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(54) LOUDSPEAKER WITH THERMAL CONTROL

(57) An apparatus for providing speaker protection, comprising: a gain unit for scaling an audio signal to be coupled to a speaker; a speaker model for estimating the temperature behaviour of the speaker due to the scaled audio signal; a controller for controlling the gain of said gain unit based on the estimated temperature behaviour to avoid overheating of the speaker; wherein the speaker model is characterized by a plurality of speaker parameters including thermal time constant.

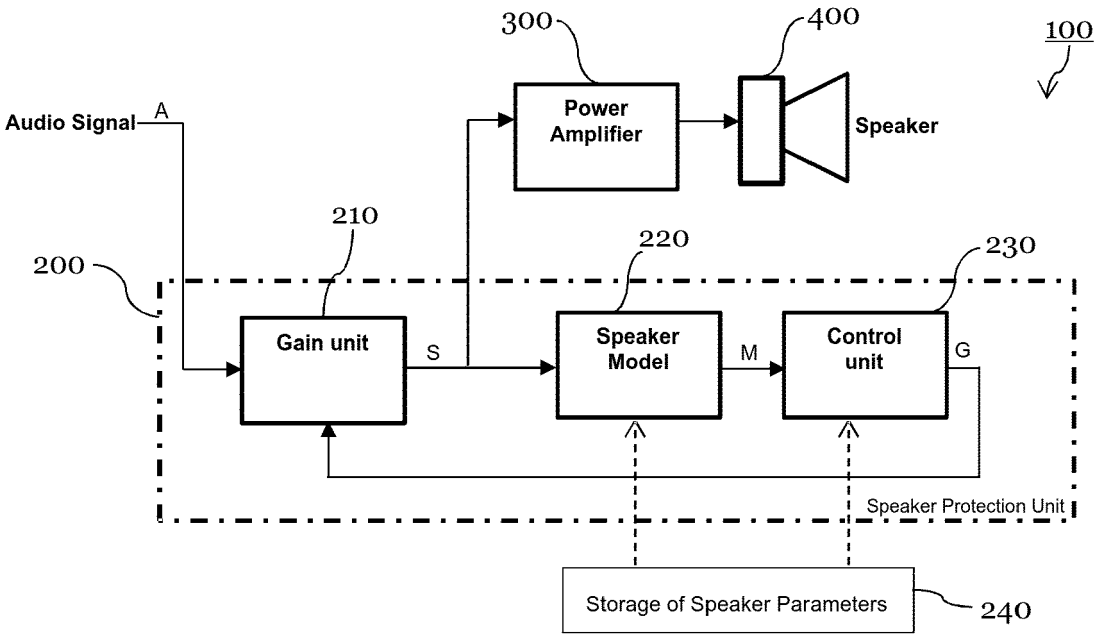


Figure 1

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Description

[0001] The present invention relates generally to speaker systems, and more particularly, to a mechanism which protects a speaker from thermal damage if driven by a high power amplifier.

TECHNICAL BACKGROUND

[0002] Most power delivered to the speaker of an audio product is converted to heat which raises the internal temperature of the speaker. If the heat exceeds critical temperature levels (e.g. of used materials, glue joints, etc.) then the speaker gets damaged or destroyed.

[0003] Normal audio signals like speech or music exhibit a large ratio between peak- and average power - hence the maximum output power of an audio system gets applied to the speaker only rarely and only for short periods of time while the average power is significantly lower. Due to the comparatively long thermal time constants of a speaker, the temperature rise remains manageable as long as average power stays within the specification of the speaker.

[0004] There are, however, situations where maximum output power gets applied to a speaker for extended periods of time - e.g. when applying heavy compression to an audio signal (i.e. average power lifted closer to peak power by sound-boosting features), misuse of user-adjustable equalization, etc. In such situation, there is a risk of speaker damage. This is especially critical for audio products which are able to generate high power levels or where speaker capabilities are constrained due to product form factor etc.

[0005] It is therefore necessary to implement a protection mechanism to speakers which:

- allows high power to be delivered to the speaker while it can still be handled safely (e.g. short peaks when the speaker's internal temperature is still below critical limits)
- limits power delivered to the speaker if this would endanger the speaker (e.g. prolonged application of high average power which would drive an already heated-up speaker above critical limits)

[0006] To date, there are some known protection mechanisms for speakers. However, they have limitations as further discussed below. In one example, the speaker is protected by limiting the power offered to the speaker to a predetermined 'safe' value. This method ignores the current thermal status of the speaker - i.e. whether the speaker temperature is still low (and thus the speaker is still able to handle high power) or the speaker is already heated up by preceding signal (and thus can only handle a limited amount of power before exceeding critical temperature limits). This protection method is therefore either too conservative (i.e. sound and loudness is limited even if unnecessary) or presents some risks (i.e. if limit is placed somewhere higher than 'safe' value, then the speaker may still get damaged).

[0007] In another example, by measuring signal voltage and current supplied to the speaker, the speaker impedance can be calculated and the internal speaker temperature can be calculated from the speaker impedance. If the temperature becomes too high, the power supplied to the speaker is reduced. This mechanism requires extra hardware for the current measurement and has limited accuracy. Specifically, other factors such as eddy currents at high signal frequencies affect the speaker impedance and may therefore lead to wrong conclusions on the speaker temperature. Moreover, when there is no signal, the speaker impedance cannot be calculated and needs to be estimated by using other methods.

[0008] In a further example, by measuring speaker temperature via sensors placed in the speaker. The power supplied to the speaker is reduced if the temperature approaches critical limits. This method requires a non-standard speaker and creates additional hardware complexity. Therefore, increasing the unit cost of the speaker system.

