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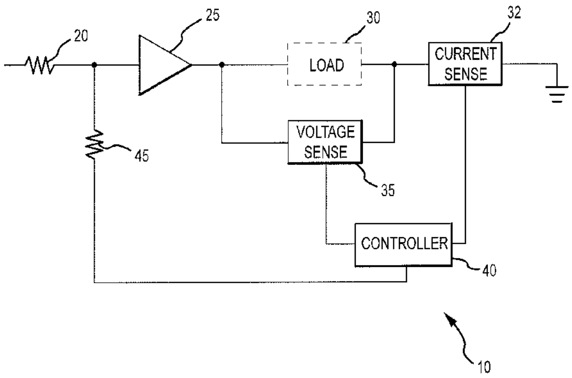

FIGURE 1

(57) **Abstract:** Embodiments of the present invention provide methods and devices for controlling a command signal applied to a load. In embodiments of the invention, current through and voltage across a load are determined and the values of both are used to generate a hybrid control signal. For example, in some embodiments the hybrid control signal is generated by taking a weighted summation of the current and voltage control signals. In other embodiments, a percentage of the difference between the current and voltage control signals is added to one of the current or voltage control signals to generate the hybrid control signal. In one embodiment, a potentiometer is used to generate the hybrid control signal.

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DRIVERS AND METHODS FOR DRIVING A LOAD

CROSS-REFERENCE TO RELATED APPLICATION(S)

[001] This application claims the benefit of U.S. Provisional Application No. 60/886,746, filed January 26, 2007, which application is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[002] This invention relates to drivers and methods for driving a load such as a loudspeaker.

BACKGROUND OF THE INVENTION

[003] Most audible devices rely upon some form of loudspeaker transducer to transform electrical signals into acoustic waves. These transducers are anything but perfect devices, and introduce numerous forms of distortion into the transformation process. One particularly troublesome characteristic of most loudspeakers is the fact that the impedance is non-linear with respect to both frequency and excitation level. A small variation in the loudspeaker can yield a major variation in perceived performance.

[004] Prior systems utilize either voltage or current control to address the variable impedance presented to a driver by a loudspeaker. However, controlled acoustic power remains an elusive goal. Generally, a loudspeaker transducer's impedance increases as the frequency applied to the transducer decreases. Accordingly, a voltage-controlled amplifier driving a loudspeaker transducer is limited by the increasing impedance in that, below a certain frequency, the current put through the increased impedance is too low to produce acceptable levels of sound. A current-controlled amplifier is able to produce sound at these lower frequency, higher transducer impedance points, but suffers from a risk of ruining the loudspeaker. As the impedance increases and the amplifier continues to put out constant current, the voltage can rise unacceptably high, blowing out the speaker.

[005] Accordingly, an improved method for controlling a signal applied to a loudspeaker transducer is needed.

SUMMARY

[006] Aspects of the present invention relate to methods and devices for controlling a command signal applied to a load. According to one aspect of the present invention, current through and voltage across a load are determined and the values of both are used to generate a hybrid control signal. For example, the hybrid control signal may be generated by taking a weighted summation of the current and voltage control signals. A percentage of the difference between the current and voltage control signals may also be added to one of the current or voltage control signals to generate the hybrid control signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] Figure 1 is a schematic diagram of a driver according to an embodiment of the present invention.

[008] Figure 2 is a schematic diagram of a driver according to an embodiment of the present invention.

[009] Figure 3 is a schematic diagram of a system according to an embodiment of the present invention.

