 2 takes the default value 1.

During a substep 43, the parameter $G_n(f)$ representative
20 of the templates of the elements of the reproduction unit 2 is determined by thresholding on the parameter $H_n(f)$ in the case where the latter is measured, defined by the user, or provided by external means, otherwise, $G_n(f)$ takes the default value 1.

25

Step 40 then comprises a substep 44 of determining the active elements at the frequency f considered.

During this substep, a list $\{n^*\}(f)$ of elements of the
30 reproduction unit that are active at the frequency f is determined, these elements being those whose template $G_n(f)$ is non zero for this frequency. The list $\{n^*\}(f)$ comprises N_f elements and it is transmitted to the decoder 1 by the optimization signal OS. It is used to
35 select the parameters corresponding to the active elements at each frequency f among the set of parameters. The parameters of index n^* correspond to the n^{th} active element at the frequency f .

During a substep 45, the parameter $L(f)$ representative of the order of operation of the module for determining the filters at the current frequency f , is determined in the following manner:

- the simulation means 8 calculate the smallest angle a_{min} formed by a pair of elements of the reproduction unit by means of a trigonometric relation, such as for example:

10

$$a_{n1*,n2*} = \arccos(\sin\theta_{n1*}\sin\theta_{n2*}\cos(\phi_{n1*}-\phi_{n2*}) + \cos\theta_{n1*}\cos\theta_{n2*})$$

$$a_{min} = \min(a_{n1*,n2*})$$

among the set of pairs $(n1*, n2*)$ such that $n1* \neq n2*$;

15 - the simulation means 9 determine the maximum order $L(f)$ which is the largest integer obeying the relation

$$L(f) < \pi/a_{min}.$$

During a substep 46, the parameter $RM(f)$ defining the radiation model for the elements constituting the reproduction unit, is determined automatically taking the spherical radiation model as default.

During a substep 47, the parameter $W_1(f)$ which describes the spatial window representative of the distribution in space of constraints of reconstruction of the acoustic field in the form of weighting of Fourier-Bessel coefficients is determined in the following manner:

30 - if the parameter $W(r, f)$ representative of the spatial window in the spherical reference frame is provided or input, $W_1(f)$ is deduced from its value by applying the expression:

$$W_1(f) = 16 \pi^2 \int_0^\infty W(r, f) j_1^2(kr) r^2 dr$$

35 - and if the parameter $R(f)$, which represents a radius when the spatial window is a ball of radius

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$R(f)$, is provided by external means or input, $W_1(f)$ is deduced from its value by applying the expression:

$$W_1(f) = 8\pi^2 R^3(f) \left(j_l^2(kR(f)) + j_{l+1}^2(kR(f)) - \frac{2l+1}{kR(f)} j_l(kR(f)) j_{l+1}(kR(f)) \right)$$

otherwise, $W_1(f)$ is deduced from $L(f)$, by applying the expression:

$$W_1(f) = 8\pi^2 R^3 \left(j_l^2(kR) + j_{l+1}^2(kR) - \frac{2l+1}{kR} j_l(kR) j_{l+1}(kR) \right) \text{ with } R = \frac{L(f)c}{2\pi f}$$

- As a variant, if the spatial window is not specified, the simulation means 8 allocate the parameter $W_1(f)$ a default value, for example a Hamming window of size $2L(f)+1$, evaluated in 1.

The parameter $W_1(f)$ is determined for the values of l ranging from 0 to $L(f)$.

During a substep 48, the parameter $\{(l_k, m_k)\}(f)$ is deduced from the parameters $L(f)$ and $\bar{x}_{n^*}$, in the following manner:

Firstly, the means 9 calculate the coefficients

$$G_{l,m,n^*} = y_l^m(\theta_{n^*}, \phi_{n^*})$$

where $(\theta_{n^*}, \phi_{n^*})$ is the direction of the reproduction element 3_{n^*} .

Secondly, the means 9 calculate the coefficients

$$G_{l,m} = \sqrt{\sum_{n=1}^N G_{l,m,n^*}^2}$$

Thirdly, the means 8 calculate, with the aid of a supplementary parameter ε , the list of parameters $\{(l_k, m_k)\}(f)$, referred to as C and which is initially empty. For each value of the order l , starting at 0, the means 8 carry out the following substeps:

- search for $G_l = \max(G_{l,m})$;
- determination of the list C_l of coefficients (l,m)

- 29 -

such that $G_{1,m}$ (in dB) lies between $G_1 - \varepsilon$ (in dB) and G_1 (in dB).

If the sum of the number of terms in C and of the
 5 number of terms in C_1 is greater than or equal to the number N_f of active reproduction elements at the frequency f , the list C is complete, otherwise, C_1 is added to C and the search for G_1 is restarted for $l+1$.

10 In the case where the elements 3_{1*} to 3_{N_f*} are in a horizontal plane and where the list of the $\{(l_k, m_k)\}(f)$ is neither input, nor provided, the simulation means 8 perform a simplified processing:

15 The list of coefficients $\{(l_k, m_k)\}(f)$ takes the form:

$$\{(0,0), (1,-1), (1,1), (2,-2), (2,2) \dots (L_1, -L_1), (L_1, L_1)\}$$

where L_1 is chosen so that the number of elements in this list is less than the number N_f of elements 3_{n*} active at the frequency f . The value taken by L_1 may be
 20 the integer part of $(N_f-1)/2$, but it is preferable to take a smaller value for L_1 .

During a substep 49, the parameter $\mu(f)$, which represents at the current frequency f the desired local
 25 capacity of adaptation, varying between 0 and 1, is determined automatically, taking the default value 0.7 for example.

Thus, the simulation means 9 make it possible, during
 30 step 40, to supplement the signals SL, RP and OS in such a way as to deliver to the means 12 for determining reconstruction filters the set of parameters necessary for their implementation.

35 As a function of the parameters input or measured, some of the simulation substeps described are not carried out.

- 30 -

The simulation step 40 consisting of the set of substeps 41 to 49, is repeated for all the frequencies considered. As a variant, each substep is carried out for all the frequencies before going to the next
5 substep.