[0009] US 2013/0022208A discloses apparatus and methods for providing protection for audio transducers, in which the signals sent to the transducers are also coupled to a power monitoring circuit. The power monitoring circuit measures and controls both the average and peak power of an amplifier output into a load. The protection mechanism however does not take into account the current thermal situation of the speaker such as when heated up by preceding signals then less power can be handled safely compared to a situation where the speaker is still cold.

SUMMARY OF THE INVENTION

[0010] It is an object of the present invention to provide a protection mechanism to a speaker which protects the speaker against thermal damage while avoiding unnecessary reduction of sound output. The protection mechanism allows full power to be delivered to the speaker as long as the temperature of its critical component is still within safe area. The protection mechanism gradually reduces power delivered to the speaker as its temperature approaches a critical limit where damage could occur. The protection mechanism acts gradually without disruptive impact to the listening experience.

[0011] The protection mechanism is model-based and thus no sensor hardware is needed to determine internal temperature of the speakers. There is no need for non-standard speakers with built-in sensor. Instead, standard speakers can be used.

[0012] The object is solved by an apparatus for providing speaker protection having the features of claim 1. Further advantageous developments of the invention are the subject of the dependent claims.

[0013] According to a first aspect of the present invention, an apparatus for providing speaker protection com-

prises a gain unit, a speaker model and a controller. The gain unit is arranged for scaling an audio signal to be coupled to a speaker. The speaker model is arranged for estimating the temperature behaviour of the speaker due to the scaled audio signal. The controller is arranged for controlling the gain of the gain unit based on the estimated temperature behaviour to avoid overheating of the speaker. The speaker model is characterized by a plurality of speaker parameters including thermal time constants of speaker elements.

[0014] Within the concept of the present invention, the speaker model comprises at least one low pass filter for applying to the (RMS-converted) scaled audio signal. The low pass filter(s) has time constant(s) equivalent to the thermal time constant(s) of corresponding speaker element(s). In case of multiple low pass filters, the relative contribution (scale factor) of each low pass filter to the model output corresponds to the speaker element it represents.

[0015] Within the concept of the present invention, the speaker parameters further include sustainable power which describes the amplifier output power which can be sustained by the speaker over extended period of time without internal temperature exceeding critical limits.

[0016] Within the concept of the present invention, the speaker model comprises an equalization unit for representing the frequency dependence of actual thermal speaker behaviour. For instance, at a specific frequency the critical temperature may be reached already with lower signal level than at other frequencies - this would be represented by a proportional boost at such specific frequency to make the speaker model equally more sensitive there.

[0017] Within the concept of the present invention, the speaker model is also suitable for speaker time constants which differ for heat-up and cool-down situations. This is accomplished by comparing the input to the low pass filter(s) with its output and depending on the result applying the matching parameter set. For example, if the input exceeds the current output value of the low pass filter then speaker temperature will rise over time and therefore parameters valid for such heat-up situation will be used.

[0018] Within the concept of the present invention, the controller reduces the gain of the gain unit when the estimated temperature behaviour by the speaker model approaches said sustainable power of the speaker. The controller may be realized by one of the known standard techniques such as PID controller or two-point controller.

[0019] Within the concept of the present invention, the speaker parameters are specific for the speaker in use and are obtained from speaker characterization.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

Figure 1 is a block diagram of the speaker system containing a speaker protection unit according to an embodiment of the present invention.

Figure 2 is a schematic view of the speaker model in the embodiment of Figure 1.

Figure 3A illustrates the relationship of speaker impedance against frequency of the speaker of Figure 1.

Figure 3B illustrates the equalization with respect to the frequency-dependent power handling capability of the speaker of Figure 1 according to an embodiment of the present invention.

Figure 4 is a schematic view of the control unit in the embodiment of Figure 1.

Figure 5A is a plot of the measured voice coil temperature against time for the speaker of Figure 1 during heat-up phase.

Figure 5B is a plot of the measured voice coil temperature against time for the speaker of Figure 1 during cool-down phase.

Figure 6A is a plot of the model-calculated voice coil temperature against time for the speaker of Figure 1 during heat-up phase.

Figure 6B is a plot of the model-calculated voice coil temperature against time for the speaker of Figure 1 during cool-down phase.

GENERAL DESCRIPTION OF THE EMBODIMENTS

[0021] In the following, embodiments and modifications of the present invention are described with reference to a system containing one power amplifier and one speaker. However, it is to be understood that the present invention is not limited to one power amplifier and one speaker. On the contrary, the present invention also applies to systems including multiple speakers and amplifiers. It is also noted that embodiments discussed below can be combined with each other and the invention is not specifically restricted to the structure and arrangement of the specific embodiments and modifications discussed below.

A. OVERVIEW

[0022] Figure 1 is a system overview showing the elements that may be present in a speaker system 100 which contains a speaker protection unit 200 according to an embodiment of the invention. The speaker system 100 further comprises a power amplifier 300 and speaker 400. The speaker protection unit 200 comprises a gain unit 210, a speaker model 220 and a control unit 230.

[0023] As shown in Figure 1, an audio signal (A) from an audio signal source (not shown) is sent to the gain unit 210 and the audio signal (A) is scaled by a factor according to a gain control signal (G) from the control unit 230. The resulting signal (S) is sent to both the speaker 400 (via the power amplifier 300) and to the speaker model 220.

[0024] The speaker model 220 replicates the thermal behaviour of the speaker 400 according to speaker parameters stored in the memory unit 240. As this speaker model 220 is driven by the same signal (S) which is also sent to the speaker 400, the speaker model output (M) represents the temperature inside the speaker 400.

[0025] Advantageously, the model output represents a power figure which is equivalent to the temperature inside the speaker - i.e. the power which (if applied for extended period of time) would result in same temperature inside the speaker as the current temperature. This allows the controller 231 to be run entirely on level of 'Power figures' and avoid the conversion to temperature figures (which would be complex due to non-linearity introduced by thermal compression).

