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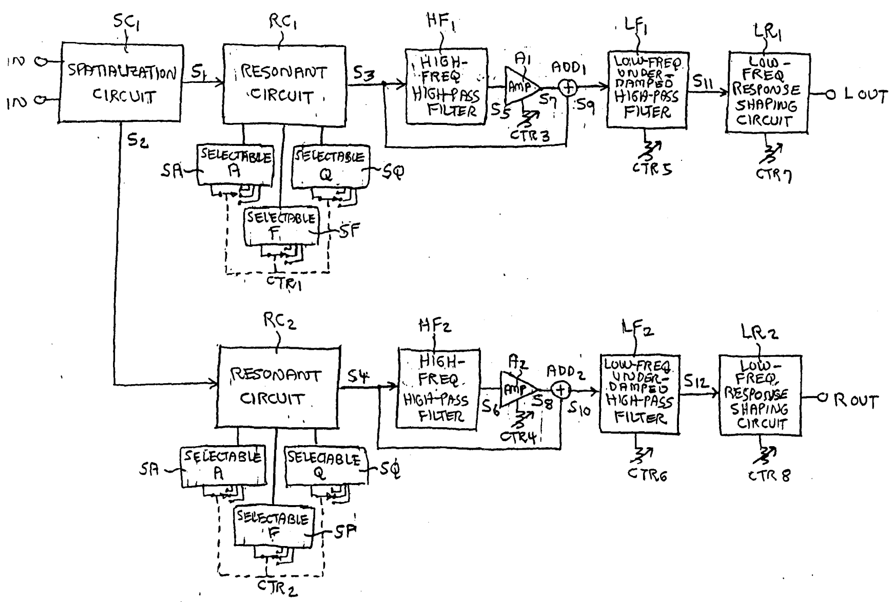
(54) **Compensation system for planar loudspeakers**

(57) A frequency response compensation system incorporating conventional and unconventional cascaded equalization circuits, in which the frequency response aberrations of a planar diaphragm loudspeaker mounted in an architectural ceiling, wall, or in other enclosure having a limited depth dimension are optimally corrected. A multi-section switch is comprised in a resonant circuit to enable single-control selection of pre-set amplitude (A), frequency (F) and bandwidth (Q) parameters corresponding to various enclosure depths. A low-frequency underdamped high-pass filter and a low-frequency response shaping circuit may each be included in the system to compensate for a low-frequency roll-off resulting from the limited depth dimension of the enclosure. A high-frequency equalization circuit, in which high-pass filtered and non-filtered signals are summed, introduces a rapid rate-of-change shelved equalization required to compensate for a rapid high-frequency response roll-off resulting from the application of decorative finishing materials to the planar loudspeaker diaphragm. A stereophonic spatialization circuit may also be included and utilizes modified stereophonic signal cross-coupling to compensate for the reduced levels of room reverberant sound information associated with in-wall planar loudspeakers.

FIG.5.



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Description

[0001] This invention relates generally to frequency compensation systems and, more particularly, to a method and apparatus utilizing a combination of specially-adapted cascaded equalization circuits to compensate for the frequency response of a planar diaphragm loudspeaker under various circumstances. A stereophonic spatialization circuit may be incorporated in the system.

[0002] For decades, conventional loudspeaker diaphragms have had a cone-type construction made from pressed paper or the like. In more recent years, certain advances in dynamic loudspeaker design have been provided by the advent of planar diaphragm loudspeakers. Presently there are a variety of planar loudspeakers using differing materials and having differing constructions and configurations. However, in general, such planar loudspeakers typically include a relatively stiff and substantially planar diaphragm that is coupled at its rear surface to a loudspeaker driver. The driver presses on the rear surface of the diaphragm and causes sufficient vibration of the diaphragm to efficiently produce sound. Generally, the frequency response of a planar loudspeaker is determined by the type and density of the material used for the diaphragm, and the area, thickness and contour of its sound producing region, as well as the type, position and configuration of the driver. Each of these parameters is chosen to achieve an acceptable degree of fidelity in the reproduction of sound in both the low and high frequency ranges.

[0003] Some of the advantages provided by planar loudspeakers over loudspeakers utilizing conventional cone-type diaphragms include greater dispersion of sound and economy of manufacture. A further advantage of certain planar loudspeakers is that the front surface of the diaphragm can be molded to take on the appearance of a relatively large acoustic tile, permitting unobtrusive installation of the loudspeaker in ceilings of commercial structures formed of like-appearing acoustic tiles. Alternatively, the front surface of certain planar loudspeakers can be molded smooth and flat and installed in an architectural ceiling or wall in such a manner that the front surface of the planar diaphragm is parallel to, and flush with, the front surface of the ceiling or wall. This type of installation of planar loudspeakers in walls or ceilings, which will be referred to as "in-wall," enables a common decorative finishing material to be applied to the diaphragm and surrounding ceiling or wall surface, thereby making the loudspeaker non-visible from the exterior side of the wall or ceiling.

[0004] Various problems can arise in such in-wall installations of planar loudspeakers. For example, the rigidity of the decorative finishing material applied to both the diaphragm and the surrounding ceiling or wall can result in a rapid low-frequency roll-off, thus diminishing the quality of the low-frequency sound produced by the loudspeaker. Also, the mass of decorative finishing material can have a filtering effect on high frequency sounds, resulting in a rapid high-frequency roll-off that diminishes the quality of high-frequency sound produced by the loudspeaker.