In another embodiment, all the parameters involved are provided to the decoder 1 and step 40 then comprises only the substep 41 of receiving and verifying the
10 signals SL, RP and OS and the substep 44 of determining the active elements at the frequency f considered.

The simulation means 8 implementing step 40 are for example computer programs or electronic cards dedicated
15 to such an application or any other appropriate means.

Step 50 of determining reconstruction filters and the means 12 which implement it will now be described in greater detail.

20 Represented in figure 7 are the means 12 of determining reconstruction filters which comprise a module 82 for determining transfer matrices with the help of the parameters of the signals SL, RP and OS as well as the
25 means 84 for determining a decoding matrix D^* .

The means 12 also comprise a module 86 for storing the response of the reconstruction filters and a module 88 for parameterizing reconstruction filters.

30 Represented in figure 8 are the details of step 50 for determining reconstruction filters.

Step 50 is repeated for each frequency of operation and
35 comprises a plurality of substeps for determining matrices representative of the parameters defined previously.

Step 50 of determining reconstruction filters comprises a substep 51 of determining a matrix W for weighting the acoustic field with the help of the signals $L(f)$ and $W_1(f)$.

5

W is a diagonal matrix of size $(L(f)+1)^2$ containing the weighting coefficients $W_1(f)$ and in which each coefficient $W_1(f)$ is found $2l+1$ times in succession on the diagonal. The matrix W therefore has the following

10 form:

$$W = \begin{bmatrix} W_0(f) & 0 & \dots & \dots & \dots & \dots & \dots & 0 \\ 0 & W_1(f) & \ddots & & & & & \vdots \\ \vdots & \ddots & W_1(f) & \ddots & & & & \vdots \\ \vdots & & \ddots & W_1(f) & \ddots & & & \vdots \\ \vdots & & & \ddots & W_1(f) & \ddots & & \vdots \\ \vdots & & & & \ddots & W_L(f) & \ddots & \vdots \\ \vdots & & & & & \ddots & W_L(f) & 0 \\ 0 & \dots & \dots & \dots & \dots & \dots & 0 & W_L(f) \end{bmatrix}$$

Likewise, step 50 comprises a substep 52 of determining a matrix M representative of the radiation of the reproduction unit with the help of the parameters $N_{l,m,n^*}(f)$, $RM(f)$, $H_{n^*}(f)$, $\bar{x}_{n^*}$, and $L(f)$.

M is a matrix of size $(L(f)+1)^2$ by N_F , consisting of elements M_{l,m,n^*} , the indices l,m designating row $l^2 + l + m$ and n^* designating column n . The matrix M therefore has the following form:

20

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$$\begin{bmatrix}
 M_{0,0,1*} & M_{0,0,2*} & \cdots & M_{0,0,N_f*} \\
 M_{1,-1,1*} & M_{1,-1,2*} & \cdots & M_{1,-1,N_f*} \\
 M_{1,0,1*} & M_{1,0,2*} & \cdots & M_{1,0,N_f*} \\
 M_{1,1,1*} & M_{1,1,2*} & \cdots & M_{1,1,N_f*} \\
 \vdots & \vdots & & \vdots \\
 M_{L,-L,1*} & M_{L,-L,2*} & \cdots & M_{L,-L,N_f*} \\
 \vdots & \vdots & & \vdots \\
 M_{L,0,1*} & M_{L,0,2*} & \cdots & M_{L,0,N_f*} \\
 \vdots & \vdots & & \vdots \\
 M_{L,L,1*} & M_{L,L,2*} & \cdots & M_{L,L,N_f*}
 \end{bmatrix}$$

The elements $M_{l,m,n*}$ are obtained as a function of the radiation model $RM(f)$:

- 5 - if $RM(f)$ defines a plane wave radiation model

$$M_{l,m,n*} = y_l^m(\theta_{n*}, \phi_{n*}) H_{n*}(f)$$

- if $RM(f)$ defines a spherical wave radiation model

$$M_{l,m,n*} = y_l^m(\theta_{n*}, \phi_{n*}) H_{n*}(f) \xi_l(r_{n*}, f)$$

- 10 - if $RM(f)$ defines a model using the measurements performed of the spatio-temporal responses, with recourse to the plane wave model for the missing measurements, then $M_{l,m,n*} = N_{l,m,n*}(f)$ for the indices $l, m, n*$ provided and the current frequency f . The remainder of the $M_{l,m,n*}$ is
- 15 determined according to the relation:

$$M_{l,m,n*} = y_l^m(\theta_{n*}, \phi_{n*}) H_{n*}(f)$$

- if $RM(f)$ defines a model using the measurements performed of the spatio-temporal responses, with recourse to the spherical wave model for the
- 20 missing measurements, then $M_{l,m,n*} = N_{l,m,n*}(f)$ for the indices $l, m, n*$ provided and the current frequency f . The remainder of the $M_{l,m,n*}$ is determined according to the relation:

$$M_{l,m,n*} = y_l^m(\theta_{n*}, \phi_{n*}) H_{n*}(f) \xi_l(r_{n*}, f)$$

25

In these expressions $\xi_l(r_{n*}, f)$ is defined by the

expression:

$$\xi_l(r_{n*}, f) = \sum_{k=0}^l \frac{(l+k)!}{2^k k! (l-k)!} \left(\frac{j 2 \pi r_{n*} f}{c} \right)^{-k}$$

The matrix M thus defined is representative of the radiation of the reproduction unit. In particular, M is representative of the spatial configuration of the reproduction unit.

When the method uses the coefficients $N_{l,m,n}(f)$, the matrix M is representative of the spatio-temporal responses of the elements 3_1 to 3_N and therefore in particular of the room effect induced by the listening region 4.

Step 50 also comprises a substep 53 of determining a matrix F representative of the Fourier-Bessel functions, perfect reconstruction of which is demanded. This matrix is determined with the help of the parameter $L(f)$, as well as the parameters $\{(l_k, m_k)\}(f)$ in the following manner.