DETAILED DESCRIPTION

[010] Embodiments of the present invention provide methods and devices for controlling a command signal applied to a load. While embodiments of the present invention may be advantageously used to control command signals applied to a loudspeaker transducer, it will be appreciated that embodiments of the present invention may be used to control a signal applied to any kind of load, particularly loads presenting a variable impedance to an amplifier. Embodiments of the present invention advantageously combine current and voltage control to generate a hybrid control signal representing aspects of both current and voltage control. For example, in some embodiments the hybrid control signal is generated

by taking a weighted summation of the current and voltage control signals. In some embodiments, controlled constant electrical power is applied to the load. Certain details are set forth below to provide a sufficient understanding of embodiments of the invention. However, it will be clear to one skilled in the art that embodiments of the invention may be practiced without various of these particular details. In some instances, well-known circuits, digital blocks, control signals, timing protocols, audio elements, and software operations have not been shown in detail in order to avoid unnecessarily obscuring the described embodiments of the invention.

[011] By applying hybrid control, some embodiments of the present invention advantageously allow for a loudspeaker to reproduce lower frequencies than would be obtainable using either voltage control, where the current through the loudspeaker may become too small to allow for proper operation or current control, where the danger of blowing out the loudspeaker may limit the loudspeaker operation.

[012] Figure 1 shows a schematic block diagram of a controlled driver 10 according to an embodiment of the present invention. An input signal is applied to a command resistor 20 and then coupled to an amplifier 25. The amplifier 25 produces a command signal to be applied to a load 30. As described above, the load 30 may include a loudspeaker transducer or other variable impedance load. A current sensor 32 measures a current through the load 30 and develops a current control signal indicative of the current through the load. Although the current sensor 32 in Figure 1 is shown coupled between the load 30 and ground, it is to be understood that the current sensor 32 may take on a different configuration, or be coupled to a different reference voltage, so long as it produces a current control signal indicative of the current through the load. A voltage sensor 35 measures a voltage across the load 30 and develops a voltage control signal indicative of the voltage across the load. The voltage control signal and the current control signal are both received by a controller 40. The voltage control signal and current control signals may be, for example, voltages or currents. The controller 40 produces a hybrid control signal based on a combination of the voltage control signal and the current control signal.

The hybrid control signal is applied to a feedback resistor 45 and ultimately adjusts the command signal applied by the amplifier 25 to the load 30.

[013] The controller 40 may develop the hybrid control signal based on the current and voltage control signals in a variety of ways. If the controller 40 passes the current control signal only, the driver 10 operates as a current controlled driver. If the controller 40 passes the voltage control signal only, the driver 10 operates as a voltage controlled driver. In embodiments of the present invention, the hybrid control signal developed by the controller represents a combination of both the voltage and current control signals. In some embodiments, the controller 40 may be set to take a weighted summation of the current control signal and the voltage control signal to produce the hybrid control signal. In some embodiments, a weighted average may be taken of the current control signal and the voltage control signal. In some embodiments, the controller 40 selects the hybrid control signal to be at some point in between the values of the current control signal and the voltage control signal. That is, the controller 40 selects a point from, for example, 0 to 100 percent between the voltage control signal and the current control signal where, for example, 0 percent represents the current control signal, and 100 percent represents the voltage control signal. Generally, the controller computes a difference between the two signals and adds a certain percentage of that difference on to either the current or voltage controlled signals. Adding 70.7 percent of the difference between the current and voltage controlled signals to the voltage controlled signal will generally yield a controlled constant electric power. In other embodiments, the percentage may be different to achieve a constant power based on irregularities of the amplifier or load. In still other embodiments, a different hybrid combination of current and voltage control is used that may not yield constant electric power. In other embodiments, the percentage is between 0 and 100. In some embodiments, the percentage is 50 percent. In still other embodiments, the percentage is between 20 and 80 percent. Generally, any percentage may be used. The percentage chosen will depend on the desired amplifier performance and the characteristics of the load.

[014] In some embodiments, the method used to combine the current control signal and the voltage control signal is set for the driver 10 and the driver 10 continues to utilize the same combination ratio throughout its operation. In other embodiments, the method for combining the control signals, such as how much each signal is weighted in determining the hybrid control signal, varies according to each application of the amplifier, or indeed in some embodiments is constantly adjusted during operation of the driver 10 according to the desired performance of the amplifier, characteristics of the load 30, and/or characteristics of the audio input signal. In some embodiments, then music genre detection is used to determine how the control signals are combined – classical music may be treated differently than, for example, rap music. Additionally, the current and voltage feedback signals may be independently weighted by frequency in some embodiments. In this manner, one of the voltage or current control signals could be more heavily weighted at certain frequencies to address limitations of the loudspeakers or protect their operation.