[0026] The control unit 230 compares speaker model output (M) with the critical limit (sustainable power) of the speaker 400 and calculates the gain control signal (G). As long as there is no risk of exceeding this critical limit, the gain control signal (G) assumes a neutral value so that the gain unit 210 applies unit gain to the audio signal (A). If speaker model output (M) approaches this limit (i.e. estimated temperature inside the speaker 400 comes close to critical value), gain control signal (G) is adjusted to gradually reduce the gain of the gain unit 210 to less than unity. As a result, the signal (S) driving the speaker 400 is reduced to keep internal temperature within safe boundaries.

[0027] The present invention allows the system to fully utilize the capability of the speaker up to its thermal limit at all times while avoiding the cost and complexity of actual temperature measurement via sensors inside the speaker.

[0028] The speaker parameters (e.g.: time constants, sustainable power, etc.) used in the speaker model 220 and in the control unit 230 are determined once at design time via a speaker characterization process which will be further described below.

B. SPEAKER MODEL

[0029] The speaker model 220 simulates the relationship between power applied to the speaker 400 and resulting temperature rise at the most critical element within the speaker (in a conventional loudspeaker, the most critical element is usually the voice coil), such that the protection mechanism of the control unit 230 has information about the estimated internal speaker temperature without requiring a temperature sensor in the speaker itself.

[0030] The temperature rise depends on the specific characteristics of the speaker in use. Therefore, the speaker model 220 needs to be tailored according to the used speaker 400 via speaker characterization during product development stage.

[0031] Figure 2 is an illustrative example for a typical speaker. The main building blocks of the speaker model 220 include equalization unit 221, power conversion unit 222, and low pass filters 223, and phase detection unit 224:

1. EQUALIZATION UNIT

[0032] Figures 3A and 3B illustrates the general relationship of the speaker impedance and input signal frequency. Depending on the construction of the speaker and its enclosure, the power absorbed by the speaker may vary depending on the frequency of the audio input signal. Figure 3A illustrates this for a typical bass reflex enclosure. Firstly, at the bass port resonance frequency 302, the speaker impedance 301 exhibits a minimum, and thus a maximum of power gets absorbed by the speaker from the power source (amplifier output) at this frequency. Secondly, voice coil movement is minimal (due to damping by the bass port) and thus there is less heat transfer from voice coil to its surrounding due to reduced air convection. Both factors combined lead to a higher temperature rise, and the power needed to reach critical temperature 303 shows a minimum at this frequency.

[0033] In order to reproduce the thermal behavior of the speaker, the speaker model needs to take such frequency dependency into account. This is achieved by applying a corresponding equalization to the input signal (S) via the equalization unit 221 - e.g. frequencies where the speaker reaches critical temperature already at low power level get boosted accordingly (resulting in signal (S') such that also the output of the speaker model (M) reaches its full value already at same low power level).

[0034] The actual need and complexity of such equalization strongly depends on the specific speaker characteristics. Also for a practical implementation some simplification may be possible - e.g. frequencies for which the power to reach critical temperature is higher than what the used amplifier can provide may be disregarded for the equalization etc.

[0035] Figure 3B illustrates this for the case of a typical bass reflex enclosure. Highest values of the power curve 304 can be neglected as the power amplifier anyhow would not be able to deliver them. Most remaining parts of the power curve 304 can then be approximated by a straight line (odB - i.e. no equalization).

[0036] For the specific frequency identified in Figure 3A ('lowest impedance'), the power curve 304 shows a marked dip compared to all other frequencies - i.e. the critical temperature is reached already with much less power . This area therefore needs to be taken into account also in a simplified case - the speaker model needs to be made equally more sensitive for this specific frequency. This is achieved by applying a corresponding

equalization 305 at the input of the speaker model. In the illustrated case, the power curve 304 shows that approximately 5dB less power is required at 30 Hz to reach critical temperature - hence equalization 305 needs to introduce a 5 dB boost at this frequency such that speaker model exhibits the same behaviour.

2. SIGNAL TO POWER CONVERSION UNIT

[0037] Thermal effects on the speaker depend on the applied power from the input audio signal instead of the applied current/voltage. According to an embodiment to the present invention, signal (S') before propagating to the low pass filters 223 is converted by a signal to power conversion unit 222 to a signal (P) representing power levels based on the relationship P = S'^2.

3. LOW PASS FILTERS

[0038] When applying power signal to a speaker, the internal temperatures rises only gradually over time depending on the thermal time constants (TC) of the involved elements - e.g. depending on speaker size, the voice coil may exhibit a TC between seconds and few minutes, the magnet and frame may have a TC between few minutes and hours, etc. Moreover, these elements interact - e.g. heating up of the voice coil leads to transfer of thermal energy (e.g. via radiation and convection) to the surrounding magnet / speaker frame which also starts to heat up (albeit at much slower rate due to bigger TC of magnet / frame). This in turn increases the ambient temperature of the voice coil and contributes to further rise of voice coil temperature.

[0039] To replicate this thermal inertia of the involved speaker elements, the power signal (P) is subjected to low pass filter(s) 223 which each represents a specific element of the speaker, for instance, voice coil, speaker frame, etc.

[0040] The time constants TC of each low pass filter 223 and relative contribution to the overall speaker model output (M) is determined in the speaker characterization process. In an alternative embodiment, if for a specific speaker the parameters differ for heat-up and cool-down phase, then the current phase is first detected by phase detection unit 224, and the parameters will be switched-in accordingly.

[0041] In the following mathematical representation of the speaker model according to an embodiment of the invention, the parameters for 'heat-up' phase containing suffix 'h' or the parameters for 'cool-down' phase marked with suffix 'c' are used in respective situations.