With the help of the list $\{(l_k, m_k)\}(f)$, calling K the number of elements (l_k, m_k) of the list $\{(l_k, m_k)\}(f)$, the matrix F constructed is of size K by $(L(f)+1)^2$. Each row k of the matrix F contains a 1 in column $l_k^2 + l_k + m_k$, and 0s elsewhere. For example, for a configuration of the reproduction unit of so-called "5.1" type, whose list $\{(l_k, m_k)\}(f)$ can take the form $\{(0,0), (1,-1), (1,1)\}$, the matrix F may be written:

$$F = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \dots & 0 \end{bmatrix}$$

When the parameter $\mu(f)$ is zero, the decoder reproduces only the Fourier-Bessel functions enumerated by the parameters $\{(l_k, m_k)\}(f)$, the others being

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ignored. When $\mu(f)$ is set to 1, the decoder reproduces perfectly the Fourier-Bessel functions designated by $\{(l_k, m_k)\}(f)$ but reproduces moreover partially numerous other Fourier-Bessel functions among those available up to order $L(f)$ so that globally the reconstructed field is closer to that described as input. This partial reconstruction allows the decoder 1 to accommodate reproduction configurations that are very irregular in their angular distribution.

10

Substeps 51 to 53 implemented by the module 82 can be executed sequentially or simultaneously.

Step 50 of determining reconstruction filters thereafter comprises a substep 54 of taking into account the set of parameters determined previously, implemented by the module 84 so as to deliver a decoding matrix D^* representative of the reconstruction filters.

20

This matrix D^* is delivered with the help of the matrices M , F , W and of the parameter $\mu(f)$ according to the following expression:

$$D^* = \mu A M^T W + A M^T F^T (F M A M^T F^T)^{-1} F (I_{(L+1)^2} - \mu M A M^T W) \\ \text{with } A = ((1-\mu) I_N + \mu M^T W M)^{-1}$$

25

where M^T designates the matrix which is the conjugate transpose of M .

The elements $D^*_{n,l,m}$ of the matrix D^* are organized in the following manner:

30

$$\begin{bmatrix} D^*_{1,0,0} & D^*_{1,1,-1} & D^*_{1,1,0} & D^*_{1,1,1} & \cdots & D^*_{1,L,-L} & \cdots & D^*_{1,L,0} & \cdots & D^*_{1,L,L} \\ D^*_{2,0,0} & D^*_{2,1,-1} & D^*_{2,1,0} & D^*_{2,1,1} & \cdots & D^*_{2,L,-L} & \cdots & D^*_{2,L,0} & \cdots & D^*_{2,L,L} \\ \vdots & \vdots & \vdots & \vdots & \cdots & \vdots & \cdots & \vdots & \cdots & \vdots \\ D^*_{N_f,0,0} & D^*_{N_f,1,-1} & D^*_{N_f,1,0} & D^*_{N_f,1,1} & \cdots & D^*_{N_f,L,-L} & \cdots & D^*_{N_f,L,0} & \cdots & D^*_{N_f,L,L} \end{bmatrix}$$

The matrix D^* is therefore representative of the

configuration of the reproduction unit, of the acoustic characteristics associated with the elements 3_1 to 3_N and of the optimization strategies.

- 5 In the case where the method uses the coefficients $N_{l,m,n}(f)$, the matrix D^* is representative in particular of the room effect induced by the listening region 4.

Subsequently, during a substep 55, the module 86 for
 10 storing the response of the reconstruction filters at the current frequency f supplements for the frequency f the matrix $D(f)$ representative of the frequency response of the reconstruction filters, by receiving the matrix D^* as input. The elements of the matrix D^*
 15 are stored in the matrix $D(f)$, by inverting the method, described previously with reference to figure 6, for determining the list $\{n^*\}(f)$. More precisely, each element $D_{n^*,1,m}^*$ of the matrix D^* is stored in the element $D_{n^*,1,m}(f)$ of the matrix $D(f)$. The elements of $D(f)$ that
 20 are not determined on completion of this substep are fixed at zero.

Such a use of the list $\{n^*\}(f)$ makes it possible to take account of heterogeneous templates of the
 25 reproduction elements 3_1 to 3_N .

The elements $D_{n,1,m}(f)$ of the matrix $D(f)$ are organized in the following manner:

$$\begin{bmatrix} D_{1,0,0}(f) D_{1,1,-1}(f) D_{1,1,0}(f) D_{1,1,1}(f) \cdots D_{1,L,-L}(f) \cdots D_{1,L,0}(f) \cdots D_{1,L,L}(f) \\ D_{2,0,0}(f) D_{2,1,-1}(f) D_{2,1,0}(f) D_{2,1,1}(f) \cdots D_{2,L,-L}(f) \cdots D_{2,L,0}(f) \cdots D_{2,L,L}(f) \\ \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \quad \quad \quad \vdots \\ D_{N,0,0}(f) D_{N,1,-1}(f) D_{N,1,0}(f) D_{N,1,1}(f) \cdots D_{N,L,-L}(f) \cdots D_{N,L,0}(f) \cdots D_{N,L,L}(f) \end{bmatrix}$$

30

The set of substeps 51 to 55 is repeated for all the frequencies f considered and the results are stored in the storage module 86. On completion of this processing, the matrix $D(f)$ representative of the

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frequency responses of the set of reconstruction filters is addressed to the module 88 for parameterizing reconstruction filters.

5 During a substep 58, the reconstruction filters parameterization module 88 then provides the signal FD representative of the reconstruction filters, by receiving the matrix $D(f)$ as input. Each element $D_{n,1,m}(f)$ of the matrix $D(f)$ is a reconstruction filter
10 which is described in the signal FD by means of parameters which may take various forms.