[015] Figure 2 shows a schematic block diagram of a driver 150 according to an embodiment of the present invention. An input signal 100 is presented to command resister 101 which, in conjunction with feedback resistor 102, controls the output voltage of operational amplifier 103. The output of op amp 103 drives non-inverting power amplifier 104, the output of which is capable of driving an output transducer 107 at the desired power. Although the invention is described in terms of "op amps," other forms of differential amplifiers may alternatively be used, where appropriate. Additionally, various resistive elements used to implement the op amps in Figure 1 are not shown in the diagram of Figure 1 to avoid obscuring the disclosed embodiment of the invention.

[016] Power amplifier 104 drives transducer 107 through resistor 105. The resistor 105 is a current sensing resistor and may form part of an embodiment of the current sensor 32 shown in Figure 1 Op amp 106 may also form part of an embodiment of the current sensor 32 shown in Figure 1 and converts the voltage drop across 105 (proportional to the current through transducer 107) into a voltage indicative of current through transducer 107. Accordingly, op amp 106 outputs the current control signal. Op amp 108, directly measures the voltage across transducer 107 and is an embodiment of the voltage sensor 35

shown in Figure 1. Op amp 108 therefore outputs the voltage control signal. The gain of op amp 106 is assumed to be whatever is required to yield the same voltage as is output from op amp 108 when transducer 107 exhibits the expected nominal impedance. In other words, no difference voltage will exist between op amps 106 and 108 when transducer 107 impedance is nominal in the embodiment shown in Figure 2.

[017] The controller 40 of Figure 1 is implemented in Figure 2 as a potentiometer 110 and a voltage follower 109. The outputs of op amps 106 and 108, the current and voltage control signals, each drive one end of potentiometer 110. The wiper of potentiometer 110 drives voltage follower 109, which in turn drives feedback resistor 102. At one end of potentiometer 110 travel, op amp 109 outputs a voltage representative of the voltage across transducer 107 (controlled voltage operation); and at the other end of potentiometer 110, op am 109 will output a voltage representative of the current through transducer 107 (controlled current operation). Due to the equivalent gains of op amps 106 and 108, the position of potentiometer 110 will be inconsequential when transducer 107 impedance is nominal. The potentiometer operates as a voltage divider between the voltage control signal and the current control signal, and positioning the wiper at an appropriate position results in an output hybrid control signal that combines the values of the current and voltage control signals as described above. Accordingly, where 0 represents a position of the wiper yielding constant current control, and 1 represents a position of the wiper yielding constant voltage control, the wiper may be set to any intermediate position to achieve a hybrid control, as described above with reference to percentages.

[018] In that op amp 109 drives feedback resistor 102, overall amplifier loop feedback is therefore continuously variable from voltage to current control by potentiometer 110. Potentiometer 110 may be adjusted from controlled voltage operation, through controlled power operation, to controlled current operation of the amplifier. When adjusted to reflect relative efficiency at the operating points to be linearized, availability of both voltage and current control components allow the present invention to automatically equalize transducer performance. Although an analog implementation is shown in Figure 2, it

should be understood that embodiments of the present invention may be implemented using digital circuits and control blocks as well.

[019] The drivers 10 and 150 shown in Figure 1 and 2 generally may form part of an amplifier utilized in a loudspeaker system. The drivers 10 and 150 in some embodiments may form a driver for one or more loudspeakers. The drivers 10 and 150 in some embodiments may be included in a pre-driver for an amplifier system, or may reside in a modulator of an amplifier.