[0042] The output M(n) of the speaker model 220 represents a power level which corresponds to the current speaker temperature ('temperature-equivalent power') and is the summation of M1(n) - the speaker model output component contributed by a first speaker element having a thermal time constant TC_{1x} and scale factor k_{1x}, and $M_2(n)$ - the speaker model output component contributed by a second speaker element having a thermal time constant TC_{2x} and scale factor k_{2x}. TC_{1x}, TC_{2x}, k_{1x}, k_{2x} are specific for the speaker in use.

$$M(n) = M_1(n) + M_2(n)$$

and

$$M_1(n) = a_{1x} * M_1(n-1) + b_{1x} * P(n) * k_{1x}$$

$$M_2(n) = a_{2x} * M_2(n-1) + b_{2x} * P(n) * k_{2x}$$

where

$$a_{1x} = \exp(-1/TC_{1x})$$

$$b_{1x} = 1 - a_{1x}$$

$$a_{2x} = \exp(-1/TC_{2x})$$

$$b_{2x} = 1 - a_{2x}$$

(n) represents the current value;
(n-1) represents the last calculated value;
Suffix 'x' to be substituted by 'h' if P(n) > M(n-1) or otherwise by 'c'

[0043] According to an embodiment of the invention, a_{1x}, b_{1x}, a_{2x}, b_{2x} are precalculated at design time based on speaker characterization.

C. CONTROL UNIT

[0044] Figure 4 presents an overview of the components in the control unit 230 according to an embodiment of the invention, which comprises a controller 231 and power conversion unit 232.

1. CONTROLLER

[0045] The controller 231 compares the output (M) of the speaker model 220 with a power level corresponding to critical temperature, Pwr_sust - the power sustainable over extended period of time without exceeding temperature limit inside the speaker.

[0046] Existing standard techniques can be selected to implement the controller functionality (e.g. PID, two-point ...) according to the advantages and disadvantages of respective techniques.

2. POWER CONVERSION

[0047] The output of the controller 231 (G_pwr) is on the level of 'Power' as its input (M) is on power level. Since the gain unit 210 operates on signal levels, the output of the control unit 230 needs to be converted accordingly (square root operation). The resulting output signal (G) is fed to the gain unit 210 to control the gain applied to the audio signal (S).

D. GAIN UNIT

[0048] The gain unit 210 adjusts the gain on the signal passed to the speaker (and in parallel coupled to the speaker model) based on the control signal (G) determined by the control unit 230, i.e.:

$$S = G * A$$

[0049] In normal situation a unity gain is applied (i.e. no attenuation).

[0050] If the control unit 230 determines according to the output of the speaker model 220 that speaker 400 approaches the critical temperature, then the control unit 230 generates a gain control signal (G) less than 1. This reduces the signal (S) passed to the power amplifier 300 and speaker 400. Since this equally reduces the input signal (A) to the speaker model (M), a closed control loop is formed with the result that speaker temperature is kept below critical limit at all times while still allowing the maximum amount of power to be sent to the speaker, which at current condition of the speaker is still safe.

[0051] In an alternative embodiment of the invention, the gain may also be a limiter or compressor where the threshold level is adjusted by the control signal (G).

[0052] In an alternative embodiment of the invention, the speaker system 100 implements multi-channel or multi-band arrangements involving multiple speakers (e.g. woofer, tweeter, etc.). Advantageously, a separate speaker model and controller per speaker is implemented. Gain setting may then either be done independently per speaker or in a combined manner (e.g. gain for all bands set to the same lowest value of all controllers) to keep spectral balance of sound output unchanged.

E. SPEAKER CHARACTERIZATION

[0053] According to an embodiment of the invention, the speaker protection mechanism is tailored to the specific properties of the speaker in use. These properties are determined in a 'speaker characterization' step, performed once during development of the system. This results in a set of speaker parameters used by the speaker protection mechanism (ref. Figure 1). The process described below represents an example for a typical bass reflex speaker.

1. DETERMINE FREQUENCY DEPENDENCY OF SPEAKER THERMAL BEHAVIOUR

[0054] As a first step of the speaker characterization procedure, audio signals of different frequencies are applied to the speaker and the speaker impedance (mainly contributed by voice coil impedance) is measured.

[0055] Referring back to Figure 3A which is a plot of speaker impedance 301 against signal frequency for a typical speaker with bass reflex enclosure. At the frequency of lowest impedance 302, a maximum of power is absorbed by the speaker when driven by an amplifier acting as voltage source in the characterization platform.

[0056] The frequency of lowest impedance 302 usually coincides with the frequency where voice coil excursion is lowest due to damping by port resonance. Therefore, heat transfer by air convection from voice coil to surrounding areas is less effective.

[0057] Both factors combined lead to higher temperature rise than at other frequencies - therefore the frequency of lowest impedance needs to be taken into account via the equalization unit 221 in the speaker model 220, as explained in [0037] to [0038] and Figure 3A.

2. DETERMINE THERMAL SPEAKER PARAMETERS

[0058] As a second step of the speaker characterization procedure, a stationary signal at a safe power level (e.g. 30% of rated power to avoid risk of speaker damage) is applied to the initially 'cold' speaker and the rising voice coil temperature is monitored. After temperature has reached a stable value, the signal to the speaker is removed and the monitoring of voice coil temperature continued until it has fallen close to original 'cold' value. The evolution of voice coil temperature over time during both heat-up and cool-down phase is captured.

[0059] Example of the measured speaker voice coil temperature data 501, 502 at respective heat-up and cool-down phases are shown in Figures 5A and 5B. The measurement is performed at least for a signal using the most critical frequency (identified in the first step of the speaker characterization procedure described above) and for a signal representing the entire frequency band of interest (e.g. pink noise).

[0060] From this measured voice coil temperature data 501 and 502, the key speaker parameters such as sustainable power and thermal time constants and scale factors can be derived.