[0005] Moreover, the resulting severe limitation in the depth of air space behind the planar diaphragm creates unusual and adverse acoustic conditions. Specifically, the back surface of the planar diaphragm constitutes the first of two opposing and closely spaced flat parallel surfaces, and the interior wall or other surface opposite the diaphragm constitutes the second of such closely spaced flat parallel surfaces. The existence of two closely spaced flat parallel surfaces, in which one surface is acoustically active and the remaining surface is rigid (and therefore acoustically reflective), can result in detrimental resonant modes.

[0006] Acoustically absorbent material placed between the above-described parallel surfaces tends to damp such resonant modes, but only above a specific frequency. This is due to the fact that the longest quarter-wavelength of sound energy that may be absorbed is limited by the thickness dimension of the absorbent material within an available air space in the ceiling or wall. As a practical matter, the interior dimension of most architectural walls, and hence the maximum separation between such parallel surfaces, is about 3½ to 6 inches, which restricts the lowest absorbed frequency to a range of about 200 to 800 Hz., depending on the separation. Additionally, a very substantial dip in frequency response occurs at the "one-quarter wavelength frequency," a wavelength equal to four times the distance between the parallel surfaces; and, an undesirable rapid roll-off occurs in the low frequency region below the lowest absorbed frequency. The planar loudspeaker may be housed in its own enclosure having depth dimensions that vary between about 4 and 6 inches, and in some cases the only enclosure, if any, is the architectural structure itself (i.e., an interior or opposing surface inside the wall or ceiling). This results in corresponding variations in the lowest absorbed frequency, as well as corresponding variations in the amplitude, frequency and bandwidth of the frequency response dip.

[0007] In addition, the sound quality produced by in-wall mounted planar loudspeakers can suffer from the acoustics of a room, including the placement or location of the loudspeakers within the room, such as when a wall or ceiling speaker is mounted near a corner of the room. As a final consideration, loudspeakers that are flush mounted on a ceiling or wall surface introduce reduced levels of room reverberant sound information relative to non-flush mounted loudspeakers. This results in diminished spatial sound qualities.

[0008] It is known that improvements in sound reproduction may be realized through processing of the source signal that is input to a loudspeaker. It is also known that cross-coupling two stereo channels can improve the stereo effect perceived by a listener. In general, systems have been proposed and utilized which modify and cross-couple signals in various ways to achieve these improvements. However no such systems are known that provide specific circuits, combinations or circuits, and circuit control features required to specifically compensate for the aforedescribed problems with planar loudspeakers and improve the stereo effect provided by such loudspeakers.

[0009] Accordingly, there is a need for an effective signal processing system to compensate for the above deficiencies in the frequency response of planar loudspeakers and to enhance their stereo effect that is simple and economical to manufacture. The present invention fulfills these and other needs.

[0010] Briefly, and in general terms, the present invention resides in a signal processing system, including a method and apparatus, that comprises specially-adapted cascaded equalization circuits, in which the frequency response aberrations of a planar diaphragm loudspeaker resulting from mounting the loudspeaker in an architectural ceiling, wall, or similar enclosure having a limited depth dimension, and/or from covering the diaphragm with decorative material, and/or from room acoustics, are optimally corrected. The invention further resides in a system for stereophonic spatialization of planar loudspeakers that serves to compensate for the reduced levels of room reverberant sound information associated with in-wall mounting of such loudspeakers.

[0011] In a presently preferred embodiment, and by way of example only, a first cascaded equalization circuit consists of a resonant circuit in which a multi-section switch enables single-control selection of pre-set amplitude (A), frequency (F) and bandwidth (Q) parameters corresponding to various planar loudspeaker enclosure depths. This resonant circuit is typically tuned to a mid-frequency when the planar loudspeaker is wall-mounted, and is typically tuned to a low-mid-frequency when the planar loudspeaker is ceiling-mounted. The resonant circuit is of the gyrator-type in the preferred embodiment of the present invention. In some instances, a single set of the A, F and Q parameters provide adequate frequency response correction, in which case the multi-section switch may be eliminated.

[0012] A second cascaded equalization circuit in the preferred embodiment consists of an unconventional high-frequency shelving equalization circuit that introduces a rapid rate of shelved boost, typically between 6 and 24 dB per octave at a corner frequency of 4 KHz, and typically providing an adjustable maximum boost ranging from 3 dB to 24 dB, which compensates for a wide range of decorative surface material and its corresponding effect on the high-frequency response of the planar loudspeaker. In the preferred embodiment, the high-frequency shelved equalization circuit comprises a fourth-order Chebyshev high-pass filter, the output of which is amplified by an adjustable gain amplifier and then mixed with a sample of the unfiltered input signal, thereby producing a rapid rate-of-change shelf boosted high-frequency equalized signal.

[0013] A third cascaded equalization circuit in the preferred embodiment may consist of an underdamped low-frequency high-pass filter. Such underdamped filter provides a peaked amplitude in a low-frequency region below the primary system resonant frequency of the loudspeaker/enclosure combination, thereby extending the low-frequency response of the loudspeaker. The underdamped filter also provides a sharp cut-off below the low-frequency region, which serves to substantially eliminate excessive diaphragm excursions normally associated with the application of low-frequency boost equalization.

[0014] Finally, a fourth cascaded equalization circuit in the preferred embodiment may consist of a low-frequency shaping circuit which enables user-adjustability of the loudspeaker mid-bass and low-frequency output levels to further compensate for the application of decorative material and in accordance with room acoustic conditions and user preference.