[020] A system 300 according to an embodiment of the present invention is shown in Figure 3. An audio input signal is provided to an amplifier 310, which is configured to drive one or more loudspeakers, such as loudspeakers 320 and 330 shown in Figure 3. One or more drivers according to an embodiment of the present invention is present in the amplifier 310 to receive the audio signal and drive one or both of the speakers 320 and 330 using the hybrid control methods described above. In some embodiments, however, the hybrid control method is used only to control audio signals corresponding to certain frequencies of the audio input signal, in particular embodiments, to certain low frequencies. While in some embodiments, the hybrid control methods described herein are applied to all frequencies of the audio signal, in some embodiments of the present invention the hybrid control mechanisms are applied selectively to certain frequencies, and in some embodiments lower or bass frequencies. This is because at lower frequencies, the impedance of the loudspeaker may generally be more suitable for hybrid control than at higher frequencies where the impedance curve may be less appropriate.

[021] Accordingly, in some embodiments, the hybrid control techniques described are applied only to portions of an input signal corresponding to frequencies below a threshold frequency. The threshold frequency may generally be between 100Hz up to about 6kHz. In one embodiment, the hybrid control methods described are applied to portions of an input audio signal having frequencies at or below 2kHz.

[022] Loudspeakers may have a crossover frequency specifying the appropriate frequencies within the audio signal for individual transducers to reproduce. For example, in the embodiment of Figure 3, the transducer 330 may be intended to produce bass

sounds, and use of the hybrid control methods described may be advantageous below 200Hz. The transducer 320 may receive the higher frequency portions of the audio signal and use of the hybrid control methods described may be advantageous at other frequencies for the transducer 320, such as frequencies where the transducer 320 exhibits undesirable impedance variation. In some embodiments, the frequencies at which the hybrid control methods are applied are set based on characteristics of the loudspeaker transducers.

[023] From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention.

CLAIMS

What is claimed is:

1. A method of driving a load with an amplifier, the method comprising:

applying a command voltage to the load;

generating a voltage control signal representative of a voltage across the load;

generating a current control signal representative of a current through the load;

combining the voltage control signal and the current control signal to generate a hybrid control signal; and

adjusting the command voltage based on the hybrid control signal.

2. The method of driving a load according to claim 1 wherein the act of combining the voltage control signal and the current control signal includes taking a weighted summation of the current control signal and the voltage control signal.

3. The method of driving a load according to claim 1 wherein the act of combining the voltage control signal and the current control signal includes generating the hybrid control signal having a value between the current control signal and the voltage control signal.

4. The method of driving a load according to claim 3 wherein the act of combining the voltage control signal and the current control signal comprises calculating a difference between the current control signal and the voltage control signal and adding a percentage of the difference to one of the current control signal and the voltage control signal.

5. The method of driving a load according to claim 4 wherein the act of combining the voltage control signal and the current control signal further includes applying the voltage control signal and the current control signal to a potentiometer having a wiper and setting the wiper based on the percentage.

6. The method of driving a load according to claim 5 wherein the percentage changes over time and the wiper setting changes as the percentage changes.

7. The method of driving a load according to claim 4 wherein the load has expected impedance characteristics and the percentage is chosen according to the expected impedance characteristics.

8. The method of driving a load according to claim 4 wherein the percentage is 70.7 percent and added to the voltage control signal to achieve constant power operation.

9. The method of driving a load according to claim 1 wherein the voltage control and current control signals are both voltages, and the act of combining the voltage control and current control signals includes applying the voltage control and current control signals to a voltage divider.

10. The method of driving a load according to claim 1 wherein the load includes a loudspeaker.

11. A method of improving bass performance of a loudspeaker receiving audio input, the method comprising:

determining a threshold frequency below which to apply hybrid control; and

controlling operation of an amplifier driving the loudspeaker for frequencies at or below the threshold frequency, the act of controlling the operation comprising:

applying a command voltage to the loudspeaker;

generating a voltage control signal representative of a voltage across the loudspeaker;

generating a current control signal representative of a current through the loudspeaker;

combining the voltage control signal and the current control signal to generate a hybrid control signal; and

adjusting the command voltage based on the hybrid control signal.