For example, the parameters of the signal FD that are associated with each filter $D_{n,1,m}(f)$ may take the
15 following forms:

- a frequency response, whose parameters are directly the values of $D_{n,1,m}(f)$ for certain frequencies f ;
- a finite impulse response, whose parameters
20 $d_{n,1,m}(t)$ are calculated by inverse temporal Fourier transform of $D_{n,1,m}(f)$. Each impulse response $d_{n,1,m}(t)$ is sampled and then truncated to a length particular to each response; or
- coefficients of an infinite impulse response
25 recursive filter calculated with the help of the $D_{n,1,m}(f)$ with conventional adaptation procedures.

Thus, on completion of step 50 the means 12 for determining reconstruction filters deliver a signal FD
30 to the means 11 for determining control signals.

In this embodiment, this signal FD is representative of the following parameters:

- spatial configuration of the elements of the
35 reproduction unit;
- acoustic characteristics associated with the elements of the reproduction unit, in particular the frequency responses and the spatio-temporal responses

representative, among other things, of the room effect induced by the listening region 4;

- optimization strategies, in particular the spatio-temporal functions upon which one imposes the reconstruction, the distribution in space of constraints of reconstruction of the acoustic field and the desired local capacity of adaptation to the spatial irregularity of the configuration of the reproduction unit 2.

10

The means 12 for determining reconstruction filters may be embodied in the form of software dedicated to this function or else be integrated into an electronic card or any other appropriate means.

15

Step 60 of shaping the input signal will now be described in greater detail.

When the system is implemented, it receives the input signal SI which comprises temporal and spatial information of a sound environment to be reproduced. This information may be of several sorts, in particular:

- a sound environment coded according to an angular distribution such as for example the format commonly dubbed "B format";

- a description of a sound environment by means of position information for virtual sources which make up the sound environment and signals emitted by these sources;

- a sound environment coded in multichannel mode, that is to say by means of signals intended to power loudspeakers whose angular distribution is fixed and known and which includes in particular the so-called "7.1", "5.1" quadriphonic, stereophonic and monophonic techniques;

- a sound environment given by its acoustic field in the form of Fourier-Bessel coefficients.

As was stated with reference to figure 3, during step 60, the shaping means 6 receive the input signal SI and decompose it into Fourier-Bessel coefficients representative of an acoustic field corresponding to the sound environment described by the signal SI. These Fourier-Bessel coefficients are delivered to the decoder 1 by the signal SI_{FB}.

10 As a function of the sort of input signal SI, the shaping step 60 varies.

With reference to figure 9, the decomposition into Fourier-Bessel coefficients will now be described in the case where the sound environment is coded in the signal SI in the form of the description of a sound scene by means of position information for the virtual sources of which it is composed and of the signals emitted by these sources.

20 A matrix $\mathbf{E}$ makes it possible to allocate a radiation model, for example a spherical wave model, to each virtual source s . $\mathbf{E}$ is a matrix of size $(L+1)^2$ by S , where S is the number of sources present in the scene and L is the order to which the decomposition is conducted. The position of a source s is designated by its spherical coordinates r_s , θ_s and ϕ_s . The elements $E_{l,m,s}$ of the matrix $\mathbf{E}$ may be written in the following manner:

$$E_{l,m,s}(f) = \frac{1}{r_s} e^{-2\pi j r_s f/c} y_l^m(\theta_s, \phi_s) \xi_l(r_s, f)$$

Also introduced is the vector $\mathbf{Y}$ which contains the temporal Fourier transforms $Y_s(f)$ of the signals $y_s(t)$ emitted by the sources. $\mathbf{Y}$ may be written:

$$35 \quad \mathbf{Y} = [Y_1(f) Y_2(f) \dots Y_S(f)]^t$$

The Fourier-Bessel coefficients $P_{l,m}(f)$ are placed in a

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vector P of size $(L+1)^2$, where the $2l+1$ terms of order l are placed one after another in ascending order l . The coefficient $P_{l,m}(f)$ is thus the element of index l^2+l+m of the vector P which may be written:

$$P = E Y$$

As represented with reference to figure 9, the obtaining of the Fourier-Bessel coefficients $P_{l,m}(f)$, constituting the signal SI_{FB} , corresponds to a filtering of each signal $Y_s(f)$ by means of the filter $E_{l,m,s}(f)$, then by summing the results. The coefficients $P_{l,m}(f)$ are therefore expressed in the following manner:

$$P_{l,m}(f) = \sum_{s=1}^S Y_s(f) E_{l,m,s}(f)$$

Deployment of the filters $E_{l,m,s}(f)$ may be effected according to conventional filtering procedures, such as for example:

- filtering in the frequency domain;
- filtering with the aid of a finite impulse response filter; or
- filtering with the aid of an infinite impulse response filter. It is a matter of the most direct procedure which consists in deducing a recursive filter from the expression $E_{l,m,s}(f)$, for example with the aid of a bilinear transform.

In the case where the signal SI corresponds to the representation of a sound environment according to a multichannel format, the shaping means 6 perform the operations described hereinafter.

A matrix S makes it possible to allocate to each channel c a radiation source, for example a plane wave source whose direction of origination (θ_c, ϕ_c) corresponds to the direction of the reproduction element associated with the channel c in the

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multichannel format considered. S is a matrix of size $(L+1)^2$ by C , where C is the number of channels. The elements $S_{l,m,c}$ of the matrix S may be written:

$$S_{l,m,c} = y_l^m(\theta_c, \phi_c)$$

5

Also defined is the vector Y which contains the signals $y_c(t)$ corresponding to each channel. Y may be written:

$$Y = [y_1(t) \ y_2(t) \ \cdots \ y_C(t)]^t$$

- 10 The Fourier-Bessel coefficients $p_{l,m}(t)$ grouped together as previously in the vector P are obtained through the relation:

$$P = S Y$$

- 15 Each Fourier-Bessel coefficient $p_{l,m}(t)$ constituting the signal SI_{FB} is obtained by linear combination of the signals $y_c(t)$:

$$p_{l,m}(t) = \sum_{c=1}^C y_c(t) S_{l,m,c}$$

- 20 In the case where the signal SI corresponds to the angular description of a sound environment according to the B format, the four signals $W(t)$, $X(t)$, $Y(t)$ and $Z(t)$ of this format decompose by applying simple gains:

$$\begin{aligned} p_{0,0}(t) &= \frac{1}{\sqrt{4\pi}} W(t) \\ p_{1,1}(t) &= \sqrt{\frac{3}{8\pi}} X(t) \\ p_{1,-1}(t) &= -\sqrt{\frac{3}{8\pi}} Y(t) \\ p_{1,0}(t) &= \sqrt{\frac{3}{8\pi}} Z(t) \end{aligned}$$

25

Finally, in the case where the signal SI corresponds to a description of the acoustic field in the form of the Fourier-Bessel coefficients, step 60 consists simply of signal transmission.