[0015] In a further aspect of the present invention, a stereophonic spatialization circuit may be utilized that cross-couples an attenuated, equalized and inverted left channel (L) signal with an unmodified right channel (R) signal, and cross-couples an attenuated, equalized and inverted R-signal with an unmodified L-signal, which serves to compensate for the reduced levels of room reverberant sound information associated with wall-mounted loudspeakers. This cross-coupling circuit is believed unique in that it applies mid-frequency equalization to the cross-coupled signal components only, and not to correlated L and R input signal components, by means of a pair of resistor/capacitor networks separately connected to a pair of operational amplifiers.

[0016] Certain of the above described equalization and stereophonic spatialization circuits may be implemented as the only element comprising the cascaded equalization circuit; and each circuit may be implemented in either the analog or digital domain. Moreover, they are each useful in audio signal processing applications in which planar loudspeakers may be substituted by non-planar audio transducers, or in which no loudspeakers are utilized at all.

[0017] These and other advantages of the invention will become apparent from the following detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

FIG. 1 is a schematic diagram of a prior art spatialization circuit;

FIG. 2 is a schematic diagram of a spatialization circuit stage in accordance with a preferred embodiment of the present invention;

FIG. 3 is a block diagram of a prior art resonant circuit;

FIG. 4 is a block diagram of a resonant circuit in accordance with a preferred embodiment of the present invention;

FIG. 5 is a block diagram of a preferred embodiment of the overall compensation system of the present invention, providing optimal compensation for wall-mounted planar loudspeakers; and

FIG. 6 is a block diagram of an alternative embodiment of the overall compensation system of the present invention, providing optimal compensation for ceiling-mounted planar loudspeakers.

[0018] Referring now to the drawings, and particularly to FIG. 1 thereof, there is shown by way of background a schematic diagram of a prior art cross-coupling spatialization circuit as described in the applicant's own prior U.S. Patent No. 5,400,405. In this spatialization circuit, the high frequencies cross-couple in an additive manner and the remaining spectrum of frequencies cross-couple in a subtractive manner. Specifically, the left (L) input signal A_{in} is simultaneously applied to the non-inverting input of operational amplifier A1 through resistor R1, and to the non-inverting input of operational amplifier A2 through resistor R2 and capacitor C1 connected in series. Similarly, the right (R) input signal B_{in} is simultaneously applied to the non-inverting input of operational amplifier A2 through resistor R3, and to the non-inverting input of operational amplifier A1 also through resistor R2 and capacitor C1. At low frequencies where the reactance of C1 is high compared to the resistance of R2, signals A_{in} and B_{in} drive the non-inverting inputs of operational amplifiers A1 and A2 through resistors R1 and R3, respectively, with minimal stereo signal cross-coupling. At high frequencies, where the reactance of C1 becomes low compared to the resistance of R2, positive polarity cross-coupling is introduced between the left and right channels as determined by the values of R1, R2 and R3.

[0019] In the prior art spatialization circuit of FIG. 1, broadband negative polarity cross-coupling between the respective outputs A_{out} and B_{out} of the stereo channels is introduced by the bilateral circuit branch having resistor R4 connected between the inverting inputs of operational amplifiers A1 and A2. R4 thereby interacts with feedback resistors R5 and R6, each of which is connected from the output of one of the operational amplifiers to its inverting input. The high frequency positive polarity cross-coupling introduced by capacitor C1 and resistor R2 acts to increase the common-mode content of the two channels in the high frequency range, and thus reduces the stereo separation at high frequencies, in effect converging to a degree the high frequency imaging toward a central perceived source point for enhanced localization, while the broadband negative-polarity cross-coupling introduced by resistor R4 acts to increase the perceived stereo ambience by increasing the non-common-mode reverberant signal content in each channel.

[0020] FIG. 2 shows a preferred embodiment of the spatialization circuit stage of the present invention, in which mid-frequency equalization is applied to cross-coupled signal components only, and not to correlated L and R input signal components. In FIG. 2, left input signal A_{in} is simultaneously applied to the non-inverting input of operational amplifier A1, and to the inverting input of operational amplifier A2 through resistor R2. Right input signal B_{in} is simultaneously applied to the non-inverting input of operational amplifier A2, and to the inverting input of operational amplifier A1 through resistor R1.

[0021] As shown in FIG. 2, resistors R3 and R5 and capacitor C1 form a first compensation network coupled from the output A_{out} of operational amplifier A1 to its inverting input and through resistor R1 to cross-coupled input signal B. The first compensation network thus introduces mid-frequency equalization to the cross-coupled input signal applied to operational amplifier A1 through resistor R1. However, such equalization does not apply to correlated L and R input signal components that are present equally at inputs A_{in} and B_{in}. This is the case since, under such circumstances, the inverting and non-inverting input signal components at operational amplifier A1 are identical, thereby inducing the output signal of operational amplifier A1 to follow the input signals resulting in substantially zero signal across the first compensation network. Hence, the first compensation network is non-effective for such correlated signal components. Resistors R4 and R6 and capacitor C2 form a second compensation network coupled from the output B_{out} of operational amplifier A2 to its inverting input. The second compensation network introduces mid-frequency equalization to the cross-coupled input signal applied to operational amplifier A2 through resistor R2; however, for the above reason, such equalization does not apply to correlated L and R input signal components that are present equally at inputs A_{in} and B_{in}. The output of operational amplifier A1 constitutes a left spatialized output signal A_{out}, and the output of operational amplifier A2 constitutes a right spatialized output signal B_{out}. Each of these output signals could be applied as inputs to stereo output stages or amplifiers, which then provide stereo output signals to a corresponding pair of stereo planar loudspeakers (not shown).