12. A method of improving bass performance according to claim 11 wherein the threshold frequency is 2kHz.

13. A method of improving bass performance according to claim 11 wherein the threshold frequency is above 100Hz.

14. A driver for driving a load, the driver comprising:

an amplifier configured to apply a command signal to the load;

a voltage sensor coupled to generate a voltage control signal indicative of voltage across the load;

a current sensor coupled to generate a current control signal indicative of current through the load;

a controller having a first input terminal, a second input terminal, and an output terminal, the controller configured to receive the voltage control signal at the first input terminal, the current control signal at the second input terminal and generate a hybrid control signal at the output terminal based on both the current control signal and the voltage control signal; and

a feedback device coupled to receive the hybrid control signal and operable to modify the command voltage based on the hybrid control signal.

15. The driver of claim 14 wherein the voltage sensor comprises a second amplifier having a first input terminal, a second input terminal, and an output terminal, the first and second input terminals coupled to measure a voltage across the load, the output terminal of the second amplifier coupled to the first input terminal of the controller.

16. The driver of claim 14 wherein the current sensor comprises a resistive element coupleable between the load and a reference voltage such that a voltage across the resistive element will be indicative of a current through the load, the current sensor further comprising a third amplifier having a first input terminal, a second input terminal and an output terminal, the first and second input terminals of the third amplifier coupled to measure a voltage across the resistive element and the output terminal of the third amplifier coupled to the second input terminal of the controller to deliver the current control signal indicative of the current through the load.

17. The driver of claim 16 wherein the reference voltage is a ground.

18. The driver of claim 14 wherein the controller comprises a voltage divider having a first input terminal, a second input terminal and an output terminal, the voltage divider including a first resistive element between the first input terminal and the output terminal and a second resistive element between the second input terminal and the output terminal, the voltage divider configured to generate the hybrid control signal at the output terminal wherein the hybrid control signal is a voltage between the voltage control signal and the current control signal.

19. The driver of claim 17 wherein the voltage divider is configured to output the hybrid control signal representing a percentage of a difference between the voltage control signal and the current control signal added to one of the current control signal and the voltage control signal.

20. The driver of claim 19 wherein the percentage is 70.7% and the percentage of the difference is added to the voltage control signal for constant power operation.

21. The driver of claim 19 wherein the voltage divider comprises a potentiometer having a wiper, the percentage set by the wiper.

22. The driver of claim 14 wherein the load comprises a loudspeaker.

23. An audio system, the system comprising:

a loudspeaker;

a driver comprising:

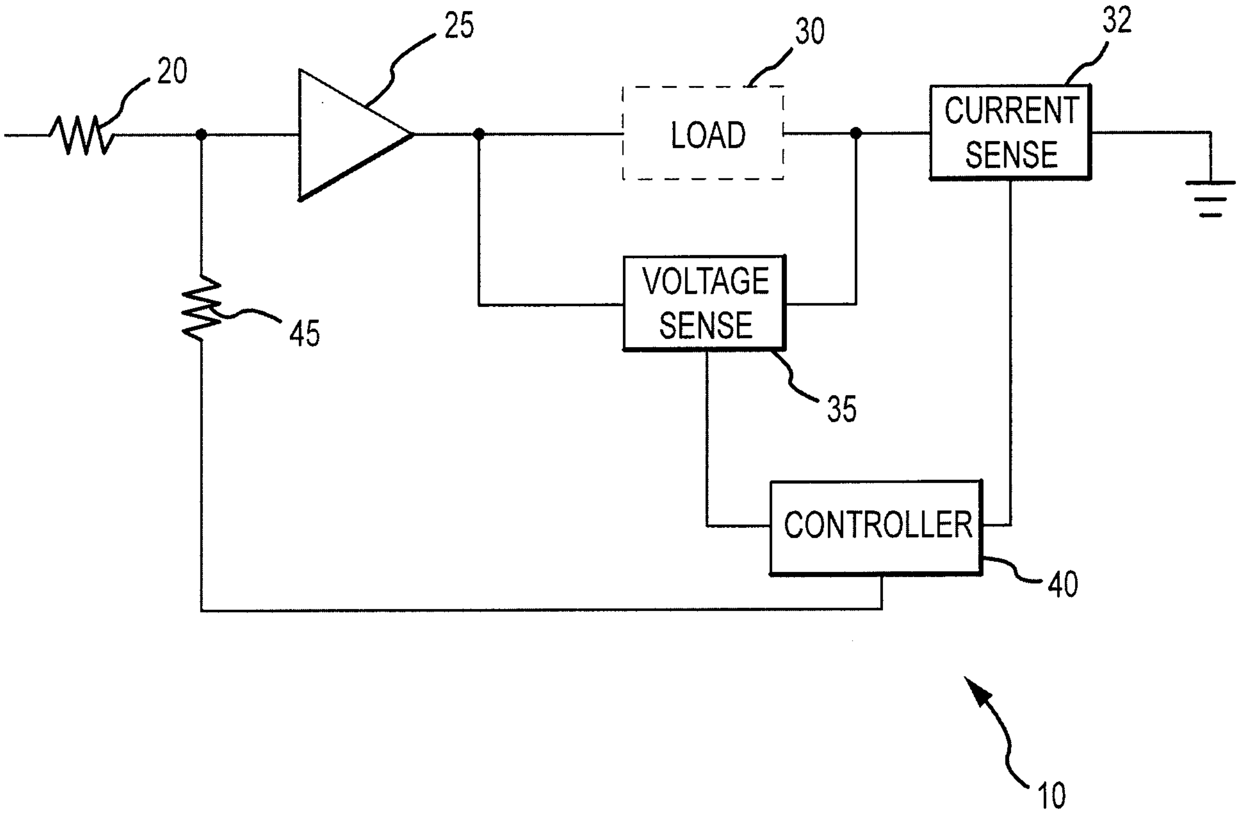
an amplifier configured to apply a command signal to the loudspeaker;

a voltage sensor coupled to generate a voltage control signal indicative of voltage across the loudspeaker;

a current sensor coupled to generate a current control signal indicative of current through the loudspeaker;

a controller having a first input terminal, a second input terminal, and an output terminal, the controller configured to receive the voltage control signal at the first input terminal, the current control signal at the second input terminal and generate a hybrid control signal at the output terminal as a function of both the current control signal and the voltage control signal; and

a feedback device coupled to receive the hybrid control signal and operable to modify the command voltage based on the hybrid control signal.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25
30
LOAD
32
CURRENT SENSE
VOLTAGE SENSE
45
35
CONTROLLER
40
10