30

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Thus, on completion of the shaping step 60, the means 6 deliver, destined for the means 11 for determining control signals, a signal SI_{FB} corresponding to the decomposition of the acoustic field to be reproduced into a finite number of Fourier-Bessel coefficients.

The means 6 may be embodied in the form of dedicated computer software or else be embodied in the form of a dedicated computing card or any other appropriate means.

The step 70 of determining control signals will now be described in greater detail.

The means 11 for determining control signals receive as input the signal SI_{FB} corresponding to the Fourier-Bessel coefficients representative of the acoustic field to be reproduced and the signal FD representative of the reconstruction filters arising from the means 12. As stated previously, the signal FD integrates parameters characteristic of the reproduction unit 2.

With the help of this information, during step 70, the means 11 determine the signals $sc_1(t)$ to $sc_N(t)$ delivered destined for the elements 3_1 to 3_N . These signals are obtained by the application to the signal SI_{FB} of the reconstruction filters, of frequency response $D_{n,l,m}(f)$, and transmitted in the signal FD .

The reconstruction filters are applied in the following manner:

$$V_n(f) = \sum_{l=0}^{L_n} \sum_{m=-l}^l P_{l,m}(f) D_{n,l,m}(f)$$

with $P_{l,m}(f)$ the Fourier-Bessel coefficients constituting the signal SI_{FB} and $V_n(f)$ defined by:

$$V_n(f) = \frac{SC_n(f)}{r_n} e^{-2\pi j r_n f / c}$$

where $SC_n(f)$ is the temporal Fourier transform of $SC_n(t)$.

- 5 According to the form of the parameters of the signal FD, each filtering of the $P_{l,m}(f)$ by $D_{n,l,m}(f)$ can be carried out according to conventional filtering procedures, such as for example:
- the signal FD provides the frequency responses $D_{n,l,m}(f)$ directly, and the filtering is performed in the frequency domain, for example, with the aid of the usual block convolution techniques;
 - the signal FD provides the finite impulse responses $d_{n,l,m}(t)$, and the filtering is performed in the time domain by convolution; or
 - the signal FD provides the coefficients of infinite impulse response recursive filters, and the filtering is performed in the time domain by means of recurrence relations.

20

Represented in figure 10 is the case of the finite impulse response filter.

- The number of samples individual to each response $d_{n,l,m}(t)$ is defined $T_{n,l,m}$, this leading to the following convolution expression:

$$v_n[t] = \sum_{l=0}^L \sum_{m=-l}^l \sum_{\tau=0}^{T_{n,l,m}-1} d_{n,l,m}[\tau] p_{l,m}[t-\tau]$$

- Step 70 terminates with an adjustment of the gains and the application of delays so as to temporally align the wavefronts of the elements 3_1 to 3_N of the reproduction unit 2 with respect to the element furthest away. The signals $sc_1(t)$ to $sc_N(t)$ intended to feed the elements 3_1 to 3_N are deduced from the signals $v_1(t)$ to $v_N(t)$ according to the expression:

35

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$$SC_n(t) = r_n v_n \left(t - \frac{\max(r_n) - r_n}{c} \right)$$

Each element 3_1 to 3_N therefore receives a specific control signal sc_1 to sc_N and emits an acoustic field which contributes to the optimal reconstruction of the acoustic field to be reproduced. The simultaneous control of the whole set of elements 3_1 to 3_N allows optimal reconstruction of the acoustic field to be reproduced.

Furthermore, the system described can also operate in simplified modes.

For example, in a first simplified embodiment, during step 50, the module 12 for determining filters receives only the following parameters:

- $\bar{x}_n$ representative of the position of the element 3_n of the reproduction unit 2;
- w_1 describing, directly in the form of weighting of the Fourier-Bessel coefficients, a spatial window representative of the distribution in space of constraints of reconstruction of the acoustic field; and
- L , imposing the limit order of operation of the means 12 for determining reconstruction filters.

In this simplified mode, these parameters are independent of the frequency and the elements 3_1 to 3_N of the reproduction unit are active and assumed to be ideal for all the frequencies. The substeps of step 50 are therefore carried out once only. During substep 52, the matrix M is constructed with the help of a plane wave radiation model. The elements $M_{l,m,n}$ of the matrix M simplify into:

$$M_{l,m,n} = y_l^m(\theta_n, \phi_n)$$

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In this simplified mode, $\mu = 1$ and the list $\{(l_k, m_k)\}(f)$ contains no terms. During substep 54, the module 84 then determines the matrix D directly according to the simplified expression:

$$D = (M^T W M)^{-1} M^T W$$

The storage of the response of the reconstruction filters is no longer necessary, and substep 55 is not carried out. Likewise, the filters described in the matrix D having simple gains, substep 58 is no longer carried out and the module 84 provides the signal FD directly.

During step 70, the determination of the drive signals is performed in the time domain and corresponds to simple linear combinations of the coefficients $p_{l,m}(t)$, followed by a temporal alignment according to the expression:

$$SC_n(t) = r_n v_n \left(t - \frac{\max(r_n) - r_n}{c} \right)$$

with
$$v_n(t) = \sum_{l=0}^L \sum_{m=-l}^l p_{l,m}(t) D_{n,l,m}$$

20

The module 11 then provides the drive signals $sc_1(t)$ to $sc_N(t)$ intended for the reproduction unit.