[0022] It can be noted that stereophonic cross-coupling, without the use of a balanced differential amplifier stage to separately derive difference signal components, is in general known in the arts. A special case cross-coupling circuit variation, however, is shown and described above and provides a pleasing spatialization effect using minimum parts count circuitry.

[0023] Turning now to FIG. 3, there is shown a block diagram of a prior art resonant circuit RC having an input channel $CH1_{in}$ and an output channel $CH1_{out}$, in which variable A, variable F and variable Q represent the amplitude, frequency and bandwidth characteristics of the resonant circuit, respectively. In FIG. 3, each of these characteristics is controlled separately from the other characteristics by variable controllers VA, VF and VQ, respectively.

[0024] In a further aspect of the present invention, FIG. 4 illustrates a resonant circuit RC similarly having an input channel $CH1_{in}$ and an output channel $CH1_{out}$, in which selector SA, selector SF and selector SQ determine amplitude, frequency and bandwidth characteristics, respectively. The selectors SA, SF and SQ are all mechanically coupled to one another by means of a single-control selector. Thus, this single-control configuration differs from prior art adjustable resonant circuits in that the later utilize multiple independently-adjustable parametric values. Output channel CH2 could be applied to as input to a power amplifier that provides an output signal to a planar loudspeaker (not shown).

[0025] In FIG. 5 there is shown a block diagram of the preferred embodiment of the present invention for providing optimal compensation for wall-mounted planar loudspeakers, in which left stereo source signal L_{in} and right stereo source signal R_{in} are applied to spatialization circuit SC1. Spatialization circuit SC1 is the same as spatialization circuit SC shown in FIG. 2, and provides as outputs left spatialized signal S1 and right spatialized signal S2. Signal S1 is applied to a first resonant circuit RC1, and signal S2 is applied to a second resonant circuit RC2. Resonant circuits RC1 and RC2 are identical to the resonant circuit RC shown in FIG. 4, in which selector SA, selector SF, and selector SQ determine amplitude A, frequency F and bandwidth Q characteristics, respectively. As discussed above, all RC1 selectors mechanically couple to one another by means of single-control selector CTR1, and all RC2 selectors mechanically couple to one another by means of single-control selector CTR2. RC1 provides as output left-equalized signal S3, and RC2 provides as output right-equalized signal S4.

[0026] Signal S3 is simultaneously applied to the input of high-frequency high-pass filter HF1 and to an input of adder ADD1. High-pass filter HF1 provides as output left high-frequency filtered signal S5, which is applied the input of operational amplifier A1 having a gain that is adjustable by control CTR3 and having as output left amplified high-frequency filtered signal S7. Signal S7 is applied to an input of adder ADD1, and thereby summed with signal S3 to provide left high-frequency boosted signal S9. Signal S4 is simultaneously applied to the input of high-frequency high-pass filter HF2 and to an input of adder ADD2. High-pass filter HF2 provides as output right high-frequency filtered signal S6, which is applied the input of operational amplifier A2 having a gain that is adjustable by control CTR4 and having as output right amplified high-frequency filtered signal S8. Signal S8 is applied to an input of adder ADD2, and thereby summed with signal S4 to provide right high-frequency boosted signal S10.

[0027] Signal S9 is applied to the input of low-frequency underdamped high-pass filter LF1 having a low-frequency peak that is adjustable by control CTR5 and having as output left low-frequency peaked signal S11. Signal S10 is similarly applied to the input of low-frequency underdamped high-pass filter LF2 having a low-frequency peak that is adjustable by control CTR6 and having as output right low-frequency peaked signal S12. In turn, signal S11 is applied to the input of low-frequency response shaping circuit LR1 that is adjustable by control CTR7, and having as output system left output signal L_{out}, and signal S12 is applied to the input of low-frequency response shaping circuit LR2 that is adjustable by control CTR8, and having as output system right output signal R_{out}.

[0028] A block diagram of an alternative embodiment of the present invention, providing optimal compensation for ceiling-mounted planar loudspeakers, is shown in FIG. 6 in which left stereo source signal L_{in} and right stereo source signal R_{in} are applied to a first resonant circuit RC3 and to a second resonant circuit RC4, respectively. Resonant circuits RC3 and RC4 are identical resonant circuit RC in FIG. 4 above, in which selector SA, selector SF, and selector SQ determine amplitude A, frequency F and bandwidth Q characteristics, respectively. Again, as described above, all RC3 selectors mechanically couple to one another by means of single-control selector CTR9, and all RC4 selectors mechanically couple to one another by means of single-control selector CTR10. Resonant circuit RC3 provides as output left-equalized signal S13, and resonant circuit RC4 provides as output right-equalized signal S14.

[0029] Signal S13 is simultaneously applied to the input of high-frequency high-pass filter HF3 and to an input of adder ADD3. High-pass filter HF3 provides as output left high-frequency filtered signal S15, which is applied the input of operational amplifier A3 having a gain that is adjustable by control CTR11 and having as output left amplified high-frequency filtered signal S17. Signal S17 is applied to an input of adder ADD3, and thereby summed with signal S13 to provide left high-frequency boosted signal S19 which constitutes a first system left output signal L_{out1}. Signal S14 is simultaneously applied to the input of high-frequency high-pass filter HF4 and to an input of adder ADD4. High-pass filter HF4 provides as output right high-frequency filtered signal S16, which is applied the input of operational amplifier A4 having a gain that is adjustable by control CTR12 and having as output right amplified high-frequency filtered signal S18. Signal S18 is applied to an input of adder ADD4, and thereby summed with signal S14 to provide right high-frequency boosted signal S20 which constitutes a first system right output signal R_{out1}.