I. SUSTAINABLE POWER (PWR SUST)

[0061] Once temperature has stabilized at the end of the heat-up phase, the voice coil impedance can be determined (due to temperature coefficient of used voice material, this can change significantly at elevated temperature) and from this, the power actually absorbed by the speaker can also be determined.

[0062] Based on the power actually absorbed by the

speaker, the power required to reach the critical voice coil temperature (i.e. the temperature which the voice coil can still withstand permanently without damage) can be calculated.

[0063] Taking into account the temperature dependence of the voice coil impedance, the corresponding amplifier output level can be determined, which can be sustained by the speaker over extended period of time. This is then the parameter "sustainable power" (Pwr_sust).

[0064] Preferably, the value of Pwr_sust obtained using pink noise serves as reference point for the controller 231 in Figure 4.

[0065] Preferably, the value of Pwr_sust obtained using the critical frequency 302 is used to determine the characteristics of the equalization unit 221 in the speaker model 220 in Figure 2.

[0066] According to an embodiment of the present invention, the process of determining Pwr_sust takes the effect of thermal compression into account. This provides the benefit that the actual speaker protection algorithm can be operated on the level of 'temperature-equivalent power' figures, instead of 'voice coil temperature' which would require more complex or iterative calculations at run time and thus complicate the implementation.

II. TIME CONSTANTS (TC) AND SCALE FACTORS FOR LOW PASS FILTERS

[0067] The time constants (TC) and scale factors for low pass filters 223 in Figure 2 can be determined from the measured voice coil temperature data points 501 and 502 in Figures 5A and 5B, e.g. by converging low pass filter parameters towards minimized difference between measured- and model-calculated data points (e.g. sum of squared error terms). Scale factors indicate how much each speaker element (represented by its corresponding low pass filter in the speaker model) contributes to total speaker temperature (represented by output of model). For example, if for a given power supplied to the speaker, the voice coil temperature rises by 70 deg. Celsius against its surrounding (which is the speaker frame / magnet); and the speaker frame / magnet itself rises by 30 degree Celsius against its surrounding (which is ambient air), then the total speaker (voice coil) temperature rise is 100 degree Celsius with the voice coil contributing 70 % and the speaker frame / magnet contributing 30% - these are then the scale factors for the two corresponding low pass filters in the speaker model. Scale factors are determined in the same process as determining the time constants by minimizing the sum of squared error terms.

[0068] Figures 6A and 6B respectively show the model data points 601, 603 based on the following example model parameters set for best match to measured data 501, 502 during the heat-up and cool-down periods. Error curves 602, 604 respectively correspond to the model-calculated data points 601, 603.

TC_{1h}	38 sec	TC_{1c}	100 sec
k_{1h}	60%	k_{1c}	60%
TC_{2h}	1380 sec	TC_{2c}	3250
k_{2h}	40%	k_{2c}	40%

[0069] The model parameter set resulting in lowest error term is then used for the low-pass filters 223 of the speaker model 220 in Figure 2.

[0070] Depending on construction of speaker and enclosure a model based on less or more low pass filters may be appropriate to best represent the measured data. A model based on two time constants as indicated in the embodiment of the invention should however be sufficient in most cases. Additional time constants may e.g. be needed in case the heat transfer through the speaker cabinet to ambient air is contributing significantly (e.g. ceramic enclosure material with large heat capacity)

[0071] Implementations and embodiments of the invention have been described herein by way of example. It is obvious to a person skilled in the art that the invention is not restricted to the details of the above-described embodiments and that the invention can be implemented in other forms without departing from the characteristics of the invention. The embodiments described should be regarded as illustrative, not restrictive. Thus, possibilities for the implementation and use of the invention are restricted only by the appended claims. Hence, different implementation alternatives for implementing the invention defined by the claims, including equivalent implementations, are included within the scope of the invention.

REFERENCE SIGNS

[0072]

100	speaker system
200	speaker protection unit
210	gain unit
220	speaker model
221	equalization unit
222	signal to power conversion unit
223	low pass filters
224	phase detection unit
230	control unit
231	controller
232	power to signal conversion unit
240	memory unit
300	power amplifier
301	speaker impedance
302	frequency of lowest impedance
303	power needed to reach critical temperature
304	power curve
305	equalization
400	speaker
501	measured voice coil temperature at heat-up

phase
502 measured voice coil temperature at cool-down phase
601 voice coil temperature model at heat-up phase
602 error of voice coil temperature model at heat-up phase
603 voice coil temperature model at cool-down phase
604 error of voice coil temperature model at cool-down phase

Claims

1. An apparatus for providing speaker protection, comprising:

   a gain unit for scaling an audio signal to be coupled to a speaker;
   a speaker model for estimating the temperature behaviour of the speaker due to the scaled audio signal;
   a controller for controlling the gain of said gain unit based on the estimated temperature behaviour to avoid overheating of the speaker;
   wherein the speaker model is **characterized by** a plurality of speaker parameters including thermal time constants scale factors of speaker elements.

2. The apparatus for providing speaker protection according to claim 1, wherein said plurality of speaker parameters further include sustainable power and critical frequency of the speaker.

3. The apparatus for providing speaker protection according to claim 1, wherein said speaker model comprises at least one low pass filter for applying to the scaled audio signal, said low pass filter has a time constant corresponding to one of said thermal time constants of speaker elements.

4. The apparatus for providing speaker protection according to claim 3, wherein said speaker model comprises an equalization unit for boosting said scaled audio signal at said critical frequency before said low pass filter to avoid overheating of the speaker at said critical frequency.

5. The apparatus for providing speaker protection according to claim 4, wherein said speaker model determines whether the speaker is in heat-up phase or cool-down phase by comparing the boosted audio signal and the estimated temperature behaviour; and wherein said low pass filter has different characteristics in heat-up phase and cool-down phase.