In another simplified embodiment, during step 50, the module 12 for determining filters receives the following parameters as input:

- x_n , representative of the position of the element 3_n of the reproduction unit 2;
- $\{(l_k, m_k)\}$, constituting the list of spatio-temporal functions whose reconstruction is imposed; and
- L , imposing the order of operation of the means 12 for determining reconstruction filters.

In this simplified mode, the parameters are independent

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of the frequency and the elements 3_1 to 3_N of the reproduction unit are active and assumed to be ideal for all the frequencies. The substeps of step 50 are therefore carried out once only. During substep 52, the matrix M is constructed with the help of a plane wave radiation model. The elements $M_{l,m,n}$ of the matrix M simplify into:

$$M_{l,m,n} = y_l^m(\theta_n, \phi_n)$$

Substep 53 of determining the matrix F remains unchanged. In this simplified mode $\mu = 0$ and during substep 54, the module 84 determines the matrix D directly according to the simplified expression:

$$D = M^T F^T (F M M^T F^T)^{-1} F$$

The storage of the response of the reconstruction filters is no longer necessary, and substep 55 is not carried out. Likewise, the filters described in the matrix D having simple gains, substep 58 is no longer carried out and the module 84 provides the signal FD directly.

During step 70, the determination of the drive signals is performed in the time domain and corresponds to simple linear combinations of the coefficients $p_{l,m}(t)$, followed by a temporal alignment according to the expression:

$$SC_n(t) = r_n v_n \left(t - \frac{\max(r_n) - r_n}{c} \right)$$

$$\text{with } v_n(t) = \sum_{l=0}^L \sum_{m=-l}^l p_{l,m}(t) D_{n,l,m}$$

The module 11 then provides the drive signals $sc_1(t)$ to $sc_N(t)$ intended for the reproduction unit.

It is apparent that according to the invention, the control signals sc_1 to sc_N are adapted to best utilize

the spatial characteristics of the reproduction unit 2,
the acoustic characteristics associated with the
elements 3_1 to 3_N and the optimization strategies in
such a way as to reconstruct a high-quality acoustic
5 field.

It is therefore apparent that the method implemented
makes it possible in particular to obtain optimum
reproduction of a three-dimensional acoustic field
10 regardless of the spatial configuration of the
reproduction unit 2.

The invention is not limited to the embodiments
described.

15

In particular, the method of the invention can be
implemented by digital computers such as one or more
computer processors or digital signal processors (DSP).

20 It may also be implemented with the help of a general
platform such as a personal computer.

It is also possible to devise an electronic card
intended to be inserted into another element and
25 adapted for storing and executing the method of the
invention. For example, such an electronic card is
integrated into a computer.

In other embodiments, all or part of the parameters
30 necessary for the execution of the step of determining
reconstruction filters is extracted from prerecorded
memories or is delivered by another apparatus dedicated
to this function.

CLAIMS

1. A method of controlling a reproduction unit (2) for restoring an acoustic field so as to obtain a reproduced acoustic field of specific characteristics substantially independent of the intrinsic characteristics of reproduction of said unit (2), said reproduction unit (2) comprising a plurality of reproduction elements (3_1 to 3_N), characterized in that it comprises at least:
- a step of establishing a finite number of coefficients representative of the distribution in time and in the three dimensions in space of said acoustic field to be reproduced;
 - 15 - a step (50) of determining reconstruction filters representative of said reproduction unit (2), comprising a substep (54) of taking into account at least spatial characteristics of said reproduction unit (2);
 - 20 - a step (70) of determining at least one control signal (sc_1 to sc_N) for said elements (3_1 to 3_N) of said reproduction unit (2), said at least one signal being obtained by the application, to said coefficients, of said reconstruction filters; and
 - 25 - a step of delivering said at least one control signal (sc_1 to sc_N), with a view to an application to said reproduction elements (3_1 to 3_N) so as to generate said acoustic field reproduced by said reproduction unit (2).
- 30
2. The method as claimed in claim 1, characterized in that said step of establishing a finite number of coefficients representative of the distribution of said acoustic field to be reproduced comprises:
- 35 - a step consisting in providing an input signal (SI) comprising temporal and spatial information for a sound environment; and
 - a step of shaping (60) said input signal (SI) by

decomposing said information over a basis of spatio-temporal functions, this shaping step (60) making it possible to deliver a representation of said acoustic field to be reproduced corresponding to said sound
5 environment in the form of a linear combination of said functions.

3. The method as claimed in claim 1, characterized in that said step of establishing a finite number of
10 coefficients representative of the distribution of said acoustic field to be reproduced comprises:

(
- a step consisting in providing an input signal (SI_{FB}) comprising a finite number of coefficients representative of said acoustic field to be reproduced
15 in the form of a linear combination of spatio-temporal functions.

4. The method as claimed in any one of claims 2 or 3, characterized in that said spatio-temporal functions
20 are so-called Fourier-Bessel functions and/or linear combinations of these functions.

(
5. The method as claimed in any one of claims 1 to 4, characterized in that said substep (54) of taking into
25 account at least spatial characteristics of said reproduction unit (2) is carried out at least with the help of parameters representative, for each element (3_n), of the three coordinates of its position ($\bar{x}_n$) with respect to the center (5) placed in the listening zone
30 (4), and/or of its spatio-temporal response ($N_{1,m,n}(f)$).

6. The method as claimed in claim 5, characterized in that said substep (54) of taking into account at least spatial characteristics of said reproduction unit (2)
35 is carried out moreover with the help:

- of parameters ($W_1(f)$) describing, in the form of weighting coefficients, a spatial window which specifies the distribution in space of reconstruction

constraints for the acoustic field; and

- of a parameter $(L(f))$ describing an order of operation limiting the number of coefficients to be taken into account during said step (50) of determining reconstruction filters.