[0030] Signal S19 is applied to the input of low-frequency underdamped high-pass filter LF3 having a low-frequency peak that is adjustable by control CTR13 and having as output a second system left output signal L_{out2}, thereby providing a left output option having increased low-frequency output. Signal S20 is applied to the input of low-frequency underdamped high-pass filter LF4 having a low-frequency peak that is adjustable by control CTR14 and having as output a second system right output signal R_{out2}, thereby providing a right output option having increased low-frequency output.

[0031] Of course, in the preferred embodiments of FIGS. 5 and 6, the output signals are intended to be applied as inputs to stereo output stages that provide stereo output signals to a corresponding pair of stereo planar loudspeakers (not shown). However, as noted above, it is also contemplated that each of the circuit stages shown in the drawings may be useful in audio signal processing applications utilizing non-planar audio transducers, or no loudspeakers at all.

[0032] Those of ordinary skill in the art will appreciate from the foregoing description that the present invention provides for a simple and economical system that effectively compensates for the diminished sound reproduction capabilities of planar loudspeakers that can result when mounted in walls, ceiling and similar enclosures, and provides enhanced stereo reproduction from such planar loudspeaker systems. While a particular form of the invention has been illustrated and described, it will be apparent that this invention may be embodied and practiced in other specific forms, *e.g.*, in analog or functionally equivalent digital implementation, without departing from the spirit and essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all variations, substitutions and changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

Claims

1. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker, wherein the planar loudspeaker is mounted in an enclosure having a limited depth, the method comprising processing the audio signal through a mid-frequency resonant equalization circuit having a multi-section switch that provides single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters correlated to the depth dimension of enclosure to produce a modified audio signal, and applying a modified audio signal as input to an audio power amplifier to the planar loudspeaker.

2. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker as set forth in claim 1, in which said mid-frequency resonant equalization circuit comprises fixed amplitude, frequency and bandwidth resonant parameters correlated to a single depth dimension of the enclosure.

3. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker, wherein the planar loudspeaker is mounted in an enclosure having a limited depth, the method comprising processing the audio signal through a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost, and applying a modified audio signal as input to an audio power amplifier to the planar loudspeaker.

4. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker as set forth in claim 3, in which said high-frequency equalization circuit comprises a fourth-order Chebyshev high-pass filter.

5. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker, wherein the planar loudspeaker is mounted in an enclosure having a limited depth, the method comprising:

processing the audio signal through a mid-frequency resonant equalization circuit having a multi-section switch providing single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters correlated to the depth dimension of enclosure;
processing the audio signal through a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost; and
applying a modified audio signal as input to an audio power amplifier to the planar loudspeaker.

6. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker as set forth in claim 5, and further including processing the audio signal through an underdamped high-pass filter that provides an amplitude peak in a low-frequency region and a sharp cut-off below said region, thereby extending the low-frequency response of said loudspeaker.

7. A method of modifying an audio signal to compensate for the frequency response of a planar loudspeaker as set forth in claims 5 or 6, and further including processing the audio signal through a low-frequency shaping circuit for providing user-adjustability of mid-bass and low-frequency output levels of said loudspeaker.

8. A method of processing a pair of stereo input audio signals, consisting of an L-signal and an R-signal, for enhancing the stereophonic spatialization effect via planar loudspeakers, comprising:

cross-coupling an attenuated, equalized and inverted L-signal with the unmodified R-signal; and
cross-coupling an attenuated, equalized and inverted R-signal with the unmodified L-signal, wherein said cross-coupled signals are separately equalized in a mid-frequency region, and wherein correlated signals are not equalized.

9. A method of processing a pair of stereo input audio signals as set forth in claim 8, and further including processing audio signals corresponding to the L-signal and the R-signal each through a mid-frequency resonant equalization circuit having a multi-section switch that provides single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters correlated to the depth dimension of enclosure to produce modified signals.

10. A method of processing a pair of stereo input audio signals as set forth in claim 9, and further including processing audio signals corresponding to the L-signal and the R-signal each through a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost.

11. A method of processing a pair of stereo input audio signals as set forth in claim 10, and further including processing audio signals corresponding to the L-signal and the R-signal each through an underdamped high-pass filter that provides an amplitude peak in a low-frequency region and a sharp cut-off below said region, thereby extending the low-frequency response of said loudspeaker.

12. A method of processing a pair of stereo input audio signals as set forth in claims 10 or 11, and further including processing audio signals corresponding to the L-signal and the R-signal each through a low-frequency shaping circuit for providing user-adjustability of mid-bass and low-frequency output levels of said loudspeaker.

13. A method of processing a pair of stereo input audio signals as set forth in claim 8, and further including processing audio signals corresponding to the L-signal and the R-signal each through a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost.

14. A frequency response compensation system comprising a mid-frequency resonant equalization circuit having a multi-section switch providing single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters correlated to the depth dimension of enclosure.

15. A frequency response compensation system as set forth in claim 14, in which said mid-frequency resonant equalization circuit comprises fixed amplitude, frequency and bandwidth resonant parameters.