FIGURE 1

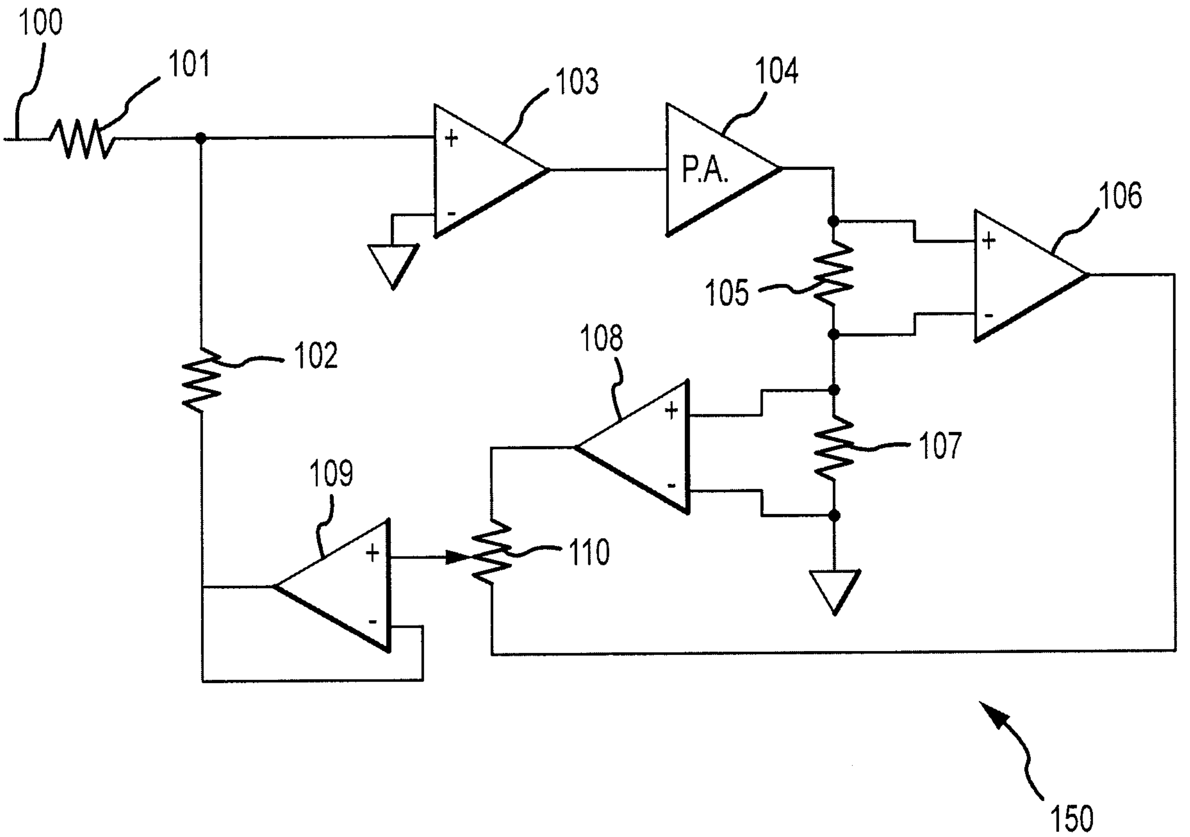

FIGURE 2

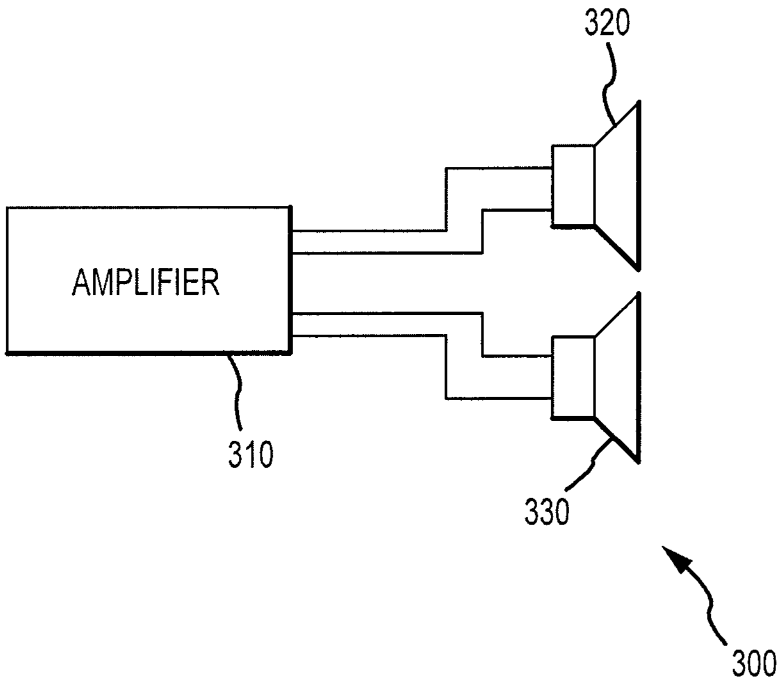

FIGURE 3