6. The apparatus for providing speaker protection according to claim 1, wherein said controller reduces said gain of the gain unit when the estimated temperature behaviour by said speaker model approaches a critical value corresponding to said sustainable power of the speaker.

7. The apparatus for providing speaker protection according to claim 1, wherein said controller is a PID controller.

8. The apparatus for providing speaker protection according to claim 1, wherein said controller is a two-pointed controller.

9. The apparatus for providing speaker protection according to claim 1, wherein said speaker parameters are specific for the speaker in use.

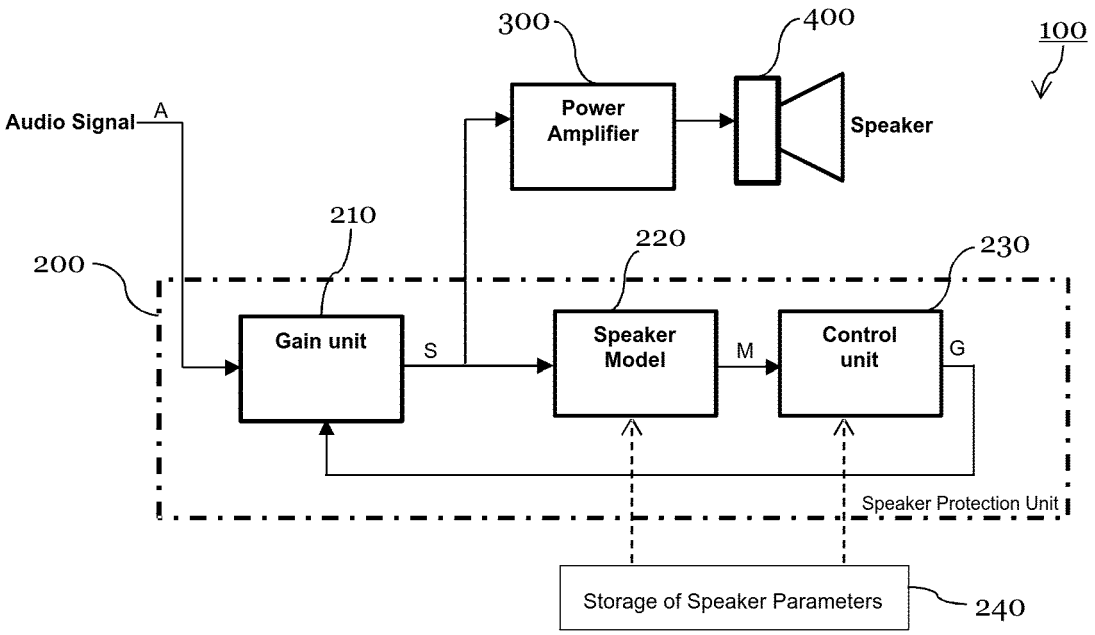


Figure 1

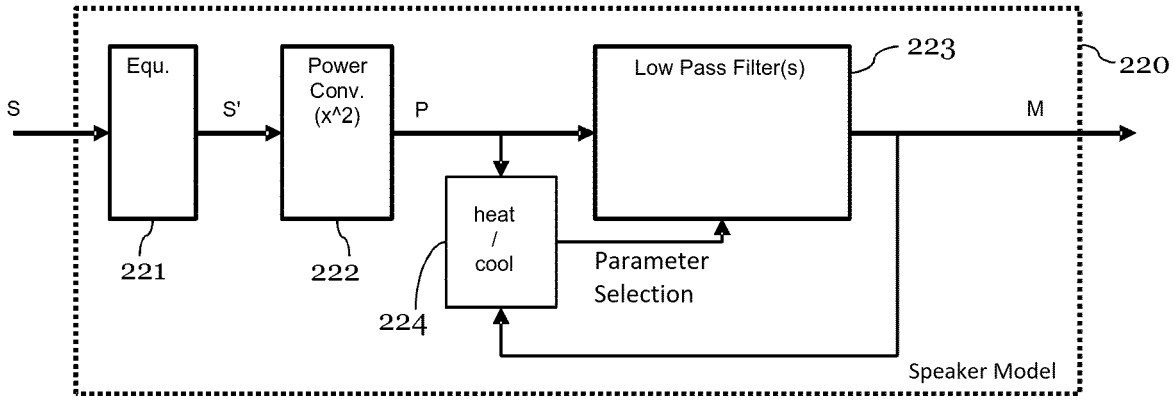


Figure 2

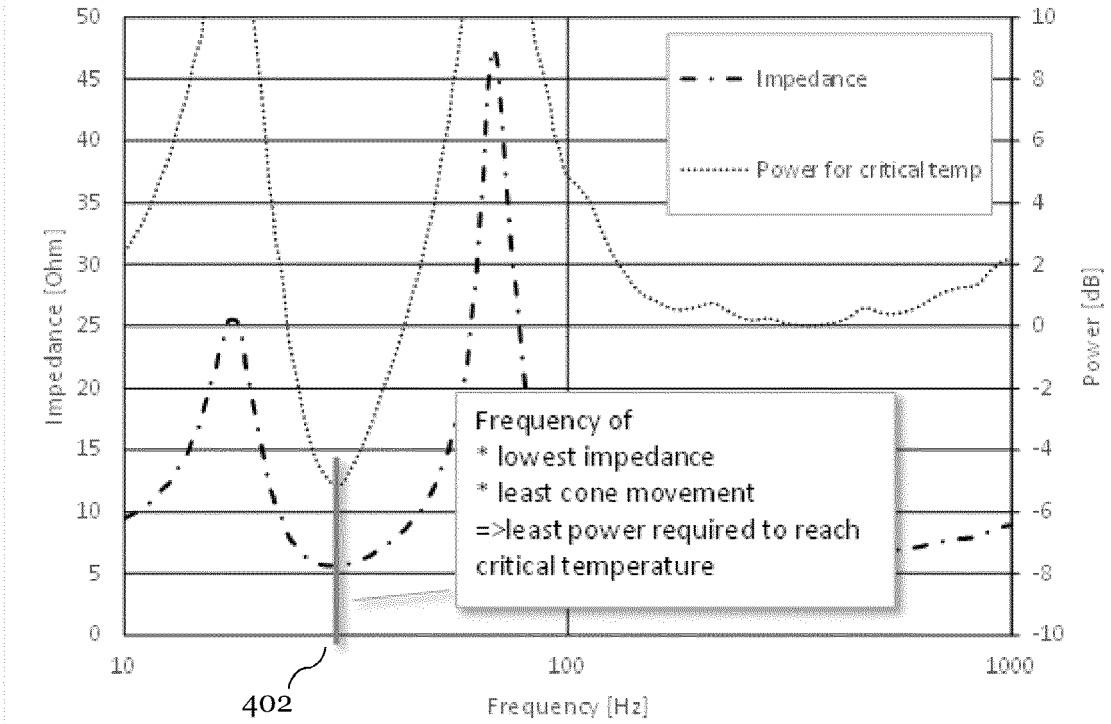


Figure 3a

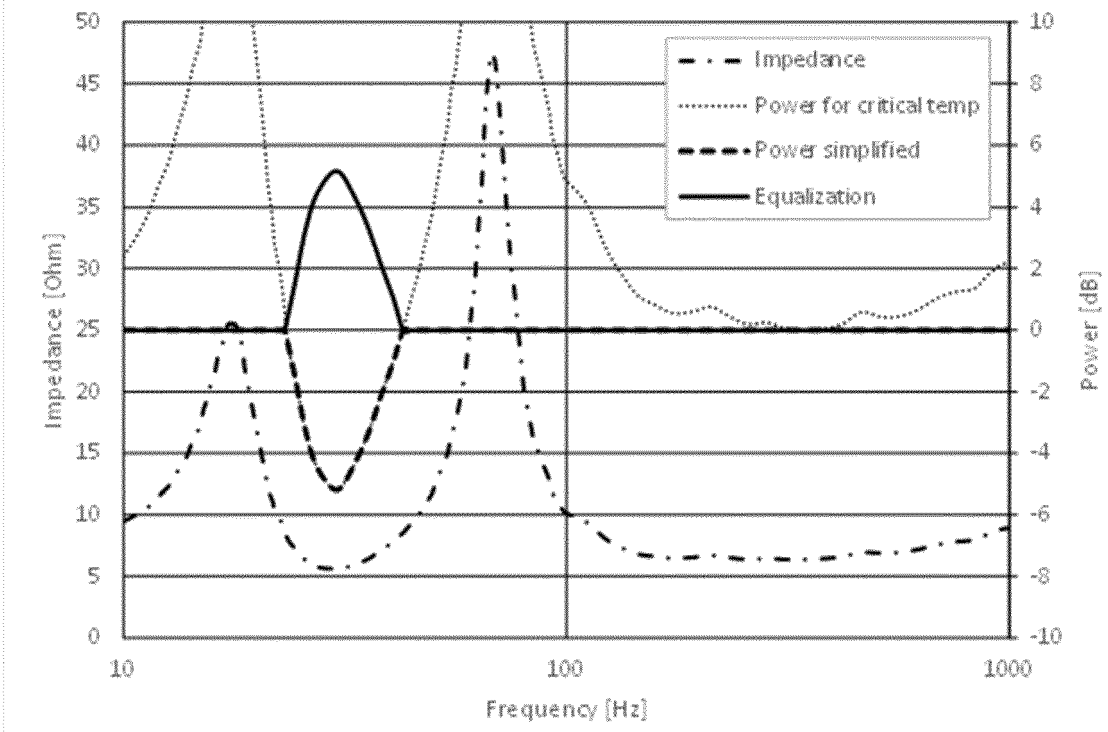


Figure 3b

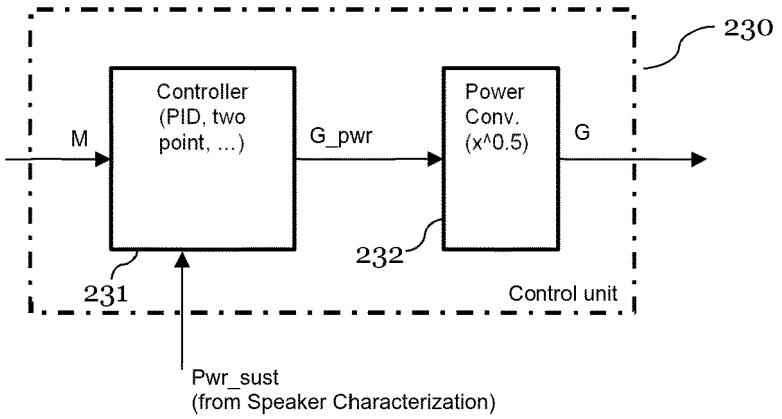


Figure 4

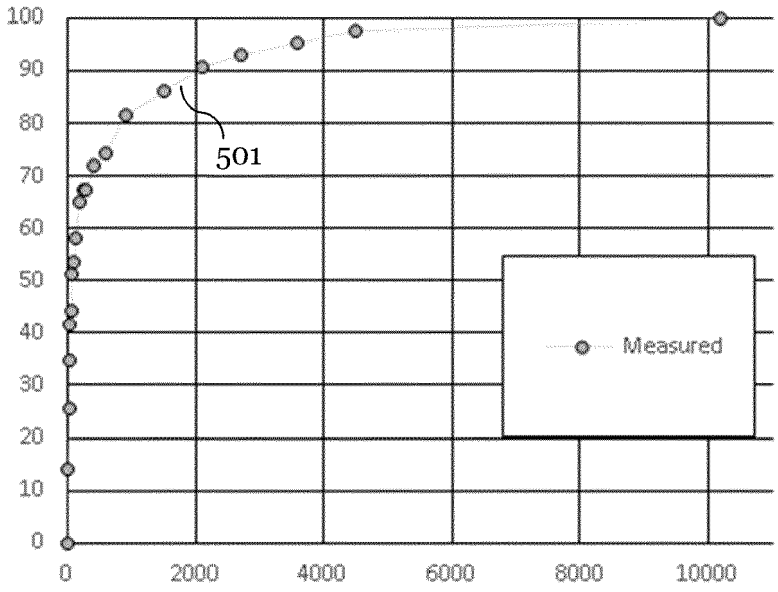


Figure 5A