16. A frequency response compensation system comprising a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost.

17. A frequency response compensation system as set forth in claim 16, in which said high-frequency equalization circuit comprises a fourth-order Chebyshev high-pass filter.

18. A frequency response compensation system of cascaded equalization circuits comprising:

a mid-frequency resonant equalization circuit having a multi-section switch providing single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters; and
a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost.

19. A frequency response compensation system of cascaded equalization circuits as set forth in claim 18, and further including an underdamped high-pass filter that provides an amplitude peak in a low-frequency region and a sharp cut-off below said region.

20. A frequency response compensation system of cascaded equalization circuits as set forth in claims 18 or 19, and further including a low-frequency shaping circuit.

21. A stereophonic spatialization circuit for processing a pair of stereo input audio signals consisting of an

L-signal and an R-signal, to enhance the stereophonic spatialization effect of loudspeakers, comprising:

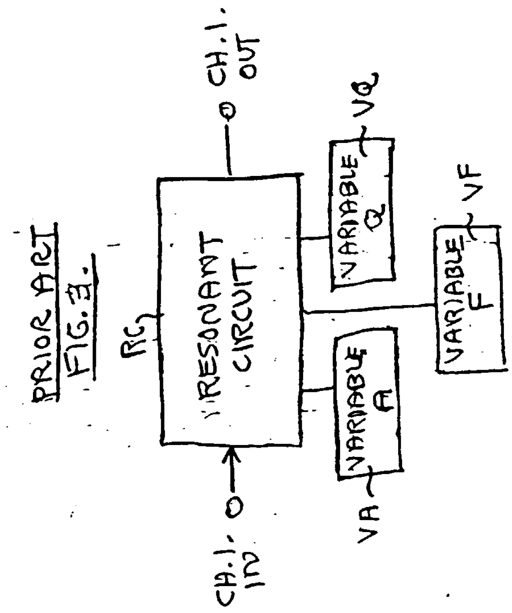
a cross-coupling circuit for cross-coupling an attenuated, equalized and inverted L-signal with the unmodified R-signal; and
a cross-coupling circuit for cross-coupling an attenuated, equalized and inverted R-signal with the unmodified L-signal,
wherein said cross-coupled signals are separately equalized in a mid-frequency region, and wherein correlated signals are not equalized.

22. A stereophonic spatialization circuit as set forth in claim 21, and further including a frequency response compensation system of cascaded equalization circuits comprising:

a mid-frequency resonant equalization circuit having a multi-section switch providing single-control selection of pre-set amplitude, frequency and bandwidth resonant parameters; and
a high-frequency equalization circuit including a high-pass filter applied to an adjustable gain amplifier, the output of which is mixed with an unfiltered signal thereby providing a rapid rate-of-change high-frequency shelved boost.

23. A stereophonic spatialization circuit as set forth in claim 22, wherein the frequency response compensation system further includes an underdamped high-pass filter that provides an amplitude peak in a low-frequency region and a sharp cut-off below said region.

24. A stereophonic spatialization circuit as set forth in claims 22 or 23, wherein the frequency response compensation system further includes a low-frequency shaping circuit.


PRIOR ART
FIG. 3.
RC
RESONANT CIRCUIT
CH. 1. IN
CH. 1. OUT
VARIABLE A
VARIABLE Q
VARIABLE F
VA
VQ
VF

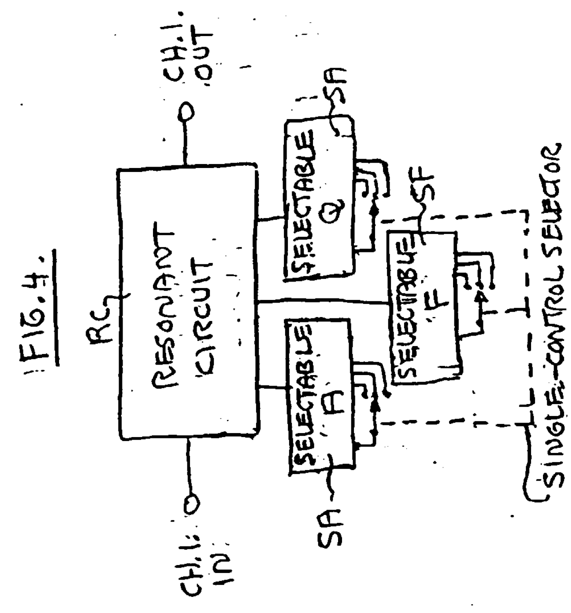
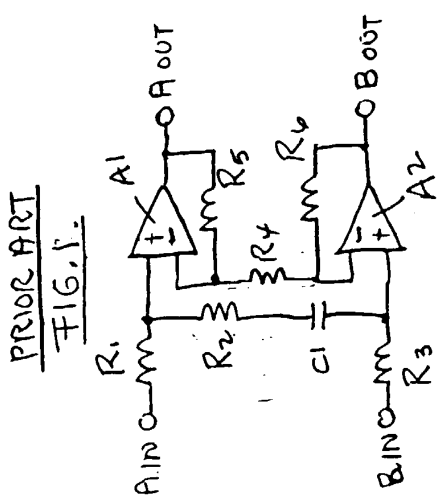