7. The method as claimed in one of claims 5 or 6, characterized in that said substep (54) of taking into account characteristics of said reproduction unit (2) is carried out moreover with the help:

- of parameters $(\{(l_k, m_k)\}(f))$ constituting a list of spatio-temporal functions whose reconstruction is imposed; and
- of a parameter $(L(f))$ describing an order of operation limiting the number of coefficients to be taken into account during said step (50) of determining reconstruction filters.

8. The method as claimed in one of claims 5 to 7, characterized in that said step (54) of taking into account at least spatial characteristics of said reproduction unit (2) is carried out moreover at least with the help of one of the parameters chosen from the group consisting:

- of parameters $(\bar{x}_n)$ representative of at least one of the three coordinates of the position of each or some of the elements $(3_1$ to $3_N)$, with respect to the center (5) placed in the listening zone (4);
- of parameters $(N_{l,m,n}(f))$ representative of the spatio-temporal responses of each or some of the elements $(3_1$ to $3_N)$;
- of a parameter $(L(f))$ describing an order of operation limiting the number of coefficients to be taken into account during said step (50) of determining reconstruction filters;
- of parameters $(\{(l_k, m_k)\}(f))$ constituting a list of spatio-temporal functions whose reconstruction is imposed;

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- of parameters ($G_n(f)$) representative of the templates of said reproduction elements (3_1 to 3_N);
- of a parameter ($\mu(f)$) representative of the desired local capacity of adaptation to the spatial irregularity of the configuration of said reproduction unit (2);
- of a parameter ($RM(f)$) defining the radiation model for said reproduction elements (3_1 to 3_N);
- of parameters ($H_n(f)$) representative of the frequency response of said reproduction elements (3_1 to 3_N);
- of a parameter ($W(r,f)$) representative of a spatial window;
- of parameters ($W_1(f)$) representative of a spatial window in the form of weighting coefficients; and
- of a parameter ($R(f)$) representative of the radius of a spatial window when the latter is a ball.

9. The method as claimed in one of claims 5 to 8, characterized in that it comprises a calibration step (30) making it possible to deliver all or part of the parameters used in said step (50) of determining reconstruction filters.

10. The method as claimed in claim 9, characterized in that said calibration step (30) comprises, for at least one of the reproduction elements (3_n):
- a substep (34) of acquiring signals representative of the radiation of said at least one element (3_n) in the listening region (4); and
 - a substep (39) of determining spatial and/or acoustic parameters of said at least one element (3_n).

11. The method as claimed in claim 10, characterized in that said calibration step (30) comprises:
- a substep (32) of emitting a specific signal ($u_n(t)$) to said at least one element (3_n) of said reproduction unit (2), said acquisition substep (34)

corresponding to the acquisition of the sound wave emitted in response by said at least one element (3_n); and

5 - a substep (36) of transforming said signals acquired into a finite number of coefficients representative of the sound wave emitted, so as to allow the carrying out of said substep (39) of determining spatial and/or acoustic parameters.

10 12. The method as claimed in claim 10, characterized in that said acquisition substep (34) corresponds to a substep of receiving a number of coefficients representative of the acoustic field generated by said at least one element (3_n) in the form of a linear
15 combination of spatio-temporal functions, which coefficients are used directly during said substep (39) of determining spatial and/or acoustic parameters of said at least one element (3_n).

20 13. The method as claimed in any one of claims 9 to 12, characterized in that said calibration substep (30) furthermore comprises a substep of determining the position in at least one of the three dimensions in space of said at least one element (3_n) of said
25 reproduction unit (2).

14. The method as claimed in any one of claims 9 to 13, characterized in that said calibration step (30) furthermore comprises a substep (38) of determining the
30 spatio-temporal response ($N_{1,m,n}(f)$) of said at least one element (3_n) of said reproduction unit.

15. The method as claimed in any one of claims 9 to 14, characterized in that said calibration step (30)
35 furthermore comprises a substep of determining the frequency response ($H_n(f)$) of said at least one element (3_n) of said reproduction unit (2).

16. The method as claimed in any one of the preceding claims, characterized in that it comprises a step (40) of simulating all or part of the parameters necessary for carrying out said step (50) of determining
5 reconstruction filters.

17. The method as claimed in claim 16, characterized in that said simulation step (40) comprises:

- a substep (41) of determining missing parameters
10 from among the parameters used during said step (50) of determining reconstruction filters;
- a plurality of calculation substeps (42, 43, 44, 45, 46, 47, 48, 49) making it possible to determine the value or values of the missing parameter or parameters
15 as defined previously as a function of the parameters received, of the frequency, and of predetermined default parameters.

18. The method as claimed in claim 17, characterized
20 in that said simulation step (40) comprises a substep (44) of determining a list ($\{n^*\}(f)$) of elements of the reproduction unit that are active as a function of the frequency, and in that said calculation substeps are carried out just for the elements of said list.

25
19. The method as claimed in any one of claims 17 or 18, characterized in that said simulation step (40) comprises a substep (45) of calculating a parameter ($L(f)$) representative of the order of operation
30 limiting the number of coefficients to be taken into account during said step (50) of determining reconstruction filters with the help of at least the position in space of all or part of the elements (3_n) of the reproduction unit.

35
20. The method as claimed in any one of claims 17 to 19, characterized in that said simulation step comprises a step (47) of determining parameters ($W_1(f)$)

representative of a spatial window in the form of weighting coefficients with the help of a parameter ($W(r,f)$) representative of the spatial window in the spherical reference frame and/or of a parameter ($R(f)$) representative of the radius of said spatial window when the latter is a ball.

21. The method as claimed in one of claims 17 to 20, characterized in that said simulation step (40) comprises a substep (43) of determining a list ($\{l_k, m_k\}(f)$) of spatio-temporal functions whose reconstruction is imposed with the help of the position of all or part of the elements (3_n) of the reproduction unit (2).

22. The method as claimed in any one of the preceding claims, characterized in that it comprises a step of input (20) making it possible to determine all or part of the parameters used during said step (50) of determining reconstruction filters.