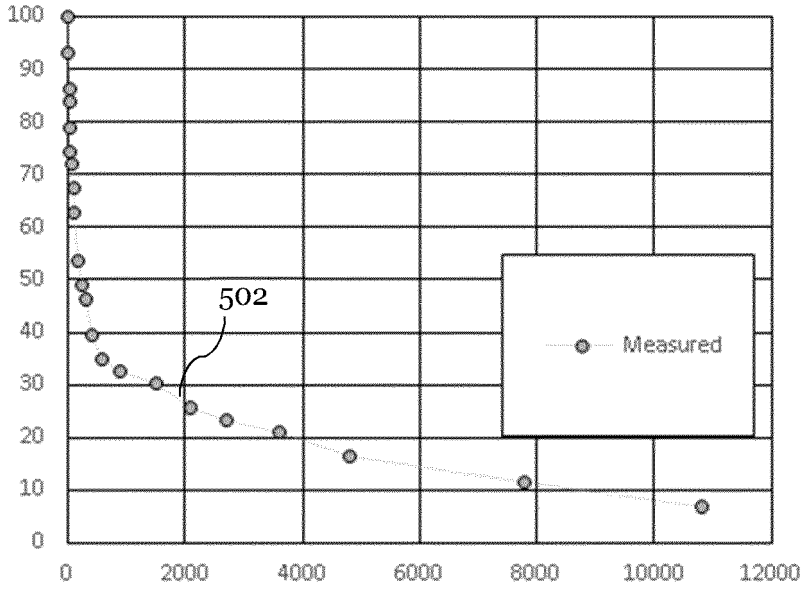

100
90
80
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
10000
12000
502
Measured

Figure 5B

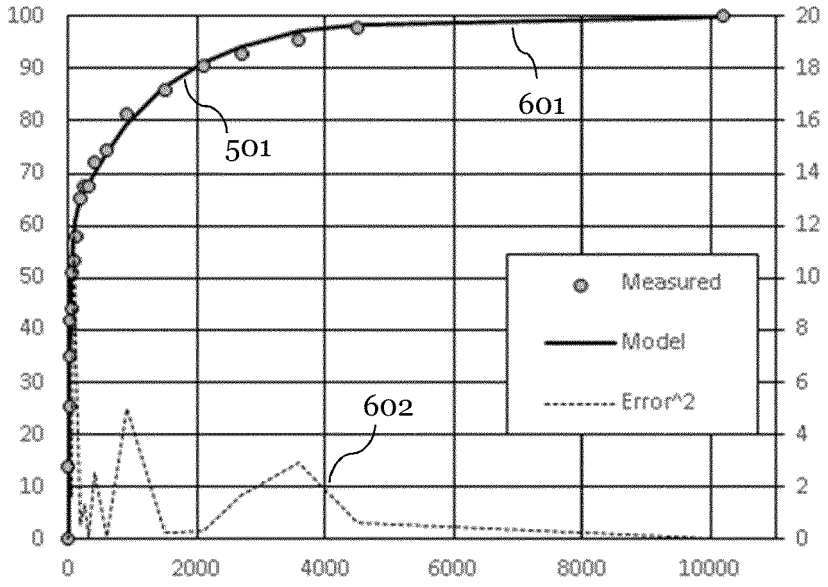


Figure 6A

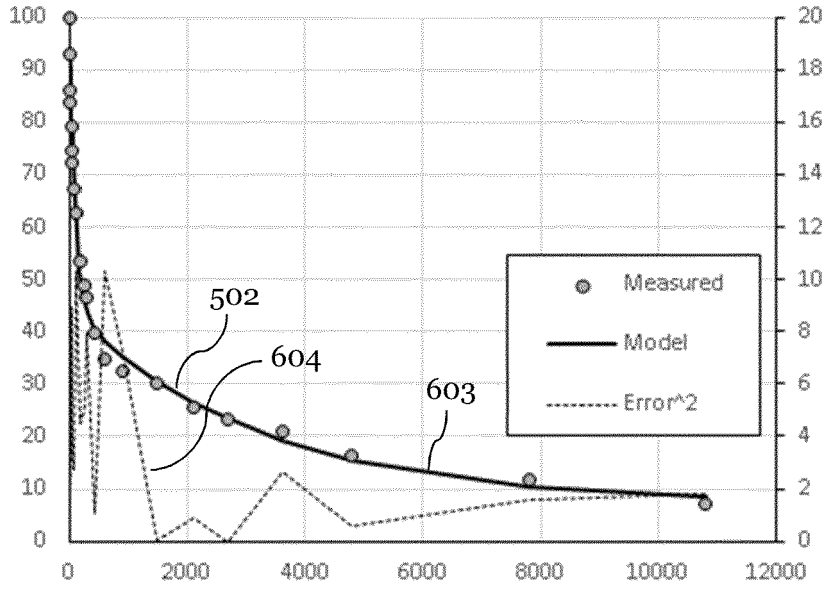


Figure 6B

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EUROPEAN SEARCH REPORT

Application Number
EP 17 18 9159

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	11 January 2018	Bensa, Julien

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