FIG. 4.
RC
RESONANT CIRCUIT
CH. 1. IN
CH. 1. OUT
SELECTABLE A
SELECTABLE Q
SELECTABLE F
SA
SF
SINGLE-CONTROL SELECTOR


PRIOR ART
FIG. 1.
A IN
B IN
A OUT
B OUT
A1
A2
R1
R2
R3
R4
R5
R6
C1

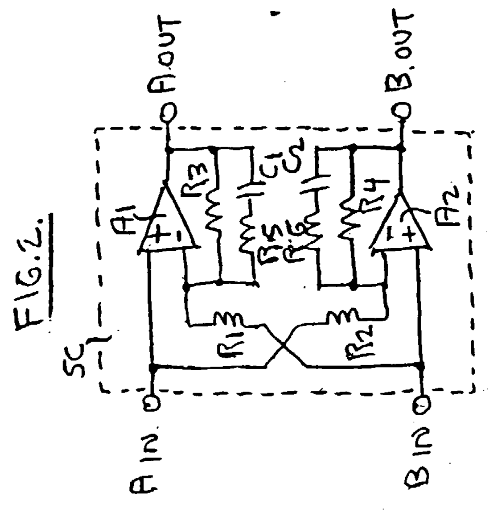


FIG. 2.
SC
A IN
B IN
A OUT
B OUT
A1
A2
R1
R2
R3
R4
R5
R6
C1
C2

FIG.5.

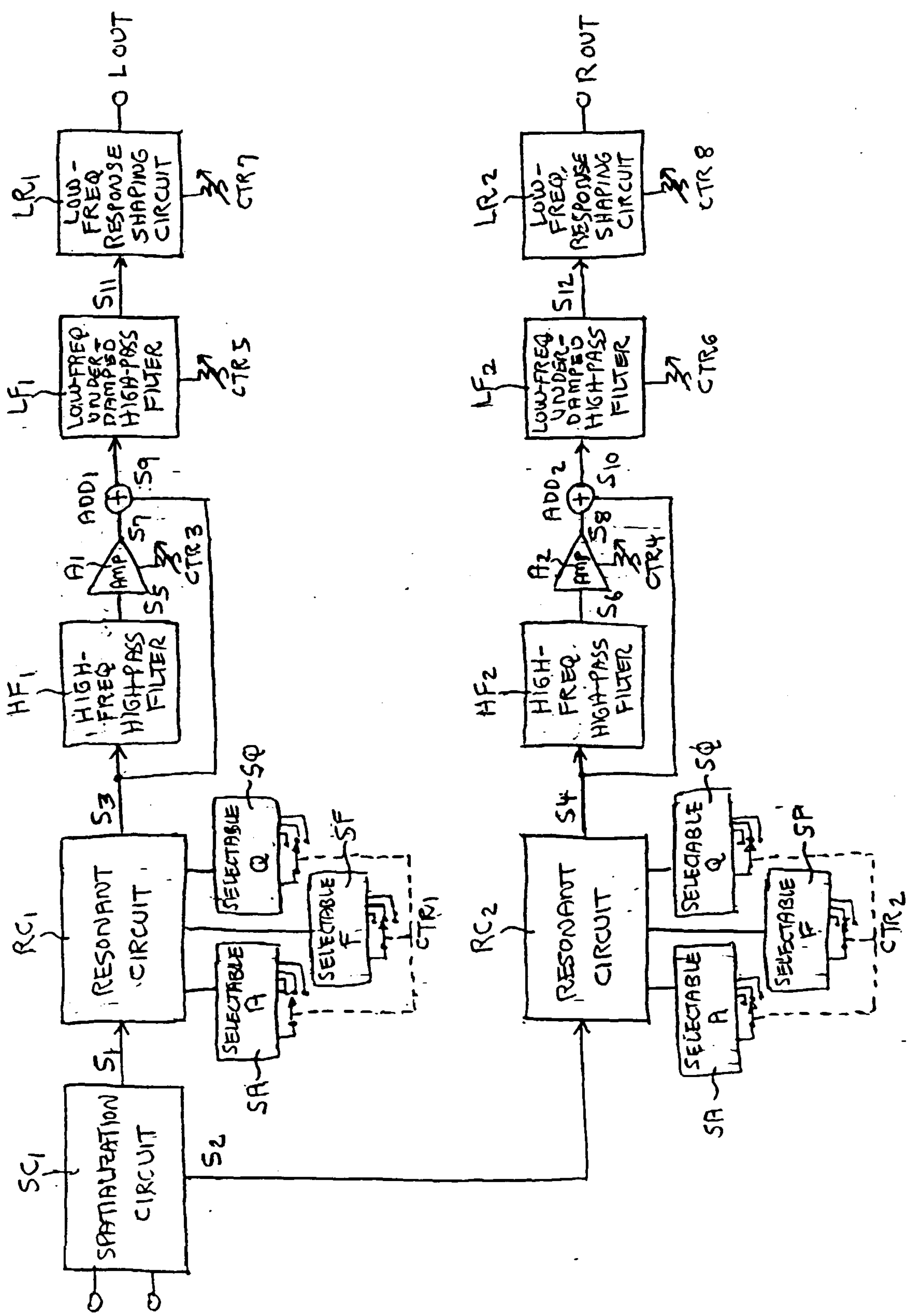
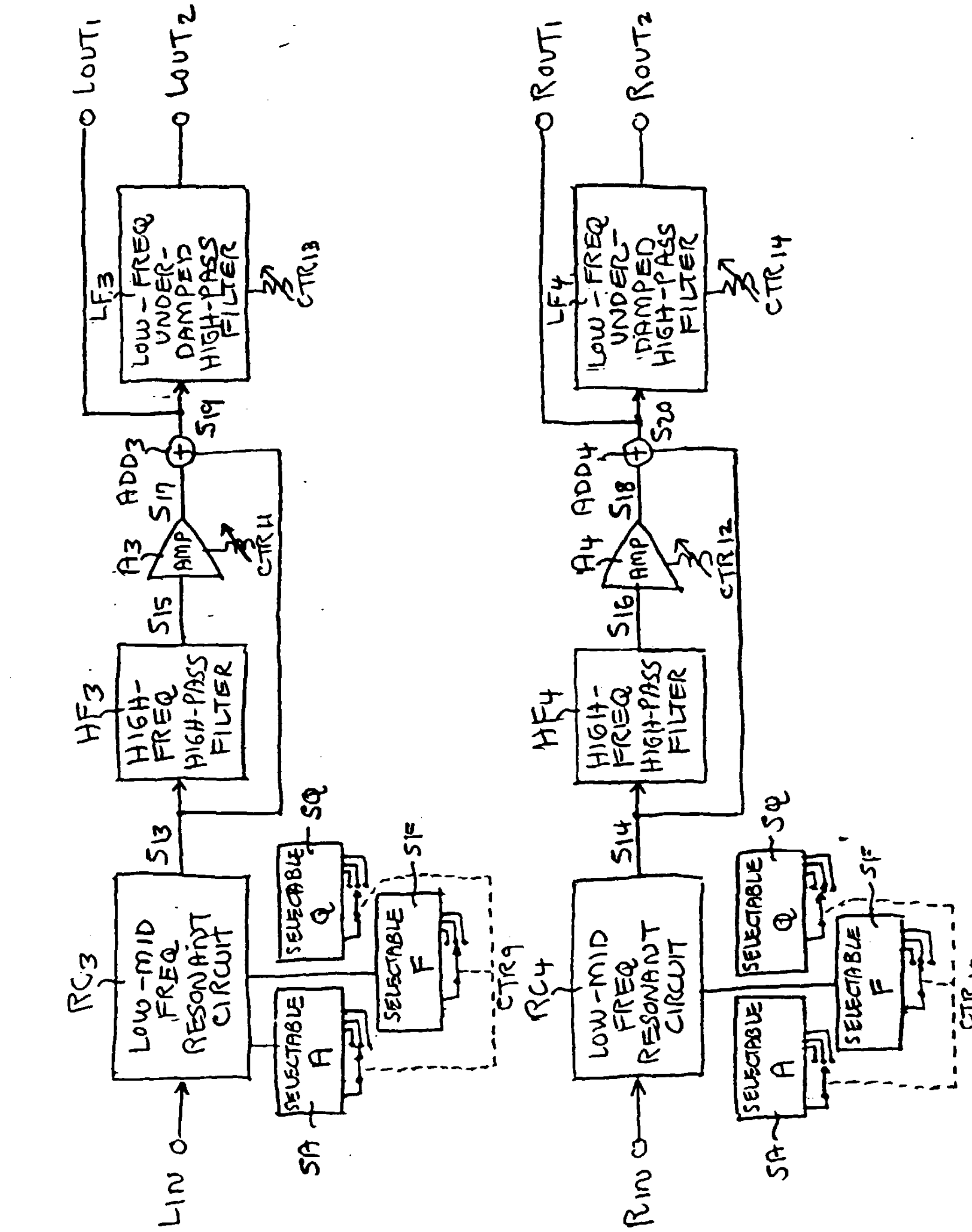