23. The method as claimed in any one of the preceding claims, characterized in that said step (50) of determining reconstruction filters comprises:

- a plurality of calculation substeps (51, 52, 53) carried out for a finite number of frequencies of operation and making it possible to deliver a matrix (W) for weighting the acoustic field, a matrix (M) representative of the radiation of the reproduction unit (2), and a matrix (F) representative of the spatio-temporal functions whose reconstruction is imposed; and

- a substep (54) of calculating a decoding matrix (D^*), carried out for a finite number of operating frequencies, with the help of the matrix (W) for weighting the acoustic field, of the matrix (M) representative of the radiation of the reproduction unit (2), of the matrix (F) representative of the

spatio-temporal functions whose reconstruction is imposed, and of a parameter ($\mu(f)$) representative of the desired local capacity of adaptation to the spatial irregularity of the reproduction unit, representative
5 of the reconstruction filters.

24. The method as claimed in claim 23, characterized in that said calculation substep (52) making it possible to deliver a matrix (M) representative of the
10 radiation of the reproduction unit (2) is carried out with the help of parameters representative for each element (3_n):
- of the three coordinates of its position ($\bar{x}_n$) with respect to the center (5) placed in the listening zone
15 (4); and/or
- of its spatio-temporal response ($N_{1,m,n}(f)$).

25. The method as claimed in claim 24, characterized in that said calculation substep (52) making it
20 possible to deliver a matrix (M) representative of the radiation of the reproduction unit (2) is carried out moreover with the help of parameters representative for each element (3_n) of its frequency response ($H_n(f)$).

26. A computer program comprising program code instructions for the execution of the steps of the method as claimed in any one of claims 1 to 25, when
said program is executed on a computer.

27. A removable medium of the type comprising at least one processor and a nonvolatile memory element, characterized in that said memory comprises a program comprising instructions for the execution of the steps of the method as claimed in any one of claims 1 to 25,
35 when said processor executes said program.

28. A device for controlling a reproduction unit (2) for restoring an acoustic field, comprising a plurality

of reproduction elements (3_1 to 3_N), characterized in that it comprises at least:

- means (12) of determining reconstruction filters representative of said reproduction unit (2), adapted
5 so as to make it possible to take into account at least spatial characteristics of said reproduction unit (2); and
- means (11) for determining at least one control signal (sc_1 to sc_N) for said elements (3_1 to 3_N) of said
10 reproduction unit (2), said at least one signal being obtained by application of said reconstruction filters to a finite number of coefficients representative of the distribution in time and in the three dimensions in space of said acoustic field to be reproduced.

15

29. The device as claimed in claim 28, characterized in that it is associated with means (6) for shaping an input signal (SI) comprising temporal and spatial information for a sound environment to be reproduced,
20 which means are adapted for decomposing said information over a basis of spatio-temporal functions so as to deliver a signal (SI_{FB}) comprising said finite number of coefficients representative of the distribution in time and in the three dimensions in
25 space of said acoustic field to be reproduced, corresponding to said sound environment, in the form of a linear combination of said spatio-temporal functions.

30. The device as claimed in claim 29, characterized
30 in that said spatio-temporal functions are so-called Fourier-Bessel functions and/or linear combinations of these functions.

31. The device as claimed in any one of claims 28 to
35 30, characterized in that said means (12) for determining reconstruction filters receive as input at least one of the parameters from the following parameters:

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- parameters $(\bar{x}_n)$ representative of at least one of the three coordinates of the position of each or some of the elements $(3_1 \text{ to } 3_N)$, with respect to the center (5) placed in the listening zone (4);
- 5 - parameters $(N_{1,m,n}(f))$ representative of the spatio-temporal responses of each of some of the elements $(3_1 \text{ to } 3_N)$;
 - a parameter $(L(f))$ describing an order of operation limiting the number of coefficients to be
 - 10 taken into account in the means (12) of determining reconstruction filters;
 - parameters $(G_n(f))$ representative of the templates of said reproduction elements $(3_1 \text{ to } 3_N)$;
 - a parameter $(\mu(f))$ representative of the desired
 - 15 local capacity of adaptation to the spatial irregularity of the configuration of said reproduction unit (2);
 - a parameter $(RM(f))$ defining the radiation model for said reproduction elements $(3_1 \text{ to } 3_N)$;
 - 20 - parameters $(H_n(f))$ representative of the frequency response of said reproduction elements $(3_1 \text{ to } 3_N)$;
 - a parameter $(W(r,f))$ representative of a spatial window;
 - parameters $(W_1(f))$ representative of a spatial
 - 25 window in the form of weighting coefficients;
 - a parameter $(R(f))$ representative of the radius of a spatial window when the latter is a ball; and
 - parameters $(\{(l_k, m_k)\}(f))$ constituting a list of spatio-temporal functions whose reconstruction is
 - 30 imposed.

32. The device as claimed in any one of claims 28 to 31, characterized in that each of said parameters received by said means (12) of determining

35 reconstruction filters is conveyed by one of the signals from the group of the following signals:

- a definition signal (SL) comprising information representative of the spatial characteristics of the

reproduction unit (2);

- a supplementary signal (RP) comprising information representative of the acoustic characteristics associated with the elements (3_1 to 3_N) of the reproduction unit (2); and
- an optimization signal (OS) comprising information relating to an optimization strategy,
- so as to deliver, with the aid of the parameters contained in these signals, a signal (FD) representative of said reconstruction filters representative of said reproduction unit (2).

33. The device as claimed in claim 32, characterized in that it is associated with means (7) for determining all or part of the parameters received by said means (12) for determining reconstruction filters, said means (7) comprising at least one of the following elements:
- simulation means (8);
 - calibration means (9);
 - parameters input means (10).

34. The device as claimed in any one of claims 28 to 33, characterized in that said means (12) for determining reconstruction filters are adapted for determining a set of filters representative of the position in space of the elements (3_1 to 3_N) of the reproduction unit (2).

35. The device as claimed in any one of claims 28 to 34, characterized in that said means (12) of determining reconstruction filters are adapted for determining a set of filters representative of the room effect induced by the listening zone (4).