SC1
SPATIALIZATION CIRCUIT
IN
IN
S1
S2
RC1
RESONANT CIRCUIT
SELECTABLE A
SELECTABLE F
SELECTABLE Q
SA
SF
SQ
CTR1
S3
HF1
HIGH-FREQ HIGH-PASS FILTER
S5
A1
AMP
CTR3
S7
ADD1
S9
LF1
LOW-FREQ UNDER-DAMPED HIGH-PASS FILTER
CTR5
S11
LR1
LOW-FREQ RESPONSE SHAPING CIRCUIT
CTR7
L OUT
RC2
RESONANT CIRCUIT
SELECTABLE A
SELECTABLE F
SELECTABLE Q
SA
SF
SQ
CTR2
S4
HF2
HIGH-FREQ HIGH-PASS FILTER
S6
A2
AMP
CTR4
S8
ADD2
S10
LF2
LOW-FREQ UNDER-DAMPED HIGH-PASS FILTER
CTR6
S12
LR2
LOW-FREQ RESPONSE SHAPING CIRCUIT
CTR8
R OUT

FIG.6.


LIN
RC3
LOW-MID FREQ RESONANT CIRCUIT
SELECTABLE A
SELECTABLE Q
SELECTABLE F
SA
SQ
SF
CTR9
S13
HF3
HIGH-FREQ HIGH-PASS FILTER
S15
A3
AMP
CTR11
S17
ADD3
S19
LF3
LOW-FREQ UNDER-DAMPED HIGH-PASS FILTER
CTR13
LOUT1
LOUT2
RIN
RC4
LOW-MID FREQ RESONANT CIRCUIT
SELECTABLE A
SELECTABLE Q
SELECTABLE F
SA
SQ
SF
CTR10
S14
HF4
HIGH-FREQ HIGH-PASS FILTER
S16
A4
AMP
CTR12
S18
ADD4
S20
LF4
LOW-FREQ UNDER-DAMPED HIGH-PASS FILTER
CTR14
ROUT1
ROUT2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 99304682.0

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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
VIENNA	17-11-1999	GRÖSSING

CATEGORY OF CITED DOCUMENTS

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